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GROWTH AND PROPERTIES OF STACKED SELF-ASSEMBLED $In_{0.5}Ga_{0.5}As$ QUANTUM DOTS

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Abstract

Self-assembled $In_{0.5}Ga_{0.5}As$ quantum dots (QDs) were grown using metal-organic chemical vapor deposition (MOCVD) on GaAs (100) substrate with different number of stacking QDs layers. Surface study using atomic force microscopy (AFM) shows that surface morphology of the self-assembled QDs change with different number of stacking QDs layers caused by the previous QDs layers and the thickness of the GaAs spacer layers. PL measurement shows variation in the PL spectra as a function of number of stacking layers of $In_{0.5}Ga_{0.5}As$ QDs. The PL peak positions blue-shifted from 1225 nm to 1095 nm and dramatically increase in intensity with increasing number of stacking QDs layers.

Keywords : Quantum Dots, $In_{0.5}Ga_{0.5}As$, MOCVD, AFM, and Photoluminescen

1. INTRODUCTION

Low-dimensional semiconductor systems have been widely studied by many researchers over the past two decades. Many experimental and theoretical studies have been conducted to the development of the sizes, uniformity, and optical properties of nanostructures such as quantum wires and quantum dots (QDs). The low-dimensional structures show unique physical properties, particularly interesting for novel optoelectronic devices such as QDs lasers with low threshold current density, high temperature stability, and high material and differential gain [2]. Recently, many works has been conducted to improve the performance of the QD lasers, in particular, stacked QD structures have been widely employed to increase the density of the QDs and then to increase the modal gain of the QD lasers [2, 3]. A number of experiments have demonstrated that the optical properties of QD lasers depend strongly on the number of QDs layers. However, the accumulation of strain by stacking the QDs layers can cause misfit dislocations and undulated interfaces that greatly degrade the performance of the lasers [3]. The artificial molecules can be realized by stacking layers of self-assembled QDs, and the vertically coupling effect can be controlled by changing the spacer layer thickness [4].

Self-assembled $In_xGa_{1-x}As/GaAs$ QDs is one such system that has optoelectronic applications, especially for laser devices. It is of particular interest also due to the strain and larger energy band offsets compared to $Al_xGa_{1-x}As/GaAs$ QDs and thus provides additional device design benefits and flexibility [5]. The possibility of using $In_xGa_{1-x}As$ QDs on GaAs, which offers lower power operation as well as significant improvements in cost/performance ratio due to the availability of inexpensive GaAs substrate, makes this technology promising [6]. High quality $In_xGa_{1-x}As$ QDs can easily be fabricated using either MBE (molecular beam epitaxy) or MOCVD (metal-organic chemical vapor deposition) via a self-assembled process known as Stranski–Krastanov growth mode. The growth procedure is effective in increasing the uniformity of the $In_xGa_{1-x}As$ QDs due strong influence of growth kinetics on the QDs. The electronic states of QDs critically depend on size, shape and composition of the QDs, therefore the way these structures are fabricated plays a crucial role in their optical behavior [7]. This paper investigates the morphology and optical properties of the $In_{0.5}Ga_{0.5}As$ QDs grown on GaAs (100) substrates with different number of $In_{0.5}Ga_{0.5}As$ QDs layers. The results find significant differences in the sizes, density and the optical properties of $In_{0.5}Ga_{0.5}As$ QDs.

2. EXPERIMENT

Self-assembled $In_{0.5}Ga_{0.5}As/GaAs$ QDs with different number of stacking QD layers were grown using MOCVD at pressure of 76 Torr. Prior to the growth, native oxides on the substrates were thermally dissociated at 750 ºC under arsine ambient in the III-V growth chamber followed by 200 nm thick GaAs buffer layer grown at 650 ºC with V/III fixed at 80 during deposition. Before $In_{0.5}Ga_{0.5}As$ QDs growth, the reactor temperature was stabilized at the $In_{0.5}Ga_{0.5}As$ QDs growth temperature (550 ºC) under AsH_3 flow to protect the surface. All $In_{0.5}Ga_{0.5}As$ QDs samples were grown at temperature of 550 ºC. The flow rates for TMGa, TMIn and AsH_3 were kept at 2 sccm, 100 sccm, and 32 sccm, respectively, with V/III ratio fixed at 10 during the deposition of self-assembled $In_{0.5}Ga_{0.5}As$ QDs. Growth parameters and growth time were kept constant for each layer of self-assembled $In_{0.5}Ga_{0.5}As$ QDs growth. A 25 nm GaAs spacer layer was grown between each QDs layer using same parameter growth as the GaAs buffer layer. Finally, uncapped self-assembled $In_{0.5}Ga_{0.5}As$ QDs were grown on the GaAs spacer layer. A schematic diagram of the samples structure with different number of stacking is shown in Figure 1.

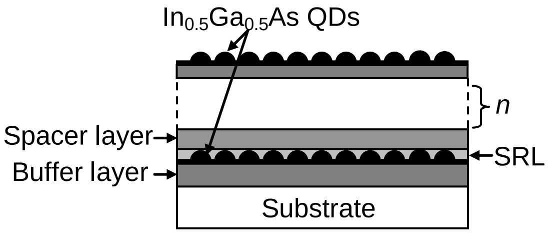

Figure 1. Schematic of *n*-stacked structures QDs

The morphology of the structure and surface density analysis of the self-assembled $In_{0.5}Ga_{0.5}As$ QDs on the top layer were performed using AFM and PL measurement was used to investigate the optical properties of self-assembled QDs with different number of stacking QD layers.

3. RESULT AND DISCUSSION

Figure 2(a) and (b) shows the result of AFM analysis i.e. the density, average height and average diameter of the dots on the top most layers of the $In_{0.5}Ga_{0.5}As$ QDs for all QDs samples. The average size (width and height) of the single-layers, double, three, and four stacks $In_{0.5}Ga_{0.5}As$ QDs was 35 nm × 13 nm, 26 nm × 9 nm, 35 nm × 21 nm, and 38 nm × 14 nm, respectively. This result suggests that the large dots formed on the upper layer were originated from the surface roughness. The variation size of the dots on the upper layer is dependent on the morphology of QDs in the under layer and also on the structures of the barrier (spacer layer) as shown in another results [8]. Zhang et al. [9] showed that in the growth of multiple-stacked QDs, the strain field created by the QDs strongly affects the subsequent growth of the barrier and QDs layers. The dots density changes with the evolution of the dots size, where the dots density for the single-layer, double, three and four stacks QDs was 1.14×10^{10} cm^{-2}; 2.41×10^{10} cm^{-2}; 1.16×10^{10} cm^{-2}; and 1.04×10^{10} cm^{-2}, respectively. The mean dots size was increased with increasing number of $In_{0.5}Ga_{0.5}As$ QDs stacking as reported by Wasilewski et al. [10] and Ilahi et al. [11]. The decrease in the dots density was due to the coalescence of several dots to larger dots. It then causes the mean dots size to increase. The non-uniform strain field in the GaAs spacer layers created by the underlying dot layer is believed to be the source for the nucleation of big dots on upper layer [9]. It occurs due to gradual decrease in the critical thickness for the two-dimensional to three-dimensional growth mode transitions. In contrast to this, our result shows that the increase in the dots density was the result of QDs stacking [3, 4]. In another result, the dots density does not change with number of dots layer and the dots were vertically correlated [12].

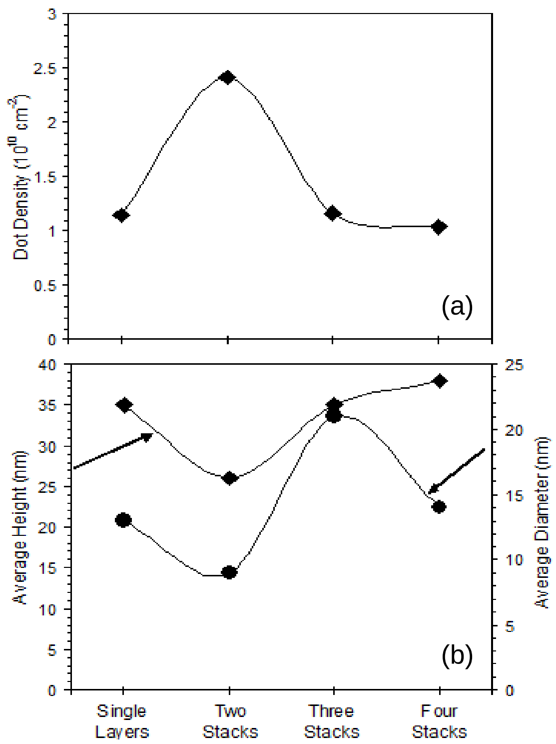

Figure 2. (a) The area density, (b) diameter and height of self-assembled $In_{0.5}Ga_{0.5}As$ QDs as a function of number of QDs stacking

Figure 3. shows the shift in the room temperature PL spectra due to different number of QDs stacking. The spectrum

peaks positions were blue-shifted at 1225 nm, 1195 nm, 1145 nm, and 1095 nm for the one, two, three and four stacks QDs, respectively. The blue-shift indicates that the size, dot density, and shape of the QDs were effectively changed with number of stacking $In_{0.5}Ga_{0.5}As$ QDs. The inhomogeneous distribution of strain in the QDs stacking may contribute to the QDs morphology. Spacer layer thickness was also contributed to the formation of the dots in the upper layers. Ilahi et al. [11] presented that the buried dots will be generated on the top if the spacer layer is less than the decay length of a preferential nucleation site. However, in the growth of stacking QDs, the parameter of the spacer layer is important to keep the shape of the dots.

The increase in the PL intensity with increasing number of stacking can be ascribed to the $In_{0.5}Ga_{0.5}As$ QDs layers. Yang et al. [3] had shown that the increase in the intensity with number of stacking was caused by the increase in the dots density of the stacking QDs. In contrast to this, our measurement shows (Figure 1), the increasing number of stacking increases the PL intensity, but at the same time decreases the dots density. This was influenced by the indium fraction in the stacking $In_{0.5}Ga_{0.5}As$ QDs layers. The increase in the PL intensity does not followed by the decrease in the FWHM (full width at half maximum). The FWHM of the three stacking QDs was 0.08 eV. This was greater than for the single, two and four stacks QDs, where the FWHM was about 0.12 eV, 0.15 eV, and 0.13 eV, respectively. These narrow FWHMs were attributed mainly to the suppression of relative dots size fluctuation in the vertical direction [13]. The blue shifted and width of the FWHM is generally attributed to the decreasing of electronic coupling between stacked QDs. The increase in the FWHM from three to four stacking QDs was due to the existence of defect in the structures from stacking QDs. The stacking $In_{0.5}Ga_{0.5}As$ QDs have important effect in optical properties of QD devices.

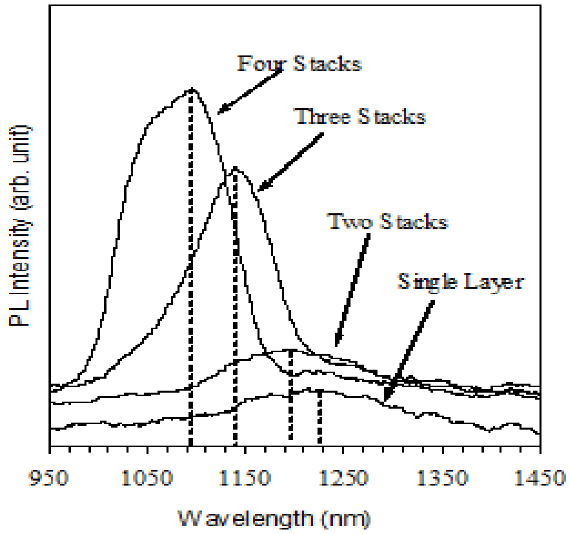

Figure 3. PL spectra of $In_{0.5}Ga_{0.5}As$ single layer QDs, two stacks, three stacks and four stacks $In_{0.5}Ga_{0.5}As$ QDs structures at room temperature

The quantity and quality of the QDs structures have strong influence on the luminescence feature [14]. If we compare between the PL measurement and AFM analysis, the increase in the PL intensity with stacking does not follow by the increase in the dots density. The blue-shifted of the PL spectrum with stacking can also be ascribed to reduction of quantum size effect due to the increase in effective dots height [13]. The shift of the peak depending on the indium content in the overgrown QDs layers has been well explained by strain relaxation and size increase of the overgrown QDs [15]. Large dots were present on the surface is influenced by the structures of the first dots and GaAs spacer layers. While the barrier atoms deposited on top of the QDs were unstable and have a tendency to diffuse away from the QDs regions, the QDs on the upper layer have a tendency to nucleate directly on top of the buried QDs [9] as presented by Ilahi et al. [11]. The variation in the average size for these dots as a function of stacking indicates the possibility of different surface morphology of the under-layer before growth of QDs. It was affected by the buried dots after the growth of the GaAs spacer layers due to the effect of uneven strain distribution in the stacking QDs. This is the result of the lattice mismatch between the $In_{0.5}Ga_{0.5}As$ and GaAs and it propagates in the growth direction with stacking.

4. CONCLUSIONS

Variable stacking self-assembled $In_{0.5}Ga_{0.5}As$ QDs were successfully grown on GaAs (100) substrate by MOCVD. AFM result showed that size, shape, uniformity and density of the sample changes with the different number of QDs stacking where the dots density decreases with increase number of stacking. The first dots and spacer layer thickness affects the formation of top most $In_{0.5}Ga_{0.5}As$ QDs. PL spectrum shows that peak position blue-shifted and its intensity increases with increasing number of stacking. It can be ascribed to reduction of quantum size effect due to the increase in the dots size. The PL-FWHM for three-stack QDs is better than the other samples. Narrow FWHM was attributable to the suppression of the relative dots size fluctuation in the vertical direction. Evolution of size, shape, uniformity and density of the stacking $In_{0.5}Ga_{0.5}As$ QDs influences the PL spectrum peak position and PL intensity.

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