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ION PLATING OF SOLAR CELL ARRAYS

Final Report, March 12, 1977—December 31, 1978

By
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Endurex Corp.
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MASTER

U.S. Department of Energy

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Contract Number 954728

Final Report For The Period:

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I. SUMMARY

Endurex has been engaged in a feasibility study to determine practicality of utilizing Endurex ion plated films to serve as anti-reflective and/or protective encapsulants for solar cell arrays. It has been demonstrated that thin films of oxide materials between 1000 and 2000 Å thick will protect a photovoltaic device from degradation in salt spray. Additionally, transmissivity data accumulated on Endurex coatings show that the anti-reflective (AR) properties of this film are equal to any achieved by more widely used processes.

The Endurex ion plating process is capable of being scaled up to meet 1986 throughput goals at a cost which is in line with 1986 cost goals. An additional benefit that may be realized by the utilization of ion plating is that it is an effluent free process utilizing no wet chemistry.

II. INTRODUCTION

ITW/Endurex gasless ion plating differs from other vacuum processes, and offers advantages these other processes do not possess.

Figure 1 is a diagram of physical vapor deposition (pvd), the simplest method of vacuum deposition in which the depositant is simply evaporated in the source and condenses on the substrate. Although high rates of deposition are possible with pvd, the films characteristically have shown poor adhesion due to low deposition energy which is in the order of 0.1 to 1.0 electron volts (eV). Physical vapor deposition is also limited to line of sight coverage from the source.

A second technique is sputtering. Figure 2 shows a schematic of the sputtering technique. From the diagram, it is seen that sputtering is a secondary process; that is, Argon ions are accelerated in an electric field and used to bombard the depositant material, imparting some of their energy to atoms of the depositant. These atoms can escape their cohesive bonds and travel through the vacuum to deposit on whatever surface they hit. Deposition energies using sputtering are in the order of 10 to 100 eV, which makes the adhesion better than that by pvd. Coverage is line of sight and deposition rates are very low, even with magnetic enhancement and other special techniques.

PHYSICAL VAPOR DEPOSITION (PVD)

DEPOSITION ENERGY:
~ 0.1-1 eV

FIGURE 1.

FIGURE 2.

(4)

PRESSURE: $\sim 10^{-2}$ T (AR)

- HIGH RATE
- GOOD ADHESION
- WRAP-AROUND COVERAGE
- ELECTRICAL CHARACTERISTICS OF FILMS ALTERED BY ENTRAPMENT OF AR AND DEPOSITION OF POLYATOMIC PARTICLES

CLASSICAL ION PLATING

(MATTOX)

DEPOSITION ENERGY:
.1 eV - 10,000 eV

FIGURE 3.

(5)

II. INTRODUCTION (continued)

Classical ion plating is shown in Figure 3. In this method, depositant atoms from vaporization sources travel through an intense argon plasma. Approximately 3% of these atoms are ionized in passage and are accelerated toward the substrate by a high negative DC potential, the other 97% are deposited by pvd. However, the intense argon bombardment increases their adhesion by "hammering in" the deposited atoms. Deposition rates are as high as those for pvd, adhesion is good, and coverage out of the line of sight is possible due to multiple scatterings in the high pressure argon. Classical ion plating cannot be used to deposit material on non-conductive substrates without special techniques. More importantly, in electrical applications, the film deposited by this method can have relatively high electrical resistance due to entrapment of argon and deposition of polyatomic particles.

Although each of these three techniques has certain advantages for particular applications, Endurex gasless ion plating has special advantages when applied to encapsulation problems. Figure 4 shows a schematic of this process. The depositant atoms are evaporated from the source into an RF field, where they are ionized and then accelerated by a DC field toward the substrate. Approximately 50% of the depositant is ionized and the energy of deposition is in the order of 1000 - 10,000 eV. One can quickly see that argon entities and polyatomic depositions are eliminated and, therefore, the resistivity of the films approaches that of the pure material. This method also is capable of high deposition rates and wrap-around or out of line of sight coverage.

GASLESS ION PLATING

DEPOSITION ENERGY:
1 - .10,000eV

FIGURE 4.
(7)

III. CANDIDATE MATERIALS

The selection of candidate encapsulants occupied the first weeks of the Endurex program. At the outset it was deemed desirable to endeavor to utilize materials which were both protective and anti-reflective. Materials with such dual characteristics are obviously appealing due to the fact that they, by their nature, could potentially reduce the number of processing steps necessary in the fabrication of solar cell arrays. A list of candidate materials appears in Table I.

Subsequent deposition of the various candidate materials yielded results which allowed Endurex to eliminate several of these as potential encapsulants. Magnesium fluoride was eliminated because of its poor bonding characteristics. Vinyl trimethoxy silane was eliminated for two reasons: (1) it is extremely poisonous, and (2) its natural state being that of a liquid renders it inappropriate for our process. Both SiO_2 and $\text{ZrO}_2/\text{TiO}_2$ cannot be evaporated using either resistance heating or induction heating and were excluded on that basis. Electron beam deposition and sputtering will allow one to obtain films from these substances, but neither technique is readily available to us at present. The recent efforts by Endurex to refine our reactive deposition technique has generated optimism that some of the eliminated materials may still be viable candidate encapsulants. Three evaporants were chosen as the most promising candidates for the program: Silicon Monoxide (SiO), Aluminum Oxide (Al_2O_3), and Tantalum Pentoxide (Ta_2O_5). The criteria were tenacity of adhesion, ease of evaporation and transmissivity.

IV. ANTI-REFLECTIVE

The purpose of an anti-reflective (AR) coating is to decrease the amount of sunlight reflected from the surface of the device. Another way of saying this is that the AR coating increases optical transmission. The net effect is that more photons are absorbed in the cell. In most cases, the AR coating is deposited on the face of the cell; however, the superior adhesion and abrasion resistance of Endurex ion plated AR coatings might allow use of the AR coating on the outer cover. Optical transmissivity data of Endurex ion plated AR coatings can be found in Table II.

Endurex AR coatings have been deposited on many surfaces exhibiting excellent adhesion and AR properties. Among the materials successfully coated in this manner are: DuPont Lucite, SAR, Pyrex, Soda Lime Glass, Silicon, and even paper. This capability allows the array manufacturer to utilize less expensive superstrates or cover sheets. Additionally, it may become practical to eliminate texture etching.

V. PROTECTIVE FILMS

The ability of these films to protect a surface from degradation has been explored a great deal during the life of the contract. Initial efforts involved the utilization of moisture sensitive solar cells and Endurex ion plated films. The results were encouraging. An ion plated film of 1000 Å of silicon monoxide (SiO) did reduce the power decay of the humidity sensitive cells. The test measured the relative power decay of solar cells with ion plated SiO against solar cells with conventional vacuum deposited SiO. The test was run at 100% relative humidity and 70°C for a period of 400 hours. The results are graphically displayed in Table III. Although both groups of cells exhibited power decay, the ion plated specimens showed a drastically reduced rate of decay.

The objective at this point became total encapsulations, i.e., no degradation rather than reduced degradation. Toward this end, several test procedures were developed. The turnaround time for getting test results from JPL was fairly extensive. As a result, several quick tests were developed which would yield results in a more timely manner. Metal test coupons were fabricated from corrodible materials such as copper. Candidate encapsulants were then deposited on a portion of these coupons in varying thicknesses. Subsequently, the coupons were exposed to atmosphere for a number of days. In all cases the ion plated portions of the coupons retained their original luster, whereas the unplated portion began to corrode within 24 hours of exposure.

V. PROTECTIVE FILMS (continued)

A more harsh test was performed on these partially protected coupons. They were exposed to hydrogen sulfide (HS) in an effort to locate possible pinholes or micro fissures in the plating which would account for the inability of the ion plated film to totally stop the degradation of the solar cells. The test was successful in this regard. Pinholes were identified. Scanning electron micrographs similar to that appearing in Figure 5 identified the cause of these pinholes as polyatomic particles or "comets" emanating from the evaporation source.

FIGURE 5

One of the characteristics of the Endurex ion plating process is the ability to ionize and direct the course of the evaporant. Consequently, it is not limited to "line of sight" applications. Subsequent depositions performed "out of the line of sight" of the filament source produced films free of pinholes. The results of tests performed on these films will be addressed later in this section.

Success or failure in the protection of corrodible metal coupons may or may not be indicative of success or failure in the protection of photovoltaic devices. Consequently, parallel efforts were directed toward protecting something more closely resembling a metalized solar cell.

A test coupon was devised which consisted of two metal traces very close together on a ceramic substrate. See Figure 6.

FIGURE 6
Metalized Ceramic

A drop of water bridging the two unprotected traces will cause a short, measurable by a simple continuity test. Once Endurex has ion plated a protective coating onto the coupon, the water drops should not affect the electrical readings (i.e., no continuity).

This was not the case, indicating problems other than the pinhole phenomenon previously discussed. The metalization pattern on the test coupon, and the metalization pattern on an actual solar cell consists of a silk screened silver paste which is subsequently fired. The resultant metalization is very porous and irregular. Figures 7 and 8 are scanning electron micrographs of this metalization system.

FIGURE 7
Metalization on Solar Cell

FIGURE 8
Metalization on Test Coupon

As one can readily see, attempting to protect such a surface with 1000 to 2000 Å of evaporant is akin to attempting to protect a coral reef with a bucket of paint.

To solve this dimensional scale problem, Endurex applied its own corrodible metalization system, and in turn, protected it with a pinhole free film of aluminum oxide (Al_2O_3). Resultant cells thus protected were exposed to salt spray (ASTM B-112) for 24 hours. Cells thus exposed exhibited very little corrosion, whereas unprotected cells with the same metalization system showed total degradation of the metalization (no metal left on the silicon).

VI. CONCLUSIONS AND RECOMMENDATIONS

Endurex ion plated anti-reflective (AR) coatings have been shown to produce results similar to AR coatings deposited in other ways. However, they offer an advantage in the area of adhesion over the conventionally deposited films. Additionally, ion plated anti-reflective (AR) coatings have an advantage over conventionally deposited AR coatings in that their crystallographic structure may be adjusted through variation of processing parameters. Changes and/or adjustments in process parameters may cause desirable alterations in crystallography, thereby maximizing cell output. Also, the function of the AR coating can be enhanced if one were to deposit a conductive AR coating such as indium-tin oxide. One now has not only the enhancement of the AR coating, but additional benefits of extra conductivity which adds in the collection of the electrons. It is recommended, therefore, that further investigations be made toward the goal of optimizing the AR coating by changing its crystallographic structure and conductivity.

Work in the area of encapsulation and protection has shown the feasibility of providing some degree of protection to a photovoltaic device with an ion plated film. Of equal importance, however, were the efforts expended in metalization which made thin film encapsulation possible. This work, when coupled with metallurgical studies performed for other customers, has led us toward the recommendation that further investigations be made in the area of ion plated metalization

VI. CONCLUSIONS AND RECOMMENDATIONS (continued)

systems. Endurex has developed, for example, metal alloys which possess inherent corrosion resistance for use in the automotive industry. These alloys when applied to the field of photovoltaics could reduce the need for exotic encapsulants, thereby reducing cost.

The Endurex ion plating process is adaptable to high volume production and can be extremely cost effective. Although the process is performed in a vacuum, air to air conveyORIZED systems do exist. Such a system would allow the deposition of the conductor and the AR coating in the same processing step.

The extremely good adhesion of ion plated films, coupled with the handbook value conductivity of ion plated films, may additionally allow a manufacturer to eliminate sintering or heat curing. This allows savings as far as labor and processing time, as well as savings in energy consumption.

TABLE I

CANDIDATE COATING MATERIALS

- 1) Aluminum Oxide
- 2) Magnesium Fluoride
- 3) Vinyltrimethoxy Silane
- 4) Zirconium Oxide/Titanium Dioxide
- 5) Indium/Tin Oxide
- 6) Tin Oxide
- 7) Silicon Monoxide
- 8) Silicon Dioxide
- 9) Tantalum Pentoxide
- 10) Silicon Nitride

TABLE II
OPTICAL TRANSMISSION

Table III

POWER DECAY OF HUMIDITY SENSITIVE
CELLS FROM EXPOSURE TO
100% RH AT 70°C