# Front Dicing Technique for Pre-isolation of Concentrator Silicon Solar Cells

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**Introduction** 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, edge effects therefore become relatively more predominant as loss mechanisms.

First results of a novel isolation technique designed to mitigate this problem are presented, and proof-of-concept demonstrated with LGBC cells (Laser Grooved Buried Contacts). Using this technique, cell performance at concentration is increased with no net increasing in the number of processing steps and no additional resource consumption, therefore providing an easily implemented route to reducing cost per Watt.

**Background** Edge recombination and its relative importance as a loss mechanism for small high-efficiency Si solar cells has been considered previously [1-6]. 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 [7]. SunPower demonstrated a 250-Sun 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 [3].

**Approach** 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

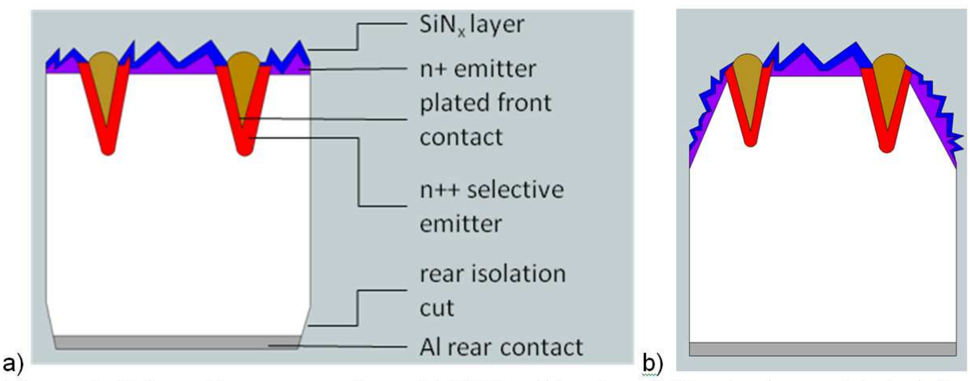



*Figure 1:* Schematic cross-section of LGBC cell having a) Standard rear-side isolation and b) Front Dicing Technique approach.

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 Figure 1 for schematic structure comparison). Cells are then completed as normal [9] intact within a wafer, therefore keeping the number of processing steps constant.
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. Theoretically this distance could be minimised using FDT, with the benefit of maximising active area and Si useage, thus further reducing cost per watt.

**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. Speed, 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.

**Structure** FDT grooves on the order of 30 – 80 µm were created. No wafers were broken during processing.
It was found that of the depths considered, only the grooves achieving approximately 30 % of the wafer thickness could be considered for snapping. Of such wafers, only one combination of laser parameters resulted in being able to reproducibly separate the cells from each other. It is however necessary to note that this separation was markedly more difficult and 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 not easy to distinguish from the front surface.
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.

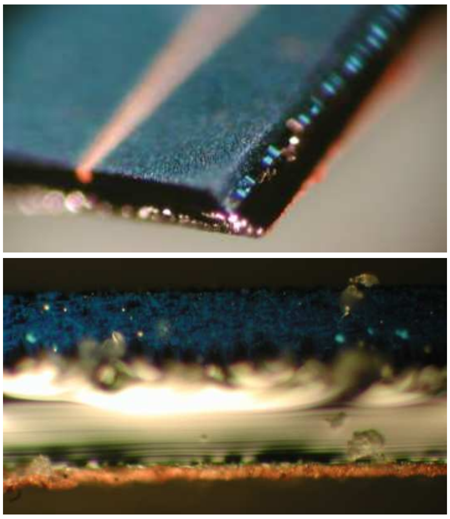
a)
b)


*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 a FDT isolated edge.

**1 Sun Performance** 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. Note that this approach essentially reduces edge effects.

| | Jsc [mA/cm2] | Voc [mV] | FF | Eff [%] |
|---|---|---|---|---|
| FDT | 30.96 | 606 | 79.4 | 14.90 |
| Std | 30.17 | 607 | 80.6 | 14.76 |

*Table 1:* Average 1Sun cell parameters comparing FDT to the Standard process (scribed but not separated cells measured together in a block).

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 added front side texture of the FDT grooves, improving light-trapping. These grooves also increase the amount of surface and emitter area, which perhaps leads a higher $J_{02}$ and thus lower $V_{OC}$ and FF values.
Note that overall performance of the batch of cells presented here is lower than that of previous batches having the same design; average of 16.25% in blocks at 1Sun was obtained previously, with best individual cells achieving above 17% at 10Suns (main difference being higher $J_{sc}$). Although not ideal, these lower values do not detract from relative comparisons important for this first feasibility study.

| | IQE (%) at Wavelength (nm) | | | |
|---|---|---|---|---|
| | 405 | 860 | 950 | 990 |
| FDT | 87.97 | 89.51 | 75.86 | 71.53 |
| Std | 87.79 | 89.79 | 74.26 | 66.79 |

*Table 2:* Internal Quantum Efficiency (IQE) for FDT and Standard isolation processes at different wavelengths (scribed but not separated cells measured together in a block).

Internal Quantum Efficiency (IQE) of measured blocks at four wavelengths is presented in Table 2. FDT grooved cells are comparable 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 and do not decrease IQE.

## 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 un-isolated values and linearized around 5Suns. Resulting average solar cell parameters are presented in Figure 3.

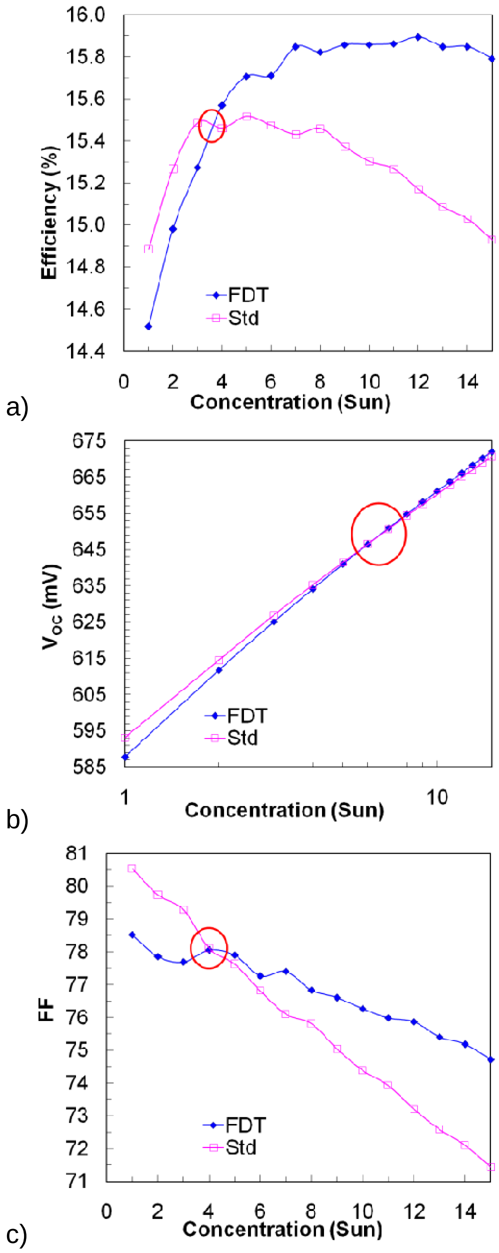



*Figure 3:* a)Efficiency, b)$V_{OC}$ and c)FF results as a function of concentration comparing FDT and Standard isolation. Cross-over point where FDT becomes advantageous is highlighted (average over cleaved cells measured individually).

Unlike when measured in blocks, when measured individually FDT cells perform worse at 1Sun when compared to Standard isolated cells. The cause is attributed to the cleaved cell surface, with one possible explanation for this drawing on a simulation of the relative proportion of edge surface recombination attributed to different regions at low illumination intensities (note only 0.001-1Sun simulated). It was shown that the relative contribution of recombination in the space charge region (SCR) decreases while recombination in the base becomes more dominant as illumination intensity is increased [4]. 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 would be emphasized by damage induced by fracture. As illumination intensity is increased and recombination in the base region becomes increasingly important, FDT cells become advantageous since the amount of exposed base surface area is decreased. FF, $V_{OC}$ and efficiency values are higher for FDT cells above ~5Suns (these particular cells intended use is at 10Suns). Note that while series resistance for FDT cells is lower than for Standard cells (~12% less, most likely due to more metal coverage on additional diagonal surface and wider rear metal by the thickness of a laser groove), which would also cause FF of FDT to be superior as illumination level is increased, the fact that both $V_{OC}$ and FF are relatively higher for FDT cells indicates that recombination is also an important factor.

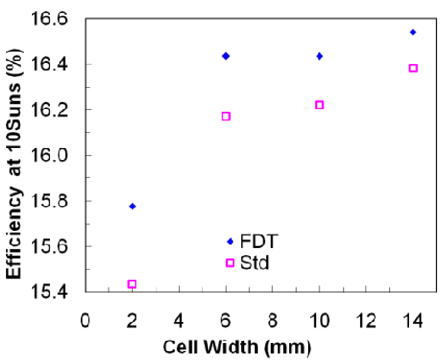



*Figure 3:* Efficiency at 10Suns as a function of cell width.

Larger cells were also fabricated, keeping length constant at 60 mm while varying width. Figure 4 shows resulting efficiencies at 10Suns as a function of width, indicating that the advantage of FDT is 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 edge recombination as a factor in the degradation of cell performance.

**Conclusions** The presented Front Dicing Technique is designed to mitigate losses due to edge effects for small size Si concentrator cells. First results for LGBC cells in Narec's pilot production line are discussed. It is shown that efficiency, FF and $V_{OC}$ all increase with increasing concentration when compared to cells processed with the standard sequence. Using this technique, cell performance at concentration is increased with minimal extra processing effort and no additional resource consumption, therefore providing an easily implemented route to reducing cost per Watt.

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