Fabrication of All-Aluminum p-Type Silicon Solar Cells

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Abstract and Introduction:

Two substantial impediments to the large scale adoption of photovoltaic solar cell technologies are the high-cost and scarcity of the materials used to produce them. Of the numerous potential solar cell structures—substrates, passivation layers, and anti-reflection coatings being some of the most common—the silver front finger electrode is perhaps one of the most widely-used in solar cell design. The high-cost and relative scarcity of silver, then, would bottleneck the implementation of photovoltaic devices, which use silver as the front finger electrode material. Therefore, there is an imperative to replace silver with a cheaper and more abundant metal.

The use of aluminum as a replacement for silver as the front finger electrode material was investigated. The aluminum was deposited via electroplating to construct a simple p-type silicon solar cell. The cell's various operational parameters were measured, then compared to a control device.

Figure 1: Process flow for the fabrication of this study's p-type solar cell. The silicon wafer was received with the first two steps already completed.

Experimental Procedure:

The p-type silicon substrate was partially processed when received. Specifically, both surfaces were textured, and the n-type silicon layer was formed via the diffusion of phosphorus. A silicon nitride (SiN_x) layer was then applied via plasma-enhanced chemical vapor deposition (PECVD), followed by a screen-printed aluminum backside contact, which was subsequently fired. The front surface then went through the following treatments to form the front-contact finger pattern: photoresist application, patterned UV-exposure, alkaline development/selective photoresist removal, hydrogen fluoride (HF) bath for SiN_x and silicon dioxide (SiO_2) removal. Then, nickel was sputtered into the etched pattern. Finally, aluminum was electroplated onto the nickel. See Figure 1 for the fabrication process. See Figure 2 for the schematic of the finished cell.

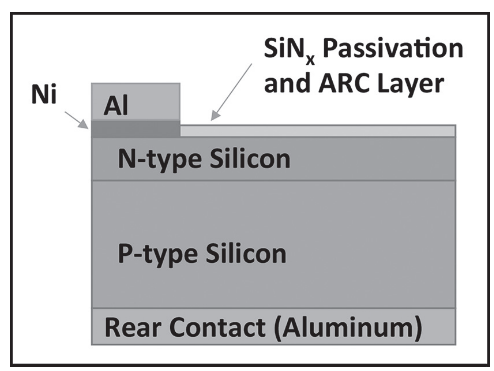

Figure 2: Illustration of the finished device's structure. The relative thicknesses are not to scale. Note that the back surface field (BSF) is not shown.

Results:

The finished solar cell was characterized using a Sun 2000 Solar Simulator from ABET Technologies (see Table 1). The following parameters can be directly obtained by fitting the I-V data to a simple, idealized solar cell model: efficiency, fill factor, short-circuit current (J_{SC}), open-circuit voltage (V_{OC}), series resistance (R_{Series}), and shunt resistance (R_{Shunt}).

Our group's device was compared to another group's solar cell. The reference cell's structure is almost identical to this study's cell; the difference being that the reference cell uses a silver front contact, and has no intermediary seed layer between the front contact material and the silicon substrate, as opposed to the nickel layer in this study's device (see Figure 2).

Arguably, the most important parameter in the analysis of solar cells is efficiency. The efficiency of the reference cell is significantly higher than our group's solar cell (a discrepancy of 4.4 percentage points absolute). The poor performance of our cell is likely due to a combination of factors. Fabrication errors in conjunction with non-optimized cell parameters—parameters being any cell quantity whose value can be controlled during fabrication, including: layer thickness, diffusion temperature/time, front finger dimensions, etc.—are partially culpable for our device's poor performance. For instance, it is hypothesized that the silicon-nickel and/or the aluminum-nickel interfaces have high contact resistances, which could be alleviated by optimizing the electroplating procedure.

The fact that our group's device efficiency was due to fabrication errors and/or poorly optimized cell specifications, was corroborated by our cell's substandard R_{Shunt} and R_{Series} (see Table 1). A poor R_{Shunt} is often associated with manufacturing defects, which implies that fabrication errors—such as contamination and sample damage—occurred during the assembly of the cell. The potentially high contact resistances between the front contact layers may contribute to the cell's high series resistance. The detrimentally high R_{Series} is a probable contributor to the marginally decreased J_{SC} and J_{MP} values of our cell, relative to the reference (see Table 1).

	Our Lab's Cell	Reference Cell	Percent Difference
Efficiency [%]	12.4	16.8	35
J_{SC} [mA/cm^2]	31.8	35.5	12
V_{OC} [V]	0.60	0.61	2
R_{Shunt} [Ω-cm^2]	183	808	342
R_{Series} [mΩ-cm^2]	1030	393	62

Table 1: Table of various solar cell parameters (Efficiency, J_{SC}, V_{OC}, R_{Shunt}, and R_{Series}) for this study's device and a reference device. Also shown: the percent difference between the two solar cell devices.

It should be noted that our group's solar cell has values for J_{SC} and V_{OC} that are reasonably similar to the reference's values. It is therefore believed that if the problems of the poor R_{Shunt} and R_{Series} are addressed, the solar cell designed by our group will be able to perform at a level comparable to, or better than, the reference device.

Conclusions and Future Works:

A cell employing an aluminum front contact was fabricated and characterized. The device has a poor efficiency relative to the reference, which is likely due to substandard R_{Series} and R_{Shunt} values. The poor values of R_{Series} and R_{Shunt} are due to fabrication errors and non-optimized cell parameters. These flaws will have to be addressed to increase the efficiency of the device, and thus demonstrate the efficacy of aluminum as an alternative front contact material.

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