Abstract

Recently, it was shown that thin films of aluminum oxide (Al₂O₃) provide an excellent level of surface passivation on low-resistivity p- and n-type silicon wafers. Al₂O₃ is a wide bandgap (~8.8 eV for bulk material) dielectric which consists of different crystalline forms. On contrary amorphous Al₂O₃ films are used for passivation layers with a somewhat lower bandgap (~6.4 eV) and with a refractive index of ~1.65 at a photon energy of 2 eV. The films are therefore fully transparent over the wavelength region of interest for solar cells. Research groups at IMEC and the Eindhoven University of Technology (TU/e) showed that Al₂O₃ films prepared by Atomic Layer Deposition (ALD) lead to excellent levels of surface passivation of n-type and p-type Si compared to Chemical Vapor Deposition (CVD) method. It was found that the hydrogen content of the Al₂O₃ films is very important for the chemical passivation of c-Si. However, the films prepared by CVD-based techniques exhibit a lower hydrogen content (typically 2-3 at%) and this hydrogen is mostly bonded to the (excess) O as –OH groups.

Considering the importance of hydrogen content in the Al₂O₃ film for passivating solar cell, we optimize our ALD Al₂O₃ process (temperature and purging) for passivating different types of solar cell. We can get very uniform passivation over 156 mm x 156 mm substrates (a Standard Deviation of IV₅₀ of 1.3%). Very high IV₅₀ and low Jₚ were achieved for highly boron doped p+ emitter n-type Si solar cell as well as plain FZ based solar cell.

Precursors used and Instrumentation

- TMA (98%) was used as Al source, which was obtained from Strem.
- DI Water was used as O source.
- All films were deposited on a GEMStar ALD system with cassettes.
- TMA precursor held at room temperature.
- H₂O precursor held at room temperature.
- All films grown at a temperature range of 200°C to 250°C.
- Commercial textured solar plate (156 mm x 200 mm) with highly B doped were used.
- All the deposited solar cell were annealed in N₂ for 20 minutes.
- Simon Instruments minority carrier lifetime test were performed with 25 points mapping.

Performance of Industrial Type Solar Cell with Al₂O₃

This relation is often quoted by Fraunhofer. This analytical expression agrees well with quokka 3D cell model. Very high efficient cell requires IV₅₀ of ~675 mV, which means Jₚ is ~75 fA/cm². Also the coating should be uniform over 156 mm x 156 mm cell.

Performance of Industrial Type Solar Cell with Al₂O₃

The performance of typical ALD Al₂O₃ on 8” Si substrate using standard recipe at 250°C with 12 s purging is shown at the left graph. The growth rate is ~0.5 Å/cy and the non-uniformity is 0.39%. With p-type float zone wafer IV₅₀ of 700 mV and 703 mV were achieved after anodizing.

Summary

We present excellent saturation current densities Jₚ and high IV₅₀ over a 156 mm x 156 mm textured boron doped p-type silicon wafers with passivation by an efficient thermal ALD Al₂O₃ process: both IV₅₀ and Jₚ reach target values: center of IV₅₀ is around 674 mV while Jₚ is around 59 fA/cm². And the non-uniformities of IV₅₀ and Jₚ are 0.2% and 9%.

References

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Figures

Performance of Investigated Cell with Al₂O₃

The same recipe was performed on a commercial textured solar cell with highly B doping. 15 mm of ALD Al₂O₃ showed a tighter distribution of IV₅₀ of 676 - 666, which is comparable to the result obtained from p-type float zone wafer. However the Jₚ measurement showed large variation.

Finally we lowered the temperature to 200°C and maintained the purging time to 7s gave good passivation with tight distribution of IV₅₀ and low Jₚ. But the median value of Jₚ is still higher than target value and the variance is larger than 70 to 110 fA/cm².