DEVELOPMENT OF REAR PASSIVATED LASER GROOVED BURIED CONTACT (LGBC) LASER FIRED CONTACT (LFC) SILICON SOLAR CELLS USING THIN WAFERS

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ABSTRACT: The cost per watt peak of solar modules must be reduced to ensure long term commercial viability. Manufacturing costs can be reduced by using thinner silicon wafers. Thin wafers are also advantageous in that they have lower bulk recombination. However, as wafer thickness is reduced, surface recombination becomes a limiting factor for cell efficiency. The advantages of thin cells can be exploited by incorporating a good rear passivation. The FP7 funded project '20Plμs', aims to produce well passivated 20% efficiency solar cells on 100μm Cz monocrystalline wafers.In this paper we describe the integration of a AlO_x/SiO_x rear passivating layer into a high efficiency LGBC solar cell structure fabricated using 100μm and 160μm thick industry standard Cz Si. These cells have significantly higher open circuit voltages (V_{oc}) and short-circuit current densities (J_{sc}) than standard LGBC cells and hence show potential for higher cell efficiencies.

Keywords: Silicon, cost reduction, back contact

1 INTRODUCTION

The photovoltaic community continues to strive to reduce the cost per watt peak (Wp) of solar modules. To achieve this cost reduction, manufacturing costs need to be cut and solar cell efficiencies must be improved. Manufacturing costs can be significantly reduced by purchasing 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.

The objective of FP7 funded project '20Plμs' is to develop solar cell processes using industrial Czochralski-grown (Cz) monocrystalline silicon wafers that are substantially thinner than the current standard of approximately 180μm. Solar cells as thin as 50μm will be produced. The processes developed in this project will be optimised and transferred into a pilot production line aiming to achieve efficiencies of 19.5% on large area ($150cm^2$) 100μm thick silicon wafers at a yield comparable to standard production lines. This shall help drive down production costs and save Si resources from today's 8g per Wp to 3g per Wp

The high efficiency Laser Groove Buried Contact (LGBC) solar cell was invented by M.A. Green and S. R Wenham in 1984, and is currently manufactured by Narec Solar, UK [1]. A direct write laser process is used to form trenches on the front of the cell. The trenches are then Ni-Cu 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 metallisation 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 resistance. Rear surface passivation is provided by an aluminium doped back surface field (Al-BSF). The Al-BSF is formed by depositing a thin layer of aluminium by DC magnetron sputtering which is subsequently sintered at high temperature. At best, this produces a rear surface recombination velocity (SRV) of 1400cm/s.

In order to exploit the advantages of thin cells, a superior rear surface passivation layer must be incorporated into a high efficiency LGBC solar cell structure. In this paper we describe the integration of a thin plasma-enhanced-chemical-vapour-deposited (PECVD) AlO_x rear dielectric layer into the fabrication of high efficiency LGBC solar cells using 100μm thick industry standard Cz Si wafers [2]. Back contact through the rear dielectric layer is achieved using a laser process to form locally fired contacts (LFC) [3]. Typical SRVs of these AlO_x layers, featuring metal contacts, range from 50 – 100cm/s. A schematic diagram of this LGBC/LFC solar cell is given in Figure 1.

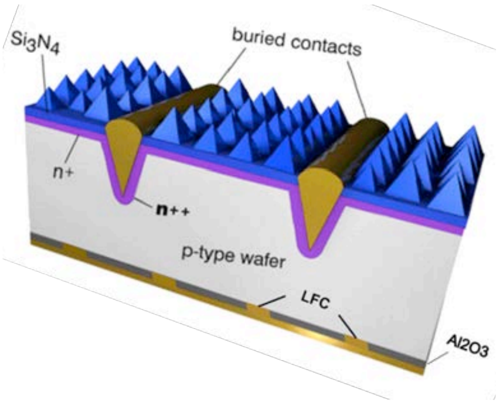

Figure 1: Schematic of rear passivated LGBC/LFC silicon solar cell

Previously researchers have demonstrated 140μm thick, rear passivated cells on Float Zone monocrystalline silicon wafers with cell efficiencies exceeding 20% [4][5].

In this work 100µm and 160µm thick LGBC/LFC solar cells have been successfully fabricated using industrial Cz monocrystalline silicon. These cells have significantly higher open circuit voltages (V_{oc}) and higher short-circuit current densities (J_{sc}) than standard LGBC cells and hence show potential for higher cell efficiencies.

2 APPROACH

LGBC and LGBC/LFC solar cells were processed using commercially available 200µm thick, p-type boron-doped Cz silicon wafers with a resistivity of 2-3 Ωcm.

The process steps for each cell type are summarised in Figure 2. Note that the saw damage etch time was adjusted to produce solar cells 100µm and 160µm thick. Both cell structures were processed together through the standard LGBC front-side process steps, up to and including groove etch. A heavy phosphorous diffusion was used to highly dope the grooves, forming the selective emitter. LGBC solar cells were diffused on the front side only. The LGBC/LFC solar cells were diffused both in the grooves and on the rear to obtain an effective phosphorus gettering of the Cz Si bulk. The LGBC/LFC cells were then processed at high temperature to achieve an emitter doping profile equivalent to that of standard LGBC. An Al-BSF was formed on the rear of the LGBC cells, providing both rear passivation and rear contact. Following a plasma etch to remove the rearside doping, the LGBC/LFC cells were passivated on the rearside by a 10nm layer of AlO_x and a 90nm layer of SiO_x. These layers were deposited using PECVD. Back contact through the rear dielectric layer involved the deposition of a 2µm aluminium layer and laser processing to form locally fired contacts (LFC) [3]. All the cells were metallised using a standard electroless Ni and Cu plating process. Note that the as-deposited rear-side Aluminium on the LGBC/LFC cells was protected by a mask during electroless plating.

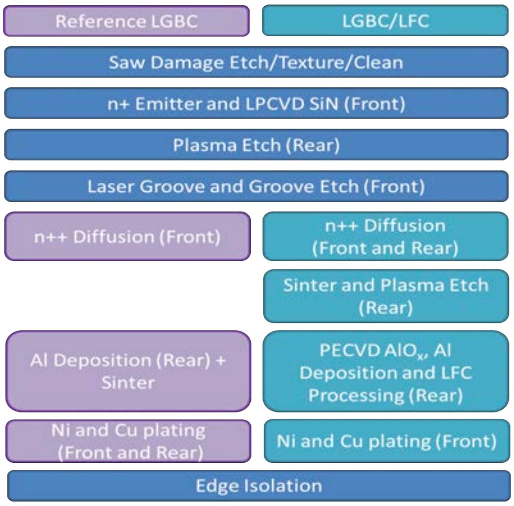

Figure 2: Simplified Process flow for LGBC and LGBC/LFC silicon solar cells

3 RESULTS AND DISCUSSION

Typical cell test parameters for each cell structure and cell thickness are summarised in Table I.

Cell Structure	Cell Thickness	Efficiency [%]	Voc [mV]	Jsc [mA/cm²]	FF [%]
LGBC	160µm	17.7	610	35.43	82.0
LGBC/LFC		18.3	640	37.30	76.8
LGBC	100µm	16.7	601	34.61	80.0
LGBC/LFC		16.9	625	36.33	74.5

Table I: Typical cell test parameters for standard LGBC solar cell and LGBC/LFC solar cell

The superior rear passivation provided by the AlO_x/SiO_x layer in the LGBC/LFC cells results in significantly higher V_{oc} than the standard LGBC solar cells. A typical 100µm LGBC/LFC cell had a V_{oc} of 625mV, compared to 601mV for a typical 100µm LGBC solar cell. The 160µm LGBC/LFC cell had a V_{oc} of 640mV, compared to a V_{oc} of 610mV for the standard 160µm LGBC cell. Typical J_{sc} of the LGBC/LFC cells is around 5% higher than the standard LGBC cells. Note that the efficiencies of the LGBC/LFC cells are limited by relatively low fill factors (FF), suggesting that efficiencies can be further improved by optimizing series and shunt resistances.

The effective lifetime versus carrier density plots derived from suns-Voc measurements for a LGBC cell and a LGBC/LFC cell are shown in Figures 3 and 4 [6].

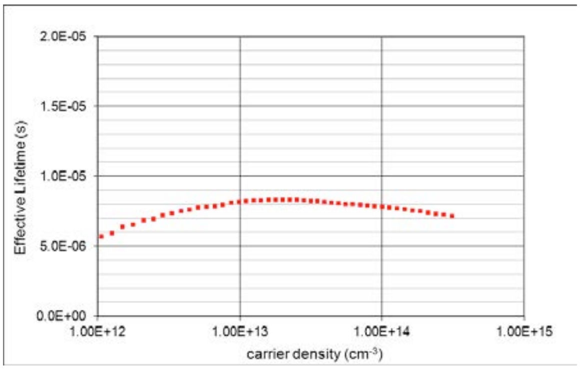

Figure 3: Example of Suns-Voc effective lifetime for a Narec Solar LGBC solar cell

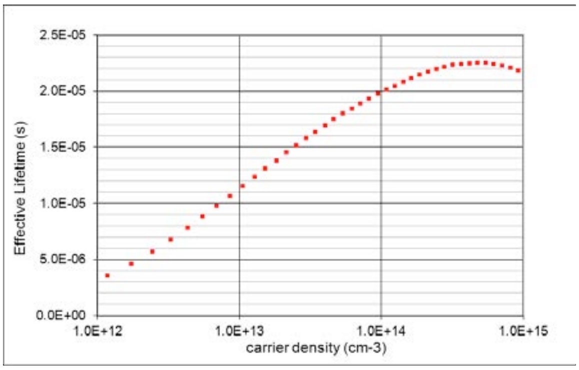

Figure 4: Example of Suns-Voc effective lifetime of a LGBC/LFC cell

The effective lifetime of the LGBC/LFC cell increases with increasing carrier density significantly more than that observed with the standard LGBC cells. The difference between the rear sides of each cell structure can also be observed in terms of Quantum Efficiency at longer wavelength. Internal Quantum Efficiency, shown in figure 5, was derived from External Quantum Efficiency (EQE) measurements shown in figure 6. Figure 5 clearly shows that the LGBC/LFC solar cell with AlO_x/SiO_x passivated rear surface has higher internal quantum efficiency (IQE) at longer wavelengths than the standard LGBC cell. The higher IQE of the LGBC/LFC results from reduced recombination at the effectively passivated rear surface.

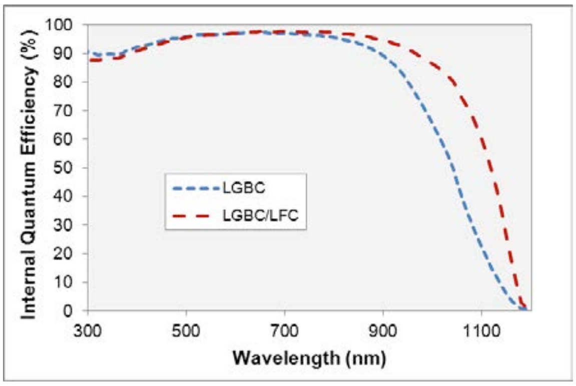

Figure 5: Internal quantum efficiency of (i) a standard LGBC solar cell with full-area Al-doped back surface field and (ii) a LGBC/LFC solar cell with AlO_x/SiO_x passivated rear surface.

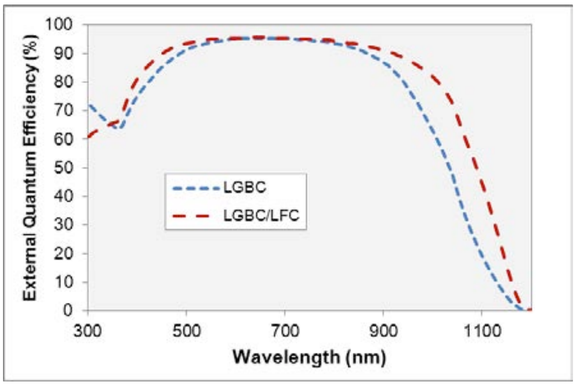

Figure 6: External quantum efficiency of (i) a standard LGBC solar cell with full-area Al-doped back surface field and (ii) a LGBC/LFC solar cell with AlO_x/SiO_x passivated rear surface.

Also, as shown in figure 7, the deposition of AlO_x/SiO_x on the rear of the LGBC/LFC solar cell, results in superior rear reflectance compared to the aluminium back surface field of the standard LGBC solar cell, which in turn, leads to an increase in J_{sc}.

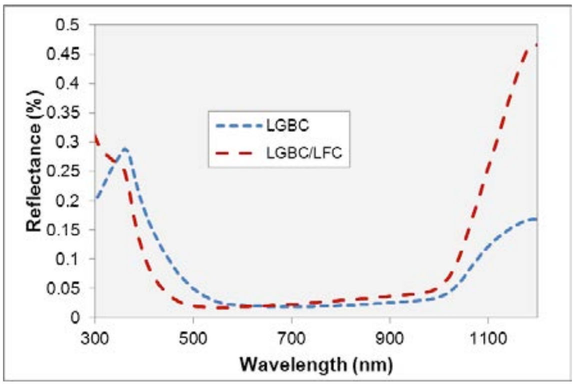

Figure 7: Reflectance of (i) a standard LGBC solar cell with full-area Al-doped back surface field and (ii) a LGBC/LFC solar cell with Al_2O_3/SiO_x-passivated rear surface.

The data shown in figures 5 and 6 was taken from a $4cm^2$ area in the center of each cell. The uniformity of EQE across the cell was determined using LBIC mapping measurements of standard LGBC and LGBC/LFC solar cells. Measurements were taken at wavelengths of 750, 790, 863 and 950 nm and are shown in figures 8 and 9.

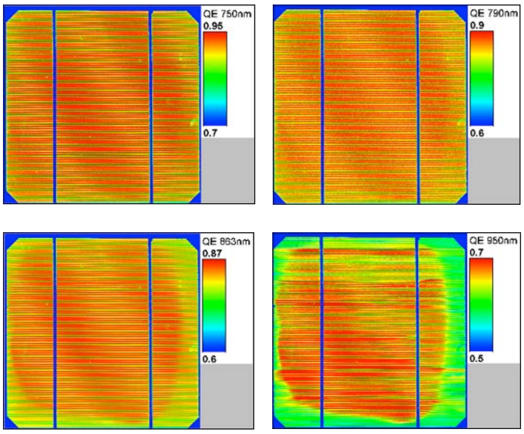

Figure 8: EQE maps determined using LBIC measurements of standard LGBC solar cell taken at wavelengths of 750, 790, 863 and 950 nm.

There is a region of low EQE around the edges of the LGBC cell which can be observed on EQE maps determined using LBIC measurements taken at 863nm and 950nm. This can be attributed to unintentional rear side Phosphorous doping, which increases the surface recombination velocity of the Al BSF.

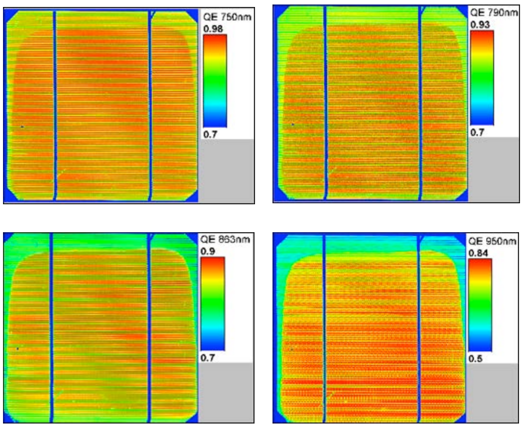

Figure 8: EQE maps determined using LBIC measurements of LGBC/LFC solar cell taken at wavelengths of 750, 790, 863 and 950 nm.

There is also a region of low EQE around the edges of the LGBC/LFC cell. In this case, the low EQE region can also be observed on all maps determined from LBIC measurements taken from 750nm and 950nm. In contrast to the LGBC cell, the region of low EQE on the LGBC/LFC map has sharply defined edges and is mainly distributed at the top of the wafer. The shape of this region corresponds to unintentional rear side deposition of LPCVD SiN, which should be removed during the rear side plasma etch process. It is possible that the plasma etch has left a residual, thin layer of SiN, that is no longer visible by eye. This step could be replaced by using a mask to protect the rear during LPCVD SiN deposition.

The central regions of all the EQE maps are in good agreement with the EQE measurements shown in Figure 6. Again, the LGBC/LFC cell has higher EQE at longer wavelength than the standard LGBC cell.

4 CONCLUSIONS

The integration of a AlO_x/SiO_x rear passivating layer into a high efficiency LGBC solar cell structure fabricated using 100µm and 160µm thick industry standard Cz Si has been described. The superior passivation quality of the AlO_x/SiO_x compared to the Al BSF, has resulted in a significant increase in open circuit voltage for 100µm and 160µm cells. The higher IQE of the LGBC/LFC cell at longer wavelength, derived from the higher external quantum efficiency, results from reduced recombination at the effectively passivated rear surface. The improved rear reflection at longer wavelength of the AlO_x/SiO_x layer, compared to the Al BSF also contributes the increase in J_{sc}. Further process development, required to fully exploit the advantages of thin cells will be reported in future publications.

5 ACKNOWLEDGEMENTS

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