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Application of laser in multicrystalline silicon surface processing

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Manufacturing and processing

ABSTRACT

Purpose: Surface texturisation is a common technological process in solar cell manufacturing aiming at a reduction of the light reflection losses. The standard alkaline texturing of multicrystalline silicon for solar cells is not effective because of random orientation of the grains. In this paper a method of laser texturisation has been proposed to overcome these difficulties.
Design/methodology/approach: The microstructure of laser textured surface was investigated by DSM 940 OPTON scanning electron microscope (SEM). Electrical parameters of produced solar cells were characterized by measurements of I-V light characteristics under standard AM 1,5 radiation.
Findings: The analysis performed in the paper revealed the existence of laser-damaged layer on the textured surface which has to be removed prior to successive technological steps to obtain solar cells of satisfactory performance.
Research limitations/implications: It is suggested that future work should be done to develop a better post-scribe etching technique to remove the laser damaged layer.
Originality/value: It seems to be very promising method since it can be applicable in industry.
Keywords: Surface treatment; Solar cells; Multicrystalline silicon; Laser processing

1. Introduction

Lasers find widespread application in materials processing. They are successfully applied in industrial processes including welding, cutting, drilling, ablation deposition and surface treatment [1, 2].

Lasers are used to generate coherent and monochrome light that is characterised by small divergence of the beam, small diameter of the spot and very high power density of radiation. Lasers applied in surface engineering generate infrared light whose power density is in the range 10^3-10^8 W/cm^2 [3].

Laser radiant flux incident on the non-transparent surface of material is partially reflected and absorbed. The amount of incident laser radiant flux that is reflected and/or absorbed depends on the wavelength of laser beam, physical properties of material and its surface. The quantity of heat absorbed by the material at the point of laser beam interaction depends on its absorption coefficient, wavelength and power density of laser beam and time of exposure [1, 4].

The higher is the temperature of heated material the higher is absorption of incident radiation. The highest temperature of upper layer is obtained at point that corresponds to place related to the highest power density. Distribution of temperature on the top surface corresponds to the distribution of power density in the cross-section of laser beam [5].

The heat accumulated in the top layer penetrates inwards material as a consequence of heat transfer. As a result, upon laser processing so-called heat affected zone with structural defects may be created [6-12].

The paper analyses possible implementation of laser treatment in texturing of multicrystalline silicon solar cells.

Texturization enhances the absorption of light through the following phenomena [13-16]:

- incoming light rays that are reflected from one tilted (by texturing) surface may strike another surface resulting in an improved probability of absorption, and therefore reduced reflection,
- the light rays refracted within the silicon propagate at an angle, causing them to be absorbed closer to the junction than this process could occur in the case of planar surface which is especially relevant in material with diffusion lengths comparable to or less than the cell thickness,
- long-wavelength photons which are reflected from the rear surface coming back to the front may encounter an tilted silicon surface, improving the chance of being internally reflected, either at the silicon interface or at the glass surface, and providing next chance for absorption.

The third phenomenon is referred to as light-trapping, and gives an improved response especially to infrared light.

Surface texturing for enhanced light absorption applied in monocrystalline silicon solar cells has been historically obtained by creating randomly distributed pyramids by alkaline chemical etching. However, this technique works correctly only for monocrystalline silicon wafers whose top surface has uniform crystallographic orientation. The random nature of the crystal orientation of multicrystalline silicon wafers makes such technique much less effective for this material because only a small fraction of grains in the top surface have the same crystal orientation. In addition, alkaline etching can cause unwanted steps and crevasses between the grains disabling achieving effective morphology of the textured surface [13, 15, 17].

The paper presents results on the development of surface texturing by means of laser processing and investigation of the influence of laser texturization on the operational properties of the cells.

2. Experimental

"As cut" p-type boron doped multicrystalline silicon wafers (produced by Bayer) were used as a substrate. Wafers had the following parameters: thickness ~ 330 μm, resistivity 1 Ωcm and area 5 cm x 5 cm.

Fabrication of solar cells have been proceeded according to the following steps:

1. Saw damage removal
   "As cut" wafers have on both sides distorted layers resulting from sawing. For this reason, about 10 μm has been etched off from each face in 20% KOH solution at temperature 80°C.
2. Surface texturization
   In order to decrease light reflection coefficient front surface of the cell has been textured. The texture in the form of perpendicular grooves (Fig. 1) has been produced by means of Q-switched Nd:YAG laser operating at wavelength of 1064 nm. Parameters of laser treatment were as follows: maximum output power 50 W, pulse repetition frequency 15 kHz, diameter of the laser spot 20 μm and laser beam speed 60 mm/s. The optimum laser parameters were determined experimentally by creating textures with different laser settings.

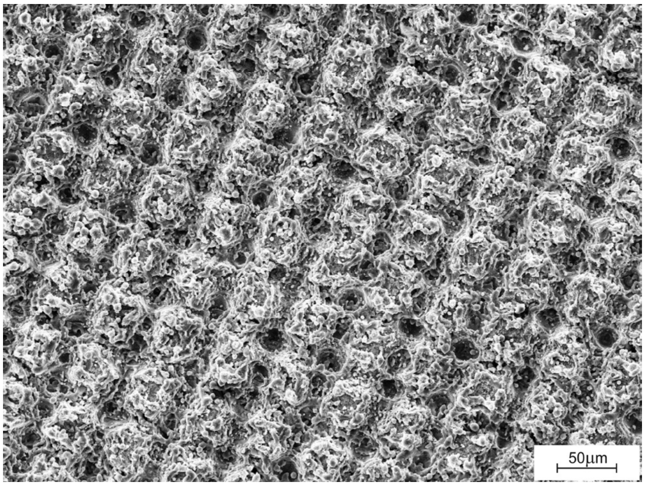

Fig. 1. SEM image of front side of laser textured multicrystalline silicon surface

3. Laser induced surface damage removal
   Defects introduced into the top surface by laser texturization have been removed by etching in 20% KOH solution at temperature 80°C.
4. Contamination removal
   The wafers were subjected to:
   - acid etching in 95% H_2SO_4:H_2O in volume ratio 1:1,
   - acid etching in 2% HCl,
   - acid etching in 10% HF

   to neutralise potassium ions remained after alkaline etching, remove metallic contamination and native oxides.
5. Phosphorous diffusion
   To create a n^+-p junction, phosphorous diffusion was performed. Emitter of sheet resistance 45 Ω/□ was formed at temperature 850°C using liquid $POCl_3$ as the dopping source.
6. Junction insulation and phosphorous-silicate glass (PSG) removal
   To remove the parasitic junctions from wafers 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.
7. Antireflection coating (ARC) deposition
   The ARC layer of titanium dioxide (TiO_2) was deposited by means of chemical vapour deposition from $(C_2H_5O)_4Ti$ heated at temperature of 100°C. The temperature of the Si substrate was 300°C.
8. Screen-printing and co-firing of metal contacts
   The front and back contacts were formed by screen-printing technology. Front contact was printed with silver Du Ponte PV 145 paste. It was designed in the form of comb-like pattern consisting of fingers of 120 μm width with 2.5 mm spacing and one collection busbar 2 mm thick. Applied pattern of the front contact shades about 7.2% of the front surface of the cell. Back contact was printed with aluminium Ferro CN 53-101 paste.

After screen-printing wafers were dried in air atmosphere at temperature of 150°C. Then co-firing was performed in an infrared belt furnace at peak temperature 880°C and belt speed 165 cm/min.
After the screen-printing the high-temperature was required to burn off organic compounds of the pastes applied and to sinter metallic grains together to form a good conductor. Moreover, it should be pointed out that front paste was printed on an insulating ARC and the back contact on the parasitic n-type rear layer formed during diffusion.
Upon firing, the active components of the front paste penetrate ARC to contact emitter n-type layer. On the other hand, back paste penetrates the parasitic back emitter to reach base p-type silicon and neutralise parasitic junction produced in diffusion on the back side of the wafer.

The illuminated I-V parameters were measured under standard AM 1.5 radiation.

The microstructures of textured surfaces were investigated by DSM 940 OPTON scanning electron microscope (SEM).

3. Results

Texture consisting of perpendicular grooves 40μm in depth was produces by means of laser treatment. Detailed inspection of the top surface under scanning electron microscope revealed microcracks and crevasses (Fig.2) on the textured surface resulting from high temperature gradients appearing in laser treatment. It is a direct consequence of physical phenomena such as heating, melting and rapidly cooling involved in the laser processing resulting in changes in structure of textured surface.

The melted silicon residue and damages significantly reduce solar cells performance (Table 1). Therefore, the sequence of manufacturing steps was designed to remove laser-induced damaged layer. Experiments showed that the distorted layer was etched off much faster compared to base crystalline silicon.

Table 1 shows a comparison of main electrical properties of manufactured solar cells comprising: short circuit current (I_{SC}), open circuit voltage (V_{OC}), fill factor (FF) and efficiency (E_{ff}). After texturing, etching was performed and parameters for the cells with different thickness of removed distorted layer are reported. Additionally, the parameters of the cell without texture and a cell without etching step removing laser-induced damaged layer after texturing are also enclosed for comparison.

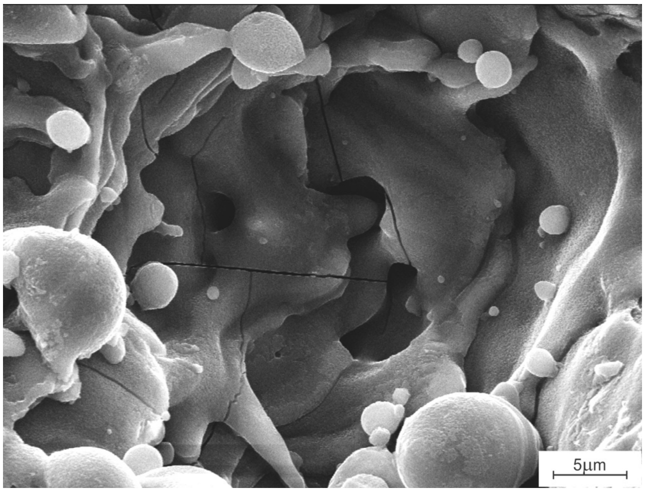

Fig. 2. SEM micrograph of textured surface with microcracks resulting from laser treatment

As it can be seen, cell without laser damage removal shows drastically low conversion efficiency. Furthermore, results demonstrate that the thicker is the removed damaged layer the better obtained electrical properties. However, it can be observed that if the removed layer is too thick the cell performance starts to decrease. It is related to the fact that etching causes the texture to flatten out, reducing its optical effectiveness. Consequently, etching step after texturing has to be a trade-off between improvement of electrical and deterioration of optical properties of the cell.

4. Conclusions

Laser texturing has been shown to have great potential as far as its implementation into industrial manufacturing process of solar cells is concerned. However, it should be emphasised that it has also some drawbacks. The performed experiments revealed the existence of laser-induced damaged layer on the top surface of the processed material. Therefore, chemical etching has to be performed to remove the melted silicon residues and laser induced defects prior to successive technological steps. It appeared that etching by means of potassium alkali made it possible to increase

Table 1.
The parameters current-voltage characteristic solar cell with and without laser texturisation

No.	Solar cell	Thickness of removing layer from surface	I_{SC} [mA]	V_{OC} [mV]	FF	E_{ff} [%]
1.	Without texturisation	-	630	552	0.74	10.2
2.	With texturisation	-	305	340	0.59	2.4
3.	With texturisation and removing laser damage	20 μm	561	525	0.74	8.7
4.		40 μm	720	578	0.76	12.6
5.		60 μm	659	561	0.73	10.7
6.		80 μm	645	578	0.66	9.9

cell efficiency by 10.2% in comparison with cells without damage removal. Laser textured cells reached efficiency of 2.4% higher compared to untextured (reference) cells. Furthermore, it should be pointed out that patterns produced by laser treatment in the surface texture can easily be implemented without any additional masking.

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