Progress using Merck SolarEtch for crystalline silicon solar cells

Annual Report

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Introduction

In previous reports we have demonstrated efficiencies of greater than 20% on our Delta-STAR device architecture on a 4 cm^2 float zone silicon substrate, which utilizes Merck Isishape to open vias on the rear passivating dielectric of the device. Typical crystalline silicon solar cells have a fully metalized rear side of the solar cell which limits the cell's voltage and current due to inferior passivation and reflection properties, respectively. Using a device structure with a passivated rear side allows for voltage and current enhancement beyond that of typical cells, the challenge however, for this type of structure is how to contact the rear side of the cell. Merck Isishape provides a unique solution to removing the rear dielectric to allow for contact without creating damage like other solutions such as laser ablation or without many time consuming steps like photolithography. Our goal in this phase of our research was to transfer the Delta-STAR processing sequence from small area cells on float zone silicon to a industry standard 239 cm^2 cell size and cheaper Czochralski grown silicon material.

Experimental

$POCl_3$ Approach

A comparison of the $POCl_3$ Delta-STAR process and a Full aluminum BSF solar cell is shown below in figure 1 .

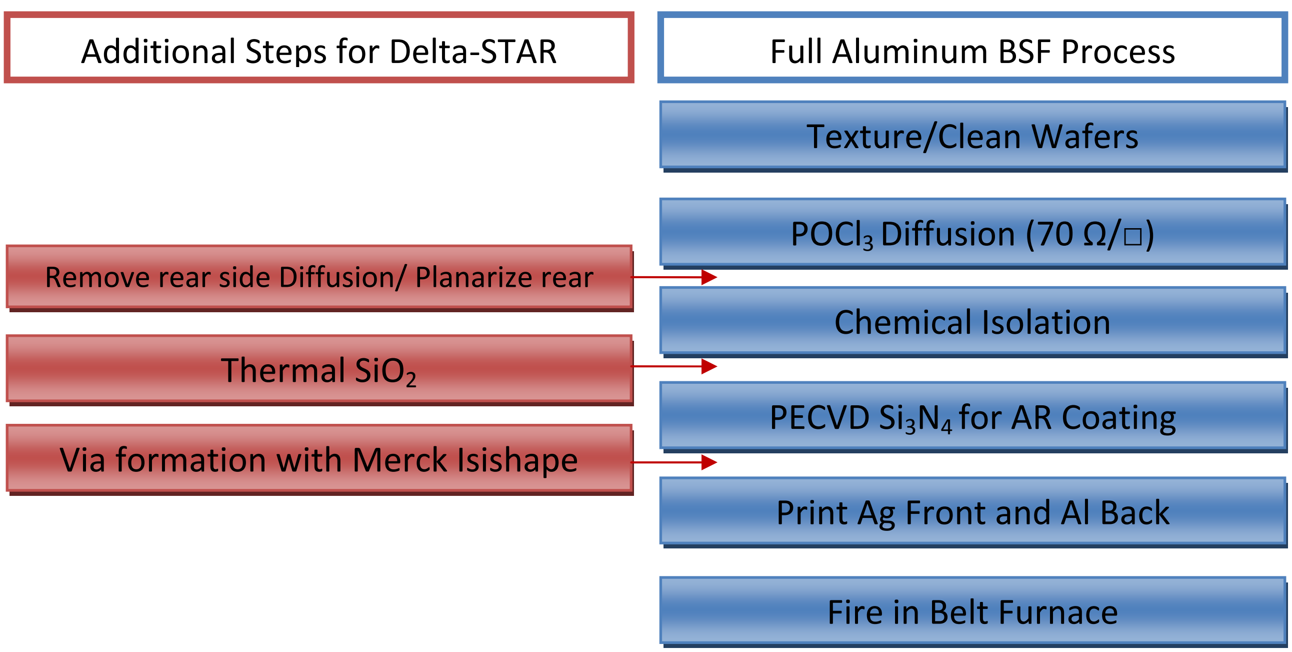

Figure 1 Process flow for full aluminum BSF and $POCl_3$ Delta STAR Process

Figure 2 is an example of some typical vias formed with Merck Isishape for this experiment, the etching paste was cured at 340C for 90 seconds and cleaned in 0.05% KOH for 90 seconds at 50C in an ultrasonic bath. The vias are completely clean in the center but a residue can be seen around the edges.

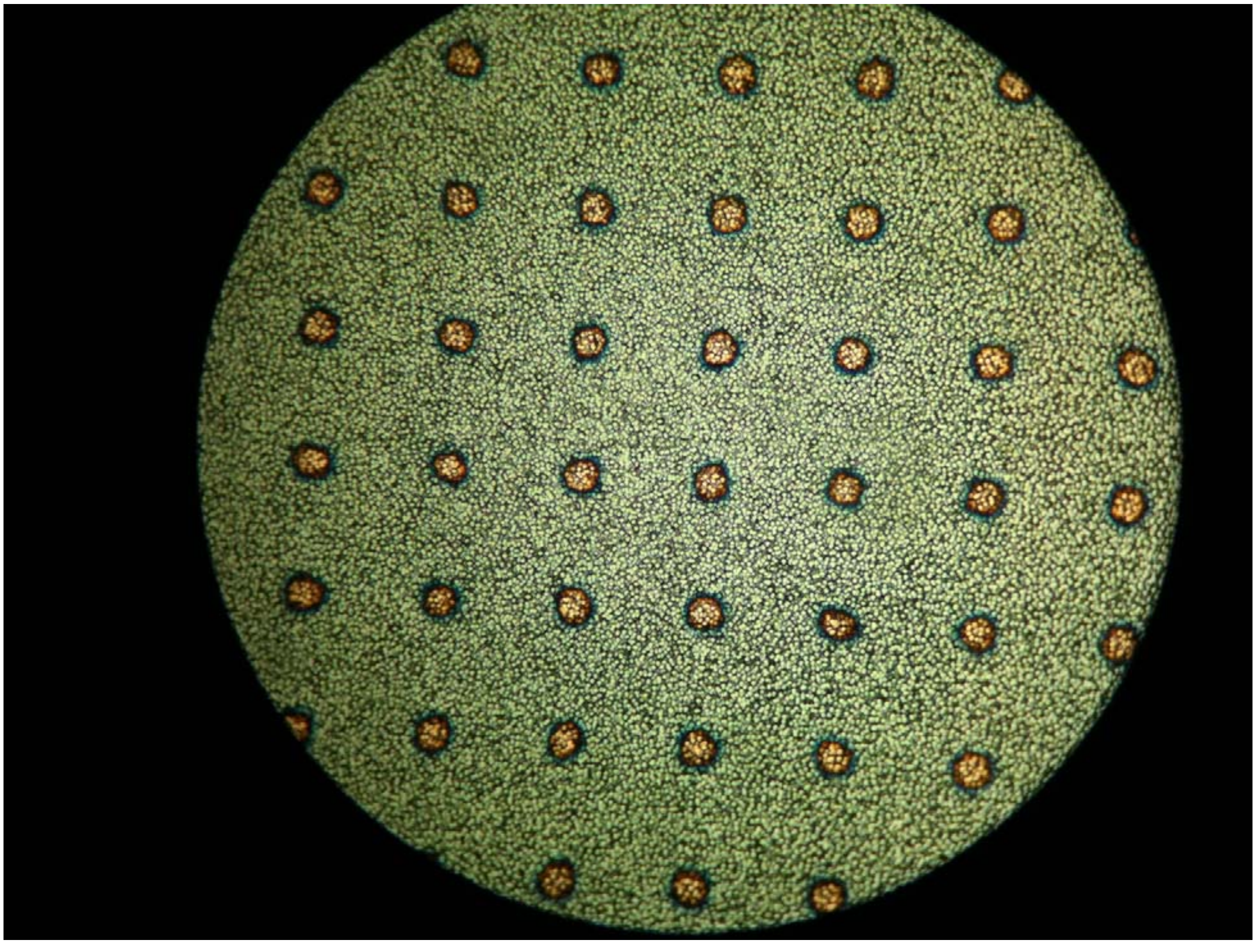

Figure 2. Vias etched into SiO_2 using Merck Isishape

Table 1 shows the results of the experiment detailed in figure 1.

Table 1.

Cell Name	Voc (mV)	Jsc (mA/cm²)	FF	Eff (%)	n factor	Rseries (ohmcm²)	Rshunt (ohmcm²)
LBSF 1	625	36.4	0.734	16.7	1.53	0.772	3056
LBSF 2	627	36.1	0.710	16.1	1.54	1.351	3306
LBSF 3	629	36.3	0.739	16.9	1.43	0.903	3384
Full BSF	627	36.0	0.758	17.1	1.06	1.178	2183

The Delta-STAR ("LBSF") cells did not exhibit a high open circuit voltage that would be expected of a dielectric passivated rear cell and the cell current only showed minimum improvement over the Full BSF cell. To explore why the open circuit voltage was lower than expected we performed an light beam induced current,LBIC, scan of an area of one of the Delta-STAR cells, this test gives us a map of the quality and uniformity of passivation on the cell, the results of the scan can be seen in figure 3.

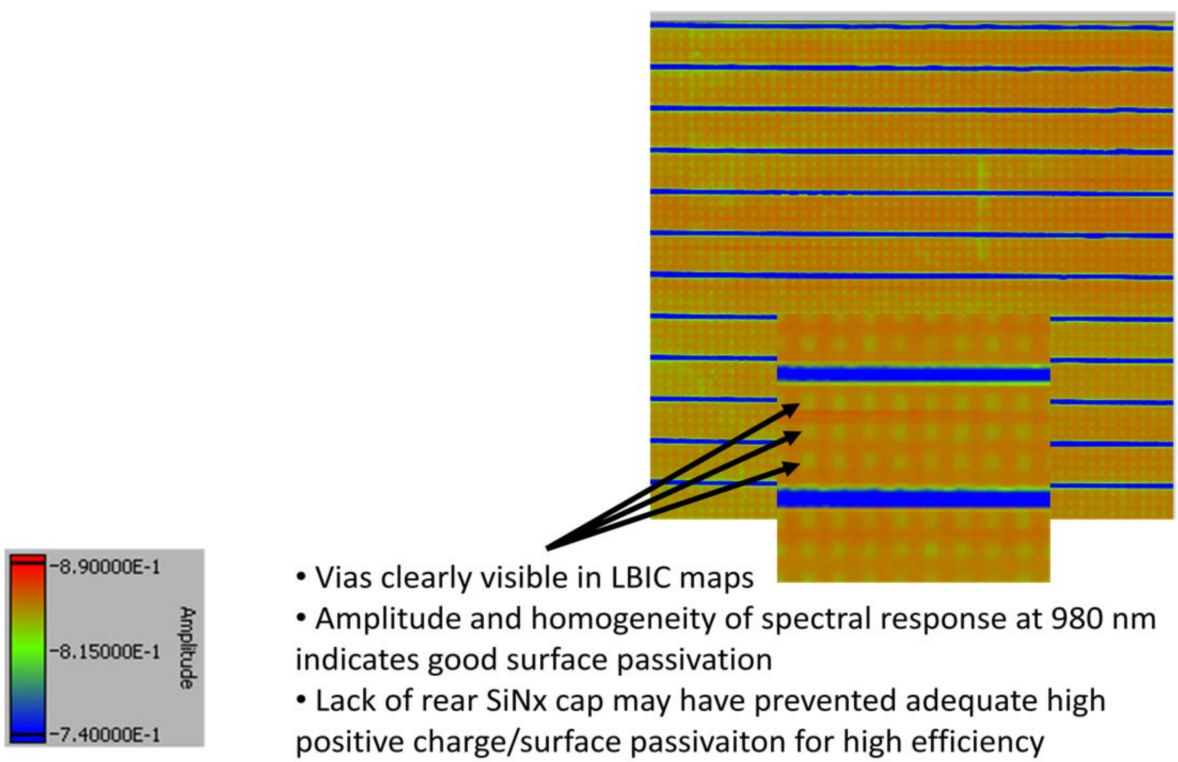

Figure 3 Results of LBIC scan

From the LBIC scan it appears that the passivation is uniform and it is unclear why the open circuit voltage is not improved over the Full BSF, we believe that it could be due to a poor quality surface formed when planarizing the rear side of the cell during processing.

P Implant Approach

This approach uses a phosphorus field and selective emitter implantation instead of $POCl_3$ and also utilizes single side textured wafers to start with to avoid the poor surface left from removing the diffusion and texturing on the rear. The process flow can be seen in figure 4

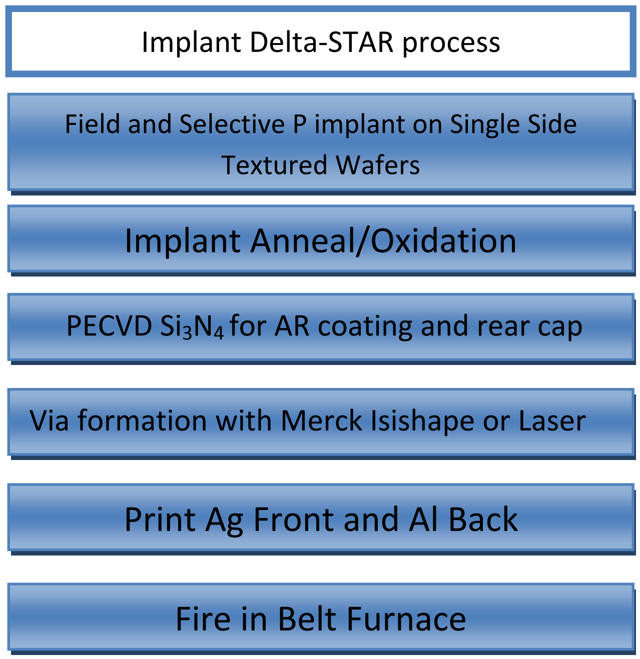

Figure 4, Process flow for Implant Delta-STAR process

The results of this experiment are shown in table 2. The implant Delta-STAR results are more promising than the $POCl_3$ process. These cells showed improved Voc, Jsc and FF over the $POCl_3$ Delta-STAR cells, however the cells with etching paste vias had inferior Voc, Jsc and FF compared with identical cells that had laser opened vias. We believe this could be due to an incomplete BSF formed at the edge of via's formed by the etching paste due to incomplete etching at the edges. This effect can be seen in figure 5.

table 2.

ID	Via opening methods	Voc (mV)	Jsc (mA/cm2)	FF	Eff (%)	n-factor	Rs (ohm.cm)	R-shunt (ohm.cm)
SGJ-11-2-66	etching paste	642	36.9	0.748	17.7	1.50	0.67	8179
SGJ-11-2-67	etching paste	639	36.5	0.738	17.2	1.57	0.74	3265
SGJ-11-2-68	etching paste	634	36.3	0.742	17.1	1.55	0.65	6669
SGJ-11-2-69	etching paste	643	36.5	0.754	17.7	1.53	0.49	7914
SGJ-11-2-72	etching paste	638	36.4	0.738	17.1	1.67	0.49	1784
SGJ-11-2-79	laser vias	649	37.7	0.766	18.7	1.24	0.76	3738
SGJ-11-2-82	laser vias	647	37.2	0.754	18.2	1.42	0.82	6006
SGJ-11-2-84	laser vias	649	37.5	0.737	17.9	1.35	1.22	7001
PJ-11-9-25	laser vias	652	38.2	0.779	19.4	1.08	0.85	10854
PJ-11-9-26	laser vias	651	38.1	0.774	19.2	1.07	0.91	7893
PJ-11-9-27	laser vias	653	38.2	0.774	19.3	1.08	0.90	11273
PJ-11-9-28	laser vias	652	38.2	0.782	19.5	1.06	0.80	14699
PJ-11-9-29	laser vias	653	38.2	0.772	19.3	1.07	0.83	7455

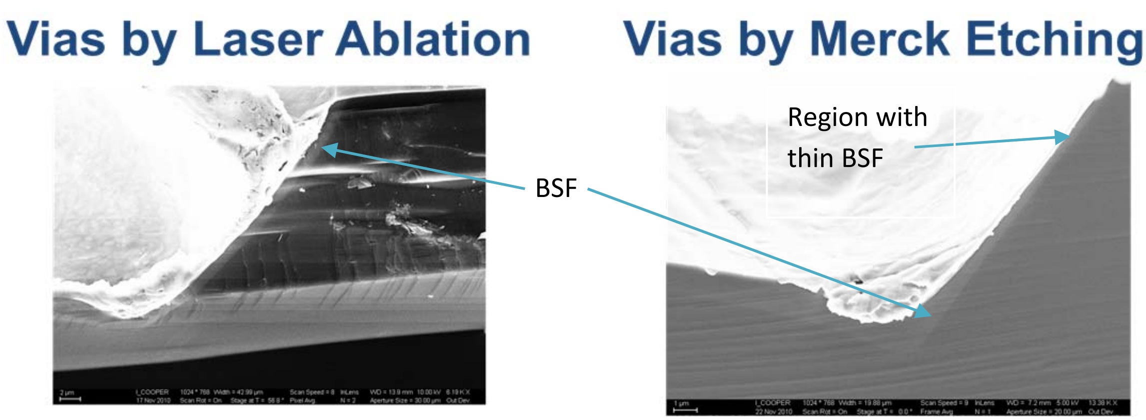

Figure 5, LBSF from Al fire through in etching paste and laser vias

Incomplete LBSF Simulations

This approach to understand the effect an incomplete BSF could have on solar cell performance; device simulations were done using Sentaurus Device. In these simulations we varied the doping profile at the edge of the rear contact to understand what role these regions affect the device characteristics. In these simulations we took care to use realistic physical models and device characteristics in these simulations. The physical models used were Scharfetter (lifetime) , Philips mobility model, Fermi statistics, Auger recombination, SRH recombination in the bulk and at surfaces. The modeled cell parameters and device structure are shown in Table 3 and Figure 6 respectively.

Table 3

Modeled Cell Parameters	
Substrate Thickness	180 μm
Width	500 μm
Front Contact Half Width	35 μm
Rear Contact Half Width	50 μm
Substrate Doping	8.10E15 /cm3
Bulk Lifetime	300 μs
FSRV	20000 cm/s
Contact SRV	1000000 cm/s
BSRV	50 cm/s
BSF Peak Doping	5E19 /cm3
BSFDepth (Gaussian)	2 μm
Emitter Peak Doping	7E19 /cm3
Emitter Depth (Gaussian)	0.4 μm
Offset	0 - 4 μm
Rs	0.6 Ω-cm2

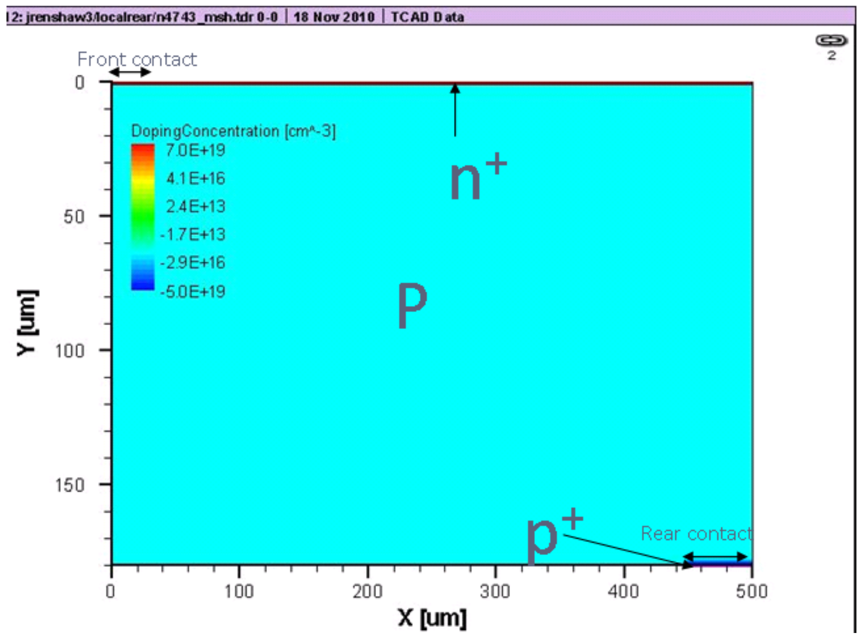

Figure 6, Modeled solar cell domain

To vary the BSF profile over the edge of the contact we created a variable called the offset that is basically the distance from the edge of the rear contact to the region of the BSF that is at peak doping. By varying the offset we can effectively vary the BSF over the edge of the contact. The effect of the offset can be seen in Figs 7 a,b, and c

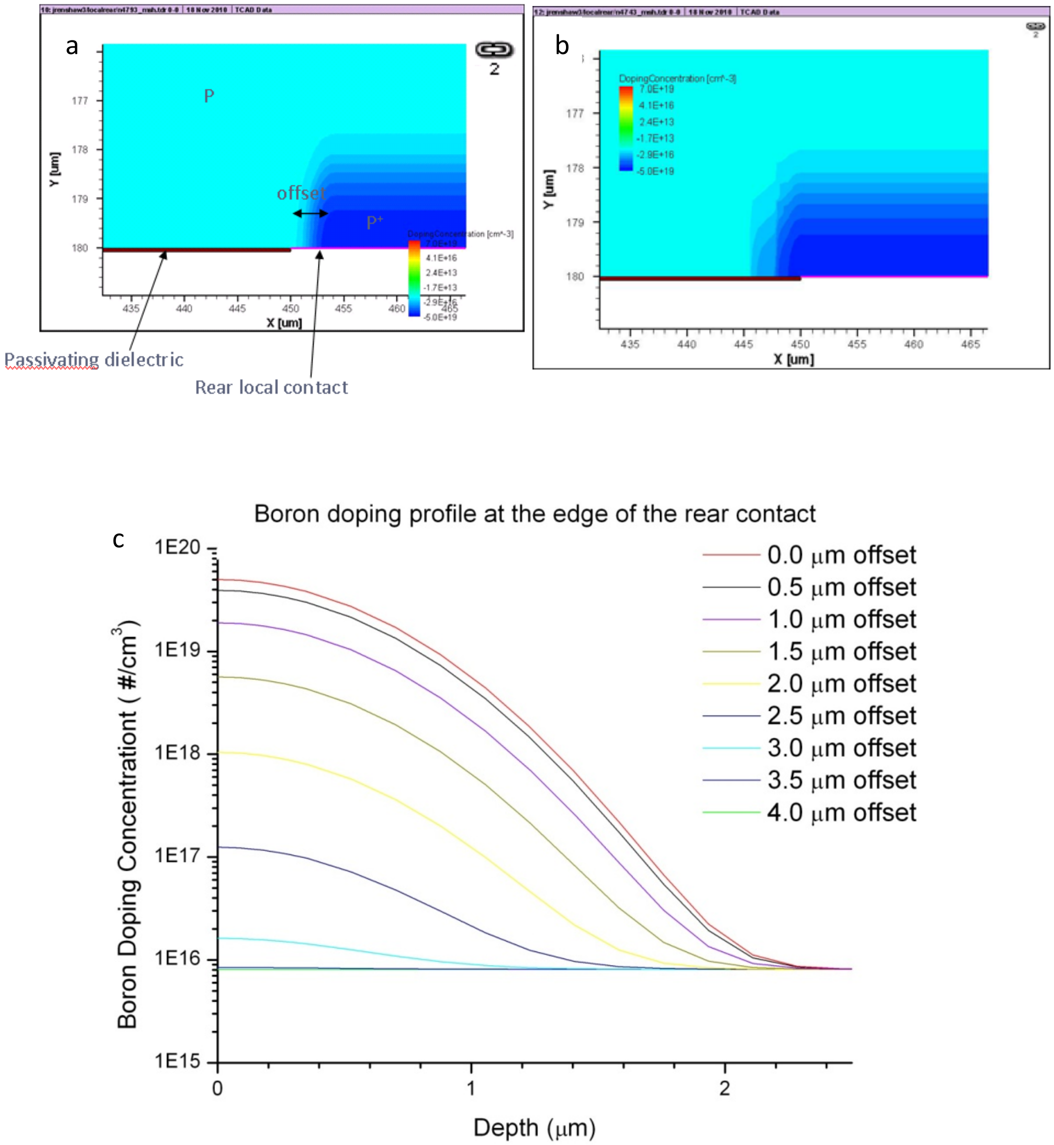

Fig 7(a), An example of a simulation with a large offset, (b), An example of a simulation with no offset,(c), The resulting profiles taken from the edge of the rear contact as a function of offset.

The results of the varying BSF profile over the edge of the rear contact can be seen in figure 8. The solar cell parameter affected by most varying the offset is the open circuit voltage, our simulations show that the Voc can drop as much as 20 millivolts if the BSF at the edge of the rear contact is absent. The short circuit current density is also reduced by about 0.5 mA for the worst case scenario. These effects combine for a 0.8% predicted loss in efficiency for the worst case. These simulations confirm our suspicion that the poor BSF at the edge of the rear vias could be responsible for the poorer performance of the etch paste created vias over the laser ablation created vias.

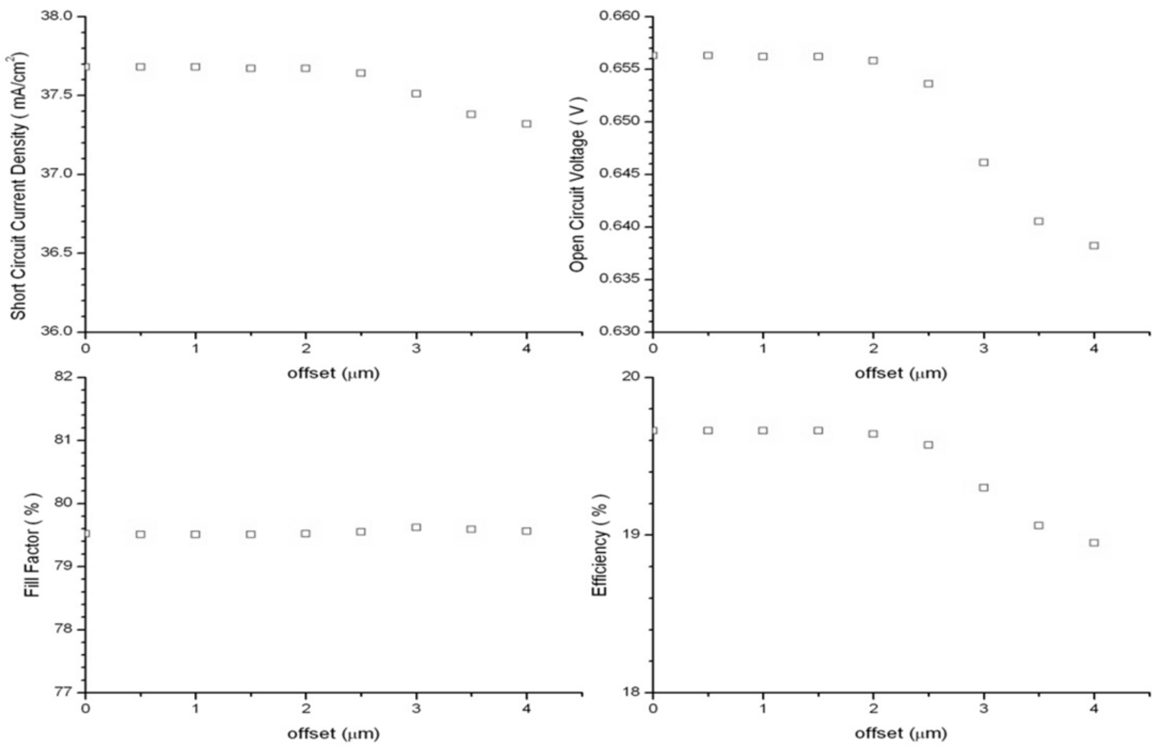

Fig 7(a), An example of a simulation with a large offset, (b), An example of a simulation with no offset,(c), The resulting profiles taken from the edge of the rear contact as a function of offset.

Conclusion

We have shown that the Merck Isishape can be used with $POCl_3$ and implant diffusion processes in order to create large area front and rear passivated silicon solar cells. We found that the implant method produces superior results to $POCl_3$ with a best cell efficiency of 17.7%. We were unable to determine why the laser is superior to the etching paste for creating vias on large area substrates while the two methods were essentially identical on small area substrates.