Extended Abstracts of the 2008 International Conference on Solid State Devices and Materials, Tsukuba, 2008, pp. 796-797

H-6-2

One-dimensional and Two-dimensional Spectral Diffusion in InP/InAs/InP Core-Multishell Nanowires

Ken Goto[1], Michio Ikezawa[1], Shinichi Tomimoto[1], Bipul Pal[1], Yasuaki Masumoto[1], Premila Mohan[2], Junichi Motohisa[2] and Takashi Fukui[2]

[1]Institute of Physics, University of Tsukuba
1-1-1, Tennodai, Tsukuba, Ibaraki, 305-8571, Japan
Phone: +81-29-853-4350 E-mail: s0630389@ipe.tsukuba.ac.jp
[2]Graduate School of Information Science and Technology, Hokkaido University
Kita 14, Nishi 9, Kita-ku, Sapporo, Hokkaido, 060-0814, Japan

1. Introduction

Core-multishell nanowire (CMS-NW) is a new class of nanowire containing quantum well and wire structures in it. It shows bright luminecsence, applicable for photonics devices [1]. Core-multishell nanowire has advantages over the carbon nanotube in the selectivity of the composition materials and in the formation of heterojunctions. Much effort has been innovated of the growth and fabrication of such structures. However, there are very few information about the electronic structure and optical properties of these new class of structures.

In this paper, we report our optical study of InP/InAs/InP CMS-NWs. It consists of an ultrathin InAs layer, and an InP core and an InP outer shell with the higher band-gap. They are in a wurtzite structure with cross-sectional hexagonal symmetry and translational symmetry along the wire [2]. The InAs layer at the side of the CMS-NW acts as a strained quantum well (QW), and the InAs at the corner of the sample acts as a strained quantum wire (QWR). Photoluminescence (PL) and time-resolved PL (TR-PL) spectroscopy were made for the sample. PL spectrum has multiple peaks due to monolayer (ML) scale variation of InAs layer. A blue shift of the PL peaks with cube-root dependence on the excitation power is explained by the band bending in the type-II configuration. Transient processes of excitons in InP/InAs/InP CMS-NWs were studied by TR-PL measurements. We examined the TR-PL in three regions of time, hundred picoseconds by using up-conversion technique, nanoseconds by using a streak-camera and hundred nanoseconds by using time-correlated single photon counting (TCSPC) technique, respectively. Spectral diffusion in both QW and QWR of the InP/InAs/InP CMS-NW were observed.

2. Sample and Experiments

Sample

Our sample is a vertically oriented InP/InAs/InP CMN arrays with 400nm period, uniformly grown by using selective area metalorganic vapor phase epitaxy. Further details of the sample structure and growth procedure are given in Ref. [2]. Schematic vertical and horizontal cross-sections of the CMS-NW are shown in Fig. 1(a).

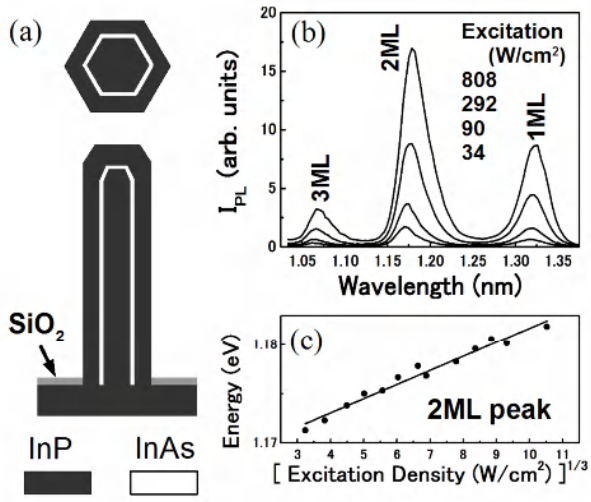

Fig. 1: (a) Schematic vertical and horizontal cross-sections of the CMS-NW. (b) PL spectra at 4 excitation densities. (c) Excitation density dependence of the PL peak energy.

Experiments

The PL spectra from this sample were measured at 2 K in a superfluid helium cryostat. A tunable CW Ti:Sapphire laser for excitation below the InP barrier energy was used. PL signal was dispersed in a double monochromator, and detected by means of a liquid N_2-cooled InGaAsP photomultiplier tube, and a photon counter. The TR-PL spectra were measured by using a liquid helium continuous flow optical cryostat. The up-conversion and streak-camera measurements were made by using a picosecond Ti:Sapphire laser with 82 MHz repetition rate. For the TCSPC measurements, we reduced the laser repetition rate to 820kHz by using a pulse picker to probe a longer time-span TR-PL.

3. Results and discussion

PL measurements

Typical PL spectra of the sample are shown in Fig. 1(b). Multiple peaks coming from one ML variation of InAs layer thickness in PL spectra appear. Further, the excitation power dependence of PL spectra for 4 excitation densities are plotted in Fig. 1(b). Blue shift of each peak is observed clearly. The peak energy position increases in proportion to

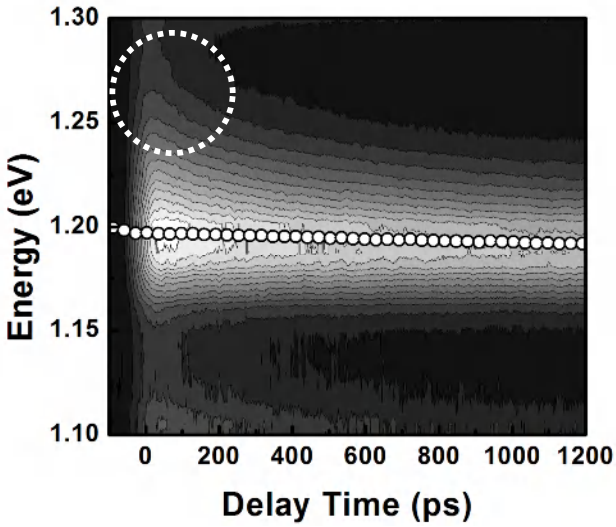

Fig. 2: Contour map of TR-PL spectra. Dotted plots are spectral weight of the peak at each time.

the third root of the excitation density, as shown in Fig. 3(c). This blue shift is caused by the band-bending effect in a type-II QWs system [3].

TR-PL measurements

Firstly, we measured rise time of PL by using the up-conversion technique with time resolution of 0.3 picoseconds. The PL rise time at the lower excitation power is about 50 picoseconds. PL rise time becomes shorter with the increase of excitation power.

The PL decay is measured for nanoseconds by using a synchroscan infrared streak-camera. We measured the PL decay around the 1–3ML PL peak. Figure 2 is contour map of these TR-PL spectra. The fast decay appears at higher energy side of the PL peak (dashed circle). We consider that the fast decay is caused by a relaxation of the band-bending effect. We estimated density of photo-excited carriers and the blue shift, and found that the density was 2.1×10^{10} cm^{-2} and the blue shift appeared at the higher energy side of the PL peak by 130 meV, in good agreement with the experiment.

Spectral diffusion, furthermore, was observed in figure 2 (dotted plot). We consider that inhomogeneous broadening due to well width fluctuation and inhomogeneous strain in our sample causes spectra diffusion. Photo-excited carriers move to the lower-energy nearly positions and moves in the CMS-NW. It shows that the spectral weight is shifted towards the lower energy as time evolves. In fig. 2, the energy shift are found to be about 5 meV. To observe this phenomenon in a longer time-span, we measured TR-PL spectra by using the TCSPC technique.

Figure 3 shows the spectral diffusion in 10-nanosecond time domain. A kink appears at 1 ns. While fast and large energy shifts are observed in the time region less than 1 ns, slow and small energy shifts appeared in the time region more than 1 ns. The difference between two spectral diffusion rates depends on dimensions of the region where

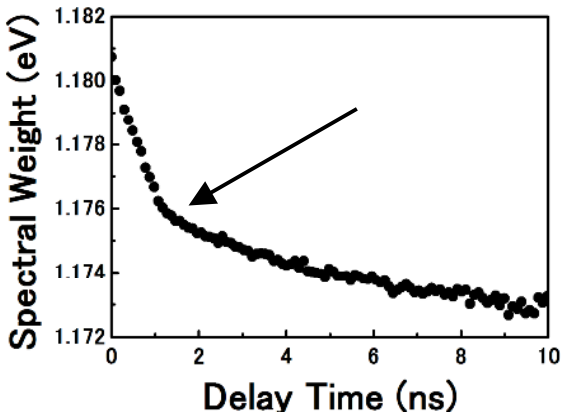

Fig. 3: Spectral diffusion in 10-nanoseconds time domain. A kink is appeared, as is shown by an arrow.

photo-excited carriers are confined. The carriers, confined in the QW area at the side of the CMS-NW, can move easily in two-dimension plane. On the other hand, the carriers confined in the QWR part at the corner of the CMS-NW cannot move so easily, in comparison with the carriers confined in the QW area. This is due to the fact that the carriers can move only in one-dimension region and that the carriers hardly find the lower energy nearly positions in the wire. Consequently, a kink appears as shown in Fig. 3.

We calculated energy levels of both QW and QWR by using finite element method, and found that the difference of energy level between QW and QWR was 5 meV. This value exactly agrees with the energy shift from the beginning to the kink point. Accordingly, the carriers in the QW area move toward the QWR region showing 5 meV spectral diffusion.

4. Conclusions

In conclusion, PL and TR-PL from CMS-NW were measured. PL shows multiple peaks due to the InAs layer thickness. PL peaks shift to the higher energy with a cube-root dependence on the excitation density. It indicates that the CMS-NW has the Type-II band alignment. TR-PL was measured for three time regions. A relaxation of band-bending effect causes fast PL decay. Spectral diffusions showed two stages depending on two-dimension and one dimension. The photo-excited carriers in the CMS-NW move from the well region to the wire region.

References

[1] F. Qian, S. Gradecak, Y. Li, C. Y. Wen, and C. M. Lieber, Nano Letters **5** (2005) 2287.

[2] P. Mohan, J. Motohisa, and T. Fukui, Appl. Phys. Lett. **88** (2007) 133105.

[3] T. T. Chen, C. L. Cheng, Y. F. Chen, F. Y. Chang, H. H. Lin, C.–T. Wu, and C.–H. Chen, Phys. Rev. B **75** (2007) 033310.