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Laser texturization in technology of multicrystalline silicon solar cells

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ABSTRACT

Purpose: This paper presents technology of multicrystalline silicon solar cells with laser texturization step. The texturing of polycrystalline 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 80ºC 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.

Design/methodology/approach: The topography of laser textured surfaces were investigated using DSM 940 OPTON 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 light characteristics under standard AM 1.5 radiation.

Findings: Solar cells manufactured from laser-textured polycrystalline 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. Etching of textured surface in 20% KOH solution at temperature of 80ºC subsequent to laser processing shows to have a greatly increased impact on electrical performance of solar cells.

Research limitations/implications: Continued etching to remove laser induced defects cause the texture to flatten out reducing it optical effectiveness.

Originality/value: This paper demonstrates, that laser processing is very promising technique for texturing multicrystaline silicon independent on grains crystallographic orientation compared to conventional texturing methods in technology of solar cells.

Keywords: Surface treatment; Photovoltaics, Silicon solar cells; Texturization; Laser processing

1. Introduction

Taking into account rapidly growing demand for energy and the fast depletion of conventional energy sources deposits, the development of new energy sources has become a challenge to today's world. Moreover, what is even more important, the use of fossil fuels such as coal and crude oil, being nowadays prevailing sources of energy, leads to unacceptably high concentration of harmful gases in the atmosphere. This, in turn, leads to ozone depletion and global warming that may destructively influence natural environment. One of the most important alternative for conventional sources of energy is solar energy. It is referred to as solar radiation that reaches the earth. Solar energy can be converted directly or indirectly into other forms of energy such as heat and electricity. A direct conversion of solar energy into electricity is performed by photovoltaic devices referred to as solar cells [1-3].

The main drawback in the use of photovoltaic technology is the intermittent and variable character of solar light. However this technology has many significant advantages compared with conventional sources of energy. It is pollution free and clean, has no moving parts, produces no noise and requires very little maintenance. It does not require connection to a power grid since it can operate as a standing alone system. It is very promising alternative as far as environment protection is concerned since the use of this technology may significantly reduce chemical, radioactive and thermal pollution. Therefore, it may be helpful in reducing the greenhouse effect. In addition, it may be treated as a renewable and virtually inexhaustible source of energy in the context of expected duration of sun activity. As a consequence, it is very attractive new technology for power generation [1, 4, 5].

In the paper, the research to improve the performance of multicrystalline silicon solar cells is taken up. It was concentrated on the minimization of optical losses by appropriate texturization of front surface of solar cells. There are many publications relevant to the increase of incident sunlight absorption by means of surface texturization [5-17]. In texturing multicrystalline silicon some problems arise. It appears that most of texturing methods used for monocrystalline silicon are inefficient for multicrystalline silicon since random distribution of grains with different crystallographic orientation. Therefore, laser surface processing was applied for texturization of multicrystalline wafers. The influence of laser processing parameters on texture shape was investigated.

2. Technology of multicrystalline silicon solar cells

Technology of multicrystalline silicon solar cells with laser texturization step have been performed according to the nine steps (Fig. 1).

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.

2.1. Saw damage removal

Multicrystalline silicon wafers obtained by wire sawing of multicrystalline ingot that were used as a base material had highly distored layers on both sides (Fig. 2). Therefore, about 11 μm of material has been etched off in 20% KOH solution at temperature of 80°C to remove damages resulting from sawing (Fig. 3).

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.

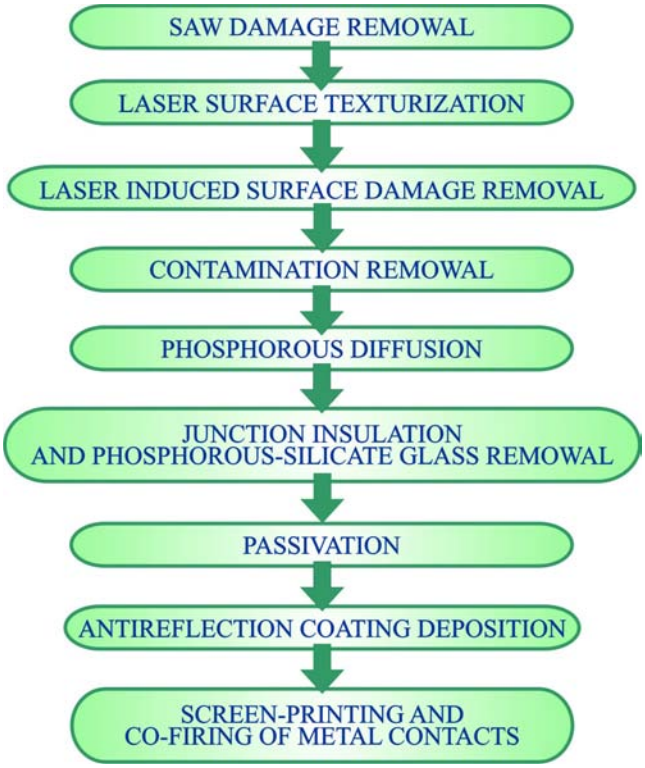

Fig. 1. Technology of multicrystalline silicon solar cells

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. Values of effective reflectance calculated from the integral formula (1) for wafers before and after saw damage removal are equal to 25.97 %, 34.08 %, respectively.

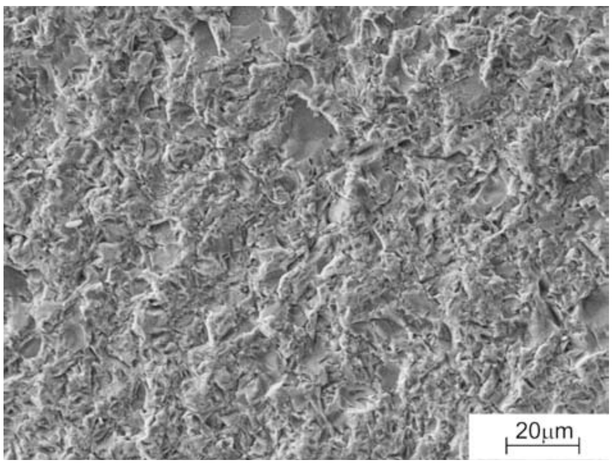

Fig. 2. The topography of silicon wafer surface before saw damage removal

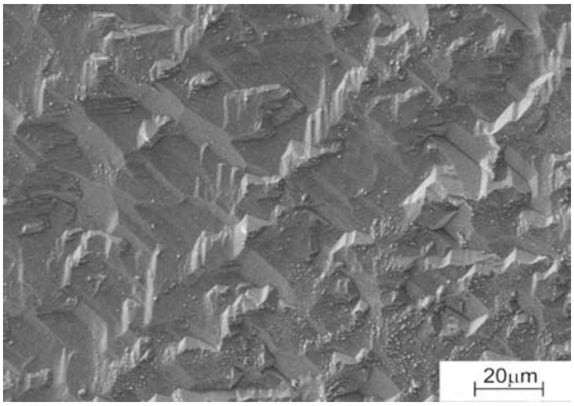

Fig. 3. The topography of silicon wafer surface after saw damage removal

2.2. Laser surface texturization

In order to reduce optical losses the front surface of the cell has been textured. Texturization was carried out by means of diode-pumped pulsed neodymium-doped yttrium aluminium garnet laser crystal (Nd:YAG) 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 as well grid of grooves with spacing of 50 μm were produced. Figures 4 and 5 demonstrates that performed laser processing allowed for obtaining uniform texture with no impact due to the random crystallographic orientation of different grains.

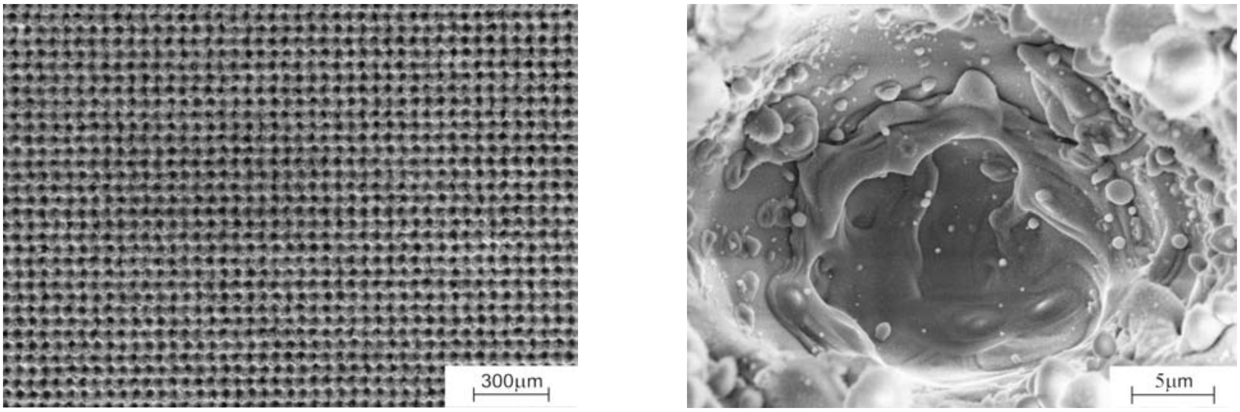

Fig. 4. SEM micrograph of texture corresponding to grid of grooves

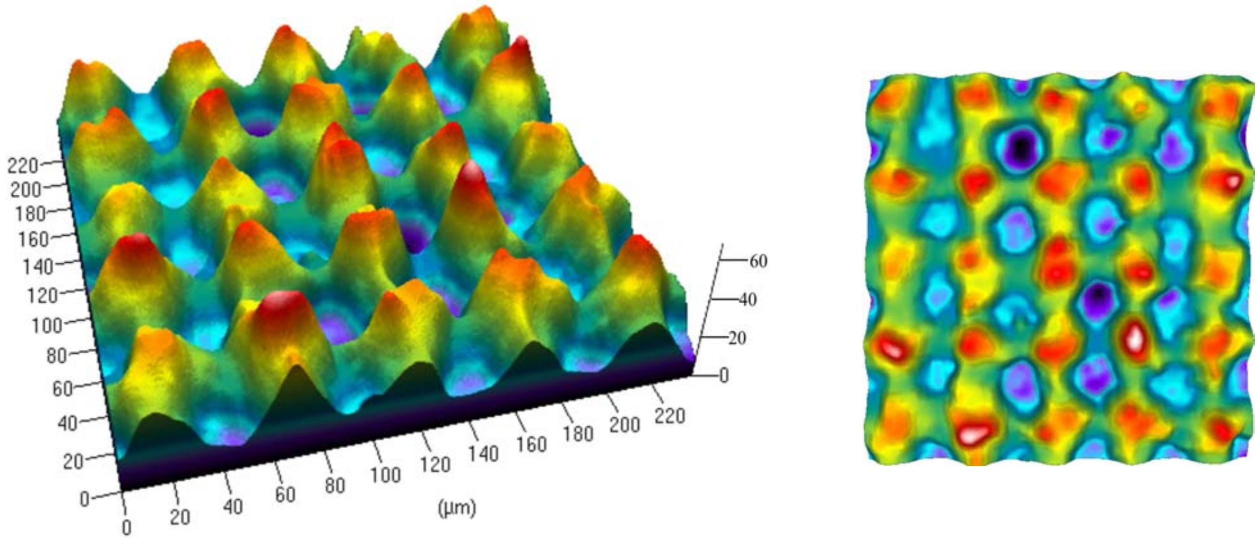

Fig. 5. 3D and 2D confocal laser scanning microscope topographies of texture corresponding to grid of grooves

2.3. Laser induced surface damage removal

Solar cells produced from laser-textured polycrystalline 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. Detailed inspection of laser textured surface revealed laser induced damage layer that was removed by etching in 20% KOH solution at temperature of 80°C. Figures 6, 7 shows textured surface after post-texturing alkaline etching.

Conditions of laser processing exert significantly on optical properties of laser textured wafers. Laser texturing of silicon wafers allows for decreasing of reflectance compared to reflectance of untextured wafers (Fig. 8, 9). Wafers with texture corresponding to grid of grooves demonstrate smaller reflectance in comparison to wafers with texture corresponding to paraller grooves as far as the same conditions of laser processing are concerned. In case of both types of texture with the progress of etching of laser textured wafers increase in reflectance is observed (Tab. 1).

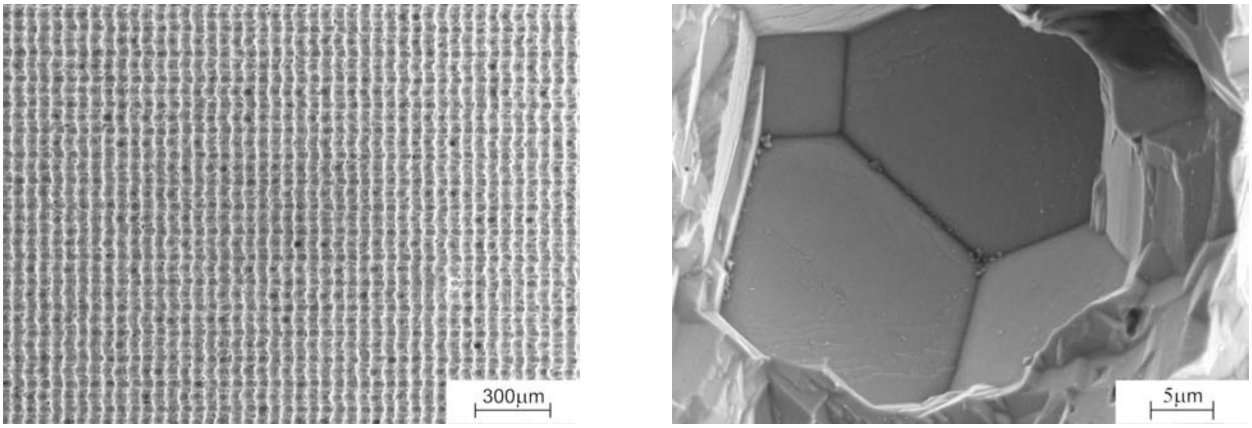

Fig. 6. SEM micrograph of texture corresponding to grid of grooves after removal of distorted layer of thickness 40 μm

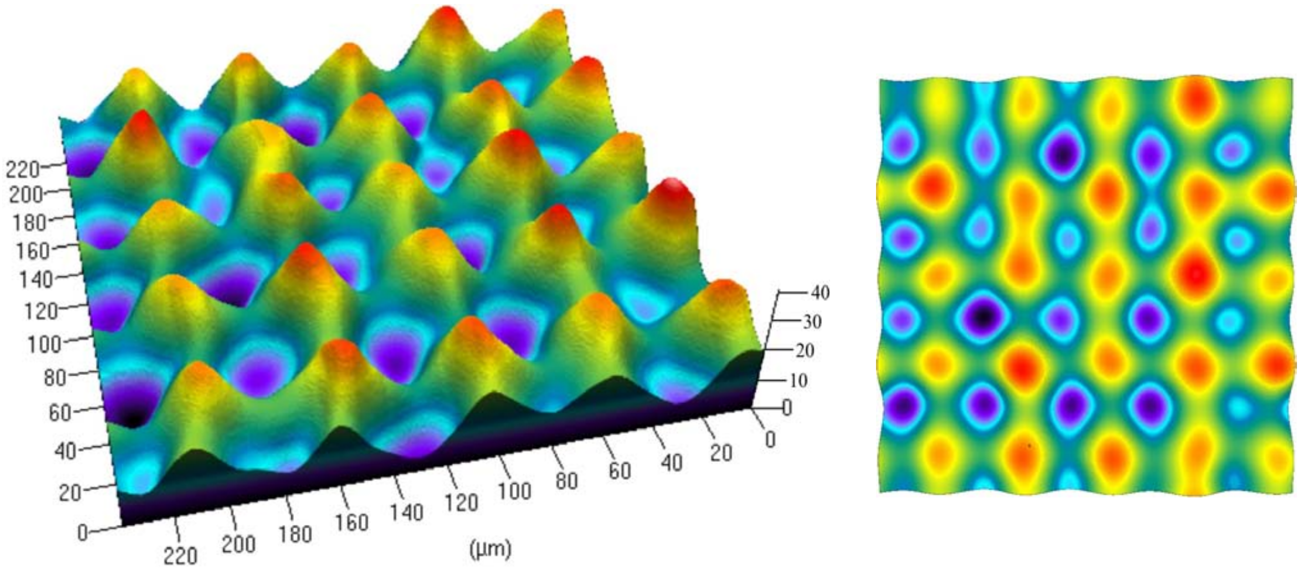

Fig. 7. 3D and 2D confocal laser scanning microscope topographies of texture corresponding to grid of grooves after removal of distorted layer of thickness 40 μm

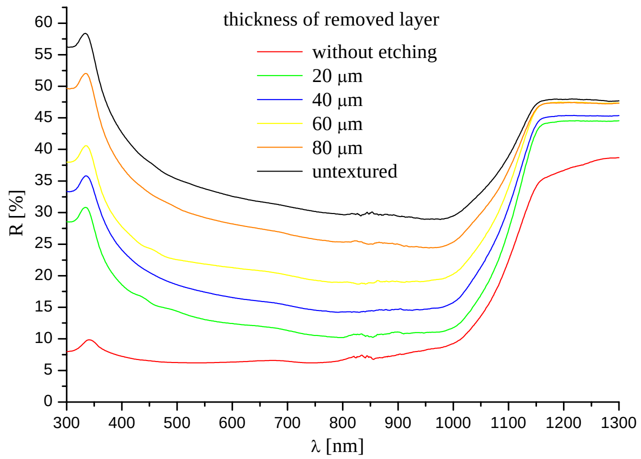

Fig. 8. Reflectance for wafer with texture corresponding to parallel grooves after removal of laser induced damage layer of different thickness

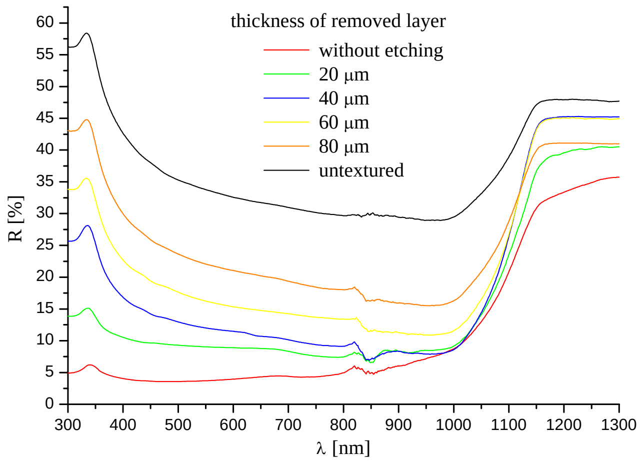

Fig. 9. Reflectance for wafer with texture corresponding to grid of grooves after removal of laser induced damage layer of different thickness

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
texture corresponding to parallel grooves	
without etching	12.44
20	17.58
40	21.21
60	25.35
80	30.52
texture corresponding to grid of grooves	
without etching	10.56
20	14.26
40	16.38
60	19.42
80	22.94

2.4. Contamination removal

The wafers were subjected to acid etching in 47 % H_2SO_4 : H_2O, then in 2 % HCl and finally in 10 % HF to neutralise potassium ions remained after alkaline etching, remove metallic contamination and native oxides.

2.5. Phosphorous diffusion

In order to produce p-n junction wafers were dopped by phosphorous in open tube furnace using conventional liquid phosphorous oxide trichloride ($POCl_3$) as a dopant source. Diffusion was carried out at temperature of 850 °C.

2.6. Junction insulation and phosphorous-silicate glass removal

To remove the parasitic junctions from edges the wafers were stacked surface by surface with foil separation and immersed in the 65 % HNO_3 : 80 % CH_3COOH : 40 % HF solution in volume ratio 5 : 3 : 3. Next, the PSG was removed by immersion in 10 % HF solution. Finally, wafers were dried in a purified air.

2.7. Passivation

Reduction of the surface recombination velocity was achieved by surface passivation. The thin layer of silicon dioxide (SiO_2) was formed at a temperature of 800°C for 5 minute in oxygen and nitrogen atmosphere.

2.8. Antireflection coating deposition

Layer of titanium oxide (TiO_x) was deposited to minimize reflection on the front side by means of chemical vapour deposition (CVD) from $(C_2H_5O)_4$ Ti heated at temperature of 100 °C. The temperature of the silicon substrate was 300°C.

2.9. Screen-printing and co-firing of metal contacts

The front and back contacts were formed by screen-printing. Front metallization was printed with silver Du Ponte PV 145 paste. It was designed in the form of fingers of 120 μm width with 2.5 mm spacing and one collection busbar 2 mm thick (Fig. 10a). Applied pattern of the front contact shades about 8 % of the front surface of the cell. Back contact was printed with aluminium

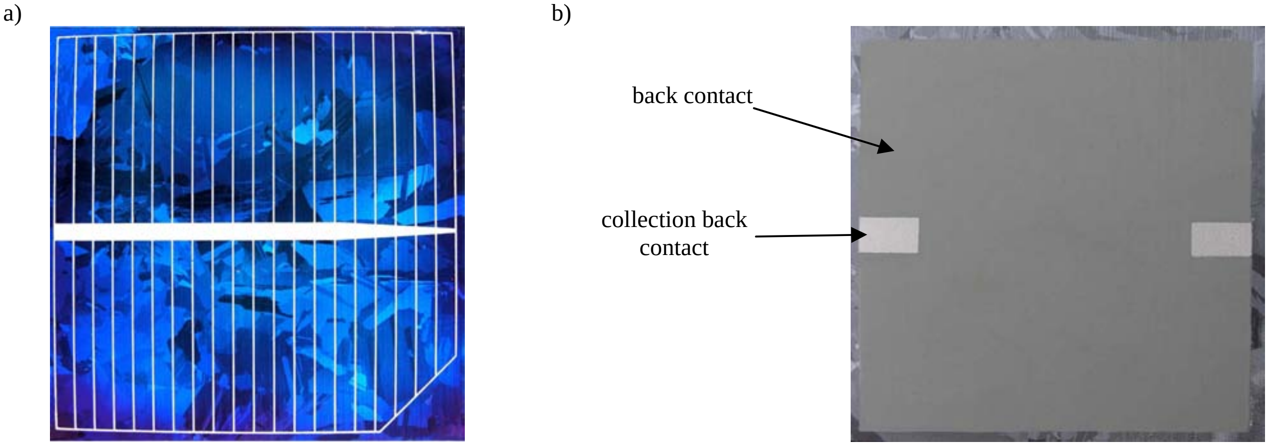

Fig. 10. Metal contacts a) front contact, b) back contact

Ferro CN 53-101 paste. The two collection back contacts (Fig. 10b) were printed with silver paste with 2% aluminium and bismuth glaze.

After screen-printing wafers were dried in air atmosphere at temperature of 150°C. Screen printing and drying were followed by co – firing in infrared belt furnace at peak temperature of 880 °C and belt speed 165 cm/min.

The high-temperature processing after the screen-printing was required to burn off organic compounds of the pastes applied and to sinter metallic grains together to form a good conductor.

3. Electrical properties of silicon solar cells with laser textured surface

Photovoltaic cells manufactured from the wafers with texture corresponding both parallel grooves and grid of grooves with laser beam scanning velocity 50 mm/s, spacing between grooves 0.05 mm and after etching off laser induced damage layer of thickness 40 µm demonstrate the best efficiency of 11.93% and 12.67%, respectively (Tab. 2). In case of solar cells of the best efficiency obtained from wafer with texture corresponding to parallel grooves short circuit current increases by 94.02 mA and open circuit voltage by 23.86 mV compared to cells manufactured from untextured wafers. Photovoltaic cells of the best efficiency produced from wafers with texture corresponding to grid of grooves show the boost of short circuit current by 97.37 mA and open circuit voltage by 29.3 mV in comparison with cells manufactured from untextured wafers. Solar cells produced from wafers with texture corresponding to grid of grooves demonstrates higher by 3.35 mA value of short circuit current and greater by 5.44 mV value of open circuit voltage compared to cells manufactured from wafers with texture corresponding to parallel grooves.

Current-voltage characteristics of solar cells manufactured from laser textured wafers after removal of laser induced damage layer of different thickness are shown in Figs. 11, 12.

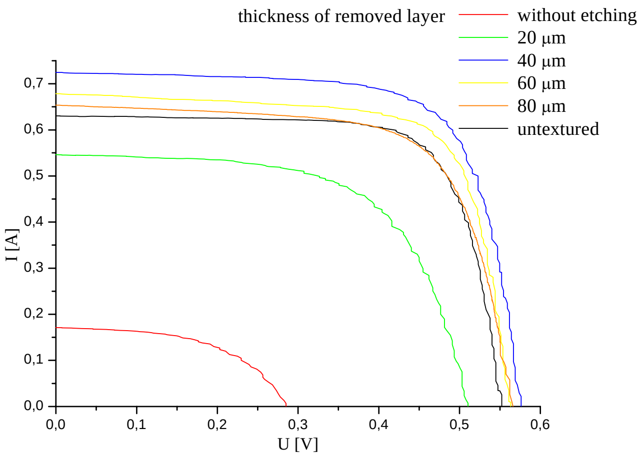

Fig. 11. Current-voltage characteristics of solar cells manufactured from wafers with texture corresponding to parallel grooves after removal of damage induced layer of various thickness

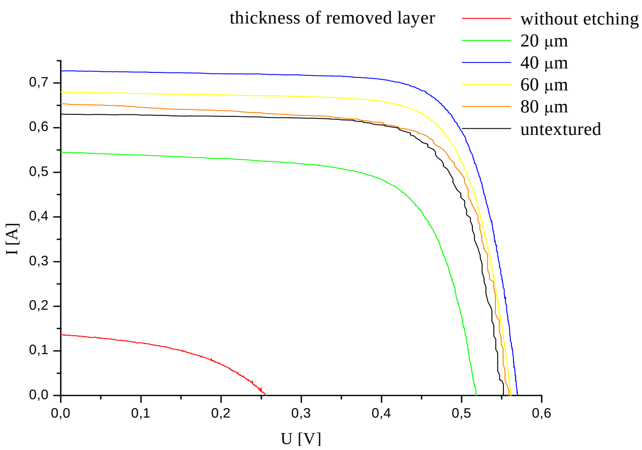

Fig. 12. Current-voltage characteristics of solar cells manufactured from wafers with texture corresponding to grid of grooves after removal of damage induced layer of various thickness

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

Thickness of removed layer [µm]	ELECTRICAL PROPERTIES						
	U_{OC} [mV]	I_{SC} [mA]	I_m [mA]	U_m [mV]	P_m [mW]	FF	E_{ff} [%]
untextured	552.55	630.11	573.32	447.10	256.33	0.74	10.21
texture corresponding to parallel grooves							
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
texture corresponding to grid of grooves							
without etching	256.28	135.95	85.32	178.09	15.20	0.44	0.61
20	520.33	544.77	469.02	416.19	195.20	0.69	7.77
40	581.85	727.48	661.90	480.33	317.93	0.75	12.67
60	560.44	679.46	607.04	469.34	284.91	0.75	11.35
80	558.51	653.57	577.88	459.58	265.59	0.73	10.58

4. Conclusions

Direct conversion of solar energy into electricity, environmentally benign, pollution free, renewable and virtually inexhaustible source of energy are the main advantages of photovoltaics. This paper presents technology of multicrystalline silicon solar cells with laser texturization step. It was demonstrated, that laser processing is very promising technique for texturing multicrystaline silicon independent on grains crystallographic orientation compared to conventional texturing methods.

Texturing of polycrystalline silicon surface using Nd:YAG laser makes it possible to increase absorption of the incident solar radiation. However, solar cells produced from laser-textured polycrystalline silicon wafers demonstrate worse electrical performance than cells manufactured from the untextured wafers after saw damage removal as well as wafers textured by etching in alkaline solutions. This results from the laser-induced defects introduced into the laser-processed layer that reduce electrical quality of textured silicon surface limiting performance of the cells. 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. This additional technological operation 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 untextured wafers after saw damage removal as well as wafers textured by etching in 40% KOH:IPA:DIH_2O solution. However, continued etching to remove laser induced defects caused the texture to flatten out reducing it optical effectiveness. With the appropriate selection of the laser processing conditions the uniform texture corresponding to parallel grooves and grid of grooves can be produced.

The best solar cells manufactured from the laser-textured wafers with texture corresponding to parallel grooves as well as grid of grooves with laser beam scanning rate 50 mm/s, spacing 0.05 mm and after removal by etching of 40 µm of laser damage layer demonstrate 11.93 and 12.67% efficiency, respectively.

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