353

ERDA/JPL/954350-76/2

FLOATING SUBSTRATE PROCESS

Second Quarterly Progress Report, March 29, 1976—June 20, 1976

M. Garfinkel
R. N. Hall

June 25, 1976

Work Performed Under Contract No. SRD-76-074

General Electric Company
Schenectady, New York

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Solar Energy

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FLOATING SUBSTRATE PROCESS

Large Area Silicon Sheet Task
Low-Cost Silicon Solar Array Project

Second Quarterly Progress Report
Subcontract No. 954350

by

M. Garfinkel, Program Manager
R. N. Hall, Principal Investigator

Period Covered: March 29, 1976 to June 20, 1976

June 25, 1976

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This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS7-100 for the U. S. Energy Research and Development Administration, Division of Solar Energy.

The JPL Low-Cost Silicon Solar Array Project is funded by ERDA and forms part of the ERDA Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays.

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ABSTRACT

A Horizontal Boat Furnace has been built and operated which permits the surface scum to be blown out of the crystal nucleation zone. Supercooling results obtained in this apparatus are similar to those obtained earlier, and appear to be limited by nucleation at the melt-crucible surface. An electromagnetic pump has been successfully incorporated into this apparatus. First examples of seeded surface growth have been observed using web-dendrite material as the nucleating seed.

Further examination of the spontaneously nucleated surface platelet growth shows them to be approximately 30 microns thick with long axis along a $\langle 112 \rangle$ direction. The platelet faces are not oriented in any particular crystallographic direction. Closely spaced $\langle 111 \rangle$ crystal plates grow down into the melt from the underside of the surface platelet.

A new principle has been suggested, based upon the possibility that the concentration of silicon in the surface layer of the Sn-Si alloy melt is higher than in the bulk. This principle may be used to provide an effective driving force for promoting silicon surface growth.

An experimental configuration has been developed permitting accurate measurements of the uptake of silicon from silane. Single pass efficiencies greater than 30 percent, corresponding to the deposition of solid silicon at 1.8 microns/min, have been measured. It has been determined that silicon is incorporated into liquid tin at the same rate as it is deposited upon silicon substrates. The rate of incorporation is independent of the degree of melt saturation.

Tin melts have been driven into saturation by means of silicon input from silane and dichlorosilane. Silicon melt concentrations achieved by gas stream input have been limited to the saturation value because of crystal growth nucleated by silicon deposited upon the tray walls.

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TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
1	INTRODUCTION.	1
2	TECHNICAL DISCUSSION	2
	Furnace Construction	2
	Horizontal Boat Furnace	2
	Seeded Growth Apparatus.	2
	Crystal Growth	3
	KB-15 Platelet Growth	3
	Growth From Web Dendrite Seeds	4
	Growth Enhancement by Fluid Flow	6
	Crystal Growth in the Horizontal Boat Furnace.	6
	Silicon Deposition.	7
	Boron Nitride Trays	7
	Gas to Solid Conversion Efficiency	8
	Melt Saturation	8
	Use of Dichlorosilane	9
	Problems	13
3	TENTATIVE CONCLUSIONS AND RECOMMENDATIONS.	14
4	PROJECTED ACTIVITIES	15
5	NEW TECHNOLOGY	16
	Appendix I--UPDATED PROGRAM PLAN	17
	Appendix II--MAN HOURS AND COSTS.	19

LIST OF ILLUSTRATIONS

<u>Figure</u>		
1	Side View of Seeded Growth Apparatus	3
2	Section of Surface Crystal Grown During KB-15 Showing Parallel Platelet Growth Which Extended Down Into the Melt	4
3	Seeded Growth Formed Around the Edges of a Web Dendrite During Experiment HB-6.	5

LIST OF ILLUSTRATIONS (Cont'd)

<u>Figure</u>		<u>Page</u>
4	Oriented Platelet Growth at One End of the Section of Web Dendrite Which was Used as a Seed	5
5	Temperature Variation of the Deposition Rate of Silicon From Dichlorosilane.	10
6	View of the Quartz Tray After H-51.	10
7	Schematic View of the Meniscus at the Tray Wall for the Wetted and Unwetted State.	11

Section 1

INTRODUCTION

This research program began January 6, 1976. Its objective is to demonstrate the feasibility of the floating substrate sheet growth process for the growth of silicon sheet. This process is an approach to the formation of single-crystal silicon by direct epitaxial conversion from a gaseous silane. Incoming feedstock gas impinges upon a silicon substrate which is floating upon a thin pool of liquid tin. Single-crystal silicon grows to the desired thickness by means of vapor phase epitaxy. Nucleation of fresh substrate silicon takes place by rapid growth from the edge of the growing sheet into a region at the surface of the liquid tin which is supersaturated in the silicon. The process lends itself to continuous operation with the growing sheet being continuously withdrawn from the growth zone.

Since the epitaxial growth of silicon is well known and presents no problems, the current effort will focus upon the nucleation and rapid growth of substrate silicon from supercooled melts. We will perform studies of (1) supercooling; (2) crystal growth from a supercooled Sn-Si alloy; (3) silicon uptake into tin from silanes; and (4) surface growth. The goals of this contract are the growth via this process of single-crystal silicon having 0.5 cm² area and the determination of the velocity of propagation of single-crystal silicon along a hot tin surface which has been supersaturated with silicon.

During the first quarter, laboratory apparatus was designed, built, and used to study the supercooling of Sn-Si melts and the uptake of silicon from silane. Values of supercooling of Sn-Si melts as high as 78°C at 1100°C and 39°C at 1200°C were observed. These results were limited by nucleation caused by foreign material floating on the surface of the melt. Spontaneously nucleated planar platelet growth was observed at the Sn-Si supercooled surface having growth rates of approximately 0.5 cm/min.

Homogeneous nucleation of silane decomposition was studied at 1015°C and 1135°C. The flow rates of HCl required to suppress gas phase decomposition were determined for silane flow rates up to 4.5×10^{-3} mole/min. Initial silicon uptake experiments showed that at least 20 percent of the incoming silicon contained in a flowing silane gas stream can be incorporated into liquid tin at 1040°C.

In the second quarter, the studies of supercooling and of the interaction of silane with tin melts were continued and extended.

Section 2

TECHNICAL DISCUSSION

FURNACE CONSTRUCTION

HORIZONTAL BOAT FURNACE

The measurements of supercooling which were made in the Vertical Furnace appeared to be limited by heterogeneous nucleation induced by foreign material floating on the surface of the melt. This debris could be blown radially outward by the axial cooling jet, but not far enough to eliminate its ability to initiate crystal growth. In an attempt to circumvent this problem, we assembled a horizontal growth apparatus consisting of an elongated quartz or boron nitride boat heated by a graphite susceptor, as described in Monthly Report No. 5. In operation, an axial flow of N_2/H_2 gas is used to sweep any surface film to one end of the boat which is maintained at a higher temperature than the rest of the melt. In this way nucleation at the surface could be eliminated, and we expected to be able to obtain better information on supercooling, since it would then be limited either by homogeneous nucleation or by contact with the crucible.

This apparatus has been further modified by the addition of electrodes which can be used to generate electromagnetic pumping of the Sn-Si alloy and produce forced circulation of the liquid metal. Holes were drilled through the boat and susceptor so that a pair of 1.5-mm-diameter tungsten wires, 8 mm apart, could be passed through the melt from one side to the other. A permanent magnet is used to provide a transverse field of 750 Oe. With this arrangement, vigorous flow of liquid can be observed when a few amperes are passed between the two tungsten wires.

SEEDED GROWTH APPARATUS

A new furnace has been designed and is now being constructed. It will be used to conduct experiments on crystal growth using seed crystals which are floated on the surface of the Sn-Si melt. Its design features include provision for electromagnetic pumping of the liquid metal and thermal gradients which are expected to inhibit crystal growth upon the crucible walls.

The design of this furnace is indicated in Figure 1. The melt A is contained in a tray B made of boron nitride. It is heated by a graphite susceptor C which is designed so that the left end of the tray, as well as its side edges and bottom, will be held at a higher temperature than the end where seeded growth is to take place. This temperature distribution is aided by graphite side rails which form a part of the susceptor and overhang the edges of the tray to help maintain a high temperature along the edges. The growth region

Figure 1. Side View of Seeded Growth Apparatus (see text for labels on apparatus A through F).

is cooled by radiation and by a gas jet which can be directed upon the melt surface near the end of the seed crystal. The seed D is introduced through an opening in the right end of the furnace, and floats on the surface of the melt. Forced circulation in the melt can be produced by passing a current between a tungsten wire E and an electrode F which is positioned at the right end of the tray. This electrode, which will be made of graphite or tungsten, is intended to be wetted by the alloy so that a thin layer of liquid will be drawn into the thin space between D and F. This layer is made thin so that excess Si in the alloy will be able to diffuse to the overlying seed rather than forming a deposit on the electrode.

CRYSTAL GROWTH

KB-15 PLATELET GROWTH

Further observations have been made on the crystal shown in Figure 6 of the First Quarterly Progress Report. This crystal was grown in the Vertical Furnace and formed on the surface of the melt during run KB-15. It has been broken open so that the parallel platelet growth described on page 2 of Monthly Report No. 4 could be observed more clearly. A photograph of this section is shown in Figure 2. The thickness of the surface crystal is approximately 30μ , while the parallel platelets run about 3μ to 9μ in thickness and are spaced approximately 20μ to 40μ apart.

Figure 2. Section of Surface Crystal Grown During KB-15 Showing Parallel Platelet Growth Which Extended Down Into the Melt.

This crystal is of interest because it appeared to grow rather rapidly over the surface of the melt and because it has a thickness which is appropriate for solar cell fabrication. It is not clear whether the parallel platelet growth took place as the surface crystal was growing or whether it took place later as the charge was being cooled.

GROWTH FROM WEB DENDRITE SEEDS

On page 2 of Monthly Report No. 4 we described the results of preliminary attempts to initiate surface growth using web dendrite seed crystals which were floated on the surface of a Sn-Si melt. These experiments were unsuccessful, but we have since obtained results in which seeded growth was clearly evident.

HB-6 was carried out in the Horizontal Boat Furnace described above, using electromagnetic stirring. The charge consisted of 80 grams of Sn in which 0.74 gram of Si had previously been dissolved. A 9 cm section of web dendrite was placed on the charge, which was then heated while maintaining a pumping current of 4 amp until most of the dendrite dissolved. The temperature was then gradually reduced, and oriented crystals could be seen to be growing outward from the edges of the web.

Figures 3 and 4 show the appearance of the web crystal after removal of the Sn phase by solution in mercury. Many flat crystals can be seen growing out from the edges of the web, all having the same orientation with their flat faces parallel to the plane of the web. It appears evident from this experiment that twinned dendrite crystals can be used to initiate flat platelet growth from Sn-Si alloys with much the same effectiveness as in growth from Si melts.

Figure 3. Seeded Growth Formed Around the Edges of a Web Dendrite During Experiment HB-6. The horizontal band at the top is one of the dendrite "rails." The white area below it is the web. Irregular holes have been dissolved in the web by tin and have been partly filled by seeded platelets as the system cooled down. The arrow points to a large platelet.

Figure 4. Oriented Platelet Growth at One End of the Section of Web Dendrite Which was Used as a Seed

GROWTH ENHANCEMENT BY FLUID FLOW

During a recent visit as a consultant to our Laboratory, Professor J. W. Mitchell suggested a new principle which might provide an effective driving force for promoting crystal growth along the surface of the melt. He pointed out that the composition of the surface layer of the Sn-Si alloy can be expected to differ from that of the bulk liquid by an amount which depends upon the enthalpy of solution. The liquidus curve of the Sn-Si system indicates that the enthalpy of solution of Si in Sn is negative, which implies that the Si atoms are "repelled" by the liquid. In such a case, the surface layer of the alloy should contain a somewhat greater concentration of Si than the bulk of the liquid. Setting up a circulatory flow pattern in the liquid which sweeps the surface layer toward the growing edge of a surface crystal would result in an accumulation of Si atoms there, resulting in an increased supersaturation at precisely the location where it would be most effective in accelerating the growth of this edge. The electromagnetic pumping electrodes were added to the Horizontal Boat Furnace in order to test the effectiveness of this idea.

CRYSTAL GROWTH IN THE HORIZONTAL BOAT FURNACE

Preliminary experiments HB-1 through -3 were carried out in the Horizontal Boat Furnace, but the temperature variation along the length of the boat was rather large and no quantitative results on supercooling were obtained. Provision for electromagnetic pumping was then made and the pitch of the r-f heating coil was changed to flatten the temperature profile. This configuration was used for HB-4 through -7.

A weight ratio of 0.009 Si/Sn was used in HB-4. Pyrometer measurements (corrected for emissivity) indicated a solution temperature of 1100°C. Crystals did not form until the temperature was decreased to 1031°C. The supercooling observed in this experiment, 69°, is not significantly different from the results previously reported using the Vertical Furnace. The same charge was remelted as HB-5 for a demonstration experiment and did not yield any further scientific results. HB-6 produced seeded growth on a web dendrite as described above. HB-7 used a new charge with a higher solution temperature. The results of this experiment are still being evaluated.

We have not yet noticed any effect of electromagnetic pumping upon crystals growing at the melt surface, except perhaps in the case of HB-6. This experiment did yield seeded growth whereas none had been observed in similar unstirred experiments. A larger negative enthalpy of solution would help to make this effect observable. An attractive way to demonstrate this phenomenon would be to use Pb-Sn alloy as the solvent instead of pure Sn. Si is quite insoluble in Pb to the extent that they form two immiscible liquid phases. Alternatively, one could use a solvent in which Si has a strong positive enthalpy of solution and reverse the direction of flow of the liquid. In view of the importance that this effect could have for the Floating Substrate

process, it seems appropriate to take some pains to try to demonstrate its existence.

SILICON DEPOSITION

Experiments involving the interaction of silanes with tin were extended through run H59. Work not described in earlier reports includes the use of BN trays, additional silane to silicon uptake efficiency measurements, and preliminary experiments with dichlorosilane as the silicon-bearing gas species. Table I summarizes these efforts.

TABLE I

(L or S After Run # Designates Large or Small Reactor)

<u>RUN #</u>	<u>T</u> (°C)	<u>H₂</u> <u>Liter</u> <u>min</u>	<u>SiH₄</u> <u>cc/min</u>	<u>t</u> (min)	<u>δw</u> <u>gm.</u>	<u>F</u>	<u>COMMENTS</u>
H46 L	1005	4	27.3	26	.140	.157	B.N. Crucible
H47 L	1020	4	27.3	137	-	-	Tin Splashed
H48 L	1000	4	23.6	31	.154	.160	B.N. Crucible
H48'L	995	4	23.6	102	.360	.123	Continuation of H48
H49 L	1060	4	62.5*	22	.0786	.072	Dichlorosilane-Si Sub.
H50 L	960	4	62.5*	20	.0171	.016	Dichlorosilane-Si Sub.
H51 L	1190	4	62.5*	20	.146	.145	Dichlorosilane-Si Sub.
H52 L	1100	4	62.5*	21	.1065	.105	Dichlorosilane-Si Sub.
H53 L	1000	4	62.5*	20	.036	.035	Dichlorosilane-Si Sub.
H54 L	1050	4	62.5*	24	.136	>.072	Dichlorosilane-Tin
H55 S	1050	4	27.3	34.5	.268	.369	Silicon Substrates in Tray
H56 S	1050	2	20	20	.180	.359	B.N. Crucible
H57 S	1040	2	20	15	.128	.341	Continuation of H56
H58 S	1050	2	20	15	.128	.341	Continuation of H57
H59 S	1050	2	20	15	.129	.340	Continuation of H58

*These are flow rates of SiH₂Cl₂.

BORON NITRIDE TRAYS

Run H46 was our initial effort at using boron nitride (BN) as the tray material in a silicon uptake experiment. The tray was machined from Union

Carbide HBR grade material. It was soaked in methanol and prefired to 1300°C prior to use in an attempt to eliminate the 4 percent oxide used as a binder. This treatment was insufficient. Examination of the tray after the run revealed small globules of a vitreous material adhering to the entire tray surface including the part covered by the tin charge. Presumably the oxide is present as CaB_4O_7 whose melting point of 986°C is below the run temperature of 1005°C. Subsequent HBR BN trays, used in runs H48 and H56 through H59, were fired in vacuum at 1680°C for 4 hours to remove the tetraborate.

These trays did not break upon cooling, thus allowing a sequence of experiments to be performed upon a single charge of tin. They also seemed to inhibit somewhat the mass motion associated with the hydrodynamic instability. They were not, however, as clean as the quartz trays. More scum was observed when they were used, especially in the case of H46.

GAS TO SOLID CONVERSION EFFICIENCY

Examination of the results given in Table I for the uptake of silicon from silane and of data reported previously reveals a consistent picture. The measured efficiencies fall into two groups: one associated with the small, 2.5 cm by 5.7 cm reactor, and the other obtained from the large reactor. Approximately 30 percent to 35 percent of the silicon in a silane stream passing over hot tin is taken into solution in the small reactor, whereas 15 percent is taken up in the large one. This difference is no doubt connected with the different geometry, especially the longer average gas diffusion distance in the bigger reactor.

Runs H56 through H59 are a sequence of silicon uptake experiments performed with a single tin charge. The melt started with no silicon content at the beginning of H56 and ended with 0.564 gram of silicon corresponding to 70 percent of saturation at the conclusion of H59. There was no significant change in uptake efficiency through this sequence. This, coupled with the 31 percent reported last month for H43 which had the same geometry and which started at 88 percent of saturation, confirms our earlier tentative conclusion that the efficiency of silicon uptake is independent of degree of saturation.

Run H55 had silicon wafers as substrates and had exactly the same gas flow geometry as the sequence H56 through H59. The wafers were placed in the bottom of the tray, covering 61 percent of its area. The silicon deposition efficiency for this run, normalized for area, was 37 percent. We conclude that the deposition rate of silicon from SiH_4 is independent of whether the substrate is solid silicon or liquid tin.

MELT SATURATION

Several experiments were designed with the objective of bringing the Sn-Si alloy melt to saturation and beyond. Runs H43 and H44, for example,

were begun with enough solid silicon added to the tray so that silane flows below the threshold of homogeneous gas phase nucleation could drive them to saturation in a short time. These experiments began at 88 percent of saturation. Runs H47 and H48 were simply run long enough for the melts to be saturated directly from the gas stream.

In none of these cases were we able to supersaturate the melt. Below saturation, the tray walls were kept clean by the mass motion and silicon dissolution associated with the hydrodynamic instability. The meniscus remained concave down under these circumstances. As the melt approached saturation, however, it was observed to attach itself to the tray wall along those regions where the "scum" happened to be. The meniscus in these regions was now turned up. With additional silicon input from the silane gas stream, crystals were observed growing in towards the melt from the tray wall. These crystals were nucleated by the solid silicon deposits on the tray wall which could no longer be dissolved by the melt because it was saturated. Silicon deposition on the tray walls thus prevented us from driving the Sn-Si melts beyond saturation.

USE OF DICHLOROSILANE

The deposition of silicon upon the inner tray walls by silane has been the source of two serious problems: the hydrodynamic instability, and the initiation of undesirable crystal growth from the walls as the melt is brought to saturation by the gas stream. We conducted a series of experiments to determine whether the use of dichlorosilane would produce less silicon deposition on the walls.

Deposition upon silicon wafers was studied in runs H49 through H53. The flat susceptor was used to minimize direct heating of the tray walls.

The wafers were placed on the bottom of a standard quartz tray to reproduce as nearly as possible the geometry with tin as the substrate. The work coil was adjusted so that the temperature of the tray bottom was uniform to better than 2°C . Deposition rates were determined by measuring the weight gain of the wafers for given deposition time. Hydrogen was the major constituent of the gas stream at 4 l/min and the dichlorosilane was kept at 62.5 cc/min.

The results obtained are shown in Figure 5. The data have all been normalized to the tray area of 20.5 cm^2 . There is a marked variation with temperature. The rate increases with T up to the value 12 mg/min at 1200°C --corresponding to 15 percent conversion efficiency.

The tray sidewalls were not heavily coated. Only the bottom 3 mm or so accumulated any silicon--the top 2/3 remaining clean because of the rapid falloff of deposition on the relatively cool walls. This is shown in Figure 6.

Figure 5. Temperature Variation of the Deposition Rate of Silicon From Dichlorosilane. Deposits were made upon silicon wafers 13 cm^2 in area

Figure 6. View of the Quartz Tray After H-51. The area covered by the silicon substrates and the silicon deposits partly up the walls are clearly visible

In run H54, dichlorosilane was used as the silicon source and tin was the substrate. The flat susceptor was used and the walls of the quartz tray were kept cool with quartz paper reflective insulation. The operating temperature of 1050°C was chosen so that the tray walls, expected to be 100° to 200°C cooler than the melt, would not collect much silicon. Gas flows were the same as in the test runs using silicon wafers, 4ℓ/min of H₂ and 62.5 cc/min of SiH₂Cl₂.

There was very little mass motion during this run, indicating that we had achieved a substantial reduction in the wall deposition rate. Nevertheless, after 15 minutes of dichlorosilane input the melt, which hitherto had not wetted the quartz, was seen to adhere to the front wall of the tray. Subsequent examination showed that the tin-silicon alloy had wetted the front third of the tray and that silicon had been deposited in a band approximately 1 mm high along the entire length of the wetted region. This may be understood with the aid of Figure 7.

Figure 7. Schematic View of the Meniscus at the Tray Wall for the Wetted and Unwetted State

In the initial, unwetted, state the upper section of the tray wall (above the horizontal plane of the melt) picks up silicon deposits quite slowly in spite of the fact that it has unrestricted access to the dichlorosilane gas stream. The reasons for this are the low temperature of this upper section resulting from the low thermal conductivity of quartz, and the rapid decrease in the deposition of silicon from dichlorosilane as the temperature falls below

1000°C. Silicon deposition upon the hot lower section of the tray is similarly light as a result of the limited solid angle that it subtends with the gas stream. With the melt well below saturation, this relatively light silicon deposition is quickly absorbed by the liquid. The walls remain clean, they are not wetted, the upper section remains relatively cool, and the low deposition rate is maintained. As saturation of the melt is approached, dissolution of the wall deposits proceeds more slowly. At the point when the deposition rate exceeds the dissolution rate, the melt begins to wet the tray wall. The meniscus flips up and the wetted portion of the tray wall immediately adjacent the tin-quartz interface now has unrestricted access to the dichlorosilane. The deposition rate increases substantially in a narrow band along this interface because the tray wall in this band is heated by direct conduction from the alloy melt. A thick silicon deposit is thus formed in a narrow band immediately above the edge of the wetted region.

Silicon crystals were observed to be growing out from the wall in the region where the melt was attached after a time that, on the basis of the silicon wafer data of Figure 5, should have been insufficient to saturate the melt. Subsequent weighing of the sample verified this, yielding a weight gain of 0.136 gram compared with the value of 0.127 gram predicted by the data of Figure 5. Solid silicon weighing 0.466 gram had been added to the tin charge at the outset of H54 making a total of 0.602 gram of silicon in the melt--only 73 percent of the amount required for saturation at the operating temperature of 1050°C.

There are several possible explanations for this apparently premature onset of saturation. There was some tin loss from the bath since a white solid, presumably SnCl_2 , was observed to deposit downstream of the tray upon the cool reactor walls. The measured weight gain is thus the net difference between the silicon gain and the tin loss, so the actual silicon uptake may have been considerably larger. The weight of silicon from dichlorosilane required to saturate the melt is 0.363 gram, nearly three times the observed 0.136 gram. Since the measured value is quite close to the number expected from the deposition data upon silicon, this explanation is unlikely. While there was some tin loss it probably was not large. Additional work will be required to determine the rate of tin loss to the dichlorosilane.

Another possible explanation is nonuniform, heavier deposition of silicon toward the front of the tray. This is unlikely since it was not seen in the experiments done with silicon wafers.

The most probable explanation is that the silicon crystals grew because the melt temperature along the wetted interface at the tray wall is lower than that of the main body of liquid. This region, therefore, becomes saturated well before the rest of the tin. The meniscus along the wetted periphery had climbed approximately 2 mm higher than the main melt surface, making it quite reasonable that the temperature at the melt-wall interface was at the 1005°C required for local saturation.

PROBLEMS

To achieve continuous sheet growth by the Floating Substrate Process, it will be necessary to design the system so that silicon is not deposited from the Sn-Si alloy upon the walls of the tray. In some of the supercooling experiments, we have observed that the first crystals to appear are often attached to the crucible walls, indicating that nucleation had taken place at that interface. Since it will be desirable to achieve as much supersaturation as possible without this happening, it appears desirable to conduct some experiments to measure supersaturation in the presence of several different supporting materials such as quartz, boron nitride, sapphire, and tungsten.

The deposition of silicon upon the tray walls of our current simple experimental apparatus has been a continuing problem. While the use of dichlorosilane has reduced this deposition substantially, we are still unable to achieve melt supersaturation by means of silicon input from the gas stream. A gas curtain configuration will be required to solve this problem.

Section 3

TENTATIVE CONCLUSIONS AND RECOMMENDATIONS

We have established that silicon can be incorporated into tin with single-pass efficiency greater than 30 percent and that this rate is independent of the degree of melt saturation. Measured incorporation rates have been $0.42 \text{ mg/cm}^2\text{-min}$ corresponding to deposition of solid silicon at 1.8 microns/min . It has been possible to drive tin melts to saturation directly from the vapor. We have been unsuccessful in achieving supersaturation from silane because of the deposition of silicon upon the tray walls which cannot be suppressed without the use of gas curtains. In the interest of a timely demonstration of process feasibility, we recommend that the study of HCl etching of crystalline nuclei in the melt be deferred.

In examining the crystals that were grown from solution during the supercooling experiments, we have noted that alloys containing higher concentrations of Si (3.5 wt percent) yield much larger crystals which are often in the form of interlocking coplanar platelets, whereas those containing less silicon (1.5 wt percent) produce much smaller hopped triangles and needles. This indicates that sheet growth will be favored by growth at higher temperatures where at saturation the tin contains a higher concentration of silicon.

In view of the possibility that silicon enrichment in the surface layer of the Sn-Si alloy can be used to accelerate the growth at the edge of the seed crystal through a circulatory flow in the alloy, we plan to look carefully for this phenomenon during future experiments. We also propose to try other alloy systems such as Sn-Pb-Si and Au-Si in the hope of observing this effect.

It is further recommended that measurements be made of supercooling in contact with various materials which could be used for tray construction, to determine those least likely to induce nucleation of crystal growth on the walls of the tray.

Section 4

PROJECTED ACTIVITIES

The major focus of our efforts for the next period will be upon surface growth.

We plan to continue our experiments using the Horizontal Boat Furnace to observe the effects of forced circulation upon crystal growth, using seeds floated on the surface of the melt.

We also plan to measure nucleation on potential tray construction materials, using small droplets of Sn-Si alloy.

The Seeded Growth Apparatus will be completed shortly, and we plan to place it in operation so as to conduct crystal growth experiments under conditions which more closely simulate those anticipated for the final sheet growth furnace.

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Appendix I

UPDATED PROGRAM PLAN

PROGRAM PLAN FLOATING SUBSTRATE PROCESS.

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Appendix II

MAN HOURS AND COSTS

Previous man hours were 532 hours of scientist/engineer effort and 576 hours of technical specialist and shop time. Total charges for the first quarter, not including fee, were \$48,744. Second quarter charges to June 20, 1976 are 554 hours of scientist/engineer time and 656 hours of technical specialist and shop time. Charges for this quarter, not including fee, are \$55,811. Cumulative totals for the first two quarters are 2,318 man hours and \$104,555 dollar costs, not including fee.

Planned/Incurred Costs
Direct Labor Hours
Contract 954350
Begun January 6, 1976

Floating Substrate Process