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Characterization of highly stacked InGaAs quantum dots structures grown with ultrahigh-rate MBE growth technique

Fumihiko Tanoue[1,2], Hiroharu Sugawara[1] , Kouichi Akahane[2]and Naokatsu Yamamoto[2]

[1] Graduate School of System Design, Tokyo Metropolitan Univ.
6-6, Asahigaoka, Hino, Tokyo 191-0065, Japan
E-mail: tanoue-fumihiko@sd.tmu.ac.jp
[2] National Institute of Information and Communications Technology (NICT)
4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan

1. Introduction

Performances of quantum dots (QDs) laser diodes are expected to be improved by putting larger number of QDs into their active region. Because surface density of QDs is limited by their lateral size, higher stacking of QD layer are required. Self-assembly of more than 60-stacked layers of strained semiconductor quantum dots were reported by solid source molecular beam epitaxial growth with sophisticated strained compensation technique [1]. On the other hand, the authors recently pointed out that much simpler ultrahigh-rate MBE growth technique [2,3] could be utilized to fabricate up to 19 stacked InGaAs strained QD layers [4]. In this paper, we prepared up to 49 stacked InGaAs QD layers using this technique and investigated their structural and optical properties.

2. Experimental

All the samples were prepared on GaAs (001) substrate by solid source MBE. Each $In_{0.4}Ga_{0.6}As$ QD layers were grown by supplying 8-monolayer (ML) solid sources (In, Ga, and As) at 1.0 ML/s at the substrate temperature of 500 °C, following growth interruption under As irradiation for 15s. Samples A, B, C, D, E and F involved 7, 12, 19, 24, 39 and 49 stacks of QD layers, each separated by GaAs spacers of 50, 30, 20, 16, 10 and 8 nm-thick, respectively. The total thickness of QD layers are kept to be 400 nm, which is determined to coincident the active layer thickness of QD laser diode with single optical mode at 1-μm wavelength [5]. The size and surface density of QDs were evaluated from AFM observation of the top QD layer. Photoluminescence (PL) measurement was carried out at room temperature using a YVO4 laser operating at 532 nm.

3. Results and Discussions

Figure 1 shows AFM images of surface quantum dots. Their lateral shapes became from circular to elliptic elongated toward [110] direction.The diameters of QDs were evaluated to be lengths projected along [110] and [1-10] direction, which are summarized in Figure 2. The diameters along [1-10] direction were almost unchanged to be 50 nm, while the diameters along [1-10] direction doubled from 48.8 nm (Sample A) to 94.7 nm (Sample F)

Figure 3 shows heights of surface QD. Their height increased from Sample A to C, and was almost the same value of 7 nm for Sample D and F. The density of surface QDs are summarized in Table I: they were monotonically decreased from 7.7 to 3.8 x10^{10} cm^{-2}.

Figure 4 shows PL spectra obtained from A to F. Samples A to E exhibited PL emission at 1-μm photonic waveband, and red shift in luminescence peak was observed from 1.19 eV (A) to 1.15 eV (E). Sample B, C and D showed stronger luminescence peaks as compared to A, which may be attributed to the increase of total number of dots. On the other hand, Sample F showed little peak, which should be due to little quantum confinement of carriers because the dot height being comparable to GaAs spacer thickness. Sample E showed weaker peak than sample D, but further investigation is required to elucidate this mechanism.

4. Conclusions

We fabricated up to 49 stacked layers of InGaAs QD layers with ultrahigh-rate MBE growth technique, and their optical properties were investigated. Under the total thickness of active regions kept constant to be 400nm, 24 stacked QD layers with 16 nm-thick GaAs spacer (Sample D) indicated the strongest luminescence peak.

Acknowledgements

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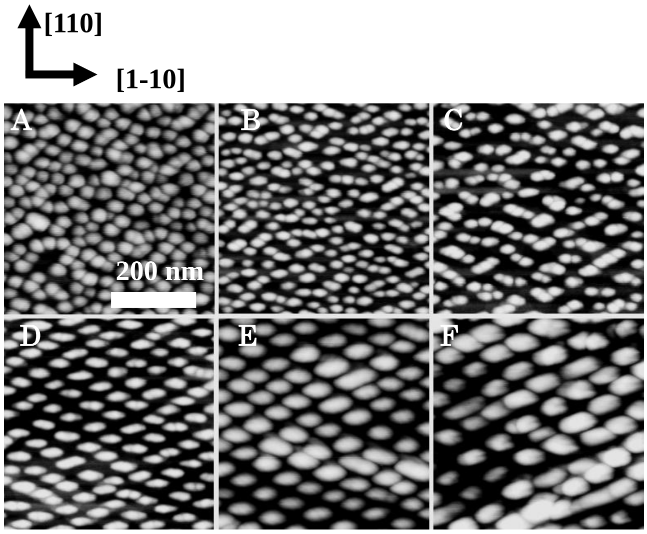

Fig. 1 AFM images of samples.

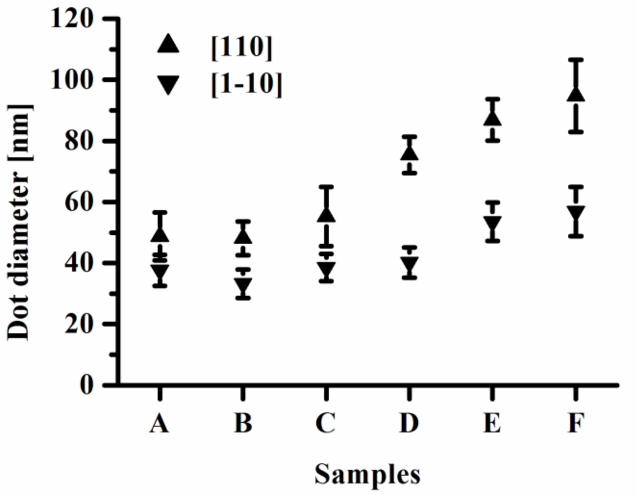

Fig. 2 Dot diameters of samples. Lines indicated coefficient of variation (CV).

Parameter	A	B	C	D	E	F
M: stacking numbers	7	12	19	24	39	49
spacer thickness [nm]	50	30	20	16	10	8
N_{QD}: surface density x10^{10} [cm^{-2}]	7.8	9.2	7.4	5.2	3.0	2.7
PL center energy [eV]	1.19	1.18	1.16	1.15	1.15	--
FWHM [meV]	77	75	72	63	69	--

Table I Parameters of samples.

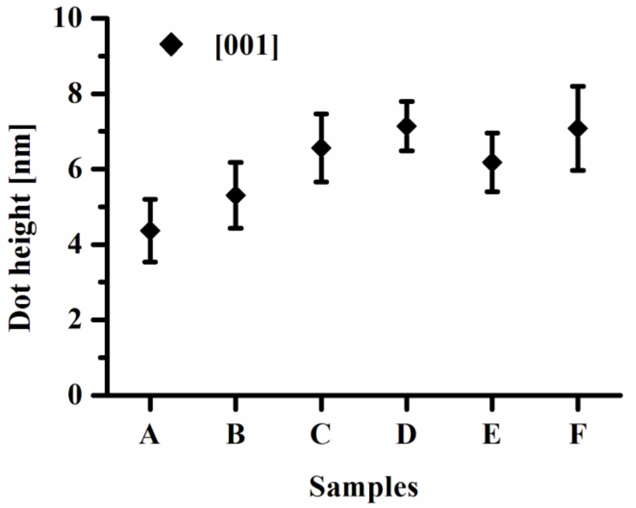

Fig. 3 Dot height of samples.

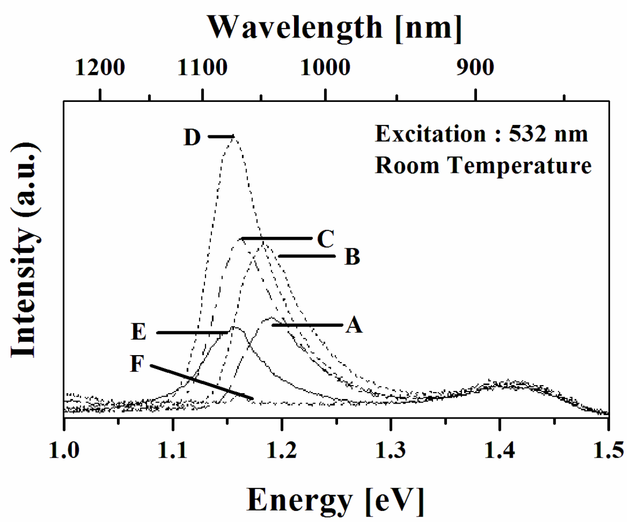

Fig. 4 Photoluminescence of samples.