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Edge isolation of solar cells using laser doping

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ABSTRACT

A technique of using laser doped isolation lines to separate shunted edge regions from the active area of a solar cell is presented. Photoluminescence images are used to investigate the effectiveness of the edge isolation. Screen-printed silicon solar cells are fabricated to demonstrate the ability of the technique to remove the shunt path from the front emitter to rear contact whilst minimising edge recombination. It is found that a reduction of J_{02} by on average a factor of more than three is possible compared to the standard method of cleaving for these laboratory cells, yielding an average improvement in FF of 1.7%$_{abs}$, and 0.5%$_{abs}$ efficiency increase. The J_{02} values achieved using this process are comparable to those achieved on solar cells with edges passivated with a thermal oxide.

1. Introduction

An important step in the fabrication of solar cells is to remove the conductive path formed by the emitter diffusion wrapping around the edges of the device. If this edge region is not isolated or removed, photogenerated current can flow from the front to the rear of the device without passing through the external circuit, leading to a low shunt resistance (R_{sh}) and consequently a low fill factor (FF). Edge isolation can be performed in a number of ways. The most popular industrial techniques include plasma barrel etching [1], laser grooving of an isolation trench [1–3], and more recently single-side wet chemical etching [4]. In all of these cases, the physical removal of the silicon creates an interruption in the conductive path through which the carriers flow to the edge. On laboratory samples, where high throughput is not required, a laser can also be used to scribe the rear side followed by mechanically cleaving the edges to physically remove the edge region of the cells. While these techniques are effective at removing the linear shunt, they introduce varying degrees of damage and recombination sites to the cell edge. An increase in the dark saturation current in the space charge region (J_{02}) occurs if the junction is exposed at the damaged edge, leading to a reduction in FF [5,6]. The effect of a poorly passivated or damaged edge region is clearly observed under low illumination on both solar cells [7,8] and lifetime test structures [9–12], a scenario in which there are fewer generated carriers which can consequently travel with low resistance to the edge regions to recombine.

Edge recombination can be a particularly significant parasitic loss mechanism in small-area solar cells, such as laboratory-scale high efficiency solar cells, concentrator solar cells, and novel devices which rely on small area solar cells to be interconnected for low current, high voltage applications [13,14], as the losses are accentuated due to the large perimeter to area ratio present in these types of structures [15]. Several methods have been used to perform edge isolation in a manner to minimise the amount of recombination at the edge region, typically introducing an isolation groove around the edge [9,16] or partially cutting the cell out of the host wafer [17] at the front end of processing, such that the groove or cut face can be damage etched and well-passivated with a thermally grown oxide. Water-jet guided lasers have also been used [14,18] as an alternative to conventional laser edge isolation to reduce the damage induced by laser heat. Other methods have involved leaving a gap between the active area of the solar cell and the edge of the wafer with the use of an aperture to shade the edges [7,19].

1.1. *Laser doping as a method for isolation*

Boron laser doping has been shown to be one possible method to isolate regions of high recombination from the active area of a device on a sample with a phosphorus emitter [12]. The laser doping process is described in detail in reference [20]. The p-type laser doped region interrupts the flow of electrons through the n-type emitter and thus electrically isolate the regions on either side of the laser doping from each other. In Fig. 1(a), an electron beam induced current (EBIC) image showing the presence of the p-n junction (bright region) is superimposed on a scanning electron

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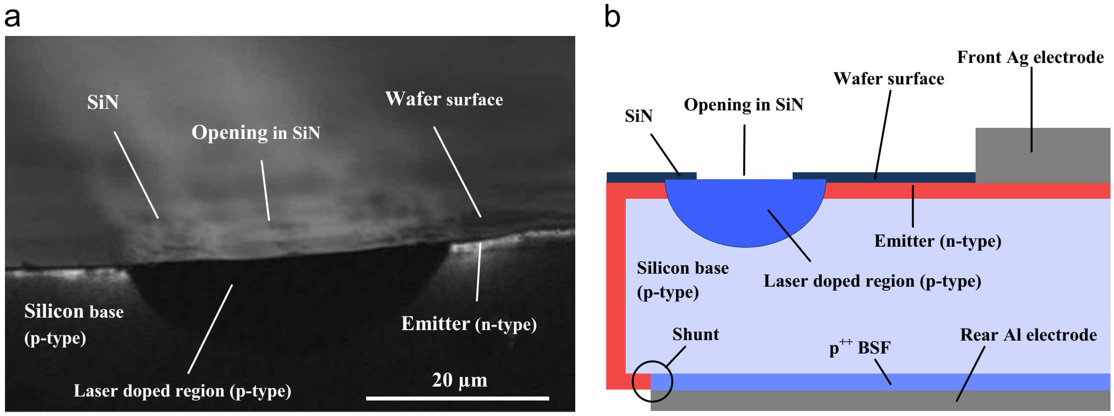

Fig. 1. (a) Combined EBIC/SEM images at ×2000 magnification of p-type laser doping through an n-type thermally diffused emitter (thermally diffused p-n junction is visible as the bright region near the surface of the silicon) (b) Schematic showing corresponding regions of the structure implemented onto a p-type screen-printed solar cell (not to scale).

microscope (SEM) image of the same cross section of a p-type laser doped line overcompensating an n-type emitter. In Fig. 1(b), the corresponding regions are shown schematically and the application of this technique for solar cell edge isolation is illustrated. In this paper, this technique is applied to small-area screen-printed solar cells.

1.2. Process optimisation

Test structures were fabricated to determine the optimum processing conditions for effective laser doped edge isolation. The ideal edge process should 1) isolate the edge region electrically (i.e. remove the linear shunt caused by the n$^+$/p$^+$ overlap) and 2) introduce as little additional recombination as possible (to maintain a low J_{02}).

2. Material and methods

Industrial grade 156 mm × 156 mm pseudo-square Czochralski (CZ) grown p-type random pyramid textured wafers with a resistivity of 1–3 Ω cm were used in this experiment. The wafers were cut down into 16 smaller 38 mm × 38 mm samples to enable processing in the laboratory. After RCA cleaning, samples were diffused in a POCl$_3$ tube furnace to form a shallow n-type emitter on both sides with a sheet resistance of approximately 60 Ω/cm^2. Following PSG removal in HF, a 75 nm SiN$_x$ layer was deposited on both sides of the samples using a remote microwave Roth & Rau AK400 PECVD system at a deposition temperature of 400 °C. To perform the edge isolation, wafers were first spin-coated at 2000 RPM with Filmtronics PBF1 boron dopant source for 40 s, and baked at 130 °C for 10 min to remove solvents from the dopant source. The samples were then processed with a 15 W 532 nm CW laser with a Gaussian beam distribution and scanning optics. The spot size at the focal point had a diameter of 22 µm and the total power reaching the stage was approximately 13 W, corresponding to an average power density of 3.42 MW/cm^2. The energy delivered to the silicon was varied by changing the laser scan speed and maintaining a fixed power. The scan speeds used varied from 0.2 to 1 m/s. These speeds were expected to yield junction depths in the range of 8–11 µm and sheet resistances in the range of 5–20 Ω/cm^2 [20].

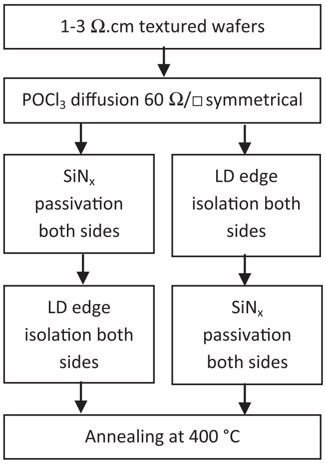

Fig. 2. Process flow for laser doped edge isolation test structures.

In all cases, laser doped isolation lines were formed ~3–4 mm from each edge of the wafer, on both sides to form a symmetrical structure. On half of the wafers, the laser doped edge isolation was performed prior to SiN$_x$ deposition whilst on the other half the isolation was performed after SiN$_x$ deposition. After the removal of the boron dopant source in DI water, all samples were annealed at 400 °C for 5 min in a Centrotherm belt furnace to improve surface passivation and passivate laser induced defects. The process flow is shown schematically in Fig. 2. Calibrated photoluminescence (PL) images were taken of the samples under open circuit conditions using a BTi LIS-R2 tool and under illumination levels corresponding to approximately 1 Sun and 0.1 Sun to obtain spatial maps of τ_{eff} using the method described in [21]. To determine the effectiveness of the laser doped isolation, line profiles were taken from the images, providing τ_{eff} as a function of distance from the edge of the wafer. The line profiles are a useful way to visualise how τ_{eff} varies from the centre of the wafer out to the edge and the extent to which carriers are 'pulled' into areas with high recombination rates – in this case, the edge and the laser doped isolation lines.

3. Results and discussion

3.1. Comparison of laser scan speeds – before nitride deposition

The results of the PL characterisation of the test structures, shown in Fig. 3(a) and (b), show the relative effectiveness of the isolation provided by laser doping at different speeds prior to the deposition of SiN$_x$. PL counts are plotted as a function of distance from the edge of the wafer (defined at 0 mm) to the centre of the wafer (≈20 mm from edge) for two different illumination