# Progress of the LAB2LINE Laser Grooved Buried Contact Screen Printed Solar Cells Hybrid p-type Monocrystalline Process

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ABSTRACT: Laser grooved buried contact (LGBC) solar cell technology is an attractive method for the production of solar cells designed to operate at one sun, and at low to medium concentration. This is mainly due to the low shading of the solar cell front by the grid contact and the front selective emitter under it, which ensures better collection for the short wavelength light. However, compared to standard screen printed solar cells, LGBC cells have a higher efficiency but require a more complex manufacturing process. As part of the EU funded project, “Lab2Line” we are marrying the screen printed and LGBC solar cell processing techniques in order to produce high efficiency 1 sun solar cells on large area (125x125 mm) wafers at the lowest cost. Using improved processing steps, this project aims to produce industrially scalable production of high efficiency, fully Screen Printed, Laser Grooved, Buried Contact Solar Cells (SPBCSCs) on large area monocrystalline wafers.

## 1 INTRODUCTION

The vast majority of industrially produced solar cells use p-type boron doped silicon and have a homogeneous emitter, a PECVD Silicon Nitride antireflective and passivating coating and have screen printed metal contacts on the front and rear of the cells. The current conversion efficiency for this technology is in the range of 15% in industry [2]. In order for PV to become a financially viable source of energy there needs to be increased cell and module efficiencies and a reduced production cost to reduce the cost per Wp [4, 5]. Laser grooved buried contact solar cell (LGBC) technology is attractive for the production of high efficiency solar cells designed to operate at one sun, and at low to medium concentration. This is mainly due to the reduced shading loss of the front contact of the solar cell and the selective emitter. However, although LGBC cells have a higher efficiency at one sun, (up to around 18% at an industrial scale) compared to standard screen printed solar cells they require a more complex manufacturing process.

The laser grooved buried contact (LGBC) solar cell has been manufactured commercially by BP Solar in Madrid since 1992 and by NaREC since 2005.

The LGBC solar cell has several advantages over the standard screen-printed cell. A local, highly doped front contact grooves and a lower doped emitter elsewhere on the cell front promotes a good blue response and, along with the large contact area between the electroless metal plated buried contacts and the silicon, a low contact resistance. High purity copper is plated into the grooves which is low resistivity and promotes good cell fill factors. Also the widths of the fingers are about a third of that achieved through screen printing, reducing shading.

The screen printed process has fewer steps and the process time is shorter. However the blue response is reduced due to the homogeneous emitter and the fill factor suffers from the higher resistivity contact fingers. In the LGBC process the rear back surface field (BSF) is formed by depositing a thin layer of aluminium by DC magnetron sputtering which is sintered into the wafer at high temperature. This yields a rear surface recombination velocity of around 1400 cm/s [6]. However, when using a screen printed and fired Al rear there are reports in literature of a rear surface recombination velocity as low as 900-200 cm/s [7,8].

As part of the EU funded project, “Lab2Line” we are marrying the screen printed and LGBC solar cell processing techniques in order to produce high efficiency 1 sun solar cells on large area (125x125 mm) wafers at the lowest cost. A fine line, screen printing technology has been used previously [1, 2, 3] along with LGBC processes to produce solar cells on multicrystaline Si. Using improved processing steps, this project aims to produce industrially scalable production of high efficiency, fully

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Screen Printed, Laser Grooved, Buried Contact Solar Cells (SPBCSCs) on large area monocrystalline wafers.

## 2 APPROACH

### 2.1 Hybrid process

The work has been focused on the integration and optimization of the two technologies. A hybrid process has therefore been designed and is shown schematically in Figure 1. Firstly the most critical issues for matching the two technologies have been identified; the laser groove morphology must be modified so that the screen printed contacts are able to be printed directly into the laser grooves on the front of the wafer. In the LGBC production process at NaREC a pulsed Nd:YAG laser with a wavelength of 1064nm is used to ablate silicon from the front of the wafer and form the grooves required in the process. To produce a good cell fill factor and low shading (around 5% total shading loss for a one sun cell) the groove morphologies are nominally 35µm wide and 45µm deep after alkaline etching to remove the thermal damage produced by the laser. Screen printed front contacts are usually in the range of 100-125 µm wide and are therefore incompatible with the groove morphology optimised for the LGBC process.

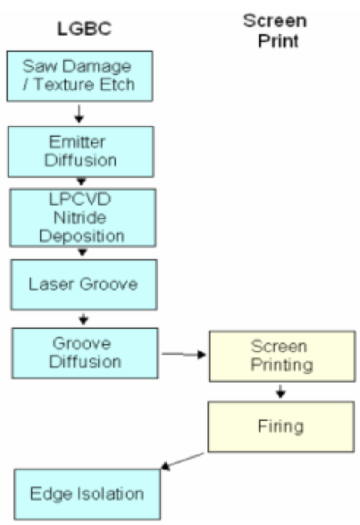


**Figure 1.** The hybrid process designed to produce SPBCSCs.

The work has initially been focused on developing a technique to carry out “fine line” screen printing. This has involved the optimisation of non-planar screen printing by modifications to the screen design and reducing the opening width. In order to match the screen printed contacts to the laser grooves, optical alignment of the screen printed pattern to the groove pattern has been carried out. To gain the accuracy required for this process, deep laser grooves are formed parallel to the edges of the wafer at the same time as the front contact grooves are formed. The wafers are cleaved along these grooves forming an optically recognisable datum which is a fixed distance and orientation from the front contacts. These last setups are crucial when dealing with large area cells which have a large number of front contact fingers.

Also the development of a new groove morphology compatible with the screen printing process has needed.

## 3 EXPERIMENT

### 3.1 Initial Hybrid Cell Processing (Design1)

In order to produce a groove with depth and width parameters compatible with the fine line SP process, the standard LGBC grooves were modified [4]. It was found that a groove of width ~70µm and depth ~45µm was produced by scribing each groove 4 times with the centre of the laser scribe moved by 16µm from scribe to scribe.

Initially, cells were processed with a standard finger centre to finger centre spacing equivalent to a standard LGBC cell at 1.5mm. This produced a cell with 82 fingers and two 1.5mm wide busbars yielding a shading factor of final printed wafer of 8.4%. This has been identified as one of the most limiting factors for hybrid cell efficiencies. Indeed if the standard LGBC process, which yields to a front 5% shading, is increased to 7.9% it can produce a reduction of 0.53 mA/cm$^2$ in $J_{sc}$. Previous results showed indeed a maximum current for LGBCSC of 33.75 mA/cm$^2$.

### 3.2 Screen printing.

With the screen print mask in direct contact to the wafer, complete superposition of the printed and grooved patterns is possible, even though in this way larger finger are inevitable.
To allow the silver paste to go through the 400 mesh screen, it has been diluted to the correct rheology and the squeegee pressure and velocities adjusted to both be as high as possible to facilitate the correct fine line printing required and at the same time to maximise the groove filling. This procedure gives good printing resolution which obtains complete groove filling and good adhesion as shown in the SEM images in Figure 2.

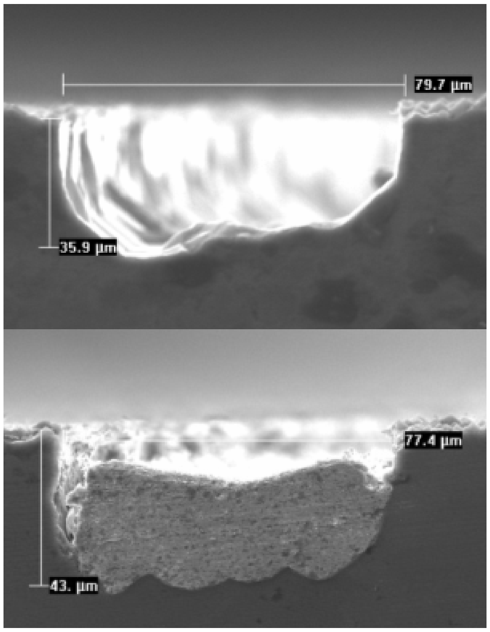


**Figure 2.** Laser formed groove 'finger' before and after screen printing.

After drying in a conventional IR furnace Al paste has then been printed on the back using a low mesh count screen (200) and dried in IR belt dryer. The co-firing step has been carried out in an IR belt furnace having three active zones. When completed the cells have been cut using a dicing saw in order to isolate the edge to prevent shunting and also to remove any areas showing poor alignment between the screen print and the grooves. We remark that large area alignment is feasible, but the complete alignment on 125 mm side pseudo-square is also related to the finger number: the more fingers, the higher the systematic error in repositioning of both laser and screen printing from the first finger to the last. So when printing through an 80 finger mask, an error of 1 µm for each groove means 80 µm displacement from the first to the last, which can result in an incomplete alignment at the border edges. This has yielded a maximum cell size of 80.3cm$^2$ [9]

3.3 Modified Hybrid Cell Processing (Design2)

Using in-house developed modelling software which calculates the shading and $I^2R$ losses for various front contact designs [10], the optimum front contact design for the hybrid cells having 70-80µm fingers was modelled for a cell of size of 122x122mm with two busbars each 1mm wide. This process gave an optimum of 66 fingers with 5% shading factor which is equivalent to the shading factor of a standard LGBC solar cell. Using 200µm thick typically 1 Ohm-cm CZ wafers and processing through the standard LGBC process gives an efficiency with this design of 16% with $V_{oc}$ of 608mV and a FF of 77%.

Batches of both cell designs have been processed, noting that for Design2 (66 finger design) a batch of 100 wafers has been processed and fully characterised in terms of IV, spectral response and LBIC measurements.

4. RESULTS AND DISCUSSION

4.1 Transport Data

In Figure 3 and in Table I the comparison between typical SPLGBC solar cells produced to Design1 and Design2 and are compared to LGBC solar cells processed through the standard electroless process to Design2. It must be noted that the cells processed to Design1 were with wafers to the same specification to the wafers used for Design2, however the thickness used was 300µm.

If we consider standard LGBC process thinning of wafers results in a decrease in performance due to the modest rear SRV of 1400cm/s However using thinner wafers instead can help increase the efficiency for SP cells providing the rear SRV is low enough. Indeed considering the SPLGBC cells, it can be seen that cells processed using the optimised front contact design (Design2) on thin substrates have a larger $V_{oc}$, $J_{sc}$ and FF. The FF improvement would not be expected for a design with a larger finger spacing as the emitter resistive losses will have increased. Although not reported in Table I, SPLGBC cells with Design2 front contact have produced $J_{sc}$ values up to 34.7mA/cm$^2$ and $V_{oc}$ up to 620mV. The maximum $J_{sc}$ possible if this increase was due to reduction in shading alone is approximately 33.5mA/cm$^2$.

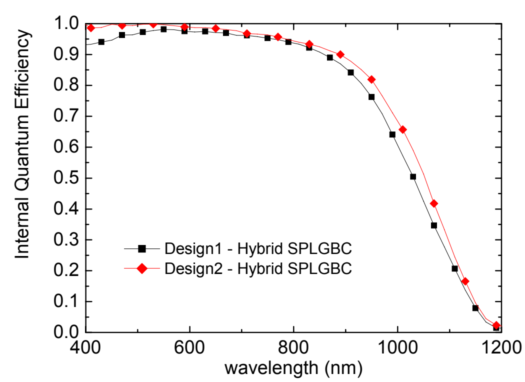


**Figure 3.** Internal Quantum Efficiency comparison of Design1 and Design2 screen printed cells

As a result one can conclude that part of this observed improvement is due to an improvement in cell processing, namely

a) emitter formation,
b) silver front contact paste
c) rear BSF formation/gettering.

| | LGBC process Electroless chemical plating (Design2) | Hybrid SPLGBC cells (Design1) | Hybrid SPLGBC cells (Design2) |
|---|---|---|---|
| $V_{oc}$ (V) | 0.608 | 0.59 | 0.614 |
| **$J_{sc}$ (mA/cm$^2$)** | **34.32** | **32.53** | **34.57** |
| FF % | 76.7 | 76.47 | 76.6 |
| **Efficiency %** | **16.01** | **14.68** | **16.25** |
| Shadowing % | 5 | 8.94 | 5.4 |
| Cell Area (cm$^2$) | 140.7 | 80.90 | 134.56. |

**Table I.** I-V measured parameters.

In particular:

a) Wafers processed to front contact design 2 went through an extra annealing step before SP and firing to drive the emitter deeper into the cell and therefore reduce the surface P doping concentrations. This has been needed to consider all the thermal treatment experienced by the wafers in the standard LGBC cells, which are avoided in the hybrid process as showed in Fig. 1

b) As previously noticed [9] the low Voc was attributed to the front silver paste characteristic, quite aggressive during firing. A new paste has been used, especially designed for making contact directly on silicon. Also the use of less finger in the front grid design has allowed the use of a snap off distance, which in turn allowed to better resolved print, and full aligned cell. This together with the deeper emitter and optimized firing condition, led to better Voc and lower contact resistivity.

c) The use of new and better performing paste for the individuated firing temperature profile yielding better BSF formation, which led to Ld=234$\mu$m BSRV=855cm/s, BSf depth=5.2 $\mu$m as estimated from IQE measurements.
Indeed LBIC measurements carried out yield an average diffusion length of design 2 cells of 310µm on a 200µm thick wafer. For design 1 cells the diffusion length is averaging 180µm with the LGBC cells giving around 180-200µm on 200µm wafers.

## 4.2 INDUSTRIAL FEASIBILITY

The aim for the LAB2LINE EC funded project is to demonstrate that a hybrid SP/LGBC p-type solar cell process is industrially feasible and able to achieve average efficiencies of 17% and best cell efficiency of 18% with cells larger than 100cm$^2$ in size on batch sizes of 100. To date we have demonstrated that over 15% is possible with best cell values of 16.25% on fully screen printed process. We are currently exploring the possibility of an integration of back passivated rear contacted and front screen printed cell to get higher efficiency up to 18%. Anyway the majority of equipment used for this work has industrial scale equipment but without the automation available to large scale production. This would enable to easily transfer the process to large scale production and due to increased automation, the distribution of cell parameters observed in this demonstration work would be reduced.

## 6 ACKNOWLEDGEMENTS

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