Optimization of ALD Al_2O_3 for Surface Passivation of Solar Cell

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Abstract

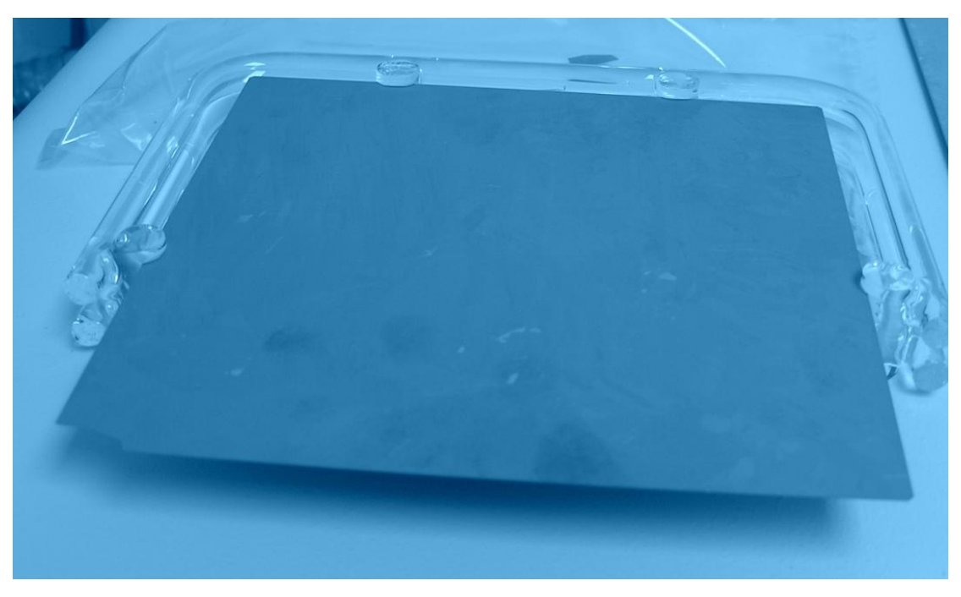
Recently, it was shown that thin films of aluminum oxide (Al_2O_3) provide an excellent level of surface passivation on low resistivity p- and n-type silicon wafers. Al_2O_3 is a wide bandgap (~8.8 eV for bulk material) dielectric which consists of different crystalline forms. On contrary amorphous Al2O3 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[1] and the Eindhoven University of Technology (TU/e)[2] showed that Al_2O_3 films prepared by Atomic Layer Deposition (ALD) lead to excellent levels of surface passivation of *n*-type and *p*-type c-Si compared to Chemical Vapor Deposition (CVD) method. It was found that the hydrogen content of the Al_2O_3 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..

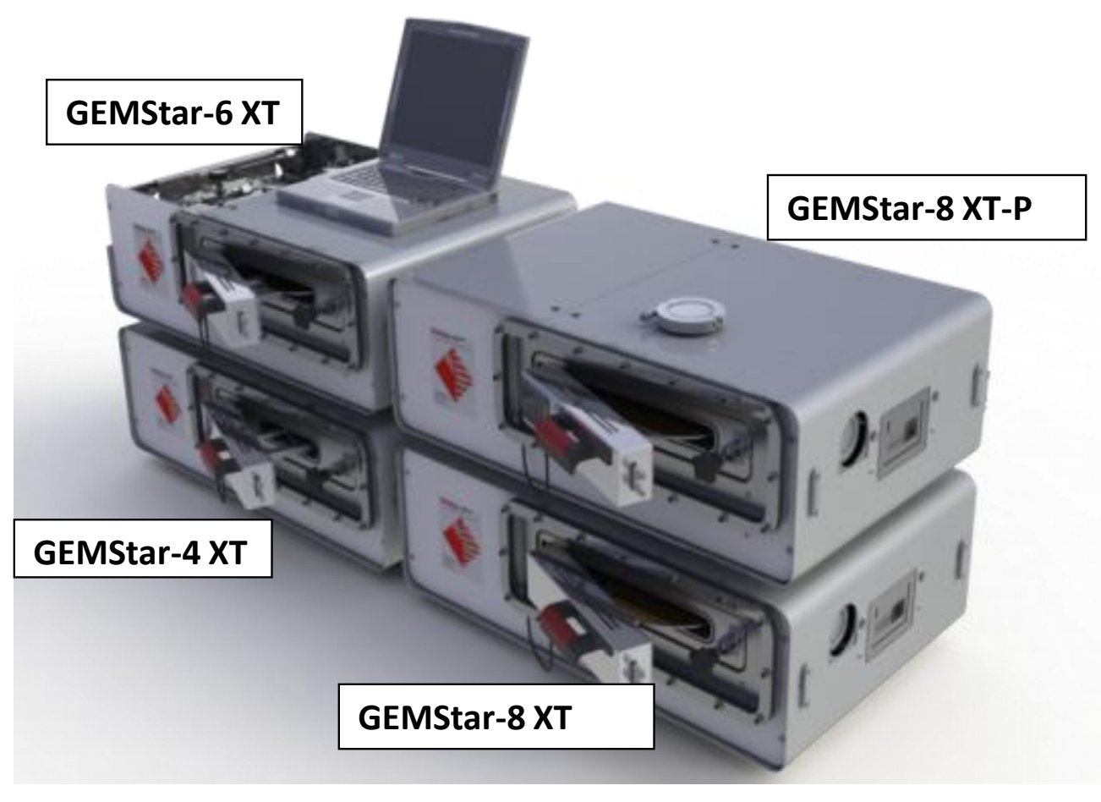
Considering the importance of residue hydrogen content in the Al_2O_3 for passivating solar cell, we optimize our ALD Al_2O_3 process (temperature and purging) for passivating different types of solar cell. We can get very uniform passivation over 156 mm x 156 mm substrates (a Standard Deviation of iV_{oc} of 1.3%). Very high iV_{oc} and low J_{oe} were achieved for highly boron doped P+ emitter n-type Si solar cell as well as plain FZ based solar cell.

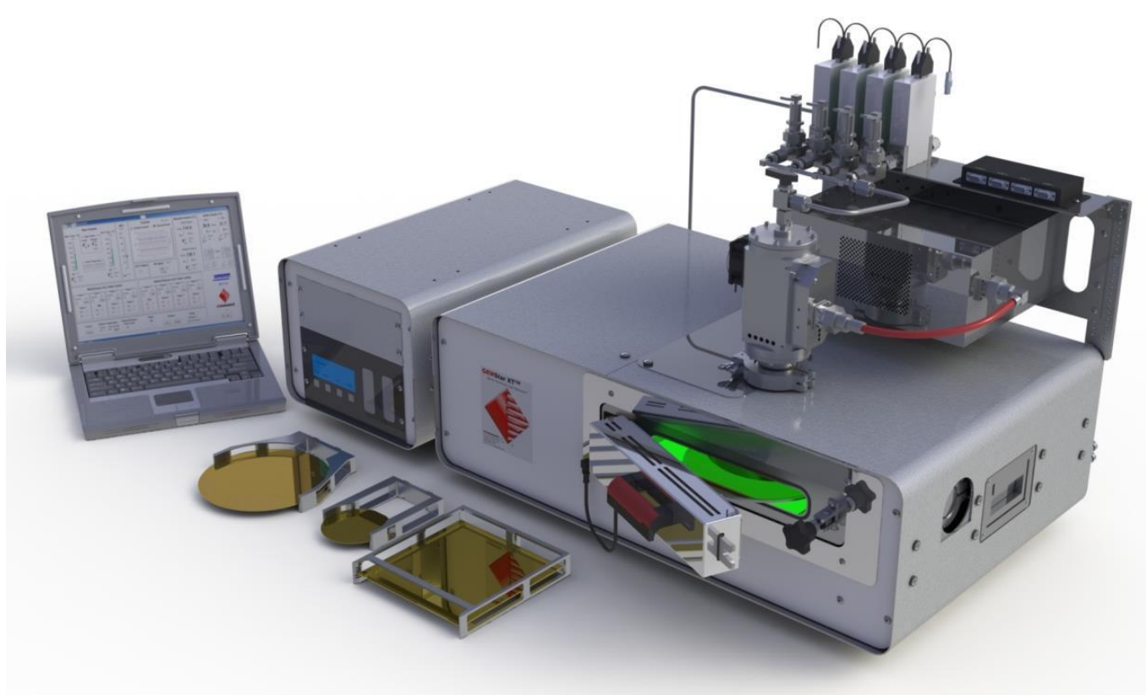
1. G. Agostinelli *et al*., *Sol. Energy Mater. Sol. Cells* **90** 3438-3443 (2006)
2. B. Hoex *et al*., *Appl. Phys. Lett.* **89** 042112 (2006)

Precursors used and Instrumentation

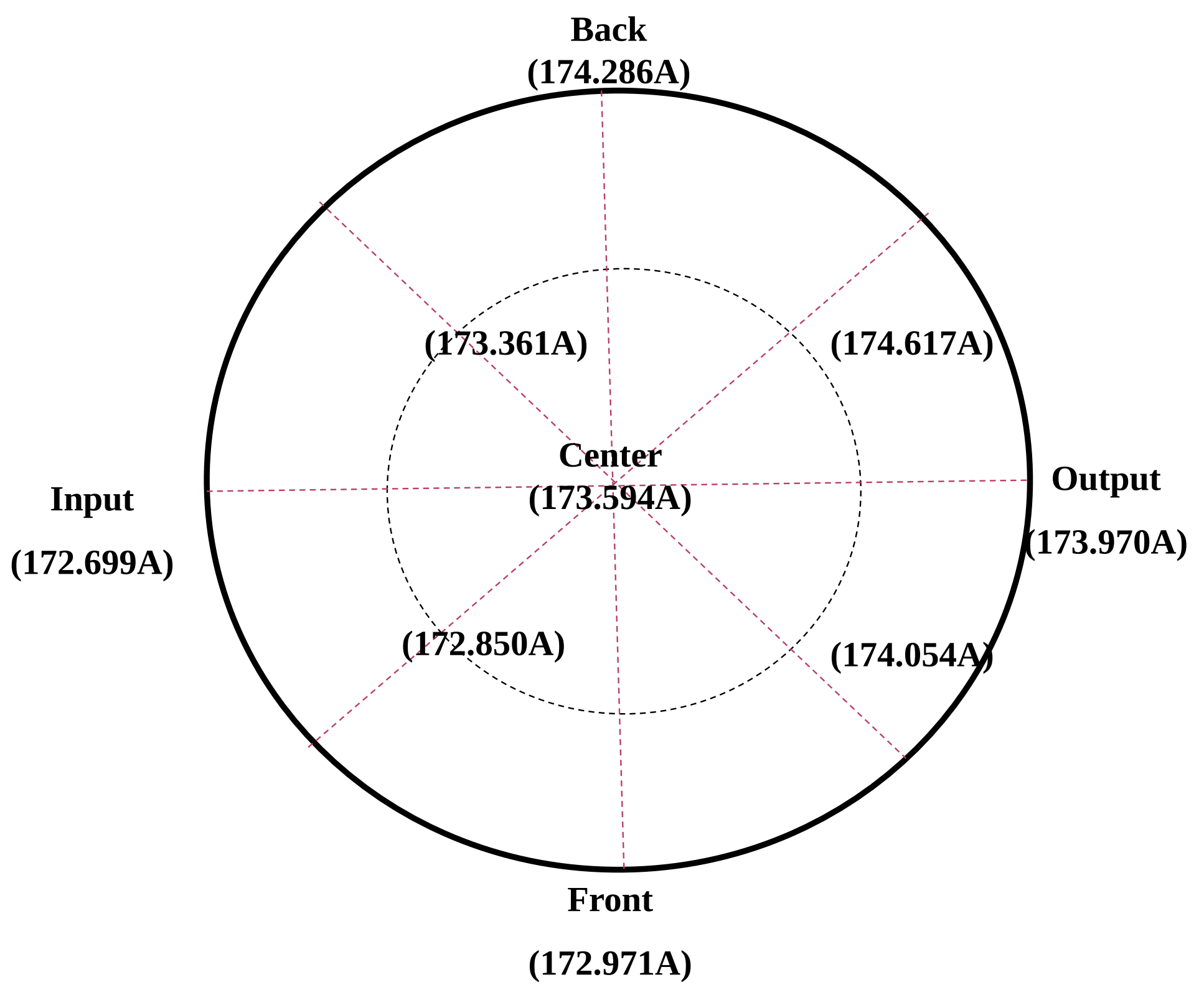
- TMA (98%) was used as Al source, which was obtained from Strem.
- DI Water was used as O source.
- All films were deposited on a GEMStar ALD system with cassettes.
  - TMA precursor held at room temperature,
  - H_2O precursor held at room temperature,
  - All films grown at a temperature range of 200 ℃ to 250 ℃.
  - Commercial textured solar plate (156 mm x 156mm) with highly B dosed were used.
- All the deposited solar cell were annealed in N_2 for 20 minutes.
- Sinton Instruments minority carrier lifetime test were performed with 25 points mapping.





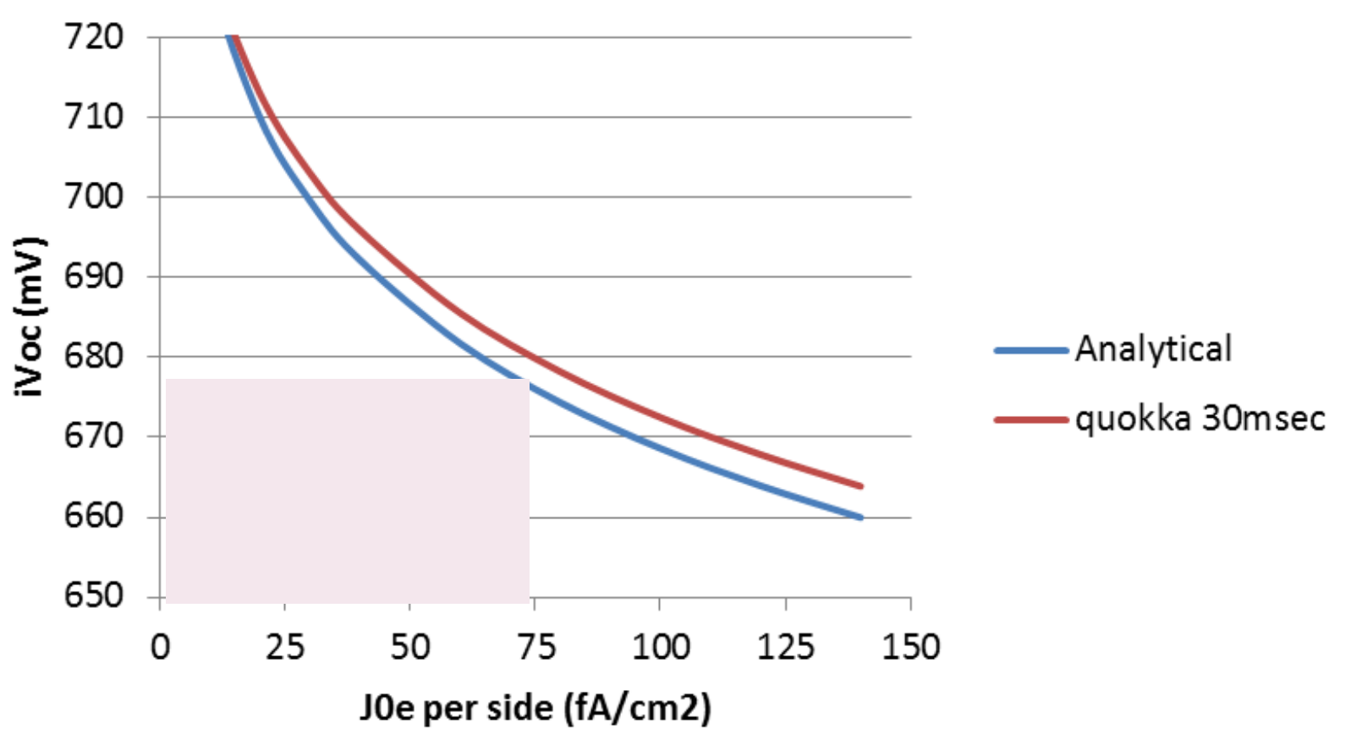


Performance of Industrial Type Solar Cell with Al_2O_3



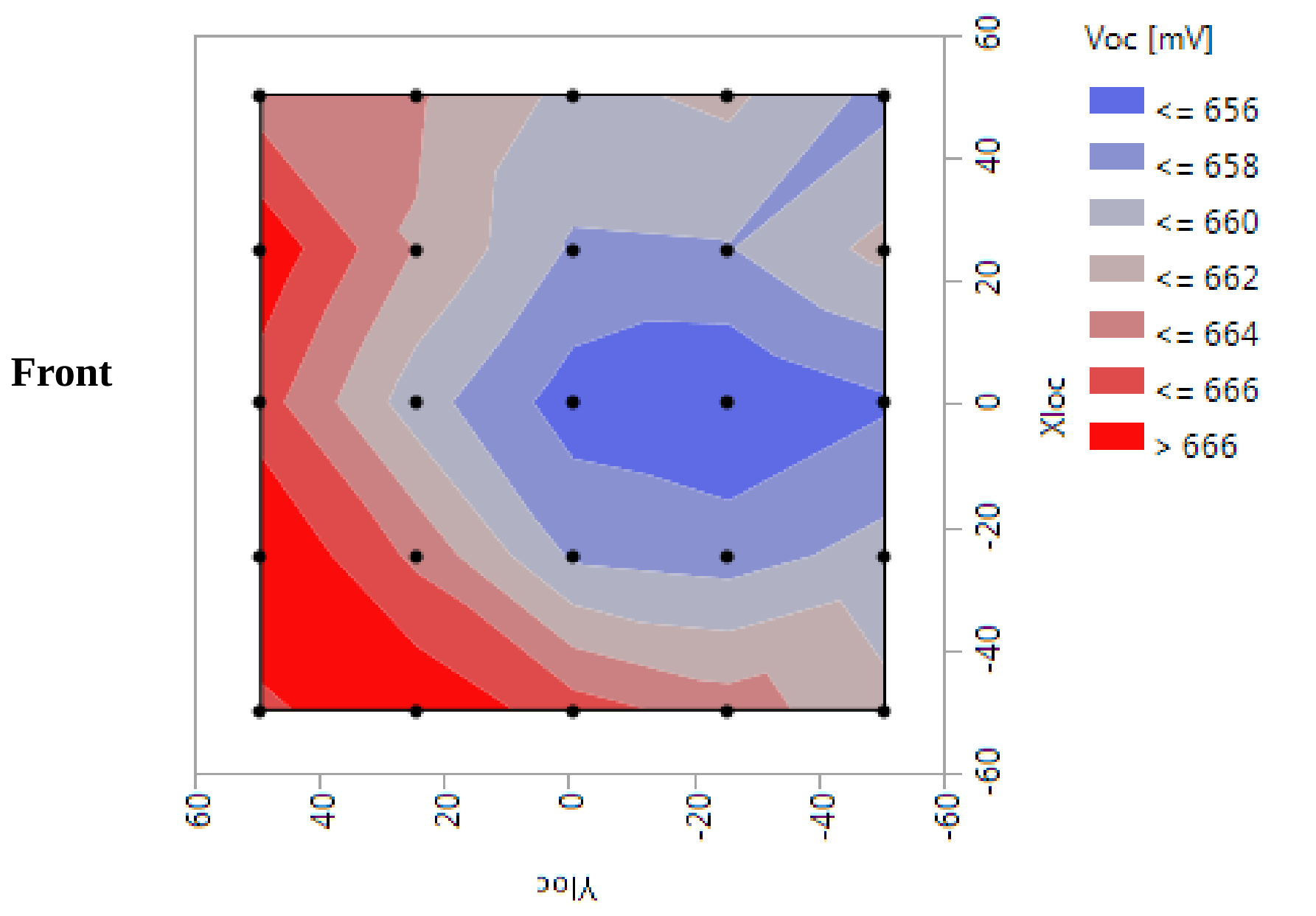
The performance of typical ALD Al_2O_3 on 8" Si substrate using standard recipe at 250 °C with 12 s purging is shown at the left graph. The growth rate is 1.05 Å/cy and the non-uniformity is 0.39%. With p type float zone wafer iV_{oc} of 700 mv and 703 mv were achieved after annealing.

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{J_{sc}}{2J_{0e}}+1\right)$$

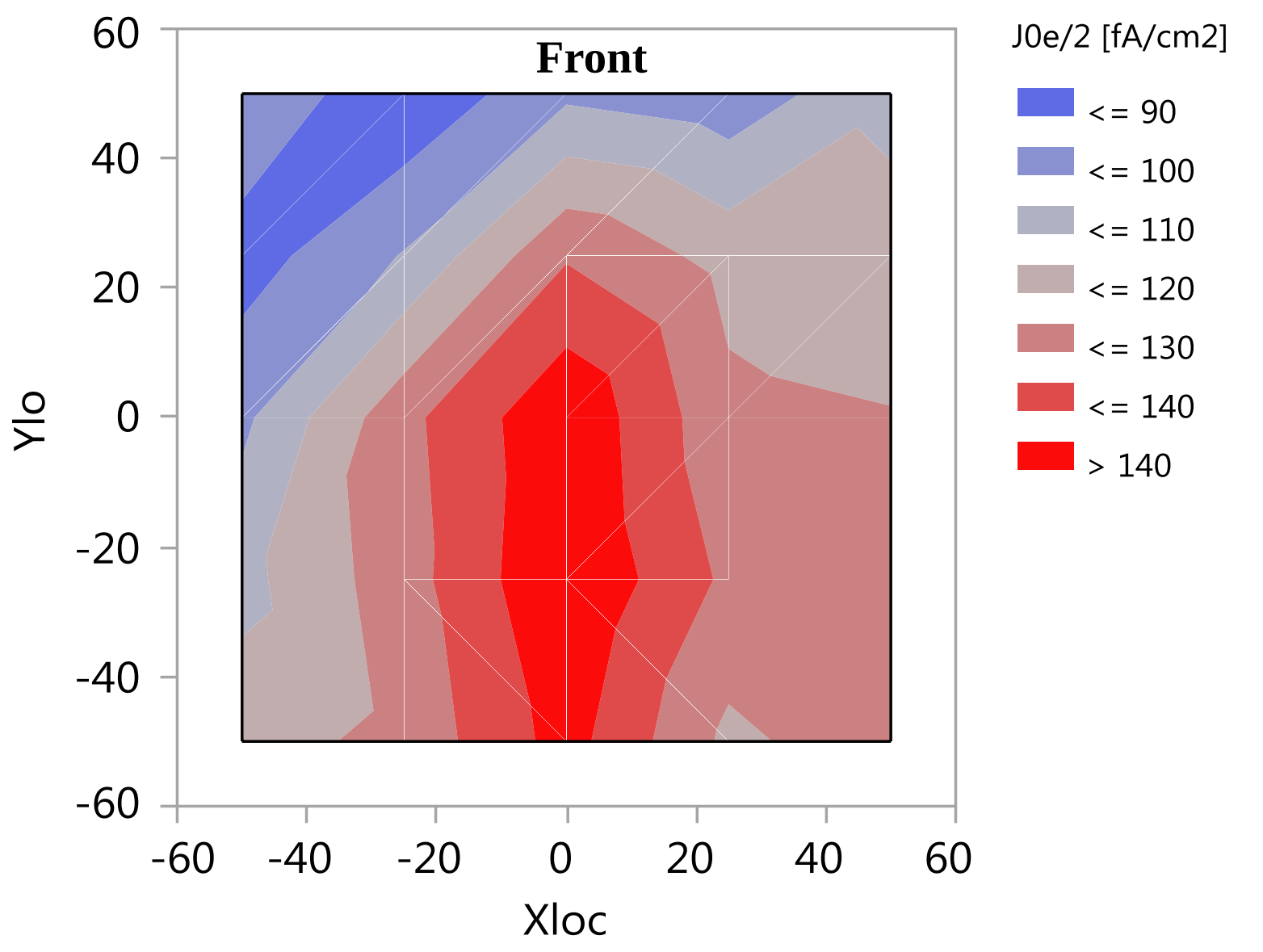


This relation is often quoted by Fraunhofer. This analytical expression agrees with quokka 3D cell model . Very high efficient cell requires iV_{oc} of ~ 675 mV, which means J_{oe} < 75 fA/cm². Also the coating should be uniform over 156 mm x 156 mm cell.

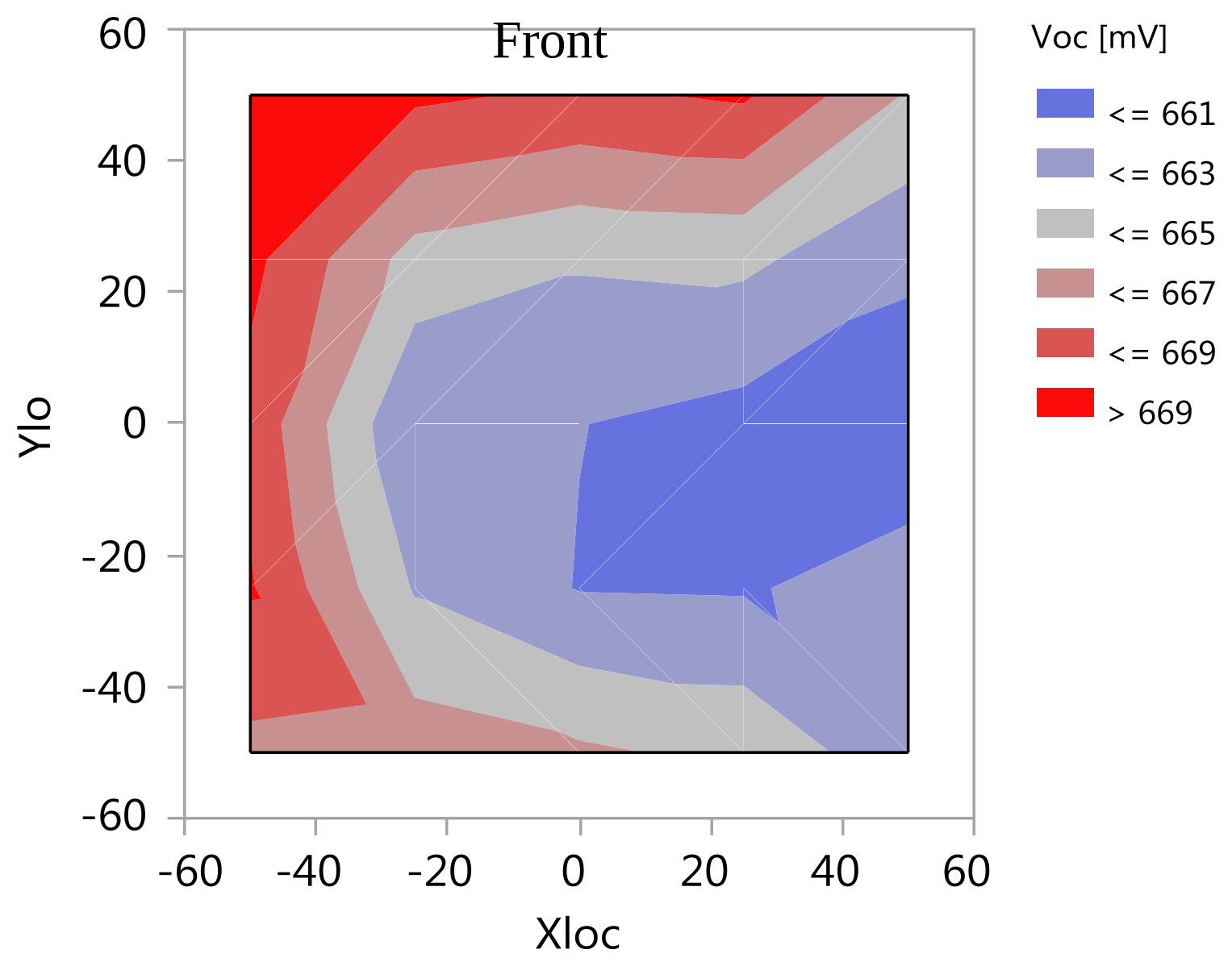
Performance of Industrial Type Solar Cell with Al_2O_3

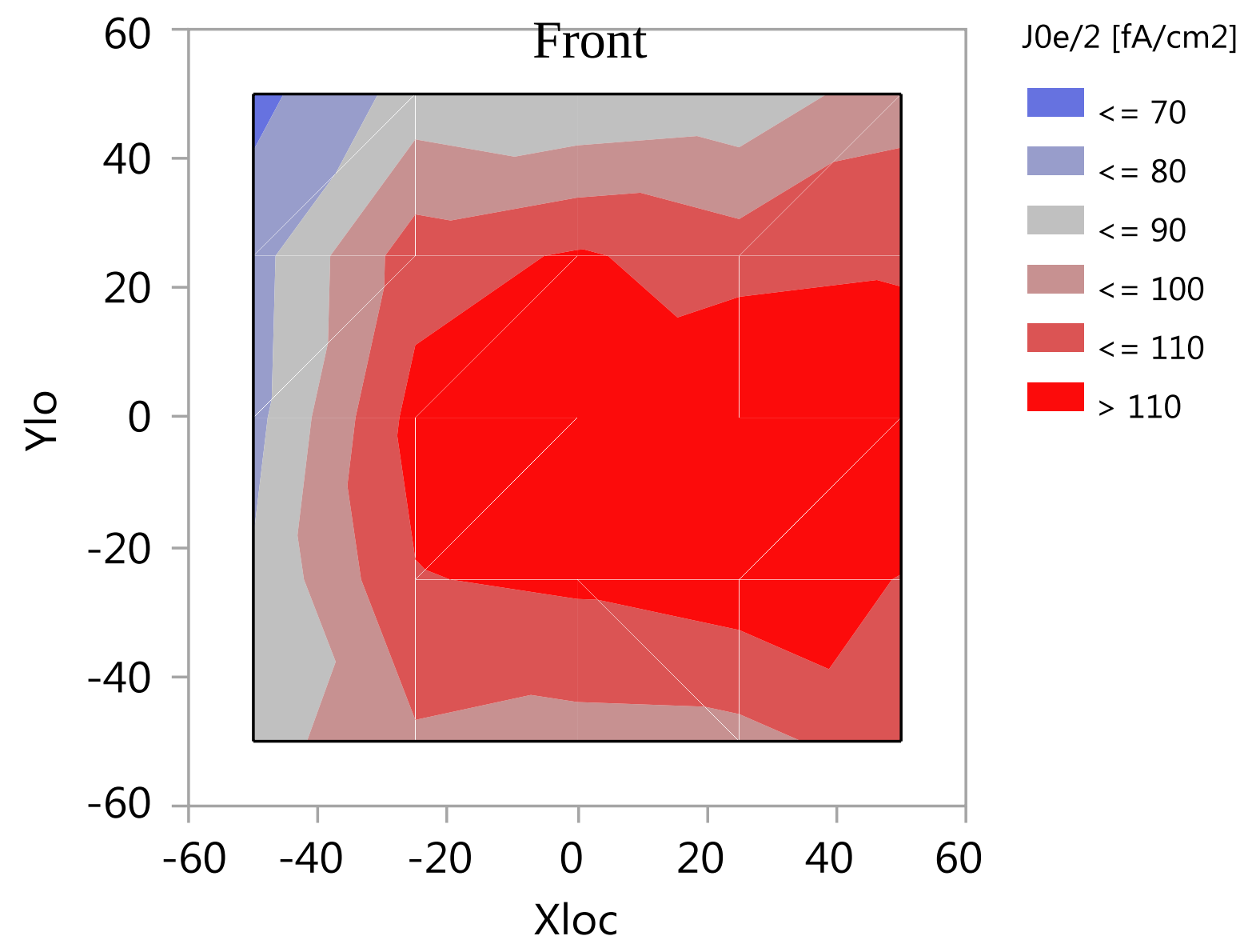


The same recipe was performed on a commercial textured solar cell with highly B doping. 15 nm of ALD Al_2O_3 showed a tighter distribution of iV_{oc} of 656 – 666, which is comparable to the result obtained from p- type float zone wafer. However the J_{oe} measurement showed large variation.

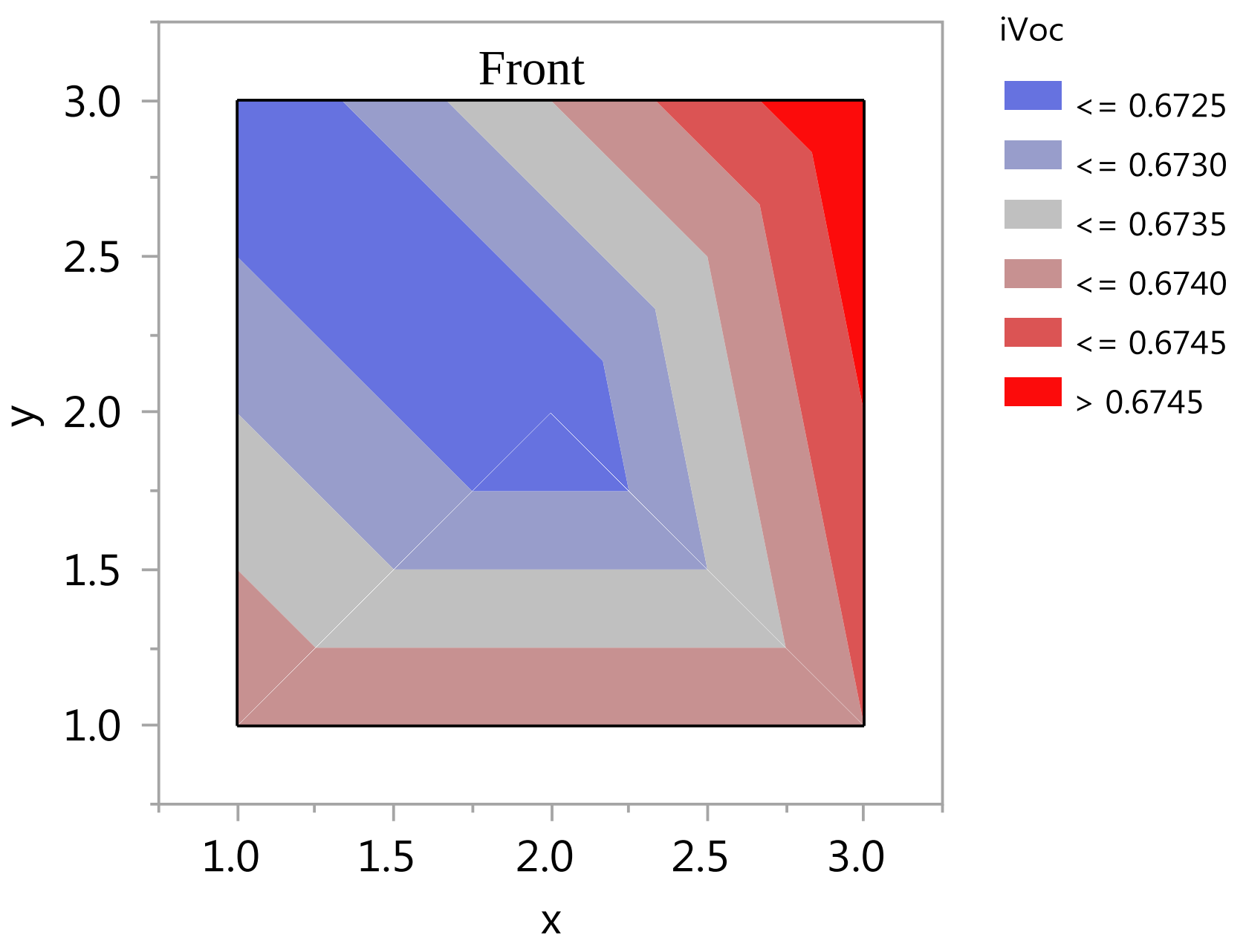


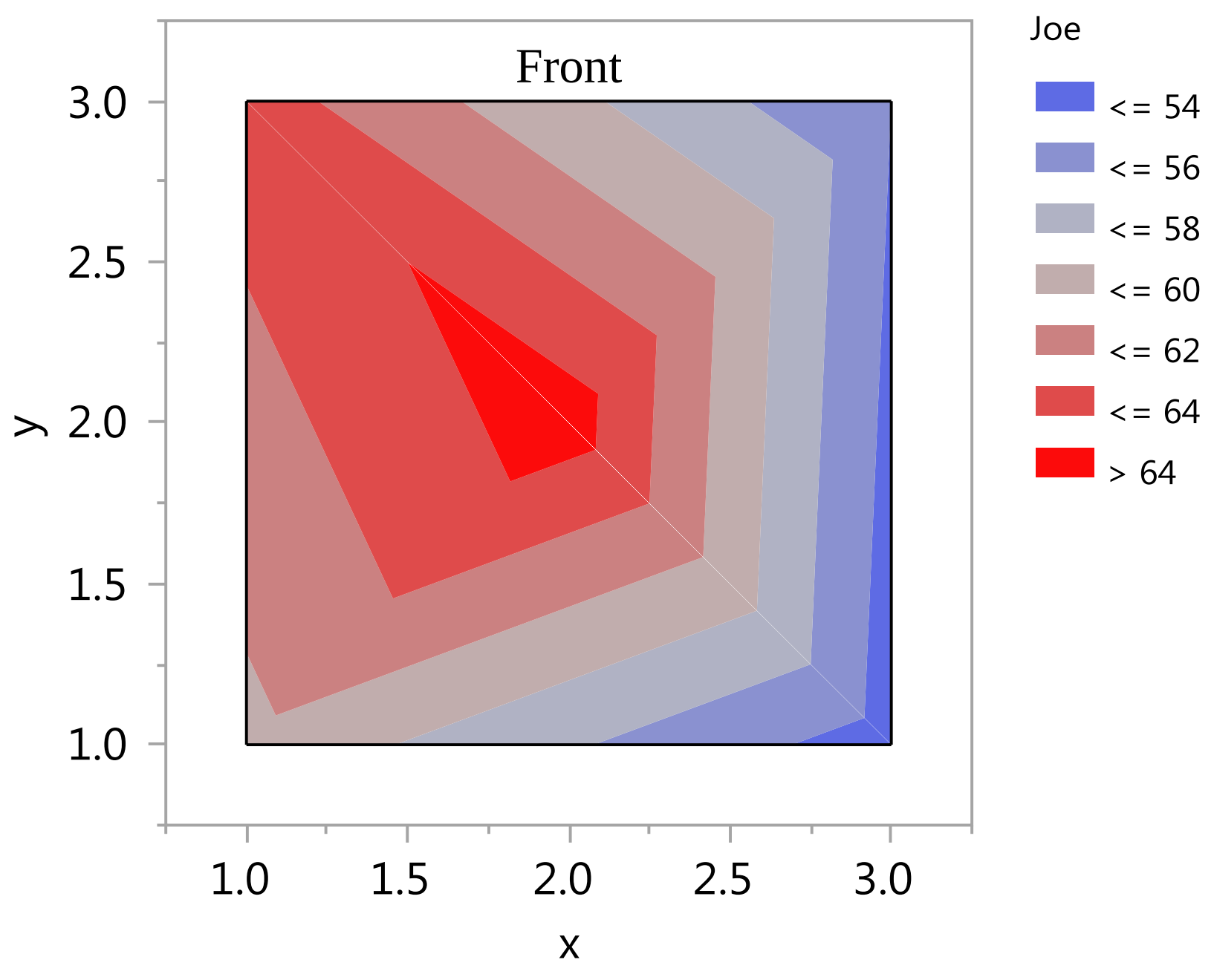
However the J_{oe} measurement of the same sample done under same recipe showed large variation from 90 to 140 fA/cm². Also the median value is far off the target value:75 fA/cm²





Increase the thickness to 30 nm while shortening the purging time to 7s gave good passivation with tight distribution of iV_{oc} and lower J_{oe}. But the median value of J_{oe} is still higher than target value and the variance is larger from 70 to 110 fA/cm².





Finally we lowered the temperature to 200 °C and maintained the purging time at 7s. We got very uniform passivation over the highly B doped textured Si wafer. The iV_{oc} varies from 673 mv to 675 mv while J_{oe} varies from 54 fA/cm² to 64 fA/cm². Most importantly both numbers reach target value or blow. It showed the excellent efficiency and super uniformity of the thermal Al_2O_3 done on GEMStar ALD tool. In the future, the lower thickness will be evaluated for throughput consideration. Also multi-wafer will be tested.

Summary

We present excellent saturation current densities J_{oe} and high iV_{oc} over a 156 mm x 156 mm textured boron diffused p-type emitters on n-type silicon with passivation by an efficient thermal ALD Al_2O_3 process: both iV_{oc} and J_{oe} reach target values: center of iV_{oc} is around 674 mv while J_{oe} is around 59 fA/cm² ; And the non-uniformities of iV_{oc} and J_{oe} are 0.2% and 9%.

Acknowledgements

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References

•D. R. Beaulieu et al "*Nano-engineered ultra high gain microchannel plates*", Nucl. Instr. Meth. A 607 (**2009**) pp. 81-84.
•D.R. Beaulieu et al "*Plastic microchannel plates with nano-engineered films*", Nucl. Instr. Meth. A 633 (**2011**) pp. S59-S61.
•N. Sullivan, et al, "*Novel microchannel plate device fabricated with atomic layer deposition*", 9th AVS-ALD, Monterey CA, July 19-22, **2009**.
•A. Yamada; et al., "*Atomic layer deposition of ZnO transparent conducting oxides*", Applied Surface Science 112 (**1997**) 216-222.
• G. Agostinelli *et al*., *Sol. Energy Mater. Sol. Cells* **90** 3438-3443 (2006)
• B. Hoex *et al*., *Appl. Phys. Lett.* **89** 042112 (2006)
• G. Dingemans and W. M. M. Kessels; "*Status and prospects of Al2O3-based surface passivation schemes for silicon solar cells*". J. Vac. Sci. Technol. A 30(4), **2012**, 040802-1 to 040802-27.
•D. Gorelikov, H. Li, J. Narayanamoorthy, N. Sullivan; "*High surface area /high aspect ratio ALD process optimization using anodic aluminum oxide*"; ALD **2013**, San Diego, CA, July 28–31.
• J. Narayanamoorthy, D. Gorelikov, H. Li, , N. Sullivan; "*Large Area MCPs Coating by ALD*"; C-ALD **2014**, Shanghai, China;
• H. Li, et al., "*Low Temperature (LT) Thermal ALD Silicon Dioxide Using Ozone Process*"; ALD **2014**, Kyoto, Japan.
• H. Li, J. Narayanamoorthy, N. Sullivan, "*Low Temperature (LT) Thermal ALD Oxides Using Ozone Process*", MRS Spring **2014**, San Francisco, CA.
• H. Li, Mary Moore, N. Sullivan, J. Narayanamoorthy, "*Low-Temperature Atomic Layer Deposition of Platinum Using (Methylcyclopentadienyl)trimethylplatinum and Ozone* ", AVS Fall **2015**, San Jose, CA.
• H. Li, J. Narayanamoorthy, D. Gorelikov, N. Sullivan, "*Characterization of ALD Undoped and Doped ZnO Films*", ALD **2015**, Portland, OR.