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Light Emission from Individual Self-Assembled InAs/GaAs Quantum Dots Excited by Tunneling Current Injection

Katsuhiko Yamanaka, Kenji Suzuki, Satomi Ishida and Yasuhiko Arakawa
Institute of Industrial Science, University of Tokyo, 7-22-1 Roppongi, Minato-ku, Tokyo 106, Japan
Phone/Fax: +81-3-3402-6231(2351)/+81-3-3402-5078
E-mail: yama@iis.u-tokyo.ac.jp

1. Introduction

Due to progress in the use of scanning tunneling microscopes (STM), it has been possible to use a STM tip as an excitation source which gives a very high lateral precision in the excitation. The injected minority carriers diffuse and recombine with the majority carriers in the sample. The light emission from this recombination is called scanning tunneling luminescence (STL). Some measurements on various quantum structures have already been reported, such as quantum wells[1], quantum wires[2,3], and recently quantum dots[4]. However, STL measurements with spatial resolution of quantum dots have not been intensively investigated. In this paper, we report on the first observation of spatially resolved STL image and emission spectra of single InAs/GaAs self-assembled quantum dot.

2. Experimental Setup and Samples

The measurement system is an ultra-high-vacuum (UHV) low temperature STM with an optical detection system. The sample can be cooled to about 100K with liquid nitrogen. Since an electron beam gun is also attached, both CL and STL can be measured.

We prepared samples with InAs/GaAs quantum dot structures using the Stranski-Krastanov growth mode by MBE. After the deposition of a 200nm Si-doped n-type GaAs buffer layer, non-doped InAs quantum dots were formed, followed by a growth interrupt of 1 min before an n-type GaAs cap of 20 nm thickness was deposited. The density of Si is 3.2×10^{18} /cm^3 in each doped layer and from AFM and STM investigation, the diameter is 20nm – 30nm and the density was about 5.5×10^{10} /cm^2. Finally, an As passivation layer is formed in order to protect the sample surface from oxidation during transportation in air from MBE to STM. As passivation layer is removed in the UHV STM chamber.

From PL or CL investigations, the emission from GaAs bulk and the InAs quantum dots was observed around 800nm-860nm, 920nm–1300nm, respectively. In STL measurement, we use a low-noise PMT and photon counting method, in order to detect the weak luminescence. However, this PMT can detect light under 1mm wavelength, so we cannot detect all wavelength of the emission from the dots. We also use a high-wavelength pass filter that passes longer than 850nm, to detect only emission from the dots.

3. Results

Figure 1(a) shows the 200x200nm^2 spatially resolved STL image of InAs quantum dot, with bias voltage –10V (hole injection to the n-type sample) and tunneling current 1μA. Brighter regions of the image are those which emits more photons. This 2-dimensional image consists of 11 lines, of length 200nm and interval 20nm, as shown one of them (marked A-B) in Fig. 1(b). We can see a circular region in Fig.1(a) and a clear peak in Fig. 1(b). We can also see some small bright region or sharp peaks in each image, these are noises caused by instability of the STM at high bias voltage and tunneling current.

Figure 2 shows STL spectrum from a bright region with a tunable band-pass filter. The bandwidth of the filter is about 7nm. The scan speed of the filter, the tunneling current, the bias voltage are 1nm/min, 1mA, and -10V, respectively. Only a single peak at 984nm was observed with the FWHM of 6nm, which is limited by the bandwidth of the band-pass filter. Since the wavelength of around 984nm is the region of InAs dot emission, this peak can be attributed a single InAs quantum dot.

By taking the account of the fact that the diameter of the bright region and the average lateral size of InAs quantum dots are about 50nm and 25nm, respectively, the spatial resolution of this system can be estimate to be about 40nm. This resolution is the highest so far obtained as the spatially resolved luminescence images taken by optical nanoprobing techniques such as μ-photoluminescence and near-field photoluminescence. We believe the spatial resolusion is mainly determined by the lateral diffusion of holes injected into a low-temperature grown GaAs capping layer.

4. Conclusion

We measured successful STL image from a single InAs quantum dot with a spatial resolution of 40nm, and also STL spectrum of single quantum dot and obtained a sharp single peak with a FWHM limited by the spectral resolution of measurement system.

References

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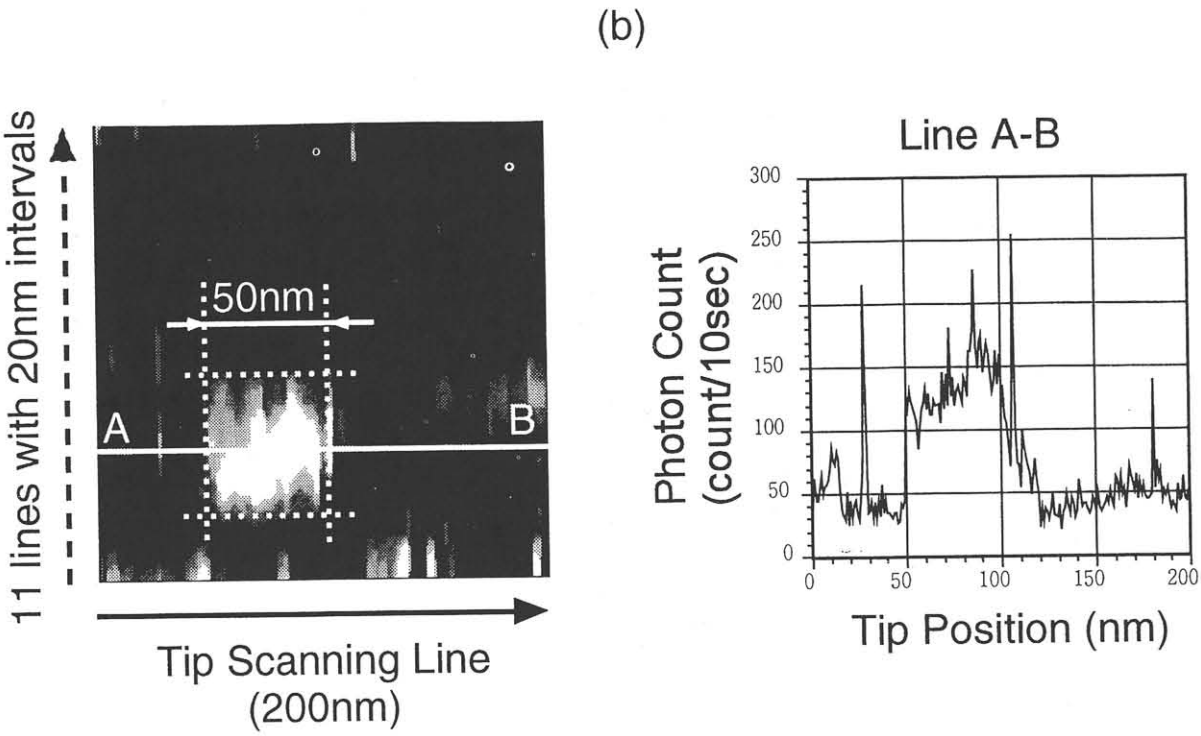

Fig.1 (a) STL Image of InAs quantum dots, with bias voltage –10V and tunneling current 1μA. Brighter region of the image are those which emit more photons. (b) Data from scanning line marked A-B in (a).

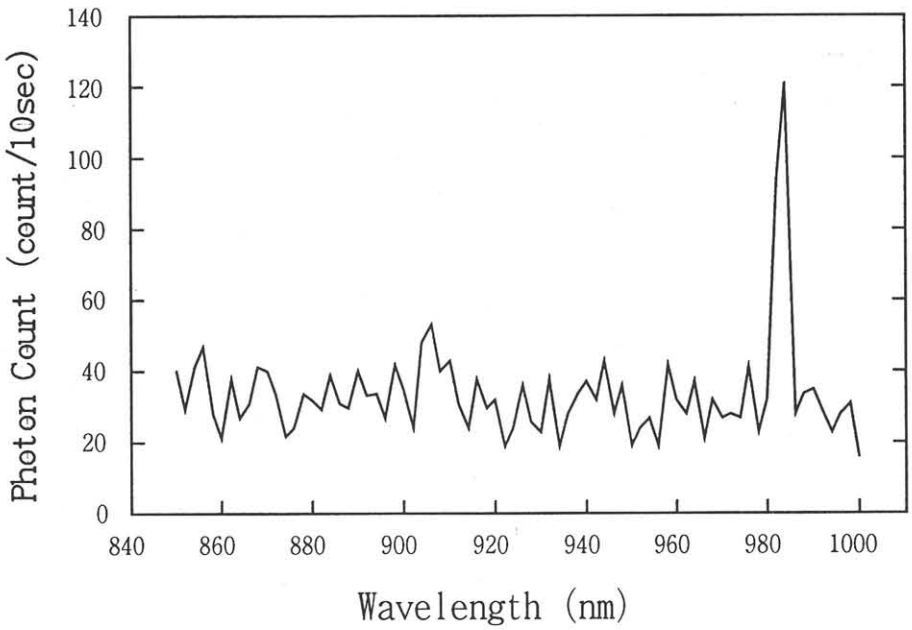

Fig.2 STL spectrum of InAs quantum dot with bias voltage –10V and tunneling current 1μA.