Development of Laser Fired Contact (LFC) Rear Passivated Laser Groove Buried Contact (LGBC) Solar Cells Using Thin Wafers

D. Morrison*, A. Cole, S. Devenport, J. Delve, K. Heasman
•G. Kocher, A. Pereau, B. Richards, J.Wilson

New and Renewable Energy Centre (NaREC), PVTC, Blyth, NE24 1LZ, UK
•Heriot-Watt University, Edinburgh, EH14 4AS
* Corresponding Author

Introduction

The high efficiency Laser Groove Buried Contact (LGBC) solar cell was invented by M.A. Green and S. R Wenham in 1984, and has been manufactured by BP Solar since 1992, and NaREC since 2005 [1]. A cross section schematic diagram of the LGBC solar cell is given in Figure 1.

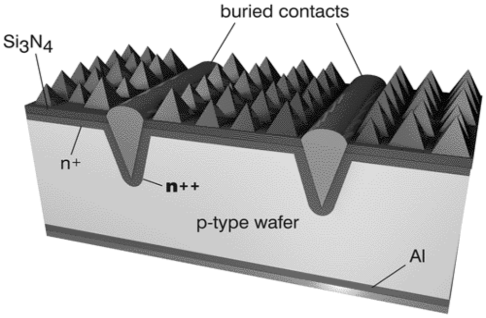

Fig 1: Schematic diagram of cross section of LGBC solar cell

A direct write laser process is used to form trenches on the front of the cell. The trenches are then metal plated to form buried contacts. The LGBC solar cell structure offers a number advantages over its screen printed counterparts. Shading losses are reduced since contacts are buried. High contact aspect ratio, a nickel silicide interface and low resistivity copper plating contribute to a decrease in contact resistance. Emitter resistance losses are minimised as finger spacing is narrower. In addition to this the buried contact structure includes a self aligned, highly doped selective emitter which reduces contact recombination. Rear surface passivation is provided by an Aluminium doped back surface field (Al-BSF).

The PV business community continually strives to reduce the cost per watt of solar modules by endeavouring to reduce manufacturing costs and increase solar cell efficiencies. Manufacturing costs can be significantly reduced by using thinner silicon wafers. In addition to cost benefits, thin silicon wafers are advantageous in that they have a higher diffusion length/cell thickness ratio, resulting in lower bulk recombination. However, as wafer thickness is reduced, surface recombination becomes a limiting factor for cell efficiency. By incorporating a superior rear surface passivation layer into a high efficiency LGBC solar cell structure, the advantages of thin cells can be exploited.

The Technology Strategy Board funded Research and Development project, ‘HIGHPOINT’ aims to produce well passivated 20% efficiency solar cells on 150µm mono wafers, at 30% lower cost than the standard LGBC process. In this paper, we describe some initial results from the HIGHPOINT project. Simulated data of cell efficiency modelled as function of cell thickness and rear surface recombination velocity is described. Electrical measurements of standard thickness (210µm) and thin cells (150µm) processed using a standard LGBC process are discussed. Finally, initial solar cell test data of standard thickness LGBC solar cells with thermal oxide rear passivation is presented. Back contact through the rear dielectric layer is achieved using a laser firing process, and electroless plating.

PC1D Solar Cell Modelling

Commercial solar cell simulation software PC1D [2], was used to model solar cell efficiency as a function of cell thickness and rear surface recombination velocity. Process parameters used in the model are given in Table 1. The model also includes the reflection properties of a SiN ARC layer and assumes a textured front surface.

Parameter	**Value**
Dopant	Boron
Bulk Resistivity	1Ω-cm
Bulk Lifetime	30µs
Emitter Resistivity	90.Ω/□.

Table 1: Process Parameters used in PC1D model

Simulations were performed assuming a rear surface passivation layer with rear surface recombination velocities (Sr) varying from 5000cm/s to 10cm/s. Analysis of quantum efficiency data on our standard cells indicates that our Al-BSF has a rear surface recombination velocity (Sr) of approx 1400cm/s.

Figure 2 shows the relationship between wafer thickness and cell efficiency for rear passivated solar cells with various rear surface recombination velocities.

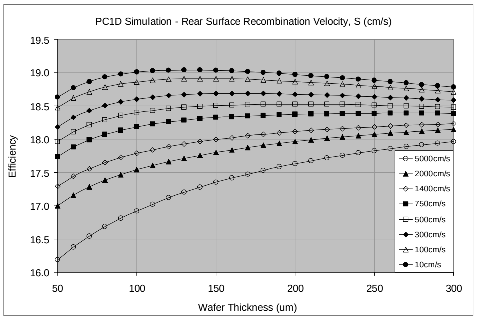

Fig 2: PC1D modelled cell efficiency versus cell thickness for various rear surface recombination velocities.

The modelled cell efficiency of a solar cell with rear surface recombination velocity greater than 1400cm/s, decreases as wafer thickness decreases. Conversely, as cell thickness is reduced, well passivated solar cells (Sr <500cm/s), show an initial increase in cell efficiency, before decreasing as cell thickness is further reduced. It is clear from the graph that it is necessary to incorporate a good rear surface passivation layer to maintain or indeed optimise efficiency of thin solar cells. Note that this is a simplified model and has not been fitted to measurement data.

Standard and Thin LGBC Solar Cells

As mentioned previously, the long term aim of the HIGHPOINT project is to process well passivated high efficiency 150µm solar cells. A study to assess the effect of reducing cell thickness to 150 µm on standard LGBC solar cells has been initiated by processing standard thickness (210µm) and thin (150µm) solar cells using our standard LGBC process.

Cells were processed using the process schedule summarised below.

1. Saw damage etch
2. Texture etch
3. Emitter diffusion
4. ARC deposition (front)
5. Laser groove (front)
6. Groove etch
7. Groove diffusion
8. Post groove diffusion clean
9. Al sputtering
10. Al Sinter
11. Plating
12. Edge isolation

With the exception of the saw damage process step, all wafers in the batch were processed together under identical process conditions. To produce 150µm thick wafers (Group D), half of the batch were placed in the saw damage etch for 19mins.The process reference wafers were given standard saw damage etch of 2.5mins (Group B).

All wafers were tested under standard test conditions (AM1.5, 1000W/m^2, 25°C) using ATS Solar Cell tester and wafer thickness was measured using ADE 6033T wafer thickness gauge. The results of these measurements are summarised in Table 2 below.

Cell Number	**Cell thickness (µm)**	**Jsc [mA/cm2]**	**Voc [mV]**	**FF [%]**	**Efficiency [%]**
2B	208.6	35.00	612.0	80.20	17.18
3B	207.8	35.20	613.1	80.15	17.30
4B	212.3	35.03	612.8	80.18	17.21
5B	208.7	35.19	613.6	80.23	17.32
Mean	**209.4**	**35.10**	**612.9**	**80.19**	**17.25**
Std. Dev.	**2.0**	**0.10**	**0.7**	**0.03**	**0.07**
6D	152.2	34.76	604.0	80.00	16.79
7D	151.8	34.76	605.6	79.94	16.83
8D	152.0	34.62	605.2	79.87	16.74
9D	151.6	34.72	603.8	80.01	16.77
10D	150.8	34.76	604.2	79.87	16.77
Mean	**151.7**	**34.72**	**604.6**	**79.94**	**16.78**
Std. Dev.	**0.5**	**0.06**	**0.8**	**0.07**	**0.03**

Table 2: ATS Cell Test Data for Standard and Thin Cells

Standard and 150µm cells had mean efficiencies of 17.25% and 16.78% respectively.
This decrease in efficiency corresponds to a reduction in Voc and Jsc. This reduction

in Voc and Jsc may be attributed to rear surface recombination, since our standard process includes an Al BSF, which has a modest rear surface recombination velocity of approximately 1400cm/s.

Both simulated and electrical data suggest that we need to incorporate a better quality rear surface passivation to improve the efficiency of thinner LGBC solar cells. The majority of development work pertaining to the HIGHPOINT project will involve integrating a low surface recombination velocity rear passivation layer into the LGBC process on 150µm thick wafers.

Project partners at Heriot Watt University are currently working towards producing PECVD dielectric layers with surface recombination velocities of <100cm/s in a material system compatible to the subsequent fabrication process.

In parallel to this work, we are developing our process to include rear surface passivating films. For development purposes we are integrating a thermal oxide rear surface passivation layer into our LGBC process. A laser firing process and electroless plating are used to form rear contacts.

The following section of this paper describes the experimental procedure for the processing of LGBC solar cells with rear thermal oxide passivation and laser fired contacts (LFC).

Rear Passivated LFC LGBC

Solar cells were processed using the process schedule summarised below.

1. Saw damage etch
2. Texture etch
3. Emitter diffusion
4. ARC deposition (front and rear)
5. Laser groove (front)
6. Groove etch
7. Groove diffusion
8. Post groove diffusion clean
9. Dry Thermal Oxidation
10. Al sputtering
11. Laser Contact Firing
12. Electroless plating
13. Edge isolation

Laser firing (using 3 different instantaneous laser powers 3.3kW, 3.7kW and 4.1kW) was used to form point contacts (1mm pitch). This resulted in a matrix of alloyed Al point contacts in a layer of unsintered Al. Standard electroless plating uses an HF based solution as a plating activator. Since both oxide and unsintered aluminium are quickly etched in HF, standard electroless plating was not compatible with the rear passivated LFC LGBC cells.

The standard plating process was modified to reduce the time in the HF solution. The Cu adhesion was very variable and only three cells were plated adequately for electrical measurements.

Wafers were tested under standard test conditions (AM1.5, 1000W/m^2, 25°C) using ATS Solar Cell tester. The results of these measurements are summarised in the table below.

Cell Number	Laser Power (kW)	Jsc [mA/cm2]	Voc [mV]	FF [%]	Efficiency [%]
RD95_1	3.3	31.26	571.8	32.44	5.80
RD95_2	3.7	34.10	576.4	44.91	8.82
RD95_3	4.1	33.99	577.5	44.12	8.66
Cell Number	**Laser Power (kW)**	**Rs [m-ohn]**	**Rsh [Ω]**	**Rsh Dark [Ω]**	**Rs Dark [m-Ω]**
RD95_1	3.3	79.8	0.2	2052	72.2
RD95_2	3.7	49.4	2.5	1902	45.1
RD95_3	4.1	50.4	1.8	2203	45.5

Table 3: ATS Cell Test Data for Rear Passivated LFC LGBC solar cells

Wafer 1 (RD95_1), fired at laser power 3.3kW, has an efficiency of 5.8%. Wafers 2 and 3, fired at higher powers (3.7kW, 4.1kW respectively) have efficiencies of 8.82% and 8.66%. All three solar cells have very low Voc and Fill Factor. Note that there is insufficient data to ascertain the effect of laser power on cell parameters.

Dark IV curves showed high series resistance (Rs) and high shunt resistance (Rsh). In contrast, light IV curves exhibited high Rs and very low Rsh. Poor FF and the difference in Rsh between light and dark IV measurements are likely to be indicative of a non Ohmic resistive rear contact.

The Sinton Suns-Voc measurement technique is a well established characterisation method for solar cells [3] In this technique Jsc and Voc are measured over a range of light intensities. S. Glunz et al have demonstrated that Suns-Voc is a useful tool for the analysis of rear contacts [4].

Figure 3 shows a plot of Light intensity versus Voc (suns-Voc) for one of our rear passivated LFC LGBC solar cells.

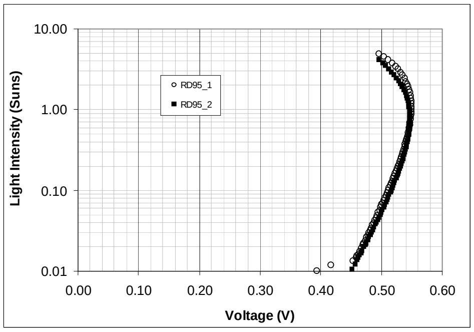

Fig 3: Light intensity versus Voc (Suns-Voc) curve for rear passivated LGBC with LFC

Above incident light intensities of around 1 sun, voltage drops with increasing light intensity.

An equivalent circuit model can be used to explain this anomalous behaviour [5]. The solar cell is modelled as a pn junction and the rear contact is represented by an opposing Schottky diode in parallel with a resistance. If the rear Ohmic contact is well formed, under 1 sun conditions the parallel resistance should be low and the diode should effectively be shorted by the resistance. If the rear contact is not well formed, the parallel resistance is not low enough to fully short the Schottky diode. The Schottky junction will build up voltage opposing the solar cell pn junction, and the overall cell voltage will not increase with increasing illumination as expected.

Cell test data and suns-Voc strongly suggest that the rear contacts are non-Ohmic. It is likely that this contact issue can be attributed to the laser firing process. Similar suns-Voc characteristics have been reported in the literature for LFC solar cells (FF 37.6%) manufactured using non-optimised laser firing conditions [4].

Conclusions:

PC1D has been used to model cell efficiency as a function or cell thickness and rear surface recombination velocity. The model showed that as cell thicknesses decrease, it becomes increasingly important to incorporate a good rear passivation layer into solar cell process.

Standard (210µm) and thin (150µm) cells have been fabricated using standard LGBC solar cell process. Thin cells showed a 0.5% reduction in cell efficiency compared to standard cells, suggesting that the standard Al BSF rear passivation was not adequate for thin cells.

Rear passivated LFC LGBC cells have been processed and characterised using standard cell test and suns-Voc measurements. Electrical data showed that rear contacts were non-Ohmic and that the laser firing process requires further development.

These results have also highlighted that a significant amount of work is required to develop a process to plate unsintered Al on an oxide passivating layer. It is also clear that in addition to providing excellent rear passivation, our project partners' PECVD passivating layer, must be compatible with our plating processes.

[1] M. A. Green and S. R. Wenham 1984 IP Australia, Patent Application Number 1984036664

[2] D.A. Clugston, P.A. Basore, "PC1D Version5:32 bit Solar Modeling on Personal Computers" Photovoltaic Specialists Conference, 1997, Conference Record of the 26th IEEE p207-210

[3] R.A. Sinton, A. Cuevas "A Quasi-Steady-State open-circuit voltage method for solar cell characterization"16th European Photovoltaic Solar Energy Conference, 1-5 May 2000, Glasgow

[4] S. W. Glunz, J. Nekarda, H. Mackel, A Cuevas "Analysing back contacts of silicon solar cells by suns-voc measurements at high illumination densities"22nd European Photovoltacic Solar Energy Conference and Exhibition, 3-7 September 2007, Milano

[5] M. A. Green, A. W. Blakers, J. Zhao, A. M. Milne, A. Wang, X. Dai 'Characterisation of 23% efficient silicon solar cells.' IEEE Transactions on Electron Devices Vol 37, No. 2, February 1990