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The formation of dense Si nanocrystals in Si/Si_3N_4 superlattices by the ultra high vacuum ion beam sputtering deposition

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During past decades, Si quantum structures (QS), such as quantum dots and layers have gathered a lot of interest, since they have wider bandgap and higher light emission efficiency compared to bulk Si, thanks to the quantum confinement effect in Si QS. Therefore it has been expected that QS thin films are applied to efficient photonic, nonvolatile memory, and photovoltaic devices, with the help of present mature Si technology. The high temperature anneal of amorphous SiO_x films has been widely used for the rapid production of robust Si QDs. However, the volume fraction of QDs in these SiO_x films is relatively low and consequently leading to poor electrical properties due to long inter-dot distance. In addition, the carrier injection into the films is not easy since oxide layers act as huge potential barrier.

In this study, the formation of dense Si nanocrystals in Si/Si_3N_4 superlattices with ultra thin Si_3N_4 layers is discussed. Si/Si_3N_4 superlattice films with Si layers of 3 nm and Si/Si_3N_4 layers of 0.3 nm were grown on Si (100) substrates at room-temperature, by an ultra high vacuum ion beam sputtering deposition. The base and deposition were $\sim 10^{-8}$ and $\sim 10^{-4}$ Torr, respectively. Transmission electron microscopy (TEM) images clearly show that the ultrathin Si_3N_4 layers well separated the adjacent Si layers demonstrating high Si volume fraction as > 90 %. By the examination of the effect of anneal temperature, this layered structure could remain even after thermal annealing up to 900 ^oC, and Si layers begin to be crystallized at 900 ^oC. High resolved TEM investigation revealed that lamina-shaped Si nanocrystals were formed with average thickness of 2.2 ± 0.6 nm. Si and N atomic distributions were monitored by an energy filtered-TEM (EF-TEM), and it is found that very low thermal-anneal induced diffusion of N atoms as 0.4 nm implies ultra thin Si_3N_4 acts as protecting layers against the intermixing adjacent Si layers at high temperature anneal.