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Laser texturisation of crystalline silicon for solar cells

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Abstract: The subject of the present work is the development of laser methods for surface texturisation. In particular, the use of Nd:YAG laser for scribing of polycrystalline silicon wafers for solar cells is investigated. At first an overview of texturisation techniques currently being used in photovoltaics are presented. Then the performed experiments are described. Next the analysis of experimental results is presented. Finally concluding remarks are enclosed.

Keywords: Photovoltaics; Solar cells; Crystalline silicon; Laser processing

1. INTRODUCTION

Today's photovoltaic market is characterized by the following trends steady improvement of conversion efficiency and reduction of the cost of solar cells [1].

An important aspect related to the choice of material is surface texturisation. As the refractive index of silicon is very high, reflection at the surface of solar cells has to be minimized. Consequently, all solar cells manufactured today have an antireflective coating consisting of transparent film of low refractive index. Even more efficient is surface texturing which not only reduces reflection but also provides oblique coupling of light into the cell. In this manner, the radiation paths are increased and enhanced absorption of radiation results [4].

Surface can be textured with many different methods resulting in different texture patterns. At present, texturisation is carried out by means of the following methods which allows to produce texture of the structure given in the bracket [5]:

- Chemical etching in KOH or NaOH with photolithographic pattern (regular inverted pyramids),
- Mechanical V-grooving (regular pyramids or grooves),
- Wet acid etching (sponge like structure with random pits),
- Electrochemical anodisation in HF solution with organic solvent (porous layer),
- Reactive ion etching (randomly distributed needles),
- Chemical etching in KOH or NaOH solution (randomly distributed upside down pyramids),
- Chemical etching in HNO_3-HF solution with photolithographic pattern (regular honeycomb).

Conventional chemical and electrochemical methods are efficient in texturing monocrystalline silicon, especially with (100) oriented surfaces. Unfortunately, these methods are inefficient for multicrystalline silicon due to the presence of multiple crystallographic grain orientations and high selectivity of etching along specific directions [6]. Therefore, presently non-chemical techniques for texturisation of multicrystalline silicon are being developed to overcome this shortcoming.

It has been show that polycrystalline silicon surface can be textured by mechanical microtexturisation. It allows to generate texture of homogeneous structure in the form of V-grooves. However, it is difficult in practical implementation because of high breakability and brittleness of polycrystalline silicon wafers. Moreover, it is known that mechanical scribing is difficult in hard materials, often produces considerable damages (surface tearing) surrounding scribe and generally requires larger separation between scribe lines [3]. Therefore, other texturisation techniques are intensively researched. One of these method is texturisation carried out by means of lasers.

Laser technology is one of the most versatile techniques used in a variety of materials processing for wide range of materials. Lasers are successfully applied in industrial processes including welding, cutting, drilling, ablation deposition and surface treatment. Strongly coherent and monochromatic laser beam focused to small spot produces high power densities. High quality laser beams make it possible to use laser technology for processing which is impossible to carry out with any different techniques. The wide range of applied power and power densities available from lasers and the possibility of accurate laser beam control are features which contribute to its successful application in many different aspects of surface processing. Laser beam of high intensity focused to small spot influences many solid materials changing photons energy into electron, thermal and mechanical energy on the surface of workpiece. Such interaction results in evaporation and removal of the thin material layer in the form of neutral atoms and molecules, positive and negative ions from material surface exposed to laser radiation [1].

This study was designed to improve fundamental understanding of the laser scribing process and the role of laser processing parameters on the quality, speed and efficiency of scribing of crystalline silicon wafers.

2. EXPERIMENTAL PROCEDURE

For experiments, boron doped p-type mono- and multicrystaline silicon wafers obtained from the ingot by wire sawing of thickness ~330 μm, area $10 \times 10\ \mathrm{cm}^2$ and resistivity $1\ \Omega\,\mathrm{cm}$ have been used. 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. Before texturisation wafers were etched in 20% potassium hydroxide (KOH) solution to remove sawing damages. In this treatment the layer of about 10 μm thickness was removed from both sides of wafers. The wafers were then rinsed in nitric acid (HNO_3) and cleaned in deionized water (DIH_2O).

Texturisation was carried out by mean of lamp-pumped neodymium-doped yttrium aluminium garnet laser crystal (Nd:YAG). Nd:YAG laser used in the experiment was able to work both in pulsed and continuous wave mode. The main parameters of the laser used are: laser wavelength (1064 nm), maximum output power (100 W), maximum speed of laser beam (30 000 mm/s), pulse repetition frequency (100 Hz÷65 kHz).

The microstructure obtained after laser processing was identified by inspection under an Opton DSM 940 scanning electron microscope (SEM) and a LEICA MEF4A optical microscope.

3. ANALYSIS OF EXPERIMENTAL RESULTS

Laser texturisation was carried out for different values of the following parameters of Nd:YAG laser:

- the movement speed of laser beam relative to workpiece varied in the range form 100 to 1000 mm/s,
- the current of circuit supplying the lamp pumping the laser ranged from 10 to 30A,
- pulse repetition frequency ranged form 0.5 to 45 kHz.

Speed and power of laser beam influence the diffusion depth of heat into the workpiece during the pulse.

As shown in Fig. 1 a, in laser processing the structure in the form of parallel grooves has been produced. Laser scribing has shown the potential for obtaining very narrow scribe widths and scribes spacing. However, some problems have been observed to occur with a heat-affected zone around the scribe. For some process parameters positive ridges have been left along the edges of the scribe line. The ridges appear to arise from melt phase at the scribe sides. The formation of ridges is driven preliminary by surface tension, the recoil momentum from the hot, expanding plume, which causes the molten phase to squirt out laterally and solidify at the edges. Additionally, Fig. 4 gives evidence of considerable residue from a melt phase during scribing. The melt-phase residue at the bottom of a scribe may lead to damages of material, which lower cell conversion efficiency.

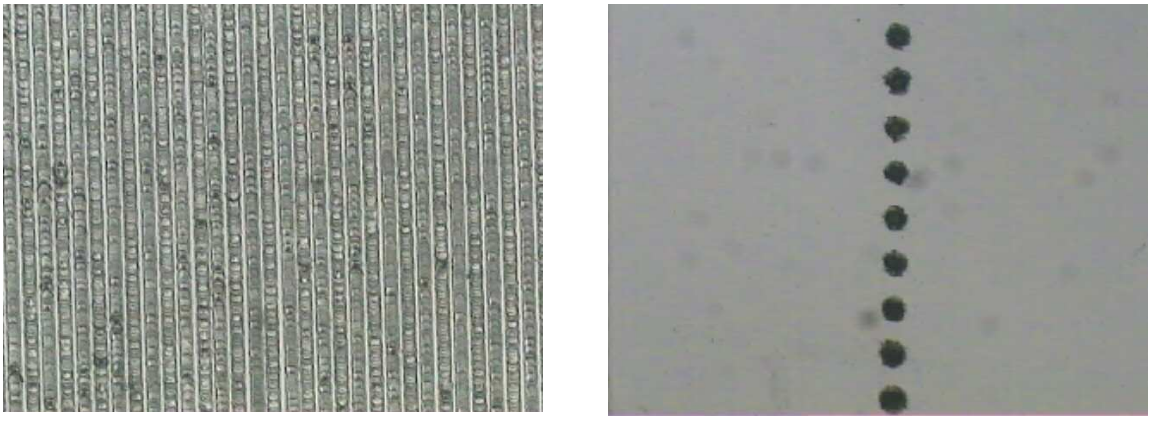

Figure 1. Optical micrographs of: a) texture structure, b) single groove (700 mm/s, 2 kHz)

Inspection of Fig. 1 b revealed that if pulse repetition frequency is small and speed of laser beam relative to workpiece is high the scribe line is discontinuous and has the form of equally spaced craters.

The relationship between increasing pulse energy density and the depth of material removed was investigated. General trend is that the pulse of higher energy can produce deeper craters with a single pulse, as depicted in Fig. 3. Furthermore, if the high-power densities are use to obtain deeper scribe line, there is likely to be significant damage surrounding the scribe in a heat-affected zone.

A detailed analysis of Fig.2 a and b revealed that laser surface processing with higher laser beam energies and laser beam speeds produces considerable tearing along the edges of the scribe line.

At higher speed of laser beam relative to workpiece, the bottom of the groove is not flat. Instead, the depth varies over narrow range along the length of the groove. Each experimental depth value was determined from the digital image of a view through an optical microscope and SEM of groove cross-section exposed by sawing the workpiece with diamond blade perpendicular to the groove.

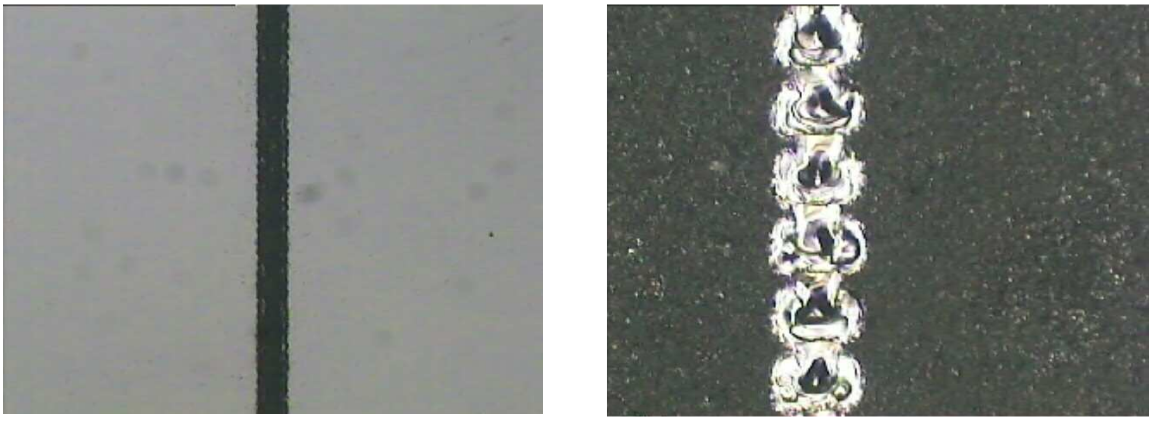

Figure 2. Optical micrographs of grooves for: a) 100 mm/s, 40 kHz, b) 600 mm/s, 5 kHz,

4. CONCLUSION

On the basis of performed research, it was found out that laser processing of multicrystalline silicon surface seems to be a promising alternative compared to conventional chemical and electrochemical texturisation making possible accurate surface treatment.

It seems that the compactness of the laser, possibility of high-speed scribing and the possibility of being easy to automate are features which can contribute to its success in industrial processes for photovoltaic applications.

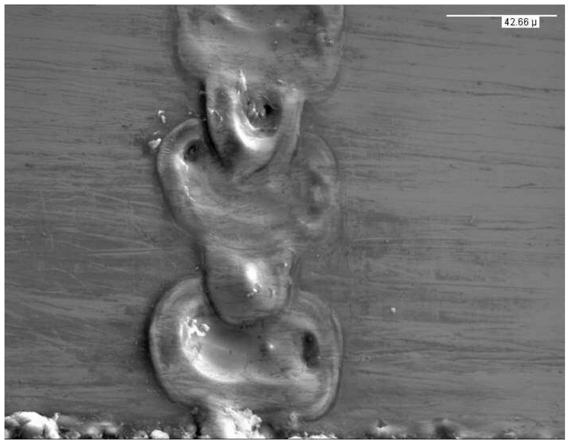

Figure 3. SEM micrograph of groove: 600 mm/s, 5 kHz

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