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Web-Dendritic Ribbon Growth

USC Solar Report No. Q-6

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Technical Content Statement

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Abstract

This is a report of the seventh quarter's work on the web-dendritic ribbon growth process at the University of South Carolina (U.S.C.) which covers the 1st quarter's work on the extension to the original program. The goal of the over-all program is to develop a multivariate semi-empirical computer model for use in understanding the web-dendritic process and defining the basic limitations of the process with particular regard to the growth rate and width. The goal of the extension program is to determine the maximum length of pull and width of the ribbon attainable in the U.S.C. facility using a tapered, four-inch diameter susceptor. In addition, through computer modeling, recommended changes in facility design are to be determined which would increase the length of pull and the width of the ribbon.

Man-Hours and Cost Totals

<u>Previous</u>		<u>Current Quarter*</u>		<u>Cumulative</u>	
Man-hours	Cost	Man-hours	Cost	Man-hours	Cost
19,179	\$261,907	1,914	\$38,715	21,093	\$300,622

*Includes estimates for last two (2) weeks of quarter.

Summary of Results

Changes in the facility design are described which have been made to minimize the mechanical vibrations and instabilities thought to be responsible for premature pull out of the web ribbon during growth. Additional design changes are described which were incorporated to improve the stability and reproducible selection of the thermal symmetry present in the furnace during the growth runs. Experiments being initiated to more accurately determine the thermal profile in and about the melt as well as to determine the thermal time constants of the system with respect to changes in the temperature controller set points are mentioned. Problems encountered to date in making the temperature measurements are briefly described. No data from these experiments has been attained as yet.

Thermal profiles resulting from an analysis of the tapered susceptor by computer modeling techniques are included and the suggestion is made that the modeling results indicate that the width of ribbon attainable with a tapered susceptor may be less than that attainable with a straight sided susceptor.

Review by Tasks

1. Web Growth

During this quarter the effort in this area has been in improving the mechanical stability of our growth facility.

a. Mechanical Stability

Considerable difficulty had been experienced in the past with premature pull-out of the ribbon from the melt during growth runs. This was assessed to be due primarily to vibrations and poor mechanical design of the pulling apparatus.

The following changes were made:

1. The mechanical vibrations present on the floor of the laboratory were measured and compared with the vibration spectra on the growth table. Very low level low frequency (≈ 3 hz) was found present throughout the room, i.e., on the floor and growth table. The air-table vibration

isolator on the growth table had little or no effect on this low frequency vibration. The vibration spectra observed on the table did not change during actual pulling of dendritic-web ribbon. These results indicate that the ripples frequently seen on molten silicon surface do not originate from mechanical vibrations introduced during the pulling.

2. A new set of high and low control fingers for adjusting the ribbon position in the crucible were fabricated and installed.
3. Reduced mechanical play in all finger controls on top furnace plate.
4. Designed and fabricated a new pull tape system.
5. The ribbon take-up reel was trimmed up for roundness.
6. Installed a teflon lower tape guide with a concentric level to decrease wander of tape during pulling.
7. A concave groove was machined in the cloth tape guide to keep the tape from wandering from side to side during pulling.
8. A one inch slot was machined in the take up reel so that the head of the screw holding the cloth tape would not protrude above the surface of the reel bed. (A protruding screw head has caused breakage of a ribbon in the past as it was being wound onto the reel.)
9. A support was fabricated and installed to keep the r.f. coil rigid and level.
10. An improved friction brake to keep a uniform tension on the cloth tape storage reel was designed and fabricated.

In addition to the previous, a new base was designed for the pedestal so that the entire pedestal column and susceptor can be re-centered each time a new charge is introduced to the crucible. This insures the placement of the charge in the thermal center of symmetry for each run.

The installation of the new base will essentially complete our efforts to improve the mechanical design of our system except for minor changes that can be anticipated from results of future growth runs.

b. Thermal stability.

The formation of third dendrites during past growth runs, as well as premature pull-out, indicated a lack of thermal stability present in our system.

During this quarter work was initiated to make differential thermocouple measurements of temperatures in and about the melt to ascertain more precisely than previously the temperatures within the furnace and the thermal time constants of the facility with respect to changes in the set-point temperature of the temperature controller. The temperature measuring system is being designed to determine temperature differences of the order of 0.25°C at the melt point of silicon.

Considerable difficulty has been experienced with the measurements due to r.f. pickup noise from the r.f. generator. Enclosing the thermocouples in molybdenum tubing protected by a quartz sheath has shown considerable promise in elimination of this problem and thermocouples of this design are presently being incorporated into the system.

It is anticipated that these static measurements, i.e., in the absence of ribbon pulling, will be completed by mid July.

2. Web Growth Analysis

Thermal modeling of the tapered susceptor design currently being used in the web growth experiments is presently being performed. A two-dimensional heat transfer model has been completed which omits the effects of the radiation ports and the slot in the thermal shield.

Numerical results obtained using the model are shown in Figure 1 which shows the isotherm geometry in the thermal shield, crucible and susceptor. Since most of the r.f. heating occurs in the lips of the susceptor, the temperature is very high in this region and is predicted to reach approximately 1700°F . The bottom of the susceptor is cold due to the high thermal resistance for heat transfer to the bottom. The large temperature gradient in the thin edge of the susceptor is revealed by the close spacing of the isotherms.

The major effects of the taper on the melt temperature distribution is to cause the bottom temperature to have a much lower temperature than the surface

Figure 1. Isotherms in the Thermal Shield, Melt, Crucible, and Susceptor for the Tapered Susceptor Design.

and to increase the radial temperature gradient. Near the center of the melt, it is seen that the temperature is approximately 10°C cooler at the bottom than that at the surface. The temperature gradient is quite small near the surface where crystal growth is occurring.

The temperature at the center of the crucible is approximately 100°C lower than that at the edge which is approximately double that temperature difference predicted for the straight side crucible. This increase in temperature gradient results from the high temperature that occurs in the lip. It is possible that the increase of the radial temperature gradient may have an adverse effect on the maximum web width that is attainable with this susceptor design.

Interpretation of Results and Applications to Program Goals

Insufficient data has been acquired on the extension program to render any interpretation of results at this time. The work involved during this past quarter has been directed towards the development of experiments and programs from which data acquired during the next quarter can be utilized to satisfy the program goals.

Tentative Conclusions and Recommendations

No conclusions can be drawn concerning the extension program at this time and no recommendations as to the program are to be made.

Projection of Activities for Succeeding Three Months

The experiments and the modeling work initiated during this past quarter are to be completed, the data analyzed and the results published in a final report which will complete the web-dendritic program at U.S.C.

PROGRAM PLAN

1. Mechanical Stability
 - Vibration in melt
 - Vibration in pull
 - r.f. coil stability
2. Thermal Stability
 - Static
 - Long term
 - System Time Constants
 - Modifications
 - Dynamic (during growth)
 - Long term
 - System Time Constants
 - Modifications
3. Modeling
 - Inclusion of radiation ports
 - Estimates of Max Width & Stability
 - Recommendations for new model
4. Reports
 - Monthly
 - Quarterly
 - Final

APRIL	MAY	JUNE	JULY	AUG
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▲ Indicates anticipated completion

▲ Indicates completion