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Structure of laser treated multicrystalline silicon wafers

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Manufacturing and processing

ABSTRACT

Purpose: The aim of the paper is to demonstrate influence of laser processing on multicrystalline silicon. This process is applied for texturization of solar cells.
Design/methodology/approach: Evaluation of results was performed by transmission electron microscope (TEM).
Findings: Performed experiments revealed that laser processing may introduce linear defects in crystallographic structure of silicon. Additionally, it was found that this kind of processing produces thin amorphous layer.
Research limitations/implications: Laser scribing introduces defects. It is important to characterize their influence on the electrical properties of silicon solar cells. It is possible to remove these defects by means of chemical etching.
Practical implications: The research presented in the paper was carried out to incorporate elaborated method into manufacturing process of solar cells of reduced reflectance from the front surface. Success of research is expected to lead to higher efficiency solar cells.
Originality/value: value of the paper lies in finding attractive method for efficient texturization of multicrystalline silicon.
Keywords: Surface treatment; Multicrystalline silicon; Laser treatment

1. Introduction

Photovoltaic (PV) energy conversion is presently the fastest growing energy technology and is expected to become a major source of power generation in the future. Solar cells are composed of various semiconducting materials. Currently more than 90% of all commercial solar cells are made of silicon. The advantage of silicon is the mature processing technology, the large abundance in the crust of the earth, and the non-toxicity that is an important consideration from the environmental perspective. Crystalline silicon solar cells address the practical and theoretical issues fundamental to the viable conversion of sunlight into electricity [1, 3, 7, 9, 16].

Nowadays, lasers of different types are used in a variety of materials processing applications for a wide range of materials. The most interesting applications of laser treatment in solar cells production are [2, 4-6, 10, 11, 13-15]:

- laser grooved buried contact for reducing contact recombination, shading losses,
- laser assisted doping process for achieving shallow highly doped junction,
- laser texturization for reduction of reflection losses from the front surface.

Since laser material processing is a process that involves many physical phenomena such as:

- transmission, absorption, and reflection of radiant energy,

- conduction, convention, and radiation of thermal energy,
- melting and solidification,
- vaporization

the selection of appropriate process parameters guaranteeing the achievement of demanded texture is generally difficult [2, 8, 10-17].

Laser processing is a promising method for texturization of multicrystalline silicon. However, it may introduce into the bulk of material some unwanted effects, having detrimental influence on the main parameters of processed silicon wafers. This, in turn, may result in reducing solar cells performance. That is why the aim of paper is to investigate the influence of laser texturization on the surface of multicrystalline silicon. Transmission electron microscope was used to characterize produced textures.

2. Experimental

The material used for experiments was commercially available boron doped p-type multicrystalline silicon wafers obtained from the ingot by wire sawing of thickness ~330 µm, area 5 cm x 5 cm and resistivity 1 Ω cm. It is worth mentioning that particular attention has been paid to cleaning step after sawing in order to avoid contamination of substrate at the start of the cell manufacturing process.

Texturization was carried out by means of diode-pumped pulsed neodymium-doped yttrium aluminium garnet laser crystal (Nd:YAG). The main parameters of the laser used are: laser wavelength ($\lambda = 1064$ nm), maximum output power ($P = 50$ W), maximum speed of laser beam ($v = 30\,000$ mm/s), pulse repetition frequency (from $f = 100$ Hz to $f = 65$ kHz).

To find the optimum parameters for low damages and high effectiveness laser texturing process different trials have been made varying pulse power, repetition frequency and scribing speed of Nd:YAG laser.

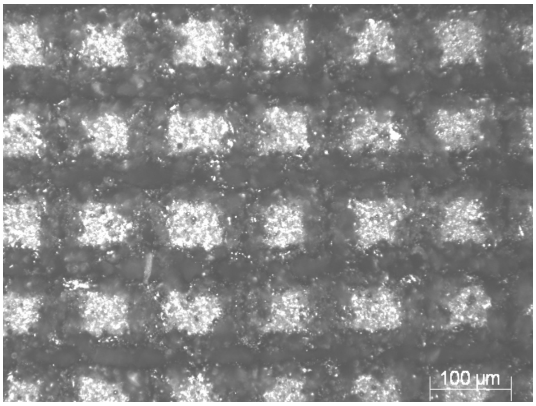

Fig. 1. Optical micrograph of laser produced texture

Surface treatment has been carried out under the following conditions: average laser power $P \approx 30$W, diameter of the beam spot $d = 20$µm, pulse repetition frequency from $f = 3$ kHz to $f = 65$ kHz, laser beam translation from $v = 1$ mm/s to $v = 100$ mm/s.

Figure 1 shows optical microscope image of criss-cross texture with spacing 110 µm produced by the laser beam with scanning speed of 40 mm/s, maximum power and repetition frequency 15 kHz.

The diffraction investigations and examination of the thin foils were performed on the JEOL JEM 3010 transmission electron microscope at the accelerating voltage of 300 kV kV equipped with the Oxford EDS LINK ISIS X-ray energy dispersive spectrometer. Thin foils were made from multicrystalline silicon wafers by cutting out disks with 3.2 mm O.D in Sonic Disc Cutter. Then, samples were thinned by means of ionic grinding wheel "Gatan".

Observations were carried out both in bright and dark field. Moreover, diffraction patterns from selected regions of textured wafers were solved using a computer program Digital Micrograph (TM) 3.6.5. Gatan Inc and ELDYF 2.1 for Windows.

3. Results and discussion

Observations performed on transmission electron microscope revealed structure of laser textured multicrystalline silicon wafer. The track of laser beam impulses can be seen in Figure 2. The precipitate taking the form of laser spot are the result of direct interaction of laser beam and silicon wafers which causes local melting of material and it's amorphization.

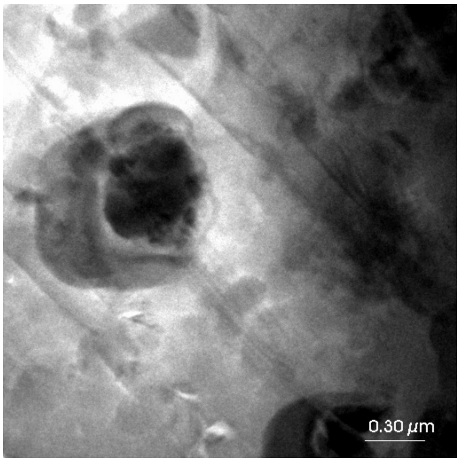

Fig. 2. Bright filed TEM micrograph of laser scribe line trace

Amorphous regions which can be seen as dark areas (Fig. 3a) are separated by areas of crystalline structure (bright regions). Crystalline phase was identified as a boron with R3m lattice, and reflexes are the result of main beam diffraction on the particles planes with zone axis [1 9 4] (Fig. 3b).

Figure 4a shows in bright field structure on the boundary of amorphous and crystalline phases. Presented diffraction patterns enabled to identify both amorphous and crystalline phase. The solution of diffraction shows that crystalline phase has the form of boron precipitate with R3m lattice. Reflexes come from the diffraction of the main beam on the articles planes with zone axis [-1 –3 –5] (Fig. 4b). Moreover, observations show linear defects in the crystallographic structure of of textured surface – edge

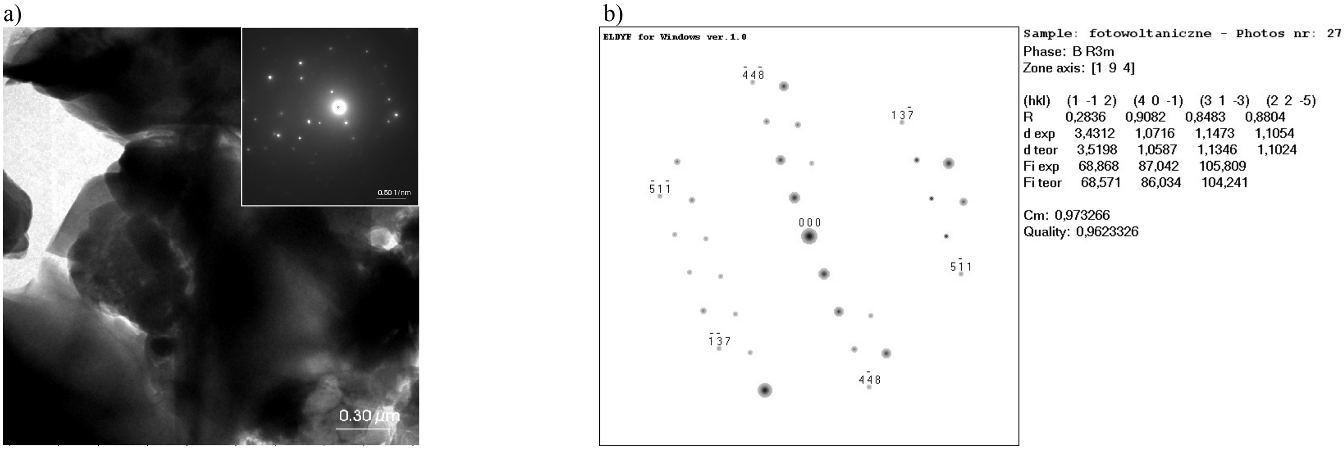

Fig. 3. a) Dark field TEM micrograph of groove rim, b) Solution of diffraction pattern

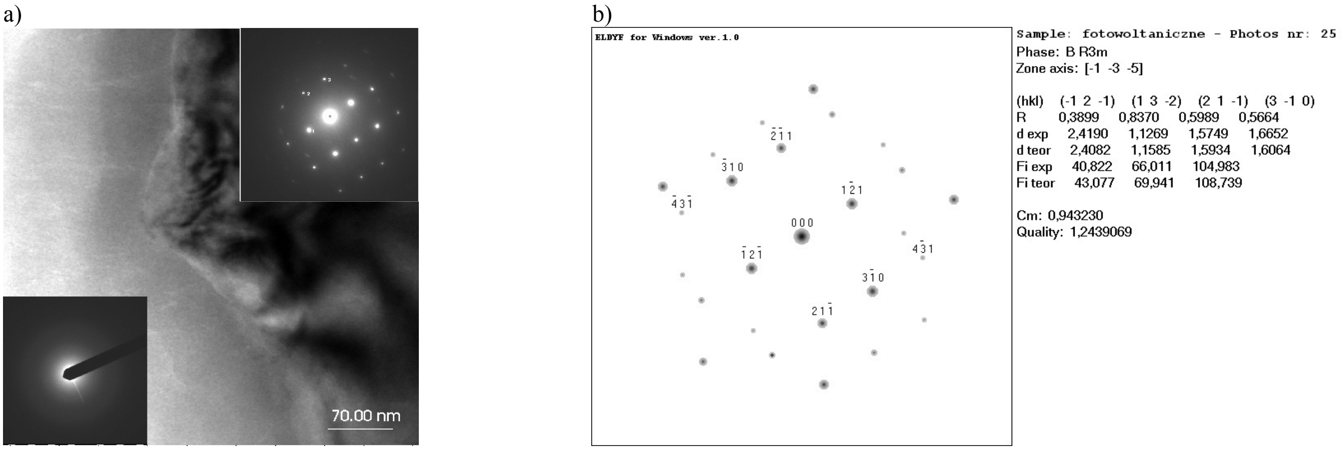

Fig. 4. a) Bright field TEM micrograph of boundary between amorphous and crystalline phases , b) Solution of diffraction pattern

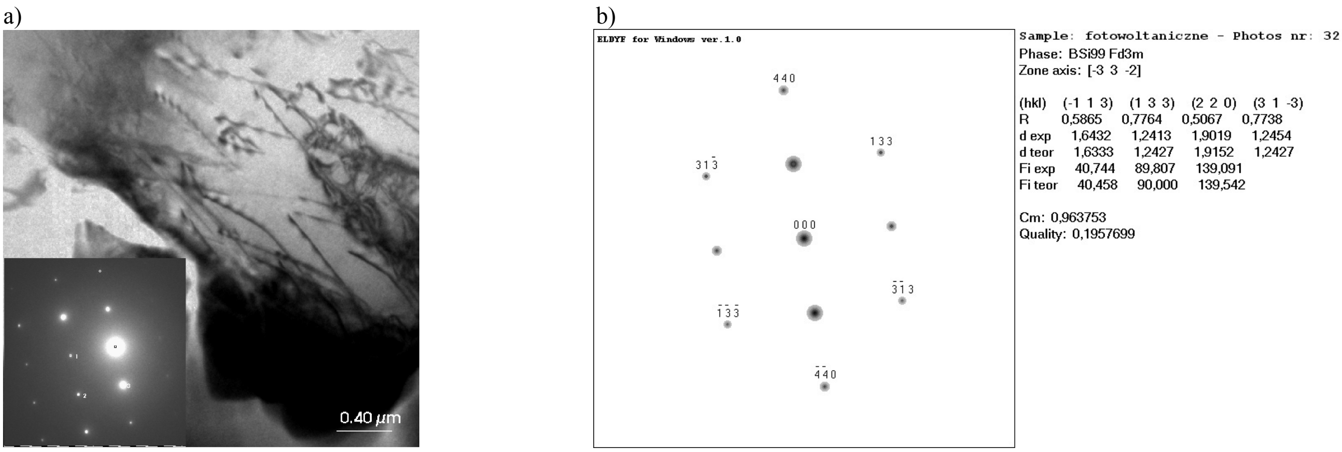

Fig. 5. a) Bright field TEM micrograph of dislocations, b) Solution of diffraction pattern

dislocations. They were formed, most likely, during transformations, melting and solidification taking place during laser treatment.

In Figure 5a edge dislocations can be seen. Crystalline phase was identified as a silicone boride of Fd3m lattice. Reflexes came from diffraction of the main beam articles planes with zone axis [-3 3 -2] (Fig. 5b).

4. Conclusions

The interaction between laser beam and multicrystalline silicon wafers causes local changes on the surface of processed material. Some of these changes appear only on the surface while the others penetrate into the bulk of the material. Detailed inspection of the laser processed surface revealed existence of amorphous regions. They were formed as a result of melting and solidification. Local changes of the state of aggregation introduced inner stresses into material resulting in linear defects (dislocations) in crystallographic structure of textured silicon.

Moreover, performed microscope observations revealed the precipitate of boron (R3m) and silicone boride (Fd3m).

Acknowledgements

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