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ION-PLATING OF SOLAR CELL ARRAYS ENCAPSULATION TASK—LSA
PROJECT 32

Second Quarterly Progress Report for the Period April—June 1980

By
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Illinois Tool Works, Incorporated
Elgin, Illinois

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Second Quarterly Progress Report
April 1980 to June 1980

on
Ion-Plating of Solar Cell Arrays
Encapsulation Task - LSA Project 32

Illinois Tool Works, Inc.
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1427 Holmes Road
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Contract Number 955506

"The JPL Low-Cost Silicon Solar Array Project is sponsored by the U.S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work is performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DOE."

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February 1981

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I. Summary

In the second quarter of this contract (April to June 1980), functional solar cells were produced having ion-plated metallizations on both front and back surfaces. These cells consisted of 3.25" diameter n on p type silicon wafers with silver front and back contacts. The performance of these cells, although encouraging, was less than that of cells currently available on the photovoltaic market. Attempts were also made to produce a cell having nonnoble (inexpensive) metallizations, utilizing aluminum, copper and 302 stainless steel. These attempts proved less successful than those utilizing silver.

II. Introduction

The ITW contract was initiated in December, 1979 to investigate, develop and demonstrate the capability to produce operational solar cells having metallizations and anti-reflective (AR) coatings deposited by gasless ion-plating, which will separately and/or in combination with a low-cost encapsulation system, meet the LSA project life, cost and performance goals. Under this contract, ITW will also investigate the ability to deposit by gasless ion-plating AR and anti-soiling coatings on glass; said coatings to be permanent and possess 20 year durability.

Ion-plating is a vacuum metallizing process where the depositant is evaporated from a source (tungsten filament, electron beam gun, etc.) into a high frequency electric field where the material is ionized and then accelerated by a DC field toward the substrate. This process combines the high deposition rates associated with physical vapor deposition and improved adhesion without entrapment of Ar gas (as in sputtering).

III. Technical Status

A. Functional Solar Cells

Work on developing functional solar cells having ion-plated metallizations has been conducted using silver as the metallization material. It is realized that solar cells having silver metallizations will most likely fail to meet the cost goals of the LSA project. However, silver was used in this study to avoid the problems associated with nonnoble metallizations (such as impurity migrations and lower conductivities) which could obscure the feasibility of the ion-plating process. The cells produced for this part of the contract consisted of n on p type 3.25" diameter wafers supplied by Spectrolab, Inc., metallized with silver to a thickness of 18,000 Å. Delineation of the front electrode pattern and back contact was accomplished with physical masks. The mask for the front electrode was made by electrical discharge machining a "christmas tree" pattern into steel shim stock (see Figure 1). The center electrode in the pattern is .138" wide at its base and tapered in three steps to .039". The side branches extending out from the center electrode are .020" wide and are spaced .125" apart. The mask for the back contact was made by cutting a 3.0" diameter hole in a piece of shim stock .010" thick, as was the case for the front electrode mask. The appropriate mask was then laid on the wafer, held in place with spring clips, and the silver deposited through the mask onto the wafer. The wafers were heated to 400°C (in vacuum) before metallizing the back contact, whereas the wafer was not heated prior to deposition of the front electrode. This preheating was necessary to produce an ohmic contact to the back surface (p-type silicon) of the wafer (as described in the previous quarterly report). Light I-V (current-voltage) curves for two of these cells, as tested by Spectrolab for ITW, are shown in Figures 2 and 3.

B. Inexpensive Metallizations

Attempts were also made during this period to metallize wafers with the nonnoble materials; aluminum, copper and 302 stainless steel. Aluminum and copper were used in this investigation because their lower costs and relatively high conductivities make them attractive as candidates for replacing silver on solar cells. The 302 stainless steel is being investigated for its potential to improve the corrosion resistance of nonnoble metallizations. These cells were produced with the same masking and preheating techniques as described for the silver plated cells. The light I-V curves are presented in Figure 4. The shape of these curves (nearly linear) indicates that even with the preheating technique, good ohmic contacts were not formed between the metallizations and the wafer.

III. Technical Status

C. Anti-Reflective Coatings

As reported in the previous quarterly report, AR coatings consisting of MgF_2 , TiO_2 , Ta_2O_5 , Al_2O_3 and indium-tin oxide (ITO) have been deposited on glass and submitted to JPL for evaluation. Of these only MgF_2 has demonstrated desirable characteristics. Further development of AR coatings has been de-emphasized in favor of concentrating future investigations on improving the performance of cells metallized by ion-plating.

IV. Conclusions and Future Activities

The results from the silver metallized cells (Figures 2 and 3) were encouraging and demonstrated the feasibility of ion-plating. The preheating employed to induce the formation of an ohmic contact between the silver and the back surface of the active wafer is, however, undesirable in terms of added cost to the process and the possibility of enhanced impurity migration at the elevated temperature (400°C). It was also found that when nonnoble metals were used, the preheating technique did not result in a good ohmic contact from being formed. The main thrust of future investigations will be to develop metallization systems which will produce ohmic contacts when ion-plated onto silicon, without preheating. The proposed method for doing this is to obtain nondiffused silicon wafers and metallize both surfaces with the same material. These wafers can then be used to quantitatively measure the contact resistance of the silicon-metal interface, allowing determination of those systems which work best (lowest contact resistance). Industrial consultants have suggested a contact resistance of $160 \text{ m} \cdot \text{cm}^2$ as the target number for a good ohmic contact. The metals to be used in this study will be nickel, titanium, aluminum, and copper, and they will be investigated as to their ability to produce ohmic contacts on both n and p type silicon.

V. Milestone Chart Discussion

In discussions with the JPL technical monitor for this contract, two modifications were made in the Milestone Chart for Phase I. The delivery of functional cells to JPL has been moved from May 1980 to December 1980, at which time Phase I of this contract is scheduled to end. Secondly, work on anti-reflective coatings has been temporarily put on hold while JPL evaluates the samples submitted to them in April. This will also allow future efforts to be concentrated on developing nonnoble metallization systems.

Figure 1 -- Front Electrode Mask Pattern

Front electrode pattern designed for 2.12" diameter wafers. This pattern was cut into 3.00" squares of .008" thick steel shim which were then used as contact "shadow" masks. Entire pattern just fits inside a 1.900" circle (all dimensions given in inches).

Figure 2 -- Light I-V Curve for ITW Cell #101-2

Light I-V curve (AM1) for cell #101-2
Illuminated area = 19.63 cm²
I_{sc} = .395A   V_{oc} = .570V
I_{mp} = .328A   V_{mp} = .460V
P_{max} = .151 watts   FF = 67%   n = 7.69%

Figure 3 -- Light I-V Curve for ITW Cell #101-3

Light I-V curve (AM1) for cell #101-3

Illuminated area = 17 cm²

$I_{sc} = .303A$ $V_{oc} = .493V$

$I_{mp} = .258A$ $V_{mp} = .400V$

$P_{max} = .103$ watts $FF = 68\%$ $n = 6.1\%$

Figure 4 -- Light I-V Curves for ITW Cell Nos. 25-1, 25-2, 25-3

Each curve is labeled with the material used for both the front and back contact of that cell. Illuminated area in each case = 22.8 cm^2 .

Milestone Chart for Phase I