Improvement of Spatial Resolution of Nano Spectroscopy Imaging Using Phase-Change Mask

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ABSTRACT

An optical mask layer using phase-change material (PCM) has been proposed for photoluminescence spectroscopy and emission energy control of semiconductor single quantum dot with band gap in the near-infrared wavelength region. In this approach, a thin film of crystalline PCM is deposited on a quantum dot sample and amorphous mark which can act as rewritable nanoaperture is formed. In this study, we reduced the size of amorphous aperture and improved the spatial resolution of this method by recrystallizing four points at the outer region of an amorphous aperture and by recrystallizing using an azimuthally polarized doughnut spot.

Key words: GeSbTe, Quantum dot, photoluminescence spectroscopy

1. INTRODUCTION

Semiconductor quantum dots (QDs) emitting in the wavelength of 1.55µm (optical communication wavelength) are remarkable as single photon sources [1]. To clarify and control the optical properties of QD, photoluminescence (PL) spectroscopy of a single QD is essential. The useful method available for single QD PL spectroscopy is near-field scanning optical microscopy (NSOM), which has resolution comparable to the aperture. However, since the aperture is much smaller than emission wavelength of QDs, light collection efficiency is attenuated [2].

As a solution to the low PL collection efficiency, an optical mask layer using phase-change material (PCM) has been shown to be promising for high spatial resolution photoluminescence spectroscopy at near-infrared wavelengths [3]. In this approach, a thin film of crystalline PCM is deposited on a quantum dot sample and amorphous mark is formed. This amorphous mark can act as a rewritable nanoaperture. An amorphous nanoaperture allows high spatial resolution of photoluminescence spectroscopy and high collection efficiency. This is due to the large optical contrast between the crystalline and amorphous phases of the PCM at visible wavelengths and its high transparency at near-infrared wavelengths. Moreover, PCM mask enables emission energy control of QDs by using volume expansion of amorphization [4].

In the previous study [3], an amorphous mark with diameter of approximately 300 nm was made with a microscope objective (NA = 0.80). For measurements at low temperature using a cryostat, however, it is very difficult to use an objective with high NA (>0.8) due to the short working distance. In this study, under restriction to use an objective with NA = 0.65, we formed smaller amorphous apertures by recrystallization at four points around the amorphous aperture and by recrystallization using azimuthally polarized beam.

2. EXPERIMENTS

As a sample investigated, a 40-nm-thick $Ge_2Sb_2Te_5$ film was deposited by sputtering method on InAs/InP self-assembled double-capped QDs. The surface of $Ge_2Sb_2Te_5$ film was covered with a 50-nm-thick SiO_2 layer to prevent from oxidation. The sample was subsequently annealed to form a crystalline phase. An amorphous aperture was formed using picosecond laser pulses (λ=532nm) through microscope objective (NA=0.65). Confocal laser scanning microscopy measurements revealed that the amorphous aperture had a diameter of approximately 500nm. In PL measurements, the sample was cooled down to 10K in a cold-finger cryostat. For PL excitation, a He-Ne laser (λ=632.8nm) was focused onto the amorphous aperture through the same objective. We employed two different methods for recrystallization to reduce the area of amorphous aperture: (i) recrystallization at four points around the amorphous aperture (1µm away from the center) (Fig.1 (a)), (ii) recrystallization using azimuthally polarized beam irradiation (Fig.1 (b)). After these processes, we performed PL measurements.

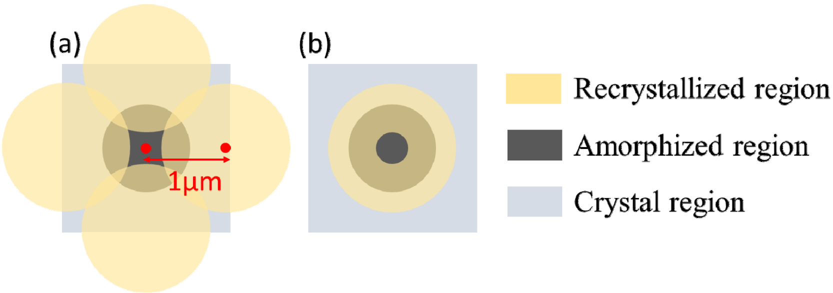

Fig.1 (a) recrystallization at four points (b) recrystallization using azimuthally polarized beam.

3. RESULTS AND DISCUSSION

Figure 2(a) shows PL spectra of the InAs QDs obtained through the amorphous aperture before (blue line) and after (red line) recrystallization at four points. After recrystallization the number of PL peaks decreased to one third, implying that the area of amorphous aperture was reduced to the same degree. Figure 2 (b) compares PL spectra obtained before (blue line) and after (red line) recrystallization with azimuthally polarized beam irradiation. We confirmed a reduction of the number of PL peaks and background emission from a large number of QDs.

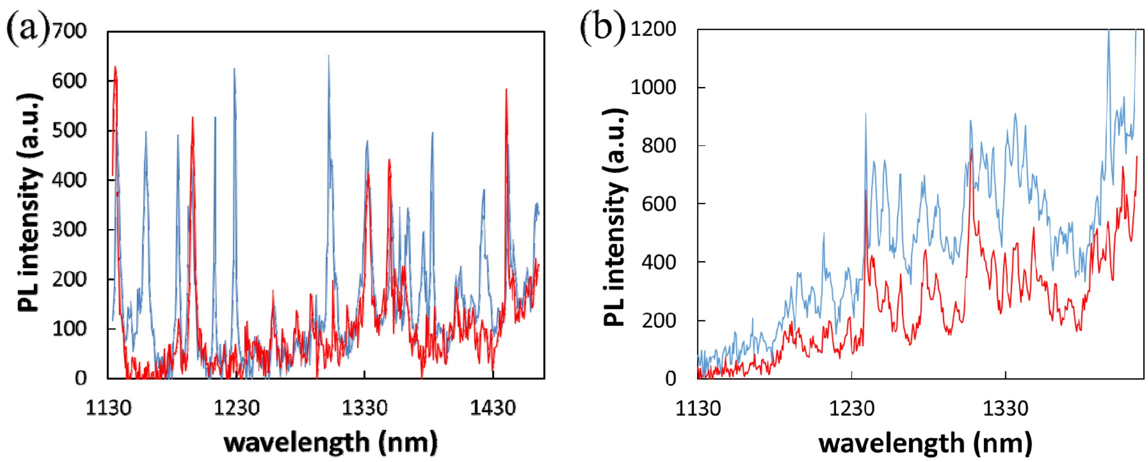

Fig.2 (a) PL spectra of the InAs QDs obtained through the amorphous aperture before (blue line) and after (red line) recrystallization at 4 points. (b) same as (a) but recrystallization using azimuthally polarized beam.

4. CONCLUSION

In conclusion, the present study has demonstrated that we improved the spatial resolution of phase-change mask by reducing the amorphous aperture size using two different methods of recrystallization. By recrystallization using an azimuthally polarized beam, we expect to realize much higher spatial resolution.

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