AFM Study of the 2D to 3D Transition in InAs Submonolayer Structures

Ronel Christian Roca and Itaru Kamiya
Toyota Technological Institute
E-mail: roca.ronel@toyota-ti.ac.jp, kamiya@toyota-ti.ac.jp

The submonolayer (SML) growth mode has been attracting attention as an alternative to the well-known Stranski-Krastanov (SK) growth mode as a method of assembling InAs nanostructures, *e.g.* quantum dots (QDs), on GaAs by MBE.[1] While the 2D to 3D transition in SK-growth has been well investigated with a critical thickness of ~1.7 ML,[2] different conditions are employed for SML-growth.[3] Here, atomic force microscopy (AFM) is utilized to study the topographical changes at the 2D to 3D transition in InAs SML nanostructures.

Uncapped InAs SML samples as shown in Fig. 1 were grown on s.i. (001) GaAs substrates by MBE. 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. For the SML structures, the GaAs layer was kept at 2.0 ML for all samples, whereas the InAs layer coverage was varied from 0.6 to 0.8 ML. Topographic images were acquired by dynamic force mode (DFM) AFM. Measurement resolution is assumed to be determined by probe tip (Nanosensors™) radius of ~7 nm.

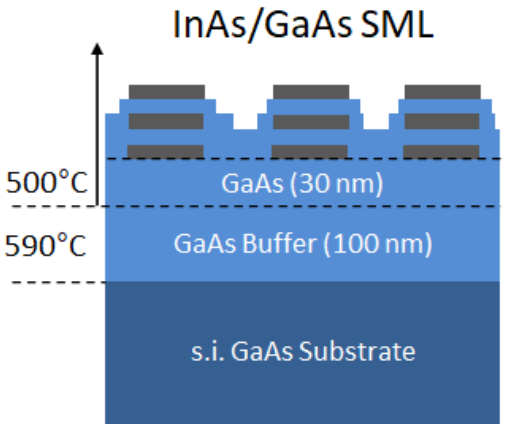

Figure 1. Schematic of 3-stack SML sample structure with 0.6~0.8ML InAs / 2.0ML GaAs.

Shown in Fig. 2(A) is a 500×500 nm^2 AFM image of the sample with 0.7 ML deposited InAs per cycle. This sample contains a total of 2.1 ML of InAs, well beyond the 1.7 ML critical thickness in SK growth. Remarkably, the image clearly shows 2D islands of InAs, indicating that this is still in the 2D growth regime. These 2D InAs islands possess topographical features resembling those of SK-grown wetting layers (WLs) and quantum well islands (QWIs).[4] Images taken of sample with 0.6 ML InAs (not shown) show largely similar features.

Shown in Fig. 2(B) is corresponding AFM image of the sample with 0.8 ML deposited InAs per cycle. This sample contains a total of 2.4 ML of InAs, which is only 0.3 ML or 14% more than that of the sample in Fig. 2(A). Equally remarkably, the image clearly shows the formation of 3D structures, indicating that the critical thickness has been surpassed, lying in the 3D growth regime. The 3D structures possess topographical features resembling those of SK-grown quantum dots (QDs). Within the AFM resolution limit, the structures appear to be pyramid shaped and 10 nm in height. We also note that the 3D structures seem to form in lower plateaus or in step-like terraces, which suggests that the onset of the formation of these 3D structures tend to deplete the InAs from surrounding 2D islands. Together, these results indicate that InAs SML structures exist in two distinct forms: 2D WL-like islands and 3D QD-like structures. Also, results suggest that the abrupt transition proceeds in a SK-like behavior.

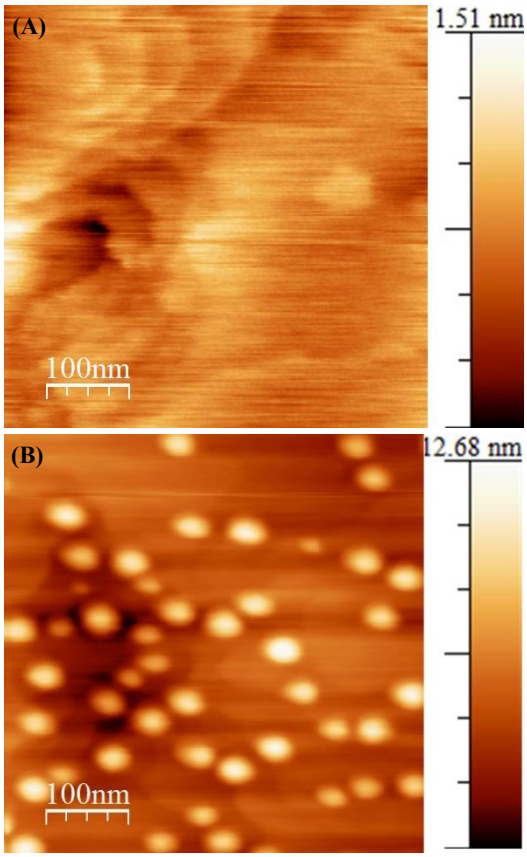

Figure 2. 500×500 nm^2 AFM images of 3-stack SML samples with (A) 0.7 and (B) 0.8 ML deposited InAs per cycle.

In conclusion, we present strong topographical evidence of the 2D to 3D transition is InAs SML nanostructures. Results demonstrate that there exists a critical thickness in the amount of InAs deposited per cycle, beyond which abrupt formation of 3D structures occurs. This work presents insight that is crucial in understanding the mechanisms of the SML growth mode.

Acknowledgement: This work was partly supported by Iketani Science and Technology Foundation.

References: 1.) Y. Kim *et al.*, J. Korean Phys. Soc. **73**, 833 (2018). 2.) I. Kamiya *et al.*, Physica E **2**, 637 (1998). 3.) I. Han *et al.*, Appl. Surf. Sci. **526**, 146713 (2020). 4.) I. Kamiya *et al.*, IEEE 39th PVSC, 14116445 (2013).