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Redshifted and Blueshifted Photoluminescence Spectra of InAs/InP Quantum Dots upon Amorphization of Phase Change Material

Nurrul Syafawati Binti Humam, Yu Sato, Motoki Takahashi, Nobuhiro Tsumori, Toshiharu Saiki
Graduate School of Science and Technology, Keio University
nurrul@saiki.elec.keio.ac.jp

ABSTRACT

We have experimentally demonstrated a new method to control the emission energy of semiconductor quantum dots (QDs), which is by applying strain using volume expansion of phase change material (GeSbTe) upon amorphization. The emission energy of QDs was shifted to both higher and lower upon amorphization of phase change material. In this study, we analysed the stress applied on QDs by developing a two-dimensional finite element model. Based on the simulation result, the energy shift is negative at the shallow area beneath the flat part of indenter. On the contrary, the energy shift is positive beneath the edge region of indenter. This result is further clarified by conducting a photoluminescence (PL) spectroscopy of InAs/InP QD sample deposited by a layer of phase change material where PL intensity mapping over amorphous region was performed. Our experimental results agree with the FEM simulation result.

Keywords: Phase change material, volume expansion, quantum dot, energy shift

1. INTRODUCTION

Semiconductor quantum dots (QDs) have shown great promise as efficient single photon emitters and entangled photon sources, making them attractive for quantum communication applications. One of the main challenges for realizing applications is precise control of energy in QDs. The three main approaches to tune emission energy are externally applied magnetic field, electric field and mechanical strain. The existing techniques have not shown precise energy control of individual QDs. Therefore, we have experimentally demonstrated a new approach to precisely control emission energy of QDs by applying a local strain on QDs using volume expansion upon amorphization of phase change material [1]. In the past experiments, we observed both redshift and blueshift of PL peak energy of QDs upon amorphization of phase change material. In this paper, we investigated the stress distribution and energy shift distribution induced by the volume expansion of phase change material by employing finite element (FE) method.

2. SIMULATION

A two-dimensional FE model was developed to investigate the stress distribution in sample. Figure 1 illustrates the geometry of the model. Simulation was simulated assuming the apex of the indenter (a-GST) applies compressive stress on the top of InP surface. An InAs QD was placed 100nm below the surface of the sample along y-axis. The indentation force was chosen to regenerate a 2meV redshift at 100nm beneath the top of InP surface. Energy shift was calculated by employing equation (1), which provides the shift of QD emission energy induced by [001] compression [2].

$$\Delta E_{e-hh} = \frac{a}{Y}(1-2v)(3\sigma^{h}) + \frac{2b}{Y}(1+v)\frac{3}{2}\sigma_{zz}^{u} \qquad (1)$$

Y and v are Young's modulus and Poisson's ratio respectively. σ^{h} and σ_{zz}^{u} are mean stress components and deviatoric stress components respectively. The first term in Equation (1) shows the energy shift due to hydrostatic stress, while the second term in Equation (1) corresponds to the energy shift due to uniaxial stress.

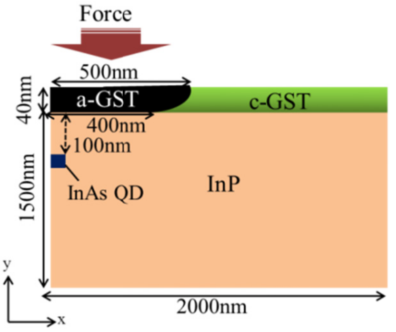

Figure 1 Geometry of model.

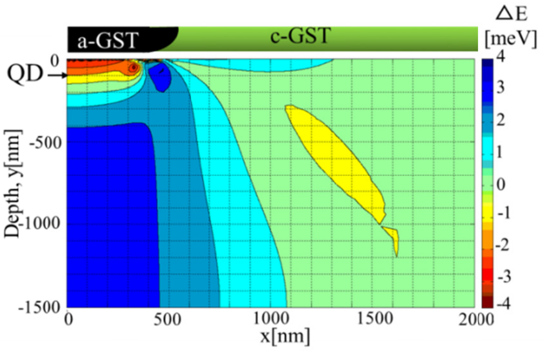

Figure 2 Energy shift distribution in simulation model.

Figure 2 presents the energy shift distribution in model obtained through calculation. In Figure 2, one can observe that the resultant compressive stress on InP causes a redshift of emission energy at the shallow area beneath the flat part of the indenter, and a blueshift of emission energy beneath the edge region of indenter. This simulation result agrees well with our previous experimental results which show both redshift and blueshift upon amorphization of phase change material.

3. EXPERIMENT

A PL spectroscopy of low density InAs/InP QD sample deposited by a layer of GeTe film was performed. All measurements were conducted at low temperature. To create an amorphous mark, a nanosecond Q-switched laser was focused through a microscope objective lense (N.A=0.65) at excitation wavelength 532nm. PL spectra were measured at every 200nm step across a 2μm×2μm area. During PL measurement, QDs were excited using He-Ne laser at excitation wavelength 632.8nm. Shift of PL peak energy of QDs before and after the formation of the amorphous mark were determined at 4 points. Point A and point C are at the edge of the amorphous mark, point B is at the center of the amorphous mark and point D is at the crystalline region.

Based on the experimental results, at point A and point C, a blueshift, 0.4meV of PL peak energy was observed. At point B, the PL peak energy was redshifted as large as 0.8meV. PL peak energy at point D did not exhibit energy shift. These results imply that the PL peak energy of QD at the center of the amorphous mark was redshifted, while the PL peak energy of QDs at the edge region blueshifted.

4. CONCLUSION

We have obtained energy shift distribution in sample by developing a two-dimensional finite element model. Redshift was obtained at the shallow area beneath the flat part of the indenter, and blueshift was exhibited at the edge region of the indenter. We have also experimentally demonstrated the validity of this simulation result by performing a two-dimensional PL intensity mapping over an amorphous mark, which shows good agreement with the simulation result.

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