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Photoluminescence Study of InAs Quantum Dots and Quantum Dashes Grown on GaAs (211)B

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1. Introduction

During the last years, there has been a great deal of interest in the fabrication and characterization of the self-organized quantum dots (QDs) and various QD systems have been grown successfully by molecular beam epitaxy (MBE) [1-4]. In addition to the QD structure, the self-organized growth has led to the formation of quantum dashes (QDHs), as demonstrated by Utzmeier *et al.* [5], who observed the formation of InSb QDHs by growing more than 3.2 monolayer (ML) InSb on InP substrates. Recently, we have obtained InAs QDHs by growing $6ML_{211}$ InAs on GaAs (211)B at high growth temperature (T_s) [6]. In this work we investigate the Photoluminescence (PL) properties of the self-organized InAs QDs and QDHs grown on GaAs (211)B substrates at various T_s.

2. Experiments

The samples were grown on semi-insulating GaAs (211)B substrates by MBE (ULVAC MBC-100). The growth process was monitored by *in situ* reflection high-energy diffraction (RHEED) (20 keV). After removing the surface oxide under an arsenic flux, a 0.5 μm GaAs buffer layer was grown at 600℃, then a 40 period GaAs/AlAs (2.3 nm/1.5 nm) superlattice was deposited, followed by a 10 nm GaAs layer. InAs nanostructures with $6ML_{211}$ of InAs were deposited at T_s ranging from 400℃ to 510℃ with As and In beam equivalent pressure ratio of 20. Finally, a 30 nm GaAs caplayer was grown at T_s 20℃ lower than the InAs growth temperature or at 480℃ for high InAs growth temperatures in order to avoid In segregation. Atomic force microscopy (AFM) was used to determine the shape of InAs nanostructures. The PL measurements were performed at temperatures (T_m) ranging from 4.5 K to 200 K in a closed-cycle He cryostat. A 514.5 nm line of Ar^+ laser was used for excitation and a standard 0.5 meter spectrometer/ photomultiplier/lock-in amplifier system was used to detect and process the photoluminescence signal.

3. Results and Discussion

When $6ML_{211}$ of InAs was deposited at low T_s (from 400 to 470℃), the RHEED pattern changed from streaky to spotty, revealing a transition from two-dimensional growth mode to three dimensional growth mode. QDs with bimodal dot size distribution were observed by AFM measurement. When the same amount of InAs was deposited at high T_s (500 or 510℃), the RHEED pattern along the $[\bar{1}11]$ azimuth was almost same as that grown at low T_s, but there was a drastic change of the RHEED pattern along the $[01\bar{1}]$ azimuth, it changed from streaky to spotty just after InAs growth and then transformed to streaky pattern again after several seconds of growth interruption, indicating the formation of a new structure. AFM measurements revealed the formation of a new nanostructure – QDHs. The QDHs have asymmetric hut-like shape and self-aligned along $[01\bar{1}]$ direction.

Figure 1 shows the PL spectra at 4.5 K of InAs QDs grown at 400 and 450℃ and QDHs grown at 510℃. We attribute the two PL peaks around 1.24 and 1.4 eV in spectrum (a) and (b) to the bimodal size distribution of QDs. The low PL efficiency of QDs is believed to be related to the poor quality of GaAs caplayer grown at low temperatures. The temperature dependence of PL spectra of InAs QDs and QDHs is shown in Fig. 2. The PL peak intensity and position of the two nanostructures showed similar temperature dependence: at low T_m the peak intensity as well as the peak position was almost independent of T_m, showing that the exciton is localized spatially in a local potential minimum. On the other hand, the peak intensity decreased drastically and peak position shifted to lower energy monotonically with the increase of T_m above a certain transition temperature (T_t). This is most probably due to the dissociation of excitons into electron-hole pairs which then escape from QDs/QDHs. T_t was found to be lower for the QDH structure. The excitation density dependent PL of QDs and QDHs has also been studied. The PL intensity of QDs exhibited a linear behavior with respect to the excitation intensity and the no shift in the peak position above experimental error was observed, whereas the intensity of QDHs exhibited a nonlinear behavior and the peak energy shifted to higher energy by increasing the excitation density. The nonlinear dependence and the blue-shift of QDH PL suggest that the mechanism of the radiative recombination in QDHs is different from that of QDs.

4. Conclusions

InAs self-organized QDs and QDHs were grown by MBE on GaAs (211)B substrates. QDs with bimodal dot distribution were formed at low T_s and QDHs was formed at high T_s. PL properties of QDs and QDHs have been studied as a function of temperature as well as excitation density. The PL peak intensity and its energy of the two different nanostructures showed similar temperature dependence. The excitation density dependence of PL peak intensity and its position, however, was found to be different for QDs and QDHs.

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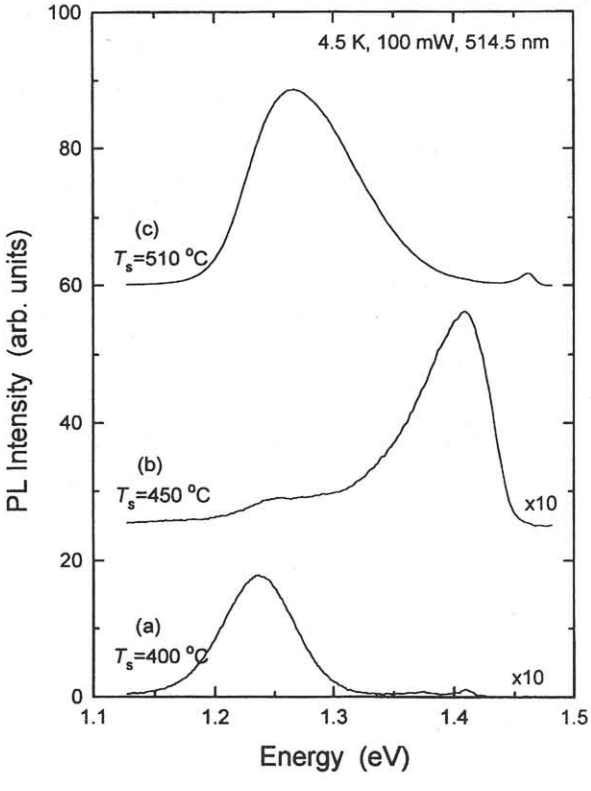

Fig. 1 PL spectra at 4.5 K of InAs QDs grown at (a) 400℃, (b) 450℃ and (c) QDHs grown at 510℃.

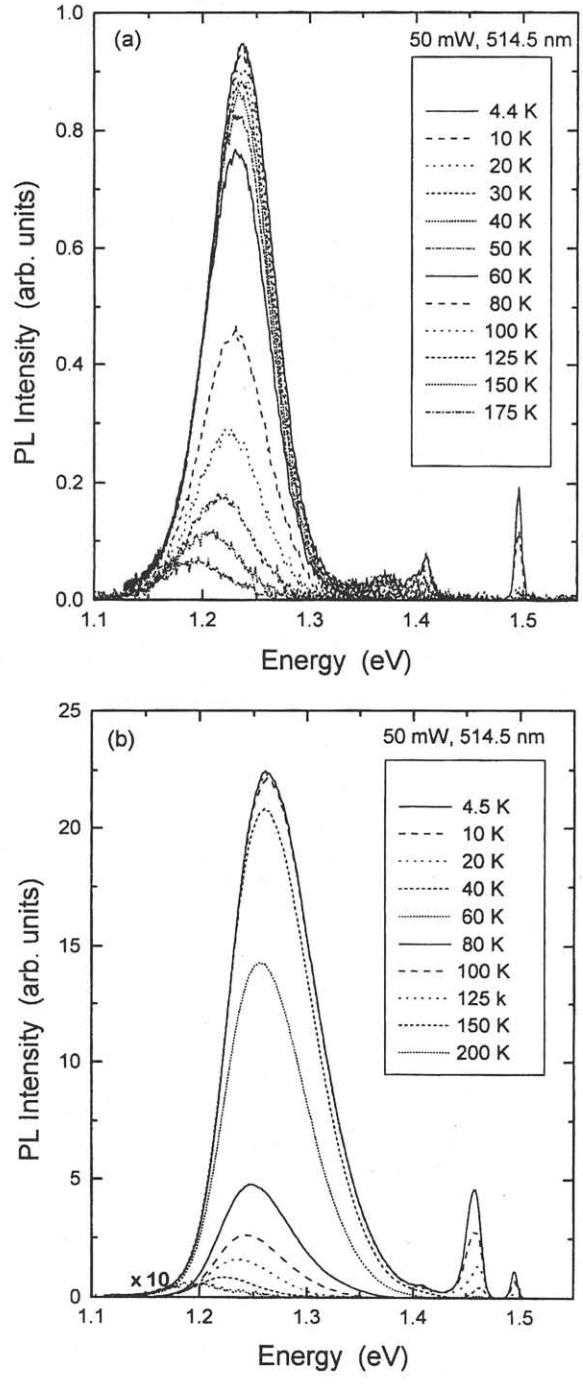

Fig. 2 Temperature dependence of PL spectra of (a) InAs QDs grown at 400℃ and (b) InAs QDHs grown at 510℃.