

Feasibility of Improving Front Metallization Lines for Photovoltaic Devices

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ABSTRACT

Screen-printing is widely used today as the metallization technique for industrial solar cells. Due to the limitation of the process, screen-printed contacts have low aspect ratio and low line conductivity that lower the efficiency of the solar cells. To address this issue, we developed a two-layer metallization process that deposited copper (Cu) as current-carrying electrodes by light induced electroplating (LIP) technique on thin screen-printed silver (Ag) paste seed layers. A nickel (Ni) layer was also deposited by LIP as the barrier and Cu adhesion layer.

A series of trials with various electrolyte compositions as well as different organic additives were investigated as part of this work. By optimizing the thickness of the plated Ni and Cu layers, line resistivity of 1.75 $\mu\text{Ohm-cm}$ as low as that of bulk Cu, 1.68 $\mu\text{Ohm-cm}$ and bulk silver (Ag), 1.59 $\mu\text{Ohm-cm}$ was achieved.

INTRODUCTION

Currently, several metal contact fabrications techniques are commonly used, but each has its own limitations. Screen-printing is normally used for commercial silicon solar cells and allows for speedy metallization at relatively low cost. However, there are several unwanted features such as low aspect ratio of the grid lines which creates large shading area on the front of the PV devices, and a high line resistance which lowers the final efficiency [1]. Photolithography and metal evaporation techniques are often used for high efficiency cells since they offer improved gridline quality, however the processes are time-consuming and expensive [2].

Light induced electroplating of silver (Ag) metal on top of the front contact grid has shown promise in reducing line resistance and increasing cell power output [1, 2, 3, 4]. It has been demonstrated by Technic Inc. that LI plating silver metal on top of the front contact grid can reduce the resistance and increase cell power output. Preliminary cell performance study data have shown that front side resistance before plating was on average 0.122 ohms while after plating it was improved to 0.054 ohms potentially producing 100% more current and therefore more power output. In addition, electroplated deposits have better aspect ratios, so they can be deposited in a thinner line, resulting in less shading of the PV material and greater electricity production by the module. This

technique has received only limited acceptance in the industry due to the cost of plating a precious metal layer, silver. The feasibility of using this technique to plate non-precious metals, such as Ni, Cu, or tin (Sn) is well desired for PV fabrication process due to the ease of the process and the use of a lower cost material. Cu has higher electrical conductivity compared to Ag and is much cheaper material. Using Cu instead of Ag as the primary current carrier for the contact metallization should allow the same benefits as shown by Technic Inc. and other groups [1,2] with a substantially lower manufacturing material cost.

EXPERIMENTAL

In this experiment, 200 μm thick 2-3 Ohm-cm p-type Czochralski Si wafers were used to fabricate the solar cell devices. A simple one step annealing spin-on diffusion process was used to dope phosphorus as the front emitter and boron as the back surface field. A 76 nm layer of silicon nitride deposited by plasma enhanced chemical vapor deposition was used as the passivation and antireflective coating layer. Narrow metal lines, 100 μm were screen-printed on top of the passivation layer before the firing process.

The test cells were then 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 [Fig.1].

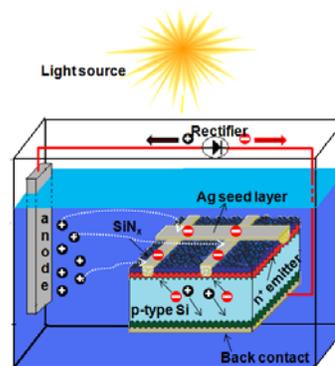


Fig 1. Light-induced electroplating process

The whole process sequence is summarized in Table 2 and the structure of the solar cells is shown in Fig. 1. This fabrication process sequence consists of a small number of process steps.

Front metallization process

A two-layer process for metallization line formation was used. A seed Ag paste layer was first deposited on the Si surface by screen printing. This seed layer formed a thin metallization line that has good mechanical and electrical contact with the cell surface. In the subsequent growth step this line was thickened by metal electroplating, using the solutions developed by Technic, to increase line conductivity.

For this experiment, commercial available Ag pastes were used as the seed layers. The thickness of the contact lines printed in this work was around 15 μm . Firing temperatures, firing time, and ambient atmosphere were studied to get optimized Ag paste seed layers with low line resistivity. It was found that using rapid thermal annealing (RTA) furnace to fire the Ag paste at 780°C resulted in the lowest line resistivity of 4 $\mu\text{Ohm-cm}$.

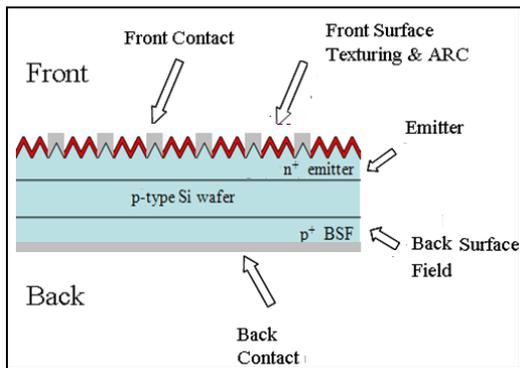


Fig. 2. Cell structure

Table 1. Process sequence for fabricated solar cells

1. Saw damage removal, texture, and wafer cleaning
2. One step phosphorus and boron spin-on diffusion process
3. Boron and phosphorus glass removal
4. Silicon nitride deposition
5. Ag paste screen printing of the front contact and drying
6. Firing of the front contact
7. Al deposition by thermal evaporation for the rear contact
8. Light-induced electroplate of Ni/Cu and then immersion plating Ag onto the front contact
9. Edge isolation

Light-induced electroplating process

The solar cells were plated in Technic Inc.'s Benchtop LIP cell [Fig.3]. Technic Inc. plated various metal stacks on the selected Ag seed layer in an attempt to find a

chemical and metal combination that produces low line resistivity and higher aspect ratio that is cost effective and usable in manufacturing. Chemical solutions from the TechniSol family of solar products were used to deposit Ni, Cu, and then Immersion Ag onto the front side contacts.

The TechniSol Ni was used to deposit a barrier layer of Ni onto the Ag paste seed layer. This layer is used to encapsulate the Ag paste and protect it from the highly acidic plating solution used in the Cu plating step. This plating bath is designed to be compatible with most of the commercially available Ag pastes.

The next step used the TechniSol Cu D-107 to deposit the main current carrying metal. This step resulted in a layer of Cu with low internal stress that was designed to lower the resistance in the front side contact which in turn lowered the series resistance of the cell. The TechniSol Cu D-107 was designed with proprietary additives to avoid the internal stress usually associated with plated Cu deposits. This minimized the forces exerted on the contact to enhance the reliability of the final product.

The final plating step used the TechniSol Silvermerse to add a very thin layer of immersion Ag onto the Cu layer. This layer preserves the Cu and makes the contact solderable for the module assembly step.



Fig. 3. Technic's Benchtop LIP cell

LI PLATED CONTACT CHARACTERIZATIONS

Resistivity measurements

Signatone Sheet Resistance Probe 4-point-probe system was used to measure the sheet resistivity of the contact lines. The geometry of the contact line was then studied by using FEI Nova NanoSEM 600 environmental scanning electrons microscope (ESEM) system operating at 10 kV accelerating voltage [Fig.4]. The final line resistivity was calculated as a product of its sheet resistivity and volume. The line resistivity was measured before and after the plating process for comparison.

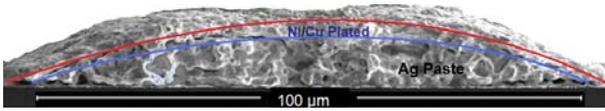


Fig. 4. SEM image of the cross section of the contact line after Ni and Cu plating.

Current-voltage measurements

The completed devices with an active area of 4 cm^2 were characterized with current-voltage (I-V) measurements in both dark and illuminated conditions. The I-V curves were collected at room temperature with a Keithley 237 source meter, under an illumination condition of AM1.5 and 100 mW/cm^2 using Solar Light's solar simulator. Calibration light intensity had been done with a monocrystalline silicon solar cell calibrated by NREL (National Renewable Energy Laboratory). Devices were measured before and after the plating process.

RESULTS

Resistivity as a function of plated metal's thickness

In order to study the line resistivity, the effects of the thickness of the plated Ni and Cu layers on the line resistivity were studied.

The thicknesses of the Ni layers were varied between 1 to $4 \mu\text{m}$ while the thicknesses of the Cu layers were kept at $6.35 \mu\text{m}$ and $12.7 \mu\text{m}$. From Fig. 5, as the thickness of the plated Ni layer increased, the line resistivity decreased. When Cu layer was plated thicker, $12.7 \mu\text{m}$ compared to $6.35 \mu\text{m}$, lower resistivity was achieved with thinner plated Ni layer.

Line resistivity of $1.75 \mu\text{Ohm-cm}$ has been achieved with $2.54 \mu\text{m}$ thick of Ni stacked with $12.7 \mu\text{m}$ thick of Cu. This line resistivity is close to that of bulk Cu, $1.70 \mu\text{Ohm-cm}$ at room temperature.

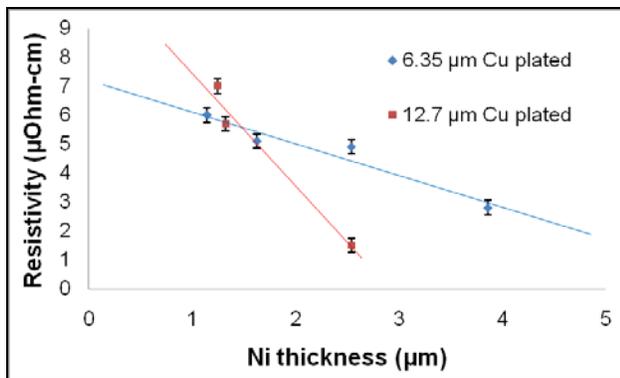


Fig. 5. Graphs showing the relative improvement of the resistivity based on the thickness of the plated Ni for $6.35 \mu\text{m}$ plated Cu and $12.7 \mu\text{m}$ plated Cu layer.

I-V characteristic

As shown in Fig. 6, the short circuit current density, J_{sc} dropped slightly after the plating process. This is due to

the wider contact line after the plating process increasing the shadow area. This can be optimized in the future by using narrower contact line for the seed layer.

After the plating process, both the shunt resistance and series resistance got improved as the series resistance decreased from $> 2 \text{ Ohm-cm}^2$ to closer to 1 Ohm-cm^2 . This led to an average 10% increase for the fill factor.

Since the open-circuit voltage and the contact resistance do not change due to the plating process, the efficiency gain depends on the current loss and the fill factor gain. The maximum efficiency gain can be achieved by minimizing the current loss and maximizing the fill factor gain. This will be the main focus for the future work.

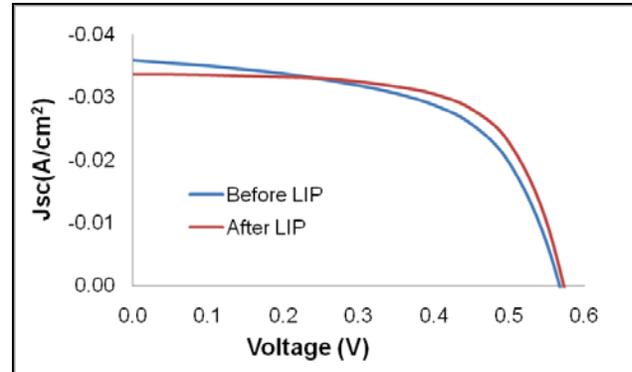


Fig. 6. Illuminated I-V measurement before and after the plating process.

CONCLUSION

In order to get to the next level of high efficiency PV devices, cell manufacturers will need to overcome the problem with the current screen-printed front metal contact. As this study has demonstrated, light-induced electroplating of low cost materials such as copper can help to solve the problems. From our initial works, LI plated copper has shown the potential to decrease the contacts' resistivity and increase the fill factor. With further works in the future, an optimized light-induced electroplating copper process can give cell manufacturers a cost-effective method of increasing cell efficiency.

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