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High bandwidth semiconductor gain material for photonic active devices with a stacked quantum dots structure grown by strain-compensation technique

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We have developed a new scheme to fabricate QDs in order to expand the potential bandwidths of QD active regions. The full-width at half maximum of photoluminescence of QDs is as high as 240 nm.

Quite a few attentions have been paid on photonic active devices with optical gain of high bandwidths. Representative in such technical areas are broadband semiconductor laser amplifiers (SOAs) [1,2] and wavelength tunable semiconductor lasers. In order to extend performances of those devices, it is indispensable to develop new semiconductor materials of higher bandwidths and more desired features.

Quantum dots (QD) structures based on III-V compound semiconductors are one of the most promising materials for this purpose [1]. In addition to its inherent broadband nature, incorporation of QD structures into active devices are expected to lead to their unique and attractive properties in device performances, which have been partially confirmed experimentally [3-5]. However, there are rooms to improve in the present methods to enlarge a variety in the QD sizes, which are directly related to spectral widths of photo-emission bands. This is because the variety is restricted by delicate balance between the surface energy and strain energy during epitaxial growths in the S-K mode.

To overcome this restriction and expand the potential bandwidths of QD active regions, we have developed a new scheme, in which a deposition condition of QD can be varied during a molecular beam epitaxy (MBE) growth. Similarly to the introduction of varied thicknesses in multiple quantum well structures, which Kuroda et al. have already applied to SOA devices [2], we have intentionally changed QD size distributions in a layer-by-layer manner through a delicate control of an amount of QD material supply and its resultant generation of strain [6]: one of the most important issues in the scheme is to control strains of QD layers and make those compensated while any degradation of crystal quality is prevented. In the experiments, the strain and composition of InGaAlAs spacer layers for InAs QDs have been accurately controlled so that their lattice constant is slightly smaller than that of the substrate. This condition prevents accumulation of strain, and consequently generation of defects or dislocations, during the stack of QDs. We have also modulated the strain given by spacer layers so as to vary the acceptable amount of InAs supply and, eventually, the QD size distribution.

MBE samples were prepared on InP(311)B substrates. The substrates were heated up to 500°C, and then a 150-nm-thick lattice-matched $In_{0.52}Al_{0.48}As$ buffer layer was grown at a growth rate of 0.5 ML/s. Finally, h-ML InAs QDs and d-nm-thick $In_{1-x-y}Ga_xAl_yAs$ spacer layers were grown alternatively, producing a stacked structure. The QD and spacer layers satisfy the strain compensation conditions so that the total strain energy of a QD layer/spacer layer pair is zero, which prevented degradation of QD quality [6]. The five QD layer/spacer layer pairs (h-ML/d-nm), starting from the buffer layer, were thus prepared and their thicknesses are 4.5/45, 4.0/40, 3.5/35, 3.0/30 and 2.5/25 ML/nm, respectively.

Figure 1 shows an atomic force microscopy (AFM) surface image of the stacked InAs QDs (topmost: 2.5 ML). Self-assembled QDs were formed even though the deposition thickness was less than that in the previous work [6], which indicates the modulated strains of the spacer layers The average lateral size in the [01-1] direction and the height of the QDs were estimated to be 58.4 nm and 3.41 nm, respectively. The density of the QDs in the topmost layer was 3.4 x 10^{10}/cm^2.

The emission spectrum of this particular sample was characterized by a standard photoluminescence (PL) measurement system. As shown in Fig. 2, intense emission from the ground state around 1.55 μm appeared at room temperature. We confirmed by using a sample grown separately that no emission occurred from the excited QD states. The full-width at half maximum is as high as 240 nm, which is about 2.5 times higher than that for the sample used for broadband SOA by T. Akiyama et al [5] , as long as the line-widths of luminescence from the ground states are concerned,. This result indicates that our new QD growth method is a promising way to expand the gain bandwidth. Intense photoluminescence at room temperature could indicate suppression of defects or dislocations generation. In the next step, feasibility of high bandwidth devices with this QD material employed should be examined.

References

[1] T. Akiyama, M. Ekawa, M. Sugawara, H. Sudo, K. Kawaguchi, A. Kuramata, H. Ebe, K. Morito, H. Imai, Y. Arakawa, Proceedings of Optical Fiber Communication Conference (OFC) (IEEE Cat. No.04CH37532), vol.2 (2004), PDP12

[2] Hiroshi Furukawa, Hideki Takakura, and Kenji Kuroda, IEEE Transactions on Instrumentation and Measurement. **50** (2001) 801

[3] Y. Arakawa and H. Sakaki, Appl. Phys. Lett. **40** (1982) 939

[4] F. Heinrichsdorff, M. H. Mao, N. Kirstaedter, A. Krost, D. Bimberg, A. O. Kosogov, and P. Werner, Appl. Phys. Lett. **71** (1997) 22

[5] T. Akiyama, H. Kuwatsuka, T. Simoyama, Y. Nakata, K. Mukai, M. Sugawara, O. Wada, and H. Ishikawa, IEEE J. Quantum Electron. **73** (2001) 1059

[6] K. Akahane, N. Ohtani, Y. Okada, and M. Kawabe, Journal of Crystal Growth **245** (2002) 31

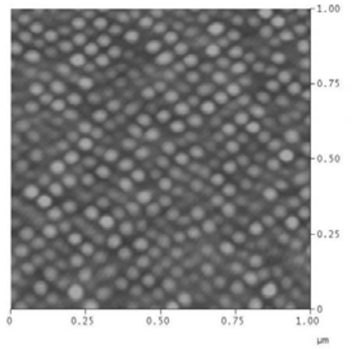

Fig. 1 AFM image of modulated stack of InAs QDs.

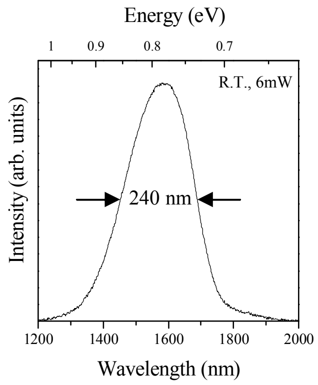

Fig. 2 PL spectrum of modulated stack of InAs QDs