Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 52-53

Invited

Magneto-Optical Study of Single InGaAs Quantum Dot

Y. Toda, K. Suzuki, O. Moriwaki, M. Nishioka and Y. Arakawa
Institute of Industrial Science,
University of Tokyo, 7-22-1 Roppongi Minato-ku, Tokyo 106, Japan.
Email: toda@yari.iis.u-tokyo.ac.jp

1. Introduction

Carrier relaxation in 0-dimensional structures is an important subject of discussion. Experimental results such as resonant photoluminescence (PL) spectra and PL excitation (PLE) spectra have shown that in self-assembled quantum dots (SADs) broad excitation resonances may be attributed either to electronic transitions reflecting the excited state spectrum or to multiphonon resonances [1]. However, these optical studies have been based on measurements of large ensembles of dots, so the results include the effects of inhomogeneous broadening which prevents accurate measurement of the optical properties of dots. Investigation of single dot properties has been accomplished by optical probing techniques with high spatial resolution. Because of the absence of the inhomogeneous broadening effect in a single dot, a narrower linewidth allows for precise measurements of luminescence character. In this work, we performed magneto-PL and PLE spectroscopy of single InGaAs/GaAs SADs using an near-field scanning optical microscope (NSOM).

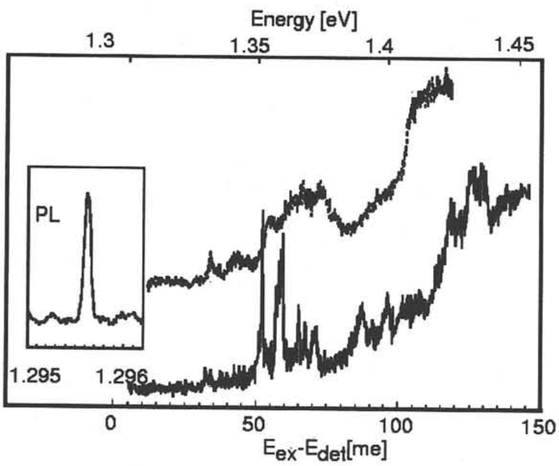

Fig. 1. PLE spectra for an ensemble of dots (top) and a single dot (bottom). The luminescence intensity is plotted as a function of energy difference between the detection (E_{det}) and the laser (E_{ex}) energies.

2. Results and Discussions

A typical magneto-optical luminescence spectrum from a single dot shows fine splittings due to the different spin states [2]. The average value of the energies of the two split peaks show diamagnetic blue shift, which is proportional to B^2. The quantitative analysis of the energy shift shows that for this dot the parabolic coefficient is $3\mu eV/T^2$. The observed diamagnetic shift thus indicates that strong confinement in the lateral direction is achieved in our SAD structures.

Figure 1 compares PLE spectra for different numbers of dots. The upper gray line is the far-field illumination-mode spectrum where the luminescence is collected from thousands of dots. As has been reported by a number of other groups, we also observe PLE peaks whose energy is independent of the detection energy. In our sample, the energy separation of these PLE resonances is estimated to be around. For convenience, we refer to these peaks as 1LO, 2LO, etc. The lower spectrum shows the PLE spectrum of a single dot. The corresponding PL spectrum is shown in the inset of Fig. 1. Although macro-PLE involves a large ensemble of dots, the 1LO peak exhibits as a narrow linewidth as is observed in the single dot PLE spectrum. Therefore 1LO peaks can be observed in single dot PLE only when the detection energy is that of the PL peaks, therefore they are not attributed to non-resonant Raman scattering. Instead, it seems to be reasonable that this feature is a resonant Raman peak, emission of GaAs LO phonon leaving an out-going energy resonant with the ground state of dot. In contrast to the sharp 1 LO peak, the 2 LO peak in the macro-PLE shows broad features involving some intense peaks. In this energy range the single dot PLE spectrum shows a number of sharp resonance lines. This indicates that the resonances observed in the ensemble measurement involves the inhomogeneous in their size, strain, and composition. In fact, the number, intensity, and width of these resonance lines in single dot PLE spectra change slightly from one to another. However some of the resonances are reproducible, and those correspond to the intense peaks in macro-PLE.

In order to investigate these 2LO features further, we performed magneto-PLE measurements on single dots. The inset of Fig. 2 (a) shows PLE spectra for detection energies in the different split branches of a PL peak at 8T. We could not observe remarkable magnetic field dependencies as reported by Wilson, et. al [3]. However, we observe small changes in the splittings as shown in Fig. 2 (b). Moreover, the diamagnetic shift shows different features in each resonance line. There exist dots which show a red-shift with increasing magnetic field. While the confinement structures are different, similar behavior is observed in the exciton localized in a thin quantum-well [4]. In the present data it is difficult to identify the origin of each PLE peak. We suppose that the different PLE structures are due to the various excited states of each dot and/or multiple phonon relaxation processes. Due to the strong lateral confinement, significant variation of the excited states energies is expected in SAD structures. Moreover, there is a strong variation even in the single phonon features. We tentatively interpret the large variation in the observed structures to be due to a convolution of these two reasons.

In summary, single dot PL and PLE measurements in magnetic field have been performed to study relaxation processes in InGaAs SAD structures. The PLE spectra show the correspondence between ensemble and single dot spectra. The magneto-optical spectroscopy of single dots allows for the study of the observed fine resonances in quantum dots.

Acknowledgements

The authors thank S. Mononobe and M. Ohtsu, Kanagawa Academy of Science and Technology for their kind arrangement on the fiber probe.

References

1. R. Heitz, M. Veit, N. N. Ledentsov, A. Hoffmann, D. Bimberg, V. M. Ustinov, P. S. Kop'ev, and Zh. I. Alferov, Phys. Rev. B 56, 10435 (1997)
2. Y. Toda, S. Shinomori, K. Suzuki, Y. Arakawa, Appl. Phys. Lett., Appl. Phys. Lett. 73, 517 (1998)
3. L. R. Wilson, D. J. Mowbray, M. S. Skolnick, L. Harris, M. Morifuji, I. A. Larkin, M. J. Steer, and M. Hopkinson, Phys. Rev. B 57, R2073 (1998)
4. W. Heller, and U. Bockelmann, Phys. Rev. B 55, 4871 (1997)

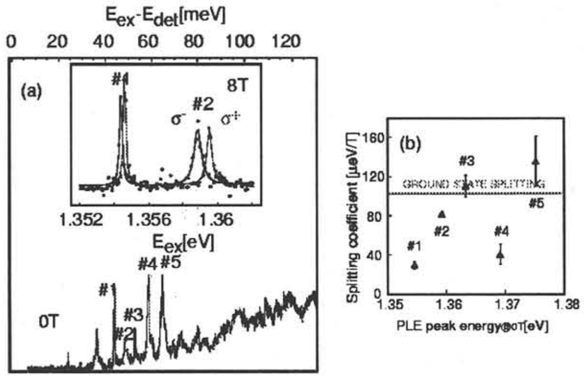

Fig. 2. (a) PLE spectra from a single dot at 0T and 8T (inset). Typical two resonant peaks are plotted as a function of excitation energy. (b) Corresponding splitting coefficients of the resonance peaks observed in (a).