Cell efficiency increase of 0.4% through light-induced plating

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This article first appeared in *Photovoltaics International* journal's second edition in November 2008.

ABSTRACT

A vast majority of silicon solar cells are manufactured using silver paste that is screen printed onto the front side of the wafer and fired to form the front-side contact. Though this method is well established within the industry, it continues to present several areas for potential efficiency improvements. The Fraunhofer Institute [1] has, among others, studied the potential of using electrodeposition of silver on top of the front side silver paste as a way to improve the front-side contact and increase cell efficiency. These results have shown cell efficiency increases of up to 0.4% absolute. This type of improvement has captured the interest of many manufacturers, but there has been a hesitancy to adopt electrodeposition as there is uncertainty as to what they can expect on their cells. Since efficiency gains are dependent upon many factors that can be unique to an individual cell, this paper provides a much-needed exploration of the potential effects of electrodeposition of silver in a way that isolates its effects from that of other factors.

Introduction

Standard PV silver pastes contain many components that are necessary for their functionality, but are not beneficial for conductivity. While pure silver metal has a resistivity of 1.59 microhm-centimeter at 20°C, most PV pastes have resistances that are two to three times that. In addition, since silver pastes flow when they are fired, there is a limitation in the aspect ratio that can be achieved. As a result, most manufacturers have to print a 120-micron or wider line for the front-side contact to achieve a cross-sectional area large enough to carry the current generated by the cell. To add to the cell manufacturer's problems, the silver paste process introduces much of the variability that cell makers experience in their efficiencies. The addition of electrodeposited silver to the cell can improve the front-side contacts and reduce the product variability.

Effect on efficiency

The effect of this process on the efficiency of a population of cells can be dependent on several factors. It can be difficult for cell manufacturers to look at data from past experiments and use those results to predict what they can expect from their cells. In an attempt to make a data set that could be more usable, an experiment was designed using 156 cells, prepared by Evergreen Solar. The electrical characteristics of these cells were measured both before and after the electrodeposition of silver metal onto the front-side contacts. Though all effects on the efficiencies were measured, the focus of the data analysis was on the change in the front-side resistance (R_{front}). This analysis gave a set of tangible results that demonstrated the impact of electrodeposited silver on cell efficiency.

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Test conditions

The test cells were manufactured using a standard process flow. After firing, the cells went through a laser edge isolation, followed by electrical testing prior to the electrodeposition process.

The test cells were processed through a light-induced plating (LIP) tool where light was introduced to the cell to generate some of the power needed for the electrodeposition process. A rectifier was used to put a voltage potential on the backside of the cell to protect the backside contact from becoming the anode and dissolving during the electrochemical reaction.

The test cells were electroplated in Technic's TechniSol Ag silver plating bath for ten minutes at room temperature. These conditions resulted in 8 – 10 microns of fine grain plated silver being deposited on top of the silver paste front-side contacts. The silver metal was plated at a current density of 1.3 amps/decimeter^2 (ASD). Subsequent testing has shown this thickness can be achieved in five minutes if the solution temperature is raised to 40°C and agitation is increased, which allows for plating to occur with a fine grain deposit at 2.6ASD.

The cells were re-tested electrically after the electrodeposition process and, as the cells had been serialized, it was possible to look at the change in the electrical characteristics for each cell.

The results

By depositing the silver metal onto the silver paste contacts, the average R_{Front} was reduced dramatically. The batch of test cells started with an average R_{Front} of 122 milliohms (as measured from bus-bar to bus-bar) prior to the deposition of silver. After the plating process, the average

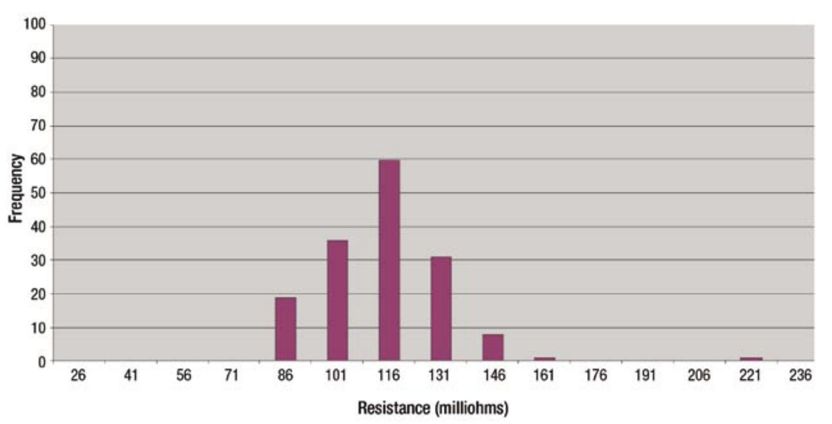

Figure 1. Front-side resistance distribution before electrodeposition.

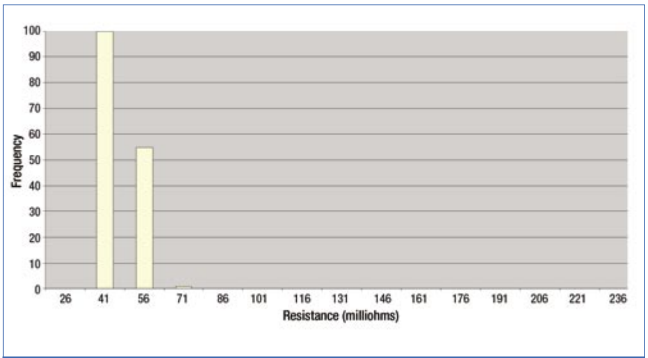

Figure 2. Front-side resistance distribution after electrodeposition.

R_{Front} was reduced to 54 milliohms. Perhaps the more telling result was the effect on the distribution of the data.

The silver paste and firing processes used in traditional cell manufacturing are wrought with variability. Whether the problems relate to screen-printing, furnace variability, or paste composition inconsistencies, the traditional process results in cells with a high standard deviation in the grid line resistances. The cells in this experiment started with a standard deviation of 18 milliohms prior to plating. After plating, the standard deviation had dropped to 6 milliohms. So, not only did the overall resistance drop, the variability in R_{Front} was reduced dramatically.

A closer look at the results on individual cells helps highlight the mechanism for improvement. If the change in the R_{Front} is plotted as a function of the initial R_{Front}, it becomes obvious that the plating process is capable of making a dramatic impact on those cells that have a high initial resistance. It is clear to see from Figure 3 that the cells with higher starting initial resistances benefited the most from the electrodeposition process.

As the resistance inherent in the common silver pastes are two to three times that of metallic silver, even a thin layer of electrodeposited silver metal quickly becomes the primary conductor on a cell's front-side contact. A cell that starts with a high quality silver paste contact only experiences a marginal improvement following the addition of metallic silver. In contrast, for cells that have a lower quality contact, the addition of the plated metal makes a dramatic difference to the ability to conduct the energy produced by the cell.

The final step for the test cells was to have them assembled into a module and subject to reliability testing. The module was tested and then subjected to 1000 hrs of damp heat conditioning (85°C at 85% relative humidity). After the conditioning, the module was then re-tested. The module using the electroplated cells experienced less than the allowable 5% degradation in power after the conditioning. In fact, the test module's power dropped by only 1% over the damp heat test.

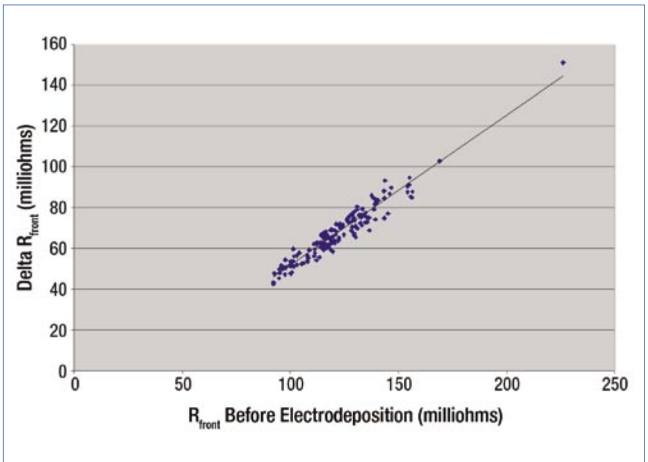

Figure 3. The reduction in the front-side resistance as a function of each cell's initial resistance.

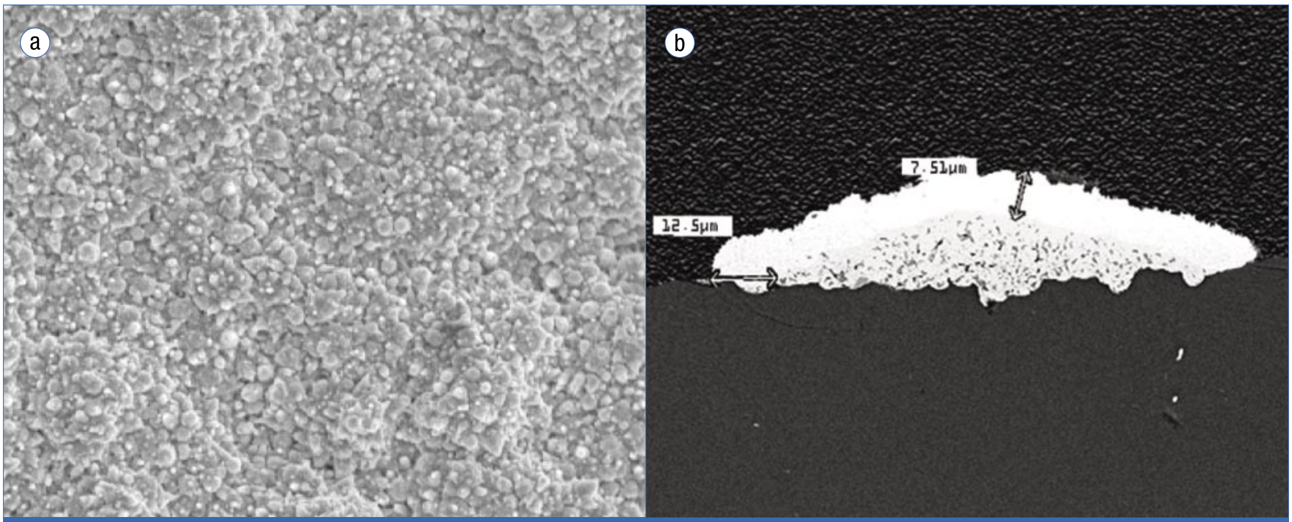

Figure 4. a) 2000× SEM of TechniSol AG surface morphology plated over silver paste at 2.0 ASD. b) Cross sectional view of front side contact plated with TechniSol Ag.

Two approaches to application

There are two ways that cell manufacturers can use electrodeposition to improve their product. Some producers have elected for a wholesale change in cell design while others may consider using electrodeposition as a remedial process to improve cells with low efficiency due to high resistance.

First approach: design change

Traditional front contacts require the fingers to be 120 microns wide to achieve enough cross sectional area to effectively allow the current to flow. This width is dictated by the shape that the contact takes during firing. Since the silver paste will flow during the contact firing, the final shape of the contact will only achieve 20 microns of height in that width. Due to this limitation, the manufacturers need these wide contacts to achieve the necessary area of approximately 1500 microns^2. The final result is that approximately 7% of the front of the cell is shaded by the resultant grid pattern.

In a cell design that uses electrodeposition to enhance the front-side contacts, it is only necessary to screen-print the fingers at 80 microns in width. With the addition of 10 microns of electrodeposited silver, the final contact width will be only 100 microns. By lowering the resistance within the contacts through electrodeposition of silver metal, it is possible to use a thinner conductor on the front side and match or exceed the conductivity of traditional cells. These thinner lines allow more light to enter the cell, and the subsequent reduction in shading translates directly into higher power output from the cells. This design change has been shown to increase cell efficiencies by 0.3 – 0.5% absolute, depending on the cell design and processing.

Second approach: remedial process

As with any process, the addition of silver electrodeposition into the cell manufacturing sequence is accompanied by an increase in processing costs. The results of this study open a possible path for manufacturers who are hesitant to add this cost to their entire product line.

The study clearly demonstrated that a certain population of the test cells benefitted the most from the electrodeposition process. As one may expect, the efficiency gains were the highest for the cells that saw the greatest reduction in R_{Front}. Even without a change in the contact design, cells that experienced a decrease in R_{Front} of 80 – 120 milliohms demonstrated an absolute increase in efficiency of 0.25 – 0.50%. As Figure 3 showed, it is possible to predict the change in R_{Front} that the electrodeposition process will induce by simply measuring the R_{Front} after firing.

This measurement does not require full characterization of the cells' electrical properties. In fact, a simple in-line resistance tester could be used to identify cells with a front-side resistance that is above a certain threshold. Those cells could then be passed through the electrodeposition process to enhance the contact and overcome the condition that is creating the increased resistance.

Since the electrodeposited silver has a different grain structure from that of the silver paste, different soldering conditions may be necessary during module assembly. Manufacturers who employ the selective strategy will have to deal with the logistics of two different product types. However, they will enjoy the benefit of increasing the efficiencies of their lowest output cells without investing in the electrodeposition process on their entire production volume.

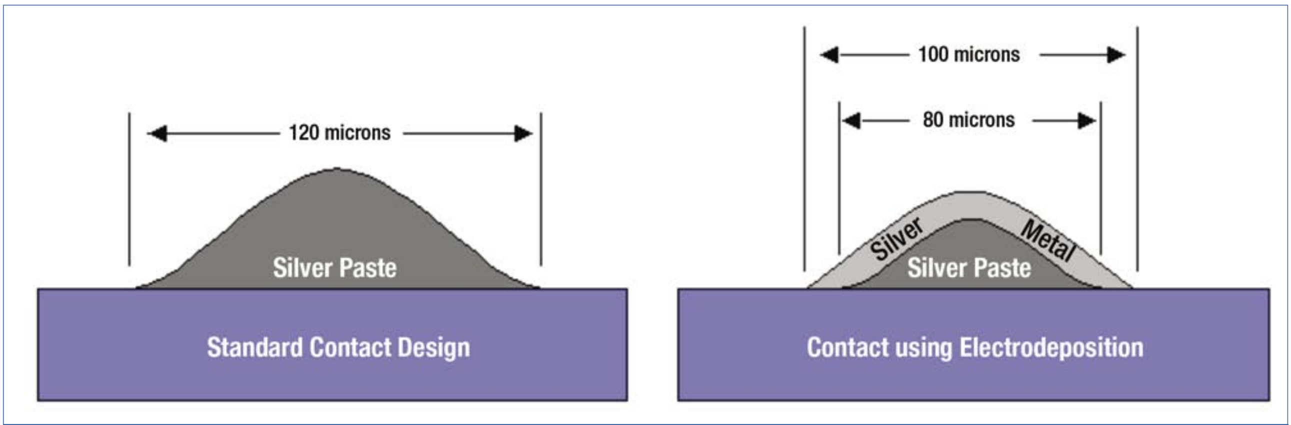

Figure 5. Traditional and alternate front-side contact cross-sectional view.

Process parameters: reducing the cost impact

The electrodeposition process is different from other processes that are used in most cell production lines. It is often the case that there is little or no electroplating experience within the manufacturer's technical staff. Keeping this in mind, there are a few essential aspects of the electroplating solution that need to be considered.

Perhaps the most important aspect to be considered is the cost of the solution. More silver is removed from the process as residue on the surface of the wafer leaving the plating tank (referred to as drag-out loss) than is deposited onto the cell. To minimize the loss due to drag-out, the concentration of silver in the solution should be kept to a minimum. A silver electrodeposition solution should be capable of running at 20g/l or less of silver metal. In addition, a silver recovery system should be installed on the rinse chambers of the electrodeposition tool to recover as much of the lost metal as possible.

Aside from the direct cost, there are also indirect costs to be considered. To reduce the overhead associated with the process, a good silver electrodeposition process will be easy to analyze and easy to control. It should also be stable and adjustable to the customer's specific requirements. Mistakes in the control of an electrodeposition process can result in the loss of precious metals, so great care needs to be taken to ensure that the responsible employees are trained by the solution supplier.

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Conclusion

Cell manufacturers are painfully aware of the problems they face with respect to the front-side contact metallization. As this study has demonstrated, there is a solution to those problems that can increase the contacts' conductivity, reduce the variability, and increase cell efficiencies. With the addition of electrodeposited silver to the front-side contacts, manufacturers have a cost-effective method of increasing cell efficiency and improving their bottom lines.

Acknowledgements

The author would like to thank **Evergreen Solar, Inc.** for their assistance in this study.

References

[1] Mette, A., Schetter, C., Wissen, D., Lust, S., Glunz, S.W. & Willeke, G. 2006, 'Increasing the efficiency of screen-printed silicon solar cells by light-induced silver plating,' *Proc. IEEE 4th World Conference on Photovoltaic Energy Conversion*, Hawaii, USA.

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