MULTI-CRYSTALLINE SILICON SOLAR CELLS LASER EDGE ISOLATION: A COMPARISON OF PROCESS RESULTS ACHIEVED WITH STATE-OF-THE-ART TRIPLED ND:YAG AND FIBER LASERS

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ABSTRACT: Laser Edge Isolation is the main laser application in photovoltaic applications. This laser process is necessary to remove parasitic emitter diffusion wrapping around the wafer edge, in order to avoid very low fill factors. We have investigated in detail, and compared the results thus obtained, the cell surface scribing realized with State of the Art Pulsed Fiber Laser (emitting at about 1070 nm) and tripled Nd:YAG (emitting at 355 nm). Using the LBIC technique, outstanding isolation efficiency was detected in case of Fiber Laser scribing. Measured LBIC signal ratio > 97% on wide parameters range, and >99% in best cases, are the fingerprint of nearly ideal isolation process. Extremely high isolation efficiency was as well detected in case of UV Laser process; LBIC signal ratio > 92% was routinely obtained on wide parameters range, and >98% in best cases.

Keywords: Characterization, Laser Processing, Multi Crystalline Silicon, Photoelectric Properties, Solar Cell

1 INTRODUCTION

In Mono and Multi-crystalline Silicon Solar Cells the parasitic emitter diffusion wrapping around the wafer edge has to be removed, in order to avoid very low fill factors. This edge isolation process can be performed by different methods, the most popular in the past being plasma barrel etching. Unfortunately, this batch process led to a disruption in the flow of the process due to offline stacking of wafers; there was then a great interest in replacing this step by an appropriate inline process. The most popular new edge isolation process [1] is laser scribing. It is naturally suitable for inline processing and the wafer doesn’t need to be touched, which is an important requirement for the handling of thin wafers.

Nd:YAG with short wavelengths (e.g. 355 nm) are nowadays the most popular laser sources used, bearing the advantage of generating less Heat Affected Zone, compared to Nd:YAG IR lasers. In addition, conventional 1064 nm lasers can micro cracks that emanate from the scribed groove and which, if reaching the edge of the wafer, can compromise structural integrity, especially for thin wafers. At mean time, IR Fiber Laser technology [2] has strongly emerged as disruptive technology in the industrial environment, for marking and micromachining in “micro” applications, as well as for cutting and welding in “macro” applications. LaserPoint made a comprehensive work [3] in order to compare the effects on crystallography of Silicon micromachined with either tripled Nd:YAG and Fiber Laser, showing outstanding results of Fiber Laser technology respect to sensitive Silicon material based applications. In this paper we compare the state-of-the-art tripled Nd:YAG and Pulsed Fiber Laser respect to edge isolation of Multi-crystalline commercial solar cells.

2 EXPERIMENTS

2.1 Laser Systems Used in the Experiments

The experiments were carried out in two different scribing system arrangements:

- The first “UV” bench setup includes:
  - A Q-switched, diode pumped Nd:YAG laser with more than 10 W average power at 355 nm, TEM₀⁰, M² < 1.2, optimized at 10-30 kHz or 40-80 kHz.
  - A high-speed x-y galvano-mechanical beam positioner equipped with a telecentric lens focusing system and a high precision x-y-z stage for accurate sample positioning, automatic self-calibration for temperature compensation and calibration for non-linearity compensation, resulting in estimated repeatability of about 5 microns.

- The second “IR” bench setup includes:
  - A pulsed fiber laser, 20 W average power, 1055 nm, TEM₀⁰, M² = 1.15, 20-100 kHz
  - A high-speed x-y galvano-mechanical beam positioner equipped with an F-Theta lens focusing system, automatic self-calibration for temperature compensation and calibration for non-linearity compensation, resulting in estimated repeatability of about 5 microns.

2.2 Samples preparation

The tests were performed on commercially available solar cells, from two different suppliers. 20x20 mm² test samples were realized by rear UV laser grooving and subsequent snapping, in order to avoid current leakage induced by Al migration to the front contact. The I-V characteristics of blank samples were measured and the selected samples (selection based on reverse breakdown voltage and current) were scribed either with UV or Fiber Laser.

2.3 Characterization techniques

I-V curves of blank and processed samples were measured in N-P and N-P-N (see figure 1) configuration and blank subtraction was applied to processed samples curve.

Figure 1 I-V configuration for N-P-N measurements.
Light Beam Induced Current (LBIC) [4] technique was applied to validate the processes. The LBIC setup works with three laser sources at 633, 780 and 830 nm, taking the laser beam power below 1mW. The laser beams are moved on the wafer surfaces using a galvanometer x-y scanner system and the beam size on the focus has a diameter of about 65 mm.

In LBIC measurements the laser isolation quality was quantified by the photocurrent signal ratio. It was defined as the ratio between the photocurrent collected when the laser beam scans the non isolated side of the cell and the photocurrent value in the isolated side.

Furthermore, microscope observation, Scanning Electron Microscope (SEM) and metallographic, were performed in order to detect the groove quality.

3 RESULTS

The main investigated parameters were the relative focus position respect to cell surface (in order to determine the process tolerance to industrialization) and lasers repetition rate (to determine the maximum isolation speed). From the I-V characteristics, in N-P and N-P-N configuration, the cell resistance was extracted (e.g. UV laser process, figure2).

![Resistance vs. focus position](image)

**Figure 2** Edge isolation with UV (355 nm) laser, showing high process tolerance.

The results are well in excess to 30 Ohms for UV Laser and Fiber Laser processes over a broad focus position (up to +/- 0.6 mm defocus, larger than optics depth of focus). The samples morphology show very clean UV and Fiber Laser scribing (figures 3 and 4) with small re-crystallization in IR process; the grooves are quite sharp, uninterrupted and negligible re-deposition (even in the IR case) was detected.

**Figure 3** Edge isolation with UV (355 nm) laser, showing high process tolerance.

**Figure 4** Edge isolation with IR Fiber Laser, high isolation efficiency at very high process speed (780 mm/s).

The UV process results in clean, damage free process, as shown in figure 4, where Backscattering and Secondary images proof the absence of micro cracks re-deposition at groove sides.

**Figure 5** Backscattering and Secondary SEM images of UV process.

On the other hand, non optimized processes, either by long focal length or large defocus, result in large, shallow grooves with evident recasting effects (e.g. in case of IR Fiber Laser), figure 6.

**Figure 6** Non optimized IR Fiber Laser edge isolation process, long focal length, 350 mm/s.

The Silicon absorption curve (figure 7), indicates that the ratio $\alpha(355\ nm)/\alpha(1070\ nm)$ is higher than $10^7$, that magnifies undesired thermal effects in case of IF Fiber Laser.
LBIC is a powerful and fast characterisation technique, able to discriminate optimum to poor scribing processes. For sake of exemplification, figure 8 show the LBIC fingerprint of good isolation, versus poor isolation at solar cell side and edges (figure 9).

Using the LBIC technique, outstanding isolation efficiency was detected in case of Fiber Laser scribing. Measured LBIC (figure 10) signal ratio > 97% on wide parameters range, and >99% in best cases, are the fingerprint of nearly ideal isolation process. Extremely high isolation efficiency was as well detected in case of UV Laser process; LBIC signal ratio > 92% was routinely obtained on wide parameters range, and >98% in best cases.

4 CONCLUSIONS

We have shown that IR Fiber Laser process time can be lower than 1s/cell, and isolation efficiency LBIC > 99% in best cases. Also, the process with UV Laser is well controlled and reliable, with process time <2 s/cell, and isolation efficiency LBIC > 98% in best cases.

5 REFERENCES