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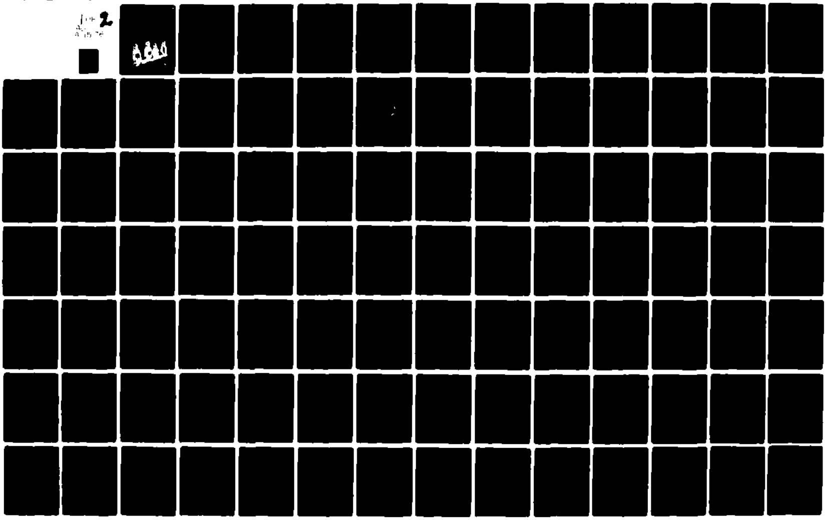

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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONR Far East,

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SQUIDs
Josephson devices
Superconducting magnetic levitation
Synchronous generators

20. Abstract (cont.)

with certain reports also being contributed by visiting stateside scientists. Occasionally a regional scientist will be invited to submit an article covering his own work, considered to be of special interest.

CONTRIBUTORS

Dr. Stuart L. Brodsky is Group Leader for Mathematics at the Office of Naval Research. He received his B.S. degree from the Illinois Institute of Technology in 1964, and his M.S. and Ph.D. degrees from Stanford University in 1965 and 1969, all in mathematics. His areas of interest include control and systems theory, differential and integral equations, and computational modeling.

Mukunda B. Das is a professor in the Department of Electrical Engineering, at The Pennsylvania State University, where he is engaged in research concerning the basic device performance and defect characteristics in GaAs, Cd and Si devices. His research in GaAs is supported by the National Science Foundation, and carried out in cooperation with Westinghouse Research Laboratories, Pittsburgh, Pennsylvania.

D. Eirug Davies was educated at the University of Wales where he received both B.S. and Ph.D. degrees. Dr. Davies has been employed as a research physicist at the Air Force's Rome Air Development Center, Hanscom AFB for the past 12 years. Dr. Davies has published extensively with over 40 publications in his main research areas of ion implantation and laser annealing. Apart from his own research, he is currently task manager for the Air Force's Research Program in fiber optics.

Leon H. Fisher, presently on the staff of ONR Far East, is on leave from California State University, Hayward. He recently completed an eight year assignment as Dean of Sciences at Hayward, where he is also Professor of Physics. Dr. Fisher has held professorships at New York University and at the University of Illinois, has led research groups at the Lockheed Palo Alto Research Laboratory and the General Telephone and Electronics Laboratory, and has been visiting professor at the University of California, Berkeley, the University of Washington, and the University of Southern California. His specialty is gaseous electronics, and his interests include ionization coefficients.

Howard Lessoff is the Head of the Electronic Material Technology Branch at the Naval Research Laboratory, Washington, D.C. His activities include research and development of compound semiconductors, technology of material preparation, and growth and direction of a contract program in electronic and electro-optic materials. Prior to joining the government in 1964, he did research on ferrite memory cores at RCA and Bell Laboratories.

Koichi Masubuchi is Professor of Ocean Engineering and Materials Science at the Department of Ocean Engineering of the Massachusetts Institute of Technology, Cambridge, Massachusetts. He received B.S., M.S., and Ph.D. degrees from the University of Tokyo. Based on a monograph prepared under a research contract for ONR, he has recently published an extensive book entitled, *Analysis of Welded Structures*.

Taiichiro Ohtsuka, Professor of Physics, is currently Chairman of the Physics Department, Tohoku University, Sendai, Japan. He is a renowned expert in low temperature physics and engineering in Japan, and has been participating as a consultant in the Japan National Railway Project to develop a superconducting train that may eventually replace the popular "Shinkansen" bullet train.

Seikoh Sakiyama, Science Advisor of ONR Far East, has had considerable industrial experience in laboratory chemistry, electronic instrumentation, and quality control methodology. His interests include computer science, linguistics, and energy technology.

Jin J. Song, a Research Assistant Professor at the University of Southern California, received her Ph.D. degree from Yale University. After joining the laser research group at USC, she has carried out (in collaboration with Marc Levinson, now with the IBM Research Laboratory, San Jose) pioneering work in developing four wave mixing techniques in nonlinear laser optics research.

CONTENTS

Cover: A contemporary Japanese woodblock print by *Gihachi Okumura* depicting winter in Japan. The capes are made from rice straw and are natural insulators as well as water repellant. The capes are still used by farmers in the cold regions of Japan. The print has been reduced by photo offset lithography.

ROBOT CONTROL IN JAPAN

Stuart L. Brodsky

INTRODUCTION

In the United States all of the professional societies with interest in automatic control are member organizations of the American Automatic Control Council (AACC). The AACC in turn is a member of the International Federation on Automatic Control (IFAC) which was established to provide an international forum for the discussion and encouragement of research and applications of automatic control. In August 1981, the 8th Triennial World Congress of IFAC was held in Japan at the Kyoto International Conference Center.

Many of the standard topics in automatic control including linear and nonlinear systems theory, identification, estimation and filtering, adaptive control, and stability theory were featured in sessions in the program as were a variety of applications. In addition, there was increased interest shown in robotics which was the subject of two technical sessions, a film series, and industrial exhibits. This article will discuss robotic control work, primarily in Japan, as reflected by the IFAC Congress, and a series of discussions held with Mr. Kanji Yonemoto, Executive Director of the Japanese Industrial Robot Association, and other university robotics researchers visited while in Japan.

JAPANESE INDUSTRIAL ROBOT ASSOCIATION

The Japanese Industrial Robot Association is an important organization promoted by industry to encourage the development and use of robotics and advanced automation. The association maintains both standing and ad hoc committees to look into a variety of important issues including technical developments, popularization of robots, safety, energy efficiency, policy information, systems, and foreign affairs. When the need for a committee is established by the association's board of directors, the board appoints a "key person" who then selects the other members of the committee with whom he will work. As an example, one committee is looking into standards that can be used to compare different robot designs. This includes terminology, testing, and measuring techniques. The ultimate intent is to guide users in determining which robot is best for a given application. One standard that has been developed is the Japanese Industrial Standard that was established in 1979 to classify robots according to differences in their methods for providing input information and instruction structures. Robots are classified from the most simple manipulators operated by a man to intelligent robots which have sensing and "thinking" capabilities that allow them to decide their own behavior. In between are the majority of currently working robots which are either programmed to perform a fixed sequence of operations, or which are trained by a man who performs the desired task which the robot memorizes and then can repeat.

Another committee is investigating computer assisted robot system analysis. This committee is looking into a variety of topics including simulation techniques and software development. Each of these committees is expected to produce an annual report which summarizes its progress during the year.

In addition to these activities, the Association sponsors an annual international symposium (last held October 1981 in Tokyo). Mr. Yonemoto proudly referred to this symposium as the place to learn the latest in robotics research. He also spoke proudly of the role his organization has played in the rapid advance in the use of robots in Japan. Over the last few years robot production has increased at a rate of 30% to 40% per year, with most of the robots produced being used in domestic industries.

RESEARCH AND DEVELOPMENT

Research and development in Japan are conducted by universities, government laboratories, and commercial companies. As one would expect, the former two are more concerned with basic research issues while the latter emphasize commercialization for specialized industrial applications.

Before discussing work at particular laboratories, some general remarks may be useful to develop a context for reading the remainder of this article. There are several research topics in robot control that are under active investigation. These include improvements in arms, hands, locomotion, and sensors. Major issues for arms relate to increasing their speed and flexibility as well as to coordinating multiple arms. Flexibility is also a concern for hands, as is developing a good tactile sensor capability. For locomotion, various mechanisms are being investigated including legs and wheels with a sensory and intelligence capability to permit the robot to avoid obstacles in its path. As for sensory development, various visual, tactile, and auditory sensors are being studied in order to provide inputs needed by intelligent robots.

The applications I viewed while in Japan were primarily for production processes. Robots for placing and retrieving parts that are machine pressed are one such example. This job, while not time consuming, can be very hazardous to humans. Related to this are robots which mount and remove parts to be machined on numerically controlled machines. Welding and painting are important production applications to which robots are being applied. Assembly of parts was the other application I saw being given extensive consideration.

LABORATORY VISITS

I will now describe the activities of several investigators and laboratories I visited or learned about while attending the IFAC Congress.

TOKYO INSTITUTE OF TECHNOLOGY

Professor Hasegawa's laboratory at Tokyo Institute of Technology is concerned with both theoretical systems questions as well as practical design issues for industrial robots. The former work is looking at the hierarchical control of the robots and its sensory systems by some local microprocessors supervised by a minicomputer. In a related area, a new design philosophy for complex sequential control systems is being developed using graphical representations. On the more practical side, Professor Hasegawa's group is engaged in developing a number of robots systems. In one system, visual sensory information has been combined with an adaptive, flexible hand with tactile sensors to do adaptive handling motions. These include, (1) handling the object after detecting position, speed, orientation, and feature parameters and, (2) measuring and recognizing the object after grasping by the adaptive hand. The arm rides along a track, which has a fixed camera at its end. This fixed camera is used to do feature extraction and to determine characteristics such as shape, size, and orientation of the object to be handled. Another camera rides with the arm and its used to determine the object's position. The arm itself has light sensors which can be used to keep the hand at different orientations to the surface of the object. The use of these sensors depends on the rays diffracted from the object so they cannot be used on transparent objects such as glass. A force sensor and slip sensor are used to control force on and slip of an object in the grasp of the arm's two fingers. The slip sensor is also used to determine when an object touches the table and the hand can release it. However, since the slip sensor is indiscriminate to up and down motion, adding weight to a container while it is being lowered will be interpreted as the object having touched the table and it will be released. Professor Hasegawa discussed the development of the particular control law used for grasping, proportional integral-differential (PID) control, explaining the steps used to remove different undesirable features such as overshooting and end point oscillations. Professor Hasegawa also briefly discussed his interest in a project intended to operate two hands cooperatively for applications requiring hand-to-hand transfer and assembly motion.

TOKYO UNIVERSITY

While in Tokyo, I also visited Professor Takano of Tokyo University. Professor Takano's personal interests are in the areas of robot structures and robot control. He described work he is performing aimed at speeding up motion of robot arms in point to point motions with no vision. He pointed out that in the past, in order to speed up motion, one had to decrease the weight of the arm, make the arm rigid, drive the robot with high power, and eliminate overshooting. In modern applications where maneuver is as important as speed these techniques are not adequate. He has introduced an arm with multiple, parallel linkages. He sees the benefits of this design as compared with standard cantilever designs as providing a more rigid, more reliable path of motion therefore capable of higher speed. It also requires one-third of the weight-holding torque needed by a cantilever structure. The control itself is determined in the following manner. One specifies the desired end point and, solving an inverse-type problem, determines the motor speeds required to hold the arm in that position. Then, knowing the starting point and the motor speeds at the starting point, a bang-bang control problem is solved to make the transition to the desired end conditions. The designer uses an interactive system to prevent the control from violating constraints present in the problem.

IFAC CONGRESS FILM PROGRAM

LABORATORY FILMS

As mentioned above, the IFAC Congress in Kyoto had a full program on robotics including talks, movies, and exhibits. The movies provided useful visual images of the capabilities of various university, government laboratory, and industrial efforts in robotics. One of the most interesting of these movies described the work of Professor Umetane of Tokyo Institute of Technology. Following studies of a snake's motion, a two-meter long mechanical model was developed which had serpentine motion. In 1974, tactile sensors were added and the robot could be made to continue to move about an object until all units making up its body touched the object with equal pressure. This allowed the robot to cling to arbitrarily shaped figures and grasp fragile objects somewhat in the manner of an elephant trunk. Using this tactile capability, the robot was also capable of maneuvering through a curved path. An effective joint actuator system was added in 1976 to allow three dimensional motion of the robot, and in 1980 wheels were added to the trunk to allow the robot to bridge ditches with its own "body." It is visualized that this system will someday be used for in-service inspection of nuclear reactors, using its mobility capability to manueuver through intricate passageways, and its tactile capability to wrap around a valve's handle to open or close it when necessary. Professor

Umetane has also started work on a four-legged walking vehicle capable of walking with stability over changing levels of flooring and of turning on the spot.

ELECTROMECHANICAL LABORATORY

Two of the laboratories of the Ministry of International Trade and Industry (MITI), the Electromechanical Laboratory and the Mechanical Engineering Laboratory's Systems and Control Section were also represented in the film series. The Electromechanical Laboratory claimed to have developed the first hand-eye system in Japan, and the first in the world to provide visual feedback. They showed a finger system developed in 1974. The system was able to perform a number of functions requiring great flexibility, but it was clear that the computing required was extensive, causing the fingers to move in a nonfluid, jerking manner somewhat like one pictures of robot motions. In one application, the fingers were shown turning a nut on a bolt. The robot was smart enough to check if the nut was on the screw before proceeding. Again, the finger motion was very slow due to the extensive computation involved. A robot's skill for handling tools were shown through construction of a wooden stand using a saw, hammer, and nail stripper. The applications seemed carefully programmed, and it was difficult to tell how capable the robots really were. Efforts are now being pursued to look at a distributed real time system for robots.

Another system being developed at the laboratory performs automatic geometric modeling. It begins with a set of primitive volumes such as bricks and cylinders. It then uses a laser pointer to break up the volume into a union of these primitive volumes. A geometric editor helps to make corrections. The technique was displayed on an object with a skeleton image being formed with hidden line suppression. Also shown was an automatic generation of a drawing using a laser tracker able to map horizonal and vertical edges on an object to 2-3 mm. The sytem was shown to produce a drawing of an object using its laser tracking device in the dark. This was apparently done to show potential energy savings provided by the system working without lights.

MECHANICAL ENGINEERING LABORATORY

The Mechanical Engineering Laboratory of MITI also displayed a number of systems. One was an omnidirectional vehicle which could run on four wheels with individual control and could rotate on a spot. The vehicle could change direction instantaneously, whether stationary or mobile. It had sensors in its wheel which allowed the vehicle to approach objects very closely and to follow a course specified by some guide. Another system was a high precision manipulator controlled by visual feedback which was used to insert a complex part into an opening with small room for error. Several medical robots were shown including MELDOG, a robot "guidedog." The system, which uses maps and landmarks to navigate, seems to be a long way from providing a practical alternative to "man's best friend." A related vehicle capable of automatic driving was also shown. The vehicle was able to avoid certain type of accidents and to stop at a dead end. In order for obstructions to be perceived by the system, they must be at least 10 cm high.

WASEDA UNIVERSITY

WABOT, a robot developed by Professor I. Kato of Waseda University was the subject of another film. WABOT was the closest to the traditional Hollywood robot that I saw. It had two legs, which it used for mobility using human-like steps. It also had a body with two arms and a head with "eyes." The system was built in a modular fashion, the body and arms, legs, and head being developed separately, with interrelationships included as design constraints. WABOT could respond to natural language and could reply verbally to instructions.

The voice was very mechanical sounding and the vocabulary both spoken and understood was very limited. WABOT could walk at request but the steps were very slow and it was clear extensive computation was going on.

INDUSTRIAL FILMS

Four Japanese companies also had films showing robots they were developing. These were Fujitsu Fanuc Inc., Mitsubishi Heavy Industry Company, Ltd., Hitachi, Ltd., and Yasukawa Electric Manufacturing Company, Ltd.

FUJITSU FANUC

The Fanuc robots are based on cylinderical coordinates and are driven by an electric servomotor. They are designed to perform in conjunction with numerically controlled machines (Fanuc is the largest producer of such machines in the world) to perform machining and assembly tasks. There are various models available depending on the weight of the objects to be handled. Tests are built into both the robot arm and the machine tool to detect faults. A group of these machines can be kept busy overnight with a single person stationed in a control room in the event of special unusual circumstances. The Fanuc robot was also the subject of an exhibit which allowed a close look at the robot in operations.

MITSUBISHI HEAVY INDUSTRY COMPANY

Mitsubishi has developed a robot for painting. The teaching can be by a skilled workman who actually moves the arm while he paints or by a point to point program which the arm follows. After training by either means, the robot is able to work at a much faster pace and with greater consistency. The training is accomplished using a stationary piece. If the piece is actually going to be painted on a moving line, information retarding the conveyor speed and characteristics are provided and adjustments are automatically made. Significant reductions in waste were achieved using the robot and poor atmospheric conditions arising from the spraying caused no problems as they would have if humans were present.

HITACHI, LTD.

Hitachi displayed an "intelligent" assembly robot with two arms. The robot determined its own motions based on visual information. This vision system is used to recognize position and orientations. The arms then move in a coordinated way using microprocessors hierarchically linked. The upper level microprocessor handles problems regarding language, vision, and coordination, while the lower level drives the arm.

YASUKAWA ELECTRIC MANUFACTURING COMPANY

Finally, Yasukawa Electric's Motoman was presented. This robot performs arc welding, which requires more advanced control, higher speed, and more accurate positioning tnan earlier robots designed for spot welding applications. It also has a gripper for parts assembly and for running computer driven processes such as turning knobs, entering cassette tapes, pushing buttons, and so forth. Additional applications, including handling and loading, were also shown. Again, emphasis was placed on the ability of the robot to work in the dark, thus saving energy. I learned that Yasukawa is making major efforts to market its robots outside of Japan.

TECHNICAL SESSIONS

Two technical sessions at the meeting were devoted to robotics. Two Russians, Petrov and Sirota, considered the problem of obstacle avoidance in a complex unknown environment. In their method, the robot proceeds in a direct line to the objective until it locates an obstacle using local sensors at which time it develops a "forbidden region." The robot then proceeds around the boundary of the region until it can again proceed in a direct path to the goal point. Hybrid computer implementation was utilized to combine the high-speed of analogue with the logical capabilities of digital for real time control.

A. Truckenbradt, of West Germany, discussed cases of robot control when elastic properties cannot be neglected. His concern is raised by demands for higher speed or less energy consumption which call for light weight structures. He gave an analysis of the effects of using a finite dimensional approximation to represent the infinite dimensional problem.

V. Marki, of Czechoslovakia, investigated a technique for recognizing three dimensional shapes and determining their sizes by grasping them with a five finger artifical hand. The author used a linguistic approach to the problem wherein an analogy is made between a tactile pattern structure and the structure of a formal language. Multilevel pattern processing is used to allow one to include effective feedbacks in the recognition process.

Most of the other talks in the sessions were either philosophical in nature (for example, how should one do robot planning and what are general scientific and technical problems of robotization?) or were standard control approaches for controlling a more complex arm or for obtaining higher speeds. In one of the former talks, I. M. Makarov of the Institute of Control Sciences of the USSR discussed a five year plan set up by the USSR State Committee for Science and Technology to lay the "foundation for developing the hardware core of robotization." He said, "The nearest necessity is unification of research and development efforts of all concerned organizations and enterprises active in the field of robot engineering in the framework of a common purpose-oriented development program."

CONCLUSION

Robotics has come a long way, but much remains to be done. Emphasis is being given to providing robots with increased speed and flexibility and with a capability to navigate through special areas where obstacles are present. Additionally, providing intelligence and the capability to coordinate multiple arms or multiple robots in order to handle more complex tasks is of great interest. Advanced computational capability resulting from advances in microelectronics, computing and computer technology should provide a favorable environment in which this development can take place.

The idea of industrial robots is considered to have begun with George C. Devol, an American, in 1954. In 1962, the first models which served as prototypes of the majority of robots in use today in Japan were imported from the United States. The Japanese first began producing their own robots in 1967. Now, robotics is an area of dramatic growth worldwide. In many countries, such as Japan and France, the government strongly backs industry in its efforts to compete in world markets. It can be expected that such support will continue to be forthcoming for efforts to develop this technology of growing importance. The United States is faced by a major international challenge in a revolutionary technology that will almost definitely be a determining factor in this country's economic competitiveness in the future.

WELDING ROBOTS IN JAPAN

Koichi Masubuchi

INTRODUCTION

This short paper describes the present status of welding robots in Japan including their development and industrial uses. Much of the information from which this paper has been prepared I gathered on my trip to Japan from May 31 through June 19, 1981. During this trip I visited a number of companies and universities, and met people in the industry as well as in academia. Discussions held with these individuals covered various subjects related to welding and include:

- automation of welding,
- applications of computers in welding,
- underwater welding, and
- reliability of welded structures.

The use of robots is an important subject in welding automation.

The technologies and applications of welding robots, and industrial robots as a whole, are rapidly expanding. Therefore, it is extremely difficult to scrutinize, in detail, the progress being made in Japan unless an extensive survey is performed. Even if such a survey is made, the results will become outdated in a few years. I did not conduct a survey on welding robots in Japan in order to prepare this report; however, I hope that the information presented is useful for readers of the *Scientific Bulletin*.

GENERAL STATUS OF INDUSTRIAL ROBOTS

As far as the industrial uses of robots are concerned, Japan is the undisputed leader of the world having installed almost 70 percent of all industrial robots. According to statistics disclosed in 1979, approximately 47,000 robots were installed in Japan, followed by 5,800 in the Federal Republic of Germany, and 3,300 in U.S.A.[1] Figure 1 shows the yearly production of robots in Japan from 1968 through 1978.[2] The data were prepared by the Japan Industrial Robot Association (Nihon Sangyo Robot Kogyokai). The production of industrial robots in Japan in 1980 was 21,000 units which was a 50 percent increase from production in 1979.[3] It is estimated that the demand for industrial robots in Japan will increase at an annual rate of about 50 percent. According to an estimate by the Nomura Research Institute (Nomura Sogo Kenkyusho) the Japanese robot industry will reach $1.5 billion in 1985 and $3 billion in 1990.[3]

DISCUSSION

During the past 10 years, I have visited Japan once or twice each year. During each visit, I discerned a certain mood prevailing in particular industries. For example the outlook, for several years, of the shipbuilding industry has been bleak. A unique atmosphere I perceived during the last visit was a strong interest in electronics technologies, including robots. I encountered the word "mechatronics" often, even in the daily newspapers. The word "mechatronics" is a combination of the words, "mechanical" and "electronics," and means the application of electronics technology to mechanical engineering. The word is unknown among my colleagues at the Massachusetts Institute of Technology, so I believe the word "mechatronics" was coined in Japan. There is strong interest in mechatronics in Japan.

I recognized, also, that there is a strong interest in the U.S.A. in industrial robots. However, if one could measure the degree of interest in this subject, I am positive that the intensity of the interest in robots is far greater in Japan than in U.S.A., and more, perhaps, than in any other country in the world. I, therefore, believe that the strong lead that Japan now holds in the development and uses of industrial robots will continue and may even increase in the future.

Japanese industries, just like those in other industrial nations, face many difficult problems such as increasing wages, inflation, difficulty in securing a skilled labor force, the high cost of energy and materials, prevention of pollution, and the stringent requirements for a work environment. In shipbuilding, and other labor-intensive industries, Japan increasingly feels competition from neighboring countries such as Taiwan and Korea, and in the future will feel competition from mainland China. Japanese industries feel that they must maintain their present position in the world market. The use of computers and electronics technologies are regarded as possible ways to solve, at least, some of these problems. Many companies are strongly interested in improving productivity, and the quality of their products, through the increased use of modern technology.

An important problem which many companies in the U.S.A., and other countries, experience is resistance from workers and unions against the increased use of robots. However, this is a problem that very few Japanese companies are concerned about. It is well-known now in the U.S.A. that Japanese companies seldom lay off employees. Although worker resistance against the introduction of robots is a significant problem in the U.S.A., this subject is not discussed here because it is not a serious problem in Japan.

It is interesting to note that the technology of industrial robots was first introduced to Japan by the U.S.A. In 1968, Kawasaki Heavy Industries, Limited (Kawasaki Jukogyo Kabushiki Kaisha) reached an agreement with Unimation, Incorporated. In 1970, Kawasaki developed its first Japanese-made robots. For a while, the production of robots was at a low level, on the order of 20 to 30 units per year. In 1976, for the first time, the production of robots at Kawasaki reached 100 units.[4] In 1980, Kawasaki produced about 450 units.

Today companies produce robots for various applications, as shown in Table 1.[5] The names of the manufacturers are shown in Romaji (Romanized Japanese) to facilitate correct identification of the companies. Also shown in parentheses are the English translations of many names. Robots are made in varying degrees of sophistication ranging from simple sequence robots to computer controlled intelligent machines. Simple robots are widely used. In 1978, simple robots represented about 85 percent of the number of robots and 68 percent of the value. The manufacturers of robots believe that robots with increasing sophistication and added value will be more widely used in the future.

The important fields of applications include:

- welding (spot welding and arc welding),
- painting,
- assembly, and
- nuclear applications.

The users of robots are increasing rapidly. The automobile manufacturing industry is still the largest single user of robots. However, many other industries are becoming interested in robots. This trend was confirmed during my visit to Japan. Even small family-owned companies are becoming users of robots.

WELDING ROBOTS

Today many different kinds of joining processes are used for various applications. Commonly used joining processes include:

- arc welding processes,
- resistance welding processes,
- oxyfuel gas welding processes,
- thermit welding,
- electron beam welding,
- brazing,
- soldering.

Arc welding processes, which include such processes as shielded metal arc welding, gas metal arc welding, gas tungsten arc welding, and submerged arc welding, are widely used for fabricating a variety of structures including ships, pressure vessesls, pipelines, and bridges. As far as total industrial uses are concerned, arc welding processes are the most important for joining metals. However, as far as the use of robots is concerned spot welding, which is a kind of electric resistance welding, has been until recently, the most important.

According to statistics compiled by the Japan Industrial Robot Association, production of welding robots in Japan in 1979 was 652 units, including 477 spot welding robots, and 175 arc welding robots.[6] They represent about five percent of 14,535 industrial robots for all applications produced in Japan in 1979. It must be noted, however, that most industrial robots are simple robots, while welding robots tend to be complex.

Most welding robots produced in earlier years were spot welding robots, and they were installed mainly in automobile manufacturing plants. It is believed that most major Japanese automobile manufacturing companies will complete the installations of spot welding robots within a few years. Therefore, the demand for spot welding robots may soon level off.

In recent years, the development and uses of arc welding robots rapidly expanded. The total value of arc welding robots produced in 1975 was only about $7.5 million which was about of that of spot welding robots.[7] The production of arc welding robots is increasing at an annual rate of about 35 percent. It is estimated that by 1985 the production of arc welding robots will reach $100 million, while the production of spot welding robots will be around $90 million.

Since arc welding processes are more widely used for various applications than spot welding, the wide use of robots in arc welding will produce far reaching effects on the metal fabrication industries. Today about 200,000 units of semiautomatic arc welding machines are installed in various industries in Japan.[8] If one assumes that about of them may be replaced by robots, there will be about 50,000 arc welding robots.

Table 2 shows names of major manufacturers of arc welding robots, trade names of their robots, and the production size.[2] The prices of arc welding robots range from $45,000 to $150,000.[6]

As an example of an advanced arc welding robot, Figure 1 shows a robot capable of multilayer welding of a nozzle to a tube.[9] This robot has been developed, and is being used, at Hitachi, Limited The welding torch can be moved in five degrees of freedom including X, Y, Z directions, swivelling motion around the Z-axis (SW), and control of the angle of the torch (BD). The torch is mounted on an L-shaped metal piece to have enough clearance to allow free movement of the torch without hitting the nozzle to be joined. As the welding progresses, the position of the torch must be changed to accommodate the change of the cross section of the weld metal. The necessary controls are done automatically by use of microcomputers.

SOURCES OF INFORMATION

I now identify major sources of information. I visited people at the following organizations:

- Brother Industries, a manufacturer of sewing machines,typewriters,
- Hitachi Limited, a manufacturer of electrical machines and appliances,
- Hitachi Shipbuilding and Engineering Company, a manufacturer of ships, offshore structures,
- Ishikawajima Harima Heavy Industries, a manufacturer of ships, jet engines,
- Kawasaki Heavy Industries, a manufacturer of ships, aircraft,
- Kobe Steel, a steel producer and manufacturer of various machines,
- Kubota, Limited, a manufacturer of agricultural and other machines,
- Mitsubishi Heavy Industries, a manufacturer of ships, aircraft,
- Mitsui Engineering and Shipbuilding Company, a manufacturer of ships, offshore structures,
- Nippon Kokan K.K., a steel producer and a manufacturer of ships and other machinery,
- Nippon Steel Corporation, a steel producer,
- Osaka Transformer Company, a manufacturer of welding and other machines,
- Sumitomo Heavy Machinery Company, a manufacturer of ships and other, machinery
- Toshiba (Tokyo Shibaura Electric Company), a manufacturer of electrical machines and appliances,
- Toyota Motor Company, a manufacturer of automobiles,
- Japan Welding Society, a technical society on welding,
- Japan Welding Engineering Society, a professional association on welding,
- Hiroshima University, a national university in Hiroshima,
- Kyushu University, a national university in Fukuoka,
- Toyota Technological Institute, a new technical university in Nagoya established by Toyota Motor Company.

Discussions with representatives of these organizations covered a wide range of subjects. However, the development and uses of welding robots were important subjects on many occasions.

I have collected various documents. These documents, and the discussions held during the visits, comprise most of the information included in this report.

SUGGESTED SOURCES OF FURTHER INFORMATION

Listed below are the names and addresses of associations and societies related to industrial robots and welding:

- Japan Industrial Robot Association
  (Nihon Sangyoyo Robot Kogyokai)
  Kikai Shinko Building
  3-5-8 Shiba Koen
  Minato-ku, Tokyo
  Mr. T. Ando, President

- Japan Welding Society
  (Nihon Yosetsu Gakkai)
  1-11 Kanda Sakuma-cho
  Chiyoda-ku, Tokyo
  Professor I. Masumoto, President

- Japan Welding Engineering Society
  (Nihon Yosetsu Kyokai)
  1-11 Kanda Sakuma-cho
  Chiyoda-ku, Tokyo
  Professor H. Kihara, President

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance given by Mr. Hiroshi Kaneno of Nittetsu Yosetsu Kogyo (Nippon Steel Welding Products and Engineering Company) in obtaining various documents on welding robots. At the request Dr. Young B. Kim, Director at the Office of Naval Research, Far East, I prepared this paper for the *Scientific Bulletin*.

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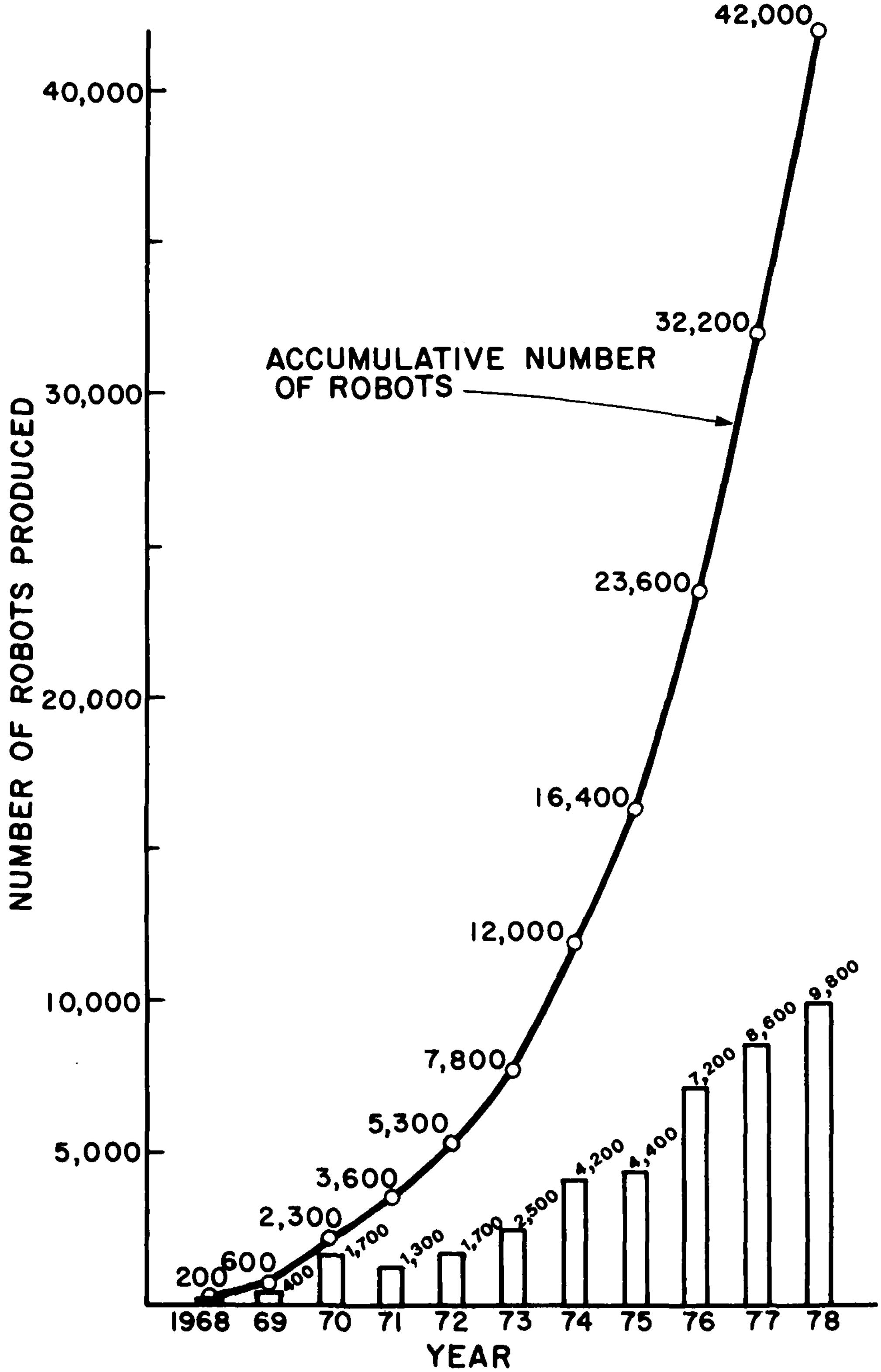

FIGURE 1 Yearly production of industrial robots in Japan

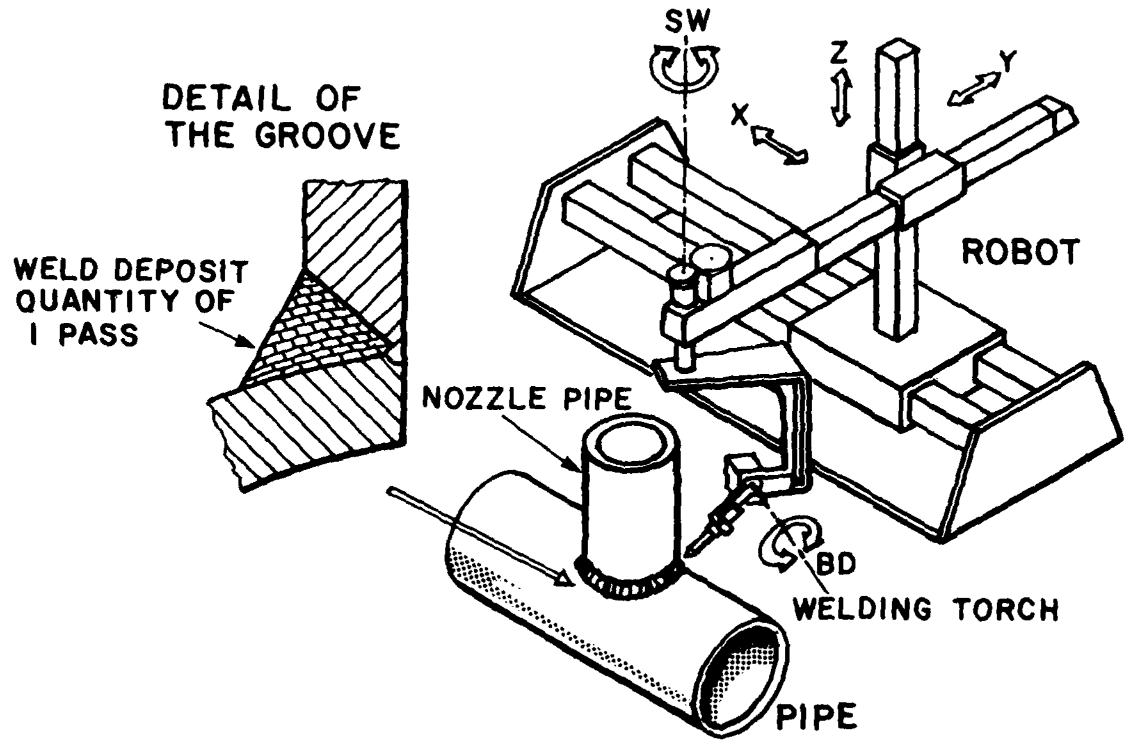

FIGURE 2 A robot capable of multipass welding of a nozzle to a tube[9]

TABLE 1. MAJOR MANUFACTURERS OF INDUSTRIAL ROBOTS

APPLICATIONS	COMPANIES
Casting	Kawasaki Jukogyo (Kawasaki Heavy Industries)
Die Casting	Showa Kuatsuki Kogyo (Showa Pneumatic Machinery Company)
Forging	Komatsu Seisakusho (Komatsu, Limited) Aida Engineering Company Kobe Seikosho (Kobe Steel Works, Limited)
Assembly	Kawasaki Jukogyo (Kawasaki Heavy Industries) Shinko Denki (Shin-Kobe Electric Machinery Company) Daido Tokushuko (Daido Special Steel Company)
Heat Treatment	Kawasaki Jukogyo (Kawasaki Heavy Industries) Fujikoshi, Limited Shinko Denki (Shin-Kobe Electric Machinery Company)
Machining and Grinding	Fujitsu FANUC, Limited Kawasaki Jukogyo (Kawasaki Heavy Industries) Shinko Denki (Shin-Kobe Electric Machinery Company) Star Seiki (Star Precision Machinery Company) Hitachi Seisakusho (Hitachi, Limited) Fuji Denki Seizo (Fuji Electric Company) Mitsubishi Jukogyo (Mitsubishi Heavy Industries) Yasukawa Denki Seisakusho (Yasukawa Electric Manufacturing Company)
Press	Aida Engineering, Limited Toshiba Seiki (Toshiba Precision Machinery Company) Orii Daido Tokushuko (Daido Special Steel Company)
Plastic Forming	Star Seiki (Star Precision Machinery Company) Kyoshin Denki (Kyoshin Electric Company) Ichiko Kogyo (Ichiko Insdustries, Limited)
Spot Welding	Kawasaki Jukogyo (Kawasaki Heavy Industries) Toshiba Seiki (Toshiba Precision Machinery Company) Mitsubishi Jukogyo (Mitsubishi Heavy Industries) Fujikoshi, Limited

Arc Welding	Yasukawa Denki Seisakusho (Yasukawa Electric Manufacturing Company) Shin Meiwa Kogyo (Shin Meiwa Industry Company) Hitachi Seisakusho (Hitachi, Limited) Fujikoshi, Limited Kobe Seikosho (Kobe Steel Works, Limited) Kawasaki Jukogyo (Kawasaki Heavy Industries) Osaka Henatsuki (Osaka Transformer Company) Matsushita Sangyokiki (Matsushita Industrial Machinery Company)
Painting	Kobe Seikosho (Kobe Steel Works) Mitsubishi Jukogyo (Mitsubishi Heavy Industries) Hitachi Seisakusho (Hitachi, Limited) Fujikoshi, Limited Tokico, Limited Kawasaki Jukogyo (Kawasaki Heavy Industries)

Note: The original list in Reference 5 also shows names of robots for inspection, nuclear, ocean, and medical applications.

TABLE 2. MAJOR MANUFACTURERS OF ARC WELDING ROBOTS[2]

NAMES OF MANUFACTURERS	TRADE NAME OF ROBOTS	PRODUCTION SIZE
A. Small-size robots with strokes of less than 1,000 mm (40 inches)		
Yasukawa Denkia	Motoman L10	A
Hitachi Seisakusho	Process Robot	E
Fujikoshi	Uniman 7000	E
Fujikoshi	Uniman 4000	C
Osaka Henatsuki	Computer Robot	C
Shin Meiwa	PW751T	E
Shin Meiwa	PW751	B
B. Medium-size robots with strokes of 1,000 to 2,000 mm (40 to 80 inches)		
Shin Meiwa	PW150T	C
Fujikoshi	Uniman 4000	D
Hitachi Seisakusho	Aros Jr.	E
Hitachi Seisakusho	Process Robot	E
Yasukawa Denki	Motoman L10	E
Kobeseiko	Arcman	E
Osaka Henatsuki	Computer Robot	E
C. Large-size robots with strokes of over 2,000 mm (80 inches)		
Shin Meiwa	PW200T	D
Hitachi Seisakusho	Mr. Aros	D
Kobe Seikisho	Arcman	E

A: Over 100 units
B: Over 50 units
C: Over 20 units
D: 6-19 units
E: less than 5 units

INTERNATIONAL SYMPOSIUM ON GaAs AND RELATED COMPOUNDS AND RELATED LABORATORY VISITS

Howard Lessoff and D. Eirug Davies

The 1981 International Symposium on Gallium Arsenide and Related Compounds was held on 20-23 September 1981, at the Oiso Prince Hotel in Oiso, Japan. After attending the conference, visits were made to a few electronic research facilities in Japan. This report will discuss both the conference and the visits made.

THE CONFERENCE

The town of Oiso is on the east coast of Japan just south of Tokyo in the area considered to be the Japanese Riviera. The location is of natural beauty and was the ninth stage of the Fifty Three Stages of the Tokaido, the route between Edo (Tokyo) and Kyoto illustrated by Hiroshige in his famous print series. The conference, initiated in 1966, was held every two years but with the growth of the III-V electronic technology it is now held every year with the location alternating between Europe, the United States and now, most likely, Japan. This year's meeting was sponsored by the Institute of Electronics and Communication Engineers of Japan, the Institute of Electrical Engineers of Japan, the Japan Society of Applied Physics, and the Japanese Association of Crystal Growth.

The meeting registration of approximately 400 included participants from 12 nations. There were 109 papers scheduled with additional late new papers and two evening discussion sessions, one on semi-insulating GaAs and the other on microwave devices.

On Monday evening, 21 September 1981, the conference banquet was held. At the banquet, the fourth GaAs Symposium Award was given to Professor G. L. Pearson of Stanford University, for his outstanding contributions to the understanding of III-V materials and device physics. Earlier award winners were Drs. N. Holoynak (1976), C. Hilsum (1978), and H. Yanai (1980).

Japan contributed 48 percent of the papers while the United States, France, and West Germany contributed 30 percent, eight percent and six percent, respectively. There were also excellent contributions from the United Kingdom, Italy, and Austria. Because of the large number of papers being presented the conference had two parallel sessions with the exception of the opening session on GaAs integrated circuits. The titles and authors of the presentations are included in Appendix I. The Proceedings of the Conference are scheduled for publication in mid-1982. Preprints in most cases may be obtained from the authors. Because of the size and the scope of the meeting, it would not be practical to describe every paper presented, but rather an attempt will be made to give an overview of the various sessions.

In the conference opening session, GaAs Integrated Circuit, F. H. Eisen gave the invited paper on the current status of the III-V Integrated Circuit technology. The session stressed the need for a semi-insulating substrate in order to achieve low parasitic capacitance or higher transconductance and isolation of devices. The papers were very optimistic for the potential of GaAs to achieve significant speed and power advantages over similar sized silicon circuits and devices. Clock frequencies as high as 3.4 GHz for flip-flop binary dividers were reported by Mitsubishi Electric Corporation. Propagation delays in GaAs are reported to be an order of magnitude better than that of silicon for the same device geometry, N. Hachizume *et al.* reported 13-stage ring oscillator exhibiting a signal delay time of 59 picoseconds per gate and a power consumption of 3.8 mW per gate, by going to 1 micron gates, the delay can be reduced to 17 picoseconds with corresponding lower power per gate. K. Asai reported a 16-bit static RAM having an address access time of 10 ns with 1.89 mW power dissipation. Less thermal instabilities have been found in LEC "undoped" substrates as developed at NRL when compared to Cr doped substrates, but dielectric encapsulation remains an important problem. The session was quite optimistic for near time applications of GaAs Integrated Circuit in high speed applications. The use of Pt as the gate metal for resistance reduction and better threshold control was suggested in a paper from Toshiba. More ideal output characteristics were obtained in normally off MESFET, with 152 mV threshold over two inch wafers and less dependence on Cr variations. A 16-bit static ram with 172 enhancement and 94 depletion mode FETs was described in work from NTT. An implant dose evaluation was performed prior to the different dose implants for the two transistor types and the resulting circuit has a 10 ns address time and a power dissipation of 1.89 mW. Other contributions included a binary frequency divider with a graded epitaxial channel for the normally off MESFETs and Schottky barrier coupled FET logic circuits, again with lower power consumption normally off FETs.

The session on Deep Levels raised more questions on what is the dominant deep level leading to semi-insulating behavior in undoped GaAs than it gave definitive answers, partially because electrical characterization will determine levels at a lower concentration than the available chemical/physical means. The so-called EL-2 donor level has been variously assigned as due to oxygen, a gallium vacancy, or gallium complexes. In a paper by Kaminaska, oxygen was used,

- to reduce silicon incorporation,
- to induce shallow donor levels, and
- to induce indirectly deep states which cause the semi-insulating behavior.

The deep states may be related to vacancy formation and possibly an arsenic on a gallium site. The antisite may be correlated with the EL-2 level. A paper by G. Bremond discussed the deep levels in indium phosphide and the rapid out diffusion of Fe and Cr from semi-insulating substrates.

Session IV on Surfaces and MIS/Interface Properties covered the range of materials from the binaries to the quaternary alloys. The invited paper by I. Lindau of Stanford University, reviewed the use of synchrotron radiation in surface investigation where one to two atomic layers can be studied. The effect of Fermi level pinning positions with amount of surface coverage for metal over layers on GaAs, InP, and GaSb was presented. D. S. Sun showed the degradation of Al contacts on GaAs is due to the surface condition of the GaAs at the time of Al deposition and is influenced by oxygen, as well as Ga or As rich surface conditions. A potential solution is to grow a GaAlAs layer prior to Al deposition. The paper by R. Kaumanns discussed methods to control the surface properties of substrates and the influence of stress on the surface state density. MIS diodes were fabricated with SiO_2 insulators on $Ga_xIn_{1-x}As$. A series of papers were presented on InP MIS diodes and FETs, with K. Ohata discussing InP MISFETs having effective mobilities of 1200 $cm^2V^{-1}s^{-1}$, and cut off frequencies of 9.5 GHz. This session had very promising connotations for high speed device applications.

Session VII, LPE Growth and Layers, was primarily on the growth of the ternary and quaternary alloys with the major emphasis on the materials electrooptical properties. K. Tabatabaie-Alavi presented a paper on the ability to grow p^+ -n InGaAs on InP as a photodetector at 1.3 μm. By controlling the background Si concentration to $10^{15}/cm^3$ or lower in InP, mobilities up to 7,800 were achieved. Very abrupt junctions were developed by controlling the vapor pressure of the Zn or Cd for "p" impurity. Y. Nakano reported an anomalous effect in the growth of p-n InP junctions for buried heterostructure lasers. If using Sn as the "n" dopant, a thin "n" layer is grown on "p" InP then no photoluminescence was observed; however, if the "n" layer is grown first followed by a "p" layer then photoluminescence is obtained. The effect was explained by the formation of a high resisitivity layer at the "p" interface and obtaining "hole" traps. Two papers on the system $Ga_{1-x}Al_xSb$ were presented. There appears to be a direct to indirect transition at x = 0.22 and a second cross over at $x \simeq 0.45$. The change of carrier lifetimes was used as a measure of the cross over positions. By growing films at lower temperatures 400°C compared to 540°C, there was a reduction in the carrier concentration by two orders of magnitude. In a late newspaper, G. H. Olsen discussed the growth of InGaAs on InP and found that the best morphology and photoluminescence occurred using substrates 2° of the (311) direction. There was considerable discussion and speculation for this substrate orientation including packing density and dangling bonds.

In the bulk crystal growth area, many papers were presented discussing the role various background impurities play in the properties of semi-insulating GaAs both "undoped," oxygen doped, or chromium doped. R. G. Wilson indicated that total impurity concentration should be below $10^{16}cm^{-3}$. At these low concentrations, high mobility material can be prepared by ion implantation. He also found that by annealing material in nitrogen rather than hydrogen, the "manganese" surface layer does not occur indicating that the Mn may be from external sources. The applicability of semi-insulating GaAs substrate for integrated circuit application was discussed in a paper by Y. Nanishi. Among the material variables considered was chromium concentration, silicon concentration, and type of crucible used. Among the conclusions was that "undoped" NRL-type material is more uniform than chromium doped material, and additional attention must be paid to the growth interface to control situations. Other papers in the session on GaAs discussed the incorporation of oxygen and silicon in GaAs. There were three papers on InP, two were concerned with crystal growth and defect density with low defect density reported for small diameter crystals. A computer controlled LEC growth method was presented by E. Kubota for automatic diameter control. Dr. Morioka discussed Fe in LEC InP and gave data demonstrating that the high resisitivity of InP is thermally stable at 750°C for 30 minutes with Fe concentrations as low as 0.22 ppma. T. Fukuda presented the results of large diameter growth of GaP single crystals by the LEC technique using automatic diameter control on (111) and (100) grown material. The dislocation density was about 1 to $10^4/cm^2$ and the mobility was 10% higher than commercial material if the LEC technique with automatic diameter control was used for growth.

The main emphasis in optoelectronics was on photodetectors and nonradiative effects in longer wavelength sources. Growth procedures involving elaborate baking schedules for reducing the background doping to $5\ 10^{14}cm^{-3}$ in LPE GaInAs was described in a paper from Bell. The resulting material was used for making p-i-n detectors and heterojunction phototransistors with gains to 1000. For avalanche devices, measurements taken at the University of Illinois indicate that the hole to electron ionization ratio in InP is only 1.34 and consistent with detector noise performance. Work at Bell Laboratories showed that such low ratios can be effectively increased to 7.510 and more in line with detector requirements by avalanching in a graded bandgap layer. Similar increases apparently occur on avalanching through superlattice layers. For sources, the leakage of carriers over heterojunction barriers was illustrated optically in a novel DH Led structure. A theoretical paper summarizing Auger processes predicts such effects to predominate over radiative recombination at least in alloys for wavelengths greater than 2 μm. There still does not appear to be a consensus as to what mechanism accounts for the poor temperature behavior of quaternary lasers.

Most of the contributions in the device processing session were directed at implanting into semi-insulating GaAs and the instability and variations associated with the substrate Cr doping. One of the two rump sessions was devoted to the topic and the general consensus appeared to be that it is better to use undoped LEC and avoid the Cr compensated material. However, no definitive direct comparison was set forth and many of the variations may be aggravated by substandard annealing procedures. Of the contributed papers, Washburn (Berkeley) showed Cr accumulation in the more densely damaged region of the implant. Work performed at Fujitsu showed better characterized profiles on using thermally matched AlN rather than SiO for encapsulation. In view of the natural affinity of Al for O_2, it is not clear whether the AlN was as pure as claimed. A capless annealing scheme using a large GaAs disc perpendicular to an Ar/H_2 gas flow was described by Nippon Telegraph and Telephone. It is still felt that the use of AsH_3 (using Ph_3 for InP) is the most controllable means of annealing III-V compounds and with the additional benefit of not introducing dielectric interface strain. A later visit to Hitachi showed that this is the procedure adopted in their very successful MESFET devices. NRL presented a paper on TEDs prepared by both ion implantation and epitaxial growth layers. Microwave and milimeter wave properties were presented. Davis of RADC discussed the use of pulse annealing in GaAs for activation of implanted layers. A late new paper by Link of Thomson CSF received a lot of interest. By using a heterostructure of n-AlGaAs, high purity n-GaAs on p-high purity GaAs excellent normally off FETs with exceptional properties were made at high frequency at 77°K noise of 0.4 to 0.5 dB and gains of 15 dB were reported. This technique of preparation of FETs received a large amount of attention and offers promise of very low noise high gain microwave and millimeter wave devices.

The session in vapor phase growth including metal-organic, molecular beam epitaxy was emphasized MOCVD and MVE. It is quite apparent that major efforts in quantum well structures and ultra-high mobility layers are being studied for both E/O and high frequency potential, with MOCVD and MBE giving the best controls in composition and thickness control.

LABORATORY VISITS

During the week following the conference at Oiso, a series of visits to laboratories in Tokyo, Kyoto, and Osaka were made. In all cases, we were excellently received. A major impression of the Japanese staff is their extreme enthusiasm concerning their work and their employer. Unlike American companies, employment in Japan usually means a lifetime commitment between the employee and the employer. Most of the personnel have an excellent command of the English language and are well aware of Western scientific literature.

THE MUSASHINO ELECTRICAL COMMUNICATIONS LABORATORY

The Electrical Communications Laboratories were established in 1891 in the Ministry of Communications; The Nippon Telegraph and Telephone Public Corporation, NTT, was established in 1952 taking over the activities of the Ministry. NTT has three major laboratories, the Musashino, the Yokosuka, and Ibaraki with the former established in 1950 where research and development is concentrated. The laboratories have functions similar to the Bell Telephone Laboratories of the Bell System with one major exception. NTT does not manufacture the communications equipment as does Western Electric for the Bell System, but rather the technology is transferred to private industry for manufacture.

The Musashino Laboratory is located in a suburb of Tokyo and is the largest of the ECL units with a staff of about 2,000. The Deputy Director is Mr. Makoto Watanabe, the former Division Director of the Integrated Electronics Development Division. The Musashino Laboratory has responsibility for research and development in electronic switching, memories, IC's future communication systems and information processing, new components and materials, as well as fundamental research in such areas as III-V semiconductors, superconductivity, optical transmission, and acoustics. The semiconductor and integrated circuits areas which were visited, were well-equipped having the latest technology in growth, characterization, and I.C. technology. Work which was discussed included the GaAs and InP material growth and characterization, MIS InP devices and GaAs IC's. Using Japanese made high pressure crystal pullers (Seidensha, SELEC) automatic diameter-controlled growth has been developed for InP having a weighing cell on the pull rod and monitoring the pull distance. Corrections have been made for buoyancy, crucible position, and rotation effects.

There are major efforts underway on III-V device growth techniques to form the active layers which include ion implantation, metal organic chemical vapor deposition, and liquid phase epitaxy. The materials being studied include, InP, InAs, GaAs, InGaAs, InGaAsP and InAsSbP. Devices under evaluation are MIS structures, integrated circuits, MES FETs, TEDs, J. FETs, phototransistors, light amplifiers, optical switches, optical sources, wave guides, and many other devices for integrated optics.

The integrated circuits area is very well-equipped with all the standard tools including Ebeam facility (Thomson-CSF, EPG102), molecular beam epitaxial equipment, and ion implantation capability. GaAs MESFETs have been made as 15-stage ring oscillators and direct coupled GaAs normally-off MESFET logic having a clock frequency of 3.4 GHZ. Much of the efforts appear to be aimed towards optical and satellite communications and longer wave length (1.3 μ m or longer). Optical fiber technology is being vigorously pushed.

KYOTO UNIVERSITY

The university was founded in 1897 as the Kyoto Imperial University and is located east of the Tohano River in Kyoto. The university, one of the most prestigious of Japan, has a large number of colleges and approximately 40 subsidiary establishments throughout Japan. There are approximately 1,275 professors and associate professors with about 260 in the College of Engineering. The University also has about 1,100 instructors (similar to Assistant Professor in the U.S.A.). The members of the faculty are mainly graduates of Kyoto University, for in Japan the selection of faculty members favors graduates of the selecting institution.

The student population in 1980 was 11,500 undergraduates and 3,250 graduate students with about 47% of the students being enrolled in the School of Engineering. Of this number in 1980, the number of foreign scholars and students in the School of Engineering is 10 and 76 respectively. The admission requirements for the university include having an excellent record in secondary schools as well as high scores on the precollege examinations. Generally the students do not live in the dormitories, but rather have housing in the surrounding area. An interesting aspect of the graduate research, at least in the areas visited, was that the students built and/or assembled their research apparatus. This included vacuum systems, epitaxial reactors, etc. This policy appears to result in the students developing excellent laboratory skills. The students have enthusiasm for their work and achievement. Long hours are spent at the university, with free evenings and weekends essentially nonexistent or, at best, very rare.

The School of Electrical Engineering was established in 1897 and consists of three departments with six chairs within each department. There are also four specialized laboratories as well as a chair for electrical engineering education. The departments are: Electrical Engineering, Electronics, and Electrical Engineering II. The specialized laboratories are Automation Research, Ionosphere Research, Ion Beam, Engineering Experimental and Institute of Atomic Energy. Each professor generally has one Associate Professor and a number of instructors. Appendix II lists the major sections of the Electrical Engineering School. Each year 120 undergraduate students are admitted and the maximum number of graduate students is 85. The undergraduates are required to take 96 credits in science and engineering as well as 44 credits in General Studies. In the senior year each student must choose one of the chairs for his graduation research work. This work is very similar to an advanced senior thesis and requires both written reports and oral exams for graduation. The graduate students at the master level must take 30 credit hours of advanced courses and complete a rigorous research program for a master's thesis. There is also a doctoral program with very difficult thesis and exam requirements. The major funding of the research programs normally is grants from the Ministry of Education. Proposals for funds are made as in the United States.

Professor H. Matsunami, Associate Professor of Semiconductor Engineering, whose activities include MOCVD of silicon carbide on silicon substrates as well as other wide band gap semiconductors, such as ZnS, ZnSe for blue light emitting devices. His group has grown SiC films up to 20 μm in thickness with carrier concentrations in the order of 10^{18}. Blue light emitting diodes have been made with the Sanyo Company now manufacturing such items. Other work in the group includes studies of InGaAsP for visible light lasers, preparation and photo-optic potential of PℓZT, studies of amorphous semiconductors, and the preparation and characterization of candidate materials for solar cells.

Professor Sasaki heads one of the few groups who have a vigorous optical device program based on GaSb as well as InP. A study to improve GaAlSbAs LPE growth is being pursued in the belief that the inadequacy of antimonide lasers is not necessarily a fundamental indirect transition problem but may be related to material and interface quality. In this regard, RADC has contracted Rockwell to investigate the MOCVD growth of this quaternary.

The potential of growing the ternary $In_{.52}Ga_{.48}As$ lattice matched to InP was recognized as early as 1972 and well before the current worldwide interest in the material. Recently, avalanche photodiodes with multiplication factors ~90 have been fabricated without the customary necessity of confining the diode's high field region to an InP layer. It is believed that the low carrier concentration achieved in the ternary enables avalanching to occur before the onset of the tunneling as is normally observed.

An integrated photoamplifier built in InP/InGaAsP appears to be another interesting device. A heterojunction bipolar phototransistor is used to modulate a double heterojunction laser. Optical gains of ~900 have been realized.

TOKYO INSTITUTE

Both campuses were visited, and at Yokohama a number of diversified projects were seen. Amorphous silicon is being investigated as a potential xerographic sensor. It is deposited by glow discharge on polyamide films and fluorine is preferred to hydrogen for satisfying the dangling bonds. The resulting material is stable to higher temperatures (~800° C) than is the case with hydrogen. Work is in progress on developing a planar glass lens. Focussing occurs as a result of varying the refractive index radially. The refractive index is modified by a field assisted diffusion of thallium from a salt into the glass. In III-V compounds, an MOCVD growth study was initiated as a result of difficulties encountered with growing InGaP by L.P.E. This is now being extended to GaInAlP (on GaAs) and to the antimonide system as well. These wider gap materials are to be used for visible leds. Work is also being done on SiC for the same purpose and on ZnCdS Se quaternary for low electron energy display panels.

Most of the injection laser work is pursued at the Yokohama campus under the direction of Professor Suematsu. The excellence of the work in this area is exemplified by a repeaterless 27 km single mode fiber they have installed to link the two campuses. Apart from serving the usual communication requirements it is also being used to relay lectures from one site to the other.

InGaAsP quaternary lasers have been fabricated to coincide with both of the 1.3 μm and 1.55 μm optimum transmission wavelengths of optical fibers. The dissolution of the low phosphorus content active layer by the subsequent InP growth in the 1.55 μm device is prevented by a thin 1.25 μm composition antimelt back region and this is no longer considered a problem. The temperature dependence of threshold current cannot be accounted for in terms of Auger mechanisms as has been suggested in the past, and Suematsu believes that it can be better explained in terms of their proposed intervalence band absorption losses. For high frequency modulation, the widths of the spectral envelope of a conventional buried heterojunction laser was found to increase as much as 80°A at 1 GHz. A single wavelength spectrum could be retained at such frequencies on incorporating distributed feedback into the structure. These lasers are now to be used as the basic source element in designing integrated optical circuits.

OSAKA UNIVERSITY

Professor Namba hosted the 1974 International Implantation Conference and his laboratory is well-known for its activities in this area. At the present conference a DLTS study on laser annealed GaAs was described. Relatively few defects were observed in contrast to the RADC work which can account for most of the deficiencies of pulse annealing on the basis of observed heavy carrier compensating effects. More recent photoluminescence measurements still being taken at Osaka showed a drastic reduction in luminescence that coincides with pulse melting and more in line with our own work.

Apart from the ruby laser used for the above, Nd, CO_2 and CW argon lasers are also available. The 5% stability of the argon system is not considered sufficient for annealing GaAs and is currently being upgraded. Some very interesting work is being done in Si with the Nd laser. By taking time resolved transmission measurements during the annealing the melt resolidification velocity can be directly measured for the first time. Maximum velocities of 4.5 $msec^{-1}$ has been obtained and as no transmission occurs over part of the cycle it is concluded that melting occurs and that the annealing is not a plasma process.

SUMITOMO ELECTRIC INDUSTRIES LTD., ITAMI

In the Itami plant, on the outskirts of Osaka, is a very large modern facility for the growth and preparation of III-V semiconductors. The plant includes compounding from the elements, Bridgman and gradient freeze method, Czochralski, including high pressure LEC techniques, epitaxial growth, wafer cutting and polishing, and characterization. Nearly all the III-V binary alloys have been, or are being produced in large quantities. The facility is indeed impressive when it is compared to any other III-V facility in the United States or

Western Europe. The plant is very much attuned to the advantages of automation with computer controlled processes playing a dominant role within the plant.

The research and development at the Osaka research, laboratory appears to be very closely coordinated with the production capability at Itami. Dr. Tsuneo Nakahara is Managing Director of the Research and Development Group at Osaka and Dr. Shin-ichi Akai, is Chief Engineer and Manager of the Semiconductor Department at Itami. Current crystals being pulled by LEC at Itami include GaP, GaAs, InP, and GaSb. There are a number of high pressure pullers similar in capacity to the Metals Research Corporation's pullers, but made in Japan by Seidensha. These pullers are facilitated for automatic diameter control and semi-insulating "undoped" GaAs (100) is now being pulled in production. The crystal slices are lapped with alumina then chemically etched in a chlorate solution to remove machine damage. The etch pit density of gradient freeze two inch wafers is about $10^4/cm^2$ and for LEC two inch wafers about $4x10^4/cm^2$. "Undoped" semi-insulated GaAs is also being grown by the gradient freeze method by stoichiometry control and control of silicon pick-up from the reactors.

APPENDIX I

The authors and conference papers were grouped into the following categories:

GaAs ICs

F. H. Eisen
Rockwell International
Microelectronics R and D Center
Thousand Oaks, CA 91360
U.S.A.

Materials and processes for GaAS integrated circuits

N. Toyoda
Toshiba R and D Center
Toshiba Corp
1, Komukai Toshiba-cho
Saiwai-ku, Kawasaki
Japan

An application of Pt-GaAs reaction to GaAs IC's

C. F. Krumm
Hughes Research Laboratories
Malibu, CA 90265
U.S.A.

Material and process sensitivity for GaAs integrated circuits

K. Asai
Musashino Electrical Communication Laboratory, NTT
Tokyo, Japan

GaAs E/D FET technology for applications to static ram

F. Damay-kavala
Thomson-CSF
Central Research Laboratory
Domaine de Corbeville
91401 Orsay-Cedex
France

Speed-power performances in sequential GaAs logic circuits

Y. Mitsui
LSI R and D Laboratory
Mitsubishi Electric Corporation
4-1, Mizuhara, Itami
Hyogo 664
Japan

Binary frequency divider using improved GaAs normally-off MESFETs

L. M. Su
Institute of Semiconductor Electronics
Aachen Technical University
Templergraben 55
D-5100 Aachen
Federal Republic of Germany

Wide gap emitter pnp bipolar transistor for GaAs SFL (substrate fed logic)

N. Hashizume
Electrotechnical Laboratory
1-1-4 Umezono, Sakura-Mura
Niihari-Gun, Ibaraki
Japan

Schottky barrier coupled Schottky barrier gate GaAs FET logic

DEEP LEVEL

T. Ikoma
Institute of Industrial Science
University of Tokyo
7-22-1, Roppongi
Minato-ku, Tokyo 106
Japan

Change of deep levels is Fe-, O- and nondoped liquid phase epitaxial GaAs after electron beam irradiation and annealing

M. Kaminaska
Massachusetts Institute of Technology
Cambridge, MA 02139
U.S.A.

Oxygen induced levels in GaAs

H. Nakashima
Central Research Laboratory
Hitachi Ltd.
Kokubunji, Tokyo 185
Japan

Deep-level photoluminescence in annealed semi-insulating GaAs

Phil Won Yu
University Research Center
Wright State University
Dayton, OH 45435
U.S.A.

Photoluminescence study in LEC GaAs

S. Sriram
Department of Electrical Engineering
Solid State Device Laboratory and
Materials Research Laboratory
The Pennsylvania State University
University Park, PA 16802
U.S.A.

Determination of deep level impurities and their effects on the small signal and LF noise properties of ion-implanted GaAs MESFETs

Y. Yuba
Faculty of Engineering Science
Osaka University
Toyonaka, Osaka 560
Japan

Deep levels in implanted and laser annealed GaAs studied by current- and capacitance-transient measurements

K. Kondo
Fujitsu Laboratories Ltd.
1015 Kamikodanaka, Nakahara-ku
Kawasaki 211
Japan

Recombination-induced deep-level formations in GaAlAs DH LEDs

K. Hikosaka
Fujitsu Laboratories Ltd.
1015 Kamikodanaka, Nakahara-ku
Kawasaki 211
Japan

Deep electron traps in MBE-grown AlGaAs ternary alloy for hetero-junction devices

G. Bremond
Laboratoire de Physique de la Matiere
Institut National des Sciences
Appliquees de Lyon
20, Avenue Albert Einstein
69621 Villeurbanne
Cedex, France

Deep impurity levels in InP

MICROWAVE DEVICES

P. R. Jay
Laboratoire Centrale de Recherche
Thomson-CSF
Corbeville BP 10
Orsay 91401
France

Comparison between microwave parameters and magneto-transconductance mobility measurements on submicron GaAs MESFETs

T. Onuma
Semiconductor Research Laboratory
Matsushita Electric Industrial Co., Ltd.
Moriguchi, Osaka 570
Japan

Fully ion implanted GaAs JFET fabrication technology

K. Lehovec
University of Southern California
Los Angeles, CA 90007
U.S.A.

Soft threshold of GaAs field effect transistors

M. Nishiuma
Semiconductor Research Laboratory
Matsushita Electronics Corporation
Takatsuki, Osaka
Japan

A GaAs monolithic low-noise wide-band amplifier

H. Yamasaki
Torrance Research Center
Hughes Aircraft Company
3100 West Lomita Blvd.
Torrance, CA 90509
U.S.A.

Design of millimeter wave FETs

S. H. Wemple
Bell Laboratories
Murray Hill, NJ 07974
U.S.A.

Design principles for source-via power GaAs FETs

B. S. Hewitt
Raytheon, SMDO
Northboro, MA
U.S.A.

The design fabrication and performance of a high power ku-band GaAs FET

Y. Tajima
Raytheon Company
Research Division
28 Seyon Street
Waltham, MA 02254
U.S.A.

A monolithic 7-12 GHz power amplifier

J. Henaff
CNET Paris-B
Department MAE
92220 Bagneux
France

New mode in GaAs monolithic saw devices

Yu V. Gulyaev
Institute of Radio
Engineering and Electronics
Academy of Sciences of the USSR
Moscow, USSR

Millimeter wave integrated circuits on GaAs

SURFACE AND MIS INTERFACE PROPERTIES

I. Lindau
Stanford Electronics Laboratories
Stanford University
Stanford, CA 94305
U.S.A.

The defect states model for Schottky barrier formation on III-V semiconductors

D. C. Sun
Institute of Industrial Science
University of Tokyo
22-1, Roppongi 7-chome
Tokyo 106, Japan

Stabilization of Schottky barrier properties of single-crystal Al/GaAs contacts prepared by molecular beam epitaxy

G. P. Li
Department of Electrical Science and
Engineering
University of California
Los Angeles, CA 90024
U.S.A.

A surface defect model for carrier transport of GaAs Schottky structures

M. Ozeki
Fujitsu Laboratories Ltd.
1015 Kamikodanaka, Nakahara-ku
Kawasaki, Japan

Surface analysis in GaAs MESFET by gm frequency dispersion measurement

R. Kaumanns
Institute of Semiconductor Electronics
Aachen Technical University
Templergraben 55
D-5100, Aachen
Federal Republic of Germany

Surface states and field effect on $Ga_{0.47}In_{0.53}As$ layers

H. Hasegawa
Department of Electrical Engineering
Faculty of Engineering
Hokkaido University
Sapporo 060
Japan

Photoionization cross section and threshold of interface states in GaAs and InP MOS structures

R. Singh
Department of Electronics and
Communication Engineering
University of Roorkee
Roorkee - 247672
U.P.
India

Interfacial properties of reactively deposited alumina film on gallium arsenide

Y. Hirayama
Department of Electronic Engineering
University of Tokyo
7-3-1 Hongo, Bunkyo-ku
Tokyo 113, Japan

Plasma anodic aluminum-oxide InP MIS diode

Y. Shinoda
Electrical Communication Laboratory
NTT Musashino-shi
Tokyo 180, Japan

High mobility in $In_{1-x}Ga\ As\ P_{1-y}$ inversion-mode MISFETs

K. Ohata
Basic Technology Research Laboratories
Nippon Electric Company, Ltd.
4-1-1 Miyazaki, Takatsuki
Kawasaki 213, Japan

Investigation on SiO_2/InP MIS system and enhancement-mode MISFETs

OPTOELECTRONIC DEVICES

J. Barnard
School of Electrical Engineering and
National Research and Resource
Facility for Submicron Structures
Cornel University
Ithaca, NY 14853
U.S.A.

Majority carrier light detectors with large gain bandwidth products

A. G. Dentai Bell Laboratories Crawford Hill Laboratory Box 400 Holmdel, NJ 07733 U.S.A.	LPE InGaAs/InP with N_d-N_A<5 x 10^{14} cm^{-3} for photosensitive devices
F. Capasso Bell Laboratories Murray Hill, NJ 07974 U.S.A.	The graded band gap avalanche diode
Y. Ohki Matsushita Research Institute, Tokyo, Inc. Higashimita, Tamaku Kawasaki 214, Japan	Fabrication and properties of practical blue-emitting GaN M-I-S diodes
S. Yamakoshi Fujitsu Laboratories Ltd. Nakahara, Kawasaki 211 Japan	Effects of carrier leakage on InGaAsP/InP double-heterostructure light emitters
A. Sugimura Musashino Electrical Communication Laboratory Nippon Telegraph and Telephone Public Corporation Musashino-shi, Tokyo 180 Japan	Band-to-band Auger recombination in III-V alloy semiconductor lasers
N. Kamata Dept. of Electronic Engineering University of Tokyo 7-7-1, Hongo Bunkyo-ku, Tokyo 113 Japan	Direct observation of carrier leakage through hetero-barrier in highly-excited AlGaAs DH LED
G. L. Pearson Stanford Electronics laboratories Stanford University Stanford, CA 94305 U.S.A.	Voltage-controlled light-switching diodes
J. C. Bouley Centre National d'Etudes des Telecommunications, 196 rue de Paris 92220 Bagneux France	Optical properties of GaInAsP lasers with a new gain-guiding stripe structure
B. A. Bobylev Institute of Semiconductor Physics Academy of Sciences of the USSR Siberian Branch Novosibirsk, USSR	Features of the contact between liquid and solid phases upon heteroepitaxy of A^3B^5 compounds and creation of optically controlled amplitude light modulators

TRANSPORT PROPERTIES

L. F. Eastman
School of Electrical
Engineering and National Research
and Resource Facility for Submicron
Structures
Cornell University
Ithaca, NY 14853
U.S.A.

The limits of electron ballistic motion in compound semiconductor transistors

H. Sakaki
Institute of Industrial Science
University of Tokyo
Roppongi 7-22-1
Tokyo 106, Japan

Physical limits and applications of extremely-high electron mobility effect in ultrafine semiconductor wire structures

M. Inoue
Osaka University
Faculty of Engineering, Suita
Fujitsu Laboratories Ltd.
Kawasaki, Japan

Transport properties of 2D hot electrons at modulation-doped $GaAs/Al_xGa_{1-x}As$ interface

Y. Takanashi
Musashino Electrical Communication
Laboratory
NTT Musashino-shi
Tokyo 180, Japan

Hot carrier study on hetero-structure avalanche photodiodes

T. P. Pearsall
Bell Laboratories
Murray Hill, NJ 07974
U.S.A.

Alloy disorder and the band-structure of lattice-matched $Ga_xIn_{1-x}As\ P_{1-y}$ alloys $(y \cong 2.1x)$

C. Papuzza
CSELT - Centro Studi e Laboratori
Telecomunicazioni S.p.A.
Via G. Reiss Romoli
274 - 10148 Turin
Italy

Energy gap and alloys scattering mobility evaluation by the di-electric model in LPE $In_{1-x}Ga_x As_y P_{1-y}$ system

L. W. Cook
Electrical Engineering Research
Laboratory, Materials Research
Laboratory and Coordinated Science
Laboratory
University of Illinois at Urbana-
Champaign
Urbana, IL 61801
U.S.A.

Ionization coefficient determination in InP by analysis of avalanche photomultiplication and noise measurements

H. Goronkin
Semiconductor Research and Development Laboratories
Motorola, Inc.
5005 E. McDowell Road
Phoenix, AZ 85008
U.S.A.

Impact ionization of shallow trade in ion implanted GaAs MESFETs

R. Kuch
Technical University of Vienna
Gusshausstr 27
A-1040 Wien, Austria

A planar gunn diode with an injection limiting FET cathode contact

H. B. Dietrich
Naval Research Laboratory
Washington, DC 20375
U.S.A.

The effect of doping level and geometrical configuration on the I-V characteristics of planar InP TEDs

LPE GROWTH AND LAYERS

K. Takahei
Musashino Electrical Communication Laboratory
Nippon Telegraph and Telephone Public Corporation
Musashino, Tokyo 180
Japan

Immiscible domain in low temperature LPE of $In_{1-x}Ga_xAs_{1-y}P_y$ on InP

I. Ohta
Matsushita Electronics Corporation
Takatsuki, Osaka
Japan

LPE growth of $In_{1-x}Ga_xP/Ga_{1-y}Al_yAs$ on GaAs

K. Tabatabaie-Alavi
Department of Electrical Engineering and Computer Science and Center for Materials Science and Engineering
Massachusetts Institute of Technology
Cambridge, MA 02139
U.S.A.

Fabrication and characterization of abrupt p^+-n InGaAs/InP heterojunctions

Y. Nakano
Musashino Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation
Musashino, Tokyo 180
Japan

Abnormalities of junctions grown on P-Type InP

Th. Voigt
Physikalisches Institut
Universitat Stuttgart
Pfaffenwaldring 57
D-7000 Stuttgart 80
Germany

Growth properties of $Ga_{1-x}Al_xSb$ and determination of its lowest conduction B and minimum

A. Sasaki
Dept. of Electrical Engineering
and Dept. of Electronics
Kyoto University
Kyoto 606, Japan

Liquid-phase epitaxal growth of $Al_xGa_{1-x}Sb$ and $Al_{1-x}Ga_x As_y Sb_{1-x}$ on (111) B-oriented GaSb

BULK CRYSTALS

R. G. Wilson
Hughes Research Laboratories
Malibu, CA 90265

Impurity densities and the redistribution of Fe and Cr in LEC GaAs

Y. Nanishi
Musashino Electrical Communication
Laboratory, NTT, Musashino-shi
Tokyo 180, Japan

Characterization of LEC-grown semi-insulating GaAs for integrated circuit applications

S. Akai
Sumitomo Electric Industries Ltd.
Itami-shi, Hyogo 664
Japan

Unintentional and intentional doping of GaAs Crystals with Si, B and O

T. Udagawa
Electronics Equipment Division
Toshiba Corporation
1, Komukai Toshiba-cho
Saiwai-ku, Kawasaki 210
Japan

Incorporation of anomalously large amount of Si into Cr-doped semi-insulating GaAs crystals

S. Shinoyama
Ibaraki Electrical Communication
Laboratory, Nippon Telegraph and
Telephone Public Corporation
Tokai-mura, Ibaraki-ken 319-11
Japan

Growth of dislocation-free InP single crystals by LEC technique

E. Kubota
Musashino Electrical Communication
Laboratory, NTT
Tokyo 180, Japan

High quality semi-insulating indium phosphide single crystals grown by a novel ADC system

M. Morioka
Sumitomo Electric Industries, Ltd.
Itami-shi, Hyogo-ken 664
Japan

Effect of Fe content on thermal stability of LEC-grown semi-insulating InP

T. Fukuda
Toshiba Research and Development
Center
Toshiba Corporation
1 Komukai Toshibacho
Saiwai-ku, Kawasaki 210
Japan

Growth of large diameter GaP single crystal by computer controlled LEC technique

H. Emori
Mitsubishi Metal Corporation, Omiya Plant
1-297, Kitabukuro-Machi
Omiya, Saitama
Japan

Determination of oxygen in GaAs by 3He activation analysis

Peng Zhengfu
Nanjing Solid State Devices
Research Institute
Nanjing
People's Republic of China

Synthesis and growth of InP single crystals in a high pressure furnace

CHARACTERIZATION

G. E. Stillman
Electrical Engineering Research
Laboratory, Materials Research
Laboratory, and Coordinated
Science Laboratory
University of Illinois at Urbana-Champaign
Urbana, IL 61801
U.S.A.

Identification of residual donor impurities in Gallium Arsenide

T. Nishino
Faculty of Engineering Science
Osaka University
Toyonaka, Osaka 560
Japan

Photoluminescence studies of acceptor impurities in InGaAsP

I. Fujimoto
Broadcasting Science Research
Laboratories of Nippon Hoso Kyokai
1-10-11 Kinuta, Setagaya-ku
Tokyo 157, Japan

Direct detection of structural changes induced by a high electric field in GaAs using a new x-ray diffraction method

A. Yamaguchi
Fujitsu Laboratories Limited
Nakahara-ku, Kawasaki
Japan

Asymmetric character of the MESFET dislocations in LPE DH InGaAsP/InP

T. Ohyama
Department of Physics
College of General Education
Osaka University
Toyonaka, Osaka 560
Japan

Material characterization through far-infrared magento-absorption in photo-excited GaAs

J. Pietzch
Lehrstuhl fur Technische Elektronik
Technische Universitat, Munchen, Arcisstrasse
21, D-8000 Munchen 2
West Germany

Analysis of EBIC-measurements for two-dimensional lifetime and diffusion length mapping

L. Forbes and C. D. Chang
Department of Electrical and Computer Engineering
University of California at Davis
Davis, CA 95616
U.S.A.

Long-term conductance transients on GaAs JFET's

Zou Yuan-xi (Chou Yuan-hsi)
Shanghai Institute of Metallurgy
Chinese Academy of Sciences
865 Change Ning Road
Shanghai 200050
People's Republic of China

Some aspects of deep levels and space charge in Gallium Arsenide

MOCVD, MBE and VPE

J. P. Duchemin
Thomson-CSF
Laboratoire Central de Recherche
Domaine de Corbeville
91401 Orsay
France

The low pressure MO VPE growth of InP and GaInAsP alloys

Y. Mori
Sony Corporation Research Center
174 Fujitsuka-cho, Hodogaya-ku
Yokohama 240, Japan

MOCVD growth and characterization of undoped AlGaAs

R. Bhat
Bell Laboratories
600 Mountain Avenue
Murray Hill, NJ 07974
U.S.A.

Acceptor incorporation in high-purity OMCVD grown GaAs using trimethyl and triethyl gallium sources

J. J. Yang
Rockwell International
Microelectronics Research and Development Center, 3370 Miraloma Avenue
Anaheim, CA 92803
U.S.A.

Electrical properties of Se and Zn in MO-CVD $Ga_{(1-x)}Al_xAs$

T. Fukui
Musashino Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, Musashino-shi
Tokyo 180, Japan

InAs-InAsSbP heterostructures grown by organometallic vapor phase epitaxy

H. Roehle
Institute of Semiconductor Electronics
Aachen Technical University
Templergraben 55
D-5100 Aachen
Federal Republic of Germany

GaP:N for LEDs grown by Mo-CVD

G. W. Wicks and C.E.C. Wood
School of Electrical Engineering
Cornell University
Ithaca, NY 14853
U.S.A.

Molecular beam epitaxial growth of III-V alloys

M. Naganuma
Musashino Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation
Musashino-shi, Tokyo 180
Japan

Photoluminescence of GaSb/AlSb superlattice grown by MBE

P. Kordos
Institute of Electrical Engineering
Slovak Academy of Sciences
Bratislava
CSSR

Vapor growth of $Ga_xIn_{1-x}As$ using an In/Ga alloy source

PROCESS TECHNOLOGIES

D. K. Sadana and J. Washburn
University of California
Lawrence Berkeley Laboratory
Materials and Molecular Research Division
Berkeley, CA 94720
U.S.A.

Direct evidence of Cr-structural defect interaction in ion-implanted GaAs

H. Nishi
Fujitsu Limited
Kawasaki 211
Japan

AlN encapsulant for fabrication of implanted GaAs IC

N. Arnold and K. Heime
Duisburg University
Solid State Electronics Department
Kommandantenstrasse 60
D-4100 Duisburg 1
Federal Republic of Germany

Chromium and tin migration during open tube diffusion into GaAs

H. Ishimura
Electronics Equipment Division,
Toshiba Corp.
1, Komukai Toshiba-cho
Saiwai-ku, Kawasaki 210
Japan

Electrical uniformities in Si^+ implanted semi-insulating Cr-doped GaAs

K. Watanabe
Musashino Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation, 3-9-11 Midoricho
Musashino-shi, Tokyo 180
Japan

Suppression of thermal conversion for semi-insulating substrate using $Ar/H_2/As_4$ ambient system

D. Eirug Davies Rome Air Development Center Hanscom AFB, MA 01731 U.S.A.	Electrical quality of pulse annealed GaAs
K. V. Vaidyanathan Hughes Research Laboratories Malibu, CA U.S.A.	Annealing behavior of Be and four group IV dopants implanted into InP
M. Otsubo LSI R and D Laboratory Mitsubishi Electric Corporation 4-1, Mizuhara, Itami Hyogo 664, Japan	Photo-electrochemical etching and defect characterization of semi-insulating GaAs
G. J. Bernotas Polytechnic Institute, Kaunas Lithuania USSR	The study of GaAs preferential sputtering

LATE NEWS PAPERS

S. Sakai Nagoya Institute of Technology	GaAlAs/GaAs and InGaAsP/InP wavelength division solar cells
R. Davis Plessey Research (Caswell) Limited	An optoelectronic integrated circuit in the GaAlAs/GaAs system
W. J. Devlin British Telecom Research Laboratories	Low threshold channelled substrate buried crescent InGaAsP lasers as sources for 1.55 μm optical communication systems
F. Capasso Bell Laboratories	Enhancement of electron impact ionization in a superlattice: a new avalanche photodiode for low noise applications
M. Ogawa University of Tokyo Shibaura Institute Technology	Appearance of negative peak in the pits spectrum from GaAs LEC-semi-insulating crystals
D. Rumsby and R. M. Ware Cambridge Instruments Limited	The effect of the water content of the boric oxide encapsulant on the purity and stoichiometry of L.E.C. Gallium Arsenide
G. H. Olsen and T. J. Zamerowski RCA Laboratories	VPE growth of InGaAs and InP on (100). (110), (111), (311) and (511) InP substrates

H. Asahi Musashino Electrical Communication Laboratory	MBE growth of InGaAlP/InGaP/InGaAlP double heterostructures on (100) GaAs
K. Masu Tokyo Institute of Technology	Preparation of $(Al_xGa_{1-x})_y In_{1-y}As$ lattice matched to InP substrate ($0\leq x\leq 0.5$, $y\simeq 0.47$) grown by molecular beam epitaxy
D. L. Miller Rockwell International	An MBE AlGaAs/GaAs heterojunction bipolar transistor
R. W. Glew The General Electric Company, Ltd.	A comparison of H_2S and H_2Se N-type doping of GaAs by MOCVD
R. Mellet CNET	Baryllium doping of Gallium Arsenide metalorganic epitaxial layers
N. Y. Link Tnomson-CSF	Low noise two dimensional electron gas MESFETs
T. Ishibashi Musashino Electrical Communication Laboratory	Exciton associated optical absorption spectra of AlAs/GaAs superlattices at 300 K

APPENDIX II

KYOTO UNIVERSITY

The Electrical Engineering School is made up of the following areas:

- Electromagnetic Theory - Professor J. Umoto
  Associate Professor T. Hara

- Measurement, Instrumentation and Control - Professor Y. Nishikawa
  Associate Professor N. Sannomiya

- Electric Power Generation, Transmission and Distribution - Professor M. Hayashi
- Electrical Machinery - Professor T. Okado
  Associate Professor T. Nitta

- Applied Electrical Sciences - Professor D. Sasaki

- Electrical Discharge Engineering -

- Fundamental Electrical Engineering - Associate Professor M. Abe

- Electron Physics - Professor R. Itatami

- Quantum Electronics - Professor A. Kawabata
  Associate Professor T. Tadashi

- Semiconducting Engineering - Professor K. Tamaru
  Associate Professor H. Matsunami

- Electronic Circuit Engineering - Professor F. Ikegami
  Associate Professor S. Yoshida

- High Frequency Engineering - Professor J. Ikenoue
  Associate Professor M. Makajimao

- Electron Devices - Professor T. Takagi
  Associate Professor K. Matsubara

- Digital System - Professor M. Magoo
  Associate Professor J. Tsujii

- Radio Communication - Professor I. Kimaro
  Associate Professor K. Takoo

- Electronic Control - Professor M. Kuwahara
  Associate Professor S. Eiho

- Upper Atmosphere Physics - Professor S. Kato
  Associate Professor H. Matsumoto

- Upper Atmospheric Radio - Professor T. Ogawa
  Associate Professor T. Yabuzaki

- Control of High Temperature Plasma - Professor K. Uo
  Associate Professor T. Obiki

- Measurement of High Temperature Plasma - Professor A. Iuyoshi
  Associate Professor S. Morimoto

- Production of High Temperature Plasma - Professor H. Akimune

- Nuclear Fusion Reactor - Associate Professor M. Wakatami

- Corpuscular Engineering - Professor Y. Hattori
  Associate Professor K. Yoshikawa

- Instrumentation and Control of Nuclear Reactors - Professor J. Wakabayashi
  Associate Professor T. Hoshino

THE FIFTH INTERNATIONAL SYMPOSIUM ON GALLIUM ARSENIDE AND RELATED COMPOUNDS

Mukunda B. Das

INTRODUCTION

The Fifth International Symposium on Gallium Arsenide and Related Compounds was held in Oiso, Japan on 20-23 September 1981. This was the first time this symposium was held in Japan. Presentations included research efforts by many private industry and universities on the latest techniques used in the fabrication and characterization of GaAs devices and IC's as well as the preparation and characterization of materials.

The Oiso Prince Hotel was the symposium site for presentations of technical papers on the following subjects: Gallium Arsenide Integrated Circuits; Deep Levels; Microwave Devices; Surface and MIS Interface properties; Optoelectronic Growth and Layers; Bulk Crystals; Characterization; MOCVD, MBE and VPE; and Process Technologies.

The United States and Japan contributed the majority of the papers. The rest of the contributions were from West Germany, France, England, U.S.S.R., and China. The largest share of papers by the U.S. and Japanese authors came from private industry and only a limited number came from universities.

CONCERN OF CURRENT RESEARCH IN GaAs AND RELATED COMPOUNDS

The primary motivation in GaAs and related compound semiconductor research is the realization of microwave and high speed digital integrated circuits including optoelectronic elements on the same substrate.

However, this goal cannot be achieved without a comprehensive research effort in the area of material preparation, device fabrication technologies, and both device and material characterization. The technical program of this symposium was well-balanced and included all these aspects. My own interests were in the area of deep level defect characterization employing electrical measurements based on simple test device structures, and I presented a paper in the "Deep Level" session based on the results of our research at The Pennsylvania State University in cooperation with the Westinghouse Research Center, Pittsburgh.

The highlights of the various technical session, in which I participated, are summarized below.

GaAs IC's

The papers of this session were concerned with materials and processes for GaAs IC's and their sensitivity to IC performance, and the rest of the papers dealt with specific IC's and their performance. Speed-power performance of 1.9 GHz and 2 mW/gate was reported in a sequential logic circuit and a maximum clock frequency of 3.4 GHz was reported for a master/slave JK flip-flop binary frequency divider. In a ring oscillator, a signal delay of 59 PS/gate at 3.8 mW/gate was also reported.

DEEP LEVEL

Results of deep level characterization by different techniques in different materials were presented in this session. The question of oxygen induced deep level, and the realization of semi-insulating GaAs was considered in two papers that provided some insight as to the physical mechanism involved. Photoluminescence data were related to Ga vacancy and As vacancy in semi-insulating GaAs. One paper reported natural deep level oscillations in test MESFET's built on LEC undoped material. Deep levels in AlGaAs and InP were also reported.

SURFACE AND MIS INTERFACE PROPERTIES

Defect states model for Schottky barrier formation was discussed in three papers providing considerable insight as to the fermi level pinning, and identification of surface defect levels at E_C - 0.68 eV and E_C - 0.83 eV. Results of frequency dispersion of tramconductance of GaAs MESFET's were reported that relate to the surface states. Six papers were presented that were concerned with insulated gate FET's and diodes on GaAs, InP, InGaAs, and InGaAsP. Anodic aluminum oxide was reported to yield minimum surface state density of 4×10^{11} eV^{-1} eV^{-2} on InP. A power gain of 7.2 dB at 4 GHz was reported for SiO_2/InP MIS FET's with channel length of 1.5 µm 900 Å-thick insulator.

TRANSPORT PROPERTIES

In this session, electron ballistic motion in short-gate FET's, and high mobility in one dimensional structures were discussed theoretically. Transport properties of two-dimensional hot electron in modulation doped GaAs/Al_xGa_{1-x} interface was tested in one paper, and hot-electron punch-through phenomena in hetero-structure avalanche photodiodes was presented in another paper. Bowing of the energy gap in lattice matched GaInAsP alloys, and its dependence on alloy disorder and the effects on the alloy scattering mobility were considered in two papers. Determination of impact ionization by avalance photomultiplication and noise measurements in InP, and impact ionization of shallow defects in GaAs short-channel MESFET's were treated in two papers. The last two papers of this session dealt with Gunn effect, one utilized an injection-limiting FET cathode, and the other involved InP planer TED structures.

BULK CRYSTAL AND CHARACTERIZATION

The bulk crystal session was devoted to impurity redistribution of Fe, and Cr and the effects of S, Si, B and O on differently prepared doped and undoped GaAs crystals. Several papers reported the results of preparation of single crystal InP including the incorporation of Fe for semi-insulating material. One paper dealt with the determination of oxygen in GaAs by ^{3}He activation analysis.

In the characterization session, several papers dealt with photothermal ionization and photoluminescence studies of shallow donor and acceptor impurities. One paper was concerned with EBIC measurements of lifetime and diffusion mapping and two other papers were concerned with deep level space-charge effects.

PROCESS TECHNOLOGIES

There were eight papers in this session including four from Japan, three from the U.S.A., and one from West Germany. Reactive sputtered aluminum nitride encapsulant was compared with CVD SiO_2 for annealing ion-implanted GaAs for IC fabrication in an interesting paper from Fujitsu Limited, Japan. A technique for the suppression of thermal conversion in semi-insulating substrate using $Ar/H_2/A_{s_4}$ ambient system was discussed in a paper from the Nippon Telegraph Corporation. Photoelectrochemical etching and defect characterization of Cr-doped semi-insulating GaAs was the subject of a paper from the Mitsubishi Electric Corporation. Electrical quality of pulse annealed GaAs, and direct evidence of Cr-structural defect using cross-sectional transmission electron microscopy were the subjects of two papers from the U.S.A. A third paper from the U.S.A. explored annealing behavior of Be, Si, Ge, Sn, and C implanted in InP with results indicating high doping efficiency with Si.

VISIT TO KYOTO UNIVERSITY

On September 25, 1981, I visited with Dr. Hiroyuki Matsunami and Dr. Shizuo Fujita of the department of Electrical Engineering. Dr. Fujita was my host, and he was representing Professor Akio Sasaki who is in charge of the InGaAs and InP compound semiconductor research. Dr. Matsunami is in charge of the Optoelectronic Materials such as ZnSe, SiC, CdTe, and InGaAsP. The laboratory facilities include CVD, RF Sputtering, VPE, and LPE equipment for the preparation of various materials, and a variety of electrical measurement setups for Hall mobility determination, DLTS technique for deep level study, EBIC technique for minority diffusion length determination, and general C/V and photocapacitance techniques for defect and impurity characterization.

I was particularly impressed by the detailed nature of the studies carried out by one group in the areas of CdTe, SiC, PLZT ferroelectric thin films, and different MIS solar cell structures; and by the other group in the area of InGaAs, InGaAsP, and other III-V mixed semiconductors including the effect of alloy scattering on mobility; band structure, phototransistors, light amplifiers, and transferred electron device.

VISIT TO THE UNIVERSITY OF TOKYO

On September 26, 1981, I visited with Professor Takuo Sugano, of the Electronic Engineering Department of the University of Tokyo. I was given a tour of the well-equipped device fabrication laboratory, and my guides were Mr. V. Q. Ho and Dr. K. Asada. Dr. Sugano's group is working on a large number of projects utilizing the state of the art facilities in the laboratory. I noted, in particular, the research efforts in the area of plasma anodization for insulated gate FET fabrication using GaAs, InP, and Si. For GaAs IGFET native oxide is formed in an oxygen plasma. IGFET's with 1 μm gate stripe width have been built that show 10 dB power gain at 10 GHz. For InP a deposited layer of Al is plasma anodized to form enhancement MISFET on Fe-doped semi-insulating substrates. A channel mobility of 1400 cm^2/V sec and interface trap density of 4×10^{11} cm^{-2} eV^{-1} have been achieved. In the case of Si selective anodic oxidation in oxygen plasma, combined with a chlorine ambient annealing process, has been shown to provide a very low surface state density ($\sim 10^{10}$ cm^{-2} eV^{-1}). I was also impressed by the electrical characterization facilities including a fully automated DLTS system.

CONCLUSION

The symposium not only provided the opportunity to focus on the emerging compound semiconductor device and material technologies, physical processes, and performance expectations, and limitations of various microwave and optoelectronic devices through the formal presentations of papers, it also provided an informal meeting place for the exchange of ideas and general discussions through personal contacts among the participants.

The quiet, relaxed, and pleasant atmosphere of the city of Oiso made the personal contacts among participants more lively and effective. The visits to Kyoto University and the University of Tokyo were particularly relevant to my own research efforts. It was also useful and worthwhile for me to have personally contacted a large number of Japanese scientists whom I had only known through their published work.

The proceedings containing full manuscripts of contributed papers and the abstracts of the late newspapers will be published by The Institute of Physics, London, as in the previous symposia, in April, 1982.

Editors Note

The list of papers (titles and authors) presented at this conference appears in the preceding article by Lessoff and Davies.

VISITS TO LASER RESEARCH LABORATORIES IN JAPAN

Jin J. Song

The high level of Japanese quantum electronics technology and the laser-related research is well-known. They keep abreast of the most up-to-date U.S. research activities in this area by sending their research personnel to U.S. laboratories, and also through the biannual topical meetings such as the U.S.-Japan light scattering symposium or the U.S.-Japan laser workshops.

During May 1981, I visited some of the leading Japanese laser laboratories which were geographically scattered from Kyoto to Sendai. Overall, the common interests of Japanese researchers were very much in line with the U.S. (or rather international) research trend. This again reflects their efficiency in information gathering. Not surprisingly, some of them acquired their early experience with lasers at U.S. laboratories. Their current interests include short duration subpicosecond pulse generation, high power UV excimer laser technology, short wavelength coherent light pulse generation, and their applications.

The research laboratories I visitied are in chronological order as follows:

- University of Electrocommunications (Chofu)
- Institute of Solid State Physics (Tokyo)
- Tsukuba University and Electrotechnical Laboratory (Tsukuba)
- Institute for Molecular Science (Okazaki)
- Kyoto University (Kyoto)
- Research Institute of Electrical Communication (Tohoku)

A brief summary of my observations and impressions at each laboratory is presented in the order shown above.

UNIVERSITY OF ELECTROCOMMUNICATIONS

Several laser-related research laboratories in Japan were visited during 11-20 May 1981. My first day on this trip was spent at the Institute for Laser Science (ILS), University of Electrocommunications in Chofu near Tokyo. The institute was established for the purpose of developing new lasers and laser materials. The director, and my host, Professor H. Takuma, is an internationally recognized laser scientist. Under his strong leadership, the several young researchers I met seemed very enthusiastic about their projects. One of the major programs was to construct electron-beam-pumped high power eximer lasers for future applications in fusion research. This project was to be more vigorously pursued with the completion of the new building now under construction. Some of the ongoing projects included the study of laser interaction with atomic vapors (sodium and rubidium) and nonlinear wave mixing laser spectroscopy in molecular beams (in particular, coherent anti-Stokes Raman spectroscopy). A project similar to the latter has been carried out by Professor R. Buyer's group at Stanford University. The research at ILS also included the investigation of lasing action in rare-earth ion-doped glass material. As an efficient pumping source for $T_m{}^{3+}$: fluorophosphate glass, the XeF laser was proposed.

The institute was very well-equipped and the experimental apparatus well-maintained. Among the lasers I saw at ILS were:

- two high power argon ion lasers (coherent radiation),

- one krypton ion laser (coherent radiation),
- two ring dye lasers (coherent radiation and spectra-physics),
- two Nd:YAG lasers and dye lasers (molectron), and
- small cw dye lasers and a homemade Nd:YAG laser.

In addition, there seemed to be no shortage in manpower as far as electronic technical support was concerned (may be due to its affiliation with the university). This was reflected in their computerized experimental apparatus, and a very sophisticated homemade high speed signal integrator which is far more efficient than a commercial boxcar integrator.

The general atmosphere of ILS was very much like that of any university laboratory in the U.S. It seemed that research topics could be chosen with a great deal of freedom and flexibility, and that their research interests were not confined to studying new laser systems. In this sense, the institute has great potential to attract imaginative scientists and to carry out frontier research in the very near future. The institute, however, was at a formative (developing) stage, and at the time of my visit they appeared to have more ideas and equipment than their research personnel could handle.

THE INSTITUTE FOR SOLID STATE PHYSICS

The Institute for Solid State Physics (ISSP) at the University of Tokyo was visited on May 12. It is widely known as one of the leading research institutes in the world with 25 years of history. Due to the limited time I had, my visit was restricted mainly to the laser physics and spectroscopy group. The group consists of three subgroups, each headed by Professors S. Shionoya, T. Yajima, and H. Kuroda, respectively. I had the opportunity to meet with all three distinguished scientists.

Professor Shionoya has been engaged in laser spectroscopy in solid state materials for more than a decade. In particular, he made significant contributions to the understanding of excited states in semiconductors, and those of ions in crystals and glasses by employing luminescence spectroscopy techniques. He was one of the first to extensively use short laser pulses to probe dynamics of optically excited states in semiconductors and insulators by observing the evolution of the luminescence spectra with nanosecond and picosecond time resolution. His work on high density electron hole plasma in direct gap semiconductors such as CdS, CdSe, and GaAs as well as on excitonic molecules in CuCl and CuBr has been the subject of an invited talk at numerous international laser spectroscopy conferences. One of the laser systems extensively used in his recent work is a broadly tunable Nd:YAG - parametric oscillator giving out 30 psec pulses. (Shorter pulses are desirable in some cases, but this system has the advantage that it can produce pulses from UV to infrared.)

Recently, Professor Shionoya's group has employed nonlinear laser spectroscopic techniques. Unlike spontaneous luminescence techniques, coherence effects of the excited states can be extracted from nonlinear spectroscopy. The wave mixing method they adopted has nothing new in itself, but very interesting material properties are being revealed. Their work is usually very thorough, meticulous, and reliable. This group is rather a newcomer in the nonlinear laser spectroscopy community. With their knowledge in materials and their background in basic spectroscopy, however, they will be as formidable and productive with their nonlinear optical work as they have been with their luminescence work.

Professor H. Kuroda's group carries out research on basic laser physics, as well as on the interaction of high power laser pulses with matter. Their samples under investigation ranged from plasma to semiconductors under strong laser pulse irradiation. One of their goals is to produce high power, short (in duration as well as in wavelength) laser pulses. A high power (100 GW) KrF laser, ≃1 TW Nd:glass lasers and a hybrid system (Nd:YAG laser plus 5-stage excimer amplifiers) were being developed for fusion research. Picosecond VUV-pulse-generation and x-ray laser action were also under study, together with stimulated Raman/Brillouin scattering in plasma.

Professor T. Yajima is well-known for his pioneering work in quantum electronics and nonlinear optics. In 1975, he proposed to apply resonant Rayleigh-type wave mixing techniques to the study of ultrafast (usually less that psec) relaxation phenomena in condensed media. Nonlinear wave mixing in transparent region (laser wavelength is below the absorption gap of the material) was fairly well understood largely through Professor N. Bloembergen's work at Harvard University. (He received the 1981 Nobel prize in physics for his contribution in wave mixing phenomena, among other things.) When the laser community was moving toward resonant wave mixing in condensed media, Professor Yajimas's proposition and theoretical prediction was timely and prophetic. Ultrafast transient phenomena was usually investigated in time domain by use of (sub) picosecond lasers. With Rayleigh-type wave mixing, picosecond phenomena can be observed in the frequency domain by long (for example, nanosecond laser pulses which are easily accessible) pulses. Professor Yajimas's group experimentally demonstrated this in dye solutions and determined longitudinal and transverse relaxation rates of the excited states of the dye molecules. Our group at the University of Southern California adopted a somewhat different wave mixing technique to measure subpicosecond relaxation rates in liquids and solids. Our technique is sometimes termed as polarization spectroscopy of Kerr-type (as opposed to Rayleigh-type) mixing spectroscopy. In polarization spectroscopy, the polarization change of the probe beam induced by the strong pump beam is examined, whereas in Rayleigh-type mixing, signal frequency is different from the probe or pump frequency. Even though there are some differences in experimental requirements and observed spectra, fundamental principles can be considered almost the same for both cases.

Professor Yajima recently employed subpicosecond laser pulses for a comprehensive study of wave mixing processes. (Comprehensive in the sense that both transient and stationary nonlinear effects are studied.) One of the new schemes is a degenerate wave mixing method which is designed to yield some information on relaxation rates regardless of the relative magnitude of relaxation times and the pulse width.

One of Professor Yajima's projects, during the past couple of years, was to produce and analyze subpicosecond pulses from a dye laser pumped by an argon laser. In 1980, his group reported the generation of pulses of ~0.13 psec duration. (Their synchronously-pumped-passively-mode-locked laser scheme is similar to the one developed by J.C. Diels at North Texas State University.) In 1981, C.V. Shank and his coworkers at Bell Laboratories at Holmdel, New Jersey, reported successful generation of 90 femtosecond (0.09 psec) dye laser pulses by employing a novel colliding-pulse-mode-locking method. Yajima's group further introduced a method of amplifying subpicosecond pulses in which the dye laser medium acts as an amplifier pumped by an Nd:YAG laser. Now that they are equipped with short, strong (amplified) pulses for nonlinear subpicosecond laser spectroscopy, they can thoroughly investigate the relationship between the spectral and temporal responses of the nonlinear optical processes. From the theoretical as well as experimental point of view, Professor Yajima's group is ahead of any researchers in the world in the area of applying wave mixing methods to the study of ultrafast relaxation processes.

TSUKUBA UNIVERSITY

Tsukuba Science City was visited on May 13 and 14. The city looked very much like a large university campus in the U.S. It was designed to house government research laboratories. The whole research complex is called the AIST Tsukuba Research Center (Agency of Industrial Science and Technology). My host here was Professor H. Shirakawa of the University of Tsukuba. Professor Shirakawa's research was centered on the preparation and characterization of doped organic polymer systems such as iodine-doped polycetylene. Due to their high electric conductivity and large optical nonlinearity, these sort of polymers have been receiving much attention from both academia and industry. In the past, Professor Shirakawa and his coworkers employed optical spectroscopy to elucidate structural details of polycetylene.

The other laboratories I visited at Tsukuba University were those engaged in optics-oriented research. The laboratories were, in my opinion, not very well-equipped and their programs were oriented for student projects. Their Raman spectroscopy apparatus, however, was very up-to-date from the laser source to the computer-controlled detection scheme.

THE ELECTROTECHNICAL LABORATORY

The Electrotechnical Laboratory (ETL) which I visited is only one of the many national research laboratories in the Tsukuba Science City. It is the largest national research organization specializing in electricity and electronics in Japan. Although the research activities of ETL encompasses a very wide range of fundamental and applied research, my visit was mainly with the laser research group in the Radio and Optoelectronics Division. Among the many subjects of their research is the study of very fundamental processes in atomic vapor. Recently, they investigated theoretically as well as experimentally, the second harmonic generation (SHG) of strong ND:YAG laser pulses in sodium vapor without an externally applied electric field. Unlike usual SHG in vapors, the spontaneously generated electric field from the laser interaction caused SHG in their case.

Significant effort was being made to develop subpicosecond lasers and high power UV and VUV coherent light sources. In this sense, their program somewhat overlaps with that of the laser group at ISSP or of Professor Takuma's group at the Electrotechnical University. I was told during my visit that ETL was ahead of others in Japan in KrF eximer laser technology. They were also quite successful in operating a subpicosecond dye laser system. The design was similar to that of Yajima's group. Picosecond pulses were also generated from flashlamp-pumped dye lasers and semiconductor lasers.

It was interesting to find out that the major research personnel involved in the successful picosecond or KrF laser projects had recently been visiting scientists at the leading research laboratories abroad (namely the National Research Council of Canada and Professor D.J. Bradeley's group at the Imperial College, London). I also noticed that they were very young scientists.

THE INSTITUTE FOR MOLECULAR SCIENCE

The Institute for Molecular Science (IMS) in Okazaki is truly an outstanding organization in terms of facility, equipment, and research personnel. The institute is involved with nearly all branches of molecular science. My host was Professor K. Yoshihara, leader of the division of electronic structure. Professor Yoshihara's team was studying electronic structure of excited states, photochemical reactions of organic compounds, transient phenomena in biology, etc. One of their probing methods was to use picosecond lasers for time resolved spectroscopy. In their study, fluorescence decays from the excited states were monitored as a function of time. The technique in itself was similar to the one used in Professor Shionoya's laboratory for their semiconductor research.

The division of molecular structure employs a wide variety of spectroscopic techniques to identify transient species in chemical reactions and to understand details of reaction mechanisms. Their light sources cover a wide range in wavelength, from microwave to UV. Their projects included the development of sophisticated high resolution light scattering spectrometer employing a Fabrey-Perot interferometer and a multichannel analyzer. Various methods of two-beam spectroscopy were included in their probing techniques. To name a few, they were IR-visible double resonance spectroscopy and two-beam thermal lensing spectroscopy, which are somewhat related to nonlinear laser spectroscopy. A CARS setup (a nonlinear wave mixing method) was being developed using nanosecond pulses.

The Division of Molecular Assembly studies the electronic properties of the organic solids by means of UV and VUV photoelectron spectroscopy. Photoconduction of organic semiconductors, photoionization processes in diatomic molecules, light scattering from graphite intercalates, and electrical property of ferrocytochrome C were also among their research subjects. The more recent push of this group, however, seemed to lie in molecular beam spectroscopy. Many newly constructed molecular beam apparatus were noticed.

What I have observed at IMS amounts to only a very small portion of their research activities. The common denominator of the various research divisions was the study of photon-molecule interactions. The large laboratory space, abundant in equipment, including all kinds of U.S.-made lasers (among them were Spectra-physics Ring dye lasers and a color center laser manufactured by Burleigh Incorporated, New York) and the technical support from the Instrument Center or Computer Center, could easily be the subject of envy of any visitor.

From the viewpoint of laser spectroscopic techniques, they seemed more interested in modifying and using already established techniques for their purposes rather than developing or adopting any new (not so well established) methods. One area which I felt they were yet to explore was coherent transient phenomena (nonlinear optical effect). This area is being extensively studied by chemists at California Institute of Technology, the University of California at Berkeley, the University of Pennsylvania, and Stanford University.

KYOTO UNIVERSITY

Professor M. Matsuoka's laboratory at Kyoto University was briefly visited on May 18. Professor Matsuoka is one of the younger Japanese laser physicists who has received international recognition. He has worked with Professor Bloembergen at Harvard University, as well as with Professor S.R. Hartmann at Columbia University. Thus, he has had the opportunity to be associated with world authorities in nonlinear optics and the related phenomena.

Professor Matsuoka was studying coherent transient effects in vapors as well as in condensed phase samples. His group first demonstrated picosecond-backward photon echo effects in sodium vapor. The backward echo scheme is attractive for the application in picosecond spectroscopy since it alleviates the use of optical shutters with slow (nsec) responses. This scheme could be related to phase-conjugation effects or Professor Yajima's recent time domain spectroscopy. Incidentally, Matsuoka carried out some of his work at IMS in Okazaki, and is a graduate of Yajima's laboratory.

A new picosecond laser system was under construction, based on the Kuizenga type Nd:YAG laser. Briefly, the Kuizenga model is a pseudo-cw-mode-locked, Q-switched laser. To my knowledge, the Kuizenga version of the Nd:YAG laser is not so simple to operate. In contrast to the modern, spacious IMS facilities, Professor Matsuoka's research was being carried out mostly in one large room in an old building. Nonetheless, they are an extremely productive group.

THE RESEARCH INSTITUTE OF ELECTRICAL COMMUNICATION

Professor H. Inaba's laboratory was located at the Research Institute of Electrical Communication, Tohoku University in Sendai. Professor Inaba had early access to laser research during his stay at Stanford University in the early 1960s. He has been a prominent figure in the international quantum electronics circle for a long period of time. His research reflects such diversity and flexibility that it did not seem possible to grasp all his activities in just one visit.

Both fundamental and applied research was being carried out. Some of their research topics were:

- study on laser radars for remote sensing of air pollutants,
- generation of coherent optical waves up to VUV,
- laser Raman and Mie scattering (application is extended to medical field),
- fabrication of semiconductor lasers-integrated nonlinear optics (picosecond, tunable, high repetition-rate), and
- development of new excimer lasers, etc.

Their recent efforts appeared to be more centered on integrated nonlinear optical devices.

As in Kyoto University, the laboratory building was old and there seemed to be a shortage of laboratory space. The research group consisted of twenty or so students and Ph.D.'s, and appeared to be well-organized and efficiently functioning. That could be one of the factors contributing to their continued success in the ever changing quantum electronics field.

THE CENTRAL RESEARCH LABORATORY OF THE MITSUBISHI ELECTRIC CORPORATION

Leon H. Fisher

INTRODUCTION

This paper is the result of a visit to the Central Research Laboratory of the Mitsubishi Electric Corporation. The following activities are described: breakdown in transformer oil with and without solid dielectric barriers, breakdown in large SF_6 gas systems, the Permanent Power Fuse (a solid sodium-sodium plasma device), gas and vacuum circuit breakers, ozonizers and production of ozone in silent discharges, and superconducting equipment. In addition, a very brief report is given of a visit to the Nagasaki Works of the Corporation.

THE MITSUBISHI COMPANIES

There are more than thirty companies in Japan with Mitsubishi in their names. These companies (with the exception of the Mitsubishi Pencil Company) originated from one enterprise started over 110 years ago. Sixteen of these companies are listed on the Tokyo Stock Exchange. Among such companies are: (asterisks indicate listing on the Tokyo Stock Exchange; terms in parentheses give an idea of the activities of the company when not self-evident)

- Mitsubishi Acetate Company, Ltd.
- Mitsubishi Atomic Power Industries, Inc.
- Mitsubishi Aluminum Company, Ltd.
- The Mitsubishi Bank, Ltd.*
- Mitsubishi Burlington Company, Ltd. (textiles)
- Mitsubishi Caterpillar Company, Ltd.
- Mitsubishi Chemical Industries, Ltd.*
- Mitsubishi Construction Company, Ltd.
- Mitsubishi Cominco Smelting Company, Ltd.
- Mitsubishi Corporation (trading company, annual volume of business about $30 billion; it is the largest trading company in Japan),
- Mitsubishi Electric Corporation*
- Mitsubishi Estate Company, Ltd.* (real estate)
- Mitsubishi Gas Chemical Company, Inc.*
- Mitsubishi Heavy Industries, Ltd.* (shipbuilding, transportation)
- Mitsubishi Kakoki Kaisha, Ltd. (construction of chemical plants)
- Mitsubishi Liquefied Petroleum Gas Company, Ltd.
- Mitsubishi Mallory Metallurgical Company, Ltd.
- Mitsubishi Metal Corporation*
- Mitsubishi Mining and Cement Company, Ltd.*
- Mitsubishi Monsanto Chemical Company
- Mitsubishi Motors Corporation
- Mitsubishi Motor Sales Company, Ltd.
- Mitsubishi Nuclear Fuel Company, Ltd.
- Mitsubishi Norton Company, Ltd.
- Mitsubishi Office Machinery Co., Ltd.
- Mitsubishi Oil Company, Ltd.

- Mitsubishi Ore Transport Company, Ltd.
- Mitsubishi Paper Mills, Ltd.*
- Mitsubishi Petrochemical Company, Ltd.*
- Mitsubishi Plastics Industries, Ltd.*
- Mitsubishi Precision Company, Ltd.
- Mitsubishi Rayon Company, Ltd.*
- Mitsubishi Research Institute, Inc.
- Mitsubishi Space Software Company, Ltd.
- Mitsubishi Steel Manufacturing Company, Ltd.*
- Mitsubishi Trust and Banking Corporation*
- Mitsubishi Warehouse Company, Ltd.*
- Mitsubishi York, Ltd.

In addition, there are a large number of companies which do not have the word "Mitsubishi" in their names, but whose origins go back to the Mitsubishi enterprise. One such company is the Kirin Brewery Company, Ltd. the manufacturer of Kirin beer, allegedly the beer of preference for all workers in Mitsubishi companies. Other such companies are:

- Asahi Glass Company, Ltd.
- Dainichi-Nippon Cable Company, Ltd.
- Dai Nippon Toryo Company, Ltd. (paint)
- Diamond Credit Company, Ltd.
- Meiji Life Insurance Company, Ltd.,
- Nippon Optical Company, Ltd.
- Nippon Ysen Company, Ltd. (mail boats)
- Tokyo Marine and Fire Insurance Company, Ltd.

At the end of World War II, there were 157 domestic as well as 52 overseas "Mitsubishi" firms. The Mitsubishi group of companies maintain a common showroom in the Marunouchi district of Tokyo.

The term "zaibatsu" was applied in Japan to a set of influential companies controlled by a single family by means of a single holding company. Zaibatsus were enormous and were generally involved in every important field of manufacture and commerce, including banking. Zaibatsus developed because the Meiji government which initially decided to operate commercial ventures itself found, after about fifteen years, that these ventures were being inefficiently operated. The government then sold off such assets as mines, shipbuilding yards, etc., to those who who had the means to buy them; for example, such people as the founder of the Mitsubishi enterprises. Officially, zaibatsus were dissolved by the Allies after the end of World War II by the Law for the Elimination of Excessive Concentration of Economic Power. The big four zaibatsus were Mitsui, Mitsubishi, Sumitomo, and Yasuda. Upon dissolution of the zaibatsus, the families controlling the zaibatsus were removed from control, the holding companies were dissolved, and those members of the wealthy families who had management positions were forced to resign and were stripped of their wealth. Some of the restrictions were removed or moderated when the San Francisco Peace Treaty was effected in 1952. Most of the companies, which were established and developed by the zaibatsus, still lead in every branch of staple industries. They operate independently; however, a strong sense of kinship survives among the companies of a given former zaibatsu, but no formal connection exists.

There were 205 companies in the Mitsubishi zaibatsu which were ordered to alter their names so that Mitsubishi did not appear in them and they were not allowed to even use the Mitsubishi logo (shown at the beginning of the paper) for a number of years (three rhombuses touching at one point, symmetrically arranged; mitsu is a Japanese word for three and bishi means rhombus or diamond shape).

The Mitsubishi enterprise was started in 1870 by Yataro Iwasaki (the Iwasaki family remained in control until the end of World War II). This was just two years after the Meiji Restoration, which was the beginning of modern Japan. This marked the end of shogun rule and the emergence of Japan from feudalism. In fact, in a situation reminiscent of what happened after World War II, the new government dissolved commercial organizations controlled by feudal lords or "clans" and enjoined them from engaging in trade; Iwasaki was given the assets and liabilities of a shipping and trading company of the Tosa clan.

THE MITSUBISHI ELECTRIC CORPORATION

The Mitsubishi Electric Corporation was founded in 1921 by taking over the facilities and business of the Electric Machinery Department of the Kobe Works of the Mitsubishi Shipbuilding and Engineering Company, Ltd. (the predecessor of Mitsubishi Heavy Industries, Ltd.). Two years later, Mitsubishi Electric entered into a manufacturing agreement with Westinghouse which resulted in Westinghouse owning 9.8 percent of Mitsubishi Electric. At the same time, Mitsubishi Electric acquired the Electric Works of the Nagasaki Shipyard of the Mitsubishi Shipbuilding and Engineering Company. Later, another plant, now known as the Itami Works, was erected to which research laboratories were subsequently added, and which is the site at which the research activities described in the present report are being carried out.

The Mitsubishi Electric Corporation is a giant, diversified electrical equipment manufacturer employing 48,000 people. From 1969 through 1977, there were over 50,000 employees and employment reached a peak of 56,000 in 1975. (Since there is no such thing as layoffs in Japan, any reduction in the work force of a company such as Mitsubishi Electric means that the corporation found employment for the people they did not need in other corporations). The corporation had sales of $3.1 billion and earnings of $75 million during the first six months of 1981; earnings were about 2.5 percent of sales. Mitsubishi Electric is about three quarters and one quarter as large as Westinghouse and General Electric, respectively. Westinghouse and General Electric have been reporting earnings of about four and six percent of sales, respectively. About 12.5 per cent of Mitsubishi Electric sales are made overseas, centering mostly on heavy electrical plants. Direct damage during World War II destroyed about one third of Mitsubishi's total assets; in addition, it lost its overseas assets.

Mitsubishi Electric is engaged in many international enterprises. For example, it is supplying railroad equipment to Spain and Australia as well as to other countries and has a joint venture with Mexico to manufacture railway cars and other equipment. It is supplying power plants and substations to Middle Eastern countries. As already mentioned, it has had a technological licensing agreement with Westinghouse since 1923; this was replaced by a technological exchange agreement with Westinghouse in 1966. In December 1981, Mitsubishi Electric and Westinghouse reached a basic agreement on the construction of an equally-owned joint VLSI circuit plant in the United States.[1] Mitsubishi Electric is now involved in over forty joint ventures and has technical agreements with fifteen companies overseas. About half of Mitsubishi Electric's exports are heavy machines, largely to developing nations.

Mitsubishi Electric manufactures every conceivable electrical device ranging from heavy electrical machinery to germanium and silicon transistors at twenty two works and ten factories. Some of these products are:

- steam and hydro turbine electric generators (superconducting generators are under development and this will be discussed in some detail later in the paper),
- electric motors ranging from heavy-duty to small motors for vacuum cleaners,
- power transformers (500 kV transformers are being manufactured; a 1000 kV-class prototype transformer has been tested and development is under way for 1200 kV transformers; research on insulating properties of oil and oil-soaked dielectrics for transformers will be discussed later in this paper),
- circuit breakers (gas and vacuum circuit breaker development will be discussed later in this paper),
- gas insulated switchgear (a complete 132 V GIS system has been supplied to Saudi Arabia),
- power fuses (the Permanent Power Fuse, PPF, will be discussed later in this paper),
- optical fibers for transmission of control data in power stations and substations,
- silicon rectifiers, germanium and silicon transistors and diodes, ICs and LSIs, printed circuit boards, air conditioning, and air cleaning equipment,
- computer systems, including small data computers and Japanese-language processors with Kanji printer systems for office processing needs,
- electronic control systems for steel plants, subway systems, pressurized-water reactors, etc.,
- waste water treatment plants (Mitsubishi Electric ozonizer work is discussed later in this paper),
- electric fans including ventilating systems for long highway tunnels,
- washing machines,
- cranes, elevators, escalators,
- fluorescent and mercury vapor lamps,
- marine electrical equipment,
- machining equipment using lasers, electron beams, and arcs (including arc welding robots able to use five different welding arms simultaneously),
- domestic and commercial sewing machines,
- light and heavy-duty refrigerating equipment,
- electric furnaces,
- electric locomotives (in 1928, Mitsubishi Electric produced an electric locomotive using only domestic components),

- satellites for communication, earth-station installations,

- rocket-borne equipment,

- radar and guidance systems,

- broadcasting equipment,

- stereo receivers, amplifiers, loudspeakers and loudspeaker systems, stereo sets, cassette decks, tape recorders, radios, headphones, and record players,

- TV sets, color picture tubes,

- automobile stereo sets, automobile radios,

- electrical automotive equipment including starters, distributors, and alternators,

- electronic fuel injection systems for automobiles,

- traffic control equipment,

- vacuum-type solar collectors and,

- education and medical systems.

The research activity of the corporation is carried out by 1600 people of which about 1100 are research workers and about 500 are technicians. Research and development activities are carried out in seven laboratories, four research and development departments, and one design center. These organizations are (along with the number of personnel, where available):

- Central Research Laboratory (400),
- Products Development Laboratory (200),
- Manufacturing Development Laboratory (300),
- Consumer Products Research Laboratory (150),
- Consumer Electronics Development Laboratory (70),
- LSI Research and Development Center (140),
- Industrial Design Center,
- Electronics Research and Development Department,
- Communications Research and Development Department (50),
- Computer Research and Development Department, and
- Materials Research and Development Department (40).

The first three organizations listed are considered to form the core of the corporation's research and development efforts and house 900 (80 with Ph.D.'s) out of the 1600 people in the corporation who are involved in research and development. These three laboratories are in one location, and are on the grounds of the Itami Works of Mitsubishi Electric (where core-type power transformers, silicon rectifiers, gas-insulated switchgear and electric locomotives are manufactured) in a suburb of Osaka, and have a floor space of 36,000 square meters. Research laboratories have been in existence and located at Itami since 1944. My visit was confined to the Central Research Laboratory. One of the other of the above organizations, the Communications Research and Development Department, is also located in Osaka but is housed at the Communication Equipment Works site.

The three laboratories located at the Itami Works are subdivided into departments as follows:

- Central Research Laboratory

  .Material Science and Devices
  .Energy Science and Electromechanical Technology
  .System Control and Information Science
  .Microcomputer Education Center

- Products Development Laboratory

  .Automotive Electronics
  .Consumer and Industrial Electronics
  .Video and Audio Recording Appliances
  .Advanced Industrial and Environmental Equipment

- Manufacturing Development Laboratory

  .Manufacturing Facilities Engineering
  .Manufacturing Process Engineering
  .Insulation Engineering
  .Materials and Components Engineering

The Central Research Laboratory has three roles:

- to carry out basic research,
- to develop technology in new fields, and
- to cooperate with and assist the works and factories of the corporation.

The Products Development Laboratory is responsible for the development of new products in cooperation with the Works. Such products include audio-video equipment, air and water pollution equipment (including ozone production and management of sludge), air conditioners, computers, and computer and electronic technology for consumer appliance and industrial equipment.

The Manufacturing Development Laboratory is involved in the automation of the corporation's production facilities as well as in the development and manufacture of labor saving machinery and equipment.

THE CENTRAL RESEARCH LABORATORY

My principal discussions were on the subject of dielectric breakdown. I had a tour of the high voltage laboratory, superconducting equipment development, and of an antibiofouling ozone system. I also gave a lecture on "Differences between American and Japanese Research Philosophy." This title was selected by Mitsubishi Electric. They preferred it to a technical presentation. The research activities I examined are now described in some detail with names in case a reader wishes to write directly for further information.

- Prebreakdown Conduction and Breakdown in Transformer Oil in Nonuniform Fields (Y. Yasojima)

Experimenters at Mitsubishi have been carrying out extensive studies of the breakdown of transformer oil in nonuniform fields. This is a natural interest for Mitsubishi Electric which manufactures transformers which operate from 3.3 kV to 500 kV and will be manufacturing transformers to operate at 1200 kV for the new ultra high voltage transmission lines being planned for Japan.

Previous workers have measured steady-state current-voltages in oil below breakdown and such currents have been measured up to tens of microamperes. The Mitsubishi Electric workers feel that these steady-state prebreakdown current-voltage measurements below breakdown in oil have not clarified the breakdown mechanism. Strictly speaking, static current-voltage measurements below breakdown cannot lead to a definitive elucidation of the mechanism of either prebreakdown conduction currents or breakdown itself, since such currents do not give the velocity of the various processes contributing to the current or to the breakdown, and to an identification of the processes at work. Only a dynamic study of prebreakdown currents leading to breakdown can make clear what processes are involved, although sometimes good guesses can be made from some of the properties of static current-voltage data. At Mitsubishi Electric, prebreakdown currents in oil are being measured as a function of time which flow during the last microsecond or so before breakdown occurs when a potential difference increasing at the slow rate of 1 kV/s is applied between the electrodes. These currents are as large as 500 microamperes.

The oil is first passed through a five micron filter and degassed in a vacuum of 10^{-3} Torr. The studies are being carried out with both dc and low frequency ac voltages up to about 75 kV and for various pressures applied to the transformer oil. The test gap consists of two 10 cm diameter plane electrodes with a small metallic prolate hemispheroid protruding from, and also insulated from, one of the plane electrodes. Three spheroids of varying dimensions were used in order to vary the degree of nonuniformity of the field; all three spheroids protruded 1 cm from the electrode but had differing diameters at the plane surface from which they protruded (0.25, 0.50 or 1.0 cm). In addition to carrying out measurements with each of the spheroids, spacings between the parallel electrodes ranged from 1.056 to 1.375 cm, corresponding to separations of from 0.056 to 0.375 cm between the tip of the protrusion and the other plane electrode. Thus, the strongest field region is between the tip of the protrusion and the part of the other plane electrode facing it. Only the prebreakdown currents flowing to the spheroid were measured.

- DC Measurements

In the dc case, currents can be measured starting at about 0.5 microseconds before breakdown and have values as high as 10 or 20 microamperes just before the current breaks into an oscillatory mode. The authors call the current up to the break into oscillations the prebreakdown current. In many cases, the prebreakdown current increases monotonically and exponentially with time. Only the monotonically growing exponential currents are analyzed. No attempt is made to analyze the current once it breaks into oscillation nor is any attempt made to analyze currents which show subsidiary peaks long before breakdown. Current-voltage curves showing nonmonotonic growth are ascribed to corona pulses due to large inhomogeneities in the electric field or to oil contamination, or "prebreakdown pulses" (origin unspecified) or to a bubble left by a previous breakdown. The three different kinds of pulses differ in shape and sometimes in time of occurrence. When pulses due to bubbles occur, the breakdown voltage is extremely low, perhaps one third of the mean breakdown value. If corona current pulses appear, they occur about several hundred nanoseconds before breakdown and the earlier corona occurs before breakdown, the lower is the breakdown potential. Breakdown voltages in oil vary statistically from trial to trial for a given gap whether or not corona or prebreakdown pulses occur or a bubble is present (even though the electrodes are seasoned by many breakdowns and damage to the oil by the discharge is minimized by a gas diverter placed in parallel with the oil gap which operates about one microsecond after breakdown). Twenty to thirty measurements were made for each electrode configuration. For example, the range in breakdown voltage for breakdowns showing monotonic growth for a spacing between parallel electrodes of 1.15 cm and a protrusion base diameter of 2.5 mm ranged from 53.9 to 61.0 kV. The Mitsubishi Electric workers feel that this statistical spread in breakdown voltages is a fundamental aspect of the breakdown. The corresponding prebreakdown currents also vary from trial to trial. If the time axes of the current-time curves for two trials for the same electrode configuration are superimposed using the breakdown time as the superposition point, then the current-time curves associated with low breakdown potentials are usually, but not always, larger than those that occur with high breakdown potentials. In the above example, the prebreakdown currents at low breakdown voltages were about four times the values obtained with high breakdown voltages for corresponding times.

The following facts emerged from the dc studies:

- For a given protrusion, the rise time and maximum value of the prebreakdown current increases with increasing electrode separation.

- A sharper protrusion reduces the breakdown voltage drastically and gives longer rise times of the prebreakdown current.

- For a given electrode configuration, a positive protrusion gives lower breakdown potentials, higher currents, and shorter rise times than a negative protrusion.

- Prebreakdown currents versus time grow exponentially and suggests to the workers that electron multiplication is going on.

- Generally speaking, the increase of pressure gives rise to an increase in the breakdown voltage with both polarities. The pressure was varied from about one to 10 atmospheres. For a negative protrusion, the increase in breakdown voltage is about 40% from one to 10 atmospheres and about 15 percent for a positive protrusion. The rate of increase of the breakdown voltage decreases at higher pressure. The difference in breakdown potentials between negative and positive protrusions increases sharply with pressure.

- AC Studies

Prebreakdown currents with ac were also studied. In the case when breakdown occurs while the plane electrode is positive the development of the prebreakdown current is often accompanied by small noisy pulses superimposed on a smooth current. In the case when breakdown occurs with the plane electrode negative, the prebreakdown current increases more smoothly and rapidly. The breakdown voltage with a positive plane is a little higher than that for the opposite polarity. Breakdown occurs near the peak of the ac applied voltage with both polarities. Sometimes breakdown occurs far earlier or later than the occurrence of the voltage peak with quite different waveform from the ordinary one.

In the case of ac breakdown, the ratio of the number of breakdowns with positive plane to those with negative plane changes as the conditioning process proceeds. When the electrode and oil are fresh, the ratio is one to one. However, the number of breakdowns with negative plane decreases with increasing number of breakdowns. When twenty breakdowns have occurred, the ratio of the positive plane to negative plane breakdown is seven to three. This ratio increases to about fourteen to one after several tens of breakdowns. At this point, the electrodes were not changed but fresh oil was introduced. The ratio fell to about two to one but never recovered the one to one ratio. This means that both the oil and the electrodes are involved in the process.

These results are all very interesting, but leave much to be explained in terms of what is going on in the breakdown of oil.

- Effects of Solid Dielectric Barriers on the AC Breakdown Voltage of Oil in a Point-to-Plane Gap (Y. Yosojima)

AC breakdown voltages and prebreakdown currents in oil gaps with and without solid dielectric barriers placed between the electrodes have been measured in a point-to-plane gap. The gap had the same configuration as was described in the work on oil breakdown above except that the electrode separations were much larger, about 1 cm. One spheroid was used and it had a base diameter at the plane to which it was attached of 2.5 mm, i.e., it was the sharpest of the three spheroids used in the pure oil study. AC voltages increasing at a rate of 0.5 or 1 rms kV/s were applied until breakdown occurred for a gap with oil only, and then with a plane dielectric barrier at some position between the electrodes. Such measurements were carried out for 0.5 mm pressboard, 0.5 mm teflon, and 80 micron kraft paper. Prebreakdown currents were also measured with and without barriers.

For the 80 micron kraft paper, there is no effect on the breakdown potential or on the nature of the prebreakdown currents if the paper is placed near the plane electrode. There is even a slight decrease in breakdown potential when the paper is placed in midgap, but if the paper is placed anywhere within a millimeter of the point electrode, the breakdown potential is increased by about ten percent.

The 0.5 mm pressboard gives an improvement in breakdown potential of about 40% when placed near the point, the effect decreasing gradually the greater the distance of the pressboard from the point electrode. One or more current pulses of short duration are observed just prior to breakdown. The 0.5 mm teflon barrier gives about the same improvement in breakdown potential when placed close to the point, but for intermediate positions is generally not as effective in improving the breakdown voltage as is the pressboard, with the plane electrode the breakdown voltage of oil is not increased.

- Impulse and AC Breakdown Characteristics of Large Scale Sulphur Hexafluoride Gas Systems (Y. Shibuya)

Compressed SF gas is being used as insulation in switchgear, substations, and power cables for voltages up to 500 kV. There is a trend to go to higher voltages and higher capacity so it is necessary to be able to obtain information necessary for the design of large scale gas insulated apparatus.

Most studies on the electrical breakdown of SF_6 have been carried out using laboratory scale electrodes. Work some years ago on laboratory scale electrodes showed that the breakdown voltage of a given electrode system in compressed SF_6 is likely to be reduced by microscopic protrusions on electrodes and foreign particles left in the system. It was also discovered that the statistical properties of the breakdown voltage depends on the area of the electrodes. The Mitsubishi Electric workers also measured the time it takes for breakdown to occur at various voltages for impulse breakdown and switching surge breakdown in SF_6 under laboratory conditions and gave empirical formulae for such curves involving area, polarity, and gas pressure. The work now being carried out at Mitsubishi Electric is designed to find out how results obtained in laboratory scale experiments can be applied to large practical systems.

The experimental apparatus consists of a section of a coaxial single phase 84 kV SF_6 GIS. Sometimes experiments are carried out with a single epoxy spacer between inner and outer conductor and at other times a section with seven epoxy spacers are used. In the latter case the bus is 4.5 m long. In a large scale GIS there are more than one hundred spacers. Both the SF_6 and spacers constitute the insulation system. However, for the experimental arrangement used, breakdown does not occur along the epoxy spacers. The minimum spacing between inner and outer conductor is 4.3 cm and the SF_6 gauge pressure is either 1 or 2 kg/cm^2.

Switching impulses and steep front impulses up to 600 kV crest and ac voltages up to 360 kV were used in these studies. Breakdown voltages with steep front impulses are less dependent on the scale of the system than are those associated with the breakdown occurring with switching impulse and ac. When switching impulses and ac voltages are applied to a system with many spacers, the most probable breakdown voltage is lower than that for one spacer because of the increase in the number of weak points on the electrodes. When steep front impulse voltages are applied, the curve of probability of breakdown versus applied voltage is very similar for the system with seven spacers or only one spacer. An explanation other than weak points must be looked for to explain this fact. The times for sparks to occur for various breakdown voltages follow the same empirical formula as was found to obtain for small scale experiments.

- Permanent Power Fuses (PPF) (Y. Wada)

The Permanent Power Fuse (PPF) was developed at Mitsubishi Electric and its development was announced in 1971 (patent rights were sold to General Electric). It has been used in field installations since 1969. It is a reusable self-healing current limiting device for use in low voltage (600 V) high kVA systems having possible fault currents as high as hundreds of kiloamperes. The PPF is not itself a switching element but is a nonlinear resistor which must be used in conjunction with a parallel resistance and switching equipment to reduce fault currents to zero. The PPF and its parallel resistor are both placed in series with a fast acting (5-6 ms) circuit breaker. If a fault current appears, the circuit breaker is not damaged since it opens at a much lower current due to the action of the PPF than would otherwise be the case and need not be replaced and the PPF recovers its normal operation in about 5 or 6 ms after the circuit breaker opens. The PPF has been subjected to continuous research and development and system studies.

Normally, current conduction in a PPF (100 to 2000 A, depending on model) occurs through metallic sodium having a resistance of about a tenth of a milliohm at 20°C. The sodium is contained in a BeO tube, BeO having been chosen because of its high thermal conductivity. The BeO tube is in turn encased first in another ceramic and then by metal. The operation of the PPF depends on having the fault current vaporize the sodium to a high pressure-high temperature plasma (about 3000 atmospheres - about 4000° K) having a resistance about one thousand times that of the sodium in its metallic state. The sodium plasma expands against a piston buffered by a high pressure inert gas, usually Argon at 10 atmospheres, which not only limits the pressure and temperature of the plasma but which also eventually helps return the fuse to normal operation. The metallic sodium vaporizes in about a millisecond after the fault current starts flowing by which time the current through the PPF has risen to about 15 kA. The current through the PPF then decreases because of its increased resistance and consequent shunting of current through the parallel resistor falling to about 7 or 8 kA in another 3 or 4 milliseconds. At this time, a rapidly opening circuit breaker activated by the large current through the system reduces the current in the system to zero in about five or six milliseconds. At this time, the compressed inert gas in the PPF recondenses the sodium into the metallic state in about 5 or 6 milliseconds and the PPF is in its normal state again ready to conduct normally and to act as a fuse again. As the PPF can function repeatedly, blackout is limited to just the amount of time that it takes to isolate the fault from the system.

Mitsubishi Electric workers have carried out experiments in a model PPF with a parallel resistor in which the sodium was enclosed in a quartz capillary with provisions for time resolved photographic and spectroscopic observations. Such observations were made under the influence of a simulated fault current. Current-time and voltage-time characteristics were also measured allowing a determination of the PPF resistance vs. time as well as resistance vs. total energy input. Radiation begins to be emitted when vaporization of the sodium begins. This radiation from sodium gas (not yet an arc) was measured from 2500 Å to 10,000 Å and was found to be very nearly black-body corresponding to temperatures between 2000° and 5000°K. An image converter camera was used for streak observation of the development of the plasma. The rapid growth of emission lasts 15 microseconds. During the time that current decreases in the PPF (and is increasing in the parallel resistor), the resistance of the plasma increases from about 100 to 400 milliohms. The value of the resistivity of the plasma is almost two orders of magnitude lower than expected classically. Thus, the plasma is a strongly nonideal one. During the time that the current in the PPF is decreasing, time integrated spectrograms show continuous black body-like radiation corresponding to temperatures between 2500°and 3400° K. During a period after the current has been decreasing in the PPF, it levels off to a constant value for a few milliseconds. During this time, self-reversed Na D lines and other broadened Na lines are observed superimposed onto the continuum spectra. During this time, Stark broadening of the Na D lines gives an estimate of 10^{18} cm^{-3} for the electron density.

A recent system study at Mitsubishi Electric showed that the PPF combined with a molded case circuit breaker effectively improves the cost effectiveness in control centers with large fault currents.

- Gas Circuit Breakers (Y. Ueda)

Extensive work is being carried out on circuit breakers at Mitsubishi Electric. Perhaps in the interest of brevity it will suffice to list the titles of papers from this laboratory for 1981:

- "Mixing Process of Arced Gas with Cold Gas in the Cylinder of Gas Circuit Breaker,"
- "An Improvement of Low Current Interrupting Capability in Self-interruption Gas Circuit Breaker,"
- "Dynamic Behavior of Gas-blasted Arcs in SF_6-N_2 Mixture,"
- "Development of 7.2 kV - 63 kA Advanced Puffer Gas Circuit Breaker,"
- "Self-flow Generation Phenomena in a Gas Circuit Breaker Without Puffer Action,"
- "SLF Interruption by a Gas Circuit Breaker Without Puffer Action."

In addition, the following paper appeared in 1982: "Dynamic Behavior of Gas-blasted Arcs in SF_6-N_2 Mixtures."

One should also mention a 1982 paper entitled "Spectroscopic Approach to the Analysis of High Current Arcs in SF_6". In this work spectroscopic observations were made on transient free burning arcs drawn by separating copper/tungsten electrodes in SF_6. The peak value of the arc current was as high as 60 kA. A new optical method making use of the continuum intensity was developed to measure temperature and pressure profiles of the arc taking the magnetic pinch force into account. The results show that the composition of the arc changes significantly at a critical instantaneous current of 10 kA. Above 10 kA the arc is composed of the electrode vapor, while below 10 kA it contains SF_6 gas.

- Vacuum Circuit Breaker Studies (Y. Murai)

In the last few years studies related to vacuum circuit breakers have been carried out at Mitsubishi Electric.

One such study investigated the statistics of breakdown between plane parallel copper electrodes in vacuum (2 x 10^{-6} Torr). The experiments were carried out for various diameter electrodes and at various electrode separations. Electrode separations, d, varied from 0.3 to 2.0 cm and impulse voltages as high as 200 kV were applied from a Marx-type generator. No matter how carefully the electrodes are conditioned, statistical scatter in the breakdown voltage still occurs. The results show that the voltage below which sparking occurs half of the time varies as $d^{0.5}$ for the more uniform fields (larger diameter electrodes) but varies less rapidly than this for the relatively more nonuniform fields.

At present, a 60 Hz vacuum arc study is in progress between carbon electrodes in which an optical multichannel analyzer is being used to get time resolved spectroscopic measurements. The base pressure for these studies is 10^{-6} Torr. The electrodes are touched and separated. Electron densities in the arc are about 10^{14} cm^{-3} and the temperature is about 60,000°K.

- Ozone Studies (N. Tabata, S. Yagi)

Mitsubishi Electric is the leading supplier of ozonizers in Japan and has about half of the Japanese market. Fuji Electric, Hitachi Electric, and Toshiba Electric are the other leading ozonizer manufacturers in Japan. In recent years, a considerable amount of interest in the subject has developed in academic circles as well. In 1980, the Ministry of Education and Culture (Mombusho) sponsored a publication (in Japanese) in which Japanese university and industrial workers summarized the worldwide status of knowledge about basic processes of formation of ozone in silent discharges as well as the status of applications. In 1981, a very modest two year grant-in-aid for basic research on production of ozone by electric discharges was made to universities and to industry by the Mombusho. Professor Y. Gosho, Electronics Department, Tokushima University, 2-1, Nanjo-mishima-cho, Tokushima 770, an active research worker in ozonizer discharges, is the administrative head of the Mombusho program for all of Japan. Fourteen universities, five industrial companies, and two government laboratories are involved. In November 1981, a small meeting on the fundamental processes in ozonizers and on applications was held at Unoyama. Representatives from both industry and universities attended. The Japan Research Group on Electrical Discharges is planning to hold an ozone meeting at Tokushima University in March 1982.

Most commonly, ozone is produced commercially by means of a silent discharge operating in air or oxygen. (A silent discharge is an ac discharge in which the gas is enclosed in a dielectric container with the electrodes outside the container.) Mitsubishi ozonizers produce ozone at rates ranging from a few ounces a day for laboratory use to almost three tons a day for heavy industrial use. Corresponding discharge powers range from a fraction of a kilowatt to almost 700 kW, frequencies vary from 60 Hz up to kilohertz for the high wattage machines and the weight of the largest ozonizer is over 17 tons.

The ozonizer program has a solid underpinning of basic research at Mitsubishi Electric which has been going on for a number of years. (Mitsubishi Electric's basic research on ozone is recognized internationally.) For example, ozone generation at high pressure and high discharge power was studied experimentally and analyzed successfully on the basis of the four reactions suggested by Devins. However, air-fed ozonizers are used more often than oxygen-fed ones and so studies were undertaken to study the mechanism of ozone generation in air-fed ozonizers, both theoretically and experimentally. Formation of ozone from oxygen is quite different than when it is formed from air. In air, a mechanism was proposed which consists of electron impact dissociation of O_2, N_2, and O_3 and of reactions between oxygen species (O, O_2 and O_3) and nitrogen oxides (NO, NO_2, NO_3 and N_2O_5). Eleven reactions were proposed to explain the formation of O_3. Various reaction rates were obtained from experimental determination of ozone formation. A catalytic series of two reactions involving NO and NO_2 were proposed for the destruction of O_3 giving a net reaction of $O + O_3$ to give ordinary molecular oxygen.

Mitsubishi Electric has developed the Melco (Antibiofouling Ozone System (MABOS) for cleaning cooling water for power plants. It incorporates adsorption of ozone by silicagel cooled to -40°C with intermittent injection of concentrated ozone desorbed from the silicagel into the cooling water circuit. MABOS is designed to suppress the proliferation of bacteria in the early stages of their exponential growth by injecting the minimum necessary amounts of ozone once a day for only five-ten minutes. Ozone adsorption and accumulation occurs for 23.6 hours and the ozone desorption and injection process lasts 0.4 hours. A conceptual design of MABOS have been carried out for a 600 MW power plant handing 90,000 m^3/hr of cooling water.

- Superconducting Equipment (T. Yamada)

.Electrical generators and motors

The power limitation of conventional electric generators lies between 1500 and 2000 MW. These limitations are of a mechanical nature. It is hoped the reduction in weight and volume of superconducting generators will eventually allow this limit to be exceeded.

A three year program at Mitsubishi Electric for a 6 MW superconducting generator was completed in March 1977. This generator is a two pole machine and operates at 2640 V at a current of 1375 A at a frequency of 60 Hz and at a rated speed of 3600 rpm. The machine requires 20 liters of helium per hour.

A 30 MW superconducting synchronous condenser is now being constructed and is scheduled to be completed in March 1982, before this report appears. This is also a two pole machine. The voltage will be 11 kV and the current will be 1576 A again at a frequency of 60 Hz and a rated speed of 3600 rpm. A refrigeration facility for the 30 MW machine has been constructed and tested successfully. A rotor has been partially assembled and has been rotated up to 3900 rpm. The superconducting field windings embedded in the rotor have been energized up to 1000 A. The rotor is made of titanium alloy. The superconducting field is a dipole magnet which consists of eight windings. Two windings are made of Nb_3Sn monolithic conductors and another six windings are made of NbTi monolithic conductors.

.Superconducting magnets for magnetically levitated trains

Japan's leadership in railroad travel is well-known. The small size and high population density of Japan makes railroad travel a very efficient and desirable method for transportation. The Bullet train or "Shinkansen" is one of the glories of modern Japan. It is incredible to realize that a high speed express Shinkansen leaves Tokyo station for Nagoya (366 km from Tokyo) every 14 minutes on the average starting at 6 a.m. and continuing until 9 p.m., arriving two hours later. After a two minute stop, the train proceeds to its next stop, Kyoto, etc. In addition to the express Shinkansen trains, there are a comparable number of high speed local Shinkansen trains. Each train has 16 cars and carries about 1600 people. This schedule is equivalent to having a high speed train leaving from New York every twelve minutes with its first stop in Washington, D.C., lasting two minutes, and then proceeding on with an equal number of local high speed trains interspersed. It is natural then to find a serious effort in Japan on magnetically levitated trains, a field which the United States gave up on some years ago.

On-board superconducting magnets and on-board refrigerators are being developed by Mitsubishi Electric for magnetically levitated trains. (The cover of *Physics Today*, 30 (1977) showed such a Japanese train.) Such equipment must be very light weight and mechanically strong. Mitsubishi Electric has constructed levitation magnets for the so-called ML-500 test vehicle (no people aboard) which has been operating for several years on a test track at the Magnetic Levitation Ground Transportation Center in Miyazaki on the island of Kyushu. The ML-500 vehicle has a length of 13.5 m, width of 3.7 m, and a height of 2.9 m and weighs 10 tons. In December 1979, the ML-500 travelled at a speed of 517 km/h. Construction of a new test vehicle the ML-500U system began in 1980. The ML-500U is composed of three cars and is designed to be able to transport people. Levitation coils are being developed for the ML-500U. Manned experiments will begin in 1982 at sustained speeds approaching 500 km/h.

.Superconducting magnets for fusion and high energy physics

The Cluster Test Coil for a fusion magnet test facility was constructed and tested successfully in February 1980. A 100 liter/hour helium liquefaction facility was used for the test. This is the first large superconducting coil in the development program of fusion magnets in Japan. The parameters of the coil are as follows:

Inner diameter	1050 mm
Outer diameter	1950 mm
Length	250 mm
Rating current	2150 A
Maximum flux density	7 T
Superconductor	Cu-NbTi
Stored energy	9 MJ
Weight (including helium vessel)	7 Tons

A larged superconducting solenoid coil was developed for the Pulsed Muon Channel of the 12 GeV proton synchrotron at the National Laboratory for High Energy Physics (KEK) at Tsukuba. The coil is cooled with supercritical helium. The coil was tested successfully in July 1980. The basic parameters are:

Inner diameter	120 mm
Outer diameter	210 mm
Length	6000 mm

Epoxy impregnated coil	
Superconductor	Cu-NbTi
Stored energy	1.1 MJ
Maximum flux density	5 T
Cooling	
Coolant	Supercritical helium
Temperature	4.5 K
Pressure	10 atmospheres

THE NAGASAKI WORKS OF MITSUBISHI ELECTRIC

I visited the Nagasaki Works of Mitsubishi Electric and a short report may be in order.

The Nagasaki works employs 3200 people, about seven percent of the total Mitsubishi Electric employment roster. It occupies 90,000 m^2 of space and is located right on Nagasaki harbor. The Nagasaki Works manufactures air-cooled steam and gas turbine generators, and turbine and boiler auxiliaries for utility power plants, both fossil fuel and nuclear, as well as for private fossil fuel plants. Diesel generating plants for supplying emergency power for schools, hospitals, hotels, and airports, as well as power for isolated communities are also manufactured. Other products include synchronous motors for such applications as blast furnace blowers for cement mills, compressors; induction motors for water and sewage pumps; high voltage switchgear, thyristor motors for tunnel blowers and for water-intake pumps. In addition to manufacturing large motors and medium generators, the works also manufactures control apparatus and systems. Rotating apparatus represents two-thirds of the activity, and control apparatus and systems represents the remaining third. Many of the products are made for export. For example, I saw a 12,500 kW four-pole motor being assembled for Argentina, a 60,000 kVA rotor for a geothermal electric power station in Mexico, a large stator for a refinery plant for Malaysia, electrical equipment for a desalination plant for Kuwait, equipment for a power plant in Shanghai for steel manufacture, and an impressive control system for subways in Hong Kong.

A great deal of attention is being paid to the control language used in control systems since software in such systems now represents 70% of the cost as compared to 30% in 1970 and 50% in 1975.

Mail for the Central Research Laboratory may be addressed to:

Mitsubishi Electric Corporation
80 Nakano, Minami Shimizu
Amagasaki, Hyogo, Japan 661

[1]Westinghouse Electric Corporation has also proposed a point venture in the United States with Mitsubishi Electric Corporation for titaniun and zirconium refining. America's second largest general electrical products maker hopes to use an idled zirconium refining facility, with an annual capacity of 1,200 tons, of an Utah subsidiary, Western Zirconium Inc. to produce 6,000 tons of titanium sponge a year. Mitsubishi now imports zirconium alloy tubeshells from Westinghouse and processes them into nuclear fuel cladding for supply to Japanese nuclear fuel makers.

THE NATIONAL PHYSICAL LABORATORY, NEW DELHI, INDIA

Leon H. Fisher

INTRODUCTION

This report is the result of a visit to the National Physical Laboratory (NPL) in New Delhi. A general outline of the laboratory's activities is given and is followed by a discussion of work being carried out on polymer electrets, on electrostatic devices involving xerography and electrostatic precipitation, on properties of silicon relating to solar cells, and on solar energy. The role of the laboratory in technology transfer is also described.

NPL is one of 42 institutions covering six disciplines operating under the auspices of the Council of Scientific and Industrial Research (CSIR). CSIR's primary role is to apply science and technology to the production of industrial products and to the setting up of technological industries. The officially stated objective of NPL is "to strengthen and advance physics-oriented research and technology to assist in their effective utilization for the public benefit."

INDIAN NATIONAL LABORATORIES

India has a long and honorable tradition in science. One need only recall such names as Bose, Raman, and Saha in physics, and that of Ramanajan in mathematics. India is investing heavily in science and technology, and has a vast and complicated network of research institutions. The total annual expenditure for scientific research by the central government is about $1.0 billion. This budget has been expanding on the average of about 15 percent per annum for the last five years. There are about 130 national laboratories in addition to about 200 other laboratories and research institutions. Each national laboratory operates under the aegis of one of the following bodies:

- Department of Atomic Energy,
- Department of Space,
- Council of Scientific and Industrial Research,
- Defense Research and Development Organization,
- Indian Council of Medical Research,
- Indian Council of Agricultural Research,
- Department of Electronics.

Since NPL operates under the auspices of the Council of Scientific and Industrial Research (CSIR), some information is given about CSIR. The combined annual budget for all of the 42 CSIR-associated institutions is about $80 million. The six disciplines, along with the number of institutions in each discipline which CSIR coordinates, are:

- Physical and Earth Sciences (5),
- Chemical Sciences (6),
- Biological Sciences (9),
- Engineering Sciences (14),
- Information Sciences (2) and,
- Fiber Technology (6).

MISSION AND ORGANIZATION OF NPL

NPL, one of the five organizations under the Physical and Earth Sciences category, was opened in 1950, and is one of the earliest institutions to have been established by CSIR.

NPL has a staff of 1200; 350 are scientists and 200 have Ph.D.'s. NPL's annual budget is about $4.0 million with an annual expenditure of about $3200 per employee including equipment and supplies.

The director of NPL is A. R. Verma, a spectroscopist, who received his graduate training under S. Tolansky at Imperial College, University of London. I am indebted to him for a long and very informative session. I spent a great deal of time with P. C. Mehendru, Assistant Director of NPL and Head of the Division of Solid State Physics. Mehendru's work will be discussed in detail later in this report.

In some ways, NPL plays a role in India similar to that of our National Bureau of Standards. It maintains physical standards, provides consulting and calibration services and provides secondary standards for industry. In addition, NPL carries out research and development, and has concentrated on long term applied projects. However, NPL does undertake short term projects sponsored by industry.

The objective of NPL, stated in the introduction, is carried out by:

- development, maintenance, and providing custody of the national physical standards (a statutory obligation),

- carrying out research on standards and on new techniques of measurement (there is an India-U.S.S.R. Working Group for Bilateral Cooperation in Standardization and Metrology; the first meeting was held in the U.S.S.R. in 1973),

- calibration of secondary standards and instruments used by government agencies and industry,

- testing of industrial products for performance, life, and effect of environment,

- undertaking applied research, design, and development work in physics-oriented technologies in order to improve, adapt, and develop indigenous and imported technologies.

NPL is divided into the following organizations and suborganizations (incomplete descriptors are included):

- Division of Standards

  Standards

  The following national standards base units are maintained:

  kilogram, 5 parts in 10^8
  meter, 5 parts in 10^7
  second and hertz, 7 parts in 10^{12}
  candela, 2 parts in 10^2
  dc volt and dc ohm, 1 part in 10^6
  gold point, silver point, $\pm$ 0.1°C
  zinc point, tin point, boiling point of water, $\pm$0.001°C

triple point of water, ± 0.0005°C
boiling point of oxygen, ± 0.002 K

The following national standard derived units are maintained:

pressure 10^{-3} to 760 Torr
force up to 3000 kgf
capacitance 10, 100, 1000 pF at 1 kHz, 5 parts in 10^{6}
ac and low frequency voltage 200 mV to 100 V at 75 Hz to 50 kHz, ± 0.02%, 100 mV to 1000 V at 50 Hz, ± 0.05%
low frequency attenuation, 1 kHz
high frequency attenuation, 30 MHz
high frequency voltage 200 mV to 30 V at 30 kHz to 100 MHz, at accuracies varying from 0.1 to 1.0%
high frequency and microwave power
sound pressure
hearing threshold (air and bone conduction)
vibration (acceleration and displacement)

Calibration and Testing

Calibration facilities exist for:

length
mass
thermometry
thermal conductivity
thermal expansion
luminous intensity
luminous flux
color temperature
refractive index
spectral transmittance and reflectance
total transmittance and reflectance
force
pressure (vacuum to high pressure)
acoustical measurements
dc ohm, voltage and current
ac and low frequency voltage, current, power, capacitance and inductance
high frequency voltage, power, attenuation and frequency
microwave frequency, attenuation, impedance and power

Environmental test facilities exist for:

dry heat
cold
damp heat
transport stress (bumps, vibrations)
constant acceleration
mold growth
salt mist

sand and dust
low and high pressure
airtightness
rapid temperature change
solar radiation
rain
assembly stress (robustness and solderability)
endurance (electrical and mechanical).

Development of instruments and systems

(In the past, such devices as sonic aids for the blind, vacuum gauges, a vacuum leak detector, a field ion microscope, and letter bomb detectors have been developed in this group.)

- Division of Specialized Techniques

Specialized techniques

Analytical chemistry
Spectrochemical analysis
Infrared

(There is a homemade far infrared spectrometer for the 200 to 400 micron range; pyroelectric infrared detectors have been made using single crystals of triglycine sulphate and ceramics of [Pb,Zr]TiO_3; interference filters.)

X-ray diffraction and spectroscopy

(X-ray analysis for identification of phases in materials such as battery grade manganese dioxide, clay samples, natural garnets, synthetic diamond grits, superconducting materials, gamma ferric oxide for magnetic tapes, manganese-zinc ferrite single crystals, etc., are carried out.)

Electron microscopy

(Activities include electron microscopy of Nb-Ti, Nb-Ta and Nb_3Sn; superconducting samples, ferrites, and fresh, old, and reclaimed greases; surface microtography of fibers.)

X-ray diffraction topography

(Facilities and activities include a Lang camera; a microfocus x-ray generator; and growth, perfection, and characterization of single and whisker crystals.)

Electron paramagnetic resonance

(Activities include ESR studies of carbon fibers, crystalline solids, plastics, and polymers.)

Mossbauer studies of rare-earth cobalt compounds

Sulfamphthalein chemical indicators

(Activities include synthesis of sulfamphthalein indicators, determination of their infrared, visible, and ultraviolet absorption spectra, and of pH for color transformation.)

Multipurpose solvent extractor

(This extractor is being used in the peanut defatting process mentioned elsewhere in the text.)

Electronics

(Projects include a digital clock for installation in public places and an automatic telephone dialing system for subscriber use.)

Cryogenics Group

Cryoproperties of Materials

(Subjects investigated include cryoproperties of insulating materials, metals, and alloys as well as thermoelectric power, electrical residual resistivity, and magnetic susceptibility measurements on palladium and palladium-tungsten alloys.)

Cryogenic plants and facilities

(Design of dewars; solid carbon dioxide generator, novel air liquefier.)

Cryoprobes

(Cryoprobes for cataract removal and retinal re-attachment.)

Superconducting materials and systems

(Program includes development of superconducting materials such as Nb-Ti and Nb Sn.)

Theoretical investigations at low temperature

Josephson tunneling

(Group carries out work on dc and ac Josephson effect devices and on standardization of volt.)

Cryochemical method of small powder preparation

- Division of Solid State Physics

Semiconductor materials and devices

Silicon technology

(Work done is discussed later in this report.)

Luminescent materials and devices

Magnetic materials

Soft ferrites
Hard ferrites and special ferrites

Piezoelectric and dielectric materials and devices

Piezoelectric materials
High voltage ceramic capacitors

Ultrasonic and piezoelectric devices
High power transducers
Ultrasonic and piezoelectric devices
Ultrasonic nondestructive testing probes
Underwater acoustic testing facility

Low-loss ceramic insulators

Carbon products
Cinema arc and other carbon products

- Division of Radio Science

Ground-based facilities for environment monitoring
Rocket and satellite experiments
Radio and space services
Aeronomy
Topside ionosphere and plasmasphere
High latitude topside ionosphere
Scintillation studies with radiotelescope
Sudden ionospheric disturbances

Environmental hazards

- Developmental Projects

Microwaves and display tubes technology
Design, development, and batch-production of microwave components, circuits, and instruments
Fabrication techniques for cathode-ray tubes and TV picture tubes
Composite displays (3-D photography; 3-D x-ray radiography).

Electrophotographic machines
Thin film devices
Liquid crystal devices

- Experimental Pilot Plants

Hydrostatic extrusion and material synthesis [this is a UNDP (United Nations Development Program) funded program]

Glass technology development and production unit development and production of electronic components

Carbon technology

Other Research and Development Activities

Development of metrological gratings
Instrumentation services
Semiconductor strain gauge transducers

POLYMER ELECTRETS

P.C. Mehendru, already mentioned as being Assistant Director of NPL and Director of the Division of Solid State Physics, heads this activity. He is a solid state physicist who, until about 1975, worked on color centers in halide crystals, on optical and ESR absorption spectra of doped halide crystals as well as on photoconductive materials such as selenium. He has about five or six graduate students who are university fellows, and who are doing their doctoral research work at NPL, an arrangement which is possible to make.

Many organic polymers have the properties of electrets. If such a thin polymer film has two metal electrodes separated from each other, but both in contact with the film, and is subjected to a strong dc electric field (ranging from tens of thousands to millions of volts per meter) at a constant temperature (usually above the glass transition temperature, ranging from about 300 to 500 K) for a long time (ranging from 2700 to 50,000 seconds), and then if the temperature is reduced to room temperature with the electric field still on (for perhaps an hour and a half), and the field is then removed, the film retains its electrified state with decay times of the order of several hours or even days at room temperature, even after the electrodes are short-circuited for about five or ten minutes. The technique often used in such studies is to measure such currents between short-circuited electrodes as a function of temperature (or its equivalent, time) under a program in which the temperature of the sample is increased linearly and slowly from room temperature to temperatures as high as 500 K at rates varying from 0.05 to 0.2 K s^{-1}. (This heating process generally takes several thousand seconds.) Under these circumstances, currents of the order of 10^{-10} or 10^{-9} A are measured and the total charge that flows during the heating process is between about 10^{-7} and 10^{-6} C. Peaks appear in these current-temperature/time curves, constituting a kind of current-temperature/time spectrum, and it is in the interpretation of these peaks, their maximum values, the temperatures at which they occur, and the charges associated with the peaks and the variation of all these quantities with the magnitude of the polarizing field, the polarizing temperature, polarizing time, and film thickness that reveals the nature of the physical processes involved. The persistent electrification of the thin films may be due to molecular dipole orientation, or may be due to charge carriers being captured in traps associated with a definite energy of activation, or both effects may occur in the same sample. The method of study is called TSD (or TSDC), thermally stimulated discharge currents. TSD studies are also going on in Japan, see this *Bulletin, 6* (2), 35 (1981).

TSD work has been described in the following books:

- *Thermally Stimulated Discharge of Polymer Electrets* by J. Van Turnhout, Elsevier, Amsterdam, 1975,

- *Thermally Stimulated Processes in Solids. New Prospects: Proceedings on an International Workshop, Montpelier, June 1976*, edited by J. P. Fillard, J. Van Turnhout, Elsevier, Amersterdam, 1978, and

- "Thermally Stimulated Relaxation in Solids," edited by P. Braeunlich, *Topics in Applied Physics*, Volume *37*, Springer-Verlag, Berlin, 1980.

In the NPL experiments, either one of two electrode/film arrangements are used. The most common one is to prepare films of thickness varying from a fraction of a micron to about one micron, then to place a circular wire of about 0.03 to 0.5 cm diameter as a wire mask on the film, then to evaporate silver on this side of the film, and then to remove the wire leaving two plane silver electrodes on the same side of the film separated by the thickness of the wire. A voltage is then applied between the electrodes producing a nonuniform fringing field. This disposition of electrodes and dielectric will be called the planar electrode configuration. In the second arrangement, which is used much less often by the NPL group, much thicker films, ranging from 30 to 200 microns, are coated on both sides with conducting material, and a field is applied which is uniform and perpendicular to the film. This second arrangement will be referred to as the sandwich electrode configuration.

A continuing systematic program at NPL on the electrical properties of such thin film polymer electrets was started about eight years ago. The justification for this program is that thin film polymers may find application as reliable photoreceptors in the field of electrophotography and that selenium in such devices may be replaced by sensitized polymers, although no work on this aspect of polymer electrets has been published by NPL. It is hoped that such studies will lead to a material with spectacular properties such as one having a normal resistivity of 10^{12} ohm cm and a resistivity of 10^{9} ohm cm under irradiation. A TSD study of x-ray irradiation of thin film polymer electrets was published by NPL about six years ago. Possible use of polymer electrets as air filters will be discussed in the next section.

Polymers being studied at NPL include:

- Polyvinal fluoride (PVF),
- Polyvinylbutyral (PVB),
- Polycarbonate (PC),
- Polyvinylidene fluoride (PVF_2), and
- Copolymers of polyvinyl chloride-polyvinyl acetate (PVC-PVAc).

The question arises as to whether the most desirable properties of a number of different polymers such as the ability to have a large charge and slow decay can be achieved by combining polymers with different properties in one sample of material. A number of copolymers made up one, three, ten, and 17 percent PVAc with the rest being PVC will be studied. These are ordered mixtures, such as are exemplified in phase diagrams.

The titles of some recent papers resulting from these studies and brief summaries are now given. For additional information on the authors of the papers, write to P.C. Menandru whose address is listed at the end of this paper.

"Electrical and Dielectric Properties of PVB I. Studies of Charge Storage Mechanism"

The charge storage properties in solution-grown PVB thin films using the planar electrode arrangement were studied as a function of polarizing field (2×10^{4} - 2×10^{6} V/m), temperature (333 - 398 K), time (5.40×10^{3} - 1.44×10^{4} s), thickness of the films (0.8 - 4.5 microns), and heating rates of depolarization (0.05 - 0.17 K/sec) by TSD. Two relaxations processes were observed at 347 K and 423 K having activation energies of 0.36 and 0.66 eV, and relaxation times at 300 K of 4.19×10^{3} and 0.86×10^{6} s, respectively. The magnitude of the maximum current corresponding to the 347 K peak and the charge associated with it increase linearly with the polarizing field. It is associated with the deorientation of the aligned dipoles involving acetate/hydroxyl groups. The peak at 423 K is attributed to the release of trapped electrons/holes.

"Electrical and Dielectric Properties of PVB II. The Effect of the Molecular Weight on the Charge Storage Mechanism"

These experiments were carried out using the planar electrode arrangement with films about one micron thick. With an increase in the degree of polymerization the quantity of charge associated with the TSD peak at 347 K decreases whereas that associated with the peak at 423 K remains constant. With a decreasing degree of polymerization the positions of both peaks are shifted toward lower temperatures; this was attributed to the lowering of the glass temperature.

"High Temperature Relaxations of PC Thin Films"

This work was carried out with one micron thick films using the planar electrode arrangement. Two relaxations were found, one at 350 and the other at 436 K, as well as a space charge polarization for large polarizing fields. The low temperature relaxation is attributed to molecular dipole orientation and the high temperature one is associated with the orientation of dipoles formed by electrons/holes on their release from their respective traps and is not due to the migration of ions.

"Mechanism Responsible for the Observed Dielectric Relaxations in PVF_2"

Dielectric relaxations of PVF_2 films were studied in the sandwich arrangement as a function of polarizing temperature (318 - 373 K), time (3.6×10^3 - 2.16×10^4 s), thickness (30 - 200 micron), nature of the vacuum deposited electrodes (copper, silver, aluminum, and indium) and the heating rates of depolarization (0.047 to 0.2 K/s). The depolarization current spectrum with silver electrodes shows two relaxation processes, one at 319 and the other at 385 K. The peak at 319 K is attributed to the migration of charge carriers with subsequent trapping into shallow traps; the peak at 385 K is associated with the detrapping of charge carriers from deeper traps. The shift in the position of the 385 K peak with increasing polarizing time or increasing temperature and the linear increase in the activation energy with polarizing temperature suggest that this peak is due to the distribution of relaxation times and activation energies. The decrease in the magnitude of the 385 K peak and the increase in the magnitude of the 319 K peak with the increase in the work function of the metals used as electrodes during polarization, show that the nature of the electrode metals plays an important role in the electrification process. The fact that the total charge involved in the discharge process is a linear function of film thickness leads to the conclusion that uniform volume polarization is operative.

ELECTROSTATIC DEVICES

Mehendru has also been working on electrostatic precipitation devices for the last ten years. One of the rewarding aspects of my visit to India is that it helped to obtain an invitation for Mehendru to be a guest of the Japan Society for the Promotion of Research and to spend some time in Japan with Senichi Masuda of the University of Tokyo on electrostatic problems, especially electrostatic precipitation. The development of electrostatic copying machines at NPL has already been mentioned, and a few further details are mentioned under the Technology Transfer section at the end of the paper. Mehendru had a technician demonstrate such a copying machine for me. It produced excellent copies, but required many manual operations. At present, NPL is especially interested in the medical uses of xerography. The character of photoreceptors, decay, fatigue, and spectral response are all of interest.

Other electrostatic devices are being developed. For example, an electric type of dust filter has been constructed from separated layers of polymers having alternate charges. With charges of 10^{-6} C, the life of the device is about 18 to 24 months. A prefilter removes particles greater than 10 microns; particles from one to two microns are then deposited by the polymer filter. Submicron particles are not deposited by the device. If dust particles are not precharged, the collection efficiency is about 60 percent. Corona discharges are to be used for particle charging, and at the time of my visit it was planned to extend these studies to fly ash. Work on using electrets for air pollution control has been going on elsewhere as is evidenced by publication of the book, *Electret Devices for Air Pollution Control*, by T. Kallard, Optosonic Press, New York, 1972.

Another problem being attacked electrostatically is the separation of raw tea leaves from stalk. The price of tea is very dependent on the amount of stalk in it; five percent stalk content may lower the price of tea by 50 percent. At the present time, removal of stalk is carried out manually on moving belts. At NPL, the dielectric constants of tea and stalk have been measured separately as a function of relative humidity. It is found that the dielectric constant is a strong function of relative humidity and that the maximum difference in the dielectric constant between tea and stalk occurs around a relative humidity of between 70 and 80 percent. If mixtures of tea and stalk can be electrified to differing degrees depending on the dielectric constant, then it may be possible to separate tea and stalk electrostatically. (Maximum charging of a body in a charging field such as is provided by corona is larger the larger the dielectric constant.) Both charging of tea and stalk by induction and by corona discharge are being investigated. Heaps of tea and stalk are kept at the appropriate humidity for about 30 minutes before being subjected to separation.

RESEARCH ON SILICON

My host during my visit to the silicon study installation was a young physicist, B. C. Chakravarty.

Extensive work is being carried out at NPL on silicon to obtain information necessary for the fabrication of solar cells. In particular, a great deal of work is being carried out on polycrystalline silicon for solar cell use in order to reduce the cost below that of the single silicon solar cell as will be discussed in the next section. In this section, we give titles and summaries of some recent papers which have been published by workers at NPL on basic aspects of silicon both in single and polycrystalline form. Before doing this, however, the method of preparation of polycrystalline silicon at NPL is given. This method applies to the papers discussed in this section as well as that part of the next section which describes NPL polycrystalline solar cell activity.

Ferrosilicon (metallurgical grade silicon) is leached resulting in material which is 95 percent silicon. HCl gas is then passed through a column filled with this leached silicon resulting in 50% $SiHCl_3$ and 50% $SiCl_4$. These two materials are separated by a single distillation and the $SiCl_4$ plays no further role in the process. The $SiHCl_3$, which is impure, is cracked on a thin hot silicon filament. This results in a silicon rod (of diameter 6 to 10 mm) with Fe content as high as 10 ppm and which contains other impurities as well. The polycrystalline silicon rods are zone melted and resolidified by passing a fast moving molten zone from one end to the other resulting in a columnar grain structure. The rod is cut into slices about 250 to 350 microns thick, and then they are lapped, etched, and diffused.

The titles and summaries of some recent silicon papers now follow (in every case the nature of the silicon and dimensions is specified). Again, for information on authors of these papers, write to P.C. Mehendru.

"Effect of Annealing on Resistivity and Photoconductivity of Solar-grade Polycrystalline Silicon and on Solar-cell Performance."

The effect of annealing on the resistivity and photoconductivity of solar grade polycrystalline silicon of grain size 100-1200 microns was studied in the temperature range of 900 to 1100°C, temperatures necessary in the processing of the material for solar cell fabrication. The majority impurity is phosphorus making the material N-type with a resistivity of 1 to 100 ohm cm. The samples were circular slices 16 mm in diameter and about 250 microns thick. It was found that both of these quantities depend strongly on the annealing temperature and on the grain size. However, the atmosphere in which annealing takes place, e.g., air, nitrogen, argon, or vacuum does not have any effect on the results. Heat cycling of the starting material causes a reduction in the short circuit current of the solar cell.

"Effect of Grain Boundaries and Grain Size Distribution on the Performance of Columnar Grain Polycrystalline Silicon Solar Cells"

The influence of grain boundaries and grain size distribution on the performance of P on N polycrystalline silicon solar cell was studied. The studies were carried out on 330 micron thick N-type wafers with columnar grain structure along the thickness. An increase in grain boundary length (or a decrease in grain size) affects the short circuit current and the open circuit voltage, but leads to no drastic deterioration in the shape of the current-voltage characteristic of the cell if the grain size is uniformly distributed. However, the presence of a fine grained region in an otherwise coarse grained cell decreases the open circuit voltage and degrades the shape of the current voltage characteristic drastically. The degradation is considered to be mostly due to the behavior of the cell being made up of two mismatched cells connected in parallel.

"Dopant Profile Analyses of Boron in Solar Grade Poly and Single Crystalline Silicon"

Diffusion of boron occuring in ten minutes in N-type solar grade poly and single crystalline silicon was studied from a paint on source at 1075°C in an ambient flowing mixture of argon and oxygen. The polycrystalline silicon had an average grain size of 50 microns. Dopant profiles were evaluated from measurements of sheet conductivity vs. depth. The surface concentration was the same, within experimental error, for both poly and single crystal, viz., 1.8×10^{20} atoms cm^{-3}. However, the junction depth is greater in polycrystalline silicon than in single crystal silicon by more than about 850 Å. The shape of the profiles observed are quite different, and this difference is attributed to fast diffusion through grain boundaries. The shape of the profile observed in polycrystalline silicon is more suited to solar cell fabrication than that occuring in single crystal silicon.

"Effect of Interfacial Stress at the Si/SiO_2 Interface on the Diffusion of Ga in (Single Crystal) Si through SiO_2"

The diffusion of gallium into bare and oxide-covered silicon was carried using the closed capsule technique. The wafers were 200 microns thick, displayed N-type conductivity, had a resistivity of 40 ohm cm, and had a (111) orientation. The diffused wafers were analyzed by anodically sectioning them. When the oxidation temperature is greater than the diffusion temperature, the effect of the oxide layer is to enhance the diffusion and the opposite effect occurs when the oxidation temperature is less than the diffusion temperature. When the oxidation temperature is equal to the diffusion temperature, there is little or no effect due to the oxide. These results were explained in terms of the stress at the Si/SiO_2 interface and the resulting strain gradient in the bulk Si.

"On the Mechanism of the Anodic Oxidation of (Single Crystal) Si at Constant Voltage"

A study was made of the constant voltage anodic oxidation of single crystal Si from a solution of ethylene glycol and 0.04 N KNO_3. The Si electrode was P-type, was cut parallel to the (111) plane and had a thickness of 300 microns. The thickness of the oxide formed was found to vary linearly with impressed voltage having a slope of 6.5 A V^{-1}. At a fixed voltage, the current decays exponentially with a linear tail and the growth of the oxide thickness follows a parabolic law. The anodization of Si is accompanied by a large electronic current density.

SOLAR ENERGY

NPL has been designated as the national center for testing the thermal performance of solar collectors and for testing solar cells. It is the leading group in the country in the field of solar energy.

- Solar Collectors

Both flat plate and parabolic cylindrical concentrating solar collectors have been developed at NPL. Facilities exist for determining the instantaneous efficiency of collectors and comparative testing of collector efficiency against a standard collector is also available. Apparatus for measuring the absorptivity and emissivity of absorber surfaces are in operation.

NPL is working on developing solar collector systems for providing hot water, space heating, and cooling. One of the first applications of solar energy in India was the installation of a space heating system by NPL, in collaboration with Bharat Heavy Electricals Limited (BHEL), a public sector enterprise, at their Hardwar factory. The system consists of an array of 110 m^2 of flat plate collectors. A three-ton solar refrigeration unit using water-ammonia has also been developed. A solar house has been constructed on the grounds of NPL in which an integrated system provides 75 percent of the total energy required for cooling, 90 percent of the heat required for space heating and almost all the energy required for hot water. The house has heavily insulated walls and double glass windows. The roof of the building is inclined to the horizontal at an angle equal to the latitude. Other solar devices which have been developed at NPL include a dryer for agricultural products, a small still which can be assembled by villagers for providing clean drinking water from brackish water (one square meter of collecting surface can provide three-four liters of pure water per day), cookers and a large scale device to remove oil from peanuts.

Two systems of parabolic cylindrical solar collectors have been developed, one in which each individual collector in an array is rotated to track the sun, and the other in which the whole array tracks the sun. Systems for pumping irrigation water have been fabricated using both flat plates and parabolic plates. Irrigation is such an important problem in India (agriculture represents 50 percent of the gross national product) that the development of solar pumps for this purpose has been given the highest priority in the solar energy program in India. In the system using parabolic solar collectors, an organic vapor Rankine cycle is coupled to an array of collectors with the organic liquid in the absorber tubes. On heating, the liquid is converted into high pressure vapor which energizes an expander.

- Photovoltaic Solar Cells

Thin Film Cadmium Sulfide-Cuprous Sulfide Solar Cells

NPL has undertaken a research and development program for the indigenous technological development of thin film cadmium sulfide: cuprous sulfide solar cells using low cost polycrystalline material. Inexpensive thin film deposition techniques are used to enable deposition of large area films reducing the number of processing steps and the number of interconnections.

The cells are constructed on ordinary window glass substrates. A back contact of thin film of silver is deposited onto the substrate. A layer of N-type CdS layer of desired structural, electrical, and optical properties is deposited onto the silver layer through masks in vacuum. The surface microstructure of this layer is then modified by chemical treatment for higher light absorption, and to increase the effective junction area to obtain larger photocurrents. The formation of the heterojunction involves deposition of a cuprous sulfide layer of thickness between 1500 and 2000Å by an inexpensive chemical dip process. The junction is then subjected to heat treatment and metallic grid contacts are applied, and the cell is hermetically sealed with epoxy and with glass. Submodules are then fabricated from cells of identical photovoltaic behavior by connecting them in series. The modular units are constructed on light weight aluminum frames. The cells fabricated at NPL have exhibited efficiencies between five and six percent and are quite stable. The area of an individual solar cell is 12 cm^2. Cell performance data suggest that that the lifetime is greater than 10 years.

Efforts are underway to increase the efficiencies to a level of about eight percent, and to develop larger area cells on integrated modules which can be fabricated in a single cycle. The laboratory is setting up a pilot line for fabrication of solar cells.

Polycrystalline Silicon Solar Cells

Work on polycrystalline silicon solar cells at NPL was started in 1977. From the silicon rods produced as described in the last section, N-type wafers are produced which normally have resistivities ranging from five to 15 ohm centimeters. However, the resistivity can vary from less than one ohm centimeter to 100 ohm centimeters from batch to batch, but the entire resistivity range is used. The cell has a P^+-N-N^+ structure which is obtained in a single step diffusion of boron and phosphorus into the N-type silicon wafers, presently 16 mm in diameter. The P^+-N-N^+ structure also permits the use of higher resistivity and reduces the variation of cell efficiency with resitivity and grain size.

Cells are given antireflection coatings similar to silicon monoxide in optical properties. The antireflection coating is porous as well as conducting, thus permitting metallization for contact on the P^+ side through the coating. Contacts on both the top P^+ and the back N^+ sides consist of Ti and Ag metal layers.

Solar cells are fabricated in batches with each batch consisting of nearly 100 cells. The maximum efficiency of cells from a single batch is normally between seven and eight percent, but a few exceptional batches show efficiencies as high as eleven percent. The maximum peak output power so far is 3.5 W at 100 mW/cm^2.

A three cell model has been used for running calculators and a 12 x 256 cell module operating at 230 V and 60 W can pump water. Efforts are being made to fabricate cells of larger area and solar cell modules for larger power applications.

Development of 25 mm diameter cells is under way. There are plans to fabricate cells of larger area using polycrystalline silicon obtained by unidirectional solidification of silicon in crucibles and by Czopchralski pulling techniques. Initial experiments with unidirectional solidification in crucibles have already yielded cells with seven to eight percent efficiency. Cells presently have evaporated contacts. Screen printed contacts will be developed for larger area cells. Large area cells will also be produced in batches of 100 or more cells per batch to both produce the solar cell modules for larger power application as well as to make the process adaptable for large scale production.

TECHNOLOGY TRANSFER

NPL has released know-how for more than 70 products and processes to industries for indigenous production. At the present time, about two million dollars per year of products are produced under NPL licenses. Some examples of such technology transfer are now given.

Based on know-how generated at NPL the government under the auspices of the Ministry of Science and Technology, has set up a publicly owned organization "Central Electronics Limited, Sahibabad" to produce ferrite and ceramic components including elements needed by the Indian telephone industry. Indigenous raw materials are being used as much as possible. For example, nickel first used in the manufacture of soft ferrites was later replaced by indigenously available and inexpensive MnO_2. Electroceramic and piezoelectric materials and components such as silver mica capacitors. ceramic capacitors, steatite bodies and piezoelectric bimorph elements are being manufactured.

A family of carbon technology products such as brushes and blocks, cinema arc carbons (the cinema is a tremendous industry in India; it is the most popular recreational activity in India), and searchlight carbons are being commercially produced as a result of NPL developments. The present production of cinema arc carbons is about a million dollars a year and is expected to grow exponentially (for a while). Technology is being released for the production of carbon thrust bearings, electrographite dynamo brushes and carbon granules for microphones.

NPL has developed microwave components at various bands and has been instrumental in setting up the first microwave industry in the country. About $100.0 thousand a year is saved annually by the production of these components.

The development of an electrostatic photocopying machine is considered to be one of the most signficant achievements of the laboratory. The cost is one-sixth that of imported machines and NPL licensees have sold a few thousand of them. NPL also developed sensitized ZnO papers for use with the machines. As mentioned earlier, these machines are not automatic, but an automatic version has also been developed.

Other processes and devices that have been licensed include:

- thermal devices based on NPL's development of liquid crystals,
- a solar collector,
- an ultrasonic interferometer,
- platinum resistance thermometers,
- crystals of rare earth fluorides,
- a solid CO_2 machine,
- single crystal silicon,
- Penning and Pirani gauges,
- an electronic desk calculator,
- color coating of sunglasses,
- vacuum leak detectors and
- 3-D photography.

Mail may be addressed to:

National Physical Laboratory,
Hillside Road
New Delhi - 110012, India

RECENT DEVELOPMENTS IN APPLIED SUPERCONDUCTIVITY IN JAPAN

Taiichiro Ohtsuka

INTRODUCTION

Although many applications of superconductivity such as the voltage standard, use of SQUIDs, and laboratory superconducting magnets have become quite concrete in the past decade, there still remain many important applications which depend on future research and development efforts. It is, therefore, interesting to look into the transition in research and development (R&D) efforts which has taken place in the past half-decade before going into a detailed review of the present status of this field.

In 1975, activities in Japan were centered on the following fields:

- superconducting materials,

- dc homopolar generators,
  3,000 kW (150V, 20,000A)

- synchronous generators,
  6 MVA machine under construction

- superconducting power transmission,
  model cables and tests

- MHD generators,
  60MJ magnet completed and tested; maximum field 6.8T;
  uniform field 4.5 T over 10 x 25 x 12 cm

- superconducting magnetic levitation,
  laboratory and model vehicle tests completed;
  Miyazaki test track construction initiated

- superconducting coaxial cables for telecommunication, feasibility tests completed (loss 0.55 db/km at 1GHz, frequency range up to 10GHz),

- practically no activity in high energy physics applications, (except for model dipole, quadrupole magnets),

- no activity on nuclear fusion magnets,

- activities in developing Josephson voltage standard,

- except for laboratory SQUID's, practically no activity on Josephson devices.

This list is to be compared with the following activities currently (1981) in progress:

- superconducting materials,
- synchronous generators,
- superconducting power transmission,
- superconducting magnetic levitation,
- high energy physics applications,

- nuclear fusion applications,
- superconducting energy storage,
- Josephson devices, in particular, logic circuit applications,
- electromagnetic ship propulsion.

I might add that activities in the development of refrigerators have grown steadily in this period. Developments in this area are primarily towards small refrigerators of 10W capacity at 4.2 K for use as onboard refrigerators on MAGLEV vehicles and foı cryopumps.

When compared with the 1975 list of activities, one finds that work on homopolar machines, MHD generators, and coaxial cables is missing, and that activity in high energy physics, nuclear fusion, and Josephson devices has been added to the 1981 list.

The 3000 kW homopolar generator which was developed by the Toshiba Company, in cooperation with the Furukawa Electric Company, the Nippon Oxygen Company, and the Toyota Machine Works underwent successful long test periods in 1974. It was to be installed for test use as a power source for copper electrolyzing at the Furukawa Electric Company, but the oil embargo problem tipped the economic balance between buying and generating one's own electricity. For this reason, it was never installed and projects on homopolar machines became dormant.

The progress in optical fiber technology, especially in the past few years, just about abolished efforts toward developing superconducting coaxial cables for telecommunication use.

The situation with MHD generators is quite different. Developments in MHD power generation are still being actively pursued at the Electrotechnical Laboratory. The generator, called MARK V, which at that time was the largest superconducting MHD magnet in the world, successfully generated 500 kW for a period of three hours. Since 1976, development work has been focussed more on research in generator channels and overall systems. For this purpose, a conventional electromagnet is being used.

The projects in the 1981 list, which have been active since 1975, have advanced and expanded considerably. Some of the additional projects are moving forward rapidly. As a whole the scope, funding, and quality and amount of work being performed has increased to an extent that it has become difficult to give a detailed account of all items. Therefore, a description of the activities will be very brief or detailed depending not only on the importance of the activities, but also on the degree of my personal involvement.

Before going into the description of developments, let me briefly describe the funding structure and the main R&D centers. Funds from the government are mainly from the following Ministries:

- Ministry of International Trade and Industry (MITI),
- Ministry of Education and Culture (MEC),
- Ministry of Transportation (MT),
- Science of Technology Agensy (STA).

Most of the funding for applied superconductivity in the past has been from MITI. MITI supervises several government laboratories of which the Electrotechnical Laboratory (ETL) has been, and is still, one of the most active research centers in applied superconductivity. MITI funds are provided not only to ETL, but also to private industries.

In the past, grants from the MEC has been limited as far as applied superconductivity is concerned. This has changed, and MEC has recently approved establishment of research centers on superconducting materials and technology at Osaka University, Tohoku University, and Kyushu University. The MEC has also approved construction of the superconducting three ring intersecting storage accelerator (TRISTAN) at the National High Energy Physics Laboratory. A substantial budget (800 million yen per year for a eight to ten year period) has also been alloted for research projects on nuclear fusion. About ten per cent of this is being directed towards research on superconducting materials and magnets.

The Science and Technology Agency (STA) supervises the National Research Institute for Metals where active research on superconducting materials is being conducted. The STA also supports much of the fusion reactor superconducting magnet research at the Japan Atomic Research Institute.

As for public corporations, the Nippon Telegraph and Telephone Public Corporation has initiated active research on Josephson devices. The superconducting magnetic levitation project conducted by the Japan National Railways has made impressive progress during the past several years.

Beside governmental and public corporation establishments, private industries, notably Hitachi, Toshiba, Mitsubishi Electric, Fuji Electric, and Furukawa Electric, have been active in R&D studies. In addition to large scale applications, research on Josephson devices is becoming progressively active at Fujitsu, Hitachi, and Mitsubishi Electric, in particular, at Fujitsu.

SYNCHRONOUS GENERATORS

The synchronous generator is one of the industrial applications of superconductivity which has been under steady development in Japan since 1974. The possibility of higher overall efficiency, smaller and lighter weight machines, lower synchronous reactance which leads to improved system stability, and the possibility to raise the output voltage are the main factors which have spurred this development.

At present, the economic crossover for SC machines is estimated to be between 500 and 1,000 MVA. One of the technical problems lies in the scale up of the machine to this size. Two different approaches have been taken in the development of SC machines:

- The "scale up" approach where one starts from small scale models and scales up stepwise confirming problems in each stage, and

- the "model rotor approach" where a large scale rotor is developed from the beginning.

The first step in the development of SC synchronous machines in Japan was the construction and tests of a 6 MVA generator. The development was subsidized by a MITI grant for the period of 1974 to 1977, and was undertaken through the cooperation of the Mitsubishi Electric Company and the Fuji Electric Company.

The tests have been successful, and the development is now in its second phase where a 30 MVA machine is to be constructed and tested. A similar MITI grant has been awarded to the two companies for the second phase project for a five year period beginning from 1979. Beside Mitsubishi and Fuji, Hitachi Limited is also developing a 50 MVA machine.

The main object of the 6 MVA machine project was to provide the feasibility of superconducting synchronous generators. The main design specifications of the machine are listed in Table 1.

The diameter of the rotor chosen, 40cm, is the maximum diameter allowed which will not give rise to transition of liquid helium to the supercritical state due to pressurization by centrifugal force.

When compared to a conventional 6 MVA rated machine, the main dimensions and weight of the SC machine are about $\frac{1}{2}$ and $\frac{1}{5}$, respectively. The synchronous reactance x_l=40% is a few tenths of a percent of conventional machines and the short circuit ratio has a very large value of 2.5.

The SC field winding consists of nine saddle shaped coils which are fastened to the torque tube by a stainless steel band. The conductor was a Nb-Ti-Ta alloy fine multifilamentary wire with 100 filaments of 40 μm diameter twisted at a 25mm pitch. The cross section of the wire is 1.6 x 3.2mm, the critical current at 5T is 1000A. The windings were vacuum impregnated in epoxy resin. Cooling channels were provided so that liquid helium first cools the SC windings and the return gas cools the torque tube and the power leads.

Twisted copper wires were used for the room temperature armature windings. The armature is immersed in oil which is circulated through a cooling system. A high current density of 14A/mm^2 was achieved by this forced cooling method.

Various tests including short circuit tests showed that the machine performed according to design specifications.

The second phase is directed towards development of a 30 MVA machine. The "model rotor" approach is being partially adopted for the 30 MVA machine in that the rotor diameter is designed to be over 70cm. This will allow tests under centrifugal force conditions which will be met in large scale machines.

The Nb_3Sn multifilamentary conductors developed by Mitsubishi will be used in part of the field windings. Tests have already been made at rotor speed of 3600 rpm with coils wound by the "wind and react" method. It is planned that techniques which will be required in future large scale machines will be developed and mastered during this phase. The 30 MVA machine will be completed by the end of the 1981 fiscal year (March 1982).

In the meantime, long term tests are being conducted on the 6 MVA machine using the 30 l/h capacity helium refrigerator-liquifier system developed for the 30 MVA machine. The 30 MVA project is planned to continue until 1984 during which time plans will be proposed for the next phase.

POWER TRANSMISSION

The development of superconducting power transmission cables is, at present, being pursued at the Electrotechnical Laboratory (ETL). Research has been centered on:

- development of SC cables and experiments on their characteristics,
- research on electric insulation at very low temperatures, and
- fundamental research on large scale refrigeration and control techniques.

Table 1

Main Design Specification Of The
6 MVA Superconducting Generator

Rating
6,250 kVA
No. of Poles
2
No. of Revolution
3,600 rpm
Voltage, Current
2.640 V x 1,375 A
Synchronous Reactance
40%

Rotor Superconducting Rotating Field
2 Dampers at room and low temperatures
magnetic fluid rotatable
He supply seal

Dimensions
Outer Diameter 39 cm
Effective Length 45 cm
Length Between Bearing 190 cm

Weight
700 kg

Stator Normal Conductor
Air gap Winding

Dimensions
Outer Diameter 110 cm
Inner " 40 cm
Total Length 168 cm

Weight
4,500 kg

For cable tests, a 10m long test facility has been constructed which consists of a 200 kVA, 10 kA, three phase current supply, current supply terminal experiment apparatus, and cable characteristic experiment instrumentation.

A Nb_3Sn tape current carrying conductor surrounded by an insulation layer and a Nb_3Sn tape shield conductor wound with the same pitch as the current carrying conductor has been found to minimize ac losses.

Some problems revealed by the tests are cable construction which leads to distortion of long cables into a snaky-like form. Electrification tests up to effective current values of 5000A, single phase, revealed local heating at portions of the cable locally stressed. Investigation on the relationship between critical current, ac losses, and local stress are being conducted.

As for large scale refrigeration, computer simulation, and identification of dynamic characteristics of very long refrigeration systems is being actively pursued.

SUPERCONDUCTING MATERIALS AND CONDUCTORS

Research and development on superconducting materials and conductor fabrication is still quite active, and has become very extensive. Not only are the national laboratories and industries involved, but universities also are participating actively in conductor research.

The mainstream in conductor development is still in development and refinement of fabrication techniques for two and three component alloy fine multifilamentary conductors, in particular, for use in pulse magnets, and intermetallic compound fine multifilamentary conductors for high field use. In parallel, research on the effects of mechanical stress, irradiation, etc., on cable characteristics have become progressively active.

As for alloy (NbTi) conductors, the development has been mainly on production techniques such as hydrostatic extrusion methods.

As for compound conductor developments, the group at the National Research Institute for Metals (NRIM), lead by K. Tachikawa, has been and is still quite active. As is well-known, the V_3Ga tape conductor developed at NRIM has been used successfully as the inner section of a hybrid SC magnet which produces 17.5T in a 31mm diameter bore. The outer section which produces 13.7T in a 160mm bore is wound with Nb_3Sn conductor. The magnet was constructed by the U.S.A. company, IGC, and has been working successfully for use in testing SC materials.

Multifilamentary V_3Ga conductors have been developed using the composite diffusion method (CDP) where a composite of Cu-Ga solid solution matrix containing 15~20 at % Ga and a vanadium core is first fabricated into thin wires, and then heat-treated at 600~650°C. Conductors which show good stability have been commercially produced by the Furukawa Electric Company. The overall critical current density of the commercial conductor is 3.3×10^4 A/cm^2 at 15T, 4.2K.

Recent progress in this area is the discovery of improvements in superconducting properties by addition of a third element to the matrix and/or the core. V_3Ga tapes with Mg added to the matrix, and Ga added to the core have shown that a critical current density of 1×10^5 A/cm^2 may be achieved at 20T. Based on these results, construction of a 20T V_3Ga magnet is being planned at NRIM.

Another compound which has been under extensive research at NRIM is V_2Hf-based C15-type Laves compounds. Addition of Zr, Nb, or Cr is known to enhance the critical temperature (9.2K), and the upper critical field Hc_2 (20T at 4.2K) considerable. For instance, $V_2Hf_{0.4}Zr_{0.6}$ show possibilities of generating 20T at 1.7K.

The V_2Hf-based compounds are highly resistive to heavy neutron irradiation which makes them attractive for application to nuclear fusion reactor magnets. Furthermore, they are not as brittle as the A15 compounds which may ease fabrication problems.

The compound which has been, and is still, under intensive development in Japan is Nb_3Sn. Nb_2Sn multifilamentary wires are being developed at Hitachi Ltd., Showa Electric Wire (an affiliate of Toshiba), Mitsubishi Electric, Furukawa Electric Companies, and NRIM and ETL. Three different methods of Nb_3Sn formation and wire fabrication are being adopted:

- the bronze method,
- inner diffusion method, and
- Nb tube method.

The bronze method is being adopted by Hitachi. In this method, Nb wires are embedded in a Cu-10 to 13% Sn matrix. Work hardening of bronze at large Sn content and embrittlement at elevated temperatures necessitates many intermediate annealing stages during drawing of the wires. The Hitachi people claim that this disadvantage may be partially overcome by the hydrostatic extrusion method which can be conducted at relatively low temperatures of 200~400°C, and thus reduces intermediate annealing stages to two or three. The method also results in more uniform Nb filaments. An elemental submatrix of the Hitachi conductor consists of 331 5 μm diameter Nb filaments on which 1 μm thickness Nb_3Sn layer is formed after reaction. The submatrix is surrounded by a Nb tube which acts as a diffusion barrier to prevent degradation of the OFC (oxygen free copper) by Sn diffusion. The ratio of the OFC, Cu-Sn, Nb areas is 3:2:1. The submatrix is stranded into various configurations according to applications.

In general, it is preferable to surround as few as possible Nb filaments with Nb diffusion barriers for better stability. This results in a production problem which may be partially obviated by the use of the "Nb tube method." In this method, bronze is enclosed in a Nb tube in a OFC matrix. NbSn is formed on the inner wall of the Nb tube. In other words, the Nb tube acts as both the conductor and the diffusion barrier. This method, which is being employed by Toshiba, requires no intermediate annealing stages during the drawing process.

In the "inner diffusion process," a Nb tube encloses a copper matrix with many Nb wires embedded in it. At the center of the matrix, a Sn core is embedded. The "bronze" problem is thus eliminated, and no intermediate annealing stages are necessary. Nb Sn is formed on the embedded Nb wires by reaction with Sn which diffuses through the copper matrix to the Nb wires. This method is being employed by Mitsubishi Electric who have tested a conductor 1.6 x 3.2mm in cross section with about 30,000 2.7 μm diameter filaments for use on their 30 MVA machine.

The wires produced by these methods all show overall critical current densities at 4.2K and 10T of few 10^4 to 10^5 A/cm^2. The ultimate quality of Nb_3Sn multifilamentary wires must be judged not only from the critical current densities, but other factors such as degree of stress degradation, stability. Various "reinforced" composites are under investigation and 10T solenoids have been built both by "prereacted" and "react after winding" methods.

SUPERCONDUCTING MAGNETIC LEVITATION

The superconducting magnetic levitation (MAGLEV) project was initiated in 1970 at the Japan National Railways (JNR). The primary reason for the initiation of this project was the estimated saturation of the Shinkansen line, in particular, between the two main cities of Tokyo and Osaka. The present Shinkansen connects the two cities, which are about 515 km apart, in three hours and ten minutes. It was proposed that the travel time between the two cities in the future system should be comparable to air transportation, i.e., about one hour. Among various high speed ground transportation systems where a maximum speed of about 500 km/hr may possibly be achieved, the superconducting system was considered preferable because of the relative ease of track maintenance.

More recently, the MAGLEV project has been promoted not only from the high speed point of view, but because of possible reduction of environmental noise.

The Miyazaki Test Center, where all tests for the MAGLEV projects are being carried out, is located in Kyushu, the southern island of mainland Japan. The primary object of the first phase tests which were initiated in 1977 was to prove the feasibility of high speed levitated operations.

The first phase tests were completed with test vehicle ML-500 in 1979, with the achievement of a record speed of 517 km/h over the seven km long test track.

Whereas high speed operation was the primary target of the first phase tests, the object of the second phase is to test performance on vehicles containing all essential features required for a commercial vehicle. To this end, the test track was converted in 1980 from the inverted T-shape to a U-shaped guideway. In parallel, test vehicle MLU 001-1 was constructed.

The total weight of this vehicle is ten tons. It carrys eight racetrack shaped superconducting (SC) magnets which are installed vertically. In contrast to the ML-500 SC magnet which consists of a pair, one for LSM (linear synchronous motor) propulsion installed vertically, and one for levitation installed horizontally, a single SC magnet vertically installed is used for both propulsion and levitation.

The magnet is 1.7m long and 0.5m wide. The cross section of the winding is 48 x 79mm. NbTi fine multifilamentary wire with a copper ratio 2 is used. The magnetomotive force achieved was 800 kAT with a maximum field of 5.4T. This satisfies the required magnetomotive force 700 kAT for levitation and propulsion of MLU-001-1.

Two SC magnets are installed in one cryostat. The total heat leak into the cryostat is 4 W at 4.2K and 66 W at the 80K thermal shield. Forty seven percent of the heat leak to 4.2K is through load supports. The total weight of the cryostat (including 2 magnets) is 650 kg.

An onboard refrigerator with a capacity of 30 W at 4.2K is installed on MLU 001-1 to compensate for the heat leak to 4 cryostats. MLU-001-3, which was constructed more recently, employs small scale refrigerators of 5 W capacity at 4.2K attached to individual cryostats. This system does not require lines for distribution of cold and adds redundancy to the onboard refrigeration system.

Tests on MLU-001-1 were initiated in 1980 on the first 4 km portion of the converted track up to speeds of 250 km/h. With the completion of MLU-001-3, the first tests on connected cars were initiated in the fall of 1981. Tests at speeds over 200 km/h have progressed successfully, and vital performance data are now being accumulated.

The third test vehicle, MLU-001-2, is expected to be completed by the summer of 1982, at which time tests on three connected cars is to be initiated. At that time, it is also planned to board a crew who will be the first people to ride a levitated vehicle.

The current level of funding for the MAGLEV project installments is about 2.0 billion yen ($20.0 million) per year of which 600 million yen is subsidized by the government. As for post-Miyazaki tests, there are plans to construct a 40 km guideway on which full-size vehicles may be tested. The plans and the target implementation date has not been announced as yet.

SUPERCONDUCTING MAGNETS FOR NUCLEAR FUSION REACTORS

The outstanding driving force for development of large scale superconducting technology in Japan has been the JNR MAGLEV project. Although the JNR project still remains a major impetus, its position as a single outstanding motive has receded to "one" of the major forces due to the rapid emergence in the past several years of activities in the fields of nuclear fusion and high energy physics.

Both fields involve monstrous amounts of funds and are diverse. As they are fields which are rapidly advancing, only a brief account will be given here.

There are two major efforts being directed towards nuclear fusion reactor magnet development. First, the so-called Large Coil Task (LCT) which is an international cooperative program supervised by the International Energy Agency (IEA) initiated in 1978. It calls for construction and tests on a half size Tokomak toroidal field coil generating 8T. The shape and dimensions are specified by the U.S.A. where actual tests will be performed. The design of details such as field winding and cooling methods are at the liberty of the individual countries participating in the Task.

The Japanese development is being conducted at the Japan Atomic Research Institute (JARI), funded primarily by the Agency for Science and Technology. The construction and installment of test facilities including a 300 l/h liquifier with a 100 kW at 44K refrigeration has been in progress since 1979.

The second effort has been directed towards development of the so-called ohmic heating coil which requires a pulse superconducting magnet with large stored energy. The required specifications are a pulse rate of about 10 T/sec, maximum field 6 to 8T, ac losses less than 0.1~0.3% of stored energy, operation mode -B to +B in 1~2 sec. (B; magnetic field).

The ETL and major industries have been participating in development of pulsed magnets. Tests at ETL on magnets constructed at ETL and by industries have progressed as follows:

No. 1 Magnet	Stored Energy	78 kJ,	de/dt=6T/3sec,	4T/1sec
No. 2 "	"	67.5 kJ,	"	4T/1sec
No. 3 "	"	363 kJ,	"	3T/5sec
No. 4 "	"	375 kJ,	"	6T/4sec

As described below, universities funded by MEC have become progressively active in this field, and a 500 kJ pulse magnet is being tested at Osaka University.

HIGH ENERGY PHYSICS

The 12 GeV protron synchrotron at KEK (National Laboratory for High Energy Physics) in Tsukuba, Japan, has been under operation since 1976. Since then several facilities have been built utilizing KEK facilities. The 500 MeV booster synchrotron is being utilized in the neutron diffraction facility and meson physics facility (attached to the University of Tokyo). A 2.5 GeV electron storage ring for synchroton radiation studies has been constructed.

As for superconducting technology developments, beam transport dipole, and quadrupole magnets have been constructed and tested. A 120mm diameter, 6m long muon channel superconducting coil (730A, 5T) has been installed at the meson physics facility. However, perhaps the most ambitious project will be the construction of the electron-proton colliding beam facility called TRISTAN (Three Ring Intersecting Storage Accelerator in Nippon) which was approved in 1981. The MEC has granted a total of about 70 billion yen for this project.

The project is planned to proceed in two phases. In phase one, the electron-positron ring with 25 ~ 30 GeV using conventional magnets will be constructed. In parallel, superconducting magnets will be tested and manufactured. In phase two, the superconducting magnet ring for 300 GeV protons will be installed. The proton beam will be provided from the existing 12 GeV protron synchrotron, and electron and position beams will be provided by the 2.5 GeV linac constructed for the photon factory (synchrotron radiation studies). Phase one, which has been authorized, was initiated in 1981 for a five year period. Total construction is planned to be completed by 1989 or 1990.

The 300 GeV proton ring will require 288 superconducting dipole magnets with a field homogeniety of $\pm 1 \times 10^{-4}$ within a horizontal aperture of 90mm in diameter and magnetic length of 4.84m. A two warm iron, warm bore test dipole magnet with a inner coil diameter of 140mm (warm bore diameter 90mm), coil length 1.1m (magnetic length 0.85m), central field 5T has already been constructed and tested. Twenty-seven NbTi conductors with 2300 9 μm diameter filaments, twist pitch 10mm and copper ratio 1.8 stranded with a 85mm pitch was used. Work will continue on these test dipoles, and a one cell test magnet system with four dipoles 6m long, and two quadrupoles 2m long is planned to be tested after which final specifications for magnet production will be fixed.

Beside accelerator magnets and detector magnets, high field (up to 10T) magnets, for future accelators, are under investigation.

Another development which is being actively pursued at KEK is on a 500 MHz superconducting cavity for use in the TRISTAN electron ring. At present, energy of about 30 GeV is expected to be obtained using normal conducting of cavities. If superconducting cavities with an accelerating gradient of E_{acc} = 3 MV/m may be obtained, the available energy of electrons and positrons may be boosted beyond 35 GeV.

Starting with 6 GHz superconducting Nb cavities, research in this area has progressed significantly, and in May 1981 a 500 MHz Nb cavity (TM_{010} mode) with an unloaded Q of over 10^{10} up to $E_{acc} \leq 6$ MV/m was reported. The Nb surface was anodized an annealed at 10^{-8} Torr, 1600°C.

JOSEPHSON DEVICES

Except for research on establishment of voltage standards at ETL which commenced

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operation in January 1, 1977, research on Josephson devices prior to 1979 was restricted mainly to SQUIDs for laboratory use. The situation has changed considerably since MEC approved a grant to universities of 600 million yen for the period 1979 to 1981 for basic research on superconducting quantum electronics. This grant covered research on:

- SQUID elements and instrumentation (including medical, geophysical applications),
- electromagnetic signal detection, and
- digital applications.

The grant not only spurred research, but also contributed to an increasing interest in Josephson devices in the electrical engineering world.

Combined with the interest and needs for high speed supercomputers, two major projects have been initiated since then. In 1980, MITI awarded a grant to Fujita, Mitsubishi Electric, and Hitachi of about 1.4 billion yen for the period 1980 to 1983 for basic research on digital applications. In 1981, MITI initiated a large scale project on high speed computers. Total funding is estimated to be about 20 to 30 billion yen for an eight year period. The project will be supervised by ETL. The project includes development of high speed logic and memory devices, development of parallel processing methods, and development of total systems. Although research on HEMT (high electron mobility transistor) and GaAs-PET is to be pursued also, major efforts are expected to be concentrated on the Josephson devices.

In addition to the MITI project, a significant number of research personnel have been directed towards Josephson devices research at the two main Nippon Telegraph and Telephone Communication Laboratories at Musashino and Ibaraki.

It is premature to predict the outcome of these projects, but judging from the amount of funds and number of researchers which have started work in this area, significant progress may be expected in the coming years.

Beside digital applications, interest in SQUID applications have increased progressively in medical and geophysical areas. The need for self-contained SQUID systems, including small scale refrigerators have grown, and although efforts are still minor gradual progress is also expected in this area.

OTHER APPLICATIONS

This report has covered only applications on which major effort is being extended. Other applications such as electromagnetic ship propulsion[1], superconducting cyclotron magnets, superconducting magnets for electron microscopes, etc., should be included to make the report complete. Effort in these areas is, at present, not substantial.

[1]Details of work being done at the Kobe University of Mercantile Marine has been presented by A. Iwata at the Naval Research Condensed Matter and Radiation Sciences Division Colloquim, February 23, 1981.

INTERNATIONAL MEETINGS IN THE FAR EAST

1982-1986

Compiled by Seikoh Sakiyama

This list will be updated and augmented in future issues of the *Scientific Bulletin*. The assistance of Dr. T. D. Grace, of the Australian Embassy, Tokyo, and Dr. M. J. McNamara, of the New Zealand Embassy, Tokyo, in supplying a list of meetings in their countries is deeply appreciated. Similarly, the assistance of Dr. E. D. Rankin, of the American Embassy, Manila, Dr. J. H. Hubbell, of the NBS, Washington, Dr. F. A. Richards, of the ONR, London, Dr. R. J. Marcus, ONR, Pasadena, and the Japan Convention Bureau, Tokyo, in providing schedules of meetings is gratefully acknowledged. Readers are asked to notify us of upcoming international meetings in the Far East which have not yet been included in this report.

1982

Date	Title	Site	For information, contact
April 14-16	International Society for Photogrammetry and Remote Sensing Symposium: Primary Data Requisition	Canberra, Australia	Australian Photogrammetric Society The Organizing Committee PO Box 14, Watson A.C.T. 2602
April 15-17	The 18th International Symposium on Advanced in Chromatography	Tokyo, Japan	Prof. N. Ikekawa Dept. of Chemistry Tokyo Institute of Technology Ohokayama, Meguro-ku Tokyo 152
April	Second International Workshop on the Malaco-fauna of Hong Kong and South China	Hong Kong	Dr. B.S. Morton Department of Zoology The University of Hong Kong
April 26-29	A Pacific Regional Work-shop on Assimilative Capacity of the Oceans for Man's Wastes	Taipei, Taiwan	Professor Jong-Ching Su SCOPE, Academia Sinica Taipei 115, Taiwan
May 7-15	General Meeting of the International Association of Geodesy	Tokyo, Japan	Prof. I. Nakagawa Geophysical Institute Faculty of Science Kyoto University Oiwake-cho, Kita-Shirakawa Sakyo-ku, Kyoto 606

Date	Title	Site	For information, contact
May 10-14	Annual Scientific Meeting of the Australian Society of Microbiology	Hobart, Australia	The National Secretary Australian Society for Microbiology Inc. 191 Royal Parade Parkville, Vic 3052
May 11-13	Hydrology and Water Resources Conference	Melbourne, Australia	The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
May 11-14	International Cryogenics Engineering Conference	Kobe, Japan	Prof. H. Nagano The Institute for Solid State Physics University of Tokyo 7-22-1, Roppongi Minato-ku, Tokyo 106
May 12-14	Microelectronics Conference	Adelaide, Australia	The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
May 14-15	The 1st Asian Metal Finishing Forum	Tokyo, Japan	The Metal Finishing Society of Japan Kyodo Bldg., 2, Kanda-Iwamoto-cho Chiyoda-ku, Tokyo 101
May 15-17	Conference on Atomic and Molecular Reactions and Structure	Adelaide, Australia	Professor I.E. McCarthy Flinders University Bedford Park, SA 5098
May 17-20	The 3rd World Conference on Lung Cancer	Tokyo, Japan	S.G. Prof. K. Suematsu The Secretariat of the 3rd World Conference on Lung Cancer National Cancer Center 5-1-1 Tsukiji, Chuo-ku Tokyo 104
May 23-28	The 16th International Congress of Dermatology (CID)	Tokyo, Japan	Japan Convention Service, Inc. Nippon Press Center 8F 2-2-1, Uchisaiwai-cho Chiyoda-ku, Tokyo 100

Date	Title	Site	For information, contact
May 24-26	The 2nd International Microelectronic Conference	Tokyo, Japan	Dr. Hisao Hirabayashi I SHM Japan Office 5-635, Hanakoganei Kodaira, Tokyo 187
May 25-30	The 2nd International Symposium on Radiation Physics	Penang, Malaysia	Professor A.M. Gbose School of Physics University Sains Malaysia Minden, Penang
May (tentative)	The 35th Annual Metals Congress	Sydney, Australia	Australasian Institute of Metals P.O.Box 263, Bondi Beach N.S.W. 2026
May 30-June 4	International Symposium on the Properties and Applications of Metal Hydroid	Toba, Japan	Suda Laboratory Department of Chemical Engineering Kogakuin University 2665-1, Nakano-machi Hachioji, Tokyo 192
June 6-10	International Symposium on Chemical Kinetics Related to Atmospheric Chemistry	Tsukuba, Japan	Dr. Hajime Akimoto The National Institute for Environmental Studies 16-2, Yatabe-cho Ogawa Tsukuba-gun, Ibaraki 305
June 7-11	The 9th International Congress on Electrocardiology (23rd International Symposium on Vectorcardiography)	Tokyo, Japan	Tokyo University School of Medicine 7-3-1 Hongo, Bunkyo-ku Tokyo 113
June 7-11	The 4th International Symposium on the Genetics of Industrial Microorganisms	Kyoto, Japan	GIM Japan National Committee Microbiology Research Foundation 2-4-6 Yayoi, Bunkyo-ku Tokyo 113
June 27-July 2	The 5th International Conference on Geochronology, Cosmochronology, and Isotope Geology	Nikko, Japan	Geological Survey of Japan Agency of Industrial Science and Technology 1-1-3 Yatabe-Higashi Tsukuba-Gun, Ibaraki 305

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Date	Title	Site	For information, contact
July 4-10	The VI International Symposium on Solute-Solute-Solvent Interactions	Osaka, Japan	Prof. H. Ohtaki Tokyo Institute of Technology at Nagatsuka Dept. of Electronic Chemistry Nagatsuta, Midori-ku Yokohama 227
July 10-16	The 5th International Congress of Plant Tissue	Yamanashi, Japan	Assistant Prof. A.Komamine Dept. of Botany Faculty of Science University of Tokyo 7-3-1, Hongo, Bunkyo-ku Tokyo 113
July 11-16	The 7th World Congress on Animal, Plant and Microbial Toxins	Brisbane, Australia	Dr. Ann M. Caneron 7th WCAPMT Zoology Department University of Queensland St. Lucia, Queensland 4067
July 26-29	The Fourth International Symposium on the Finite Element Methods in Flow Problems	Tokyo, Japan	Dr. M. Kawahara Dept. of Civil Engineering Chuo University Kasuga, Bunkyo-ku Tokyo 112
August 15-21	International Biochemical Congress	Perth, Australia	Australian Academy of Science and International Union of Biochemistry P.O. Box 783, Canberra A.C.T. 2601
August 16-20	The 13th Australian Spectroscopy Conference	Melbourne, Australia	Australian Academy of Science PO Box 783, Canberra City A.C.T. 2601
August 16-20	The Fourth International Symposium on Antarctic Earth Sciences	Adelaide, Australia	Dr. R.L. Oliver Department of Geology University of Adelaide Adelaide, S.A. 5001
August 17-20	The 2nd International Kyoto Conference on New Aspects of Organic Chemistry	Kyoto, Japan	Prof. Z. Yoshida Dept.of Synthetic Chemistry University of Kyoto Yoshida-Hommachi Sakyo-ku, Kyoto 606

Date	Title	Site	For information, contact
August 18-20	Annual Meeting of the Australian Society for Reproductive Biology	Sydney, Australia	Dr. R.H. Scaramuzzi CSIRO, Division of Animal Production PO Box 239, Blacktown N.S.W. 2148
August 22-26	The 7th Asia and Oceania Congress of Endocrinology	Tokyo, Japan	Prof. K. Shizume Dept. of Medicine 2 Tokyo Women's Medical College Kawadacho, Shinjuku-ku Tokyo 162
August 22-27	The 4th International Conference on Organic Synthesis (IUPAC)	Tokyo, Japan	Prof. T. Mukaiyama Dept. of Chemistry Faculty of Science University of Tokyo 7-3-1, Hongo, Bunkyo-ku Tokyo 113
August 23-27	The Royal Australian Chemical Institute 7th National Convention	Canberra, Australia	Executive Secretary, RACI HQ 191 Royal Parade Parkville, Vic. 3052
August 23-27	The 8th Congress of International Ergonomics Association	Tokyo, Japan	Masamitsu Oshima, Director The Medical Information System Development Center Landick Akasaka Bldg. 2-3-4, Akasaka, Minato-ku Tokyo 107
August 23-27	The 6th Australian Statistical Conference	Melbourne, Australia	Professor E.J. Williams Dept. of Statictics University of Melbourne Parkville, Vic 3052
August 23-27	The 5th Australian Institute of Physics Congress	Canberra, Australia	Vice-President Australian Institute of Physics Royal Military College Duntroon, A.C.T. 2600
August 23-27	The 13th Australian Polymer Symposium	Canberra, Australia	Dr. G. Williams Dept. of Chemical Engineering University of Adelaide G.P.O. Box 498 Adelaide 5001

Date	Title	Site	For information, contact
August 24-26	Chemical Engineering Conference	Sydney, Australia	The Institute of Engineers, Australia 11 National Circuit, Barton, A.C.T. 2600
August 24-27	The 10th Australian Ceramic Conference	Melbourne, Australia	Mr. R.Bowman, CSIRO Division of Building Research PO Box 56, Highett Vic 3190
August 25-27	The 2nd Conference on Control Engineering	Newcastle, Australia	The Conference Manager The Institute of Engineers, Australia 11 National Circuit, Barton, A.C.T. 2600
August 25-30	The 7th Sagamore Conference on Charge, Spin, and Momentum Densities	Nikko, Japan	Prof. S. Hosoya The Institute for Solid State Physics University of Tokyo 7-22-1, Roppongi Minato-ku, Tokyo 106
August 27-30	The Second International Symposium on Molecular Beam Epitaxy and Related Clean Surface Techniques	Lake Kawaguchi, Japan	Prof. R. Ueda Department of Applied Physics School of Science and Engineering Waseda University 4-1, Ohkubo 3-chome Shinjuku-ku, Tokyo 160
August 29-September 4	The 5th International Congress of Pesticide Chemistry, IUPAC	Kyoto, Japan	Rikagaku Kenkyusho (The Institute of Physical and Chemical Research) 2-1 Hirosawa, Wako-shi Saitama 351
August (tentative)	1982 International Conference on Solid State Devices	Tokyo, Japan	The Japan Society of Applied Physics Kikai-Shinko-Kaikan 5-8, 3-chome, Shibakoen Minato-ku, Tokyo 105
August (tentative)	The 4th International Conference in Australia on Finite Element Methods	Australia (undecided)	Professor L.K. Stevens Dept. of Civil Engineering University of Melbourne Parkville, Vic 3052

1982, continued

Date	Title	Site	For information, contact
September 1-3	1982 Symposium on VLSI (Very Large Scale Integrated Technology)	Kanagawa, Japan	Prof. S. Tanaka Dept. of Applied Physics Faculty of Engineering University of Tokyo 3-1, Hongo 7-chome Bunkyo-ku, Tokyo 113
September 6-10	International Conference on Magnetism-1982 (ICM-1982)	Kyoto, Japan	Prof. J. Kanamori Faculty of Science Osaka University Toyonaka, Osaka 560
September 6-10	International Conference on Nuclear Physics in the Cyclotron Energy Region	Osaka, Japan	Prof. M. Kondo Research Center for Nuclear Physics Osaka University Yamada-kami, Suita-shi Osaka 565
September 13-16	The 6th International Symposium on Contamination Control	Tokyo, Japan	Japan Air Cleaning Association 6-7-5, Soto-Kanda Chiyoda-ku, Tokyo 101
September 13-16	The Sixth International Conference on Software Engineering	Tokyo, Japan	Information Processing Society of Japan Kikaishinko Building 3-5-8, Shiba-koen Minato-ku, Tokyo 105
October 3-6	The 3rd International Dental Congress on Modern Pain Control	Tokyo, Japan	Japan Convention Service, Inc. Nippon Press Center 8F 2-2-1, Uchisaiwai-cho Chiyoda-ku, Tokyo 100
October 20-22	The International Conference on Productivity and Quality Improvement-Study of Actual Cases	Tokyo, Japan	Japan Management Association 1-22, Shiba-Koen 3-chome Minato-ku, Tokyo 105
October 24-29	The Second International Conference on Stability of Ships and Ocean Vehicles	Tokyo, Japan	Prof. S. Motora The Society of Naval Architects of Japan 15-16, Toranomon 1-chome Minato-ku, Tokyo 105

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Date	Title	Site	For information, contact
October 25-29	The 14th Plenary Meeting of 150 Technical Committee 17-Steel	Tokyo, Japan	The Iron and Steel Institute of Japan 10F Nippon Bldg., 7-1 Ohtemachi 2-chome Chiyoda-ku, Tokyo 100
November 6-9	Electric Energy Power Electronics Conference	Adelaide, Australia	The Conference Manager The Institute of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
November 17-19	The 3rd JIM (Japan Institute of Metals) International Symposium	Japan (undecided)	The Japan Institute of Metals Aza Aoba, Aramaki Sendai-shi, Miyagi 980
November	Pan Pacific Synfuels Conference	Tokyo, Japan	Japan Petroleum Institute Chiyoda-Seimei Bldg. 27-12, Nishi-Ikebukuro 3-chome, Toshima-ku Tokyo 117
November 26-December 2	The 7th International Conference on Vacuum Metallurgy	Tokyo, Japan	The Iron and Steel Institute of Japan Keidanren Kaikan 1-9-4, Ohtemachi Chiyoda-ku, Tokyo 100
December 6-10	Chemrawn II	Manila, Philippines	New Frontiers Coordinating Office International Food and Policy Research Institute 1776 Massachusetts Ave. N.W. Washington, D.C. 20036
Undecided	International Conference on Mass Spectroscopy	Hawaii, U.S.A.	Prof. T. Tsuchiya Basic Science Lecture Room Chiba Institute of Technology 1-17-2, Tsudanuma Narashino, Chiba 275
Undecided	International Rehabilitation Medicine Association Fourth World Congress	Sydney, Australia	Prof. G.G. Burniston Dept. of Rehabilitation Medicine Prince Henry Hospital Little Bay, N.S.W. 2036

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Date	Title	Site	For information, contact
Undecided	Workshop on Marine Microbiology	Seoul, Korea	Korea Ocean Research and Development Institute P.O.Box 17, Yang-Jae Seoul

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Date	Title	Site	For information, contact
February 1-11	The 15th Pacific Science Congress	Dunedin, New Zealand	University of Otago P.O. Box 6063 Dunedin, New Zealand
March (tentative)	Conference on Coastal Engineering	Queensland, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
May (tentative)	The 36th Annual Metals Congress	Pt. Kembla, Australia	Australian Institute of Metals PO Box 1144, Wollongong N.S.W. 2500
May 16-20	The 5th National School and Conference on X-Ray Analysis	Melbourne, Australia	Dr. R. A. Coyle X-Ray Analytical Association, New South Wales Institution of Technology P.O. Box 90, Parkville Vic 3052
May 16-20 (tentative)	Annual Scientific Meeting of the Australian Society for Microbiology	Brisbane, Australia	The National Secretary Australian Society for Microbiology Inc. 191 Royal Parade Parkville, Vic 3052
August 1-7	International Association for Dental Research	Sydney, Australia	Mr. Scott Gotjamanos Dept. of Pathology Perth Medical Centre Verdon Street Nedlands, W.A. 6009
August 17-24	The 4th International Congress of Plant Pathology	Melbourne, Australia	Mr. B. Price Victorian Plant Research Institute Dept. of Agriculture Victoria, Swan Street Burnley, Vic 3121

Date	Title	Site	For information, contact
August 21-27	The 5th International Congress of Immunology	Kyoto, Japan	The Japanese Society for Immunology Institute of Virus Research Kyoto University Kawaracho, Shogoin Sakyo-ku, Kyoto 606
August 27	Symposium Commemorating the 100th Anniversary of the Mount Krakatau Eruption	Jakarta, Indonesia	Dr. Didin Sastrapradja Indonesian Institute of Sciences LIPI, JL Teuku Chik Ditiro 43 Jakarta
August 27-31	The 25th International Geographical Congress	Sydney, Australia	Australian Academy of Science P.O. Box 783 Canberra, A.C.T. 2601
August 26-September 2	The 18th International Ethological Conference	Brisbane, Australia	Professor E. McBride Dept. of Psychology University of Queensland St Lucia, Qld 4067
August 28-September	The 29th International Congress of Physiology	Sydney, Australia	Australian Academy of Science PO Box 783, Canberra A.C.T. 2601
August 28-September 2	The 29th International Congress of Physiology	Sydney, Australia	Australian Academy of Science P.O.Box 783, Canberra A.C.T. 2601
August 28-September 3	The 3rd International Mycological Congress (IMC 3)	Tokyo, Japan	Prof. K. Tsubaki Institute of Biological Sciences The University of Tsukuba Sakura-mura, Ibaraki 305
August (tentative)	International Solar Energy Congress	Perth, Australia	Mr. P. Driver Honorary Secretary P.O. Box 123 Nedlands, W.A. 6009
August (tentative)	Computers in Engineering	Australia (undecided)	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600

1983, continued

Date	Title	Site	For information, contact
August (tentative)	Hydraulics and Fluid Mechanics Conference	Newcastle, Australia	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
September 19-23	The 12th World Energy Conference	New Delhi, India	Dr. R.J. Ramdebough 1620 Eye Street Suite 808 Washington, D.C. 20008
September 22-26	The 4th Asian and Australian Conference ISRRT (International Society of Radiologic Technologists)	Tokyo, Japan	Mr. Lucky Morimoto International Department The Japan Association of Radiologic Technologists 26-7, Shinkawa 1-chome Chuo-ku, Tokyo 104
October 2-5	The 3rd International Display Research Conference	Kobe, Japan	Japan Convention Services, Inc. Nippon Press Center 8F. 2-1, Uchisaiwai-cho 2-chome, Chiyoda-ku Tokyo 100
October (tentative)	The 8th International Conference on Calcium Regulating Hormone	Kobe, Japan (tentative)	Prof. T. Fujita 3rd Division Dept. of Medicine School of Medicine Kobe University 7-13, Kusunoki-cho Ikuta-ku, Kobe 650
October 29-November 3	The 71st FDI Annual World Dental Congress Federation Dentaire Internationale)	Tokyo, Japan	Japan Dental Association (Japanese Association for Dental Science) 4-1-20, Kudan-kita Chiyoda-ku, Tokyo 102
November (tentative)	Conference on Microprocessors	Australia (undecided)	The Conference Manager The Institute of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
November (tentative)	Metal Structures Conference	Brisbane, Australia	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600

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Date	Title	Site	For information, contact
December (tentative)	The 12th International Laser Radar Conference	Melbourne, Australia	Dr. C. Platt, CSIRO Division of Atmospheric Physics PO Box 77, Mordiattoc Vic 3195
Undecided	The 13th International Congress of Chemotherapy	Melbourne, Australia	Dr. B. Stratford St. Vincent's Hospital 59 Victoria Parade Fitzroy, Vic 3065

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Date	Title	Site	For information, contact
May (tentative)	5th International Soils Expansion Conference	Adelaide, Australia	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
August 24-September 1	The 3rd International Congress on Cell Biology	Kyoto or Kobe, Japan	Japan Society for Cell Biology Shigei Medical Research Institute 2117 Yamada Okayama 701-02

1985

Date	Title	Site	For information, contact
August (tentative)	International Association Hydraulic Resources Conference	Melbourne, Australia	The Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, A.C.T. 2600
October 15-18	International Rubber Conference	Kyoto, Japan (tentative)	The Society of Rubber Industry, Japan Tobu Bldg., 1-5-26 Motoakasaka, Minato-ku Tokyo 107

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Date	Title	Site	For information, contact
(Tentative)	International Microbiological Congress	Perth, Australia	Australian Academy of Science PO Box 783, Canberra A.C.T. 2601
May 11-17	Congress of the International Society of Haematology and the International Society of Blood Transfusions	Sydney, Australia	Dr. I. Cooper, President Haematology Society of Australia Cancer Institute 481 Little Londsdale Street, Melbourne Vic 3001

➵ NOTICE ➵

The Office of Naval Research Scientific Liaison Group, Tokyo was disestablished on 30 September 1981. Effective 1 October 1981, the Office of Naval Research, Liaison Office, Far East (ONRFE) has been established as a tenant of the Akasaka Press Center, Tokyo. The ONRFE office is located on the second floor of Bldg #1, Akasaka Press Center and it bears the following mail identification:

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