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Development of the laser method of multicrystalline silicon surface texturization

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ABSTRACT

Purpose: The aim of the paper is to demonstrate a laser method of multicrystalline silicon texturization. This means creating a roughened surface so that incident light may have a larger probability of being adsorbed into the solar cell. It was demonstrated, that laser processing is very promising technique for texturing multicrystalline silicon independent on crystallographic orientation of grains compared to conventional texturing methods.

Design/methodology/approach: The topography of laser textured surfaces were investigated using ZEISS SUPRA 25 scanning electron microscope and LSM 5 Pascal ZEISS confocal laser scanning microscope. The reflectance of produced textures was measured by Perkin-Elmer Lambda spectrophotometer with an integrating sphere. Electrical parameters of manufactured solar cells were characterized by measurements of I-V illuminated characteristics under standard AM 1.5 radiation.

Findings: The texturing of multicrystalline silicon surface using Nd:YAG laser makes it possible to increase absorption of the incident solar radiation. Laser processing is a promising method for texturization of multicrystalline silicon compared to conventional texturing methods applied in used technology of solar cells.

Research limitations/implications: Laser processing introduce into the bulk of material some unwanted effects, having detrimental influence on the main parameters of processed silicon wafers. Solar cells manufactured from laser-textured multicrystalline silicon wafers demonstrate worse electrical performance than cells manufactured from the non-textured wafers after saw damage removal as well as wafers textured by etching in alkaline solutions. Chemical etching by means of potassium alkali made it possible to increase cell efficiency.

Originality/value: Laser texturing has been shown to have great potential as far as its implementatnion into industrial manufacturing process of solar cell is concerned.

Keywords: Surface treatment; Photovoltaics; Solar cells; Multicrystalline silicon; Laser texturization

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MATERIALS

1. Introduction

Renewable energy comes in the form of heat, electricity or biofuel. The market is developing in these three directions, but the price differences among these three types of renewables are considerable. Heat is the cheapest and electricity is several times more expensive. Photovoltaic energy is the conversion of sunlight into electricity. A photovoltaic cell, commonly called a solar cell is the technology used to convert solar energy directly into electrical power [1-3].

Sunlight is the total spectrum of the electromagnetic radiation given off by the Sun. Sunlight is composed of photons whose energy is strongly related to its wavelength. When photons strike a photovoltaic cell, they may be reflected, pass right through, or be absorbed. Only the absorbed photons of energy greater than the energy gap of semiconductor that cell is made of may generate electricity. When enough sunlight is absorbed by the material, electrons are dislodged from the material atoms. Special treatment of the material surface during manufacturing is performed to produce p-n junction near the front surface of the cell. Consequently, the front surface of the cell is more receptive to free electrons, so the electrons naturally migrate to the surface. When the electrons leave their position, holes are formed. When many electrons, each carrying a negative charge, travel toward the front surface of the cell, the resulting imbalance of charge between the cell front and back surfaces creates a voltage potential like the negative and positive terminals of a battery. When the two surfaces are connected through an external load, electricity flows [1-7].

The major disadvantages of solar energy are [1,4]:

- The amount of sunlight depends on many factors such as: location, time of day, time of year, weather conditions and air pollution. That is why circumstances that arrives at the earth's surface may drastically change the quantity of solar energy that can be transformed to electricity.
- A large surface area is required to collect the energy at a useful rate.

The performance of a photovoltaic cell is dependent upon sunlight. Climate conditions have a significant effect on the amount of solar energy received by a photovoltaic cell and, in turn, its performance [4].

Using solar energy does have some indirect impacts on the environment. For example, manufacturing the photovoltaic cells used to convert sunlight into electricity, consumes silicon and produces some waste products. However it should be emphasized that on the other hand only few power-generation technologies have as little impact on the environment as photovoltaics. As it quietly generates electricity from light, photovoltaics produces no air pollution or hazardous waste. It doesn't require liquid or gaseous fuels to be transported or combusted. And because its energy source - sunlight - is free and abundant, photovoltaic systems can guarantee access to electric power and its supplies are unlimited [1].

Since photovoltaic technology makes use of the abundant energy in the sun, and has little impact on our environment, it can be used in a wide range of products, from small consumer items to large commercial solar electric systems .

Photovoltaics is an important technology of energy generation for many reasons. It is observed that contribution of photovoltaic energy systems to the world's energy needs permanently grows. As it was discussed solar energy technology has numerous environmental benefits. As a domestic source of electricity, it increases national security of energy supply. As a relatively young, high-tech industry, it reduces trade deficit and consequently helps to create jobs and strengthen the economy. As it costs increasingly less to produce and use, it becomes more and more affordable and available. In addition, photovoltaics frees us from the cost and uncertainties surrounding energy supplies from politically volatile regions [1-6].

Silicon is an important material in photovoltaic industry. Crystalline silicon is currently the dominant solar cell material for commercial application because it is so readily abundant. One major concern of the silicon solar cell industry is reduction of reflection of incident light with an antireflection coating, and the other is optical confinement of the incident light by textured surface. It is very interesting to investigate new alternative methods for effective texturization of multicrystalline silicon [1-4, 7-15].

Laser processing of silicon has received significant attention in the last several decades [7, 16-21]. This paper presents technology of multicrystalline silicon solar cells with laser texturization step. The texturing of multicrystalline silicon surface using Nd:YAG laser makes it possible to increase absorption of the incident solar radiation. Moreover, the additional technological operation consisting in etching in 20 % KOH solution at temperature of 80°C introduced into technology of the photovoltaic cells manufactured from laser textured wafers allows for significant improvement in their electrical performance compared to cells produced from the non-textured wafers after saw damage removal.

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 Ωcm.

Technology of multicrystalline silicon solar cells with laser texturization have been performed according to the nine steps:

- saw damage removal,
- laser surface texturization,
- laser induced surface damage removal,
- contamination removal,
- phosphorous diffusion,
- junction insulation and phosphorous-silicate glass removal,
- passivation,
- antireflection coating deposition,
- screen-printing and co-firing of metal contacts.

Texturization was carried out by means of diode-pumped pulsed Nd:YAG laser (neodymium-doped yttrium aluminium garnet) operating at wavelength of 1064 nm. Laser texturization was conducted for the following parameters: maximum output power 50 W, pulse repetition frequency 15 kHz, diameter of the laser spot 10 μm and laser beam speed 50 mm/s. Lasers settings were adjusted experimentally by producing different textures. The texture consisting of parallel grooves with spacing of 50 μm was produced. To minimize reflection losses from the front surface texturization was performed. To produce texture ALLPRINT

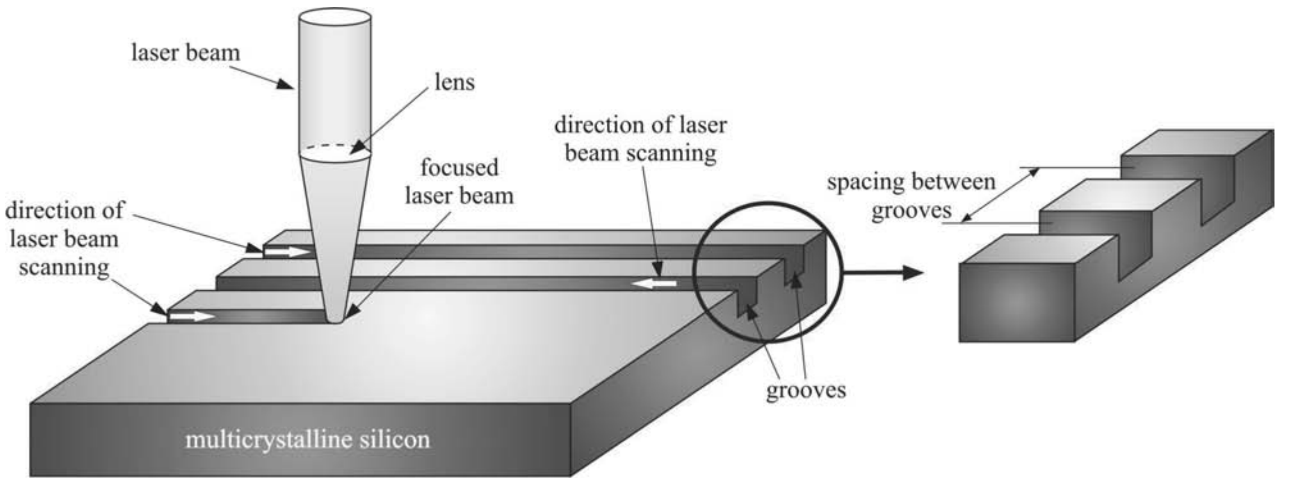

Fig. 1. Schematic diagram of laser texturization

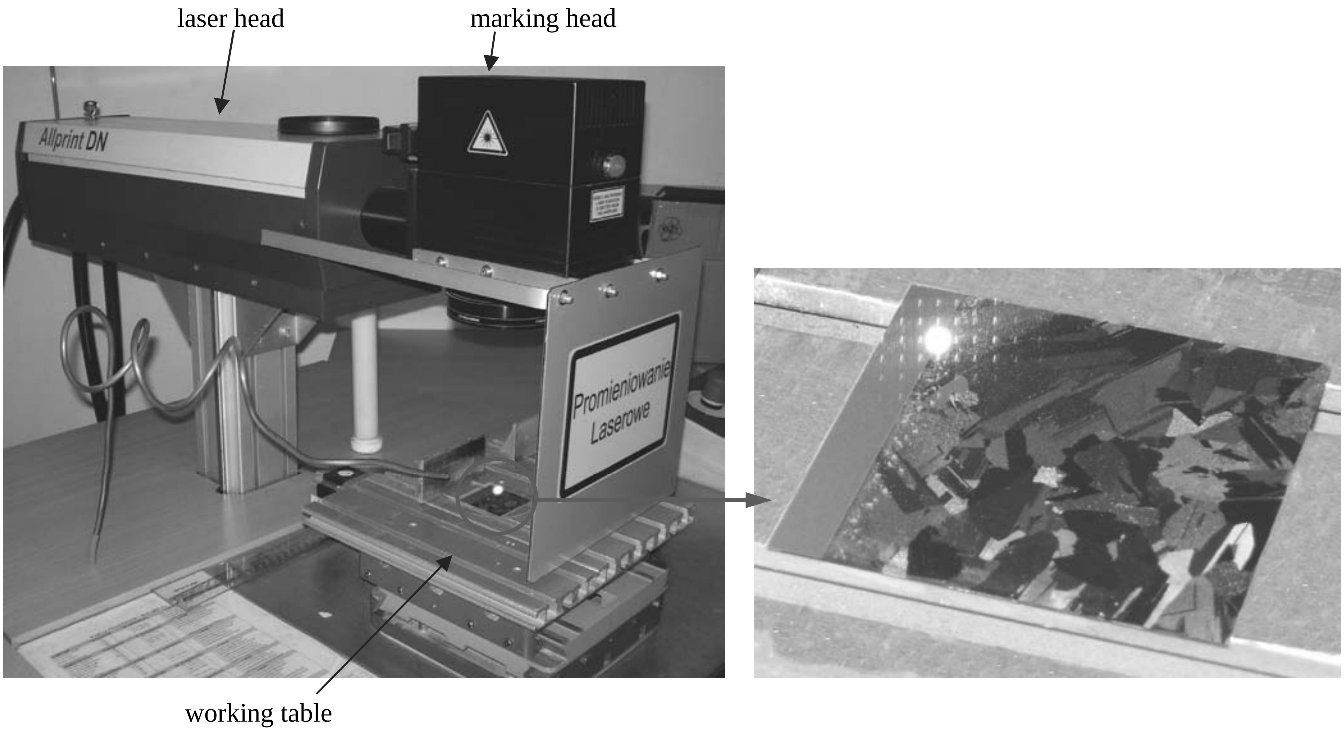

Fig. 2. Laser texturization of silicon surface

DN50A Q-switched Nd:YAG laser was used. Figure 1 shows the schematic diagram of the employed laser processing. Successive grooves were scribed with constant spacing within consecutive scanning the wafer surface by laser beam in the opposite directions. Figure 2 presents the laser texturization of silicon surface.

Laser induced damage layer was removed by etching. Many trials for different etching conditions were carried out. On the basis of these trials optimum parameters of etching treatment were adjusted and assumed to take the following values: concentration of KOH solution 20% and temperature of etching solution 80°C. For assumed values of etching parameters top layer of different thickness was removed.

The microstructures of textured surface were investigated by scanning electron microscope (SEM) and LSM5 Pascal Zeiss confocal laser scanning microscope (CLSM).The reflectance of

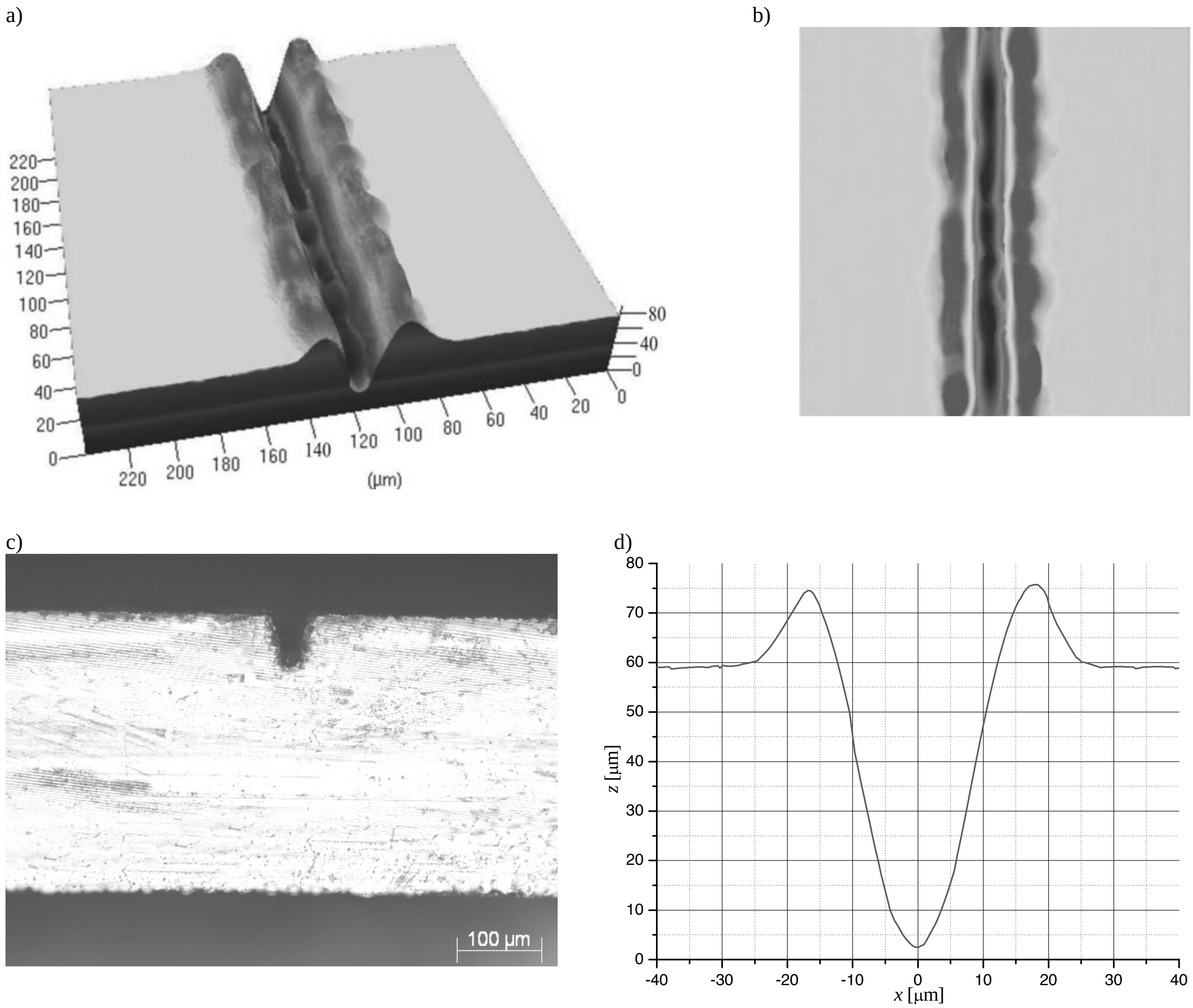

Fig. 3. Laser groove produced for the following parameters of laser beam: velocity of laser beam scanning 50 mm/s, pulse repetition frequency 15kHz: a) 3D surface topography (CLSM), b) 2D surface topography (CLSM), c) cross section of the groove d) averaged profile of groove cross section

produced textures was measured by Perkin-Elmer Lambda spectrophotometer with an integrating sphere. The solar cells were characterized by their illuminated I-V characteristic under standard AM 1.5 radiation.

3. Results

Figs. 3 and 4 show a scanning electron microscope (SEM) surface image of laser treated multicrystalline wafer. Some of material is visible at the upper edges of the grooves. An intense train of laser pulses rapidly melts the area of silicon surface local to laser irradiation. If the absorbed energy is sufficiently high some of the material is explosively evaporated from the molten layer.

Applied etching step enable to remove layer of laser induced defects from the textured surface. As a result of laser processing and subsequent etching texture of uniform structure was obtained (Fig. 5).

Additionally, the reduction of reflectance was characterized by effective reflectance defined as [18]:

$$R_{eff} = \frac{\int_{300}^{1100} R(\lambda)N(\lambda)d\lambda}{\int_{300}^{1100} N(\lambda)d\lambda} \quad (1)$$

where $R(\lambda)$ – total reflectance, $N(\lambda)$ - the solar flux under AM1.5 standard conditions.

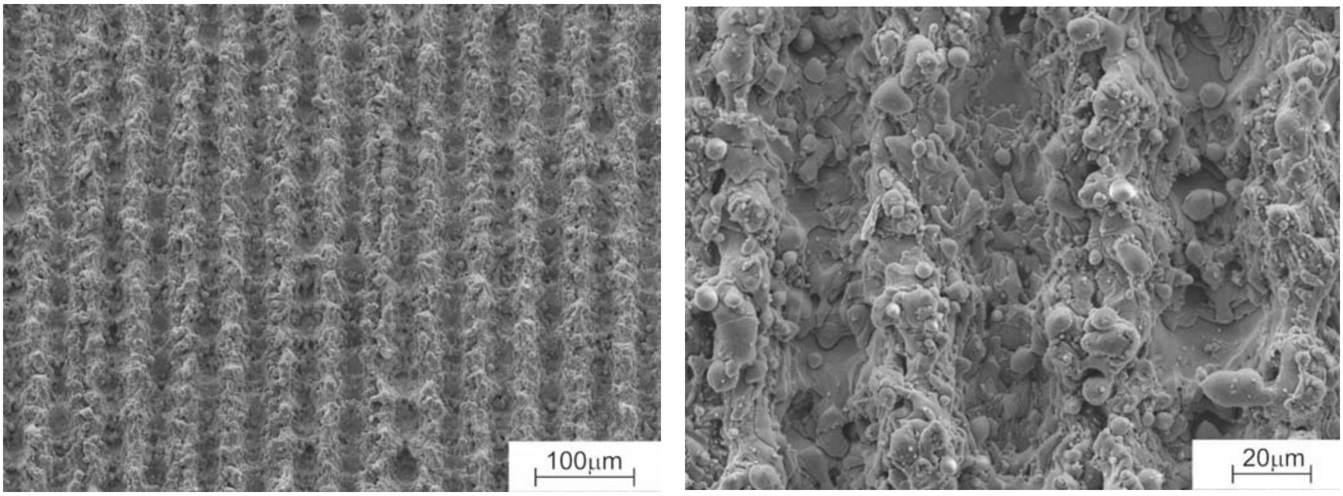

Fig. 4. SEM micrograph of texture corresponding to parallel grooves

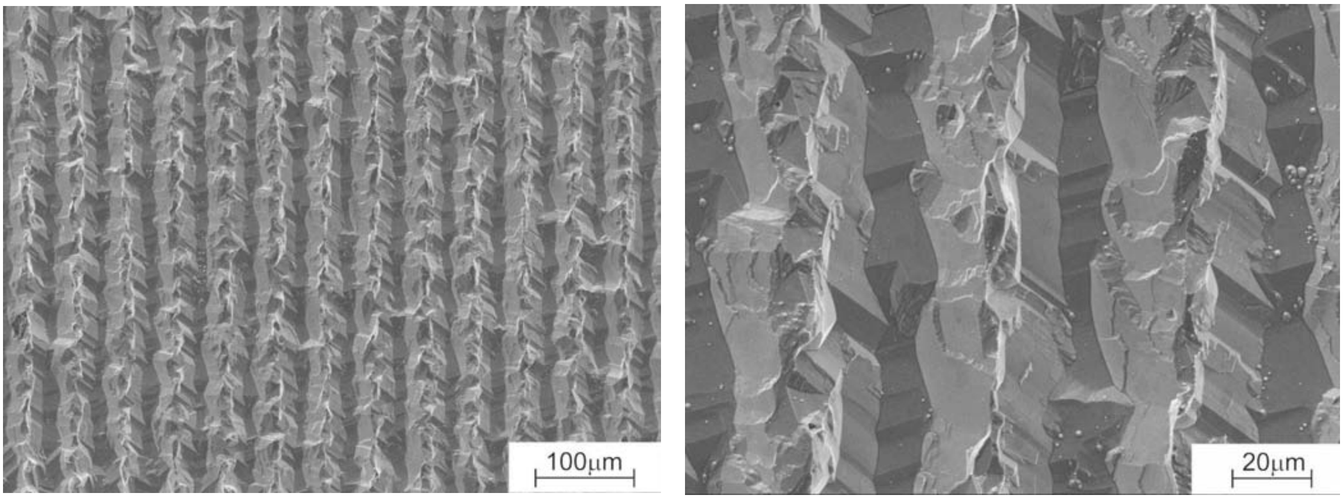

Fig. 5. SEM micrograph of texture corresponding to parallel grooves after removal of distorted layer of thickness 40 μm

In the calculation of effective reflectance spectral irradiance of sun is taken into account. Consequently, it gives adequate information about the fitting of reflectance curve of the surface to the spectrum of solar incident light. Total reflectance was measured over the wavelength range from 300 nm to 1100 nm.

Laser texturing results in significant decrease in the value of effective reflectance compared to untextured surface. Applied etching procedure causes the texture to flatten out reducing its optical effectiveness (Fig. 6, Tab. 1).

Fig. 7. depicts the current-voltage (I-V) characteristics at AM 1.5 illumination for laser textured multicrystalline silicon solar cells. Electrical properties of manufactured solar cells determined from I-V characteristics are given in the Table 2. Solar cells manufactured from laser-textured multicrystalline silicon wafers demonstrate worse electrical performance than cells manufactured from the non-textured wafers after saw damage removal. Etching of textured surface in 20 % KOH solution at temperature of 80°C subsequent to laser processing shows to have a greatly increased impact on electrical performance of solar cells.

Table 1
Effective reflectance for textured wafers after removal of laser induced damage layer of different thickness

Thickness of removed layer [μm]	Effective reflectance R_{eff} [%]
untextured	34.08
without etching	12.44
20	17.58
40	21.21
60	25.35
80	30.52

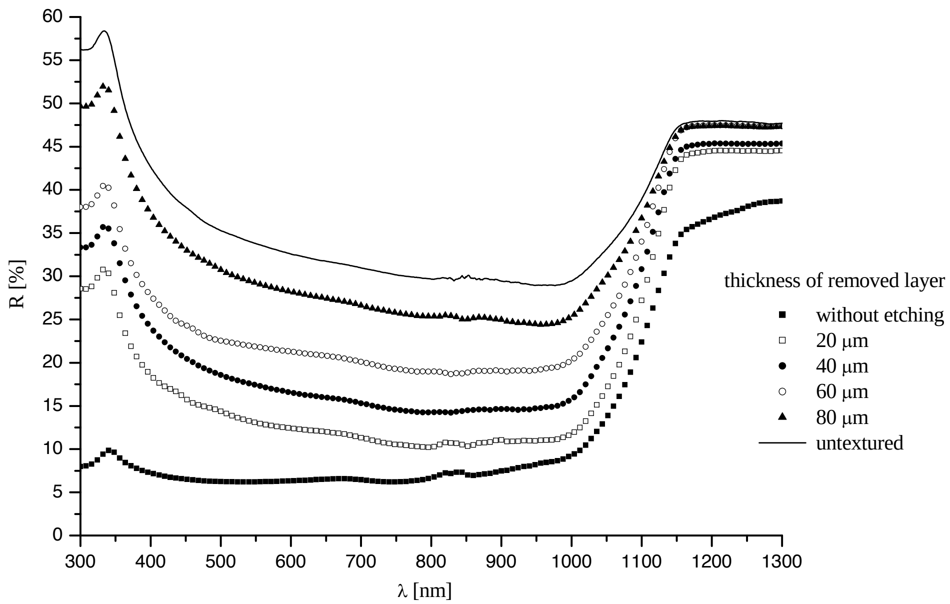

Fig. 6. Reflectance for wafer with texture corresponding to parallel grooves after removal of laser induced damage layer of different thickness

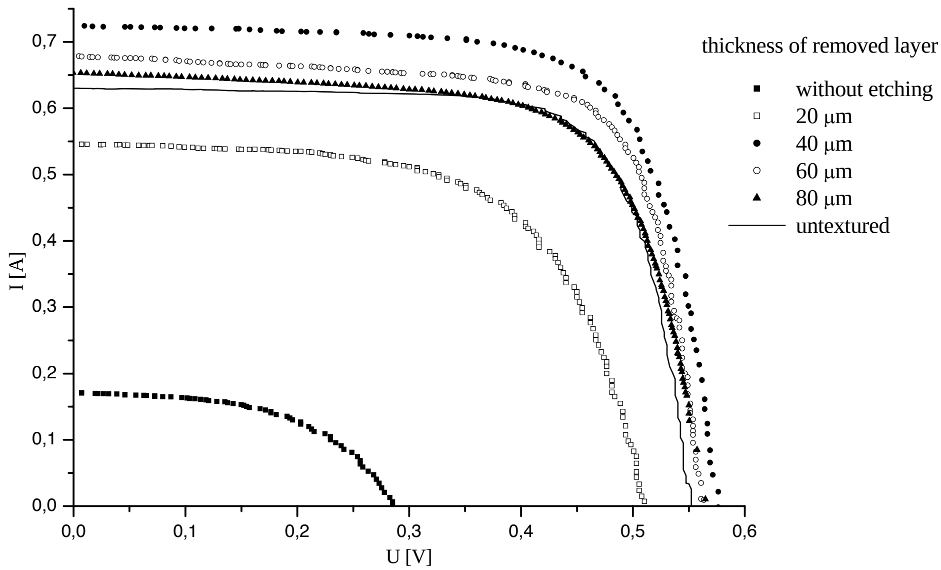

Fig. 7. Current-voltage characteristics of solar cells manufactured from wafers with texture corresponding to parallel grooves after removal of laser induced damage layer of various thickness

4. Conclusions

One of the most important alternative for conventional sources of energy is solar energy. Photovoltaic energy conversion is presently the fastest growing energy technology and is expected to become a major source of power generation in the future. To reduce optical losses texturization of top surface was carried out.

The paper presents results of crystalline silicon texturization by means of diode-pumped pulsed Nd:YAG laser. The best solar cells manufactured from the laser-textured wafers with texture corresponding to parallel grooves after removal by etching of 40 μm of laser damage layer demonstrate 11.93 % efficiency.

Laser processing of crystalline silicon surface is an interesting alternative in comparison with chemical and electrochemical texturization methods. It gives possibility of precise surface

Table 2
Electrical properties of solar cells manufactured from laser textured wafers after removal of laser induced damage layer of various thickness

Thickness of removed by etching layer [μm]	Electrical properties						
	U_{OC} [mV]	I_{SC} [mA]	I_m [mA]	U_m [mV]	P_m [mW]	*FF*	E_{ff} [%]
without etching	287.08	171.31	134.91	197.25	26.61	0.54	1.06
20	509.96	548.68	450.38	385.69	173.71	0.62	6.92
40	576.41	724.13	640.32	467.09	299.09	0.72	11.93
60	562.92	678.81	601.42	462.64	278.24	0.73	11.08
80	565.82	653.59	562.80	451.33	254.01	0.69	10.12
untextured	552.55	630.11	573.32	447.10	256.33	0.74	10.21

processing independent on crystallographic orientation of grains. It is significant result from the development of photovoltaics viewpoint where presented method may be successfully used in manufacturing of high efficiency solar cells.

References

[1] A. Goetzberger, V.U. Hoffmann, Photovoltaic solar energy generation, 2005, Berlin, Springer-Verlag.

[2] Z.M. Jarzębski, Solar Energy: Photovoltaic conversion, 1990, Warszawa, PWN, (in Polish).

[3] E. Klugmann, E. Klugmann-Radziemska, Alternative sources of energy, Photovoltaic energy, 1999, Białystok, Economy & Environment (in Polish).

[4] M.A. Green, Third generation photovoltaics: advanced solar energy conversion, 2003, Berlin, Springer.

[5] M.D. Archer, R. Hill, Clean electricity from photovoltaics, 2001, London, Imperial College Press.

[6] P. Maycock, T. Bradford, PV market update: Demand grows quickly and supply races to catch up, Renewable Energy World 10 (2007) 4-10.

[7] L.A. Dobrzański, A. Drygała, K. Gołombek, P. Panek, E. Bielańska, P. Zięba, Laser surface treatment of multicrystalline silicon for enhancing optical properties, Journal of Materials Processing Technology 201 (2008) 291-296.

[8] F. Duerinckx, J. Szlufcik, J. Nijs, R. Mertens, C. Gerhard, C. Markmann, P. Gath, G. Willeke, High efficiency, mechanically V-textured, screen printed multicrystalline silicon solar cells with silicon nitride passivation, Proceedings of the 2nd World Conference on Photovoltaic Solar Energy Conversion, Leuven Belgium, 1998, 1248-1253.

[9] R. Einhaus, E. Vazsonyi, R. Mertens, Isotropic texturing of multicrystalline silicon wafers with acid texturing, Proceedings of the 26th IEEE Photovoltaic Specialists Conference, Anahiem, 1997, 167-170.

[10] K. Fukui, Y. Inomata, K. Shirasawa, Surface texturing using reactive ion etching for multicrystalline silicon solar cell, Proceedings of the 26th IEEE Photovoltaic Specialists Conference, Anahiem, 1998, 47-50.

[11] G. Kumaravelu, M.M. Alkaisi, A. Bittar, Surface texturing for silicon solar cells using reactive ion etching technique, Proceedings of the 29th IEEE Photovoltaic Specialists Conference, New Orleans, 2002, 258-261.

[12] E.S. Marstein, H.J. Solheim, D.N. Wright, A. Holt, Acid texturing of multicrystalline silicon wafers, Proceedings of the 31st IEEE Photovoltaic Specialists Conference, Florida, 2005, 1309- 1312.

[13] P. Panek, M. Lipiński, J. Dutkiewicz, Texturization of multicrystalline silicon by wet chemical etching for silicon solar cells, Journal of Materials Science 40/6 (2005) 1459-1463.

[14] J. Rentsch, N. Kohn, F. Bamberg, K. Roth, S. Peters, R. Ludemann, R. Preu, Isotropic plasma texturing of mc-Si for industrial solar cell fabrication, Photovoltaic Specialists Conference, 2005, Conference Record of the Thirty-first IEEE, 2005, 1316- 1319.

[15] J. Szlufcik, S. Sivoththaman, J.F. Nijs, R.P. Mertens, R. van Overstraeten, Low-cost industrial technologies of crystalline Silicon solar cells, Proceedings of the Institute of Electrical and Electronics Engineers 65 (1997) 711-730.

[16] L.A. Dobrzański, A. Drygała, Laser processing of multicrystalline silicon for texturization of solar cells, Journal of Materials Processing Technology 191 (2007) 228-231.

[17] L.A. Dobrzański, A. Drygała, P. Panek, M. Lipiński, P. Zięba, Application of laser in silicon surface processing, Journal of Achievements in Materials and Manufacturing Engineering 24/2 (2007) 179-182.

[18] L.A. Dobrzański, A. Drygała, Surface texturing of multicrystalline silicon solar cells, Journal of Achievements in Materials and Manufacturing Engineering 31/1 (2008) 77-82.

[19] L.A. Dobrzański, A. Drygała, Laser texturization in technology of multicrystalline silicon solar cells, Journal of Achievements in Materials and Manufacturing Engineering 29/1 (2008) 7-14.

[20] M.J. Jackson, G.M. Robinson, Micromachining electrical grade steel using pulsed Nd-YAG lasers, Journal of Achievements in Materials and Manufacturing Engineering 20/1 (2007) 451-454.

[21] L.A. Dobrzański, J. Domagała, T. Tański, A. Klimpel, D. Janicki, Laser surface treatment of magnesium alloy with WC powder, Archives of Materials Science and Engineering 30/2 (2008) 113-116.