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Self-assembled GaAs antidots growth in InAs matrix on (100) InAs substrate

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1. Introduction

Low-dimensional physics in semiconductor nano-structures, such as quantum wells, quantum wires and quantum dots have attracted much interest in recent years. Among these nano-structures, the two-dimensional (2-D) wells and barriers have been grown since the 1970s. The defect-free zero-dimensional quantum dots (QDs) have also been achieved since the early 90's using the self-assembly growth technique. Many interesting properties and phenomena of these QDs have been studied. In contrast, the study on the growth and characteristization of quantum antidots (QADs) is seriously lacking. Recently, many interesting phenomena related to antidots have been observed [1-3]. However, in these studies, almost all the antidots were fabricated using external processing techniques, such as e-beam lithography, atomic force microscopy related methods and focused ion beam[1-5]. The defect-free, self-assembled growth of antidots was rarely studied [6-9].

In the growth of self-assembled InAs/GaAs QDs in Stranski-Krastanow mode, the surface energy minimization dominates the surface morphology of InAs layer. When the deposited amount of InAs increases to the so-called critical thickness (about 1.5ML), the 2-D to 3-D transition happens due to the strain-induced increment of surface energy. The surface energy depends on many factors, such as lattice mismatch between GaAs and InAs, substrate temperature, growth rate, III/V ratio, etc.. To obtain a quantum-size 3-D island, it is necessary to have a large enough lattice mismatch between two materials. In InAs/GaAs system, the lattice mismatch is about +7%. For InAs QDs, the strain in the dots is compressive. For GaAs/InAs anti-dots, the strain becomes tensile in the dots. The 2-D to 3-D transition for the anti-dot formation naturally also depends on the amount of lattice mismatch, material elastic constant and other material parameters. These factors determine the critical thickness under definite growth conditions. In this work, we studied experimentally the GaAs antidots growth in InAs matrix on (100) InAs substrate. Under proper growth conditions, 3-D island formation has been observed clearly by both AFM and TEM methods. The critical thickness and antidots sizes are discussed in detail.

2. Experimental result and discussion

The samples were grown on the (100) InAs substrate by a solid-source Varian Gen II molecular beam epitaxy (MBE) system equipped with an arsenic cracker cell. After native oxide desorption at 510°C, a 0.5μm InAs buffer layer was deposited before the GaAs growth. With about 40nm InAs spacer, 1.5ML, 1.75ML, 2ML, 2.25ML, and 2.5ML GaAs were deposited sequentially. After the last GaAs layer was deposited, the sample was cooled down under arsenic flux. Migration-enhanced epitaxy (MEE) method was used for each GaAs layer growth. That is, after each 0.25ML GaAs deposition, we introduced growth interruption for 10 seconds. In this 10 seconds period, the arsenic shutter was kept open for the first 5 seconds, and then closed for the next 5 seconds. The growth temperature and the growth rate for GaAs were 500°C and 0.1μm/hr, respectively. The III/V beam equivalent pressure ratio of In (Ga) was 25 (10).

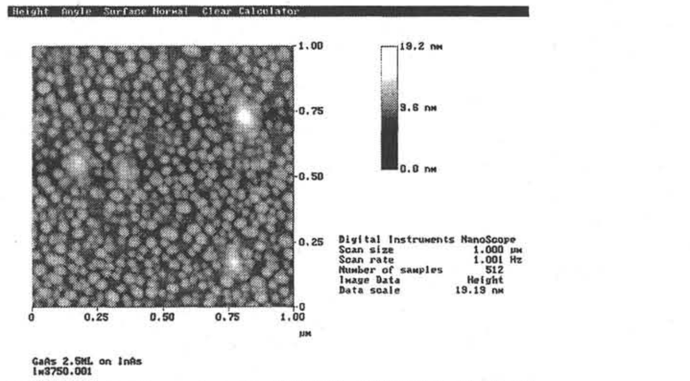
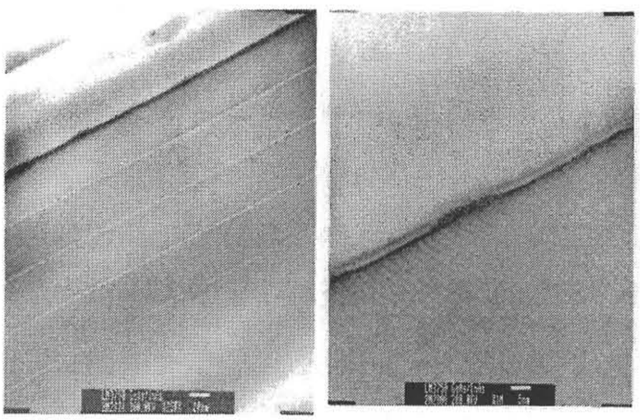


Fig.1 AFM image of 2.5ML GaAs on InAs

Fig.1 shows an atomic force microscope (AFM) image of the grown sample. The measurement was performed in the tapping mode by a DI-5000 AFM system. From the image, a clear 3-D, dot-like morphology is observed. From the surface profile analysis of the AFM, the shape of the islands is almost isotropic, with about 15-35nm in base diameter and about 2-4nm in height. The density of the GaAs antidots was about $3\text{-}4\times10^{10}cm^{-2}$ averaged over several observed $1\times1\mu m^2$ images.

Fig.2a and Fig.2b show the transmission electron microscopy (TEM) images for the sample. In Fig.2a, there are 5 layers of GaAs with different thickness as stated above. From the figure, we can see that for less than or equal to 2.25ML GaAs deposition, there is no 3-D island formation. For the fourth layer (with 2.25ML GaAs) from the bottom, strain fields in some isolated spots were observed. In the layer with 2.5ML GaAs deposition, clear quantum anti-dots were observed. The high-resolution TEM image for one of the GaAs antidots formed on the sample surface is shown in Fig.2b. From the figure, the exact size of the GaAs antidot could be obtained. The base diameter and height are about 20nm and 2.5nm, respectively. It is consistent with the AFM observation.



(a) **(b)**

Fig.2 TEM images of 5 layers GaAs (a), and one of GaAs antidots (b).

From our study, we can conclude that the critical thickness of 2-D to 3-D morphology tranisition for GaAs antodots on InAs is between 2.25ML and 2.5ML. It is considerably larger than 1.5ML, the critical thickness for InAs QD formation on GaAs.

3. Conclusion

In summary, we have grown GaAs antidots in InAs matrix successfully. The quantum-sized 3-D islands were observed clearly in both AFM and TEM measurements. From these observations, the critical thickness is determined to be between 2.25ML and 2.5ML. For 2.5ML GaAs deposition, the grown antidots have a size about 15-35nm in base diameter and about 2-4nm in height with a density about $3\text{-}4\times10^{10}cm^{-2}$.

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