# FRONT DICING TECHNIQUE FOR PRE-ISOLATION OF CONCENTRATOR SILICON SOLAR CELLS

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ABSTRACT: Silicon solar cells for concentrator applications tend to be small in size due to the use of light focusing optics and minimization of material usage. As cells become smaller, isolation of cells at their edges therefore becomes relatively more important in terms of both accuracy and cell performance. A novel isolation technique designed to address these issues is presented, and demonstrated with LGBC cells (Laser Grooved Buried Contacts) manufactured in the Narec pilot production line. As concentration is increased, cells with our Front Dicing Technique (FDT) increasingly outperform cells having our standard isolation thanks to gains in $V_{OC}$ and FF. Internal Quantum Efficiency (IQE) remains high at short wavelengths and is improved in the long wavelength region. There is no net increase in the number of processing steps and no additional resource consumption, therefore providing an easily implemented route to reducing cost per Watt.

Keywords: Concentrator Cells, Laser Processing, Buried Contacts

## 1 INTRODUCTION

### 1.1 Motivation

One important design restriction of solar cells for concentrator applications is the small cell size that is inherent to such systems. Indeed one of the main motivations for developing concentrator photovoltaics is the minimization of the use of expensive semiconductor material. However, as cell size is scaled down with the illuminated region, edge effects become relatively more important. The design of the perimeter region must therefore be reconsidered and optimized, while simultaneously keeping the goal of minimizing processing effort and cost.

In this work a novel approach to edge isolation is presented. A deep laser groove that is used to cleave cells is moved from the final to the first processing step. This Front Dicing Technique (FDT) therefore avoids laser induced damage in the final cell and minimizes the amount of unpassivated surface area. Since the change is simply in the sequence of the processing steps, effort and cost remains low.

Cells having FDT isolation are compared both at 1Sun and at concentration to cells having the Standard isolation process. Electrical and optical behaviour is discussed, as are morphology and processing parameters.

### 1.2 Background

Edge recombination and its relative importance as a loss mechanism for small high-efficiency Si solar cells has been considered previously [1-7]. For example, McIntosh et al [1] have investigated LGBC cells, finding the edge recombination current could be modelled "as an exponential shunt across the pn junction that is resistively isolated from the main body of the solar cell," and suggested a corresponding equivalent circuit. They simulated that although a stronger effect for smaller cells, edge recombination reduces cell efficiency even for large area solar cells. Altermatt et al [2] have simulated that the proportion of losses attributed to edge recombination can be minimized by increasing the distance of the cut edge from the cell active area, decreasing cell thickness, increasing illumination level, increasing cell area and by masking the periphery region. Edge surface passivation was found to only be a significant advantage if a recombination velocity < 50 cm/s could be achieved, suggesting a wrap-around emitter approach.

Oxide passivation of a rear isolating laser groove was shown to decrease edge recombination by as much as 60%, thereby decreasing $J_{02}$ and increasing FF values for n-type back contact cells [3]. SunPower demonstrated a 250Sun small size cell with localized doping prior to saw cutting, producing a passivating Edge Surface Field (ESF). Relative efficiency losses were calculated to decrease with increasing cell size and increasing ESF doping level [4].

## 2 APPROACH

### 2.1 Narec process

The LGBC solar cell has been manufactured in a pilot production line by Narec since 2005, and is readily optimised for use under concentration. The lowly-doped emitter and selective emitter structure affords good blue response and low contact resistance. The high conductivity of the fine-line buried front contacts enables the metallization pattern to be adapted to handle the large current densities under concentration. The direct writing of the front contact pattern by laser is advantageous in that it permits the metallization pattern can be changed readily, either for optimisation of the cell design or for the production of cells for different concentration factors and system geometries [8].

In the Narec LGBC process, edge isolation is carried out using laser scribing on the rear side as a final processing step, affording shunt removal and the separation of individual cells from a wafer by subsequent cleaving. Our Front Dicing Technique (FDT) uses similar laser scribing, but is applied on the front side of wafers as a first rather than last process step (see Fig. 1 for schematic structure comparison). Cells are then completed as normal [9] intact within a wafer, therefore keeping the number of processing steps constant.

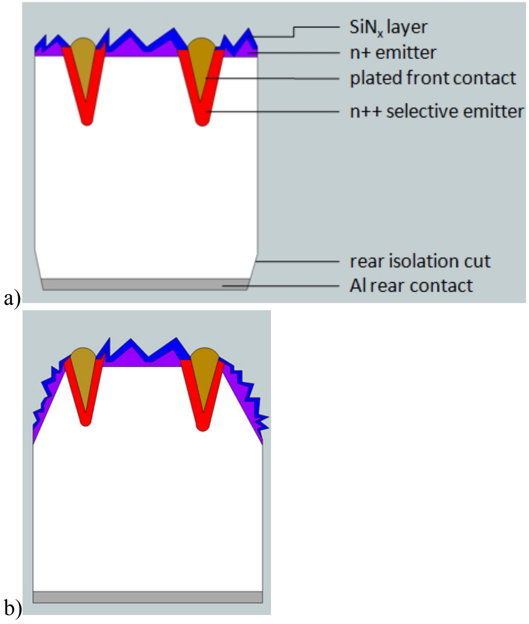


**Figure 1:** Schematic of LGBC cell having a) traditional rear-side isolation and b) Front Dicing Technique.

Since FDT is applied as a first step, saw damage and texturization etches inherent to the production sequence simultaneously remove any laser-induced damage after this pre-isolation, whereas normally any laser-induced damage resulting from the final isolation step is left untreated. In addition, the grooved area is later covered by a LPCVD (Low Pressure Chemical Vapour Deposition) nitride layer. Therefore the amount of exposed unpassivated edge area is decreased.

In addition, due to the lack of metal on the wafers, isolation and front contact grid grooving are now done on the same tool, affording improved pattern alignment. Currently 0.5 mm is left from the busbar to the isolation line, in part allowing for mismatching between tools. This distance can be minimised using FDT, with the benefit of maximising active area and Si useage, thus further reducing cost per watt.

### 2.2 Experimental Procedure

125 by 125 mm Cz monocrystalline Si wafers were processed in Narec's LGBC pilot production line. Individual cells had a length of 60 mm and a width varying between 2 and 14 mm (presented results correspond to 2 mm width unless otherwise specified). Cells were processed in a large central block due to concerns as to wafer fragility, with neighbouring cells sharing an edge.

Laser parameters were varied in order to probe a range of FDT groove depths. Power and number of passes over the location (number of swipes) were considered. Cells were manually cleaved along isolation lines as a final step to be tested at concentration

## 3 STRUCTURE

FDT grooves on the order of 30 – 130 µm were created. It was found that of the depths considered, only the grooves achieving greater than approximately 30 % of the wafer thickness could be cleaved in a consistent manner, with deeper grooves noticeably easier to snap.

Images of a finished solar cell successfully isolated along a FDT groove are presented in Figure 2. It can be seen that groove surfaces are textured with random pyramids and covered in SiN$_x$. The bottom of the groove is jagged due to this texture. By thinning the wafer at its edge, the area of exposed Si surface is decreased, thus decreasing the prospect of recombination.

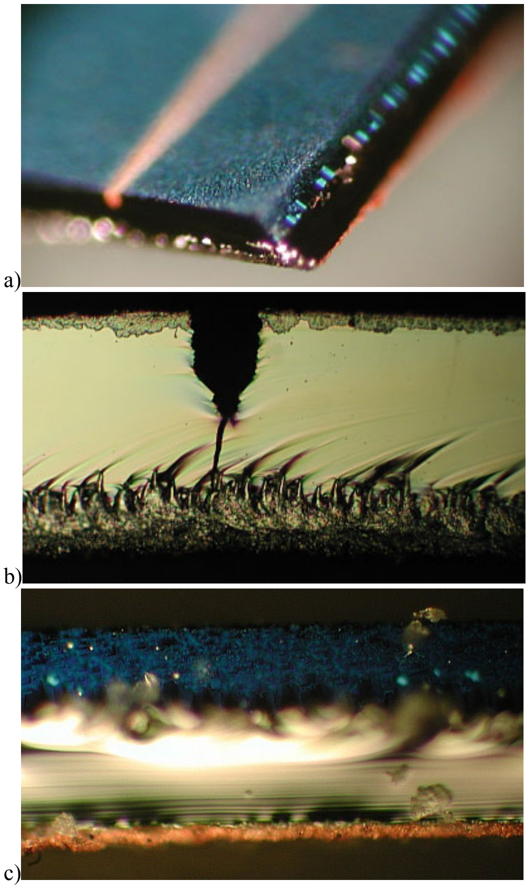


**Figure 2:** Optical microscopy images of a prototype FDT cell (wafer thickness nominally 200 µm). a)FDT isolation along right hand side edge, Standard isolation on the left. A grooved contact finger and full coverage metal can be seen. b)Side view along an edge having Standard isolation. A perpendicular FDT groove used to cleave between two neighbouring cells is shown. c)Side view along a FDT isolated edge.

It is worth noting that despite having deep laser scribes, wafers with FDT applied as a first step are still sufficiently mechanically robust. When appropriate laser parameters and groove depths are chosen, wafer breakage rates through the production line are statistically comparable to that of the standard process.

At shallow depths cleaving of cells can be more delicate than the standard process of isolating from the rear side. This is partly due to the fact that the FDT lines are harder to identify than rear side isolation lines since they are effectively camouflaged with the front surface having the same nitride coating.

However FDT grooves deeper than 100 µm increase the possibility of creating a shunt since these grooves overlap with the grooves of the front contacts which are themselves on the order of 35 µm. A group of 40 wafers with a nominal FDT groove depth of 100 µm resulted in no shunted cells, while 14% of the cells in a concurrently processed group in the same batch were shunted by increasing the groove depth to ~ 115 µm.

Therefore depths of 30 – 50 % of the wafer width can be used successfully. Cell results will be discussed shortly, but no consistent trends in performance as a function of FDT groove depth were observed within this range.

## 4 CELL PERFORMANCE

### 4.1 1 Sun results

Cells were measured at 1Sun (AM1.5, 25˚C) whilst still in a block of attached cells, with averaged results shown in Table 1. Blocks were separated from their original wafer, and isolation lines for individual cells applied but not yet cleaved along (therefore cells not electrically isolated from each other, but edge shunts are removed). This was done for ease and accuracy of measurement, effectively averaging over a large number of cells simultaneously. Individual isolated cells are difficult to measure due to their small size, and lamp nonuniformity becomes a source of uncertainty. Note that this approach essentially reduces the relative importance of edge effects.

**Table I:** 1Sun cell parameters comparing FDT to the Standard process (scribed but not separated cells measured together in a block, 56 cells per block, data averaged over 10 and 40 cell blocks for Standard and FDT type respectively).

| | $J_{SC}$ [mA/cm$^2$] | $V_{OC}$ [mV] | FF | Efficiency [%] |
|---|---|---|---|---|
| Standard | 33.07 | 613 | 80.2 | 16.2 |
| FDT | 33.21 | 613 | 80.2 | 16.3 |

Comparable results are obtained with FDT and Standard isolation approaches. The addition of FDT lines at the front-end of the process therefore does not inherently cause significant wafer damage. Higher $J_{SC}$ may be attributed to the better current collection at long wavelengths for FDT, observable in the IQE (Internal Quantum Efficiency) spectrum (Fig. 3).

FDT grooved cells have comparable IQE at low wavelengths, and outperform the Standard process at long wavelengths. This reflects the fact that unlike the Standard laser scribes on the rear side, that act as sites of high recombination, FDT grooves on the front side have been damage etched and passivated. IQE at short wavelengths therefore remains high, indicating that FDT does not cause any additional recombination in the emitter and selective emitter regions.

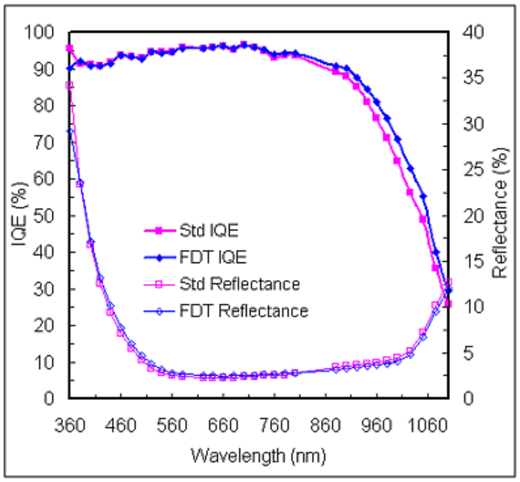


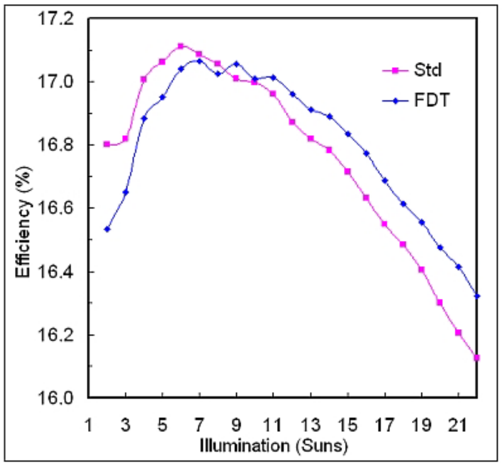
**Figure 3:** IQE and Reflectance for FDT and Standard isolation (scribed but not separated cells measured together in a block).

This IQE behaviour is confirmed with spatially resolved LBIC (Light-Beam Induced Current) scans of cell blocks (not shown), and indicates that the FDT grooves are regions of lower reflectance and higher LBIC current than the surrounding area. Conversely standard isolation lines appear as regions of low IQE. Note that although observed locally when mapped, overall reflectance for the two isolation approaches is comparable. Therefore FDT grooves do not appear to significantly contribute to light-trapping when averaged over the whole area. FDT regions also appear brighter in Electroluminesce (EL) maps of cell blocks, indicating these are regions of decreased recombination (not shown).

### 4.2 Concentration measurements

Cells were cleaved and measured individually using using a flash lamp system. Values were corrected to 25˚C, and $J_{SC}$ was normalized to 1Sun cell block values. Resulting average solar cell parameters are presented in Figure 4.

a)



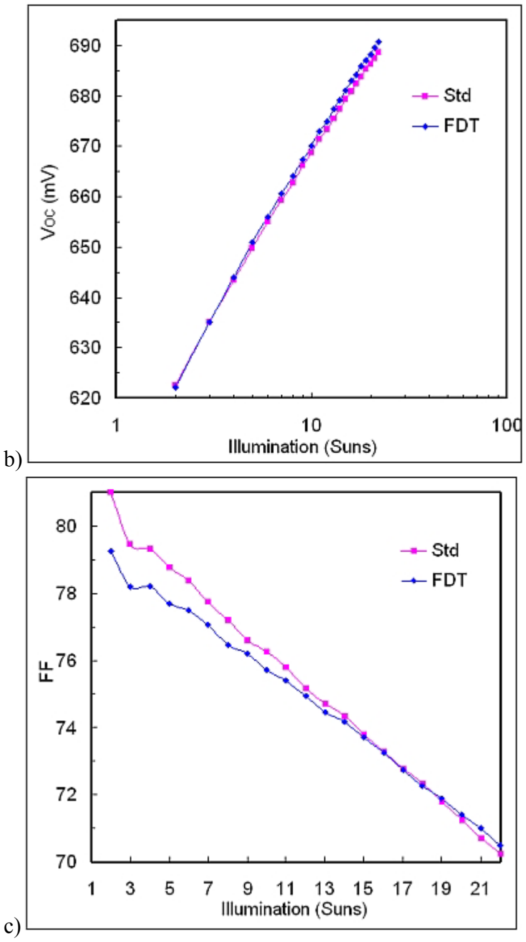


**Figure 4:** a)Efficiency, b)$V_{OC}$ and c)FF results as a function of concentration comparing FDT and Standard isolation (averaged over cells measured individually).

Unlike when measured in blocks, when measured individually FDT cells are worse at 1Sun when compared to Standard isolated cells. However, FDT type cells outperform Standard cells above 8Suns (note that these particular cells were designed for 10 – 20Suns). While the $V_{OC}$ of FDT cells starts off lower, it increases at a faster rate and is greater compared to Standard cells above 3Suns. Similarly FF is significantly lower for FDT cells at low concentration, but degrades less quickly and even surpasses Standard cells above 19Suns. This is in part due to the fact that series resistance ($R_S$) at concentration is on average 8% lower in this batch for cells having FDT type isolation, which decreases FF losses. $R_S$ may be lower since both the emitter and front contact grid area are effectively increased (without increasing overall cell area) by the FDT groove regions along the cell perimeter. Contacts perpendicularly overlapping the FDT grooves collect current that may otherwise have had to travel further.

The reason why individual FDT performance is comparatively poor at low concentration may be attributed to the cleaved edge surface (recall 1Sun measurements tabulated above do not reflect this since they were measured on cell blocks and not individual cells therefore not having cleaved edge regions). One possible explanation for this draws on the relative importance of different recombination pathways as a function of illumination. While the perimeter is the dominant factor at 1Sun, recombination in the emitter becomes increasingly important at concentration [10]. Regarding the edge surface itself, a simulation by Hermle et.al. on the relative proportion of edge surface recombination attributed to different regions at low illumination intensities (note only 0.001-1Sun simulated) suggested that the relative contribution of recombination in the space charge region (SCR) decreases while recombination in the base and emitter becomes more dominant as illumination intensity is increased [5]. It is reasonable that there may be more damage to the SCR in the case of FDT since it is cleaved from the front (compared to Standard cells being cleaved from the rear), and therefore recombination in this region could be emphasized by damage induced by fracture. However by extending the passivated emitter over the cell edge, the amount of exposed Si and the area of the base region at the edge surface is effectively decreased. Therefore as illumination intensity is increased FDT cells become advantageous since recombination in the emitter and base regions as well as $R_S$ becomes increasingly important.

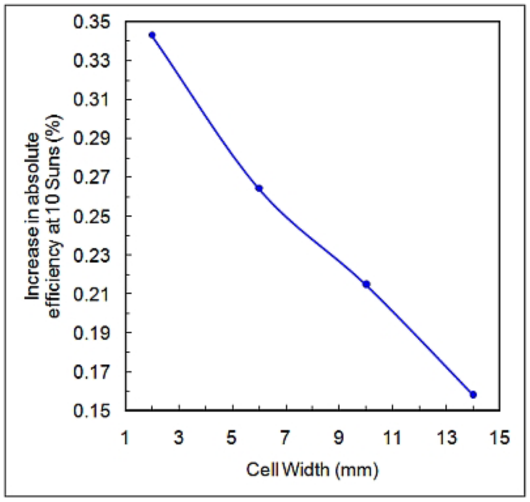


**Figure 5:** Average increase in absolute cell effciency measured at 10Suns as a function of cell width.

Larger cells were also fabricated, keeping length constant at 60 mm while varying width. Fig. 5 shows the absolute improvement in efficiency at 10Suns gained by using FDT type isolation as a function of cell width (note results are from a different batch than presented in Fig. 4). The advantage of using FDT over Standard isolation is in this case still apparent at a width of 14 mm. The decrease in relative improvement with respect to the Standard process reflects the decrease in the ratio of perimeter to surface area and the corresponding importance of this region as a factor in influencing cell performance.

## 5 CONCLUSIONS

The presented Front Dicing Technique is designed to mitigate losses due to edge effects for small size silicon solar cells for concentrator applications. LGBC cells processed in Narec's pilot production line are discussed.

It is shown that efficiency, FF and $V_{OC}$ are all improved with increasing concentration when compared to cells processed with the Standard isolation procedure. IQE in the long wavelength region is also enhanced. In addition, the modification of the processing sequence affords more accurate patterning, which in turn allows a decrease in imposed cell size tolerances and therefore the potential for better material usage. FDT requires minimal extra processing effort and no additional resource consumption, therefore providing an easily implemented route to reducing cost per Watt.

## 6 FUTURE WORK

FDT cells are currently being implemented in prototype module by project partners as part of the FP7 funded ASPIS project. Further optimization of the geometric and laser processing parameters is planned, as well as the investigation of implementing this approach with different cell types.

## 7 ACKNOWLEDGEMENTS

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