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THIN FILMS OF SILICON ON LOW-COST SUBSTRATES

MASTER

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1 January 1978 - 31 March 1978

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Prepared for

UNITED STATES

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

SAN FRANCISCO OPERATIONS OFFICE

Prepared by

K. R. Sarma, R. W. Gurtler, A. Baghdadi, M. Cota

of

MOTOROLA INC.

5005 East McDowell Road

Phoenix, Arizona 85008

Motorola Project No. 2283

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ABSTRACT

During this quarter, parametric studies of silicon deposition were conducted employing the horizontal Energy Beam system. Chemical equilibrium calculations pertaining to the Energy Beam deposition conditions were performed. These calculations indicated that the reaction efficiency for hydrogen reduction of silicon tetrachloride is over 95% for any chlorosilane concentration at the Energy Beam temperature of 4300K. Because lower temperatures exist near the substrate surfaces, the kinetics of establishing the low temperature equilibrium will determine obtainable material efficiencies. From deposition experiments, the material efficiency was found to be strongly dependent on input chlorosilane concentrations. The highest material efficiency and growth rate obtained concurrently to date were 70% and 10 μ m/min using the horizontal Energy Beam system. The Thermal Expansion Shear Separation (TESS) process for producing self supporting silicon films was further investigated.

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1.0 INTRODUCTION

The objective of this program is to develop a new method of depositing thin films of polycrystalline silicon by utilizing an Energy Beam with 1) low energy utilization, 2) high chemical efficiency and 3) high throughput. A second objective is to develop methods for separating deposited silicon films from (temporary) substrates. These self-supporting polycrystalline silicon films are subsequently grain enhanced by the RTR process to produce macrocrystalline silicon ribbon for fabricating solar cells.

During this quarter, chemical equilibrium calculations for silicon deposition under a variety of conditions (equilibrium as a function of reactor pressure, concentration of the reactants, and temperature) appropriate for Energy Beam deposition were completed. Several deposition experiments were conducted in the horizontal Energy Beam system. These experiments were aimed at testing the methods of eliminating (or minimizing) beam arcing and evaluating the effects of input gas concentrations and RF beam power on silicon deposition.

Construction of the second Energy Beam deposition system, which is to be operated in a vertical mode, is nearing completion. Fabrication of the reactor cabinet, burn-off box, and mounts for the furnace and network module is complete. This system is expected to be operational within about a month.

We continued the investigation of Thermal Expansion Shear Separation (TESS) techniques. Separated silicon films were characterized for their chemical purity by SSMS. Composition of the interfacial film on the molybdenum substrates was determined by SIMS analysis. The self supporting polysilicon films were grain enhanced by the RTR technique and are currently being fabricated into solar cells.

2.0 ENERGY BEAM DEPOSITION

2.1 CHEMICAL EQUILIBRIUM CALCULATIONS

Thermodynamic equilibrium calculations for the hydrogen reduction of chlorosilanes under conditions appropriate for the conventional chemical vapor deposition of silicon have been performed by many investigators. References 1 and 2 are examples of the most recent results of these calculations. However, calculations appropriate for the Energy Beam deposition of silicon involve temperatures up to 4300K⁽³⁾; these are not available in the literature.

During the previous year of this research program, we performed computer calculations of chemical thermodynamic equilibrium as a function of temperature between 1400K and 5000K at one atmosphere pressure and a single chlorosilane concentration (0.6 mol % SiCl₄)⁽³⁾. We have now extended these calculations to a range of chlorosilane concentrations (0.5 to 50.0% SiCl₄) and to reactor pressures of 0.5, 1.0 and 2.0 atmospheres. These calculations were performed at Arizona State University by Dr. M. L. Parsons using Gordon and McBrides computer program obtained from NASA-Lewis Research Center. This program is based on a free energy minimization criterion.

All the possible species (including the ionic species) comprising the elements Si, Cl and H for which data existed in the JANAF tables⁽⁴⁾ were considered. Figures 1 - 5 show the results of these calculations. All of the calculations were performed for equal concentrations of H₂ and He in the input. Helium was included in the calculations because it increases the stability of the Energy Beam plasma. However the effect of He on thermodynamic equilibrium is equivalent to that of reducing reactor pressure. Figure 1 shows the variation in relative concentrations of various species as a function of temperature at 1 atmosphere for an input Cl/H ratio of 0.1 (i.e., 5 mol % SiCl₄).

FIGURE 1: Relative concentrations of various species containing Si, H, Cl as a function of temperature for $P=1$ atm and $Cl/H = 0.1$.

Reaction efficiency (i.e., the efficiency of producing free silicon) was calculated from Si/Cl ratio in the input chlorosilane (0.25 for SiCl_4) and the Si (bound)/Cl ratio at equilibrium (obtained from Figure 1). In the system Si-H-Cl, the Cl/H ratio can be obtained by using different chlorosilanes - SiCl_4 or SiHCl_3 etc. (mixed with different amounts of hydrogen). Thus even though the equilibrium calculations were performed using SiCl_4 as the silicon-bearing gas, these results can be used to calculate reaction efficiencies for other chlorosilanes. For example, to calculate reaction efficiency using SiHCl_3 gas, we use (Si/Cl) input = 0.33. (This method breaks down if the input Si/Cl ratio for which the calculations were performed - 0.25 in this case - is equal to Si (bound)/Cl ratio at equilibrium.) We calculated the reaction efficiencies for SiCl_4 and SiHCl_3 because they are of interest in silicon deposition.

Figures 2 and 3 show the effect of pressure on reaction efficiency using SiCl_4 and SiHCl_3 . Reaction efficiency increases slightly with decrease in reactor pressure. Effects of input Cl/H ratio on the reaction efficiencies for SiCl_4 and SiHCl_3 are shown in Figures 4 and 5. Reaction efficiency increases with decreasing Cl/H ratio. In the case of SiCl_4 , for Cl/H ratio equal to or greater than 0.2, silicon etching occurs. Silicon etching also occurs in the case of SiHCl_3 , but only for higher Cl/H ratios (which are out of the range of our interest).

From Figures 2 - 5 we can see that the reaction efficiency increases with increase in temperature reaching a plateau (over 95% efficiency) at about 4300K for all input Cl/H ratios. Thus, increase in efficiency with further increase in temperature will be insignificant. It is fortuitous that the Energy Beam plasma temperature is also about 4300K. However lower temperatures exist in the region of the substrate surfaces. Thus, obtainable material efficiencies

FIGURE 2: Effect of reactor pressure on reaction efficiency with SiCl_4 as silicon bearing gas for $\text{Cl}/\text{H} = 0.1$.

FIGURE 3: Effect of reactor pressure on reaction efficiency with SiHCl_3 as silicon bearing gas for $\text{Cl}/\text{H} = 0.1$.

FIGURE 4: Reaction Efficiency vs. Temperature with $SiCl_4$ for various Cl/H ratios at 1 atm.

FIGURE 5: Reaction efficiency vs. temperature with $SiHCl_3$ for various Cl/H ratios at 1 atm.

will depend on the kinetics of establishing low temperature equilibrium during deposition on substrates.

2.2 BEAM ARCING

We have still encountered some beam arcing with the horizontal Energy Beam system in current use. In the case of the impinging Energy Beam deposition geometry⁽³⁾ employed earlier, the substrate acted as a target to the Energy Beam and was heated by the impingement of the beam. Thus the beam coupled to the substrate all during deposition, and no other part of the deposition system was heated by the beam directly. In the case of the currently utilized horizontal Energy Beam system, the beam flows parallel to the substrates and does not couple to any particular part of the deposition system, but disperses into the space in front of the Energy Beam nozzle. The beam seeks the path of least impedance to ground, and can be moved around by moving an external ground.

Beam arcing to the substrates can be eliminated by increasing the distance between the beam nozzle and substrates in the deposition arrangement shown in Figure 6. However this arrangement is susceptible to beam arcing to the quartz reaction chamber. Arcing to the quartz chamber occurs due to the gradual silicon buildup on the quartz tube between the nozzle and the substrate. This arcing is detrimental since the quartz chamber can be punctured.

Using the deposition arrangement shown in Figure 7, we tested the effectiveness of a vortex stabilized auxiliary flow of nitrogen in eliminating the silicon buildup on the quartz tube (and concomitant arcing). This was partially effective. Only a short length of deposition free zone was obtained, and silicon buildup on the remaining part of the quartz tube took place, though at a slower rate. Thus arc-free deposition can be carried out for a longer time with this arrangement than in the one shown in Figure 6.

FIGURE 6; One of the deposition arrangements tested. This arrangement is susceptible to beam arcing to the quartz reaction chamber.

FIGURE 7: Schematic of a deposition arrangement with a provision for using an auxiliary N_2 purge gas. N_2 is introduced from the side tube which is tangential to the circumference of the main reaction tube.

It is important to note that, even if it does occur, arcing should not be a severe problem in a continuous deposition system, which is envisioned as the long-term embodiment. In a continuous deposition system, the quartz reaction tube will be completely covered by substrates which move continuously from one end of the reactor to the other. Thus, no particular part of the substrate will be subjected to continuous beam arcing. Even if there are some local substrate temperature variations due to beam arcing, non-uniformities in deposition are not expected with the Energy Beam (unlike the situation in conventional CVD), since we have established that substrate temperature has only a minor influence on Energy Beam deposition uniformity. However, shear separation of the deposit may experience some problems due to nonuniform substrate temperatures during deposition.

For parametric studies of silicon deposition we employed the deposition geometry shown in Figure 8. In this geometry arcing does occur, but only to the inner quartz shroud, thus avoiding the danger of puncturing the main quartz chamber. This deposition arrangement was employed in most of the experiments performed during this quarter.

Another arrangement for minimizing beam arcing is shown in Figure 9. In this case, the diameter of the quartz reaction chamber near the nozzle is increased to eliminate arcing. This apparatus has been tried only recently, with encouraging results. Figure 10 shows a large area self-supporting film produced using the deposition arrangement of Figure 9.

It is also possible that problems associated with beam arcing can be essentially eliminated by suitable modifications in the Energy Beam nozzle. The present nozzle employs one electrode. Nozzle geometries employing multiple electrodes, which can be switched on and off so that discharge occurs

FIGURE 8: Horizontal deposition arrangement with an auxiliary quartz shroud.

FIGURE 9: Deposition arrangement for eliminating beam arcing to the quartz reaction chamber. The diameter of the quartz tube near the nozzle is increased.

FIGURE 10: Photograph of large area self supporting silicon film (0.006" thick) produced from the deposition arrangement shown in Figure 9.

from one electrode at a time, are expected to reduce arcing. In this case the beam will be rotating inside the reactor. We are starting to investigate such alternative nozzle geometries.

2.3 DEPOSITION EXPERIMENTS

Parametric studies of Energy Beam deposition were carried out using the deposition arrangement shown in Figure 8. Effects of the silicon-bearing gas concentration and RF beam power on morphology of the deposit, material efficiency, and growth rate were studied. Trichlorosilane was employed as the source gas in these experiments. Depositions were conducted on 0.5" x 18" strips of grafoil (graphite sheet). At the conclusion of each experiment, the weight of the deposit and the deposition uniformity were recorded.

Experiments were performed for SiHCl_3 input concentrations of 0.5 to 8.0% (by volume) and RF powers of 1.0, 1.3 and 1.5KW. A constant substrate temperature of approximately 1100°C was maintained. However two problems were encountered during these experiments. Considerable amount of deposition were taking place on the quartz shroud between the nozzle and the beginning of the grafoil substrate; these deposits were not taken into account in the calculations, Secondly the source V controller had to be sent to Tylan Corp. for calibration, requiring us to use a rotometer for controlling the input SiHCl_3 . Hence the calculations were performed assuming that the carrier gas was saturated with SiHCl_3 . In reality the carrier gas was not saturated, and the percentage of saturation decreased with increasing carrier gas flow. As a result of these two considerations, the calculations are conservative.

2.3.1 MORPHOLOGY OF THE DEPOSIT

Films ranged from a dense gray deposit (for high substrate temperatures -- i.e., the region inside the furnace) to a brown powder (for low substrate temperatures - i.e., the regions outside the furnace). An example of a temperature profile inside the furnace (measured along the center line of the reaction tube) is shown in Figure 11. The RF plasma influences the temperature measurements using a thermocouple. In the presence of the plasma the indicated temperatures are 100°C to 10°C lower than the actual temperatures depending on whether the thermocouple is close to or far from the plasma beam. Hence the profile in Figure 11 was obtained by instantaneously turning the plasma off.

A typical thickness profile of the deposit on the grafoil is shown in Figure 12. The thickness is small at the beginning of the grafoil, increasing to large values, and then decreasing further down the tube. It should be noted that there is an additional two inches of deposition area (the quartz shroud) between the nozzle and the grafoil, where the deposit appeared to be substantially thick. Examining Figures 11 and 12 we can see that there is no correlation between the substrate temperature and the deposit thickness. The deposit thickness appears to depend mainly on the fluid flow in the reactor and on the amount of silicon remaining in the gas phase. The deposit thickness at any particular distance from the nozzle was, however, uniform. In a continuous deposition system, nonuniform deposition along the length of the reactor will average out due to substrate motion.

2.3.2 MATERIAL EFFICIENCY AND GROWTH RATE

Because of the problems discussed above -- significant amount of deposition on the quartz shroud which is not accounted for, and the lack of knowledge of

FIGURE 11: Temperature profile along the center of the reactor tube - Furnace temperature setting = 1100°C, RF power = 1000 watts, Plasma H₂ = 30 l/min, Sheath He = 4 l/min.

FIGURE 12: A typical thickness profile of the deposit

the percentage of saturation of the carrier gas for different flow rates -- accurate values of the material efficiency and growth rate could not be obtained. However, some qualitative conclusions can be drawn from the results of these experiments. Material efficiency increased with decreasing concentration of SiHCl_3 in the input gas stream. Increasing the RF power of the beam from 1.0KW to 1.5KW did not significantly increase the material yield. In these experiments we calculated a maximum material efficiency of 70% and a growth rate of 10 $\mu\text{m}/\text{min}$; actual values would be higher if quantitative correction factors were available.

3.0 TEMPORARY SUBSTRATE SYSTEM STUDIES

3.1 CHARACTERIZATION OF THE TESS SAMPLES

The morphology, microstructure and chemical purity (as determined by Secondary Ion Mass Spectrometry) of self-supporting silicon films obtained by the Thermal Expansion Shear Separation (TESS) technique were reported in the previous quarterly report⁽⁵⁾. These samples were further characterized for their bulk chemical purity by Spark Source Mass Spectrometry (SSMS). This analysis was performed by CDM/ACCU-Labs at Wheat Ridge, Colorado.

Samples were prepared for the analysis first by degreasing in ethanol and acetone solutions, rinsing with deionized water, and then by removing a few microns from the surface by chemically etching with a $3\text{HNO}_3:2\text{HF}:2\text{HAc}$ solution. Results of the analysis of silicon films obtained from molybdenum, TZM and tungsten temporary substrates are shown in Tables 1 - 3. Concentrations of the elements determined by unit sensitivity based on standards (associated with *) are more accurate. The molybdenum concentration of 2.0 ppm wt. in the sample obtained from the Mo substrate is due to the presence of an inclusion. This was inferred from a strong molybdenum signal for a short duration during the analysis. Thus the actual molybdenum concentration is below the detection limits of the instrument as in the case of the other two samples. Iron and carbon can be traced back to impurities in the silicon source gas (SiHCl_3) used for silicon deposition. These results are in agreement with the SIMS analysis reported in reference (5).

Potential large effects of a molybdenum substrate on purity of deposited silicon were investigated by the following experiment. Boron doped epitaxial silicon films were grown on n-type silicon wafers (in two separate runs) with and without the presence of a large molybdenum substrate in a conventional

TABLE 1

CDM/ ACCU-LABS

11485 W. 48th Ave./WheatRidge CO 80033
(303) 423-2766

To: **Mr. K. R. Sarma**
Motorola, Inc.

DATE: **January 20, 1978**

ALR No: **35-5897-3-3**

Sample Identification No. **Mo**

Purchase Order No.

CONCENTRATION IN ppm wt.

Uranium	Terbium	Ruthenium	Vanadium
Thorium	Gadolinium	Molybdenum 2.9**	Titanium <0.06
Bismuth	Europium	Niobium	Scandium
Lead	Samarium	Zirconium	Calcium 0.56
Thallium	Neodymium	Yttrium	Potassium
Mercury NR	Praseodymium	Strontium	Chlorine 0.02
Gold	Cerium	Rubidium	Sulphur
Platinum	Lanthanum	Bromine	Phosphorus
Iridium	Barium	Selenium	Silicon Maj
Osmium	Cesium	Arsenic	Aluminum 0.09
Rhenium	Iodine	Germanium	Magnesium
Tungsten	Tellurium	Gallium	Sodium
Tantalum Instrument Source	Antimony	Zinc	Fluorine 0.23*
Hafnium	Tin	Copper 0.04	Oxygen NR
Lutecium	Indium	Nickel <0.29*	Nitrogen NR
Ytterbium	Cadmium <0.15*	Cobalt INT	Carbon 0.36
Thullium	Silver	Iron 0.34	Boron 0.04
Erbium	Palladium	Manganese 0.16	Beryllium
Holmium	Rhodium	Chromium	Lithium
Dysprosium			

All elements for which values are not entered **<0.1 ppm wt.**

NOTES: ***Determined on unit sensitivity**

****Inclusion**

NR - Not Reported

INT - Interference by a major component spectrum.

22

William R. Hilgren
Supervisor
Mass Spectrometry

TABLE 2

CDM/ ACCU-LABS

11485 W. 48th Ave./Wheat Ridge CO 80033
(303) 423-2766

To: Mr. K. R. Sarma
Motorola, Inc.
5005 E. McDowell Road
Mail Stop A112
Phoenix, Arizona 85008

DATE: January 20, 1978
ALR No: 35-5897-3-1
Sample Identification No. TZM
Purchase Order No. G. N. 387041-8590
CONCENTRATION IN ppm wt.

Uranium	Terbium	Ruthenium	Vanadium
Thorium	Gadolinium	Molybdenum	Titanium ≤ 0.08
Bismuth	Europium	Niobium	Scandium
Lead	Samarium	Zirconium	Calcium 0.39
Thallium	Neodymium	Yttrium	Potassium
Mercury NR	Praseodymium	Strontium	Chlorine 0.09
Gold	Cerium	Rubidium	Sulphur
Platinum	Lanthanum	Bromine	Phosphorus
Iridium	Barium	Selenium	Silicon Maj
Osmium	Cesium	Arsenic	Aluminum 0.07
Rhenium	Iodine	Germanium	Magnesium
Tungsten	Tellurium	Gallium	Sodium
Tantalum Instrument Source	Antimony	Zinc	Fluorine 0.10*
Hafnium	Tin	Copper 0.10	Oxygen NR
Lutecium	Indium	Nickel 0.39*	Nitrogen NR
Ytterbium	Cadmium <0.15*	Cobalt INT	Carbon 0.36
Thullium	Silver	Iron 0.11	Boron 0.13
Erbium	Palladium	Manganese 0.16	Beryllium
Holmium	Rhodium	Chromium	Lithium
Lysprosium			

All elements for which values are not entered <0.1 ppm wt.

NOTES: *Determined on unit sensitivity

NR - Not Reported

INT - Interference by a major component spectrum.

Supervisor

Mass Spectrometry

CDM/ ACCU-LABS

TABLE 3

11485 W. 48th Ave./Wheat.Ridge CO 80033
(303) 423-2766

To: Mr. K. R. Sarama
Motorola, Inc.

DATE: January 20, 1978
ALR No: 35-5897-3-2

Sample Identification No. W
Purchase Order No.

CONCENTRATION IN ppm wt.

Uranium	Terbium	Ruthenium	Vanadium
Thorium	Gadolinium	Molybdenum	Titanium <0.02
Bismuth	Europium	Niobium	Scandium
Lead	Samarium	Zirconium	Calcium 0.13
Thallium	Neodymium	Yttrium	Potassium
Mercury NR	Praseodymium	Strontium	Chlorine 0.04
Gold	Cerium	Rubidium	Sulphur
Platinum	Lanthanum	Bromine	Phosphorus
Iridium	Barium	Selenium	Silicon Maj
Osmium	Cesium	Arsenic	Aluminum 0.01
Rhenium	Iodine	Germanium	Magnesium
Tungsten	Tellurium	Gallium	Sodium
Tantalum Instrument Source	Antimony	Zinc	Fluorine 0.10*
Hafnium	Tin	Copper 0.10	Oxygen NR
Lutecium	Indium	Nickel <0.29*	Nitrogen NR
Ytterbium	Cadmium <0.15*	Cobalt INT	Carbon 0.83
Thullium	Silver	Iron <0.09	Boron 0.13
Erbium	Palladium	Manganese 0.16	Beryllium
Holmium	Rhodium	Chromium	Lithium
Dysprosium			

NOTES: All elements for which values are not entered <0.1 ppm wt.

*Determined on unit sensitivity

NR - Not Reported

INT - Interference by a major component spectrum.

William R. Edgum
Supervisor
Mo Spectrometry

CVD reactor. Deposition was conducted on two wafers placed 12" apart on the susceptor, and have a molybdenum sheet occupied most of the space between them in one run. Figure 13 shows the resistivity of these wafers as determined by a 4-point probe. The small difference could be due to run-to-run variation rather than due the presence of molybdenum. Experiments are in progress to verify this.

3.2 CHARACTERIZATION OF TESS SUBSTRATES

TESS substrates are being characterized to gain an increased understanding of the shear separation process. We are currently conducting these studies with Mo substrates. Previously we reported⁽⁵⁾ the growth of an interfacial film on the molybdenum substrate during silicon deposition as shown in Figure 14. This is a cross-sectional view of a molybdenum substrate subjected to six deposition cycles. The interfacial film was formed on both sides of the substrate. The features across the photograph are artifacts of sample polishing. The region beyond the interfacial film is the sample mounting material. The qualitative composition of the interfacial film can be obtained from the x-ray emission images produced using an SEM with an energy dispersive x-ray unit. Figures 15 and 16 show the silicon and molybdenum x-ray emission photographs obtained from the region of the substrate shown in Figure 14. These photographs clearly show the presence of a Mo-Si alloy on the molybdenum substrate.

To determine the composition of this interfacial film we employed QMAS (Quadrupole Mass Analyser for Solids) depth profiling using SIMS. This analysis was performed by Applied Research Laboratories of Sunland, California. In order to obtain high sputter rates (of about 20Å/second) a static beam probe was utilized. Figures 17(a) and 17(b) show photographs of the sputtered area of the sample at different sputtering times. Figure 17(a) shows a

FIGURE 13: Effect of the presence of a Mo substrate in a CVD reactor on resistivity of epitaxially deposited silicon with boron doping.

FIGURE 14: Cross-sectional view of a molybdenum substrate subjected to 6 deposition cycles. Viewing angle of the SEM picture was 30°.

FIGURE 15: Silicon x-ray emission picture obtained from the region shown in Figure 14.

FIGURE 16: Molybdenum x-ray emission picture obtained from the region shown in Figure 14.

FIGURE 17(a)
Optical micrograph
of a 15 μm deep crater
in the Mo-Si alloy
created by a static
beam probe in SIMS.

FIGURE 17(b)
Optical micrograph
of the 120 μm deep
crater (into the
molybdenum substrate).

These pictures explain the tailing of the silicon concentration
in Figure 18.

crater of 50 μm in diameter and 15 μm deep which is still in the interfacial film. Figure 17(b) shows a crater of 120 μm deep which is into the Mo substrate.

The silicon concentration profile through the depth of the sample is shown in Figure 18. The concentration of silicon is indicated qualitatively as intensity of the silicon signal. The sudden drop of silicon concentration occurs approximately 35 - 40 μm deep, which corresponds to the interfacial film thickness. The tailing of the silicon signal at this interface was interpreted by Dr. T. A. Watley of Applied Research Labs, as due to the crater walls obtained by static beam probe. Thus the concentration change at the interface is more abrupt than indicated by Figure 18. The silicon signal beyond this interface was also interpreted to be due to the same reason. Accurate determination of chemical composition using SIMS requires standards. However due to the lack of standards for molybdenum silicides, a standardless quantitation program was employed to theoretically estimate the composition of the interfacial film; the result was 7 at % molybdenum.

The system Mo-Si has three compounds - MoSi_2 , Mo_3Si_2 and $\text{Mo}_3\text{Si}^{(6)}$. While the solid solubility of Mo in Si is insignificant, that of Si in Mo is approximately 1 at % at 1400K (the deposition temperature). The molybdenum silicide having a composition closest to the estimated composition of 7 at % Mo is MoSi_2 with 33.3 at % Mo. It is possible that the interfacial film is composed of grains of silicon and grains of MoSi_2 (or other silicide) to have an average composition of 7 at % Mo. However, because these phases have to be formed by the diffusion of Si and/or Mo into each other, a layered interfacial film with different moly silicide layers of different thicknesses is more likely. We are planning additional experiments to examine this.

FIGURE 18: Silicon concentration profile plotted qualitatively as a function of depth through the interfacial film as determined by SIMS. The concentration of the interfacial film was estimated to be 7 at % Mo.

In the RTR technique for grain size enhancement, the effective distribution coefficient for an impurity is close to unity, and hence the dopant distribution along the length of the ribbon is not much altered. This requires that the polysilicon feedstock be uniformly doped with the desired impurity concentration. We characterized the dopant distribution in self-supporting polysilicon films produced by the TESS technique in a conventional CVD reactor. Single crystal n-type silicon wafers were placed along side the molybdenum substrate for silicon deposition with a boron dopant. The boron dopant distribution in the polysilicon films was inferred from the measurements on the epitaxial p-type films grown on the n-type wafers. Figure 19 shows the resistivity variation along the length of the apparatus measured by a 4-point probe. Figure 20 shows a typical depth profile obtained by angle lapping and spreading resistance measurements on p-type epitaxial films on n-type wafers. Resistivity is very uniform through the thickness of the film. We have to contend with a resistivity variation along the length of the ribbon of the magnitude shown in Figure 19 when using a batch type deposition reactor.

The self-supporting polysilicon films (0.006" - 0.01" thick) were grain enhanced by the RTR technique employing a scanned CO₂ laser beam. The grain enhanced films are currently being processed into solar cells using the processes - boron diffusion, phosphorous diffusion, AR coating, and metallization -- developed for CZ wafers at Motorola.

FIGURE 19: Resistivity variation along the length of the apparatus obtained by a 4-point probe.

SPREADING RESISTANCE PROFILE

FIGURE 20: Depth profile of the dopant distribution in the silicon film obtained by angle lapping and spreading resistance measurements on a test wafer.

5.0 PLANS FOR NEXT QUARTER

During the next quarter we plan to:

- . Continue investigation of the effects of Energy Beam deposition parameters on deposit quality and on the deposition process,
- . Complete the fabrication and assembly of the vertical Energy Beam deposition system and initiate deposition experiments using this system.
- . Start the investigation of methods, such as alternate nozzle geometries, to eliminate beam arcing,
- . Investigate deposition from other silicon bearing gases - SiCl_4 and SiH_4 ,
- . Continue chemical and structural characterization of the as-deposited and grain-enhanced films,
- . Fabricate solar cells from grain-enhanced films and evaluate their performance.

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