Control of density of 3D Stacked Submonolayer (SML) InAs Nanostructures by As_2 flux

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Stacked submonolayer (SML) growth of InAs nanostructures by MBE has been gaining interest recently for various optoelectronic applications.[1] In contrast to the well-known Stranski-Krastanov (SK) growth of InAs nanostructures, stacked SML growth involves the cycled deposition of SML-thick InAs and few ML-thick GaAs. We have recently reported evidence of the 2D to 3D transition in SML InAs nanostructures.[2] This transition leads to the existence of two distinct kinds of stacked SML nanostructures: 2D islands and 3D structures.[3] Compared to the analogous transition in SK growth, the properties of the stacked SML transition is not yet well investigated. Hence, this study aims to elucidate the controllability of the density of 3D structures by As_2 flux. It will be demonstrated that a wide control of 3D structure density (10^8 ~ 10^{10} cm^{-2}) is possible simply by adjusting the As_2 flux in stacked SML growth.

All samples were grown by MBE on s.i. GaAs (001) substrates. For each sample, after oxide desorption at 600°C, a 100-nm GaAs buffer layer was grown at 590°C, followed by the growth at 500°C of a 30-nm GaAs layer and the 3-stack InAs/GaAs SML structures. No capping layer was deposited. For the SML structures, the InAs and GaAs depositions were kept at 0.8 and 2.0 ML/cycle, respectively. This condition is known to lead to the formation 3D structures.[2,3] The As_2 flux during the growth of the SML layers was varied. Three samples were prepared with As_2 beam equivalent pressures (BEP) of 6×10^{-4}, 1×10^{-3}, and 2×10^{-3} Pa. Topographic images were acquired by dynamic force mode (DFM) AFM. Measurement resolution is assumed to be limited by probe tip radius of ~7 nm.

Shown in Fig. 1 are the topographical images of the samples. As expected, 3D structures were observed for all samples, confirming that the condition is within the 3D growth regime. While the deposited amount of InAs and GaAs are same for all samples, very different densities of 3D structures were observed by altering in the As_2 flux. Note that the density of 3D structures significantly decreases with higher As_2 flux: from ~2×10^{10} cm^{-2} for sample with lowest As_2 flux down to ~6×10^{8} cm^{-2} for the one with highest flux. This confirms that the density of 3D structures can widely be controlled simply by As_2 flux in SML growth. Also note that the 3D structures for the sample with highest flux tend to be smaller (less developed) compared those with lower fluxes, suggesting that a high As_2 flux may suppress 3D growth.

In conclusion, wide control of the density of 3D structures by As_2 flux tuning has been demonstrated. While further studies are needed, these results are desirable for applications where density control is important, such as single photon sources.[4]

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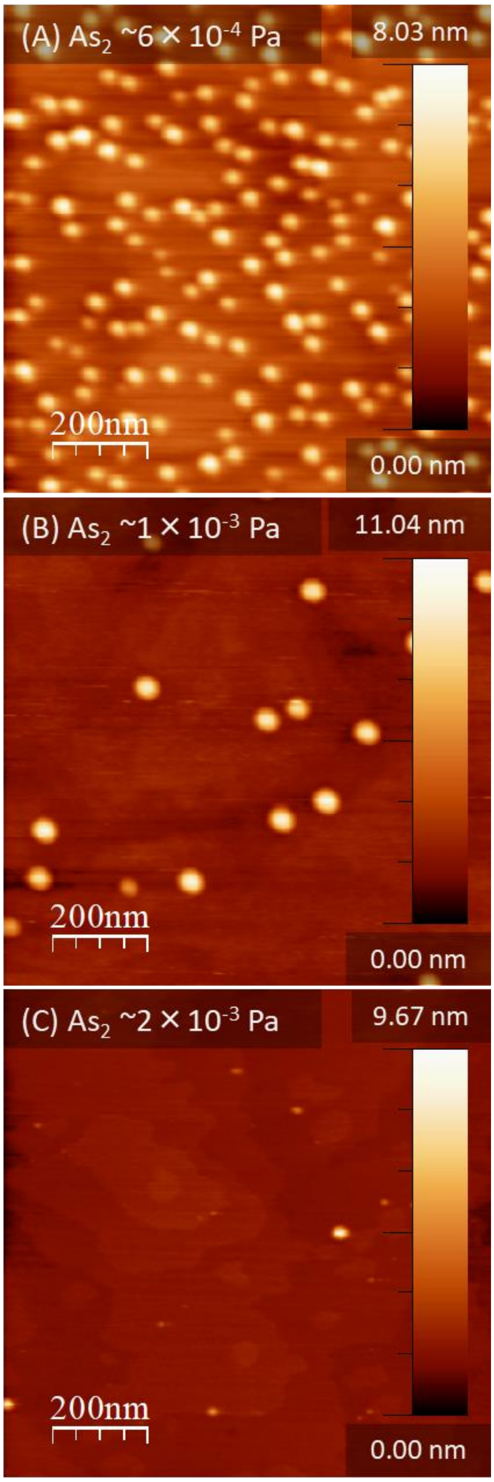

Figure 1. 1000×1000 nm^2 AFM images of 3-stack SML samples with (A) 6×10^{-4}, (B) 1×10^{-3}, and (C) 2×10^{-3} Pa of As_2 flux.