Post-growth annealing of Stacked Submonolayer (SML) InAs Nanostructures

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Stacked submonolayer (SML) growth of InAs nanostructures by MBE has been gaining interest recently for various optoelectronic applications, as an alternative to the well-known Stranski-Krastanov (SK) growth.[1] In contrast to SK growth, stacked SML growth involves the cycled deposition of SML-thick InAs and few ML-thick GaAs. We have recently reported the existence of a 2D to 3D transition in SML nanostructures, which leads to the formation of two distinct types of SML nanostructures: 2D islands and 3D structures.[2,3] 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 investigate the influence of post-growth annealing (PGA) on the 2D to 3D transition in SML nanostructures. In the case of SK nanostructures, it has been reported that PGA can spontaneously induce a transition to 3D growth from subcritical-thick wetting layers.[4]

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. After the growth of the SML structures, no capping layer was deposited and the temperature was kept at 500°C for the duration of the PGA. Samples were then quenched following the PGA. Topographic images were acquired by *ex situ* AFM. Measurement resolution is assumed to be limited by probe tip radius of ~7 nm.

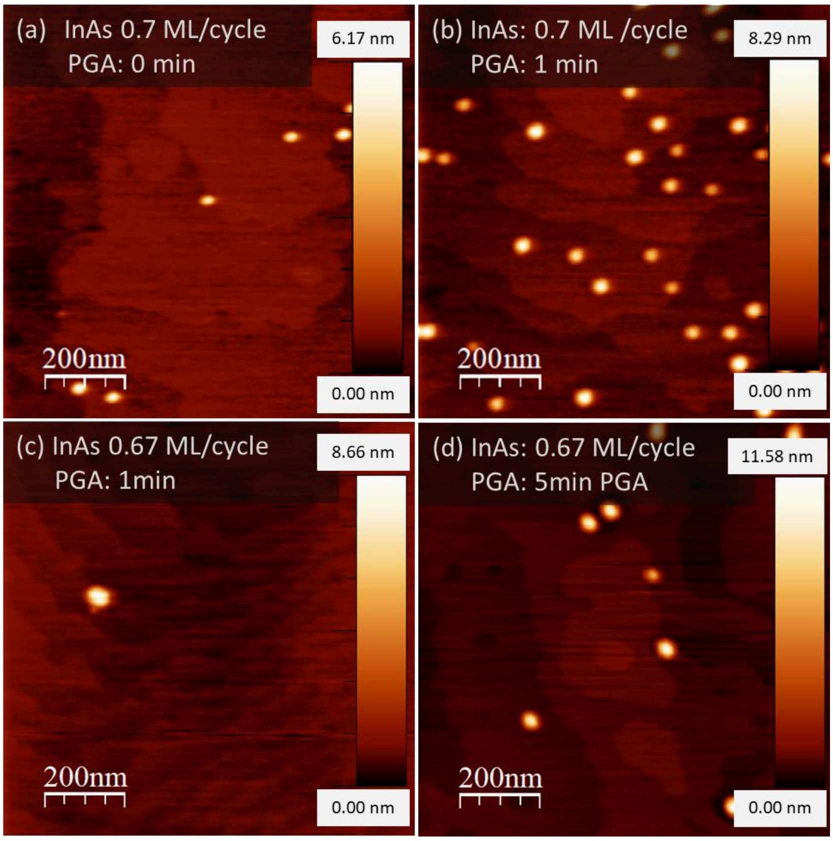

Figure 1. 1.0×1.0 μm^2 AFM images of 3-stack SML samples with (a) 0.7 or (b) 0.67 ML/cycle of InAs with various PGA conditions: (a) no PGA, (b) and (c) 1 min, and (d) 5 min. The GaAs spacer was kept at 2.0 ML.

Summarized in Fig. 1 are the topographical images of the samples. Figs. 1(a) and (b) demonstrate the effect of 1 min PGA of SML nanostructures with 0.7 ML/cycle of InAs (total InAs ≈ 2.1 ML). Even with only 1 min of PGA, the density of 3D structures was significantly increased from ~5×10^8 to ~7×10^9 cm^{-2}. This result can be understood by considering that the PGA provides more time for the development of 3D structures.[4] Figs. 1(c) and (d) show the effect of longer PGA on SML nanostructures with lower InAs of 0.67 ML/cycle (total InAs ≈ 2.0 ML). This result reveals that further increase in the 3D structure density is possible by longer PGA of 5 min, increasing the density from ~10^8 to ~10^9 cm^{-2}, even with less total InAs. This result suggests that the transition from 2D to 3D growth regime and the formation of 3D structures can take up to several minutes to fully complete.

In conclusion, the effect of PGA on the 3D structure density of InAs SML nanostructures has been elucidated. PGA provides another method to control the 3D structure density in SML nanostructures. Such control is desirable to applications requiring fine control of the 3D structure density, such as single photon sources.

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References:

1) Y. Kim *et al.*, J. Kor. Phys. Soc. **73**, 833 (2018).
2) R. Roca & I. Kamiya, Jpn. J. Appl. Phys. **60**, SBBH06 (2021).
3) R. Roca & I. Kamiya, Phys. Stat. Sol. B **258**, 2000349 (2021).
4) H. Song *et al.*, Phys. Rev. B **73**, 115327 (2006).