in-situ atomic-level 3D imaging of InAs quantum dot formation process on GaAs(001) during molecular beam epitaxy growth

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Self-assembled quantum dots (QDs) are strong candidates for advanced semiconductor laser and quantum devices. However, the precise physical mechanism of self-assembly is not well understood yet. Here we show dynamic images of InAs QD formation on GaAs(001) obtained using a unique scanning tunneling microscope (STM) placed within a molecular beam epitaxy (MBE) growth chamber: STMBE [1, 2]. These elucidate the mechanism of QD nucleation, demonstrating directly that not all deposited In is initially incorporated into the lattice, hence providing a large supply of material to rapidly form QDs via islands containing tens of atoms [2]. And Kinetic Monte Carlo (KMC) simulations based on first-principles calculations show that alloy fluctuations in the InGaAs wetting layer (WL) are crucial in determining nucleation sites at 430°C [2]. The distribution patterns of the WL reconstruction domains have been measured and statistically compared to that of QD nucleation sites by using spatial point analysis [3] and a nearest-neighbor analysis of the STM images found that the point pattern of QD precursors was similar to that of (1x3)/(2x3) WL reconstruction domains which were specific to Ga-rich fluctuation [4]. Next, by using this system, a high-quality site-controlled single InAs QD was successfully fabricated during InAs growth [5, 6]. Moreover, we have also confirmed that In atoms were favored to congregate inside hole structures, during In and As4 irradiations [7]. After forming 1.5 monolayer of InAs wetting layer (WL) on GaAs(001) surface, we applied voltage at a particular site on the WL during As4 irradiation at 300°C, creating hole structures (widths: 33−66 nm, depths: 4.9−9.7 nm). With the In and As4 irradiations, spontaneously, In atoms on the WL were congregated inside the holes, decreasing the volume of the hole structures. It was found that InAs growth rates inside the hole structures were 23-217 times larger than that at the WL growth region near the holes. And also we observed shallow trenches (trench depth: ~ 1.0 nm) around InAs QDs at 300°C [8].

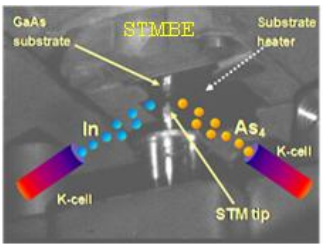

Figure 1: STMBE system

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