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Short Communication

Wavelength and polarization variations of InAs/GaAs quantum dots emission at liquid Helium temperature via microphotoluminescence spectroscopy

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ABSTRACT

In this paper, we investigate variation of the wavelength, intensity and polarization of the self-assembled InAs/GaAs quantum dots emission by microphotoluminescence spectroscopy at the liquid helium temperature. The microcavity wafer sample is grown by molecular beam epitaxy (MBE) and chemically etched into the micropillar structure (with elliptical cross section - long and short axis 2μm×1.5μm respectively). Two polarized modes of the micropillar and also quantum dot in the orthogonal axis of long and short diameters are considered and marked by H and V respectively. The analysis of the spectra shows that by increasing temperature, the quantum dot emission wavelength will be shifted towards longer wavelength, and at resonance wavelength of quantum dot and cavity confined modes which are red shifted less than quantum dot, enhancement would happen. Changes in emission wavelength and coupling of four individual quantum nanoparticles in the sample (with different spatial and spectral conditions) were studied in the temperature range ~ 5-50 K. Also, experiments show that the polarization amount and fine structure splitting for different quantum dots are different. The difference can be attributed to the deviations from the symmetric shape of quantum dots and the capping stage during next epitaxial growth. Polarization variability on- and off- resonance by changing temperature is also reported.

Keywords: *Quantum Dot; Microphotoluminescence; Microcavity; Polarization.*

INTRODUCTION

By decreasing matters structure dimensions to nanometer scale, some properties such as optical, electrical, and so on will altered. These properties have some individual ability to utilize technology and scientific application [1-3].

Quantum dots (QDs), which are nanoparticles with dimension from 2 to 10 nanometers, or equivalently diameter of putting nearly 10 to 50 atoms side by side, can be obtained from one semiconductor material which is embedded in another different one. They could restrict bonded electron-hole or in other word excitons movements which are made in the structure. The QDs, like an atom, have quantized energy level and for this reason they called artificial atom [1-2]. Recombination of excitons in the QDs accompanies to extremely sharp radiation, like an atomic one from spectral point of view, which dependent on their size. Since sample might be included enormous amount of nanoparticles with different size, the whole emission spectrum of the sample might be covered to 200 nm wavelengths. This characteristic let utilize different regions of spectrum for verity of applications [4-5]; for instance 1330 and 1550 nm wavelengths use for communication applications. Moreover, emission wavelength of a QD can be changed and tuned by either exerting an electric field or changing temperature, and consequently change of energy bandgap [5-6]. These days, by improving semiconductor growth techniques, high quality QDs in nanocavity can be grown [7].

In this paper, by employing micro-photoluminescence spectroscopy at low temperature, wavelength variation, emission intensity of InAs/GaAs QDs, and their coupling to cylinder microcavity modes are investigated. Also, polarization, and spectral splitting of several QDs are investigated at resonant state and non-resonant state with two perpendicular cylinder microcavity's modes with elliptical cross section. Temperature is controlled by liquid helium current chilling (cryogenic).

EXPERIMENTAL

Spectroscopy and Analysis of QD's emission wavelength

The planar microcavity wafer in this research is grown by molecular beam epitaxy (MBE) at the EPSRC National Centre for III-V Technologies of university of Sheffield. The QDs formed in the middle of cavity during growing while the cavity is restricted from top and down between two distributed Bragg mirror. Then, circle and elliptic patterns transmitted to the surface of wafer by electronic beam lithography, and after several chemical etching stages, microcavity pillar with elliptical and circular cross section were obtained. A typical scanning electron microscopy (SEM) image is shown in Figure 1.

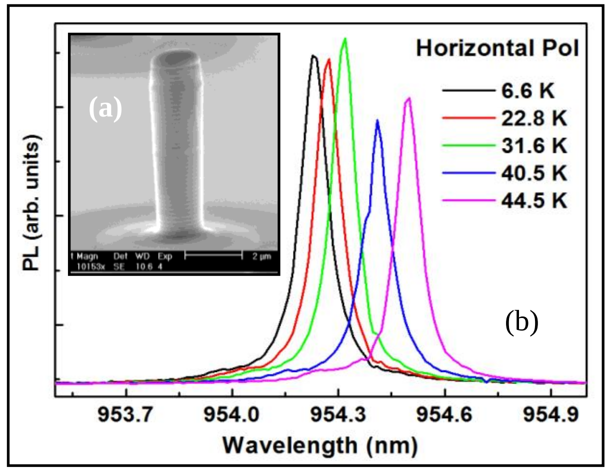

Fig. 1. a) Scanning electron microscopy (SEM) image of a cylindrical microcavity with elliptical cross section which has 2×1.5 major × minor axes diameters. b) Photoluminescence spectrum of H-polarization fundamental mode of the micropillar cavity at different temperatures. Quality factor ($Q = \lambda/\Delta\lambda$) is ~ 12000.

The samples were cooled by a closed cycle of liquid Helium cryogenic system. Then, their temperature controlled by appropriate apparatuses for doing experiments. Micro-photoluminescence setup, including double spectrometer, and other optical instruments which had been located on float optical table, enabled a spectroscopy with high quality spectral resolution. In the Figure 1b, spectra related to the larger diameter, H polarization modes of the cavity are shown which indicates a very small increasing of wavelength by increasing temperature.

Variation of emission wavelength of four QDs is investigated by increasing temperature, that three of them are illustrated in upper graph of Figure 2, which are presented by QD1, QD2, and QD3. Whereas increasing of wavelength respect to temperature for QDs is faster than cavity modes, condition of coupling and amplifying of them caused and appeared. For better comprehension and more clarity, at bottom graph of Figure 2, variation of emission wavelength of these QDs plus QD4, while temperature is increasing, has been showed.

At exciton emission wavelength of QDs, there is a displacement to larger wavelength toward temperature increasing and in consequence decrease of band gap of host matter considered. Slope of these variations is faster at higher temperatures. Coupling between QDs and H mode has taken place at 21.3, and 38.6 Kelvin which are specified by star in crossed points.

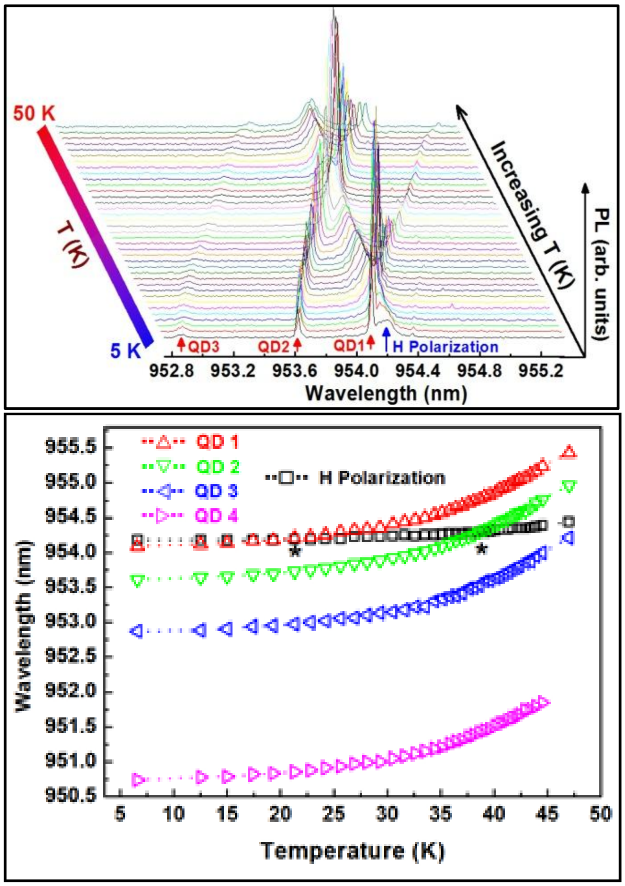

Fig. 2. Top) the graph indicates photoluminescence spectra of three QDs at different temperatures at a waterfall graph which shows the coupling and intensity increasing. Bottom) variation of wavelength of four different QDs as a function of temperature; Coupling of QD1 and QD2 to the H-Polarization fundamental mode of microcavity at 21.3 K and 38.6 K are specified with star.

RESULTS AND DISCUSSION

Investigation of polarization variations of QDs emission in base mod of nanocavity with H and V polarization

Two polarized modes of cylinder nanocavity at direction of larger and smaller diagonal are considered which are named H and V respectively. As it seen from Figure 3, in spite of entirely polarized two orthogonal modes of cavity, emission of QDs has also polarized to different degree. But, some of them have different spectral separation.

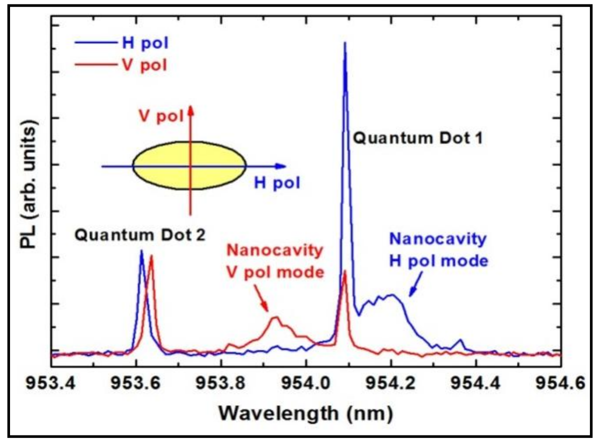

Fig. 3. Spectral polarization splitting of H, V modes of microcavity and QD1, QD2 at 6.6 K. Spectral splitting of QD2 is visible clearly

The spectral polarization splitting, for instance QD2 in Figures 3, 4 (almost 0.03 nanometer at 6.6 K), remain firm at entire temperature variations apart from some small fluctuations. However, QD1 does not have considerable spectral separation at first and this situation preserve with varying of temperature. In terms of self assembled QDs characteristic, the reason of this behaviour attributed to more symmetric shape of QD1, QD3, and QD4.

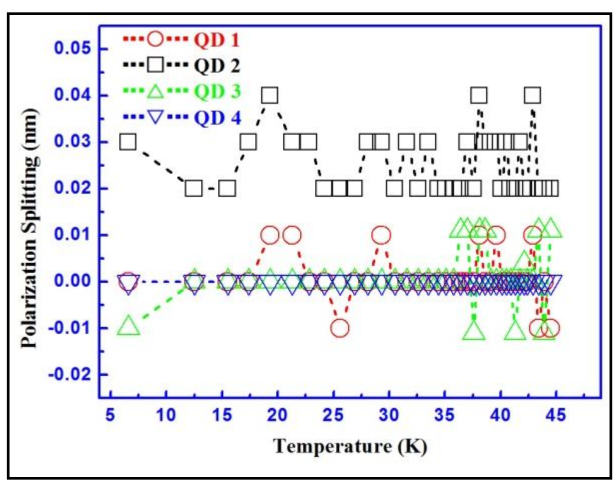

Fig. 4. Polarization splitting of four QDs indicates different values which can be attributed either to axial symmetry or partial expansion of these QDs.

Variations of emission intensity of QD at H and V polarized modes have also measured in the experiments, and shown in the Figure 5. As it can be seen in the Figure 5, QDs in resonance with the H and V polarized fundamental modes of the micropillar cavity emit an amplified emission. The H polarization modes of QDs emission are affected in smaller temperature range in comparison with V polarization mode which can be attributed to higher quality factors of the H modes respect to the V modes.

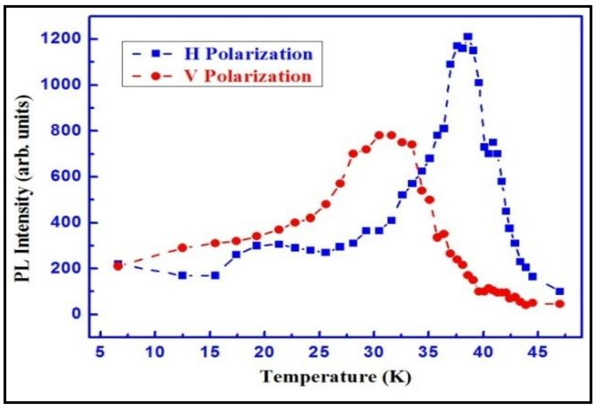

Fig. 5. Variation of emission intensity of a QD as a function of temperature in H and V polarized modes.

CONCLUSION

The cylindrical microcavities, which contain InAs/GaAs QDs, have been grown by molecular beam epitaxy (MBE) with high quality (based on SEM's images and also photoluminescence spectra). Variations of wavelength, intensity, and polarization of QDs emission has been explored by microphotoluminescence spectroscopy at the liquid helium temperature. Spectral analysis showed that with rising up temperature, the emission wavelength of QDs increase faster than cavity modes, and amplifying of them are reachable, investigable, and usable. Polarization and spectral separation of individual QDs are also different. Expansion of QDs dimension in one direction or have an asymmetrical shape respect to cavity axes can explain the difference. Amount of polarization splitting, apart from some small fluctuations, does not have any considerable changes.

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