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Correlation between Structure and Luminescence of InAs SML Nanostructures

Ronel Christian Roca and Itaru Kamiya*

Quantum Interface Laboratory
Toyota Technological Institute
Nagoya 468-8511, Japan
Phone: +81-52-809-1769 E-mail: roca.ronel@toyota-ti.ac.jp, kamiya@toyota-ti.ac.jp

Abstract

The correlation between the structural and photoluminescence (PL) properties of InAs submonolayer (SML) nanostructures at the 2D to 3D transition is investigated. Significant changes in the topography of uncapped InAs nanostructures assembled by SML growth have been observed, indicating the transition from 2D to 3D growth regime. The influence of these structural changes to the luminescence properties of the nanostructure are investigated by PL measurements.

1. Introduction

Recently, interest in the submonolayer (SML) growth mode has been rising. The SML growth mode is often proposed as an alternative to the more well-known Stranski-Krastanov (SK) growth mode for the assembly of InAs nanostructures on GaAs by molecular beam epitaxy (MBE) [1]. Compared to the single InAs deposition involved in SK growth, SML growth involves the stacked, cycled deposition of SML-thick InAs and ML-thick GaAs. Owing to larger number of growth parameters that can be adjusted, a key advantage of SML growth is the flexibility and tunability of growth. By adjusting the InAs and GaAs layer thicknesses as well as total number of stacks, the size, shape, and height of the InAs nanostructures can be controlled.

While the 2D to 3D transition in SK growth is well-investigated with an InAs critical thickness of ~1.7 ML [2], the corresponding phenomenon in SML growth is not yet well understood [3, 4]. In the present work, it will be shown that, for a given GaAs layer thickness and number of stacks, there exists a critical thickness in the deposited InAs per cycle, beyond which formation of 3D structures occurs. Therefore, SML-grown InAs nanostructures exists in two distinct forms: 2D islands and 3D structures. Furthermore, it will be shown that the resulting PL properties of these two forms of SML nanostructures are also distinct, and are influenced by their underlying structure.

2. Experiments and Results

For the present work, two sets of samples were prepared: uncapped SML samples for topographical measurements and capped SML samples for PL measurements. All samples were grown by MBE on semi-insulating GaAs (001) substrates. After oxide desorption at 600°C and growth of 100-nm GaAs buffer at 590°C, the temperature was brought down to 500°C as indicated by the transition of the RHEED pattern from 2×4 to c(4×4). This was followed by the growth of a 30-nm GaAs spacer layer, and then finally the InAs/GaAs SML structures.

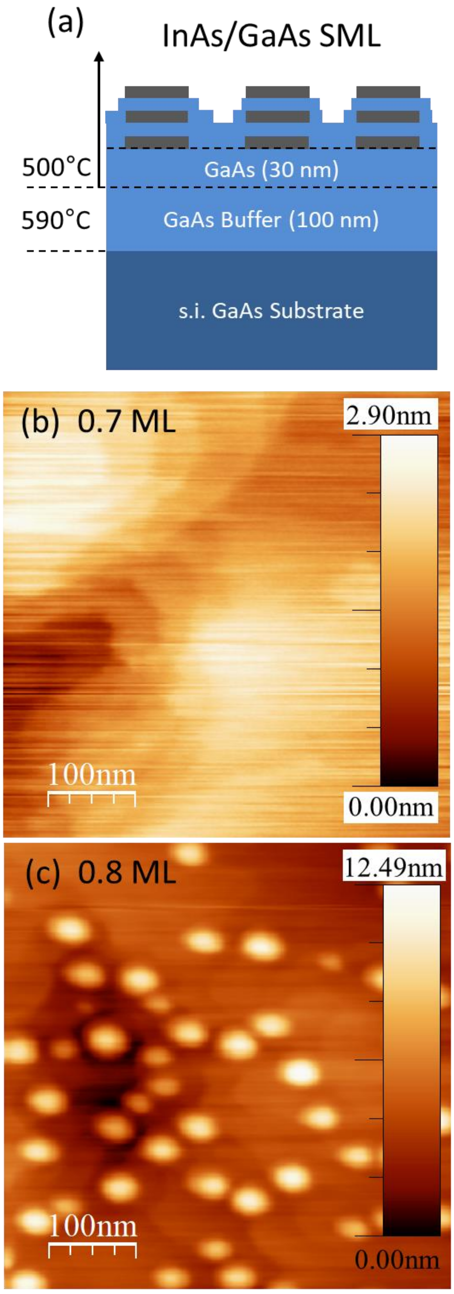

Fig. 1 (a) Schematic of the uncapped SML samples. 500×500 nm^2 AFM images of uncapped 3-stack SML samples with (b) 0.7 and (c) 0.8 ML InAs deposited per cycle. GaAs spacer was kept at 2.0 ML.

As shown in Fig. 1(a), for the uncapped samples, 3-stack SML structures with constant 2.0 ML GaAs spacer layers were prepared, while the InAs layer thickness was varied from 0.6 to 0.8 ML. In addition, similar 4-stack SML structures were also prepared, while the InAs layer thickness was varied from 0.5 to 0.7 ML. For the capped samples, corresponding 3- and 4- stack SML structures were prepared with the same growth conditions as the uncapped samples. The SML structures were then capped with a 50-nm GaAs layer.

Shown in Figs. 1 (b) and (c) are the AFM images of the uncapped 3-stack SML samples with 0.7 and 0.8 ML deposited InAs per cycle, respectively. Whereas the sample with 0.7 ML InAs is mostly flat with 2D step-like terraces, the sample with 0.8 ML InAs is full of 3D structures. These 3D structures resemble SK-grown quantum dots (QDs), however, the transition in the case of SML growth occurred with total deposited InAs of 0.8×3 = 2.4 ML, instead of 1.7 ML in SK growth. Moreover, the 3D structures tend to form on lower plateaus or on steps, suggesting that the formation of 3D structures cause the depletion of the InAs in the surrounding 2D islands. We note that the 0.6 ML sample (not shown) is mostly flat and is similar to the 0.7 ML sample. We also observed a similar trend to the topography of the 4-stack samples except that the onset of 3D structure formation occurred at 0.7 ML instead of 0.8 ML.

Shown in Fig. 2(a) are PL spectra of the corresponding capped SML samples with the same InAs deposited per cycle as those in Figs. 1 (b) and (c). As expected from the higher ammount of total deposited InAs, the 0.8 ML sample is red shifted compared to 0.7 ML sample. Remarkably, there is also a significant difference in the spectral lineshape. Whereas the 0.7 ML sample shows a narrow linewidth with FWHM of ~7 nm, the 0.8 ML sample shows a broad linewidth with a FWHM of ~45 nm. This result correlates well with the topographical observation by AFM. Since at 0.7 ML InAs per cycle, the SML structure would predominnantly be 2D with not much variation in thickness, the linewidth is expected to be narrow. Whereas, at 0.8 ML, since the SML would be in the 3D regime and the formation of 3D structures of various sizes would occur, a significant increase in FWHM is expected.

Plotted in Fig. 2 (b) are the PL FWHM against the PL peak wavelength for capped 3- and 4-stack SML while varying deposited InAs per cycle between 0.2 and 0.8 ML. The samples with 0.2 ML InAs per cycle is found at the left most, with the shortest wavelength of ~830 nm and narrowest FWHM of ~3 nm. As the InAs per cycle is increased, the wavelength starts to red shift and the FWHM starts to increase. For the 3-stack SML, this trend continues up to 0.7 ML, beyond which a sudden increase increase in the FWHM and significant redshift occurs at 0.8 ML. Correspondingly, this is onset of the formation of 3D structures as confirmed in AFM topographical measurements. For 4-stack SML, a similar trend is observed except that the transition occurred at 0.7 ML instead of 0.8 ML. Therefore, we observe a strong correlation between the structure, as observed by AFM, and the optical property, as observed by PL, in the SML structures.

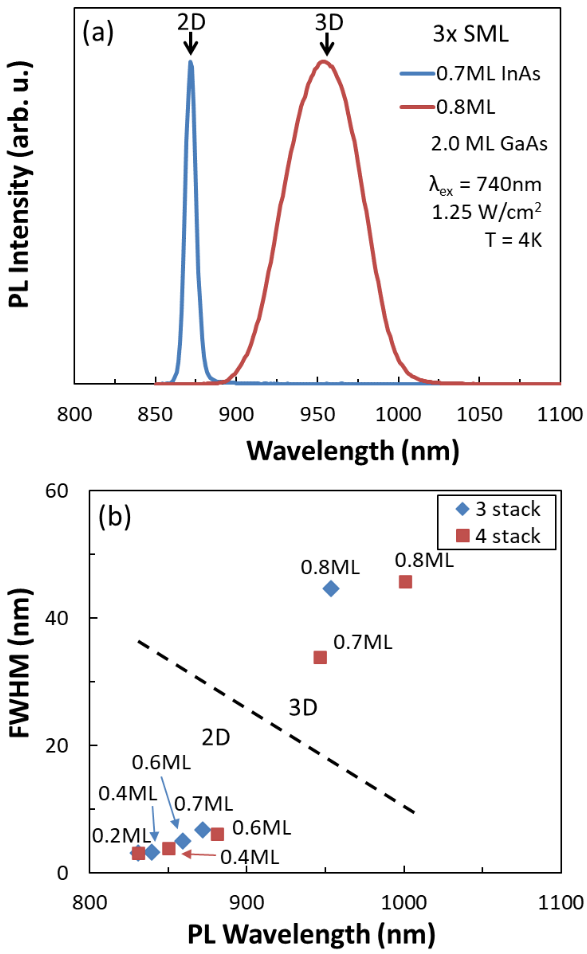

Fig. 2 (a) 4K photoluminescence spectrum capped 3-stack SML samples with 0.7 (blue) and 0.8 (red) ML InAs deposited per cycle. GaAs thickness was kept at 2.0 ML. (b) Plot of the PL FWHM as a function of PL peak wavelength for SML samples. The InAs deposited per cycle was varied from 0.2 to 0.8 ML, while the GaAs thickness was kept at 2.0 ML.

3. Conclusions

A systematic investigation of the correlation between the structural and luminescence properties of SML nanostructures has been carried out. A significant topographical change has been observed at the 2D to 3D transition by AFM measurements. A corresponding broadening of the PL spectra at the transition has also been observed. This correlates well with the observed structural changes in the SML structures.

Acknowledgements

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