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Quarterly Technical Summary

General Research

15 August 1970

Prepared under Electronic Systems Division Contract AF 19(628)-5167 by

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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INTRODUCTION

This Quarterly Technical Summary covers the period from 1 May through 31 July 1970. It consolidates the reports of Division 2 (Data Systems), Division 5 (Optics), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

Accepted for the Air Force
Joseph R. Waterman, Lt. Col., USAF
Chief, Lincoln Laboratory Project Office

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DATA SYSTEMS
DIVISION 2

INTRODUCTION

This section of the report reviews progress during the period 1 May through 31 July 1970 for the General Research Program of Division 2. Separate progress reports on Graphics, Propagation Studies, Seismic Discrimination and the Educational Technology Program describe other work in the Division.

M. A. Herlin
Acting Head, Division 2

DIVISION 2 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1970

PUBLISHED REPORTS

Technical Reports

TR No.				DDC No.
474	Millstone Hill Thomson Scatter Results for 1965	J.V. Evans	8 December 1969	AD-707501
477	Incoherent Scatter Measurements of F Region, Density, Temperatures and Vertical Velocity at Millstone Hill	J.V. Evans R.F. Julian W.A. Reid	6 February 1970	

Journal Articles*

JA No.			
3595	OH Radio Emission Associated with Infrared Stars	W.J. Wilson† A.H. Barrett† J.M. Moran	Astrophys. J. 160, 545 (1970)
3630	Detection and Estimation Practices in Radio and Radar Astronomy	T. Hagfors J.M. Moran	Proc. IEEE 53, 743 (1970)
3694	Studies of H_2O Sources by Means of a Very-Long-Baseline Interferometer	B.F. Burke† D.C. Papa† G.D. Papadopoulos† P.R. Schwartz† S.H. Knowles† W.T. Sullivan† M.L. Meeks J.M. Moran	Astrophys. J. Letters 160, L63 (1970)

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
3710	Seasonal Variation of the O to N2 Abundance in the F1 Region	L.P. Cox J.V. Evans	Accepted by J. Geophys. Res.
3720	The June 1965 Magnetic Storm: Millstone Hill Observations	J.V. Evans	Accepted by J. Atmos. Terr. Res.
3728	Very Long Baseline Interferometry of Galactic OH Sources	B.O. Ronnang† O.E.H. Rydbeck† J.M. Moran	Accepted by Radio Science

* Reprints available.

† Author not at Lincoln Laboratory.

SURVEILLANCE TECHNIQUES
GROUP 21

Group 21 operates and maintains the Millstone Radar Facility and has been responsible for the Haystack Research Facility as well. At Haystack, the emphasis is on planetary and lunar radar and on radiometric techniques. At Millstone, studies related to precision tracking capabilities under disturbed propagation conditions are conducted for the Advanced Ballistic Missile Defense Agency, U. S. Army (ABMDA).

At Millstone the instrumentation required to obtain simultaneous UHF and L-band tracking data on satellites has nearly been completed. This will make possible experiments aimed at the separation of the tropospheric and ionospheric components of refraction. The Frequency Selective Subreflector, which is the heart of this capability, was received, installed and successfully tested at high-power. New angle encoders are being installed that will permit readout of angle data to the increased precision required by this program. The Thomson scatter radar continues to be used to gather more basic data on the ionosphere under various conditions. As the above tracking data become available, they will be considered together with the Thomson scatter data in developing an improved basic understanding of ionospheric effects on tracking radar.

At Haystack, feasibility has been conclusively demonstrated for an extension, employing interferometry, of the technique of radar range-doppler mapping for the measurement of lunar surface topography. This work is partially supported by NASA. Radar observations of Mercury and Venus continue for topographic studies, orbit refinement and testing of the general theory of relativity. A bistatic radar capability was established with Haystack transmitting and the 210-foot dish at Goldstone receiving. The extra receiving aperture and low system temperature of the Goldstone site yields, approximately, an 8-dB increase in overall sensitivity over either Haystack, or the present Goldstone radar configuration, alone. This "Goldstack" radar was used in an apparently successful attempt to detect Callisto, the fourth satellite of Jupiter, and will shortly be employed in a further test of relativity which should be sufficiently accurate to indicate if the Einstein, or the recently proposed Dicke theory is correct.

Under an NSF grant, an extended radio astronomy program, primarily by university investigators, is being supported. Very long baseline interferometry continues to be a major interest. By employment of this technique at H_2O vapor wavelength (22.2 GHz) between Haystack and Kitt Peak, an angular resolution of $< 3 \times 10^{-4}$ arc sec has been achieved – the highest, it is thought, yet achieved in astronomy. Air Force Cambridge Research Laboratories also utilized Haystack in mapping the sun at 8-mm wavelength in connection with their research on the prediction of solar events (and the resulting poor communications conditions).

This is the last contribution of Group 21 to the General Research Quarterly Technical Summary. The Millstone work is already being detailed in the Laboratory's reports to ABMDA, while as of 1 July 1970, M.I.T. has assumed direct responsibility for the operation of Haystack, with support obtained from civilian agencies through the Northeast Radio Observatory Corporation (NEROC), a consortium of thirteen educational and research institutions.

DIGITAL COMPUTERS
GROUP 23

I. CIRCUIT AND NEW MACHINE DEVELOPMENT

A. High-Speed Multiplier

A high-speed array multiplier generating the full 34-bit product of two 17-bit signed (2's complement) numbers in 40 nsec was constructed and tested. The multiplier's performance is achieved primarily by the following means:

(1) The Lincoln-designed L-100 two-bit adder circuits with anticipated carry are used. Carry delay per bit is 0.8 nsec and sum delay is 2.8 nsec.

(2) Negative (2's complement) numbers are handled by treating their highest order bit as negative, all other bits as positive, and adding negative partial products directly by two variants, L-102 and L-103, of the basic L-100 two-bit adder circuit.

(3) The propagation parts for sum and carry signals between adders are such that sum delays do not significantly contribute to the overall delay.

The multiplier uses 136 of these two-bit adder circuits, mounted on a single 7 × 12-inch four-layer printed circuit card.

B. Computer-Controlled Wafer Probe

The wafer probe was tested using a 3-bit parity wafer. A fixed 12-point probe card was used to make functional tests of an area of the test wafer which was used containing 725 circuits. This represents the 57 percent of the total wafer area known to contain good devices. The yield of functional units for this area was 61 percent. Successive retests of only the good units gave yields of 59 percent and 58 percent, respectively. The probe tips were then cleaned and the entire area reprobed. The yield was 66 percent. It is interesting to note that a manual evaluation of the same area gave a yield of 43 percent. Variations in the results are due in part to the fact that the wafer has been probed many times and has pads which show considerable probe damage. Also, the discrimination level of the threshold detector currently used to determine the output caused some variation in results.

The computer generates a wafer map showing the good units and the number of the functional test failed by the bad units.

C. Interconnection of Integrated Circuits

Procedures for interconnecting chips with chemically deposited metals have been established so that test arrays can be produced.

Static and cyclic thermal testing of test arrays which use only interconnected conductors (no active devices) indicate they can tolerate over 800 hours of operation at 150°C, as well as cycling between 28° and 150°C at a rate of 1.5 hours per cycle over 500 cycles, without failure or significant changes in interconnection resistance.

II. MAGNETIC FILM ENGINEERING

A. Word Substrates

A new alloy is being used for the evaporated word line layer to replace 50% Co, 47% Ni, 3% Fe. It is 90% Co, 10% Fe and like the earlier alloy is non-magnetostrictive. Its advantages are that it may be deposited at 300°C substrate temperatures where film stress is a minimum and still have $H_c \geqslant 25$ Oe and $H_k \approx 20$ Oe. Angular dispersion is up a factor of two ($\alpha_{50} \approx 8°$), but this appears acceptable.

Efforts to provide a word line scribing resist which will damage the copper surface less than KPR has led to the use of an electroplated gold film, which could be both resist and contact protection. The process requires an easily applied intermediate film of electroless nickel between the gold and the top electrolessly plated magnetic film. The nickel provides uniform sensitization for the magnetic film.

Lines on six substrates were found to be severely undercut and lifting after scribing and etching. After investigation of the processing it appears that one step was being done improperly. Inspection procedures have been improved to catch such errors. The plating process was also modified by eliminating an etching step which was causing undercutting of the lines.

Test results on the best LCM II bits with the best type of keepered digit line show good operating margins at a word current of 500 mA, a digit current of about 225 mA and signal three to four times LCM I amplitudes. Processing variables still prevent complete testing of a word substrate.

B. Digit Substrates

Several 2.2- and 52-inch digit substrates have been made by electroplating a magnetic layer on 1-mil thick copper foil and then laminating the foil to a glass substrate with epoxy. The copper is then scribed and etched into 6-mil lines on 10-mil centers. With the use of electrodeposited copper foil and glass having sides coplanar to within 0.5-mils, the scribing of these substrates looks quite good. Ten-inch long laminated digit substrates with an electroplated keeper film have been tested for smoothness and keeper efficiency with encouraging results. The magnetic layer on the long substrates looks good in the B-H looper. Functional testing of the long substrates will be difficult and may require use of a memory stack.

A small dependence of signal amplitude on saturation direction of the digit keeper, direction of word field, and state of adjacent bits has been observed. The behavior of the digit keeper at word-current rise-time is being examined theoretically and experimentally.

C. Experimental Stack

An experimental stack with 52-inch long glass digit substrates was assembled at the end of this quarter. The digit lines are of thin evaporated copper, so digit transient and signal amplitude results will be pessimistic. Five of the 26 word substrates have LCM II word lines, while the others have twenty wide lines. The stack will be used to test for word and group noise characteristics, and to investigate stack construction and assembly. Assembly proceeded smoothly except for some word-to-digit shorts through the 1/2-mil insulation.

D. Word Decoding Matrix

Use of diode chips with passivated sides has eliminated short circuiting problems in the polimide-film conductive-epoxy matrix. The mechanical bond of the conductive epoxy to the copper conductors on the polimide-film sheet is poor, and opens occur due to lifting of the buss lines from the diode tops. A new polimide-film copper-distribution mat is being made which will provide considerably greater compliance in the copper-to-conductive-epoxy joint.

E. Optical Testing of Magnetic Films

The mechanical fabrication of the optical B-H looper for 52-inch substrates has been completed. The drive coils and optical system have been tested and perform well. A more powerful infrared emitter has been obtained to improve the signal-to-noise ratio. The wiring of the electronics for the looper is nearly complete.

PSYCHOLOGY
GROUP 25

I. DESIGNS FOR MAN-MACHINE INTERACTION ON COMPUTERS

An abbreviated field test of the IBM 360/67 Reckoner/Mediator has been carried out. About 50 scientists and engineers were invited to use the system to solve a current problem. Ten accepted, and most solved short problems in a single session. Several worked for two or three sessions to complete a problem, and in one case the system appeared to fit neatly into the daily needs of a scientist who continues to make constant use of it. Out of this experience grew the impression that there are some strong inhibitions that keep potential users, largely non-programmers, away from the system. One suspects factors such as the location and ownership of terminals and the feeling that only a programmer has a "license to compute." An effort will be made to encourage potential users to gain priority for Reckoner/Mediator usage.

Work has continued on gathering statistics and evaluating the performance of APEX. The data are being analyzed and plotted to be included in a paper on the Memory Management Algorithms in APEX.

Our research on human problem solving on-line to a computer has been discontinued. The major results, which open up a new area of human factors research with great promise, are contained in a technical report being readied for publication.

II. HUMAN INFORMATION PROCESSING

An audio apparatus has been assembled which permits quantitative evaluation of the amplitude, frequency and temporal resolution of the ear. To the best of our knowledge, all of the tests which can be made with this equipment have been made in similar form, under laboratory conditions, on normal adult humans. The purpose in developing and field testing this assembly is to ascertain the possibility that these tests can be used as predictive indicators or as a means for diagnosing marginal disabilities in elementary school students with below average learning performance.

The assembly contains two audio tone generators, a noise generator, a circuit for generating paired clicks, and pulse generators which permit pulsing the tone and noise generator in a variety of modes. These stimuli may be presented monaurally or dichotically depending on the objective in each case. Any stimuli chosen is presented repetitively at a rate which may be varied from about two per second to one every three seconds.

A large variety of auditory perceptual tests can be generated by proper manipulation of the controls.

III. EDUCATIONAL METHODS

Work by the group on the design and use of a new learning machine is reported separately in the Quarterly Technical Summary of the Educational Technology Program.

COMPUTER SYSTEMS
GROUP 28

A major activity of the quarter has been preparation for the reduction in equipment scheduled for 1 August 1970. With a single CPU instead of two operating in parallel, it will be necessary to schedule more closely and make maximum use of multiprogramming capabilities. A new version of the Batch Processing System (IBM OS/360-MVT-HASP) designed for a million bytes of main storage is in the final testing stages along with operator retraining. In order to provide maximum convenient parallel execution, five job classes have been established on the basis of storage requirements. Each class is allocated a multiple of 150,000 bytes of storage together with an appropriate amount of input/output equipment. Early testing and study indicates that this division of jobs will permit some three to five programs to operate in a concurrent multiprogrammed mode providing an increased efficiency in CPU operation on the order of 20 percent. The system has also been structured to allow operation on several different configurations in case one or two of the input/output subsystems should fail.

A major improvement in the area of human factors has been made in the CP/CMS time-sharing system during the quarter. This feature, which has been designated as the "Bakery Number" system because of its similarity to the handling of a customer queue in a bake shop, has been well received by users in its short period of existence. The bakery system permits a user to log in as long as there is a physical line available. Upon completion of the usual protocol, he is advised that he may proceed for a period of two hours or he is told his numerical place in a waiting line. From that point until he is notified that he may run, several new commands are available to him to check his progress in the queue. Alternatively, he may request five minutes of immediate service which will be granted for a maximum of three such users. Several commands have also been provided for the Operator to control and examine the queue. A very limited sampling indicates that the average user waits about fifteen minutes from log on to the beginning of his two-hour session.

Other features added to the system include the ability for remote entry of non-conversational jobs to the Batch Monitor System, modifications to the EDIT command to permit sequences of often used search and retrieval requests to be defined and called from a request file, and assignment of T-disk storage to the assembler temporary work files. Now in the process of development is a virtual access method which makes use of file space as an extension of virtual memory.

OPTICS
DIVISION 5

INTRODUCTION

This section summarizes the General Research efforts of Division 5 for the period 1 May through 31 July 1970. A complete presentation of the Optics effort may be found in the quarterly Optics Research Report and in the Semi-annual Technical Summary and Quarterly Letter Reports to the Advanced Research Projects Agency.

R.H. Kingston
Head, Division 5

R.H. Rediker
Associate Head

OPTICAL MEASUREMENTS
GROUP 52

We have continued the previously reported standing-wave saturation resonance experiments on room temperature, low pressure CO_2 absorber gas. Systematic measurements of pressure shift as a function of laser transition are currently under way with a two-cavity, grating controlled laser. In another experiment, preliminary long-term stability and stabilization techniques are studied with two independently stabilized lasers.

Preliminary experiments with our stable, internal grating controlled laser have indicated excellent stability and reproducibility. Laser operation was obtained anywhere within either the 9.6 μ or the 10.6 μ CO_2 bands, and output greater than 10 W was achieved in the more dominant laser transitions.

ENGINEERING
DIVISION 7

INTRODUCTION

The Engineering Division has supported the Laboratory's General Research program for many years by its design and fabrication of hardware for Solid State research and for the facilities at Haystack and Millstone Hills. In this quarterly report, four devices used in Solid State research are discussed, as well as the testing procedures employed in checking out the new clean rooms now being used for microelectronics research.

J. F. Hutzenlaub
Head, Division 7

ENGINEERING
DIVISION 7

I. DEVICES FOR SOLID STATE RESEARCH

A. Wire Cutter Modifications

Existing crystal wire cutters are normally designed to cut crystals at an angle to the horizontal plane. Recently, however, it was desired to cut crystals with the crystal-mount moving perpendicular to the cutting direction of the wire. For this purpose, a parallel arm mechanism has been constructed which is adaptable to the cutter. Also, a crystal mount with mitering capability or parallel slicing was introduced into the modification.

B. Heat Pipes

A heat pipe is a self-contained structure which achieves very high thermal conductance by means of two-phase fluid flow with capillary circulation. It normally consists of a sealed tube lined internally with a capillary network called a wick. Application of heat to a portion of the tube causes evaporation of the working fluid with which the wick is saturated. Heat is transferred through a central passage to the remainder of the system as latent energy, by flow and condensation of vapor. To complete the flow cycle, the condensate is returned through the wick to the heated section by capillary forces.

Applying the principle to a hollow core heat pipe has led to interesting possibilities with regard to crystal growing techniques, such as eliminating furnace temperature gradients, as well as creating sharply defined high-temperature gradients.

C. Thermo-Electron Hot Probe

It was desired to measure the local thermoelectric power in an inhomogeneous sample using a fine, heated probe. This would enable one to measure the concentration profile in a diffusion sample of a semiconductor. For this purpose, a mechanical device was developed which allows various pressures to be exerted on a probe and also conveniently attaches to a toolmaker's microscope.

D. Bridgman Furnace

The technique of lowering a tapered crucible through a furnace is known as the Bridgman-Stockbarger method. The material to be crystallized is melted in a conically tipped cylindrical crucible at a temperature high enough to ensure that all particles are molten. The crucible is then transferred through a temperature-gradient region so that solidification starts at the bottom tip of the crucible. The rate of lowering must be slow enough, usually in the order of days, to allow the heat of solidification to dissipate. A unit that will do just that has been successfully designed and developed. The ability of the mechanism to duplicate the lowering rate is extremely accurate, with a variable range from 1 inch per hour to 1 inch per week.

II. TESTING PROCEDURES FOR CLASS 100 AND CLASS 10,000 CLEAN ROOMS

During the last quarter the acceptance tests of the Class 100 and Class 10,000 Clean Rooms for microelectronic research and development were conducted. All tests were completed and systems were passed and accepted except for the vibration tests in the Class 10,000 room. This test will be conducted when personnel and equipment become available.

To insure the validity of the vendor's testing operations, an independent testing laboratory of national recognition was hired to conduct these tests. The independent laboratory tests showed that both rooms met the required specifications.

Both rooms use the vertical air flow principle, with the major difference between the rooms being the velocity and laminarity of the air through the spaces. The Class 100 system passes air at 90 fpm (ft/min) from a 100-percent filtered ceiling through a 100-percent perforated floor, while the Class 10,000 passes air at a minimum of 50 fpm using fewer filters and perforated floor panels. The contamination level for the system increases as the precise control and velocity of the air flow decreases. In addition to air flow, both systems are controlled for humidity, temperature, sound, lighting, and vibration.

Both clean room systems operate in the same basic manner. Air is forced through supply ductwork by large fans and through high-efficiency filters (99.97% > 0.3 μ) in the ceiling. The air flows down through the rooms, through a raised, perforated and dampered floor and returns to the fans through a bank of 85-percent efficient prefilters. A portion of this air is drawn off to the air conditioning units, retempered, and returned to the fan room supplemented with a small amount of fresh air for leakage makeup, exhaust makeup, and room pressurization.

Testing and certification of the clean room systems was a long and tedious process. In general, the testing required for both clean room systems was as follows.

A. HEPA Filter Smoke Tests

Each HEPA (High Efficiency Particulate Air) filter was closely checked for "in place" integrity to insure that no leaks had developed during the construction phase. This was done by injecting smoke into the air stream behind the filter while using a light-scattering photometer on the discharge side to detect any leaks. Leaks found were either patched or the filter replaced, depending on the size of the leak.

B. Contamination Level

A particulate counter, also operating on the light-scattering principle, was used to check room contamination levels on a predetermined grid. This instrument monitors the average quantity of particles larger than 0.5 μ existing per cubic foot of air while the system is in operation.

C. Temperature and Relative Humidity

Precise temperature and humidity control is required for the work in the clean rooms and these items were monitored on a grid basis using dry bulb thermometers, sling psychrometers, and temperature and humidity chart recorders. Extreme exterior design conditions were simulated as part of the test for control tolerances.

D. Laminar Flow and Uniform Velocity

The vertical laminarity of the air flow and the average velocity and quantity of air through the rooms were checked in several ways. A vane type velometer was used to check velocities at the HEPA filters, along the return air filter bank, and 30 inches above the floor in the room. The supply air fan curves were utilized by measuring fan rpm, motor amperage drawn, and static pressures to check air quantities in the duct work. Vertical laminarity was determined by photographing the travel of a column of smoke generated at the ceiling while using a gridded black background to measure its dispersion. Individual smoke drops were timed from ceiling to floor as backup data for vertical velocity readings.

E. Sound Level Test and Illumination Level

Sound pressure levels and lighting intensities were checked in accordance with our specifications using instrumentation and methods standard in this field.

F. Enclosure Pressure

The two clean room pressure levels were set to maintain a slight positive pressure differential between the two systems at a level which maintains both systems above the remainder of the facility. The system pressure controllers and gauges were tested and calibrated with an inclined manometer.

G. Vibration

Vibration testing was accomplished using accelerometers to provide point acceleration in three vectors. These were connected to chart recorders to provide a time-history record per test point. This information was later used to calculate point displacements vs frequencies.

H. 72-Hour Running Test

This test incorporates spot checking for a continuous period of not less than 72 hours: contamination levels, sound pressure, air volume uniformity, relative humidity and temperature, and simulation of extreme exterior design conditions.

SOLID STATE
DIVISION 8

INTRODUCTION

This section summarizes the work of Division 8 from 1 May through 31 July 1970. A more detailed presentation is covered by the Solid State Research Report for the same period.

A. L. McWhorter
Head, Division 8

P. E. Tannenwald
Associate Head

DIVISION 8 REPORTS ON GENERAL RESEARCH

15 May through 15 August 1970

PUBLISHED REPORTS

Journal Articles*

JA No.			
3429A	Avalanche Breakdown and Light Emission at Low-Angle Boundaries in n-ZnSe	J.P. Donnelly F.T.J. Smith	Solid-State Electron. 13, 516 (1970), DDC AD-708604
3499	Infrared Cyclotron Resonance and Related Experiments in the Conduction Band of InSb	E.J. Johnson D.H. Dickey	Phys. Rev. B 1, 2672 (1970)
3546	Transport Equation for a Fermi System in Random-Scattering Centers. II. Independent Electrons in an Arbitrarily Varying Electric Field and Strong Single-Center Potentials	J.L. Sigel P.N. Argyres†	Phys. Rev. B 1, 1845 (1970)
3552	Resistivity, Magnetoresistance, and Hall Effect Studies in $VO_x (0.82 \leqslant x \leqslant 1.0)$	J.M. Honig† W.E. Wahnsiedler† M.D. Banus T.B. Reed	J. Solid State Chem. 2, 74 (1970)
3553	MIS Electroluminescent Diodes in ZnTe	J.P. Donnelly A.G. Foyt W.T. Lindley G.W. Iseler	Solid-State Electron. 13, 755 (1970)
3557	Hall Coefficient Factor for Polar Mode Scattering in n-Type GaAs	G.E. Stillman C.M. Wolfe J.O. Dimmock	J. Phys. Chem. Solids 31, 1199 (1970)
3563	Interdiffusion in Lead Selenide	R.W. Brodersen† J.N. Walpole† A.R. Calawa	J. Appl. Phys. 41, 1484 (1970)
3579	Photoluminescence Due to Isoelectronic Oxygen and Tellurium Traps in II-VI Alloys	G.W. Iseler A.J. Strauss	J. Luminescence 3, 1 (1970)
3582	Interpretation of $M_xV_2O_5$-β and $M_xV_{2-y}T_yO_5$-β Phases	J.B. Goodenough	J. Solid State Chem. 1, 349 (1970)

* Reprints available.

† Author not at Lincoln Laboratory.

Division 8

JA No.			
3590	Thermodynamics and Calculation of the Liquidus-Solidus Gap in Homogeneous, Monotonic Alloy Systems	J.M. Steininger	J. Appl. Phys. 41, 2713 (1970)
3592	Structure and Magnetic Properties of $VOSO_4$	J.M. Longo R.J. Arnott*	J. Solid State Chem. 1, 394 (1970)
3601	Structure of the $M_xV_2O_5$-β and $M_xV_{2-y}T_yO_5$-β Phases	J. Galy* J. Darriet* A. Casalot* J.B. Goodenough	J. Solid State Chem. 1, 339 (1970)
3602	Laser Raman Spectroscopy	A. Mooradian	Science 169, 20 (1970)
3603A	Simple Model Potential Approach to the X-Ray Form Factor in Aluminium	P. Ascarelli* P.M. Raccah	Phys. Letters 31A, 549 (1970)
3610	Localized One-Electron States in Perfect Crystals as a Consequence of the Thermal Single-Determinant Approximation	T.A. Kaplan P.N. Argyres*	Phys. Rev. B 1, 2457 (1970)
3626	Simple, Versatile Techniques for Qualitative and Quantitative Evaluation of Spark Source Mass Spectrographic Plates	E.B. Owens	Rev. Sci. Instr. 41, 636 (1970)
3628	Electronic Structure of Palladium	F.M. Mueller* A.J. Freeman* J.O. Dimmock A.M. Furdyna*	Phys. Rev. B 1, 4617 (1970)
3633	Electron Mobility in High-Purity GaAs	C.M. Wolfe G.E. Stillman W.T. Lindley	J. Appl. Phys. 41, 3088 (1970)
3645	Report on the Symposium on Magnetic Semiconductors, IBM Research Center, Yorktown Heights, N.Y.	J.B. Goodenough	Phys. Today 23, 79 (1970)
3646	Quantitative Analysis of Ternary and Quaternary Semiconducting Alloys with the Electron Microprobe	M.C. Finn	Analytical Chem. 42, 1084 (1970)
3648	n-p Junction Photodetectors in InSb Fabricated by Proton Bombardment	A.G. Foyt W.T. Lindley J.P. Donnelly	Appl. Phys. Letters 16, 335 (1970)

* Author not at Lincoln Laboratory.

JA No.			
3651A	Anomalous Absorption of Microwaves by Interstellar H_2CO	M.M. Litvak	Astrophys. J. 160, L133 (1970)
3657	X-Ray Diffraction at High Pressures (A Review)	M.D. Banus	High Temperatures-High Pressures 1, 483 (1969)
3672	Laser Emission from Metal-Semiconductor Barriers on PbTe and $Pb_{0.8}Sn_{0.2}Te$	K.W. Nill A.R. Calawa T.C. Harman J.N. Walpole*	Appl. Phys. Letters 16, 375 (1970)
3681	Ultrasonic Attenuation Near the Spin-Alignment Transition of EuTe	Y. Shapira* T.B. Reed	Phys. Letters 31A, 381 (1970)
3701	Analysis of Frozen Aqueous Solutions by Spark Source Mass Spectroscopy	E.B. Owens	Analytical Letters 3, 223 (1970)
3721	Seebeck Coefficients in Vanadium Spinels	J.B. Goodenough	Materials Res. Bull. 5, 621 (1970)

Meeting Speeches

MS No.			
2610	The Physics and Technology of Surface Elastic Waves	H.I. Smith	Int'l. J. Nondestructive Testing 2, 31 (1970)
2683	Temperature and Magnetic Field Dependence of the Conductivity of EuO	M.R. Oliver J.O. Dimmock T.B. Reed	IBM J. Res. Develop. 14, 276 (1970)
2708	Optical Properties of the Europium Chalcogenides	J.O. Dimmock	IBM J. Res. Develop. 14, 301 (1970)
2778	N-P Junction Photodetector in InSb Fabricated by Proton Bombardment	A.G. Foyt W.T. Lindley J.P. Donnelly	Proceeding Detector Specialty Group Meeting, Santa Barbara, California, 12-13 February 1970 (Willow Run Laboratories, University of Michigan, 1970), p. 129

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UNPUBLISHED REPORTS

Journal Articles

JA No.			
3539	Positron Annihilation in Copper – Comparisons of Different Results	J. Melngailis	Accepted by Phys. Rev.

* Author not at Lincoln Laboratory.

Division 8

JA No.			
3631	Electrical Conductivity in Narrow Energy Bands	R.A. Bari D. Adler* R.V. Lange*	Accepted by Phys. Rev.
3659A	Direct Observation of Acoustical Activity in α-Quartz	A.S. Pine	Accepted by Phys. Rev.
3664	Magnetoreflection Studies in Bismuth	M. Maltz* M.S. Dresselhaus	Accepted by Phys. Rev.
3678A	Rigid and Nonrigid Beam Lead Substrates	F.J. Bachner R.A. Cohen R.E. McMahon	Accepted by Solid State Tech.
3682	Narrow-Band Expansions in the Hubbard Model: A Comment	R.A. Bari	Accepted by Phys. Rev.
3687	Phase Diagram of the CdTe-CdSe Pseudobinary System	A.J. Strauss J.M. Steininger	Accepted by J. Electrochem. Soc.
3716	Phase Diagram of the PbTe-PbSe Pseudobinary System	J.M. Steininger	Accepted by Metallurgical Trans.
3727	Linewidths of a Gaussian Broadband Signal in a Saturated Two-Level System	M.M. Litvak	Accepted by Phys. Rev.
3730	Si_3N_4 Masked, Thermally Oxidized, Post Diffused Mesa Process (SIMTOP)	R.A. Cohen R.W. Mountain	Accepted by IEEE Trans. Electron Devices
3737	Study of the Spin-Reordering Transition in Cr_5S6	K. Dwight N. Menyuk J.A. Kafalas	Accepted by Phys. Rev.
3738	Effects of Hydrostatic Pressure and of Jahn-Teller Distortions on the Magnetic Properties of $RbFeF_3$	J.B. Goodenough N. Menyuk K. Dwight J.A. Kafalas	Accepted by Phys. Rev.

Meeting Speeches†

MS No.			
2571-B	Ion Implantation in Compound Semiconductors	A.G. Foyt	Seminar, Fairchild Semiconductor Div., Palo Alto, California, 4 June 1970
2667A	A Gridded Thick Film Metalization Structure Employed in a Multichip Circuit Fabrication	H.H. Pichler	NEPCON '70 East, 16-18 June 1970

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MS No.			
2891	Optical Properties of the Alkalis Using the KKR-Z Method	A.R. Wilson G. Dresselhaus C.Y. Young	Conference on the Computational Methods in Band Theory, IBM, Yorktown Heights, New York, 14-15 May 1970
2898	Interstellar Molecular Masers	M.M. Litvak	Columbia Radiation Laboratory Seminar, Columbia University 29 May 1970
2901	Type Conversion and n-p Junction Formation in $Hg_{1-x}Cd_xTe$ Produced by Proton Bombardment	A.G. Foyt T.C. Harman J.P. Donnelly	Electronic Device Research Conference, Seattle, Washington, 29 June – 2 July 1970
2903	A New Technique for the Fabrication of GaAs Schottky Barrier Field Effect Transistors	W.T. Lindley C.E. Hurwitz A.G. Foyt	
2906	Growth of Oxide Crystals	T.B. Reed	International Conference on Ferrites, Kyoto, Japan, 6-10 July 1970
2922	Beam Lead Packaging	R.E. McMahon	Eastern Electronics Packaging Conference, M.I.T., 8-9 June 1970
2932	Theory of Chemical Diffusion in Ceramics	R.F. Brebrick	Materials Seminar, Aerospace Research Laboratories, Wright-Patterson Air Force Base, Dayton, Ohio, 25 June 1970
2957	Electrical Characterization of II-VI Semiconductor Compounds	F.T.J. Smith	Summer Course on Characterization of Electronic Materials, M.I.T., 3 August 1970
2965	Experiments on Bound Polarons in the Silver Halides	R.C. Brandt	Seminar, Eastman Kodak, Rochester, New York, 5 August 1970
2968	The Characterization of Electronic Materials by Means of Schottky Barrier Diodes	W.T. Lindley	Seminar, Department of Metallurgy and Materials Sciences, M.I.T., 3-4 August 1970
2969	Hall Effect and Extrinsic Photoconductivity Measurements: GaAs	G.E. Stillman	

SOLID STATE
DIVISION 8

I. SOLID STATE DEVICE RESEARCH

Long-wavelength $Hg_{0.821}Cd_{0.179}Te$ photovoltaic detectors have been fabricated by diffusion with peak detectivities near 30 μ of about 1×10^{10} cm$\sqrt{Hz}$/W at 4.2°K. Diodes fabricated from a smaller bandgap crystal showed photoresponse out to the 48 μ wavelength limit of the spectrometer used.

The $Hg_{1-x}Cd_xTe$ crystals were grown by a new technique in which the vertical ampoule remains stationary in a temperature gradient at the melting point, and growth occurs via a near steady-state mass transfer in the liquid phase. High quality single crystals produced by this technique were homogeneous in cross-section with respect to Cd-Hg ratio with a small longitudinal gradient. Temperature gradient annealing has resulted in electron carrier concentrations below 10^{15} cm^{-3} and 4.2°K mobilities in excess of 2×10^6 cm^2/V-sec.

Photovoltaic detectors have also been fabricated in p-type $Hg_{1-x}Cd_xTe$ with x = 0.50, 0.31 and 0.25 using proton bombardment to create the n-type layer. Although high sensitivity photodiodes were obtained with each composition, the best results were obtained with the x = 0.31 material. At 77°K these 15 × 15-mil diodes had zero-bias impedances of several megohms, peak detectivities at 3.8 μ of 9×10^{11} cm$\sqrt{Hz}$/W in reduced background, and peak quantum efficiencies of 29 percent.

Proton bombardment has also been used to fabricate n-p junction photovoltaic detectors in p-type PbTe. At 77°K, 5-mil-diameter diodes had zero-bias impedances up to 2 megohms, peak detectivities at 5 μ of 2.6×10^{11} cm$\sqrt{Hz}$/W in reduced background, and peak quantum efficiencies of 29 percent.

A separated medium (composite) acoustic surface wave amplifier, using low carrier concentration oxygen compensated GaAs as the amplifying medium and $LiNbO_3$ as the acoustoelectric medium, has shown 10 dB of electronic gain at a low operating voltage of 200 V/cm. The large surface depletion regions usually found in high purity GaAs are greatly reduced in this material, resulting in large acoustoelectric coupling. Expected power dissipation figures for thin crystals of over 100 dB/W are much better than any reported for Si.

A thesis describing the results of both electrical and optical measurements of europium oxide was written during this reporting period.

II. MATERIALS RESEARCH

A simple technique employing the tri-arc Czochralski furnace has been used to make melting point measurements on refractory materials at temperatures up to 2100°C. Comparison of the results with well established values for a number of elements indicates that the measurements are accurate to ±20°C.

Hall coefficient and resistivity measurements on ZnTe doped with about 2×10^{20} aluminum atoms/cm^3 have been made between 450° and 1000°C under controlled partial pressures of either

zinc or tellurium. At these temperatures low resistivity n- and p-type behavior was observed at compositions close to zinc and tellurium saturation, respectively.

Previous measurements of the resistivity of VO_x as a function of temperature from 300° to 77°K have been extended to liquid helium temperature for samples with $0.99 \leqslant x \leqslant 1.30$. The results confirm our earlier report that semimetallic behavior is exhibited by samples with $x < 1.0$ and semiconducting behavior by those with $x > 1.0$.

Conceptual phase diagrams with temperature and the transfer integral b as coordinates have been constructed for various values of the band occupancy number n_ℓ. These diagrams have been used in interpreting the magnetic and electrical behavior of a number of pyrites (MS_2 and MSe_2), including several mixed systems in which CoS_2 is one end member.

A review of high-pressure synthesis, as illustrated by studies on compounds with the chemical formula ABX_3 or $(AX_n)(ABX_3)$, where A and B are cations and X is an anion, has been prepared for publication as a chapter in Preparative Methods in Solid State Chemistry.

The sources of error in measuring volume compression by means of x-ray diffraction studies at high pressures have been analyzed. The procedures required to obtain accurate lattice parameters for the sample and for a marker material such as NaCl, used to determine the applied pressure, have been worked out.

III. PHYSICS OF SOLIDS

About twenty magnetoreflection interband transitions have been observed in the photon energy range 0.5 to 0.30 eV in a very high quality, extremely homogeneous sample of $Hg_{0.839}Cd_{0.161}Te$, which to our knowledge has the highest mobility of any crystal observed to date in this alloy system (2.6×10^6 cm^2/V-sec at 4.2°K). The data are being used to determine accurate values for the band parameters and their temperature dependence.

Recently, precise determinations of the conduction band parameters in InSb have indicated that the band edge effective mass and g-factor cannot be accurately related by the Roth conduction-valence band $\vec{k} \cdot \vec{p}$ interaction expression and a suggestion was made that higher band interactions must be considered. The details of this have been solved by considering the zincblende lattice which is appropriate to InSb as a diamond lattice plus a perturbing antisymmetric potential. The bonding p-like valence band wave functions admix with the higher antibonding p-like conduction band wave functions and this admixing accounts for the apparent discrepancy.

Polaron self-energy effects in the phonon-assisted cyclotron resonance and in the second harmonic cyclotron resonance have been observed in InSb for photon energies near twice the known optical phonon energies of InSb. The results indicate unambiguously the existence of a significant electron-TO-phonon interaction in a magnetic field.

Polaron studies are also continuing in the silver halides. By using an interferometer and magnetic fields up to 139 kG, Zeeman splitting of photo-induced, bound p-state conduction electrons has been measured in AgBr and AgCl.

Absorption and photoconductivity spectra of hydrogenic donors in high purity GaAs have been studied using far infrared lasers (HCN, DCN and H_2O) with resolutions unattainable with conventional techniques. The $1s \rightarrow 2p$ ($m = +1$) transition is found to consist of three lines; this is believed to be a consequence of differing central cell shifts of the various donors.

A preliminary investigation is under way of the statistical mechanics of a system of electrons on a lattice interacting with each other via intrasite Coulomb repulsion, and with phonons via a Fröhlich interaction. The eigenstates of the system can be obtained, but the evaluation of the partition function of the system has been found to be nontrivial, and the possibility of the existence of a phase transition for the system is under further study.

A theorem has been proven for a many particle system of either Bosons or Fermions, described by a Hamiltonian H which is an arbitrary function of creation and annihilation operators. If the eigenstates of H are denumerable, then a new set of creation and annihilation operators may be defined by an appropriate transformation, such that in the new representation H is a function of the new Boson or Fermion numbers only. The new operators represent quasiparticles of the many particle system.

Study of the magnetic properties of EuO continues. In addition to determining the magnetic critical indices, the experimental results have been analyzed in terms of the high-temperature series expansion for fcc lattices with nearest (J_1) and next-nearest (J_2) interactions to determine the value of these interactions. In contrast to previously reported results, based on low-temperature NMR and specific heat which indicate $J_2/J_1 \approx -0.12$, we find a ferromagnetic next-nearest neighbor interaction with $J_2/J_1 = 0.5 \pm 0.2$ and $J_1/k = 0.53° \pm 0.05°K$.

A general treatment has been carried out of the electrodynamic response of a quantum many-electron gas in a nonmagnetic conducting solid immersed in an applied magnetic field with the objective of studying wave propagation and looking for spin effects. Several such interesting spin effects are predicted in the plasma wave properties, both with and without spin-orbit mixing of the one-electron states.

Using a high-power 5-μCO laser, inelastic light scattering from plasmons in InSb has been observed for the first time and, by measuring samples of varying doping, the coupled plasmon-phonon modes have been studied. The density and polarization dependence of the scattering indicate that coupling to charge density fluctuations is the dominant scattering mechanism.

Raman scattering has also been carried out in trigonal tellurium with an argon laser. Dispersion arising from the screw symmetry of the lattice has been measured and the phonon symmetries and orderings near the zone center, determined from the Raman scattering selection rules, have been used to obtain the relative contributions of the deformation potential and the electro-optical effect to the electron-phonon interaction.

The Green's function method has been applied to the polaron coupling of an $n = 2$ and $n = 1$ Landau level of an electron in a magnetic field when the cyclotron frequency is close to the LO phonon frequency. Because of the simultaneous coupling of the $n = 1$ and $n = 0$ Landau levels, it is found that Raman scattering, resulting in the excitation of electrons from the $n = 0$ to $n = 2$ Landau level, will exhibit the effect of $n = 2$ and $n = 1$ level coupling.

Nonlinear mixing in GaAs of two millimeter or submillimeter signals has been analyzed for the case when the difference frequency is detected in the photocurrent. Important mechanisms at low difference frequencies seem to be carrier density modulation due to the energy dependence of the carrier lifetime and of the energy relaxation time, and carrier density modulation due to the nonlinearity of the photoexcitation of the donor states by the submillimeter sources.

IV. MICROELECTRONICS

Aluminum beam leaded devices have been fabricated and assembled with good results. Ultrasonic bonding of the beam lead chips to appropriate substrates has required considerable study and evaluation, and will continue as a development program.

Beam lead substrates of the flexible type with aluminum beam leads are being fabricated using material from several sources. Some difficulties exist in obtaining laminated aluminum polyimide sheets with appropriate properties, particularly in terms of the aluminum. Early efforts on thick aluminum resulted in severe undercutting during the etching process and, more recently, thinner aluminum has not exhibited the characteristics required for good bonding.

A new bonding method, ultrasonic ball bonding, for the general fabrication of hybrid circuits, has been implemented which eliminates elevated temperatures during the assembly period.

The laser scanner program for the evaluation of semiconductor devices has progressed sufficiently so that accurate device gain can be measured using the laser as an input.

The semiconductor clean room is operational and, although there are some remaining modifications to be made before it meets the original specifications, we expect to be able to process components within eight weeks.

Computer aided mask making has temporarily been interrupted in order to relocate the photogenerator and photorepeater in a more suitable environment. The techniques for processing masks at micron and submicron line widths will be explored in greater detail when the area is operational again.

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13. ABSTRACT

This Quarterly Technical Summary covers the period from 1 May through 31 July 1970. It consolidates the reports of Division 2 (Data Systems), Division 5 (Optics), Division 7 (Engineering), and Division 8 (Solid State) on the General Research Program at Lincoln Laboratory.

14. KEY WORDS

data systems	lasers	x-ray diffraction analysis
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psychology	educational technology	solid state physics