ACTIVE THIN-FILM TECHNIQUES MICROMIN PROGRAM

THIRD
INTERIM DEVELOPMENT REPORT
14 APRIL 1963

SYLVANIA ELECTRONIC SYSTEMS
Government Systems Management
for GENERAL TELEPHONE & ELECTRONICS

THIRD
INTERIM DEVELOPMENT REPORT
FOR
ACTIVE THIN-FILM TECHNIQUES MICROMIN PROGRAM

by

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This Report Covers the Period 23 December 1962 to 22 March 1963

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NAVY DEPARTMENT-BUREAU OF SHIPS-ELECTRONICS DIVISION
NOBSR 87633 Project Serial No. SR008-03-03, Task 9631

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Q445-3

ABSTRACT

The purpose of this investigation is to develop a process for depositing device-quality silicon and/or germanium films on polycrystalline insulating substrates by vacuum evaporation of silicon and/or germanium and to form diodes and transistors in these films.

During this quarter a total of 112 silicon vacuum depositions were made; both p- and n-type silicon films of various resistivities were deposited. A method of controlled doping of silicon films during vacuum deposition was developed. Diode characteristics with reverse breakdown up to 20 volts were obtained on vacuum deposited silicon pn junctions. A mechanical mask changer was designed, built and installed in the ultra-high vacuum system. Optical studies, electron diffraction studies, and Hall Effect measurements have been carried out on the vacuum deposited films.

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PART I

SECTION 1

PURPOSE

It is the purpose of this investigation to develop a process for depositing device-quality silicon and/or germanium films on polycrystalline substrates by vacuum evaporation of silicon and/or germanium, then to form diodes and transistors in these films. This investigation follows the previous work at Sylvania Microelectronics Laboratory in which semiconductor thin films were formed on polycrystalline substrates by hydrogen reduction of silicon tetrachloride. Diodes and transistors have already been fabricated in these semiconductor films.

The development of the technology of producing diodes and transistors in semiconductor films that have been deposited on polycrystalline substrates will be of great value for functional electronic circuits. There are two basic approaches toward forming these circuits with greater potential value in size, weight, economy, and reliability as compared with conventional circuits assembled with single components:

1. Form a circuit on and in a slice of single crystal semiconductor material (often called "solid state", "molecular", etc.).
2. Form passive networks by vacuum or chemical deposition of optimized materials on a substrate and attach prefabricated active components (thin-film circuits).

It is the ultimate aim of this investigation to further the development of a technology in which both active and passive elements in thin-film circuits will be produced by compatible techniques on the same substrate. In this way, reliability of thin film circuits will be improved by the elimination of many wire connections.

SECTION 2

GENERAL FACTUAL DATA

2.1 SYLVANIA RHEOTAXIAL APPROACH

In the rheotaxial[1] method, developed at the Sylvania Microelectronics Laboratory, a silicon layer of device quality is deposited at an elevated temperature on a thin fluid layer covering a polycrystalline substrate. The fluid layer limits the growth in the dimension normal to the fluid layer surface; in the remaining two dimensions the limit is set only by the shape of the substrate. Since the surface mobility of an atom on the fluid layer is very high and since there is no influence of the polycrystalline substrates on the orientation of the silicon film, the growth tends to follow the orientation of the initial crystallites of silicon.

The pyrolytic deposition of silicon by the hydrogen reduction of silicon tetrachloride has been used in this laboratory for producing diodes and transistors on polycrystalline substrates coated with glassy layers. The progress related to the development of a suitable glaze has been discussed in a previous report.[2] Briefly, the primary requirements are that the coefficient of expansion of the glaze should match that of silicon closely, the viscosity of the glaze should be in the proper range, and there should be a minimum of harmful impurities in the glaze. In particular, elements of Groups III or V should be avoided since these dope the silicon deposit either p-type or n-type.

2.2 PLAN OF THIS INVESTIGATION

A study is being made of the properties of silicon films deposited by vacuum evaporation on glazed polycrystalline substrates. Ultra-high (10^{-9} torr) vacuum equipment has been designed, constructed and operated for the vacuum depositions in order to minimize any contamination of the deposited semiconductor films. The substrate must be heated during the deposition so that the crystalline structure of the semiconductor would be of device quality. The ultimate aim of the investigation is the development of processes for the fabrication of silicon thin film diodes and

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1. "Rheotaxial": From the Greek, rheos- flow, fluid; taxis- arrangement.

2. Active Thin Film Techniques Micromin Program, First Interim Development Report, 12 October 1962, Bureau of Ships, Contract NObsr 87633, Sylvania Electronic Systems - East.

transistors applicable to thin film integrated microcircuits. A study is being made of the degree of vacuum required, the temperature of the substrate, the rate of deposition of the silicon, and the methods of doping the semiconductor to the proper resistivity, either p-type or n-type. The electrical properties of the deposited semiconductor films are investigated using Hall Effect, resistivity, conductivity type, lifetime of minority carriers and device characteristics in diodes and transistors. The structure of the deposited films is studied using optical microscopy, X-ray diffraction and electron diffraction.

SECTION 3

DETAILED FACTUAL DATA

3.1 PROJECT PERFORMANCE DATA

Figure 3-1 shows the schedule for completion of the various tasks under the contract.

Listed below are the technical personnel working on this project, and the man-hours spent during the reporting period.

Identification of Technicians

Name	Title	Hours
E. Rasmanis	Engineering Specialist (Project Engineer)	158
J. Cline	Engineering Specialist	517
G. Mannella	Engineering Manager	13
V. Barry	Senior Technician	504
E. Mocanu	Junior Technician	253
T. Ellis	Technical Associate	60
J. Nevers	Draftsman	22

3.2 VACUUM DEPOSITION OF SILICON FILMS

During this quarter 112 runs were made in which silicon films were vacuum deposited on glazed substrates. The effect of variations of substrate temperature was studied. Processes were developed for the deposition of silicon films of both n-type and p-type conductivities in the desired resistivity range. Runs were made in which both p- and n-type layers were deposited. Rectifier action was demonstrated in these samples by probing.

3.2.1 Doping Techniques

In order to obtain n-type silicon films of controlled resistivity, antimony was evaporated onto the substrate while silicon was being deposited. It was not considered practical to evaporate silicon from a doped source since the n-type impurities (phosphorus, antimony and arsenic) all have much higher vapor

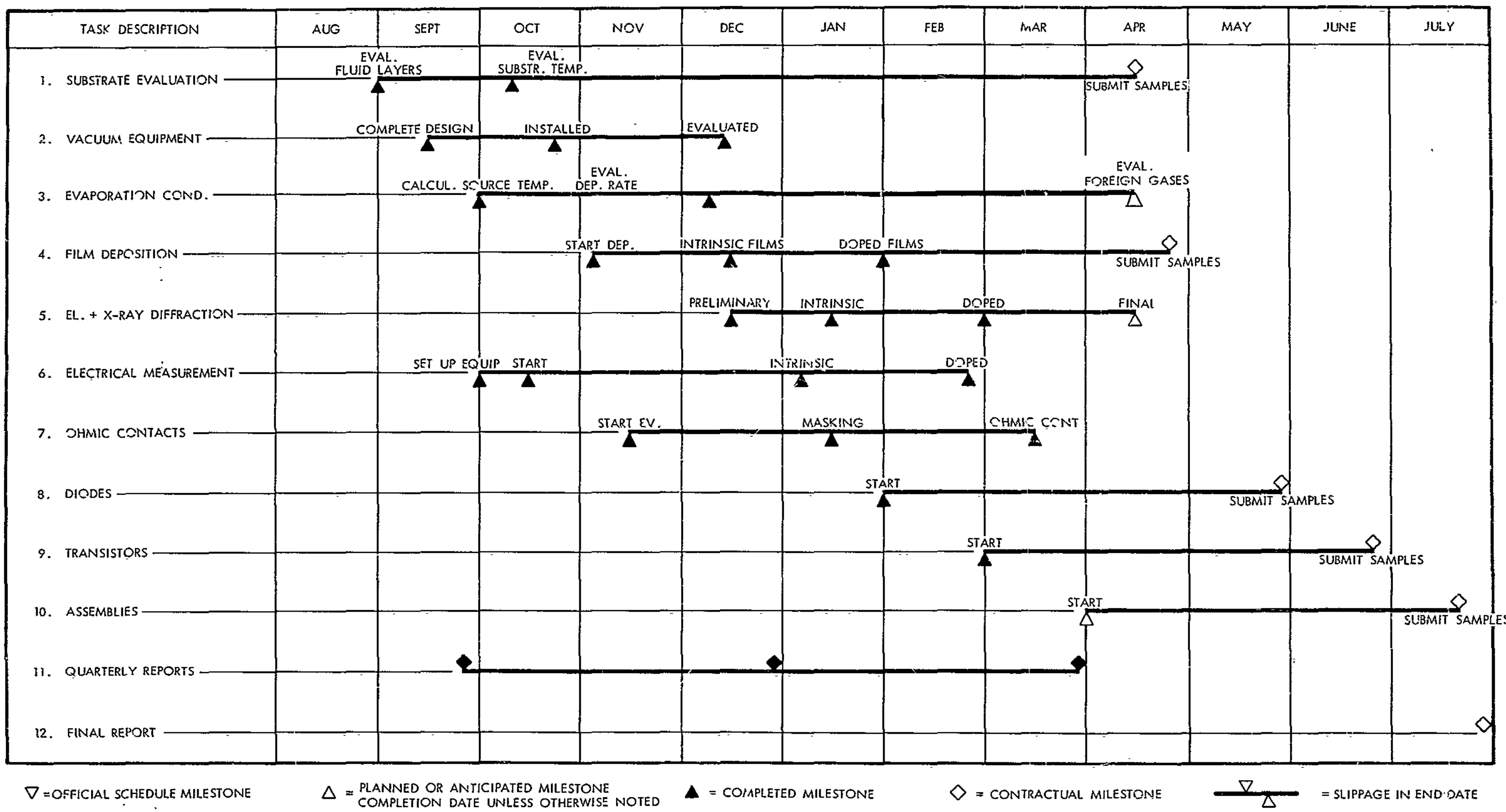

Figure 3-1. Time Schedule for Various Tasks

pressures than silicon. The temperatures at which various elements of interest have comparable vapor pressures have been compiled in Table 1 from data of Dushman.[1] If silicon doped with any of the n-type impurities were to be used as source material the concentration of impurity in the deposit would be high initially and then fall off rapidly as the impurity becomes depleted in the source.

TABLE 1[2]

TEMPERATURES AT WHICH SELECTED ELEMENTS HAVE COMPARABLE VAPOR PRESSURES*

Element	10^{-2}	10^{-1}	1	10	100	1000
Silicon	1177	1282	1357	1547	1717	1927
Germanium	1037	1142	1262	1407	1582	1797
Aluminum	882	972	1082	1207	1347	1547
Indium	670	747	837	947	1077	1242
Gallium	757	842	937	1057	1197	1372
Boron	1687	1827	1977	2157	2377	2657
Phosphorus	107	130	157	187	222	262
Arsenic						372
Antimony	382	427	477	542	617	757

*Temperatures in degrees centigrade, vapor pressures in mm Hg

A doping gun for antimony was set up as shown in Figure 3-2. A fused silica tube contained the antimony pellets. A thermocouple well provided for monitoring the antimony temperature during the deposition. Heat was provided by a bare tungsten coil 3 inches in diameter. The doping gun was supported at the cold end and positioned so that the antimony atoms emerging would impinge on the substrate area. In this way a minimum amount of antimony was deposited over the surface of the vacuum chamber and its contents.

1. Dushman, S., Scientific Foundations of Vacuum Technique, Second Edition, New York: John Wiley & Sons, Inc. 1962.

2. See above footnote.

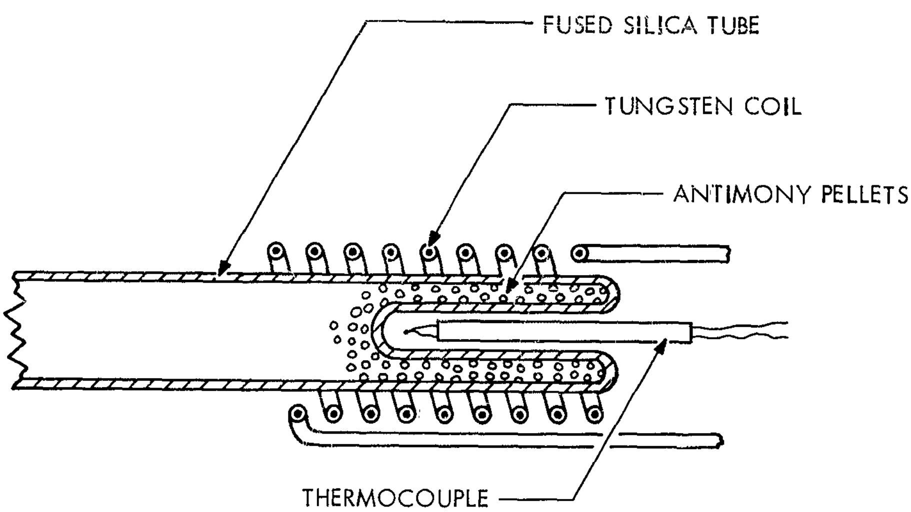

Figure 3-2. Gun System for n-type Doping

During the antimony doping experiments an intrinsic silicon source was used. Temperatures in the range 450° C to 500° C for the doping gun were used. This method was used for preparing n-type silicon deposits for Hall Effect samples and for p-n junctions.

The first attempts to deposit p-type silicon films centered on the use of boron-doped silicon sources. Even when a p-type source with resistivity as low as 0.01 ohm-cm was used, the silicon deposits still showed n-type by test with the hot-point probe. It can be seen from the data in Table 1 that boron has a much lower vapor pressure than silicon at equivalent temperatures. Thus, it is not surprising that enough boron did not deposit on the film in quantities sufficient to overdope whatever contamination was causing the n-type film. However, there is probably some combination of silicon and boron that would give a desired p-type deposit.

Further experimentation with boron-doped silicon as a source might lead to the simplest and most effective method of producing p-type films. The source holder as previously described[1] contained positions for several water-cooled copper source holders. By a mechanism operating through a bellows seal any one of the source holders could be brought directly under the electron beam without opening the chamber. Thus, the use of several pre-doped silicon sources would be practical. If a silicon source could be obtained with boron content sufficiently high to give p-type deposits, this would probably give uniform resistivities during many runs since the major constituent, silicon, is the one with the highest evaporation rate.

The second method used to obtain p-type films involved aluminum-doped silicon sources. Initially, small amounts of aluminum were added directly to the silicon in the source holder. Since aluminum has a much higher vapor pressure than silicon, as seen in Table 1, the doping is effective only for a short time before the source becomes depleted of the dopant. It was found that aluminum had to be added before each run in order to obtain p-type deposits. This method was used for depositing p-type layers both on top of and under n-type layers for pn junctions. However, it is not believed that addition of aluminum to the source would be able to produce p-type films with controllable resistivity. It is possible, on the other hand, to add silicon-aluminum alloy pellets to the source continually

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1. Active Thin-Film Techniques Micromin Program, Second Interim Development Report, 14 January 1963, Bureau of Ships, Contract NObsr 87633, Sylvania Electronic Systems — East.

during the evaporation. This is done by a dropping mechanism which gives a controllable amount of aluminum to the p-type deposit. The approach involves additional steps which add to the practical disadvantages of using this technique.

In order to secure the proper resistivity a third method of doping the depositing silicon film was tried. Similar to the method of adding antimony, aluminum was evaporated simultaneously with the deposition of silicon. When a doping gun, as shown in Figure 3-2, was tried, there was insufficient aluminum vapor available at the peak current of the tungsten coil. However, when the aluminum was evaporated directly in contact with the tungsten coil p-type deposits were obtained. A molybdenum shield was used to confine the aluminum deposition to the general region of the substrate. A plot of resistivity of the p-type silicon film versus current through the evaporation coil is shown in Figure 3-3. It can be seen that the resistivity could be varied from 0.13 to 21 ohm-cm. This method of doping the silicon film has the additional advantage of being able to produce a resistivity profile within the deposited silicon film. This contributes to the versatility of this process.

3.2.2 Source Holders

The function of the source holder is to contain the molten silicon source during the evaporation without introducing contamination. In all of the runs during this quarter the source holders were cylinders of copper with about a 3/4 inch internal diameter surrounded by water-cooled copper coils, as shown in the Second Interim Development Report. A rod of silicon was fitted into the copper cylinders with a carefully adjusted excess of silicon above the top of the copper. In this way the molten pool of silicon was surrounded by a solid silicon shell cooled by the copper during the evaporation. If too great an electron beam power was used, the liquid silicon would become contaminated with copper and the source would have to be discarded. Thus, this type of source holder imposed an upper limit on the beam power and upon the rate of evaporation of silicon. The deposition rate during most of the runs was about 4 microns per hour.

In order to achieve higher rates of silicon deposition another type of source holder was constructed. As shown in Figure 3-4, a small amount of silicon rests on top of a directly water-cooled copper holder. In this case the silicon melts and forms a flattened spherical shape under the influence of gravitational and surface tension forces. Due to the relatively small area of

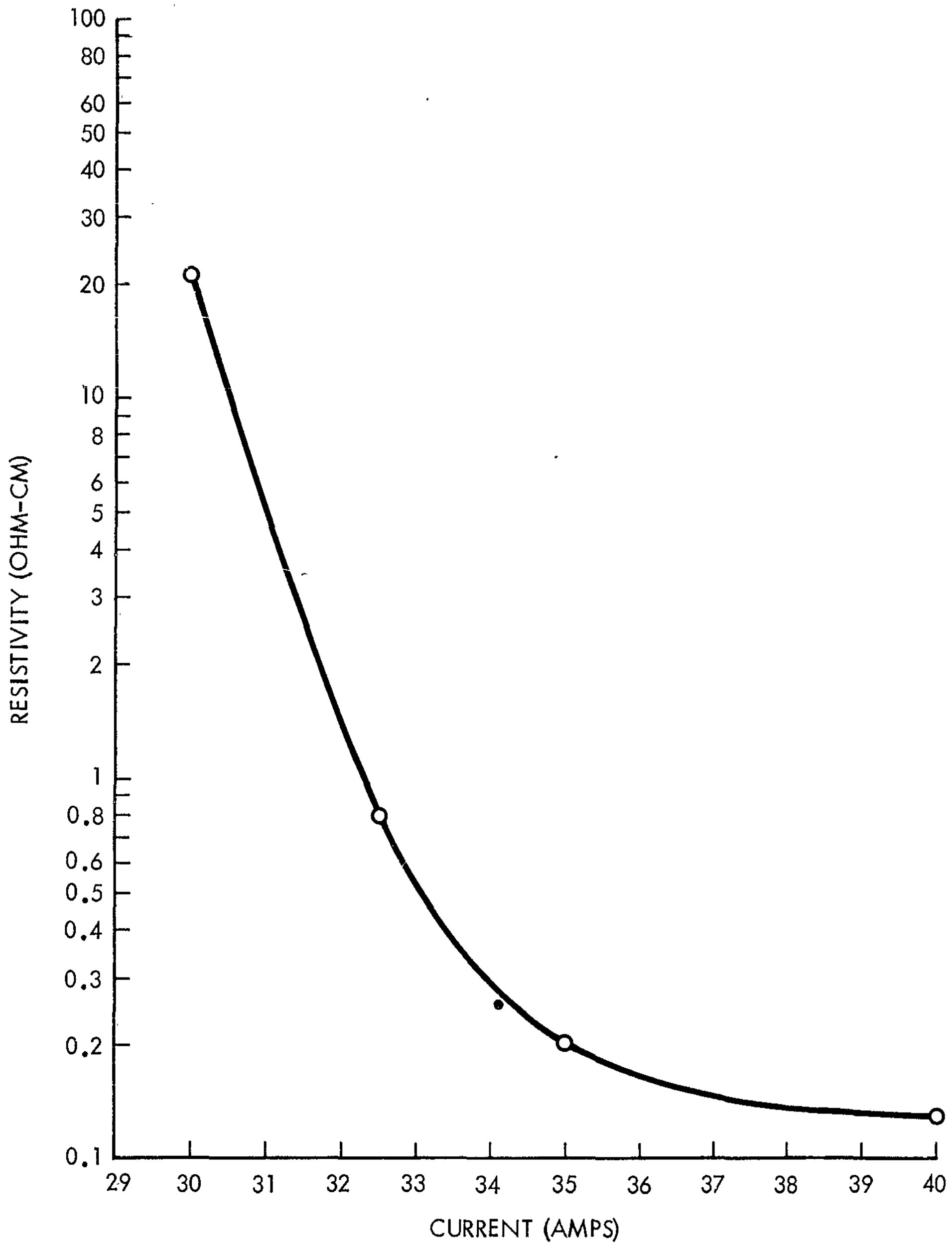

Figure 3-3. Resistivity of p-type Silicon Films as a Function of Heater Current of Aluminum Evaporation Coil

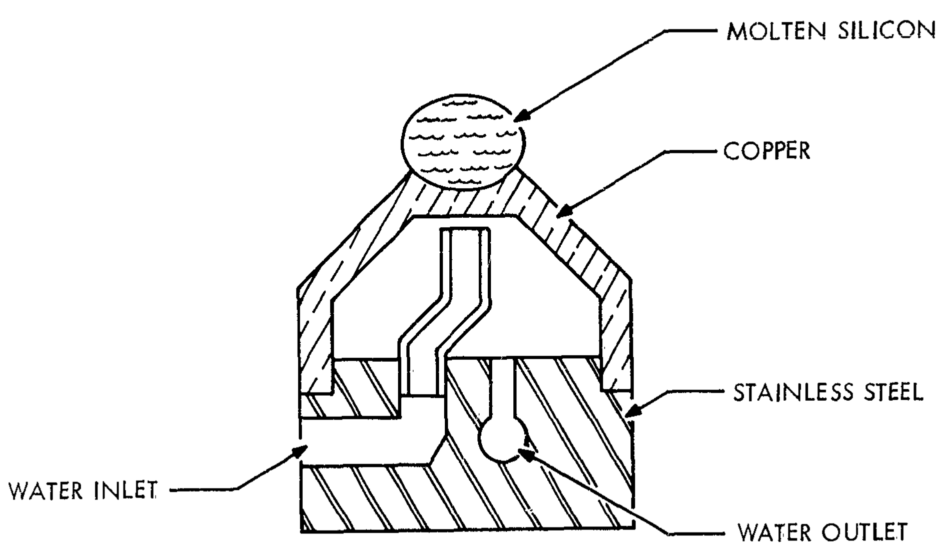

Figure 3-4. Directly Water-Cooled Copper Source Holder

contact between the silicon and the copper the heat transfer is low enough so that the copper can be kept cool by the water and the silicon can be raised to extremely high temperatures without excessive electron beam power.[1] A similar source holder has been used for the vacuum deposition of tantalum, an element with much lower vapor pressure than silicon.

3.2.3 Substrate Heater

The substrate was heated by direct radiation from a tungsten coil enclosed in a molybdenum box. Measurement of the temperature of the substrate with a thermocouple on the interior side of the substrate gives an erroneous temperature reading due to direct heating of the thermocouple by radiation from the tungsten coil. In order to obtain more reliable measurements a hole was drilled in the center of a sample substrate and the junction of a thermocouple was inserted in the hole. A calibration of substrate temperature versus current through the tungsten coil was obtained.

Many of the deposition runs showed variations in appearance of the deposit and in electrical conductivity between the center portion and the periphery. This was believed due to temperature variations. It was found that when the back of the substrate was coated with colloidal carbon, the silicon deposit was uniform in appearance and electrical conductivity. It is believed that the carbon coating produces a more uniform temperature over the entire substrate. Temperature measurements showed that the coated substrate is about 20° C hotter than the uncoated substrate, due to increased absorption of the radiation from the tungsten coil.

Higher coil currents melted the stainless steel terminals. Molybdenum terminals were constructed to enable higher substrate temperatures to be obtained. The power available from the transformer, 60 amperes at 20 volts, was found to be sufficient to obtain substrate temperatures up to 1100° C.

3.2.4 Masking for Device Fabrication

Areas of p-type and n-type layers of the size and position suitable for diodes or transistors can conceivably be produced either by evaporating through

1. Berry, R.W., "Proceedings Third Symposium on Electron Beam Technology," pp 358-366, Boston: Alloyd Electronics Corp., 1961.

metallic masks or by etching away parts of the silicon layers after evaporation. The latter method has been used successfully for producing devices from pyrolytically deposited silicon layers.[1] The etching rates and times must be very carefully controlled so that the desired layers are exposed for contacts.

It was considered that evaporation through metallic masks would be the most compatible method for use in device fabrication. To withstand the temperatures due to the heated substrate the masks were fabricated from molybdenum. Photolithographic techniques were used to delineate the holes in the mask. An acid solution was developed for etching through the 0.001 inch thick molybdenum sheet.

In the early depositions of p- and n-type layers during this quarter the mask was positioned by hand over a substrate which already had one silicon layer deposited on it. This could only be accomplished by exposing the first silicon layer to the atmosphere while the mask was being put in place. This can cause gas adsorption on the surface of the first film and oxidation upon heating, introducing defects at or near the pn junction.

In order to be able to move masks into position without opening up the vacuum chamber a mask changer was designed and constructed. A photograph of the open vacuum chamber showing the substrate heater, the mask changer and the source holders is shown in Figure 3-5. The mask changer was designed so that up to three masks could be used for transistor structures. The first mask with the collector areas is fixed in position in the substrate heater box. The frame of this mask has two pins which are used for registration of the following masks. The movable mask changer has spaces for two more masks and also a shutter area. The mask changer can be moved sidewise over the first mask by a mechanism operated from outside the vacuum chamber through a rotary seal. When the mask changer is in the proper position in relation to the substrate and first mask, it is moved over the two registration pins into contact with the first mask holder by means of a mechanism operating from the outside of the vacuum chamber through a bellows seal.

1. Active Thin Film Techniques Micromin Program, First Interim Development Report, 12 October 1962, Bureau of Ships, Contract NObsr 87633, Sylvania Electronic Systems — East.

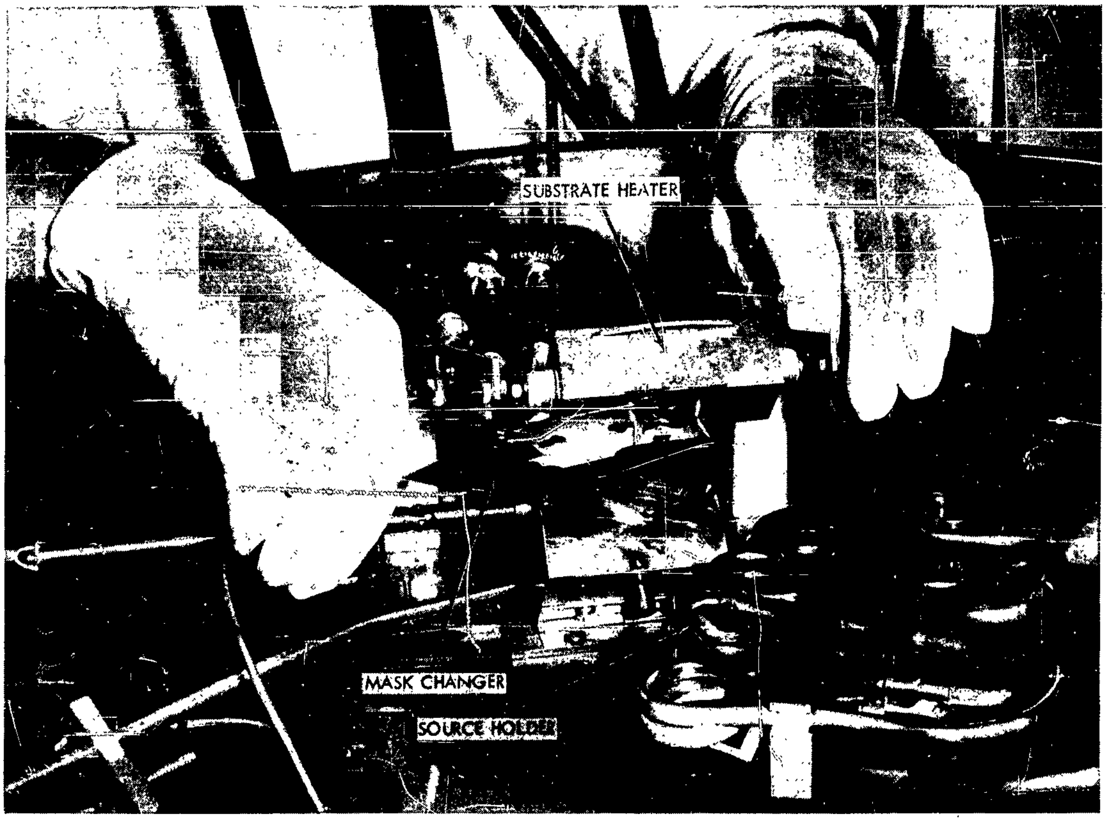

Figure 3-5. View of Vacuum Chamber Showing Substrate Heater, Mask Changer, and Source Holders

3.3 OPTICAL MICROSCOPY STUDY OF SILICON THIN FILMS

In the optical microscopy study this quarter the glassy layer isolating the silicon film from the polycrystalline alumina substrate and the surface structure of vacuum evaporated silicon films were investigated.

The glassy layer surfaces were studied before film deposition for imperfections and discontinuities. Subsequently, films were evaporated at varied substrate temperatures and studied to determine the influence of the original glaze imperfections, and any structural changes in the film surface. In some cases the silicon film was removed from an area and the glassy layer examined for replicas of nucleation or other film characteristics which may have been impressed upon that surface. Other depositions were cross-sectioned so that the interfaces between polycrystalline alumina – glassy layer and glassy layer-silicon film could be studied for possible decomposition or other layer interaction.

The surface of the glaze, isolating the polycrystalline alumina substrate shown in Figure 3-6, was studied at magnifications above 700 diameters to determine the condition of the surfaces currently being presented for film evaporation. The surface required is one of high atomic mobility and thus any defects existing in the glassy layer at the time of evaporation may alter this condition, transmitting the imperfection to the growing film.

In investigating the glaze, defects were located and found to be varieties of dust particles. These particles, organic and metallic are shown in Figures 3-7 and 3-8 respectively. Figure 3-9 illustrates a population of minute faults found in some wafers. These defects are transmitted directly to the film at temperatures below 800° C. Above this temperature only the large metallic-like defects remain, as the high temperature and more fluid state of the glassy layer eliminate the balance of the defects.

The higher substrate temperatures not only improved the glossy surface condition for the evaporation of the film but also resulted in changes in the surface structure of the silicon films. As substrate temperatures were increased from very low temperatures (and amorphous films) to higher temperatures, the corresponding films assumed structures similar to that shown in the last report for pyrolytic deposited silicon films. The sequence of structural changes is illustrated in Figures 3-10, 3-11 and 3-12.

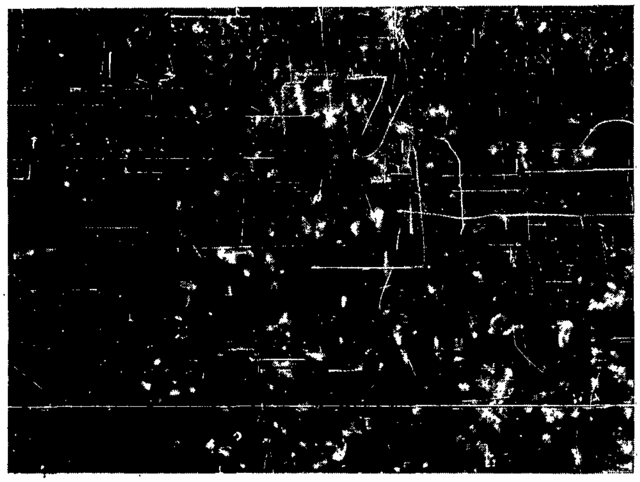

Figure 3-6. Polycrystalline Alumina Substrate (1120X)

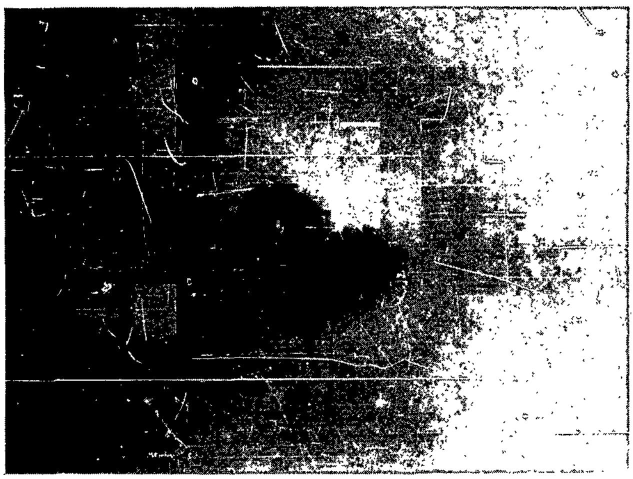

Figure 3-7. Organic Defect in Glaze (1120X)

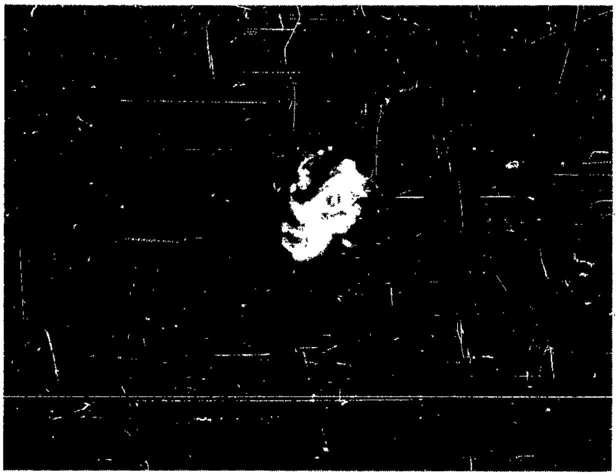

Figure 3-8. Metallic Defect in Glaze (1120X)

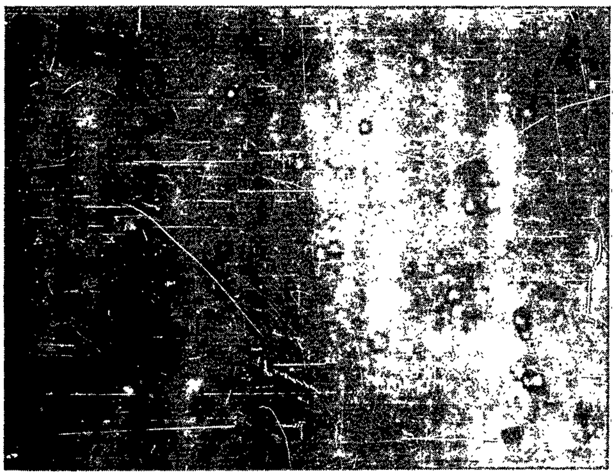

Figure 3-9. Population of Minute Faults in Glaze (1120X)

Figure 3-10. Surface Structure of Low Temperature Vacuum Evaporated Silicon Film (1600X)

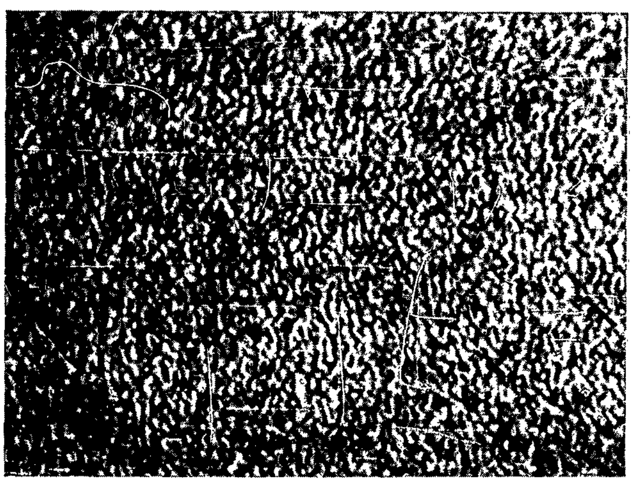

Figure 3-11. Surface Structure of Intermediate Vacuum Evaporated Silicon Film (1600X)

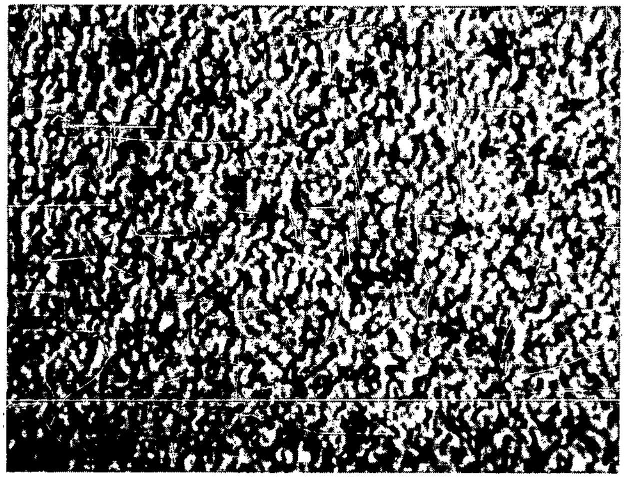

Figure 3-12. Surface Structure of High Temperature Vacuum Evaporated Silicon Film

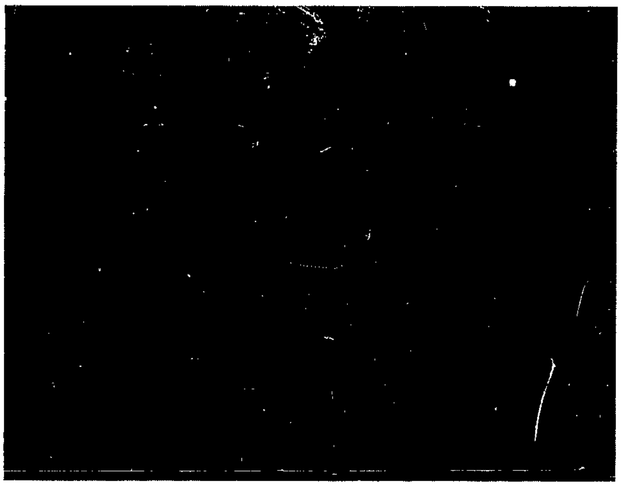

Figure 3-13. Replica of Dendritic Formation in Silicon Film Impressed Upon Glassy Layer (770X)

Selected areas of these films were removed by photolithographic and etching techniques so that the glossy layer could be examined for any visible replicas of structure or nucleation impressed upon the surface. The occurrence of such replicas was established in a March report to the Air Force.[1]

Many nucleation sites (Figures 3-13 and 3-14) were found in an intermediate temperature film indicating dendrite formation. Similar sites were also located in the surface of the film, and are presented in Figure 3-15. For the other films only structural impressions, Figures 3-16 and 3-17, were located and these were consistent with the structure size on the surface of the film.

In addition to contributing to knowledge about the nature of the films, these imprints are excellent indicators of the intimate adhesion of the silicon films to the substrate.

Films were also cross-sectioned to explore the layer interfaces for the possibility of inclusions, decomposition or other layer interaction. These specimens were prepared by bevel lapping and polishing at an angle of 5° (or 10° when improved definition of the interfaces was required). The sample cross-sectioned included films that were deposited over a range of substrate temperatures from 500°C to 800°C. In each case the results were similar. A representative sample is shown in Figures 3-18 and 3-19. It is apparent that there are no inclusions in addition to those glaze surface defects already detailed, nor any decomposition or layer interaction.

The isolating property of the glaze is also readily visible in these photomicrographs, as there is no obvious polycrystalline influence on the deposited silicon film from the polycrystalline alumina substrate. This condition is further emphasized by comparing the alumina substrate in Figure 3-6 and the surface structures of the films in Figures 3-10, 3-11 and 3-12.

3.4 ELECTRON DIFFRACTION STUDY OF SILICON THIN FILMS

Three of the vacuum deposited silicon films were examined by reflection electron diffraction using 100 KW electrons. The silicon films were undoped and deposited on substrates in the temperature range 495°C to 693°C. There were

1. Research on Silicon Single Crystal Thin Films and Devices, First Interim Technical Report, 15 March 1963, U.S. Air Force, AFSC-ASD Contract AF33(657)-10488, Sylvania Electronic Systems – East.

Figure 3-14. Replica of Dendritic Formation in Silicon Film Impressed Upon Glassy Layer (770X)

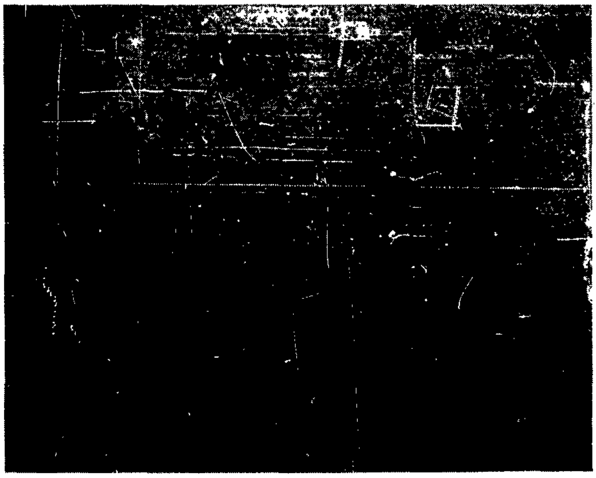

Figure 3-15. Dendritic Formation in Vacuum Evaporated Silicon Film (770X)

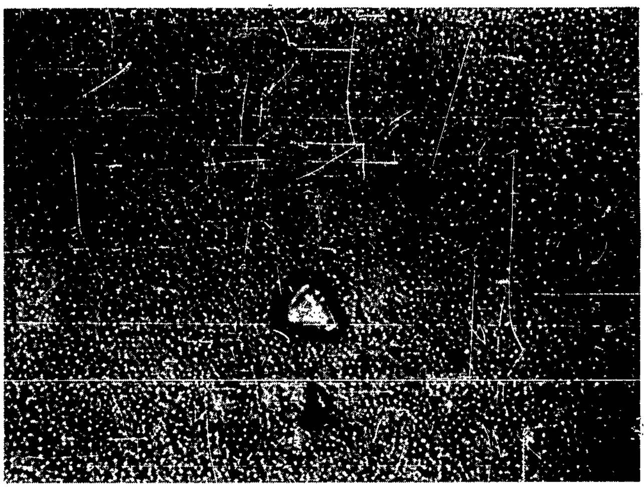

Figure 3-16. Structural Impression in Glassy Layer (770X)

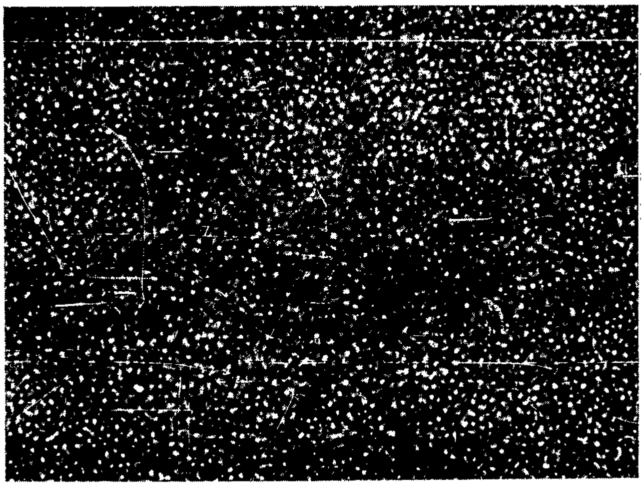

Figure 3-17. Structural Impression in Glassy Layer (770X)

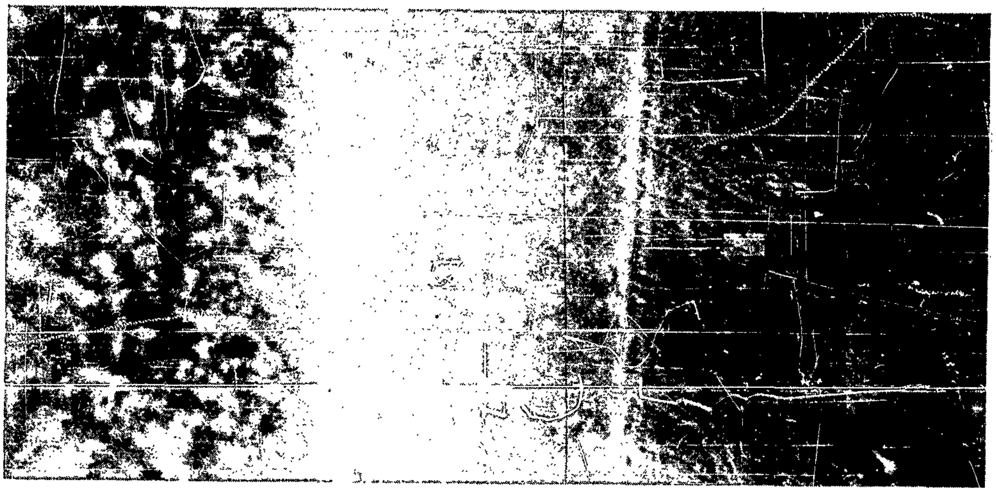

Figure 3-18. Cross Sectional View of Polycrystalline Alumina Glassy Layer and Glassy Layer-Silicon Film Interfaces (280X)

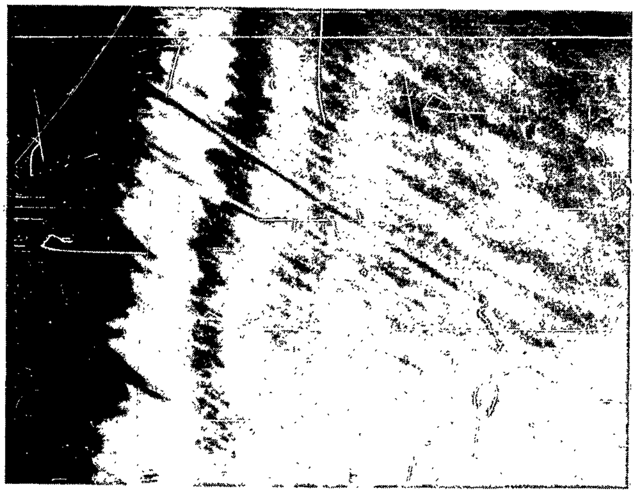

Figure 3-19. Enlarged View of Glassy Layer-Silicon Film Interface (1120X)

noticeable differences in the electron diffraction patterns as shown in Figures 3-20, 3-21, 3-22, and 3-23.

None of the deposits in this temperature range were classical single crystals. The deposit at substrate temperature 495° C, Figure 3-20, showed a tendency toward (111) in the crystallographic plane parallel to the surface of the deposit. A silicon film deposited at 581° C, Figure 3-21, showed a slight tendency toward (111). Two other silicon films deposited at 581° C, one of which is shown in Figure 3-23, however, showed preferred orientation of the (110) planes. The film deposited at 693° C, Figure 3-22, showed a tendency toward (110) and possibly a slight tendency toward (100).

It is planned to extend the electron diffraction studies especially to silicon films deposited at higher temperatures up to 1100° C.

3.5 ELECTRICAL EVALUATION OF SILICON FILMS

The rheotaxial silicon films and pn structures vacuum deposited during this program are being evaluated through measurement of electrical properties. The parameters measured included conductivity type, resistivity and Hall Effect for single layer films and forward and reverse bias voltage versus current characteristics for pn structures.

During the next quarter electrical measurement of pn structures will be expanded to include junction capacitance, minority carrier lifetime and switching time. As suitable ohmic contacts are made, the voltage versus current characteristics for forward and reverse bias conditions will be plotted to determine the conduction modes of these devices.

3.5.1 Resistivity

The extent of the impurity doping in films evaporated was obtained by measuring resistivities. The measurements were made using the four point probe method discussed in an earlier report.[1] The resistivity of the films was plotted against the doping conditions, Figure 3-3, in the initial runs and will be continued for further runs in order to calibrate the doping mechanisms in a manner suited to present requirements.

1. Active Thin Film Techniques Micromin Program, First Interim Development Report, 12 October 1962, Bureau of Ships, Contract NObsr 87633, Sylvania Electronic Systems — East.

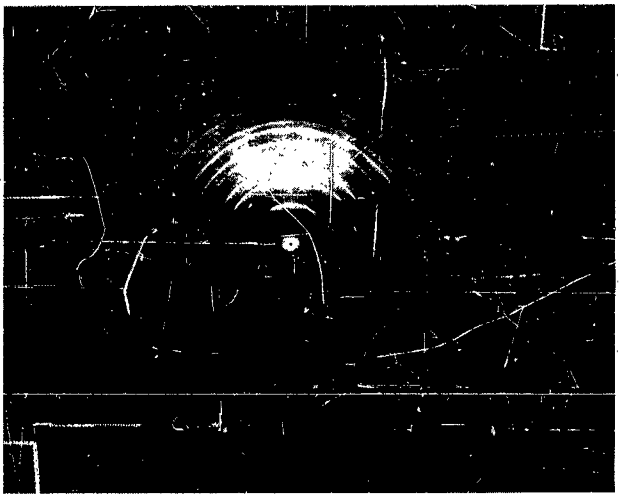

Figure 3-20. Electron Diffraction Pattern of Silicon Film Substrate Temperature 495°C

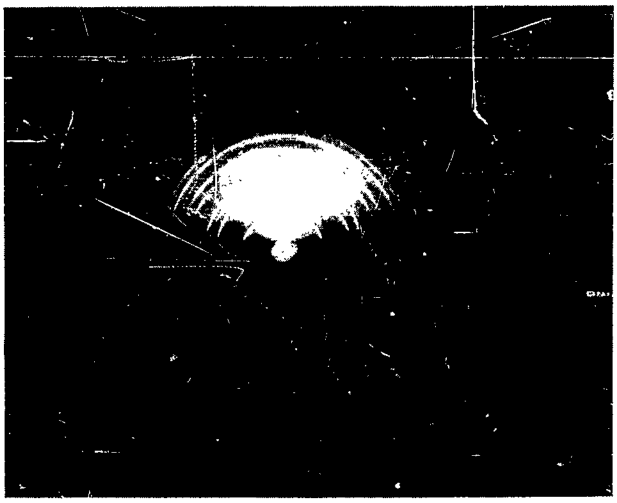

Figure 3-21. Electron Diffraction Pattern of Silicon Film Substrate Temperature 581°C

Figure 3-22. Electron Diffraction Pattern of Silicon Film Substrate Temperature 581°C

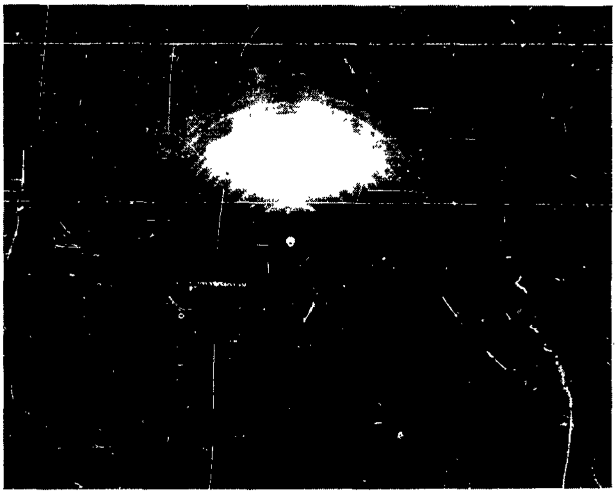

Figure 3-23. Electron Diffraction Pattern of Silicon Film Substrate Temperature 693°C

The results of the resistivity measurement of vacuum evaporated films made during this quarter are presented in Table 2. In general, these silicon film resistivities are in the range that is useful for device formation.

3.5.2 Conductivity Type

The hot probe method of measuring conductivity type described in the First Interim Development Report was used to determine the doping effects from the glaze on intrinsic type deposits as well as in monitoring the direct impurity doping of films evaporated this quarter.

3.5.3 Hall Effect Measurement

As also described in the First Interim Development Report, the Hall Effect determined the conductivity type while the Hall coefficient and charge carrier density were calculated from the Hall measurements and the mobility through a combination of independent resistivity and the Hall measurements.

TABLE 2

ELECTRICAL VALUES FOR A GROUP OF VACUUM EVAPORATED SILICON THIN FILMS

Hall Cond Type	R $cm^3/coul$	ρ ohm-cm	n $N \times 10^{16}/cm^3$	μ $cm^2/v\text{-}sec$
N	427	31.2	1.74	11.7
N	1380	22.4	0.53	52.4
N	750	9.45	0.983	67.5
N	170	2.6	6.14	56
N	26.9	4.92	27.4	4.65
N	110	5.8	0.673	19.1
N	51	2.21	1.44	19.6
P	50.1	14.3	14	2.97
P	22	0.143	3.3	13.1
P	35.2	0.198	22	16

The results obtained for these parameters are presented in Table 2. These values are similar to those obtained for silicon thin films[1] deposited by pyrolytic decomposition of $SiCl_4$. Values calculated from the equation[2] for electron mobility μ_n, as a function of resistivity ρ, in single crystal silicon, $\mu_n = 1750 + 470 \log_{10} \rho/10$ are greater than those obtained for thin films by approximately a factor of 10.

3.5.4 Diode Characteristics

During this quarter pn structures were fabricated by depositing one conductivity type of silicon on the glazed substrate and then depositing the opposite type through a mask. In Figure 3-24 a photograph of the surface of the silicon surface shows the geometrical shapes of the two deposits.

Reverse breakdowns of 15 to 20 volts were obtained by probing the diodes. Oscilloscope traces of the forward and reverse bias characteristics of diodes from two separate runs are shown in Figures 3-25 and 3-26. In one run a total of 14 diodes out of 16 had reverse breakdowns of about 20 volts, the other two about 10 volts, because they were located near the edge of the film and were mechanically defective.

In order to optimize the fabrication of diodes, further work will be required in controlling the doping levels of both p and n type silicon deposits and in obtaining suitable ohmic contacts. Electroless plating through photolithographic masks and vacuum evaporation through metal masks are the two methods of contacting presently being evaluated.

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1. Research on Silicon Single Crystal Thin Films and Devices, First Interim Technical Report, 15 March 1963. U.S. Air Force, AFSC-ASD Contract AF33(657)-10488, Sylvania Electronic Systems — East.

2. Hunter, L.P., Handbook of Semiconductor Electronics, Second Edition, McGraw-Hill Co., New York, 1962.

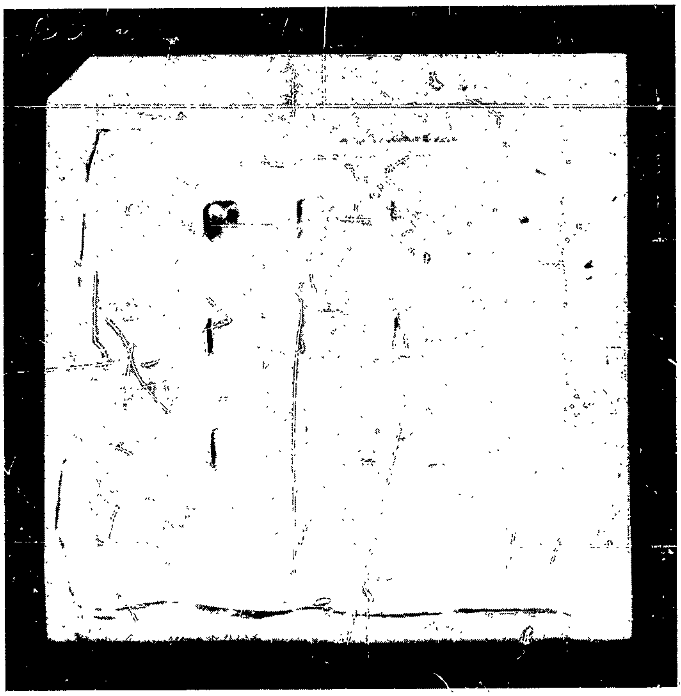

Figure 3-24. Substrate With Vacuum Evaporated Silicon Thin Film Diodes

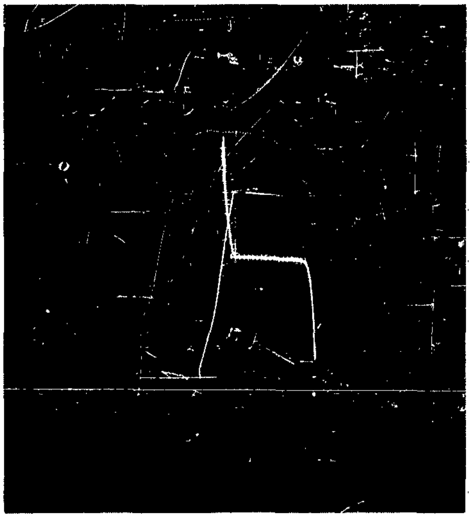

Figure 3-25. Diode Characteristics, Run No. 94, 5 volts/div. Horizontal, 100 Microamps/div. Vertical

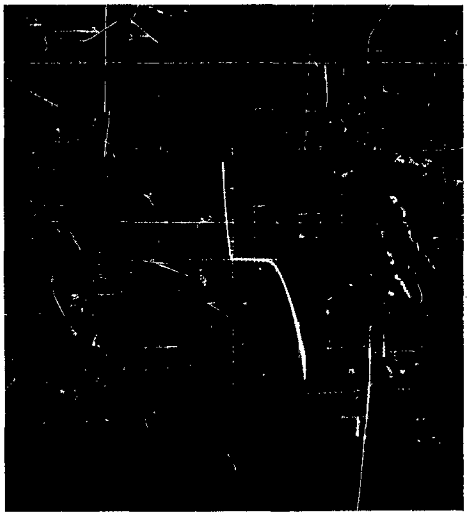

Figure 3-26. Diode Characteristic Run No. 139 10 volts/div. Horizontal, 50 Microamps/div. Vertical

SECTION 4

CONCLUSIONS

The results of vacuum depositions of silicon films of both p-type and n-type show that the film resistivity can be controlled by simultaneous evaporation of the desired dopant during the silicon deposition. The possibility of using a boron-doped silicon source for p-type deposits, although not successful within the composition ranges tried, has not been excluded.

Hall Effect measurements showed the mobility to range from 68 to 3 cm^2/v-sec, with the lowest mobility being obtained at the lowest substrate temperature.

Diode characteristics were obtained on vacuum deposited silicon pn junctions with reverse breakdowns up to 20 volts being obtained.

Electron diffraction measurements have indicated that higher substrate temperatures lead to a greater degree of preferred orientation on the vacuum deposited silicon thin films.

PART II

SECTION 1

PLAN FOR NEXT QUARTER

During the next period the major emphasis will be the development of vacuum evaporated silicon transistors and continued work on silicon thin film diodes. Deposition masks will be installed in the mask changer and adjusted to proper registration for a transistor structure. Control of resistivity of both p-type and n-type silicon will be perfected for fabrication of both diodes and transistors.

Development of ohmic contacts will be carried out using vacuum evaporation. It is planned to construct a multi-device circuit on a single substrate.

Additional optical, electron diffraction and electrical studies will be made on vacuum deposited silicon films.

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Sylvania Electric Products Inc.
Sylvania Electronic Systems – East, Waltham, Mass.
ACTIVE THIN-FILM TECHNIQUES MICROMIN PROGRAM, Interim Development Report (Unclassified Title), 14 April 1963, 37 pp. incl. 26 illus.
(Sylvania Report No. Q445-3)
(Contract No. NObsr 87633)
(Project Serial No. SR008-03-03, Task 9631) Unclassified

The purpose of this investigation is to develop a process for depositing device-quality silicon and/or germanium films on polycrystalline insulating substrates by vacuum evaporation of silicon and/or germanium, and to form diodes and transistors in these films.

During this quarter a total of 112 silicon vacuum depositions were made; both p- and n-type silicon films of various resistivities were deposited. A method of controlled doping of silicon films during vacuum deposition was developed. Diode characteristics with reverse breakdown up to 20 volts were obtained on vacuum deposited silicon pn junctions. A mechanical mask changer was designed, built and installed in the ultra-high vacuum system. Optical studies, electron diffraction studies, and Hall Effect measurements have been carried out on the vacuum deposited films.

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