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# Application of Laser Texturing in Silicon Solar Cell Technology

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Recently, a lot of attempts have been directed to increase the solar energy coupling within an active media of a solar cell. Silicon and other materials, which are used as the active media in solar cell, reflect a considerable part of solar light due to a high refraction index, in particular, at oblique light incidence. In addition, only a small part of light is absorbed in the active layer of a thin film solar cells. We present the novel Laser Beam Interference Ablation technique for direct laser patterning of active materials. As a result, a coupling and localization of solar radiation is increased in modified structures. It should be noted that the light-absorbing structures are formed on the solar cell surface without additional steps in photo etching procedure. The proposed technique is under development for application in processing of both crystalline and thin-film silicon solar cells.

*Keywords*: thin film solar cells, silicon solar cells, light trapping.

## 1. INTRODUCTION

The efficiency of solar cell can be increased by decreasing the reflection of solar radiation from the illuminated surface. In addition, the efficiency of thin-film solar cell can be improved by increasing the optical path length by light trapping within the cell. Surface texturing is an efficient method to enhance the light absorption by multiple internal reflections. As a result, the light is absorbed in a close proximity to the p-n-junction leading to the improvement of device characteristics in the case of materials with diffusion lengths comparable to a cell thickness.

There are two ways to modify the solar cell surface for trapping of the incident light. One way is the creation of randomly distributed pyramids by direct chemical etching in alkali solutions [1]. As etching rate differs in various crystallographic directions, a pyramidal structure can be formed in monocrystalline silicon solar cells. Unfortunately, this technique is not able to work effectively on polycrystalline silicon wafers. On the other hand, alkali etching can cause undesirable fractures on the surface of polycrystalline silicon solar cell [2]. Therefore, for texturing of polycrystalline silicon solar cells, the etching in *acid* solutions based on $HNO_3$ : HF [3], mechanical etching using diamond edge [4], and reactive ion etching [5] have been proposed. The other novel incoming method for texturing of polycrystalline silicon solar cells is laser ablation [6]. The subject of our research is a development of Laser Beam Interference Ablation technique for direct laser patterning. We discuss the influence of the laser beam interference texturing on optical properties of the Si polycrystalline solar cells.

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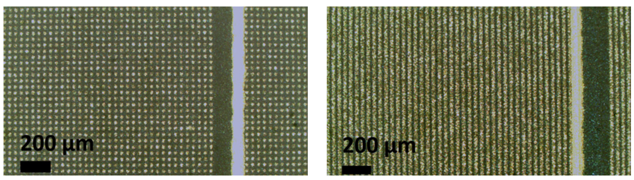
## 2. EXPERIMENT AND MEASUREMENTS

The experiments were performed on the commercial polycrystalline silicon wafers with the area of ($15 \times 15$ cm$^2$). Wafers were cut into $1 \times 2$ cm$^2$ samples. In this work, Baltic HP laser (Ekspla) with the 355 nm wavelength and pulse duration of 10 ns was used for texturing the samples, varying the number of pulses, mean laser power and pulse repetition rate. Experimental technique is presented elsewhere [7].

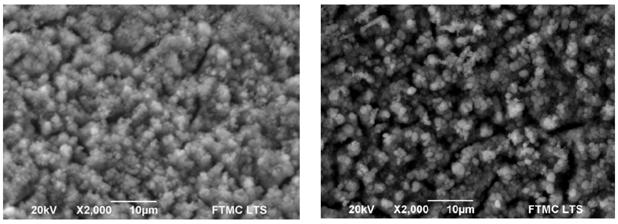
Fig. 1 shows the surface of textured samples for the samples with different texturing. It can be seen that laser patterning with a larger number of impulses results in a formation of grooves on the surface of the solar cell Fig. 1, b.




a b

**Fig. 1.** Optical microscope surface images of two solar cells modified at $P = 150$ mW, $\nu = 10$ kHz by different number of laser pulses: 100 for sample L4 (a) and 500 for sample L3 pulses (b)

For the surface morphology and chemical structure analysis, the scanning electron microscope (SEM) Hitachi TM 3000 was used. The SEM images of textured samples are shown in Fig. 2. Patterning with a larger number of pulses results in the formation of bright grained polycrystalline structure at the bottom of the textured area.




a b

**Fig. 2.** Scanning electron microscope (SEM) images of the laser textured sample surfaces: a – pulse energy 0.3 mJ, number of pulses 30 000; b – pulse energy 0.4 mJ, number of pulses 10 000

The chemical analysis has shown a decreased amount of carbon (C) and first group metals (Na, K) at the surface of the samples textured with a larger number of pulses.

Basic parameters of texturized samples, such as number of laser pulses, power and repetition rate are presented in Table 1.

**Table 1.** Parameters of texturized samples: number of laser pulses, power, repetition rate

| Sample number | Pulses | Power, mW | *ν*, kHz |
|---|---|---|---|
| L3 | 500 | 150 | 10 |
| L4 | 100 | 150 | 10 |
| L6 | 1 | 150 | 10 |
| 1 | 5000 | 150 | 2 |
| 8 | 75 | 150 | 2 |
| 10 | 25 | 150 | 2 |
| 14 | 3 | 150 | 2 |
| 15 | 1 | 150 | 2 |

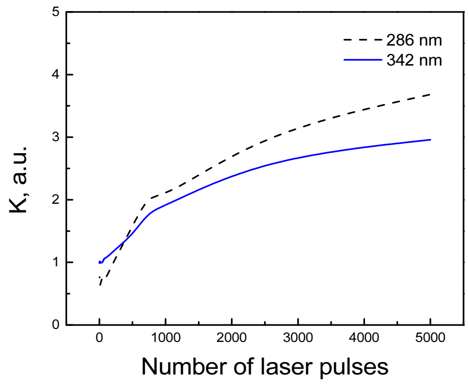



**Fig. 3.** The dependence of absorption coefficient calculated from diffuse reflectance data on the number of laser pulses at two wavelengths

The influence of laser patterning on optical properties of polycrystalline silicon photovoltaic cell were also investigated. Diffuse reflectance was studied by means of the Shimadzu UV-VIS-NIR Spectrophotometer UV-3600 coupled with the MRC-3100 unit. Measurements were performed by mounting a sample holder onto the integrating sphere. The measurable range of wavelengths falls between 240 nm and 2600 nm, covering the visible and the near infrared regions. The light absorbance was calculated from diffuse reflection data using the Kubelka-Munk theory. The results are presented in Fig. 3. As is seen, the light absorption increases with an increase of laser pulses. This dependence tends to saturate at large numbers of laser pulses.

Specular reflection of textured structures at different angles of light incidence was studied in the spectral range from 400 nm to 1200 nm. The results for one textured sample are presented in Fig. 4. It is to be noted that the reflectivity of textured samples is lower in UV than in IR range. At long wavelengths the specular reflection increases at angles of incidence exceeding 60º.

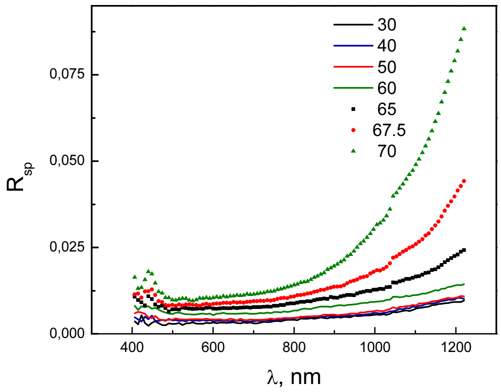



**Fig. 4.** Spectra of specular reflection coefficient $R_{sp}$ at various angles of light incidence for texturized sample L3

In Fig. 5 the dependence of specular reflection coefficient $R_{sp}$ on the angle of light incidence is shown. As is seen, the $R_{sp}$ values for both reference solar cell structures and modified samples are considerably smaller than those for c-Si. The $R_{sp}$ is only weakly dependent on the angle of light incidence even in the IR range.

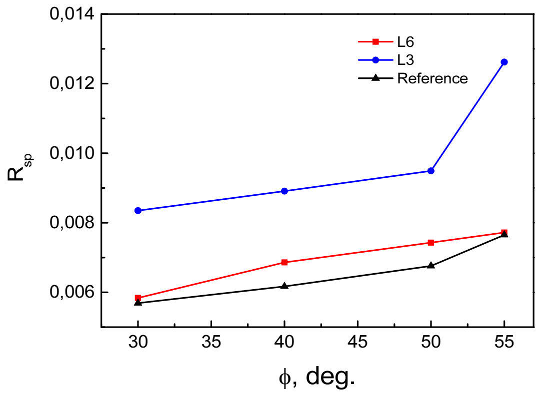



**Fig. 5.** Dependence of specular reflection coefficient $R_{sp}$ on the angle of light incidence for reference and two textured samples L3 and L6 at $\lambda = 1149$ nm

## 3. CONCLUSIONS

The influence of laser texturing on the structure and optical properties of solar cells was investigated. The optical measurements have shown that laser texturing of the polycrystalline silicon solar cells increases the light absorption in the active media. The specular reflection coefficient is weakly dependent on the angle of light incidence over a broad spectral range.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**REFERENCES**


1. **Zubel, I.** Silicon Anisotropic Etching in Alkaline Solutions III: On the Possibility of Spatial Structures Forming in the Course of Si (100) Anisotropic Etching in KOH and KOH+IPA Solutions *Sensors and Actuators A: Physical* 84/1-2 2000: pp. 116 – 125. http://dx.doi.org/10.1016/S0924-4247(99)00347-7
2. **Panek, P., Lipinski, M., Dutkiewicz, J.** Texturization of Multicrystalline Silicon by Wet Chemical Etching for Silicon Solar Cells *Journal of Materials Science* 40 2005: pp. 1459 – 1463.
3. **Marstein, E. S., Solheim, H. J., Wright, D. N., Holt, A.** Acid Texturing of Multicrystalline Silicon Wafers *Proceedings of the 31st IEEE Photovoltaic Specialists Conference* Florida, USA, 2005: pp. 1309 – 1312.
4. **Gerhards, C., Marckman, C., Tolle, R., Spiegel, M., Fath, P., Willeke, G.** Mechanically V- Textured Low Cost Muticrystalline Silicon Solar Cells With a Novel Printing Metallization *Proceeding of the 26th IEEE Photovoltaic Specialist Conference* Anaheim, USA, 1997: pp. 43 – 46.
5. **Nositschka, W. A., Beneking, C., Voigt, O., Kurz, H.** Texturization of Multicrystalline Silicon Wafer of Solar Cells by Reactive Ion Etching Through Colloidal Masks *Solar Energy Materials and Solar Cells* 76 2003: pp. 151 – 166.
6. **Lisiecki, A., Klimpel, A.** Diode Laser Surface Modification of Ti6A14V Alloy to Improve Erosion Wear Resistance *Archives of Materials Science and Engineering* 32/1 2008: pp. 53 – 56.
7. **Indrišiūnas, S., Voisiat, B., Gedvilas, M., Račiukaitis, G.** Effect of Laser Patterning on Properties of Crystalline Si Photovoltaic Cells and Substrates *Journal of Micromechanics and Microengineering* 23 2013: pp 244 – 252.