INFLUENCE OF LASER PROCESSING ON PARAMETERS OF SILICON SOLAR CELLS

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Abstract: The presented paper deals with diagnostics of crystalline silicon solar cells with structures prepared by application of laser process technologies. These laser-generated structures should help to isolate the edges of solar cells and also could be able to isolate bulk defects. At the present we are trying to optimize the laser parameters. Laser parameters affects how deep the laser notch is realized. We tried to determine what depth of the notch seems to be an ideal. Electrical models describing behavior of laser-prepared structures were proposed. The study of optical near-field and far-field will be also realized. Measurement of local radiation from solar cells during electrical excitation were carried out.

Keywords: solar cell; laser notches; PN junction; non-destructive diagnostics; defects

1. INTRODUCTION

Industrially produced solar cells still contain a large amount of defects and inhomogeneities. These can occur both in the manufacture process of silicon itself, or in the process of manufacturing the solar cell. Defects presented near the edges of the solar cell have strong influence and are caused by bad processing technology of edges. These then can exhibit lower breakdown voltage of PN junction in the reverse state in which the solar cells may find itself in the partial shading of the solar panel. Large current density is created in the defective areas, which can lead to rapid local heating and then to the local diffusion or thermal breakdown. These defects can then have a negative impact on efficiency, performance and durability of the solar cell. Looking ahead, it is desirable to locate these defects and in particular to determine their nature. [1, 2]

To suppress the influence of these defects are used laser notches. Laser edge isolation is typically achieved by scribing a notch around the perimeter of the solar cell, as close to the edge of the wafer as possible. The notch depth must extend some distance beyond the ion diffusion layer in order to give the best result. Typical notch dimensions are 20–40 µm wide and 10–20 µm deep. The matter of our study was to determine the influence of laser-prepared structures on some parameters of monocrystalline silicon solar cells [3].

2. SAMPLES UNDER INVESTIGATION

Primary solar cells we using are made from mono-crystal silicon with dimensions (7 × 4) cm^2 and a thickness of about 230 µm. The p and n layers (bottom and top-side, respectively) are formed by diffusion. The substrate is made by the Czochralsky process and diffusion with resulting resistivity about 1.2 Ωcm. The upper face of the cell is geometrically textured by pyramids to reduce the light reflection. A silicon nitride layer, which lay on the cell surface, is intended to passivate the silicon surface and again reduces the reflection losses. The cells are designed for the solar panel fabrication. Both complete cells and their broken fragments have been studied but only selected results are presented here. The screen-printed silver paste metallization was used for contacts on the front side. The back side of solar cells has a structure of Al BSF with Ag/Al busbars. The PN junction is localized close to the surface and traces pyramidal texturization. The depletion layer width is about of 0.6 μm (without the applied bias voltage) [4]. To study the effect of laser prepared notches it was chosen approach when these notches are realized between each finger contacts of the solar cell.

3. EXPERIMENTAL METHODS

Radiation generated from reverse-biased PN junction defects or their neighborhood is used to study the near field or far field local properties. It proves to be useful to measure surface radiation and to make light spots localization, to measure the radiation intensity versus voltage plot, its correlation with other, mainly noise characteristics and radiation spectrum. A scientific CCD camera G2-3200 with a 3.2 MPx resolution was used for measuring of the radiation from a PN junction close to the solar cell surface in optical far field. It uses a silicon chip cooled by dual Peltier's modules with the temperature down to -50°C. Sufficient temperature for normal working mode is of -10 °C. The Dark current of an optical sensor and a single pixel is 0.8 e/s (T = 0°C) and the doubling of its value is reached for a temperature rise of 6°C. The dynamic range of the elementary pixels with a usable range up to 16 bits is very good. A camera lens with the focal ratio of 1.2 and the working aperture of 41.7 mm is used with the camera. It is possible to measure in the useful range of wavelengths of 300 nm – 1100 nm. Since the producer defines the spectral characteristics of the particular CCD chip, photometry measurements can be performed as in our case. The mean quantum efficiency <QE> = 0.51 is reached in the interval from 300 nm to 1100 nm. The peak value of the quantum efficiency is of 0.82 at the wavelength of 647 nm [6, 7].

To evaluate the electrical parameters of the laser-modified structures we are using four-point method, in which the resistance is measured (or IV characteristic) between two unconnected contacts (removed busbar). Two electrodes are used as a current pbores connected to the current source and the other two electrodes are used to measure the voltage between the contacts. The fundamental components of the measuring apparatus for measuring the resistance between the contacts are contacting station Cascade MT150 and semiconductor device analyzer Keithley 4200 SCS. The combination of these two devices allows obtaining very precise results.

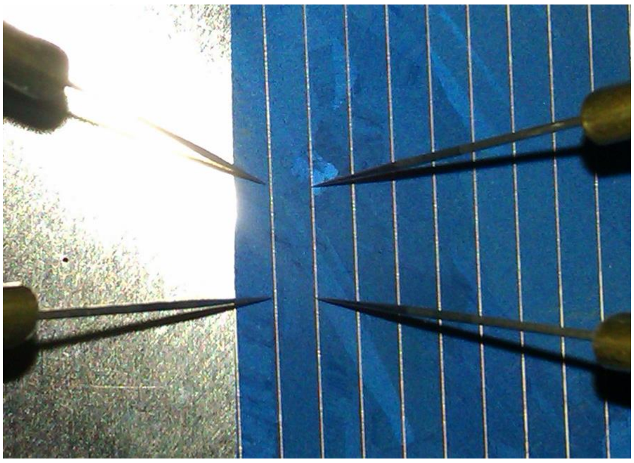

Figure 1: Illustration of the distribution of the contacting points.

For laser processing we use fiber laser SPI SP-20P, with control electronics and optics in MOPA (Master Oscillator Power-Amplifier) configuration. The laser source can operate in continuous or pulsed mode. MOPA arrangement allows to control the length and frequency of pulses in a wide range. This type of laser sources has a high efficiency, reliability and maintenance-free. Technical parameters: wavelength 1062±6 nm, performance 20 W, output power range from 10 to 100%, operating mode Pulse or Continuous.

4. RESULTS AND DISCUSSION

Laser notches are currently commonly used for the isolation edges. However, this technology is still relatively new and so the ideal parameters of notches are still searching. The notches should be deep enough to be removed PN junction.

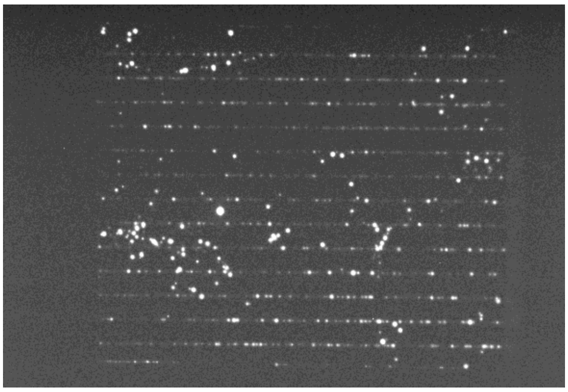

Figure 2: Electrolumisnce of PN junction in reverse direction, the sample $IO1_2$, U_R = 15,58V, I_R = 20mA, taken by CCD camera.

If the PN junction only partially removed, notch looks like a large number of local defects, see Fig. 2 and the notches with this parameters do not isolate enough.

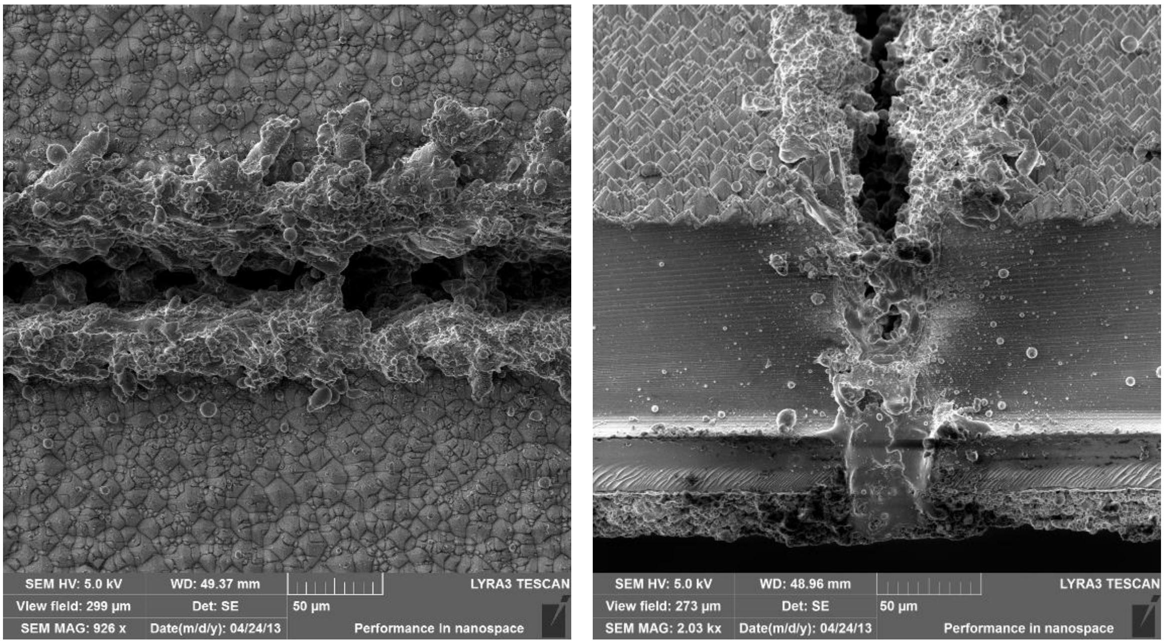

Figure 3: Detail of laser notch, sample D283.

Detail of a laser notch is shown in Figure 3. It is possible to see one of the problems, that is the melt which is formed during processing, and spilling out of notch and it is not entirely clear its characteristics and its effect on the properties and function of the solar cell.

To determine the effect of laser notches it is necessary to design an equivalent electrical model. Figure 4 shows a simplified electrical model of the replacement of resistances between two adjacent finger contacts on the solar cell without laser notch. R_M represents the contact resistance, R_C is the resistance of the transition semiconductor - metal, R_N is the resistance of n-type semiconductors. The total resistance between two contacts can then be determined as $R_T = 2R_M + 2R_C + R_N$.

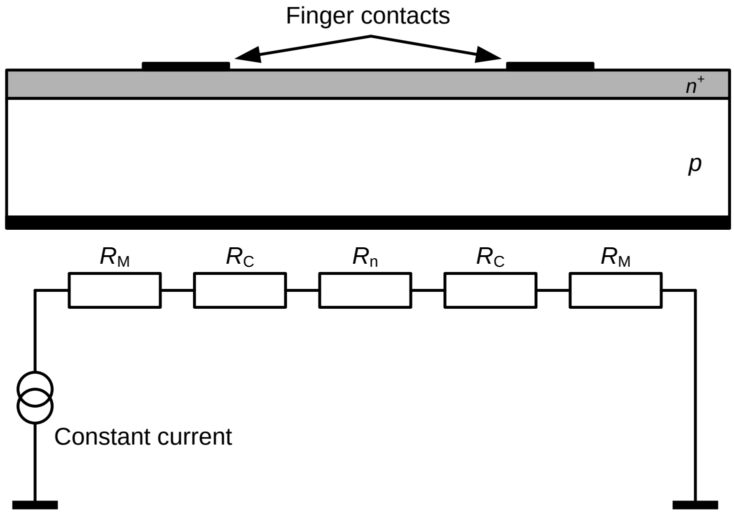

Figure 4: An equivalent circuit of a solar cell part between two neighbouring bars for a solar cell without laser-prepared structures.

We assume that surface notches extend through the PN junction to the substrate and create a channel with ohmic behaviour in the case of laser-prepared structures. The equivalent circuit of this configuration for two neighbouring finger contacts for a cell with laser-prepared structures is shown in Fig 5.

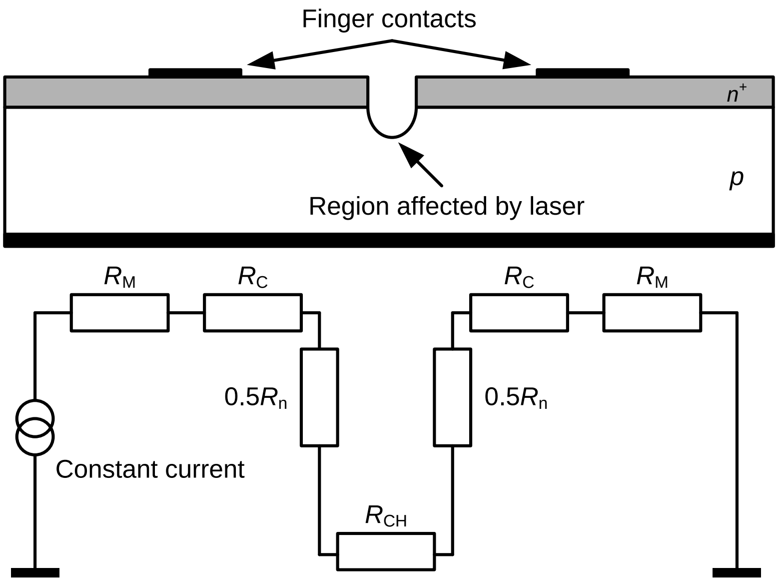

Figure 5: An equivalent circuit of a solar cell part between two neighbouring bars for a solar cell with laser-prepared structures.

Resistors R_{CH} describe laser-created channel. Because that R_C and R_M are known and R_N we can easily calculate. In addition, we consider that there is negligible current spread over the edge of the sample, and we have measured the total resistance R_T between two neighboring contacts, we can determine the added resistance of laser notch. For our measured samples is average resistance R_{CH} about 3kΩ.

5. CONCLUSION

The present article deals with the study of laser notches on solar cells. These laser-generated structures should help to isolate the edges of solar cells and also should isolate bulk defects. Our aim is to characterize the impact of these notches on some parameters of solar cells.

We can conclude that the laser-created structures that intersect the PN junction and extend to the substrate, have mainly ohmic nature. These structures cause changes in the electrical parameters of solar cells. We observe increase of the narrow-band noise level after laser processing. This fact is probably due to creation of local defects in a PN junction caused by laser notches. The optical characteristics in visible range shows that if the PN junction only partially removed, notch looks like a large number of local defects.

Models describing the electrical behaviour of laser-prepared structures were found and some of their parameters were determined based on submitted studies. For further studies will be necessary to determine alternative noise models of solar cells with laser notches.

From the measurement and microscope images there is evident that IR laser is not suitable for such application. For the proper laser isolation process the green or UV laser providing lower penetration depth, lower sample warming and lower surface damage should be used to avoid creation of conductive channels.

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