Researching All-Aluminum n-Type Silicon Solar Cells

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Abstract and Introduction:

One of the fundamental bottlenecks for silicon solar cells in reaching terawatt scales is the scarcity of silver (Ag). Furthermore the price of Ag has been rising sharply. We have proposed that Ag should be replaced by other metals. In order to improve these contacts, high doping level layers were fabricated on the both sides of our cells.

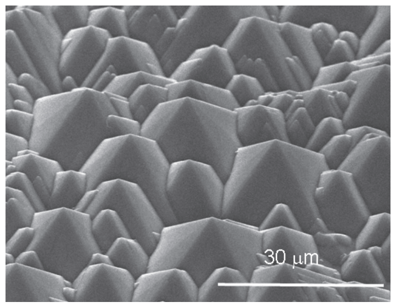

Figure 1: SEM of the surface texturing.

Generally, p-type silicon wafers are used in solar cells, but in our research n-type wafers are used. These types of solar cells have enormous potential to be high efficiency solar cells. However they have a few problems due to the surface states on the surface of the p^+-type layer. In order to increase cell performance, an aluminum oxide (Al_2O_3) layer has been chosen for a passivation layer, it is also a dielectric containing a fixed negative-charge density. This effect results in the reduction of surface recombination.

Experiment Procedure:

First the random texturing was fabricated on the both sides of a cell for reducing the reflectance. By using the anisotropic wet etching method, the pyramid shape texturing was fabricated.

Second, the diffusion processes were applied to the samples for fabrication of the cell structure. There were three steps in the diffusion processes. The n^+-type back surface field (BSF) layer was fabricated in the phosphorus diffusion process. This layer worked as a barrier against minority carriers in the n-region. The depth and the donor concentration of n^+-type layer were controlled by firing time and temperature. Boron diffusion was also applied to the cell in order to make a p^+-type layer after the first diffusion. Subsequently the sample was annealed at 1050°C in nitrogen ambient gas. This is called the "drive-in diffusion process." In order to reduce the doping concentration on the each surface of the cell, we applied the drive-in diffusion.

Third, the aluminum was sputter deposited on the both sides. After metallization, the Al_2O_3 was applied on the front surface as a passivation layer. Subsequently the front surface was covered with SiN_x. These SiN_x/Al_2O_3 layers worked as an anti-reflection coating. Finally, the sample was annealed in ambient forming gas ambient at 350°C.

Results:

By using anisotropic wet etching, the pyramid shape texturing was fabricated on the both sides (Figure 1). Reduction of reflectance was observed because of this texturing. Finally, after deposition of SiN_x, the average of reflectance became 4.53% in the range from 300 nm to 1000 nm.

After diffusion processes, depth dependent doping concentrations was measured (Figure 2). From this doping profile, we could observe that the doping concentrations on the both surfaces were still high. It means that the drive-in diffusion did not work.

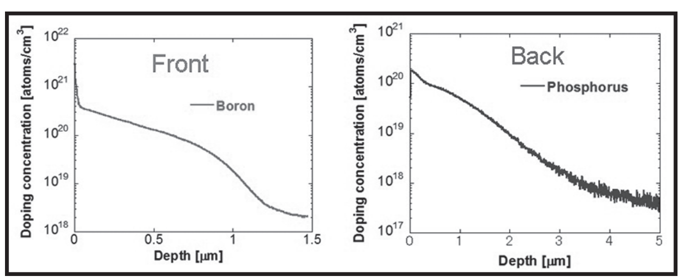

Figure 2: Depth dependent doping concentrations on the both sides.

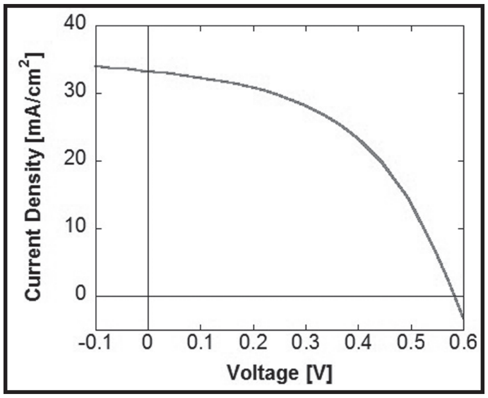

Figure 3: I-V characteristic.

After finishing all processes, all samples showed short-circuited behavior. In order to remove some parts which were short-circuited, the samples were cut into some pieces. After cutting the samples, the I-V characteristic measurement was taken (Figure 3). The surface area was 5 cm^2 and 20% of it was covered with front electrode. From this assumption, each parameter was calculated. The efficiency achieved was 9.3%.

The doping profile indicates the drive-in diffusion did not work. We assume that after the diffusion for fabrication of the p^+-layer, boron silicate glass (BSG) was formed on the surface and then during the drive-in diffusion, the boron diffused into the samples from the BSG. Because of it, the high doping concentrations on the surface were formed and some parts of the samples were short-circuited.

Each parameter was compared with some references [1, 2]. From this comparison and I-V characteristics, low fill factor showed us that there was large leakage current and series resistance (Figure 4). This series resistance included the problems of contacts however we could not investigate them separately. Low open-circuit voltage (V_{oc}) and short-circuit current density (J_{sc}) were mainly because of high recombination rate. From the doping profile, high doping concentrations on the surface and deeper junction helped recombination occur at high rates on the front surface.

Conclusions and Future Works:

In conclusion, an all-aluminum n-type Si solar cell was fabricated. The efficiency achieved was 9.3%. Random texturing was fabricated to reduce the reflectance. From J_{sc} and V_{oc}, high surface recombination was identified for the low efficiency. From the doping profile, the high doping concentrations on the surface reduce diffusion lengths and deeper junction allows recombination near the front surface.

For next steps, we should apply an *in situ* oxidation step in order to remove the BSG after the diffusion process for the p^+-layer. This process is supposed to make it possible to fabricate the samples which have the desired doping profile and do not need to cut into some pieces. Form this effect, the larger surface area of the samples improves the fill factor by reducing the leakage current and series resistance, whereas lower doping concentrations on the front surface help to reduce recombination near the front surface.

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References:

[1] J. Benick, et al., "High efficiency n-type Si solar cells on Al_2O_3-passivated boron emitter", APL, 92, 253504 (2008).

[2] M. Kesseler, et al., "High-Efficiency Back-Junction Silicon Solar Cell with an In-Line Evaporated Aluminum Front Grid", 37th IEEE Photovoltaic Specialists Conf, 2011.

	J_{sc} [mA/cm^2]	V_{oc} [mV]	FF	η [%]
Our Sample	33	590	0.48	9.3
From Some References	40	700	0.80	23

Figure 4: Comparison each sample parameters with other studies.