QUANTUM CONFINEMENT EFFECT IN SEMICONDUCTORS, QUASI QDs FORMED BY LASER RADIATION

Artur Medvid'[1], Igor Dmitruk[2], Pavels Onufrijevs[1], Dainis Grabovskis[1] and Iryna Pundyk[2]

[1]*Riga Technical University, 14 Azenes Str., LV-1048, Riga, Lavia*

[2]*Institute of Semiconductor Physics, 45, prospect Nauki, Kyiv, 252028, Ukraine*

Abstract

Nanohills on a surfaces of Ge, Si, GaAs single crystal were formed by YAG:Nd laser. The structure on a surface of Ge is characterized by patterns related to C_{6i} point group symmetry covering all the surface of the sample having translations symmetry. Photoluminescence (PL) from irradiated surfaces of Ge, Si and GaAs is found in visible range of spectrum and it is characterized by blue shift. PL from nanostructures could be explained by Quantum Confinement effect on the top of nanohills. A shift of micro-Raman scattering spectra is a good evidence of this suggestion.

Keywords: nanohills, photoluminescence, micro-Raman, YAG:Nd laser.

Introduction

Nanostructures (NSs) are the most investigated object by scientists in solid state physics, especially quantum confinement effect in quantum dots (QDs), quantum wires (QWs) and quantum wells (QWs) because at these conditions change of conductivity and valence bands structure of a semiconductor takes place.

Since the discovery of intense visible light emission in porous Si [1], a significant amount of effort has been dedicated to the production of nanostructured Si-based systems [2]. The formation of nanoparticles by ion implantation of semiconductor elements in SiO_2 layers thermally grown on crystalline Si is an alternative of special interest because of its compatibility with Si technology in the fabrication process. Several studies have used ion implantation of group IV elements in SiO_2 and heat treatment to obtain nanostructures that exhibit photoluminescence (PL). Red or infrared PL of Si-implanted oxides with post-annealing at different temperatures have been reported by authors [3]. Recently Fernandez et al. [4] have shown a correlation between the PL emission and the mean size and density of Si nanocrystals embedded in SiO_2, suggesting that the mechanism of emission is a fundamental transition located at the Si-SiO_2 interface assisted by local Si-O vibration.

In Ge-implanted SiO_2 layers the formation of Ge nanoparticles was observed upon high thermal annealing, and strong PL in the blue-vioet region was achieved, with the values of excitation and emission energy being independent of the annealing temperature and consequently of the cluster mean size [5]. These results led the authors to exclude quantum confinement effects in Ge nanoclusters and suggest that the PL emission is due to radiative transitions of oxygen deficiency centers located in the interfacial region between the clusters and oxide matrix.

On the other hand, there is the phonon confinement model developed by Campbell and Fauchet for Si nanocrystals [6]. This model is adopted for Ge nanocrystals in paper [7]. It was shown that using simultaneous micro-Raman and photoluminescence allows to determine the origin of the photoluminescence emission band.

Recently, we have shown a new possibility of formation of nanohills on the surface of Ge single crystal by YAG:Nd laser [8].

The aim of this paper is to determine origin of photoluminescence of the Ge, Si, GaAs nanohills formed by laser radiation.

Experimental part

Experiments were performed in ambient atmosphere at pressure 1 atm, T=20°C, and 80% humidity. Radiation from a pulsed YAG:Nd laser (τ_1=15 ns, τ_2=10 ns λ_1=1.06 μm, λ_2=0.532 μm, pulse rate 12.5 Hz, power P=1MW) was directed normally to the surface of single crystal Ge, GaAs and Si wafer samples. The spot of laser beam was scanned over the sample surface by a two-coordinate manipulator in 2μm step. Nanohills are arises on the irradiated surface of Ge which are self-organized into a 2D lattice at laser radiation (LR) intensity up to 28 MW/cm^2.

PL measurements of the irradiated of Ge samples with nanohills were carried out at room temperature using the 488 nm line of a He-Cd laser. The detection system consisted of double grating monochromator and a cooled FEU-62 photomultiplier. Micro-Raman scattering spectra of the irradiated and non-irradiated surfaces of Ge sample were obtained in back scattering configuration with Raman microscope. Spectra were excited with a 514.5 nm Ar+ laser source at room temperature, using a total laser power up to 2 mW. The spectral resolution was 1 cm^{-1} the beam diameter was 1 μm on the sample surface.

Similar measurements were performed on recently obtained Si and GaAs nanohills.

Results and discussion

Visible PL spectra of the irradiated surface of Ge sample are wide and non-symmetric and consist of at list two bands (Fig.1.). The maximum of PL spectra is situated at 1.7 eV. These results present a dramatic effect of PL with energy much higher than the indirect band gap of Ge we connect with quantum confinement effect on the top of nanohills.

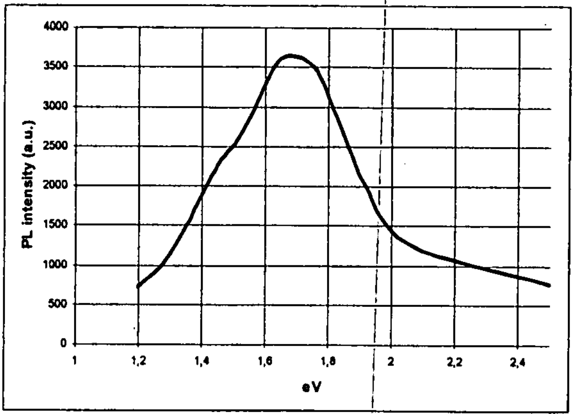

Fig. 1. PL spectra of the irradiated surface of Ge at intensity laser radiation up to 28 MW/cm^2.

An evidence of our suggestion is micro Raman scattering spectra (Fig.2.). Micro-Raman scattering spectra of the irradiated and no irradiated surfaces of Ge sample were obtained in back scattering configuration.

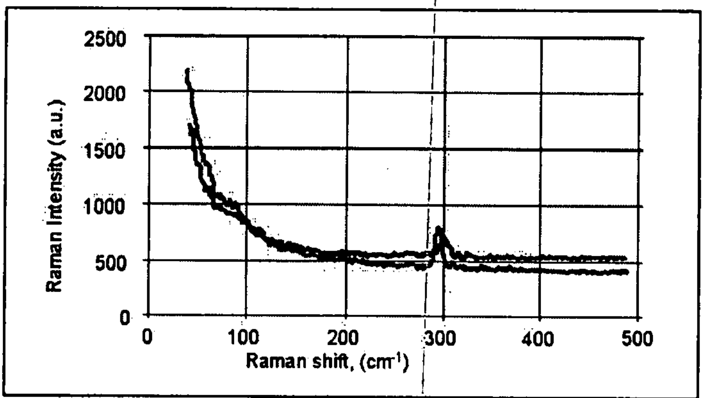

Fig. 2. Micro-Raman spectrum of the nonirradiated (black curve) and of the irradiated (red curve) surfaces by LR of Ge crystal.

Presence of line at 300 cm^{-1} of the no irradiated surface of Ge sample in Raman spectra is attributed to bulk Ge, but the irradiated surface has a line at 294 cm^{-1} is characterised by red shift of the spectrum on 6 cm^{-1}. We have found the red shift in Raman spectrum on 3 cm^{-1}, too. According to the calculated Raman line of peak frequency as a function of size for spherical Ge particles on the top of

nanohills have diameter up to 4 nm and 6nm [9]. Our calculation of band gap shift for nanodots [7] with diameters 4 nm and 6 nm gave the maximums of PL bands at 1.7 eV and 1.15 eV at parameters of Ge: m_e=0.12 m_o and m_h=0.379 m_o for electron and hole effective masses, respectively.
Calculation of QDs diameter using band gap shift for PL spectra from nanodots [9] with the maximums of PL bands at 1.68 eV and 1.39 eV at parameters of Si: m_e=0.26 m_o and m_h=0.49m_o for electron and hole effective masses, respectively, gave diameters of QDs 6.7 nm and 9.5 nm.
Calculation of QDs diameter of GaAS at parameters: E_g=0.2eV, m_e=0.065m_o m_h=0.5m_o gave diameters of QDs 11 nm.

Conclusions

1) Photoluminescence, micro-Raman and AFM scattering spectra study speak in favour of Quantum Confinement effect on the top of nanohills on the surfaces of Ge, Si and GaAs single crystal.
2) The calculation of QDs diameter using band gap shift photoluminescence spectra and peak frequency in micro-Raman spectra as a function of diameter for spherical Ge particles we have found that diameter of nano-balls on the top of nanohills is 4 nm and 6 nm.

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