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

First Quarterly Progress Report, December 1979—March 1980

By
William R. Conley

MASTER

June 1980

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Illinois Tool Works, Inc.
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Solar Energy

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First Quarterly Progress Report
December 1979 to March 1980
on
Ion-Plating of Solar Cell Arrays
Encapsulation Task - LSA Project 32

Illinois Tool Works, Inc.
Venture Group
1427 Holmes Road
Elgin, Illinois 60120

Contract Number 955506

Prepared by

William R. Conley
Principle Investigator
June 1980

Approved by

Jack C. Volkers
Project Manager

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1.0 Introduction

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). The ITW contract was initiated in December 1979 to investigate, develop and demonstrate the capability to produce operational solar cells having metallizations and 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.

2.0 Technical Status

2.1 Possible Inherent Problems

In December 1979 a list of possible inherent problems was compiled with regards to applying the ion-plating process to the metallization of solar cells, along with a series of proposed tests to determine their relative magnitude and possible solutions. These possible problems were felt to be:

1. penetration of the p-n junction during front surface metallization;
2. inability to provide metallization with good adhesion to the Si substrate;
3. inability to provide ohmic contacts (rather than rectifying contacts);
4. degradation of active cell area by Ar ion bombardment.

Since ion-plating involves the deposition of metallic ions accelerated across an electric field onto a substrate, the question arose as to whether these ions would be of sufficient energy to penetrate the front surface of an active wafer deep enough to disturb the p-n junction (approximately 4000 Å beneath the front surface). The test which was proposed to investigate this possibility was to take a completed cell (supplied by Spectrolab, 2.12" in diameter, Ag electrodes) measure its performance with a dark I-V tester, deposit material on the front surface at the highest practical deposition energy and then remeasure the dark I-V characteristics of the cell. If the p-n junction were to be damaged during plating on the front surface, the dark I-V curve should show this particularly, as a decrease in the measured shunt resistance of the cell. The dark I-V curves of three cells were measured for this experiment and their shunt resistances (R_s) listed in Table 1. To check the reproducibility of the values determined for R_s , measurements were made over a period of days for all three cells. The values obtained for R_s for a given cell were then averaged and the standard deviation (SD) for each value of R_s was calculated. The standard deviations are also listed in Table 1. The three cells were then laid on a substrate table, back surface down, (thus no material was deposited on the back surface of the cell) and a steel mask with a 1" diameter hole in it was placed on the front surface of the cell.

The mask was necessary to prevent material from depositing on the edge of the cell, which could short circuit the front and back surfaces. Ni was then ion-plated onto the cell through the mask (over existing metallizations and exposed Si) at the highest practical deposition energy. This corresponds to the cell being exposed to an RF waveform of approximately 3,500 volts peak to peak with a DC field of -500 volts superimposed on the RF. Prior to actual deposition of the Ni, the three cells were pre-cleaned by bombardment in an Ar plasma, after which the Ar was pumped out and the Ni deposited to a thickness of 3000 Å. Values of R_s for each cell were then redetermined as outlined above and are listed in Table 2 along with the R_s values obtained prior to ion-plating. Keeping in mind the SD for R_s values, it can be concluded that ion-plating caused no change in the shunt resistance of these cells and thus junction-punch through did not occur.

In order to investigate the nature of the contact between the ion-plated metallization and the Si wafer, particularly whether the contact is rectifying or ohmic in nature, it was proposed to deposit several isolated pads on an active wafer and then use a conventional ohmmeter to measure the resistance from pad to pad. It was assumed that contacts which are rectifying in nature would be evidenced by a change in the measured resistance between any two pads upon reversing the polarity of the ohmmeter and remeasuring their resistance. To check this a mask was made which had $\frac{1}{4}$ " holes punched through it on a 1" grid pattern. This mask was laid on top of the cell and held in place via a magnetic chuck. When Ni was ion-plated through this mask to a thickness of 3000 Å onto the front (n-type) surface of an active wafer, measured resistances from pad to pad were invariant with the polarity of the ohmmeter, suggesting that these contacts were ohmic in nature, as desired (see Table 3). When AL was deposited through this mask to 18000 Å onto the back surface (p-type) of an active wafer, the pad to pad resistances were very dependent upon the ohmmeter polarity (see Table 4), suggesting that these contacts were rectifying in nature. Attempts to improve the back surface contact by chemical etching and mechanically polishing the back surface prior to ion-plating proved fruitless. This problem of rectifying contact to the back of the wafer was found to be solved by heating the wafer prior to deposition of the back electrode material, as was done to obtain the data in Table 5.

Investigation into the adhesion of the ion-plated film to the Si substrate was conducted using Ni and Al pads as deposited above, without preheating the wafer. Using a standard Sebastian Tensiometer for measuring thin film adherence, the Ni pads demonstrated a pull strength of from 4000 to 4800 psi and the Al pads fell in the range of 3400 to 4800 psi (2500 psi would be considered acceptable). In all these tests, however, the Si substrate would break up before the film pulled loose. Adhesion of pads deposited on a preheated wafer was not measured with the Sebastian Tensiometer, although this type of pad has demonstrated superior adhesion as evidenced in their resistance to soldering stresses.

2.2 Functional Cells

Functional solar cells with ion-plated front and back metallizations have been produced, three of which were brought to the April PIM. These functional cells consisted of a 3.25" diameter wafer with Ag metallization front and back deposited to 18000 Å. The wafer was preheated to approximately 400°C prior to deposition of the back surface electrode, whereas the wafer was not preheated prior to depositing the front electrode. The front electrode pattern used on these cells was delineated using a physical mask made by electrical discharge machining a "christmas tree" pattern into steel shim stock. The center electrode in the pattern was .138" wide at its base and tapered in three steps to .039". The side branches from the center electrode were .020" wide and spaced .125" apart. Light I-V curves have been obtained for two of these cells and are presented in Figures 1 and 2. For the first functional cells produced, these results are encouraging. Both cells demonstrated high values for their shunt resistance (555 and 263 Ω) which is desirable, but their I-V curves also indicate larger series resistances than would be desirable, which may in part be due to the thinness of the silver metallization.

2.3 Anti-reflective Coatings

Preliminary investigation of anti-reflective coatings was begun in March using MgF_2 , TiO_2 , Ta_2O_5 , Al_2O_3 and indium-tin oxide (ITO). Of these only MgF_2 has demonstrated desirable characteristics when deposited on glass. Work will continue to improve AR characteristics of all the above with the addition of SiO_2 .

3.0 Conclusions and Future Activities

From the investigations of possible inherent problems in applying ion-plating to the metallization of solar cells, no major obstacles were discovered, although the basis process had to be modified to produce an ohmic contact on the back surface (p-type) of an active wafer (i.e. wafer preheating). Future work in the metallization of solar cells will focus on reducing series resistances and the use of less expensive metals in the metallization (i.e. AL, Ni and Cu). Initial steps in reducing cell series resistance will be to increase the thickness of the metallizations and to further develop the preheating techniques used to produce ohmic contact to the cell's back surface. Work will also continue to improve the AR characteristics of the AR coatings deposited on glass thus far, and SiO will be added to the list of AR material candidates.

MILESTONE CHART FOR PHASE I

Appendix

Table 1
Shunt resistances for
three solar cells
prior to ion-plating

Cell #	As Received	
	R_s Ω	SD Ω
1	352.00	62.05
2	466.23	43.36
3	98.10	1.54

Table 2
Comparison of shunt resistance values
before and after ion-plating

Cell #	As Received	After Ion-Plating
	R_s Ω	R_s Ω
1	352.00	382.96
2	466.23	454.92
3	98.10	98.26

Table 3
Pad to pad resistance measurements
for Ni on a n-type front surface
(values in ohms)

(+) Probe

(-) Probe				
Pad #	1	2	3	4
1	--	40	50	45
2	40	--	42	50
3	50	43	--	45
4	45	50	42	--

Table 4
Pad to pad resistance measurements
for Ni on a p-type back surface
(values in kilo-ohms)

(+) Probe

(-) Probe				
Pad #	1	2	3	4
1	--	2500	800	75
2	90	--	800	75
3	90	2500	--	75
4	90	2500	800	--

Table 5
As in Table 4 with the wafer heated
to 400°C prior to deposition of AL
(values in)

(+) Probe

(-) Probe				
Pad #	1	2	3	4
1	--	105	90	115
2	100	--	110	95
3	90	95	--	85
4	115	110	85	--

Figure 1
Light I-V curves for ITW cells #2 & #3