Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 236-237

Excitonic Luminescence from Self-Organized Quantum Dots of CdTe Grown by Molecular Beam Epitaxy

Shinji Kuroda, Yoshikazu Terai and Kôki Takita

Institute of Materials Science, University of Tsukuba, Tsukuba, Ibaraki 305-8573, JAPAN
phone : +81-298-53-5365 fax : +81-298-55-7440 e-mail : kuroda@ims.tsukuba.ac.jp

Tsuyoshi Okuno[1] and Yasuaki Masumoto[1]

[1]*Institute of Physics, University of Tsukuba, Tsukuba, Ibaraki 305-8571, JAPAN*

1. Introduction

Semiconductor quantum dots (QDs) attract attention in the viewpoint of the application for devices such as semiconductor lasers and single-electron transistors. Self-organization in the epitaxial growth onto a lattice-mismatched material is known to be a useful technique to form QDs. Up to the present, self-organized QDs of III-V semiconductors have been extensively studied[1]. On the other hand, the study of self-organized QDs of II-VI compounds is just at the beginning, as only recently have there been several reports on CdSe QDs on ZnSe[2–4]. From an applicational point of view, II-VI QDs are expected especially for efficient semiconductor lasers, with an advantage of shorter wavelengths and higher excitonic binding energy.

In this study, we investigated optical properties of self-organized QDs of CdTe on ZnTe (100) surface by molecular beam epitaxy. In this combination of materials, the lattice mismatch ratio $\Delta a/a = +6.2\,\%$ is close to that of InAs-on-GaAs (+7.2 %). Therefore the formation of self-organized QDs in a similar mechanism can be expected.

2. Sample Growth

The growth of CdTe on ZnTe(100) surface was performed by an alternate deposition of Cd and Te fluxes in an MBE chamber. When the CdTe deposition amounted to about 2.5 monolayers (MLs), the RHEED image showed a transformation to a spotty pattern, which is considered to be the onset of the Stranski-Krastonow island growth. Results of *ex-situ* atomic force microscope (AFM) measurements coincide with the above RHEED observation; the AFM image showed that the surface was almost flat at a 2 ML thickness of CdTe deposited, while on the other hand, dots were formed at a 3.5 ML thickness. Dots were cone-shaped with typical diameters of 20 ± 2 nm and heights of 2.7 ± 0.3 nm and the density was 8×10^{10} cm^{-2}. It was found that CdTe dots once formed were stable; the size and the density did not change in the atmosphere at room temperature for a few months. This is a different case from CdSe QDs on ZnSe, in which a remarkable ripening was observed[2,4].

3. Optical Properties

PL measurements were performed on the QDs samples with a ZnTe capping layer. An intensive and relatively narrow PL line due to the excitonic recombination was observed at 2.2 eV (full width half maximum 24 meV) at 4.2 K and it survived up to room temperature. Figure 1 shows the temperature dependence of the integrated PL intensity of the QDs sample (referred to as sample (c)), together with two SQW samples as reference which only have 1 ML CdTe (sample (a)) and 2 ML CdTe (sample (b)) of wetting layers, respectively. As shown in the figure, the PL intensity of sample (c) was higher than SQW samples (a), (b) by several orders at low temperatures. A quenching of the intensity at high temperatures was fitted to the equation $I = I_0/\{1 + C\exp(-E_A/k_BT)\}$, assuming the thermal escape of carriers to non-radiative recombination path with an activation energy E_A. From the fitting, we obtained $E_A = 59$ meV for samples (a), (b) and 110 meV for sample (c). This enhancement of the activation energy in QDs by a factor of two is attributed to an additional confinement of excitons in QDs[5].

In time-resolved PL measurements, the decay time of the luminescence was measured with the excitation above the band-gap of ZnTe using frequency-doubled Ti-sapphire laser. Figure 2 shows the temperature dependence of the decay

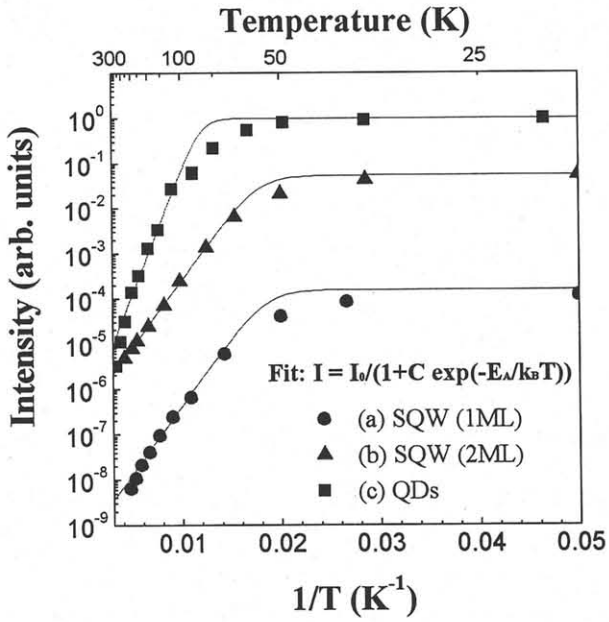

Figure 1 The temperature dependence of the integrated PL intensity in SQW samples (a), (b) and QDs sample (c). The solid lines are the results of fitting to the equation inside the figure.

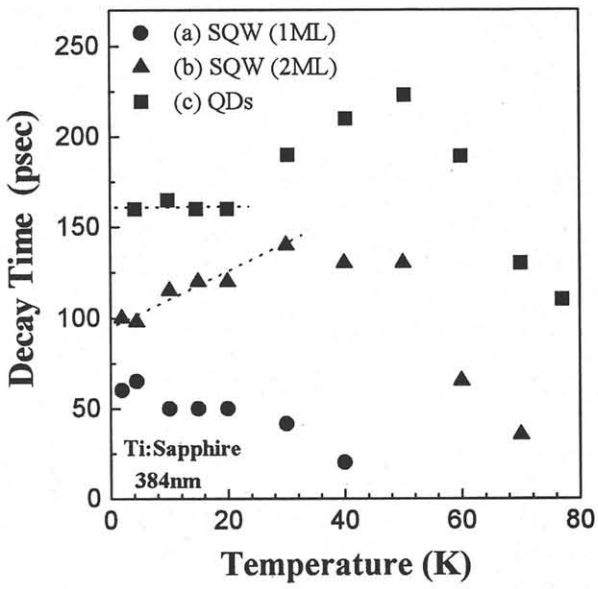

Figure 2 PL decay times as a function of temperature in samples (a) $\sim$ (c). The dotted lines are guides to the eye.

time. The behavior of the decay time in sample (b) is considered to be typical of the two-dimensional excitons; that is, a linear increase of the decay time at low temperatures is attributed to the thermal distribution of dark excitons away from the zone center[6]. On the other hand, the decay time of sample (c) exhibits a different behavior; the decay time is almost constant up to 20 K and then increases linearly with the further increase of temperature. This temperature independent region reflects the δ-function-like density of state in the zero-dimensional confinement[6,7].

4. Conclusions

We have succeeded in the fabrication of self-organized QDs of CdTe on ZnTe (100) surfaces. AFM measurements revealed that dots were cone-shaped with typical diameters $D = 20 \pm 2$ nm and heights $h = 2.7 \pm 0.3$ nm. In PL measurement, an intensive luminescence due to the excitonic recombination in QDs was observed at 2.2 eV at 4.2 K. The temperature dependence of the integrated PL intensity indicated that the activation energy for the thermal escape of carriers in QDs was enhanced by a factor of two compared with SQWs, due to an additional confinement in QDs. In time-resolved PL measurements, the decay time was constant at low temperatures, which reflects the discrete density of state of zero-dimensional excitons in QDs. From applicational point of view, the morphological stability and high PL efficiency in the green spectrum region in CdTe QDs exhibit a potentiality of this material for quantum dot lasers.

Acknowledgements

We would like to thank Prof. Kawabe for AFM measurements. This work is partially supported by the Grant-in-Aids from the Ministry of Education, Science, Sports and Culture.

References

1. R. Nötzel, Semicond. Sci. Technol. **11** (1996) 1365.
2. S. H. Xin, P. D. Wang, A. Yin, C. Kim, M. Dobrowolska, J. L. Merz and J. K. Furdyna, Appl. Phys. Lett. **69** (1996) 3884.
3. H.-C. Ko, D.-C. Park, Y. Kawakami, Sz. Fujita and Sg. Fujita, Appl. Phys. Lett. **70** (1997) 3278.
4. I. Suemune, T. Tawara, T. Saitoh and K. Uesugi, Appl. Phys. Lett. **71** (1997) 3886.
5. G. Wang, S. Fafard, D. Leonard, J. E. Bowers, J. L. Merz and P. M. Petroff, Appl. Phys. Lett. **64** (1994) 2815.
6. W. Yang, R. R. Lowe-Webb, H. Lee and P. C. Sercel, Phys. Rev. B **56** (1997) 13314.
7. H. Yu, S. Lycett, C. Roberts and R. Murray, Appl. Phys. Lett. **69** (1996) 4087.