OPTICAL PROPERTIES OF "BLACK SILICON" FOR SOLAR CELLS APPLICATION FORMED BY LASER RADIATION

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Abstract

In our recent work we have elaborated a new laser method for formation of "black silicon" consisting of micro-cones using Si substrate with or without Ni catalyst. In this paper, we continue to study of structural, optical and chemical properties of the obtained structure. Reflection index of structure depends on shape and height of micro-cone, it means depends on Nd:YAG laser intensity and number of laser pulses. SEM-EDX and photoluminescence methods were used to investigate the "black silicon" structures surface morphology, chemical analysis and optical properties.
Keywords: *Black Si, reflection, absorption, laser, micro cone*

Introduction

"Black silicon" [1] is a material, which can absorb incident light by approximately 98 %. Usually "black silicon" consists of cone like structures. In array of such micro cones light is repeatedly reflected between the spikes and absorbed almost completely [1]. From the certain angle this structure appears to be completely black to the naked eye. "Black silicon" is an excellent material for solar cells [2]. Solar cells with "black silicon" structure are proved to be more efficient, generating more current than conventional Si solar cells [1]. Also, "black silicon" can be used to make infrared detectors, which is a new application for Si.

The surface micro structuring of ordinary Si by pulsed femtosecond laser induced plasma [3] or chemical vapor deposition with catalytic metal on Si [4] are used for "black silicon" formation.

In our recent work [5], we have shown a new possibility to form "black silicon" on a surface of Si by laser radiation. In this paper, we report study of structural, optical and chemical properties of the obtained structure.

Experiments

The experiments were carried on commercial Si(111) single crystals with Ni catalyst with thicknesses d = 100 nm. Pulsed microsecond Nd:YAG laser for treatment of single crystals with following parameters was used: wavelength λ =1064 nm, pulse duration τ = 150 ms, pulse repetition rate 12.5 Hz, power P = 1.0 MW, laser intensity I=4 MW/cm^2. The threshold intensity of "black silicon" formation is 3.15 MW/cm^2. Samples were treated by laser radiation in scanning mode using motorized 2d manipulator with step 20 μm. All experiments of "black silicon" formation were performed in ambient atmosphere at pressure of 1atm, T = 20°C, and 60% humidity.

Investigations of reflection of obtained "black silicon" plates with micro-cone structure were done with Avantes AvaSpec-2048 UV/VIS/NIR spectrometer in wavelength range 200-1100 nm (spectrometer based on AvaBench-75 symmetrical Czerny-Turner construction with 2048 pixel CCD detector, resolution 1.4 nm).

For samples morphology and chemical analysis Scanning electron microscope with integrated energy dispersive x-ray spectrometer (SEM-EDX) Hitachi S-900 was used. SEM analyses were done in order to evaluate the surface morphology of "black silicon".

Photoluminescence (PL) measurements were performed by equipment Fluorolog-3, using photo detector Hamamatsu R928 and xenon lamp (450 W). The results were registered and computed by standard program „FluorEssence".

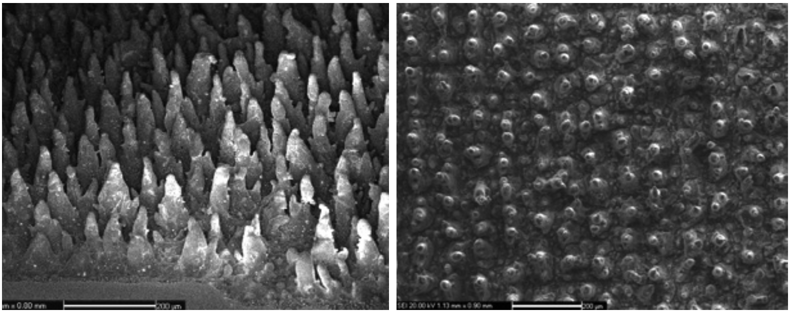
Experiments and Discussion

Treatment of p-Si(111)/Ni structure surface by laser radiation leads to formation of micro-cone like structures, which can be seen in figure 1. The cones assemble in random order without any evident pattern only aligning along with the path of laser beam.

Optical reflection measurements showed that integrated reflection of "black silicon" is by 97.73% lower than for regular Si (Fig 2). For example, in visible region of spectra at 500 nm the reflection from silicon drops approximately from 35% to 1% after micro-cone formation.

The EDX measurements showed a high content of oxygen in the processed samples. This can be explained by Si reaction with oxygen from the air during laser treatment, table 1. From EDX measurements we can conclude that micro-cone surface should contain SiO_2.

A PL spectrum shows a wide band with maximum 430 nm, which corresponds to SiO_2 layer [5] (Fig. 3a). Moreover, detailed investigation of morphology of the structure using SEM has shown formation of nano-wires on the surface of micro-cone (Fig. 3b).



a) b)

Fig. 1 SEM image of Si surface after treatment by laser radiation: a) view from the side, b) view from the top

Table 1. Detected concentration of elements by EDX in samples

Atom %			
C	O	Si	Ni
2.74	54.12	42.19	0.96

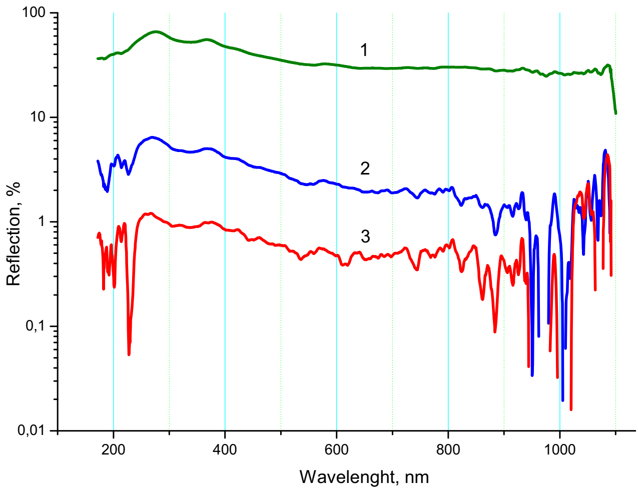
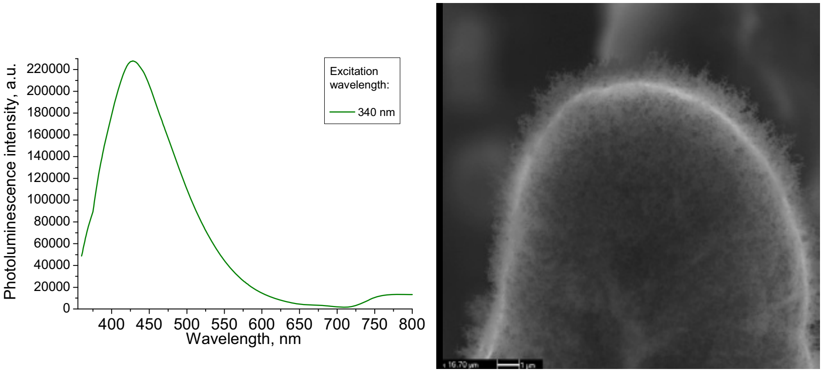


Fig. 2. The reflection spectra of Si: curve 1- Si single crystal; curves 2 and 3 "Black silicon" formed by 1600 and 2000 number of the laser pulses, respectively. Angle of incidence is 90°



a b

Fig. 3. a- PL spectra of “Black silicon” and b – SEM image of Si micro-cones with SiO2 nano-wires.

Conclusion

1. The possibility to form “Black silicon” on the surface of Si and Ni/Si structure using microsecond Nd:YAG laser radiation was shown.

2. Reflection index depends on shape and height of micro-cone, it means depends on Nd:YAG laser intensity and number of laser pulses. The reflection of “black silicon” was detected about 1%.

3. The high concentration of O atoms measured by EDX and PL spectra with maxima 425 nm is explained by formation of SiO_2 nano-wires on the surface of Si micro-cones.

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