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Selective-area growth of 4-color InAs-QD ensembles for broadband light source

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1. Introduction

Self-assembled quantum dots (QDs) have come under intense study as a promising nano-material for the development of a variety of electronic and optoelectronic devices. Self-assembled In(Ga)As-QDs are epitaxially grown via the Stranski-Krastanow (S-K) mode [1], which is driven by strains due to some lattice mismatch between the epitaxial layer and the substrate. In general, QDs grown in the S-K mode are randomly distributed in position and size over the whole substrate. Therefore, selective-area growth (SAG) of QDs is a key technology for advanced applications of the QDs to integrated electronic/optical devices.

We have developed the SAG method for self-assembled InAs-QD ensembles with different emission wavelengths [2]. In the previous work, we developed a method for the growth of QDs in selective areas with two different emission/absorption wavelengths by using a 180° rotational metal mask (MM) combined with conventional molecular beam epitaxy (MBE). Based on the SAG method, we recently proposed a broadband light source based on four-color QD ensembles, as shown in Fig. 1 [3]. This can be applied to optical image systems using low coherence light sources, so-called the optical coherence tomography (OCT) system.

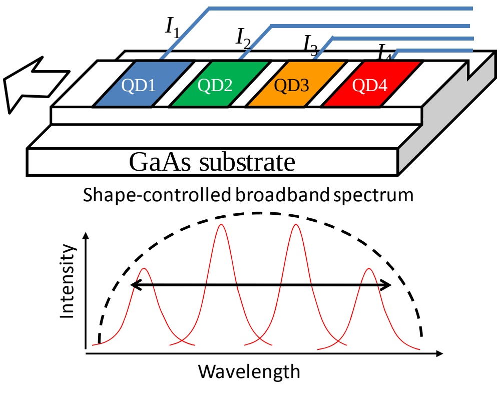


Fig.1 Schematic images of the spectrum-shape controlled broadband light source based on 4-color QD ensembles.

The OCT system requires a broadband light source, since axial resolution is governed by the coherence length (l_c), $0.44\lambda_0/\Delta\lambda$, which is inversely proportional to the bandwidth ($\Delta\lambda$) of the light source with an emission peak at λ_0. In addition, a spectrum dip is undesirable because it can result in the formation of a ghost image [4]. We report here the monolithic growth of four-color QD ensembles by the developed SAG technique using a novel 90° rotational MM that can be dedicated to broadening and controlling the shape for the QD-based broadband light source.

2. Experimental procedures

The SAG of InAs-QDs on GaAs substrate was carried out by using the MM method combined with conventional MBE. As show in Fig. 2 (a), a rotational MM made of Ta was attached to a mask holder; this can be mounted on and off a sample holder in an ultrahigh-vacuum (UHV) environment. The MM has open windows (2 mm × 8 mm) for supplying molecular beams to selective areas on a substrate during conventional MBE growth.

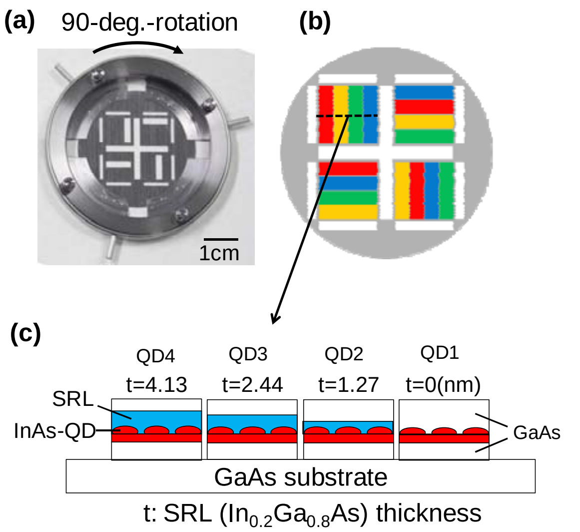


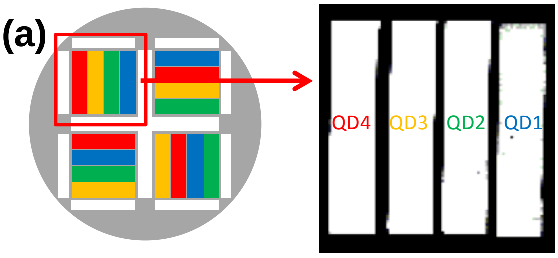
Fig.2 (a) Photograph of 90° rotational Metal-mask. (b) Schematic image of four color QD ensembles grown in selective areas. (c) Profile image of the grown QD ensembles.

The MM with open windows on the rotationally asymmetric pattern allowed the formation of four different selective-area growth regions close to each other. The emission wavelength of each QD ensemble grown in the selective areas can be tailored by deposition of $In_{0.2}Ga_{0.8}As$ strain reducing layer (SRL) [5] with different thickness. The QDs were grown by the deposition of 2.6-monolayer InAs on a GaAs substrate at around 480 °C. Subsequently, the SRL was deposited on each QD ensemble with thicknesses of 0–4.13 nm, which was followed by deposition of a GaAs capping layer. The SRL thicknesses were set to 0 nm for QD 1, 1.27 nm for QD 2, 2.44 nm for QD 3, and 4.13 nm for QD 4; this configuration of the SRL thickness enables the separation of the QD emission wavelengths ($\Delta\lambda$) to approximately 40 nm.

The grown QDs were characterized by measuring the photoluminescence (PL) at room temperature (RT); the PL intensity was also mapped. For the PL measurements, an 80-µW He-Ne (λ = 632.8 nm) excitation laser was used.

3. Results and Discussion

Figure 3 (a) shows a PL intensity map for PL emission wavelengths of 1100–1400 nm obtained from the selective-area including four color QD ensembles. It clearly exhibits that the SAG corresponding to the opening window of the MM was performed. The PL spectra obtained from the areas of QD 1-4 are shown in Fig. 3 (b). PL peaks and linewidths of the ground state (GS) and excited state (ES) emission lines of each QD are summarized in table 1.



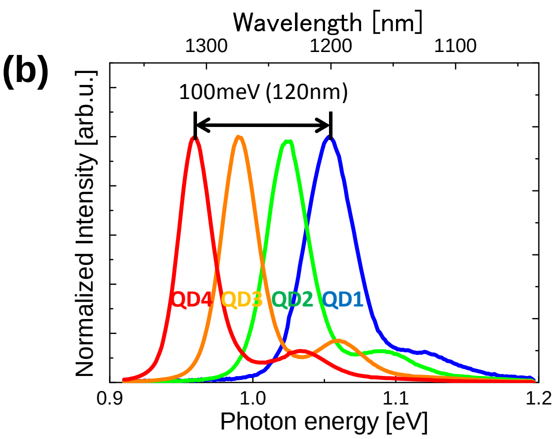


Fig.3 (a) PL intensity map obtained from selective area on a substrate. (b) PL spectra obtained from QD1-4 ensembles in the PL intensity map.

The linewidth of these PL peaks at RT, which was approximately 30–40 meV, indicates that the grown QDs had high homogeneity that was identical to that of QDs grown without using the MM. The detuning of the PL peaks was controlled well by varying the SRL thickness, and the peak shift value was approximately 100meV (120 nm). Assuming contributions of ES emissions, peak shift value is approximately 160meV (190 nm). The linewidth for the sum of the GS and ES emission lines is expected to be approximately 200meV (220 nm), which is suitable for broadband light sources.

	SRL thickness	GS	ES	FWHM
QD1	0nm	1.05eV	1.12eV	40.1meV
QD2	1.27nm	1.02eV	1.09eV	33.3meV
QD3	2.44nm	0.989eV	1.06eV	30.4meV
QD4	4.13nm	0.959eV	1.03eV	27.5meV

Table 1 PL peaks and linewidths of ground state (GS) and excited state (ES) emission lines of QD1-4

4. Conclusions

Multi-color QD ensembles were grown using a 90° rotational MM and by depositing SRL with different thicknesses on each QD ensemble. By changing the SRL thickness, peak wavelength can be shifted continuously up to 120 nm. The summation of the PL spectra obtained from QD ensembles had a width of 160 nm; this spectrum was obtained almost wholly from the GS emissions of the QDs. These results indicate the feasibility of fabricating a broadband and spectrum-shape controlled light source by the SAG of multi-color QDs, which is particularly suited for high-quality OCT imaging.

Acknowledgements

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