INFLUENCE OF LASER RADIATION ON THE PROPERTIES OF P- AND N-TYPE SILICON

G. Mozolevskis[1a], A. Medvid'[1b], P. Onufrijevs[1c], I. Dmytruk[2], I. Pundyk[2]

[1] *Laboratories of Semiconductor Physics, Riga Technical University, Azenes str. 14, Riga, Latvia*

[3] *Physics Faculty, National Taras Shevchenko University of Kyiv, prosp. Glushkova Kyiv 6, 03127 Ukraine*

[a] gatis.mozolevskis@gmail.com, [b]medvids@latnet.lv, [c]onufrijevs@latnet.lv

Abstract

In this paper we show two-stage process of nanocones formation by Nd:YAG laser radiation. It was deomstrated that in first stage after irradiation by laser p-n junction is formed. Kelvin probe force microscopy was used to measure surface potential of p-n junction after irradiation by laser. In second stage nanocones are formed. Photoluminescence spectroscopy was used to measure luminescence and its intensity dependance on intensity of laser radiation.

Keywords: *Photoluminescence, nanocones, p-n junction, silicon, laser* .

Introduction

Nowadays, nanostructures are one of the most investigated objects in semiconductor physics, especially due to Quantum confinement effect [1] in quantum dots (0D), quantum wires (1D) and quantum wells (2D) [2]. A cone possesses the following unique properties: a small cone is a quantum dot – 0D and a long one is a quantum wire – 1D with the gradually decreasing diameter from the base till the top of the cone. Where radii of cone are equal or less than Bohr' radius of electron, exciton or phonon Quantum confinement effect takes place. It is very challanging task to control doping in nanostructures [3]. In this paper we show a new way to form nanocones and control P atoms doping in silicon by Nd:YAG laser irradiation.

The first stage of nanocone formation is the formation of p-n junction in surface layer of silicon crystal. Mada in 1986 first showed a possibility to form a p-n junction by laser radiation [4]. Characteristics of p-n junction, formed by laser radiation in semiconductors, are comparable to the commercial ones, that is why laser technology has a promising future. The main advantages of this technology are low cost and the possibility to locate p-n junction fast and precisely. In this paper we show formation of p-n junctions in Laser induced periodic surface structures (LIPSS) [5].

Experiments

Nanocones were formed on n-Si (111) with SiO_2 layer and on p-Si (100) with indium tin oxide layer by Nd:YAG laser.

For p-n junction formation p-Si (111) wafer with resistivity ρ=10 Ω/cm was used. Sample was irradiated with pulsed nanosecond Nd:YAG laser with wavelength λ =532 nm, pulse duration τ =4,5 ns. Cu was electrochemicaly deposited from $CuSO_4$ solution.

For Kelvin Probe potential measurements Asylum Research MFP-3D atomic force microscope was used.

Results and Discussion

P-n junction is formed by irradiation of Si crystal with Nd:YAG laser. AFM image of surface topography is shown in Fig.1. Irradiation forms Laser induced periodic surface stractures (LIPSS). Period of these structures is the same as wavelength of laser beam. Kelvin Probe force microscopy measuerements show that these "hills" have larger surface potential difference with the tip, but "valleys" have smaller difference, that correspond to n-type and p-type silicon respectively [6]. Potential difference between p- and n-type Si was ~10 mV and period matches the period of periodic structures. Fig. 2. shows lines of electrochemicaly deposited copper on silicon surface. Cu reduction from $CuSO_4$ solution takes place at p-n junction forming lines. According to the model, p-n junction is formed in a semiconductor by strongly absorbed laser radiation due to generation and redistribution of intrinsic point defects (interstitial atoms and vacancies) in temperature gradient field, so called Thermo gradient effect (TGE) [7]. According to the TGE Si interstitials and P atoms drift to the surface, but vacancies and boron impurities to the bulk.

Fig. 3. shows photoluminescence spectra of SiO_2/n-Si structure. Photoluminescence intensity decreases by increasing intensity of laser irradiation ($I_1<I_4$). We propose that decrease of PL intensity is related to nanostructure doping with phosphorus. Electrons supplied by P doping are captured by the dangling bonds, which inactivate the nonradiative recombination processes [2].

Photoluminescence spectra of the ITO/p-Si structures with the maxima visible part of spectra obtained after laser irradiation at intensities of 1.13 MW/cm^2 and 2.83 MW/cm^2 are shown in Fig. 4. Position of the observed photoluminescence maximum compared with the bulk Si shows a significant "blue shift". The maxima of the photoluminescence at visible part of spectra are explained by presence of the Quantum confinement effect on the top of nanocones.

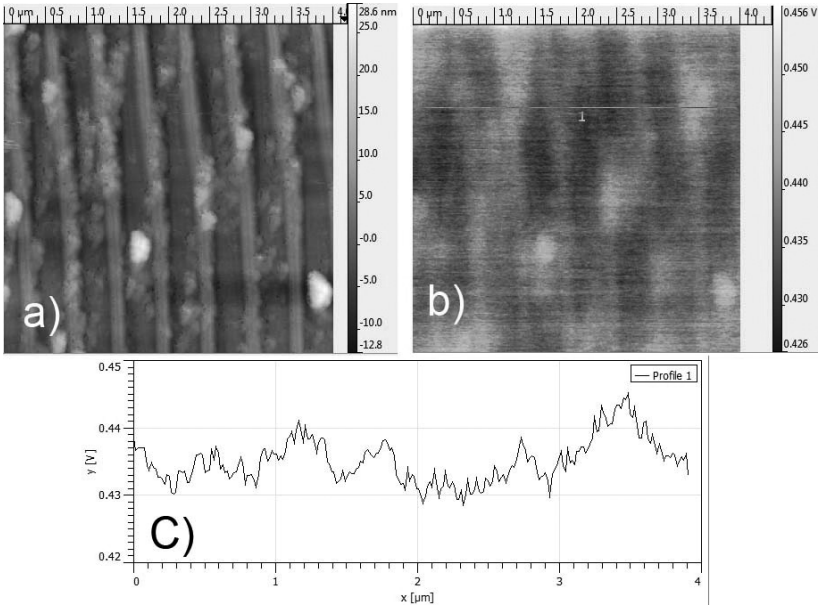

Fig. 1. a) AFM image of Si surface with LIPSS. b) Potential image of a p-Si irradiated with Nd:YAG laser with wavelength λ =532 nm. c) Surface potential relative to the probe surface potential.

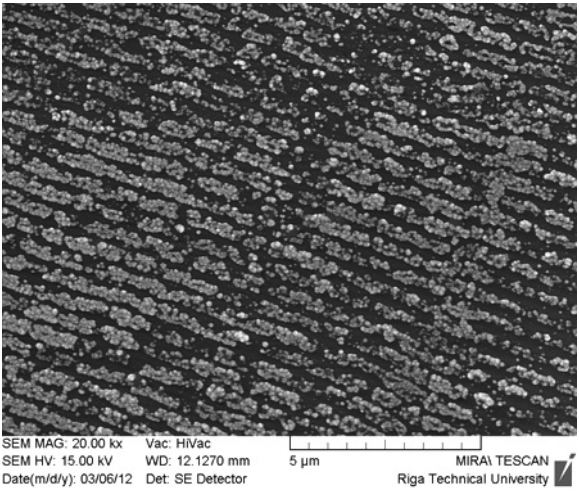

Fig. 2. SEM image of deposited Cu on silicon irradiated by Nd:YAG laser with wavelength λ =532 nm.

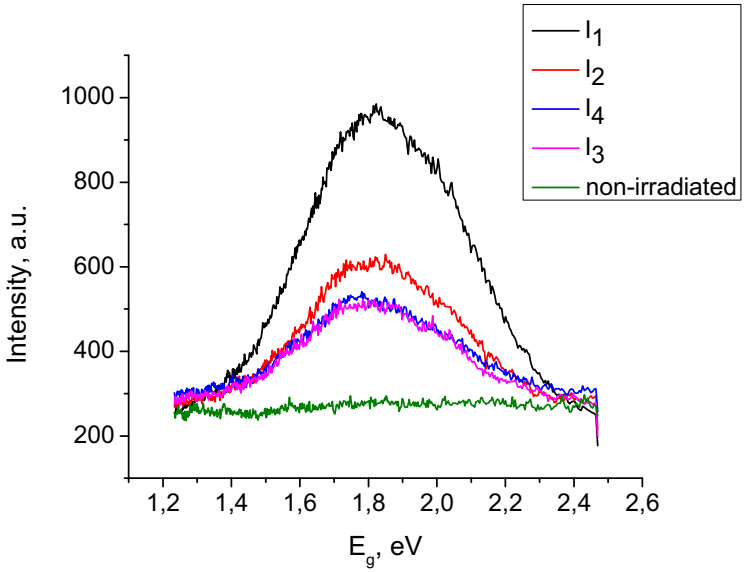

Fig.3. Photoluminescence spectra of SiO_2/n-Si structure: before and after irradiation by the Nd:YAG laser with 4 intensities $I_1<I_2<I_3<I_4$.

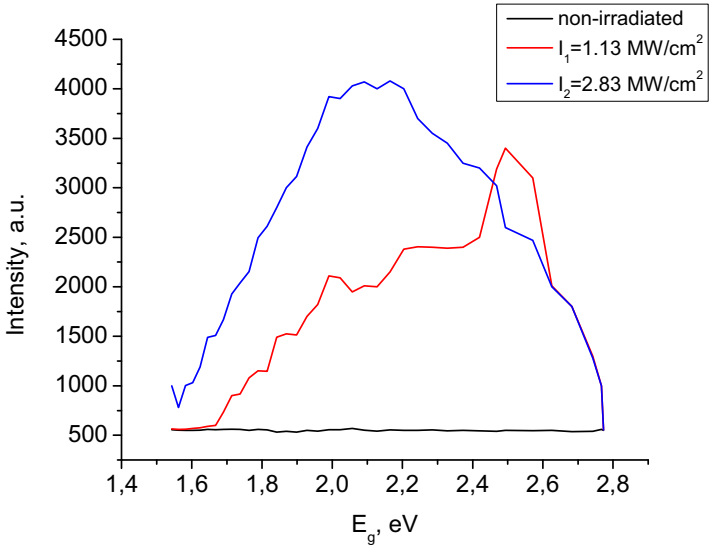

Fig.4. Photoluminescence spectra of ITO/p-Si structure: before and after irradiation by the Nd:YAG laser.

Conclusions

1. We showed a new way to form a p-n junction on the periodic irradiated surface of Si crystal (LIPSS) by Nd:YAG laser.

2. Photoluminescence intensity decreases by increasing intensity of the laser irradiation for n-type silicon. It can be explained by nanostructure P doping, where electrons supplied by P doping are captured by the dangling bonds, which inactivate the nonradiative recombination processes.

3."Blue shift" in p-Si we explain by Quantum confinement effect in nanocones.

References

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