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THIN FILM POLYCRYSTALLINE SILICON SOLAR CELLS

Quarterly Technical Progress Report No. 2 for January 1—March 31, 1980

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QUARTERLY TECHNICAL PROGRESS REPORT NO. 2
FOR PERIOD
1 JANUARY 1980 - 31 MARCH 1980

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JUNE 1980

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UNITED STATES
DEPARTMENT OF ENERGY
DIVISION OF SOLAR TECHNOLOGY
AND
SOLAR ENERGY RESEARCH INSTITUTE
UNDER DOE SUBCONTRACT NO. XS-9-8277-1

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PREFACE

This Quarterly Report No. 2, covering the period January 1, 1980 to March 31, 1980, was prepared by the Solar Energy R&D Department, I. A. Lesk, Manager, Motorola Inc., Phoenix, Arizona 85008. This report describes the work performed under SERI Contract No. XS-9-8277-1. K. R. Sarma is the principal investigator. Others who participated in this program are R. W. Gurtler, M. J. Rice, R. Legge, R. J. Ellis and W. Salina.

ABSTRACT

During this second quarter of the program, data on the effects of trace amounts (ppm level) of oxygen on the MoSi_2 substrate separation layer have been refined. Analysis of the composite substrate process has indicated that its complexity and expense are too great for practical development; as a result of this, and continued success with Mo substrates, efforts on composite substrates have been discontinued. By extensive operation of the semicontinuous plasma deposition system, operational characteristics have been further defined, permitting requirements for designing a truly continuous microcrystalline silicon film deposition system to be determined. Gas chromatography has been used to characterize the silicon deposition process using the silicon bearing gases SiCl_4 , SiHCl_3 and SiH_2Cl_2 ; In all cases, deposition efficiency was found to be higher when using plasma than with conventional CVD. Solar cell fabrication and evaluation efforts have indicated that silicon films separated from Molybdenum substrates can yield cells up to 12.8% efficiency under AM1 illumination, and with average efficiencies above 11%.

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1.0 INTRODUCTION

The objectives of this research program are: a) investigation of a semi-continuous plasma deposition system as a means for efficient, high rate deposition of polycrystalline silicon films, b) development of low-cost reusable substrates for deposition and shear separation of the silicon films, c) optimization and subsequent grain enhancement of the films through laser RTR recrystallization, and d) demonstration of at least 12% efficient, large area (greater than 10 cm²) solar cells fabricated on grain-enhanced silicon films.

During this quarter, we have refined our data on the effects of trace amounts of oxygen on the growth rate of the MoSi₂ separation layer by additional experiments. Initial economic analysis of the composite substrate process has indicated that a large amount of effort would be needed to evaluate fully its low-cost potential; as a result (and coupled with continued success using Mo substrates) we have discontinued our efforts on composite substrates.

The semicontinuous plasma deposition system has been extensively operated, generating valuable operational data. Requirements for a truly continuous system have been determined, and an initial conceptual design of this deposition system has been completed. Gas chromatography has been used to characterize the silicon deposition process using SiCl₄, SiHCl₃ and SiH₂Cl₂ as silicon bearing gases.

Several 1 cm x 2 cm area solar cells have been fabricated on silicon films deposited by a CVD method and separated from Mo substrates, after grain enhancement. These cells have exhibited AM1 conversion efficiencies up to 12.8% indicating the feasibility of high efficiency solar cells using molybdenum TESS substrate process.

2.0 SUBSTRATE SYSTEM STUDIES

2.1 MOLYBDENUM TESS SUBSTRATE STUDIES

We have previously reported that the shearing of silicon from molybdenum substrates required the formation of a MoSi_2 interfacial layer. Therefore the rate of formation of MoSi_2 was studied as a function of deposition temperature. The effect of oxygen, in the process gases, on the rate of formation of MoSi_2 was also studied. Two effects have been observed from the addition of oxygen; the rate of formation of MoSi_2 is reduced, and the silicon does not shear when >100 ppm oxygen is added throughout the deposition.

Previous results on oxygen addition had been obtained using a flowmeter too large for the lower oxygen concentrations to be accurately controlled. Therefore the flow tube was changed to obtain accurate control of small additions of oxygen. Figure 1 shows the rates obtained for five different oxygen concentrations on the MoSi_2 growth. It is postulated that oxygen impedes the diffusion of silicon through the MoSi_2 layer. Nitrogen has been shown not to cause this effect.

2.2 COMPOSITE TESS SUBSTRATE

We have previously shown (1) that composite TESS substrates Mo (0.04"): SiO_2 (1 μm): Mo (1 μm) are suitable for producing self-supporting microcrystalline silicon films. Shear separation of the silicon film was clean and reliable, and the substrate could be easily cleaned and recoated with SiO_2 and Mo . A Silox system was used for SiO_2 coating. Both sputtering and CVD were used for Mo coating.

FIGURE 1: EFFECT OF OXYGEN PRESENCE ON $MoSi_2$ INTERFACIAL LAYER GROWTH.

During this quarter, we have critically evaluated the low-cost potential of this composite substrate process. While this composite substrate offers significant cost reductions, it is necessary to expend considerable developmental effort to realize the benefit with an attendant risk. For example the present day costs of molybdenum-bearing gas sources (for e.g. MoCl_5) are too expensive and some developmental effort is needed to bring this cost down. The cost of coating the thick Mo substrate with thin layers of SiO_2 and Mo is found to be in excess of \$0.10 per peak watt of electricity produced, which is not compatible with our cost goals. Hence instead of devoting a large effort to bring this cost down, we decided to discontinue effort in this area and concentrate on regular Mo substrates, the understanding of which now indicates that their use is compatible with long range cost goals.

2.3 ECONOMICS OF MOLYBDENUM TESS SUBSTRATE PROCESS

We have established the shear separation mechanism using Moly TESS substrates. It involves formation of Kirkendall voids in the silicon film at the MoSi_2 -Si interface due to predominant diffusion of silicon, and fracture propagation through these voids. It has been found that a layer of about 9 μm of MoSi_2 has to be formed during the deposition cycle to result in Kirkendall voids big enough to cause reliable shear separation. Because the growth rate is diffusion limited, the rate of growth of the MoSi_2 layer decreases as its thickness increases. As a result after every 7 deposition cycles, part of the MoSi_2 layer has to be removed to assure formation of more than 9 μm of MoSi_2 and continual reliability of shear separation. We have verified the feasibility of improving the continued shear separation by periodic surfacing (grinding to remove part of the MoSi_2 layer) of the substrate.

The temporary Mo substrate cost can be estimated by considering the amount of Mo consumption through MoSi_2 formation (which is periodically removed) and the cost of the removal process (machining).

Considering the factor of safety we assume that substrate resurfacing is necessary following every six deposition cycles. At this point about 100 μm (4 mils) of MoSi_2 will be formed. This corresponds to about 1.2 mils of consumed Mo. Considering the size of the substrates utilized (3 in. x 12 in.) a machining tolerance of ± 0.5 mils can be assumed. Removal of an intended 4 mil thickness of MoSi_2 , thus could result in removal between 3.5 and 4.5 mils of material. At the worst case of 4.5 mils, 1.2 mils equivalent of Mo from MoSi_2 and 0.5 mils of unreacted Mo are removed for a total of 1.7 mils of Mo. For costing assumptions assume that 2 mils (50 μm) of Mo is lost after every six deposition cycles. Also for a nominal 3 in. x 12 in. Mo substrate, grinding costs are estimated to be less than \$0.50 for removal of 4 ± 0.5 mils.

Molybdenum has a density of about 10 g/cm^3 and presently costs less than \$100/Kg in fabricated forms such as sheets.

$$\begin{aligned} \text{Cost of Mo consumed in a 3 in. x 12 in. substrate for every} \\ 6 \text{ deposition cycles} &= 3 \times 12 \times 0.002 \times (2.54)^3 \times 10 \times 100/1000 \\ &= \$1.18. \end{aligned}$$

Total cost including grinding is thus \$1.68 for six deposition runs or \$0.28/run. At a 14% encapsulated efficiency, a 3" x 12" substrate will produce about 3.5 watts. This results in a Mo substrate cost contribution of about 8¢/watt.

The assumptions made are conservative, and hence the estimated cost is believed to be an upper limit. Although 8¢/watt is higher than desired, the simplicity of the total ribbon process sequence makes this estimated substrate cost contribution compatible with the long range overall cost objectives of the thin film polycrystalline silicon solar cells.

3.0 GAS CHROMATOGRAPHY

During this quarter we have continued the gas chromatographic analysis of the silicon deposition process under conventional CVD and plasma CVD conditions using the chlorosilanes - SiCl_4 , SiHCl_3 and, SiH_2Cl_2 as silicon source gases.

The general description of the gas sampling system was described previously (2). Several modifications in the procedure were made to improve the accuracy of the results. The carrier gas was changed from helium to hydrogen in order to eliminate a negative peak due to hydrogen in the sample. The carrier gas flow was increased to shorten the retention times while still obtaining good separation of the individual components. The temperature program was modified slightly, starting at 35°C column temperature, increasing at 30°C per minute after 1.5 minutes to 80°C , and the run is stopped at 4 minutes. The column cools to 35°C in 3.5 minutes so that a new sample can be taken every 7.5 minutes. With this temperature program and a carrier gas flow rate of 30.0 ml. per min., the retention times are as follows:

HCl	0.92 minutes
SiH_2Cl_2	1.75 minutes
SiHCl_3	2.52 minutes
SiCl_4	3.45 minutes

Nitrogen and argon, when present, have a retention time of 0.72 minutes and are well separated from the HCl peak. Under certain conditions a very small peak is obtained at 1.06 minutes which would seem to be due to SiH_3Cl . This falls on the tail of the HCl peak, but a feature of the Hewlett-Packard 5840 allows this small peak to be removed from the area under the HCl peak so that it does not introduce an error in the amount of HCl reported.

Deposition runs were made, duplicating previous runs, in which the weight of silicon deposited was measured. During the course of a three hour

deposition, twelve GC samples were taken and the efficiency of silicon deposition was calculated from the analysis of product gases. Poor correlation was obtained. The instrument was carefully recalibrated and the linearity of the thermal conductivity detector was tested. A non-linear response was obtained over certain concentration ranges and therefore it was found necessary to plot response vs. concentration over a much broader concentration range than had been done in the original calibration. Some previously taken data were retrievable by taking peak areas and reading concentrations from the calibration curves. Then it was possible to calculate mole % of the reaction products and deposition efficiencies. Currently it is found more convenient to use the peak areas printed out by the chromatograph and the calibration curve to calculate amounts. The chromatograph has a feature which allows the calibration of amount/area to be edited and the chromatograph would then print out the proper amounts and percentages. However this is time consuming and samples cannot be taken while editing is being done. Therefore, to monitor changing conditions by taking samples more frequently, the calculations are done manually.

Verification of the calibration was obtained by depositing silicon from SiCl_4 at 1200°C for 3 hours using plasma at 2.5 KW. The deposition efficiency was 18.0% obtained by weighing the silicon deposited and the SiCl_4 used. The gas chromatograph was used to take a sample every fifteen minutes during the run. The average efficiency calculated from the analyses was 20.2%. This is a satisfactory agreement when it is realized that some particulate silicon is carried out in the exhaust stream rather than depositing on the substrates.

Figures 2 and 3 show typical chromatograms obtained from the analyses of the exhaust gases from SiHCl_3 and H_2 at 1100°C . Figure 2 is without plasma and Figure 3 was obtained using plasma at 2.5 KW power.

FIGURE 2: CHROMATOGRAM OF THE EXHAUST GAS USING SiHCl_3 AS THE SILICON-BEARING GAS WHEN $\text{Cl}/\text{H} = 0.1$, $T = 1100^\circ\text{C}$ AND $R_F = 0$.

FIGURE 3: CHROMATOGRAM OF THE EXHAUST GASES USING SiHCl_3 AS THE SILICON-BEARING GAS WHEN $\text{G}/\text{H} = 0.1$, $T = 1100^\circ\text{C}$ AND $\text{RF} = 2.5 \text{ RW}$.

Table 1 shows the results obtained from SiHCl_3 at 1100°C while varying the Cl/H ratio and similarly Table 2 shows the results using SiCl_4 . Deposition efficiency is higher with plasma than without. The data are plotted in Figures 4 and 5 where it is clear that, at low Cl/H ratios enhancement by the plasma is greatest.

Additional data with varying temperature, gas flow rate, plasma power and Cl/H ratios will be taken using both SiHCl_3 and SiCl_4 to thoroughly characterize the reactions.

Table 3 lists the results obtained with SiH_2Cl_2 at $\text{Cl}/\text{H} = 0.02$ at 1000, 1200, and 1300°K and the deposition efficiency is plotted in Figure 6. Use of the plasma increases the efficiency greatly but it should be pointed out that homogeneous nucleation is a severe problem with SiH_2Cl_2 and the plasma accentuates this problem. Large amounts of small silicon particles are carried out of the reactor in the exhaust gas stream.

TABLE 1

GC ANALYSIS OF EFFLUENT GASES USING SiHCl_3 AS
SILICON SOURCE GAS (TOTAL REACTANT FLOW RATE
= 25 LPM, SUBSTRATE TEMPERATURE = 1100°C).

A. CVD (RF = 0)

	Cl/H				
	0.01	0.05	0.10	0.15	0.2
HCl (%)	86.2	61.1	36.7	22.9	11.5
SiH_2Cl_2 (%)	1.63	1.17	1.48	2.01	1.82
SiHCl_3 (%)	8.94	21.3	32.2	37.4	37.4
SiCl_4 (%)	3.25	16.4	29.6	37.7	49.3
n (%)	68.0	39.5	25.4	20.2	18.2

B. PLASMA DEPOSITION (RF = 2.5 KW)

	Cl/H				
	0.01	0.05	0.10	0.15	0.2
HCl (%)	95.7	67.8	46.7	30.0	19.1
SiH_2Cl_2 (%)	1.08	.56	1.16	1.41	1.00
SiHCl_3 (%)	2.15	17.1	26.0	36.1	31.3
SiCl_4 (%)	1.08	14.6	26.2	32.4	48.6
n (%)	88.1	45.9	31.0	22.4	21.5

TABLE 2

GC ANALYSIS OF EFFLUENT GASES USING SiCl_4
 AS SILICON SOURCE GAS (TOTAL REACTANT FLOW
 RATE = 25 LPM, SUBSTRATE TEMPERATURE = 1100°C).

A. CVD (RF = 0)

	Cl/H				
	0.01	0.05	0.10	0.15	0.20
HCl (%)	83.6	60.2	48.5	42.8	37.4
SiH_2Cl_2 (%)	1.82	.71	1.21	1.15	1.34
SiHCl_3 (%)	7.27	22.6	19.1	20.5	21.6
SiCl_4 (%)	7.27	16.5	31.2	35.6	39.7
n (%)	52.5	18.5	11.6	8.1	5.0

B. PLASMA DEPOSITION (RF = 2.5 KW)

	Cl/H				
	0.01	0.05	0.10	0.15	0.20
HCl (%)	93.6	69.4	50.7	44.1	37.3
SiH_2Cl_2 (%)	.71	1.55	1.24	1.47	1.19
SiHCl_3 (%)	4.96	15.5	19.4	20.3	23.2
SiCl_4 (%)	.71	13.5	28.6	34.1	38.3
n (%)	77.3	29.2	12.7	8.5	4.5

FIGURE 4: DEPOSITION EFFICIENCY AS A FUNCTION OF Cl/H RATIO WITH SiHCl_3 UNDER CVD (RF = 0) AND PLASMA CVD (RF = 2.5 kW) CONDITIONS: $T = 1100^\circ\text{C}$.

FIGURE 5: DEPOSITION EFFICIENCY AS A FUNCTION OF Cl/H RATIO WITH SiCl_4 UNDER CVD (RF = 0) AND PLASMA CVD (RF = 2.5 KW) CONDITIONS. $T = 1100^\circ\text{C}$.

TABLE 3

GC ANALYSIS OF EFFLUENT GASES USING SiH_2Cl_2
 AS SILICON SOURCE GAS (TOTAL REACTANT FLOW²
 RATE = 25 LPM, $\text{Cl}/\text{H} = 0.02$)

A. CVD (RF = 0)

	SUBSTRATE TEMPERATURE ($^{\circ}\text{C}$)		
	730 $^{\circ}\text{C}$	930 $^{\circ}\text{C}$	1030 $^{\circ}\text{C}$
HCl (%)	---	37.75	81.17
SiH_3Cl (%)	.8	---	---
SiH_2Cl_2 (%)	98.4	20.42	2.40
SiHCl_3 (%)	.8	35.98	13.22
SiCl_4 (%)	---	5.84	3.22
η (%)	---	40.7	72.8

B. PLASMA DEPOSITION (RF = 2.0 KW)

	SUBSTRATE TEMPERATURE ($^{\circ}\text{C}$)		
	730 $^{\circ}\text{C}$	930 $^{\circ}\text{C}$	1030 $^{\circ}\text{C}$
HCl (%)	72.45	78.68	93.10
SiH_2Cl_2 (%)	18.35	2.77	.65
SiHCl_3 (%)	8.69	14.50	4.44
SiCl_4 (%)	.52	4.06	1.82
η (%)	59.9	70.4	88.0

FIGURE 6: DEPOSITION EFFICIENCY AS A FUNCTION OF TEMPERATURE USING SiH_2Cl_2 AS THE SILICON-BEARING GAS (TOTAL REACTANT GAS FLOW = 25 LPM, $\text{Cl}/\text{H} = 0.02$).

4.0 MICROCRYSTALLINE SILICON FILM DEPOSITION

Many experimental runs were made using the semicontinuous plasma deposition system. The reliability of operation of this deposition system was found to be drastically affected by mechanical problems and shear separation problems; some of the problems were found to be interrelated. The observable result has been jamming up of the gas curtains by the Mo substrates, and broken silicon films. Various problems that have affected the reliable operation of the system and the solutions to these problems that we are investigating are as follows:

- (a) Occasional detachment of the Mo clips holding the substrate to the carrier belt; this results in pileup of the substrates and thus jamming of the system.
- (b) Breakage of the separated silicon films in the gas curtains at the exhaust side, resulting in their pileup and consequent jamming of the system. The initial silicon film almost always was found to break in the gas curtains because it is very thin. Large gas velocities were found to be necessary in the gas curtains to ensure effective sealing. These high gas velocities at the N_2 and vacuum curtains were found to cause fluttering of separated silicon films, occasionally resulting in their breakage. We are currently examining the possibility of using a combination of gas curtains and lip seals to minimize the gas velocity through the gas curtains.
- (c) Shear separation problems: In general the reliability of shear separation was found to be lower in the continual deposition system compared to the batch deposition systems that we investigated earlier. This is believed to be due to lack of complete effectiveness of the gas curtains at the entrance of the deposition system. If a small amount of oxygen (even at ppm levels) is present in the gas

seals and in the deposition system (see Section 2.1), it impedes MoSi_2 layer growth and which in turn results in adherence of the silicon film to the Mo substrate (2). If shear separation is not complete, it results in bowing of the substrate-silicon composite which causes jamming of the deposition system. We are planning to evaluate the effectiveness of a combination of lip seals and gas curtains at the entrance of the reactor to eliminate this problem.

One of the annoying problems with the initial deposition system was having to terminate the run when the system jammed. This problem has been solved by modifying the end seal at the exhaust of the deposition system. (An engineering drawing of this modified end seal is shown in the Appendix.) With this new end seal, when jamming occurs, the deposition system is switched to a purging mode (shutting off the plasma beam, stopping the H_2 and SiHCl_3 flows and initiating Ar gas flow), gas curtains disassembled, jammed substrates and silicon films removed, gas curtains reassembled, and silicon deposition continued in the usual manner (by turning on H_2 and SiHCl_3 flows and the RF power).

In spite of all the above problems, microcrystalline silicon films were produced in many of the experimental runs. Grain enhancement of these films is discussed in the next section. However no solar cells have been fabricated on these films during this quarter. Most of the deposition experiments were aimed at understanding the continuous system performance by changing conditions, and as a result enough good quality ribbons were not produced for solar cell fabrication and evaluation. During the next quarter we plan to run the semicontinuous deposition system on a more regular basis with the aim of producing good quality ribbons for solar cell fabrication and evaluation.

Based on experience gained with the present semicontinuous deposition system, we completed a conceptual design of a truly continuous microcrystalline

silicon film deposition system. A complete design of this system is expected to be complete by the end of next quarter.

5.0 GRAIN ENHANCEMENT

Grain enhancement is an important aspect of our overall approach for producing efficient thin film silicon solar cells. While RTR grain enhancement process is relatively more advanced than microcrystalline silicon film formation, there are several aspects of the grain enhancement process that require further development to meet the low-cost objectives. One important aspect is improvement in throughput of the process, while maintaining the quality (large grain structure, low defect density, low residual stresses) of the grain enhanced film. The throughput of the process (in $\text{cm}^2/\text{min.}$) can be increased by increasing either the width of the film or the recrystallization velocity (in $\text{cm}/\text{min.}$) or a combination of both. However, ribbon width and recrystallization velocity can not be increased arbitrarily without at the same time affecting the quality of the recrystallized film. Control of thermal ambient during the recrystallization process is crucial to maintain the quality of wider ribbons recrystallized at higher velocities. We have started further work in characterizing the thermal ambient as a function of recrystallization parameters, and in controlling this thermal ambient to improve the throughput of this process (consistent with high quality ribbon).

Microcrystalline silicon films routinely grain enhanced at 2.5 $\text{cm}/\text{min.}$ have been characterized for dislocation density and distribution. Etch pit density after Wright etching (3) has been interpreted as dislocation density. Dislocation density was found to be rather non uniform spatially, varying between 10^5 to $3 \times 10^6/\text{cm}^2$. Figures 7 and 8 are photographs revealing dislocation etch pits on the surface and cross section of a Wright etched sample. In general, dislocation density in twin bundle regions of the ribbon was found to be substantially lower than elsewhere. (See figure 7.) Average dislocation densities in the range of $10^5 - 10^6/\text{cm}^2$ are found to be typical of RTR grain enhanced microcrystalline silicon films, and may be one of the factors limiting

FIGURE 7: PHOTOGRAPHS SHOWING DISLOCATION ETCH PITS ON THE SURFACE OF A GRAIN ENHANCED SILICON FILM.

FIGURE 8: PHOTOGRAPHS SHOWING DISLOCATION ETCH PITS ON A CROSS-SECTIONAL SURFACE OF A GRAIN ENHANCED SILICON FILM.

conversion efficiency to the 11 to 13% range (see next section). Dislocation density is expected to be a function of thermal stresses experienced by the ribbon during recrystallization process. Hence we plan to further examine methods for controlling the level of thermal stresses induced during RTR processing to reduce the dislocation density.

6.0 SOLAR CELL FABRICATION AND EVALUATION

One of the important factors that determines solar cell conversion efficiency is the chemical purity of the silicon film (substrate). The Molybdenum TESS substrate is a possible source for contamination whether the deposition is by the plasma process or by conventional CVD process. Hence CVD silicon films separated from the Mo substrates are routinely used to study temporary substrate parameters and to determine the limits of performance of solar cells produced by our process (using Mo substrates).

During this quarter, solar cells have been fabricated on several CVD silicon films separated from Moly TESS substrates after grain enhancement. These ribbons were nominally 6 to 8 mils thick and low resistivity (0.3 to 0.7 Ω -cm). Single crystal control solar cells were also fabricated on 10 mil thick, 1 Ω -cm Czochralski wafers. The processing sequence employed was as follows:

1. HF dip to remove any surface oxide
2. PH_3 diffusion at 950°C for 18 min.
3. Mesa etch in $\text{CF}_4\text{-O}_2$ plasma
4. 850Å thick Si_3N_4 by LPCVD for AR coating
5. Photoresist pattern for grid contact
6. Metallize - Pd/Ni/Cu sequential plating.

The copper plating has never been used on laser recrystallized thin films before, but seemed to provide no difficulties. Solar cell characterization results are summarized in Table 4. The front contact grid used on these cells has been found to be capable of improvement; hence, it has recently been redesigned. It is estimated that, with the new design, an increase in fill factor and a reduction in shadowing will result in an improvement in efficiency by a factor of 1.05 (for cells showing high J_{SC}).

TABLE 4

SUMMARY OF SOLAR CELL RESULTS OBTAINED UNDER
AM1 ILLUMINATION.

	RIBBON CELLS		SINGLE CRYSTAL CONTROL
	MAXIMUM	AVERAGE	
V_{OC} (volts)	0.608	0.595	0.590
J_{SC} (mA/cm ²)	29.3	26.4	29.8
Fill Factor (%)	78.8	74.2	76.9
η (%)	12.8	11.7	13.5

For comparative purposes and to gain additional information, some of the laser recrystallized silicon films obtained from Mo substrates were sent to Applied Solar Energy Corporation (ASEC, formerly OCLI) for solar cell fabrication and evaluation. ASEC has employed their standard processing sequence that was used for evaluating various silicon sheet materials (e.g. WEB, EFG, HEM, SOC etc.) (4). A summary of the results obtained by ASEC (5) is shown in Table 5. It can be seen that the ASEC results and Motorola results are in good qualitative agreement with each other. It should be noted that both Motorola and ASEC process sequences were not optimized to produce the highest efficiency cells, but were intended for comparison and evaluation purposes. These results indicate that solar cells fabricated on the silicon films obtained from Mo substrates (after laser recrystallization) can approach the performance of cells fabricated on Czochralski wafers. We plan to conduct a similar investigation using plasma deposited microcrystalline silicon films using Mo substrates.

TABLE 5

SUMMARY OF THE SOLAR CELL RESULTS OBTAINED
 BY ASEC ON LASER RECRYSTALLIZED SILICON FILMS
 PRODUCED FROM Mo SUBSTRATES. (RESULTS ARE ON
 2 cm x 2 cm AREA CELLS UNDER AM1 ILLUMINATION.)

	RIBBON CELLS		SINGLE CRYSTAL CONTROL
	MAXIMUM	AVERAGE	
V_{OC} (volts)	0.596	0.585	0.585
J_{SC} (mA/cm ²)	25.9	24.7	28.75
Fill. Factor (%)	77.0	70.1	73.5
η (%)	11.6	10.2	12.4

7.0 PLANS FOR NEXT QUARTER

During the next quarter we plan to:

- . Continue TESS substrate system experiments; particularly development of periodic substrate surfacing procedures for increased substrate recyclability.
- . Continue operation of the semicontinuous plasma deposition system.
- . Complete design of a truly continuous microcrystalline silicon film deposition system.
- . Continue gas chromatographic evaluation of the silicon deposition process.
- . Continue grain enhancement studies aimed at improving the speed of recrystallization.
- . Fabricate and evaluate large area ($>10 \text{ cm}^2$) solar cells.

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3. K. R. Sarma, R. N. Legge, R. W. Gurtler, Polycrystalline Silicon Solar Cells from Recrystallized Plasma Deposited Thin Films, Accepted for publication in J. Electronic Materials.
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APPENDIX
ENGINEERING DRAWINGS

MOTOROLA INC. Semiconductor Group			
TITLE: SEAL RETAINER - BURN-OFF END			
SIZE C	CODE IDENT. NO. 04713	DRAWING NO. 0394-00-01	
SCALE <i>FULL</i>		WEIGHT	SHEET OF