SCREEN PRINTING IN LASER GROOVED BURIED CONTACT SOLAR CELLS: THE LAB2LINE HYBRID PROCESSES

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ABSTRACT: Laser Grooved Buried Contact (LGBC) solar cell technology is an attractive way for the production of solar cells designed to operate at one sun. Although LGBC cells can have higher efficiency when compared to standard screen-printed solar cells, a more complex manufacturing process is required, increasing their relative costs. In the FP6 EU funded project "Lab2Line," screen print and LGBC solar cell processing techniques are hybridized in order to produce lower cost high efficiency solar cells processed on large area mono-crystalline wafers, using techniques scalable to industry. Two hybrid approaches have been considered: in the first, screen-print (SP) is applied for both rear and front contacts; in the second process SP is applied only to the rear and then electroless plating is used to form the front contacts.
Both Lab2Line hybrid approaches offer high average efficiencies with a small performance distribution, while simultaneously presenting a more compact, cost effective option to production.
The combination of SP techniques with LGBC processes and electroless plating has led to a maximum efficiency of 17.34% for the first process and 18% (17.44% average on 171 wafers) for the latter. Modules having such cells result in FF of 79.0% and efficiency of 17.0%.
Keywords: Laser Processing, Buried Contacts, Screen Printing.

1 INTRODUCTION

Despite the world economic crisis, the global PV Market could reach between 10.1 GW and 15.5 GW of new installations in 2010, compared to 8.2 to 12.7 GW in the previous forecast year. While the announced world-wide PV production capacity would be sufficient to cover the expected evolution of the market in the coming five years, we could nevertheless see some temporary shortages due to high variations in the demand patterns which could occur. In this scenario, Europe is leading the way with almost 16 GW of installed capacity in 2009, representing about 70% of the World cumulative PV power installed at the end of 2009 [1].

It is well known the best way to continuously grow in the face of the market demand and the foreign (outside EU) country competition for European PV manufacturer is to provide high efficiency modules at low cost, in order to have the best power/price ratio. Currently, due also to the shortage of inverters, it is preferable to get the higher power density at the lowest possible cost. At the moment all the highest efficiency cells (and modules) are coming from producers outside of the EU (for example Sunpower, Sanyo, Suntech [2,3,4]).

In order to obtain high efficiency low cost cells, Laser Grooved Buried Contact (LGBC) solar cell technology offers a chance to obtain efficiencies higher than 18% on mono-crystalline CZ wafer, even if the actual state of the art involve low throughput steps like sputtering and electroless chemical plating. It is also a suitable cell design for low to medium concentration due to its low front contact shading, and its selective emitter structure.

As part of the FP6 EU funded project "Lab2Line" screen print and LGBC solar cell processing techniques were hybridized in order to produce lower cost, high throughput, high efficiency solar cells processed on large area (125x125 mm) mono-crystalline wafers using techniques scalable to industry. The work at ENEA and Narec has been focussed on the combination of front contact grid laser grooving and fine-line screen-printing in order to produce a high efficiency, high throughput, cost effective industrial process. Two hybrid approaches have been considered: a fully screen-printed cell in which Screen-Print (SP) is applied to both the cell rear and into front contact grooves and is subsequently co-fired; and also a process in which SP is applied only to the rear and then electroless plating is used to form the front contacts.

2 APPROACH

The work at ENEA and Narec has been focussed on the introduction of screen printing into LGBC process.

Indeed in the traditional LGBC process, the cell efficiency is limited by the Back Surface Field (BSF) which has a modest rear surface recombination velocity with a minimum around 1400cm/s[5]. This BSF is produced by sintering of a thin sputtered aluminium layer. In a traditional SP approach, an Al based SP paste with a thickness much greater than that of such a sputtered Al layer is deposited on the rear of the cell and then fired to form the back contact and BSF. The depth of the BSF in the SP case is greater than that for the sputtered Al layer, resulting in recombination velocities for SP cells of the order of 800cm/s [6] or lower, as measured on previous work [7].

Moreover a diffusion of phosphorous into the rear of the cell during processing can result in improved bulk lifetimes and diffusion lengths through the gettering of impurities from the bulk of the wafer. Since this diffusion forms a back diode which acts to reduce cell performance, it must therefore be compensated by a p-type dopant. Although the thin layer of sputtered Al in the LGBC process is not sufficient to compensate the n-type back diode produced by this phosphorous diffusion, the demonstrated SP approach is successful in carrying out this compensation. This kind of behaviour has previously investigated and reported [7] on this kind of cell. On the other hand the introduction of SP also to form the front contact, with the aid of fine line printing inside grooves can remove the requirement for an electroless chemical plating step which can become the rate limiting process step should the Al sputtering process be removed.

We have developed and investigated two approaches that hybridise the LGBC and the SP technologies; which are outlined below.

2.1 Hybrid Process 1 – Fully SP-LGBC cells

In this process summarised in Figure 1, the SP metallization technique is used for both front and back contacts, with SP applied over the entire cell rear and only into laser grooves on the front. SP. On the rear Aluminum compensates the back diffusion and forms the BSF, and on the front Silver forms the front contact fingers and busbars. The major issue in this case is the laser groove filling by SP, which means a modification of groove shape, paste rheology and front grid design to obtain a low shading and a well-aligned SP/groove cell (Figure 2).

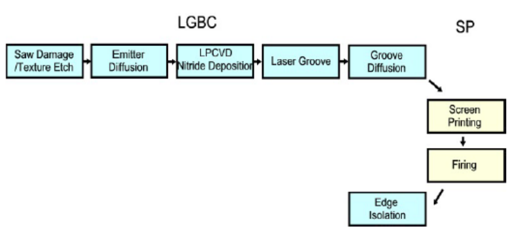

Figure 1 – Hybrid process 1, fully SP-LGBC in which SP is applied over the full rear of the cell and into front contact grooves.

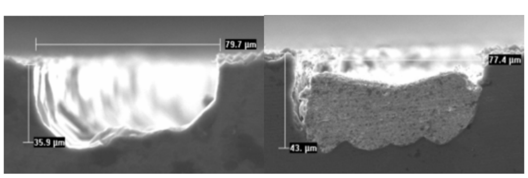

Figure 2 – Scanning electron microscope image of a modified laser groove for the Hybrid 1 process (left) and Complete filling of modified laser groove by screen print paste. The image was taken after drying and firing (right).

2.2 Hybrid process 2 – Back SP-LGBC cells.

In this approach screen printing is used only on the rear of the cell to form the BSF. The front grid has the standard groove shape and grid design for 1sun LGBC cells. After firing, the residual screen-printed aluminium is removed by chemical etching, and finally the metallization is formed using electroless plating of the convention Narec LGBC process. The process is summarised in Figure 3, while an image of the back of the cell is shown in Figure 4.

3 RESULTS AND DISCUSSION

3.1 Hybrid Process 1 – Results.

The main issue for this process is the optimisation of Screen Printing inside grooves. In order to obtain complete alignment between the groove pattern and the screen print mask, a specific front contact grid was designed. Computer modelling with PC1D[8] was used along with in-house developed software taking into account the minimum printable finger width and the maximum number of fingers which could be effectively aligned with the SP. We obtained a grid with 66 fingers. Each nominally 80µm wide which can effectively aligned [7], with good filling and adhesion, as shown in Figure 2.

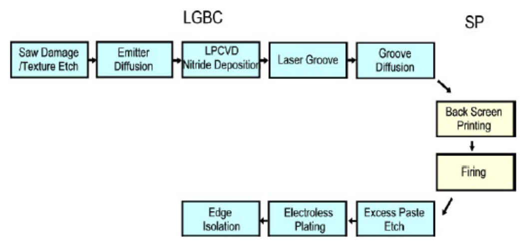

Figure 3 – Hybrid Process 2, back SP-LGBC in which SP is applied over the full rear of the cell, both the front and the rear of the cell are then plated with electroless chemical plating.

Figure 4 – Image of the rear of Hybrid Process 2 cell, after plating.

In order to make good ohmic contact of the SP silver paste to the heavily diffused silicon in the groove this required the optimisation of the paste dilution and the use of silver SP paste specifically designed to make ohmic contact directly onto silicon. After optimisation of both printing and co-firing, a large batch has been produced, resulting in an 16.70% average efficiency with best cell 17.34%, as shown in Table I, having V_{oc} in the average of 620mV, with a maximum of 632mV.

Table I: Hybrid process 1 results

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Eff %
Best cell	0.625	35.08	79.2	17.34
average	0.620	34.56	78.1	16.72

Std. dev.	0.002	0.38	2.0	0.51

Laser Beam Induced Current (LBIC) measurements carried out using a Semilab WT2000 tool are shown in Figure 5. Diffusion lengths averaging 430µm can be observed, with good uniformity over the whole area of the cell (116x116 mm). Any observed non-uniformity appears to be random in nature and no centre-to-edge effects are observed.

The long wavelength performance, evaluated in terms of Internal Quantum Efficiency (IQE), is shown in Figure 7.

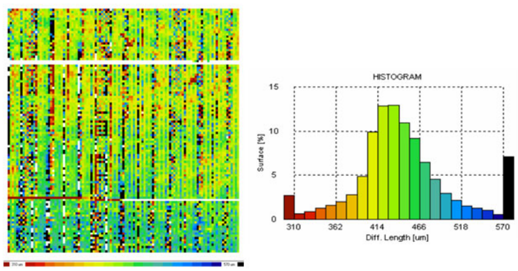

Figure 5 - LBIC scan of a Hybrid Process 1 cell. The average diffusion length is 430µm.

In theory if we optimise every step to move the average V_{oc}, J_{sc} and FF to the maximum measured, efficiencies close to 18% can be obtained with a relatively simple, high throughput and potentially low cost process sequence. Even though the IV parameters of cells produced by this process are good, the difficulties arising from the accuracy required for front screen printing alignment and a small process window for a stable co-firing process could make the Hybrid process 1 not appealing for an industrial scale up. Some of these issues could be mitigated by using an ink-jet approach for example

3.2 Hybrid Process 2 – Results.

To avoid front contact alignment issues or the larger shading produced by 80µm wide screen printed fingers, in the Hybrid process 2 we apply SP Al paste onto the rear of the cell only, which is then dried and fired. The residual SP paste remaining is etched away and the metallisation carried out with the LGBC process standard electroless chemical plating. Hence we have a LGBC front with low shading, low contact resistance and high conductivity and a SP rear which has a superior BSF and bulk gettering properties than the traditional LGBC Al sputtered rear. Hundreds of one sun cells have been produced obtaining IV results at 1 sun shown in Table II and efficiencies shown in Figure 6.

Table II: Hybrid process 2 results

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Eff %
Best cell	0.631	35.60	79.7	17.9
Average	0.623	35.30	79.1	17.4
Std. dev.	0.004	0.15	1.1	0.33

IQE of cells produced by both methods have been measured, and reported in Figure 7 together with a standard LGBC cell.

From Figure 7 the improvement in the long wavelength region is clearly appreciable. An unexpected result is the difference behaviour of the IQE for hybrid process 1 and 2 cells in the range 950-1200 nm. However, comparing this to the cells' V_{oc} values, the comparison is surprisingly inconsistent.

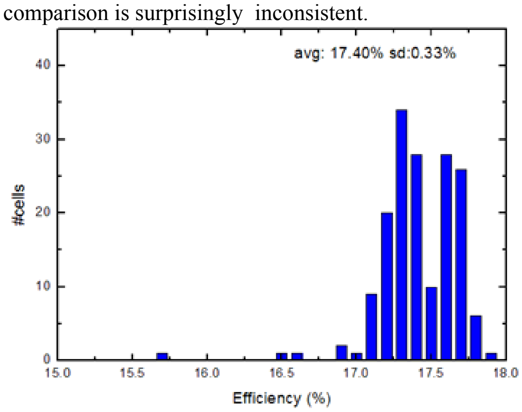

Figure 6 - efficiency distribution of cells produced with Hybrid Process 2

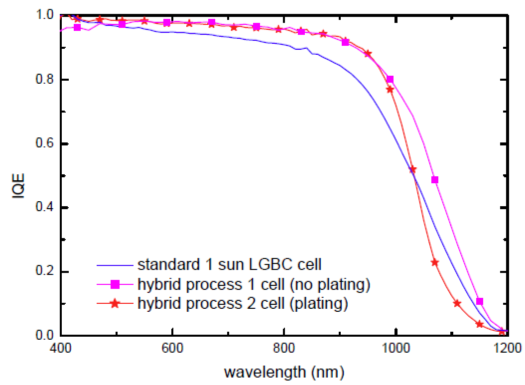

Figure 7 - Internal Quantum Efficiency of cells fabricated with Hybrid Process 1, 2 and the standard LGBC process.

Since the only difference between Hybrid processes is the chemical plating, and since we have previously noted that cells having front plating or SP have the same performances [7], we relate this effect to the metal growth on the back, over the Screen Printing.

A further small batch (circa 15) of cells was processed through the hybrid 2 process with certain process steps optimised. This yielded the results shown in table IV.

Table IV: optimized Hybrid process 2 results

	V_{oc} (V)	J_{sc} (mA/cm^2)	FF %	Eff %
Best Cell	0.629	36.05	0.799	18.11
Average	0.628	35.33	0.799	17.97
Std. dev.	0.001	0.10	0.002	0.08

4 APPLICATIONS FOR CONCENTRATOR CELLS

In order to better validate this result, the same process (hybrid 2, non-optimised) has been applied to cell for concentrator applications (2x1.6cm), optimized for 50X. The best cell achieved 19.5% at 50X and 18.9% at 100X on 200µm CZ wafers, see Figure 11. This is a 6% relative improvement for the same cells manufactured using the standard LBGC process

Also as the V_{oc} is higher than normally obtained with standard LGBC technology then this should result in lower performance degradation with increased temperature. This is especially important for concentrator applications.

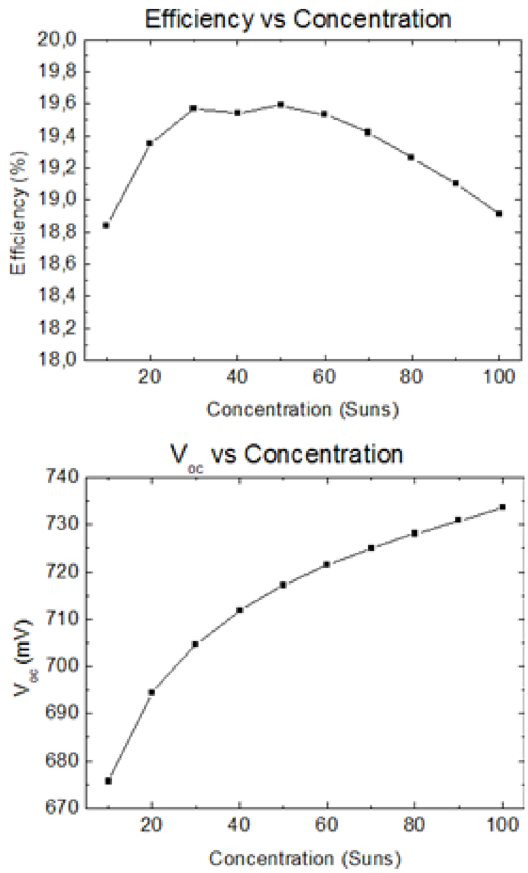

Figure 11 - Results at concentration of a Hybrid Process 2 CPV cell.

5 MODULES

Starting from 28 one sun square cells (116mm X 116mm), modules have been fabricated having a power of 64.1Wp (V_{oc} 17.50 V - I_{sc} 4.60 A - V_{mpp} 14.40 V - I_{mpp} 4,45 A) and efficiency of 17.00% over the cell area after interconnection and encapsulation (Figure 12).

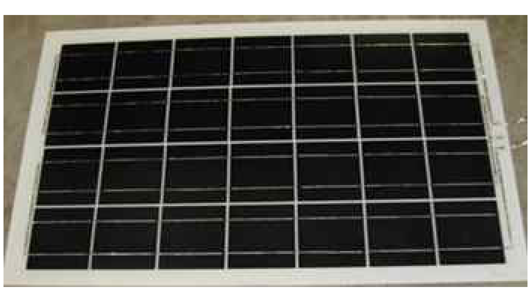

Figure 12 The Lab2Line module

6 CONCLUSIONS

In this paper we have reported the main results for the p-type work package of a 3 year FP6 project.

We have obtained excellent results in yielding high efficiency cells with a compact process using screen printing for both or one side contact, which enhances the state of the art for LGBC cells, especially considering the lower wafer thickness.

17.5% was achieved with Hybrid Process 1 (fully SP contacts) on large area wafers (125x125 mm), with a process immediately scalable to larger area (156 mm) due to the uniformity measured by LBIC.

18.11% was achieved on large area (136 cm^2) wafers, with the Hybrid Process 2, which could be further improved by adjusting specific process steps such as further work on the plating technique or optimisation of the emitter doping profile. Applying the same Hybrid process 2 to concentrator cells yields a 6% relative improvement in efficiency compared to standard Narec LGBC cells when using like for like wafers. Other benefits include faster processing, (Al sputtering is currently a bottle neck) and improved uniformity, which is also scalable to larger wafers such as 156mm pseudosquares.

We have therefore shown two processes that hybridise the screen printing process and the LGBC solar cell process which yields benefits in efficiency, process time and uniformity, especially in application of concentrator cells. Narec hopes to offer these new hybrid cells commercially in the future.

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