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Surface Modification of Titanium Foil Substrates in Experimental Solar Cells

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ABSTRACT. A case study involving surface smoothing of titanium foil was obtained from a solar cell research company. It was believed that the rougher surface of metals was responsible for low solar cell efficiency when using titanium foil rather than glass as a substrate. A method was needed to reduce the surface asperity height of the titanium foil from the existing 1 μm to less than 0.1 μm. Several methods were investigated. The recommended method was the use of an excimer laser, a laser powered by excited noble gas-halide molecules as a lasing medium.


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CASE STUDY

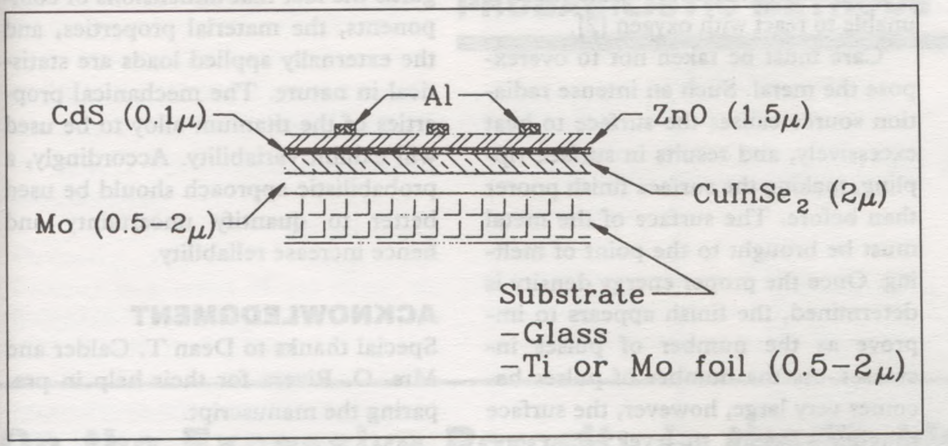
This case study was obtained from a solar cell research company in Los Angeles, California. The case study was to determine a method to finely polish titanium foil substrates used in experimental photo-voltaic cells or solar cells. The goal was to determine a method to reduce the surface asperity mean height of a titanium foil from the existing 1 μm to less than 0.1 μm.

Most solar cells are layered on ceramic glass substrates. These cells have an efficiency of about 15%. The efficiency of the cells refers to their ability to convert incident light into electrical energy. Cells layered on a metallic substrate have a much lower efficiency, around 7%. It is believed that the relatively uneven surface of a metal, compared to the smooth surface of a ceramic glass, is the reason for this decrease in efficiency.

A solar cell is a conglomeration of several crystals of different substances. A typical arrangement is shown in Figure 1. The substrate, the base layer, is a very important part, as it provides the support for all of the subsequent layers. Although glasses provide the normal substrate for most solar cells, metals are just as applicable. The company is interested in replacing ceramic glass substrates with metallic foils (such as titanium) because a metal foil is lighter and more flexible in bending. Light flexible solar cells would be more suitable in applications such as satellites, where the solar cells could be bent to follow the body contours of the satellite.

Ceramic glasses can be polished to have an almost perfectly smooth surface. This is shown in the surface contour plot in Figure 2A. Metals, on the other hand, show lines and depressions from machining and other shaping processes. The surface contour plot of the

FIGURE 1 Typical Solar Cell Arrangement



titanium foil sample is shown in Figure 2B. The surface roughness is probably due to the mechanical nature of the means of metal removal, that is, machining and polishing. Mechanical polishing does not provide a completely uniform surface because there are small particles that are doing the removal. If the asperity height is to be less than 0.1 µm, the particles used in polishing have to be smaller than 0.1 µm in diameter. Such mechanical polishing can be done. However, there are some difficulties: the company required that the foil be polished in 1-square foot sheets at a time, it is difficult to secure the metal foil while it is being polished, and great care must be taken not to polish excessively in one spot, as this could produce a hole in the foil (the foil has an average thickness of only about 1.5 mil), so other means of removing surface asperities must be examined.

ALTERNATE METHODS

Chemical or electrochemical milling and polishing are two possibilities. Unfortunately, these types of polishing attack the surface uniformly. This means that not only the asperities but also material are removed from the surface of the metal from the spaces existing between the asperities. This does not smooth the surface uniformly, but extends the existing contours to greater depths.

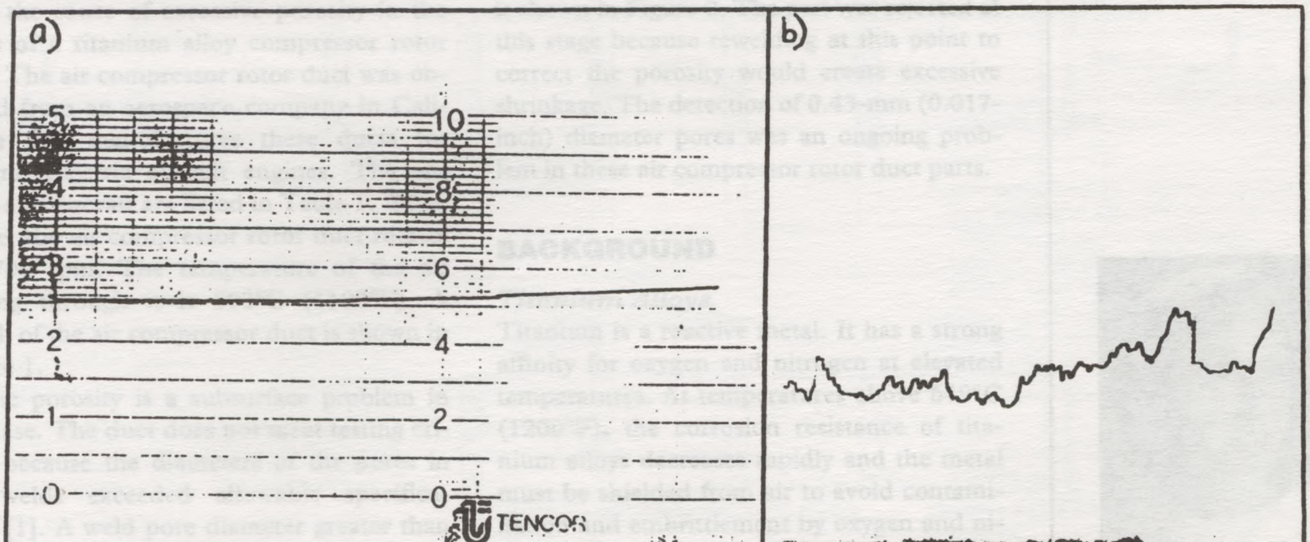
Another possibility is to use alternative foil production methods to create a smoother foil surface from the start. However, this is impractical as the company already has titanium foil that they wish to use.

RECOMMENDED METHOD

The viable alternative appears to be surface modification by use of an excimer laser [1, 2]. A laser beam can be very intense and can be controlled in shape, size, and strength. Because of its intensity, it has the potential for high energy transfer in a very short time. This limits the area that is actually affected by the laser radiation, especially in the case of metals because of their high thermal conductivity. Only a small layer of the metal, around 10–20 nm, is affected, and the remaining heat is transferred to the lattice in an extremely short time, approximately 10^{-11} to 10^{-12} seconds [1].

Excimer lasers rely on excited noble gas-halide molecules as a lasing medium [1]. The excited state of the molecules is very short so that pulse radiation also is very short—in the area of tens of nanoseconds and with very high intensities. Because of their high output power, excimer lasers have become an attractive tool in semiconductor processing, including fabrication of premium solar cells [1, 3]. *The laser pulses will bring only the surface of the metal to its melting point.* Excimer lasers also allow for easy control of the

FIGURE 2 Surface Contour Plots. (a) Glass, (b) Titanium Foil



wave length, which varies in the 157- to 350-nm range, the cross section of the beam, and the energy density measured in Joules/cm² [1].

It was demonstrated experimentally that the excimer laser can be used to modify the surface of titanium alloys [2]. Tests were conducted using a Lambda Physik laser. The pulse duration was 20 ns and the energy density was varied from 8 to 90 mJ/mm². Experiments also were conducted to study the effect of various gaseous media by testing in four different atmospheres, air, oxygen, helium, and nitrogen. The optimum combination of 40 mJ/mm² with approximately 32 pulses using the Lambda Physik in air gave the desired surface roughness of less than 0.1 μm [2].

A helium atmosphere would help in reducing the titanium, as it oxidizes readily at temperatures near the melting point. Various nonreactive gases, such as helium, seem to help the most at higher energy densities. They allow for a more uniform surface, as the metal is unable to react with oxygen [2].

Care must be taken not to overexpose the metal. Such an intense radiation source causes the surface to heat excessively, and results in surface rippling, making the surface finish poorer than before. The surface of the metal must be brought to the point of melting. Once the proper energy density is determined, the finish appears to improve as the number of pulses increases. As the number of pulses becomes very large, however, the surface roughness seems to level off at one particular value [2].

CONCLUSION

Surface modification with an excimer laser is recommended. The energy density and number of pulses have to be determined experimentally to find the right combination for the specific titanium alloy that is to be modified.

The deterministic approach in conventional engineering design disregards the fact that dimensions of components, the material properties, and the externally applied loads are statistical in nature. The mechanical properties of the titanium alloy to be used will exhibit variability. Accordingly, a probabilistic approach should be used better to quantify uncertainty and hence increase reliability.

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