Influence of $In_xGa_{1-x}As$ Underlying Layer on the Structural of the $In_{0.5}Ga_{0.5}As$ Quantum Dots Grown by MOCVD

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Abstract

The single layer $In_{0.5}Ga_{0.5}As$ quantum dots (QDs) were grown on a thin $In_xGa_{1-x}As$ underlying layer by metal-organic chemical vapour deposition (MOCVD) via Stranski-Krastanow growth mode. The effect of different indium composition in the $In-xGa_{1-x}As$ underlying layer was investigated using atomic force microscopy (AFM). AFM images show that the QDs structures were formed on the surface. The dots formation on the surface changes with different composition of $In_xGa_{1-x}As$ underlying layer. Increasing indium composition in the underlying layer resulted to formation of higher density and smaller size dots. Several large dots were also formed on the surface. Growing of underlying layer reduces the lattice mismatch between $In_{0.5}Ga_{0.5}As$ and GaAs, and decreases the critical thickness of the dots. This strongly influences the dots nucleation on the surface. Growth of quantum dots using underlying layer is one way to modify dot formation in order to achieve uniform QDs of right size and high density, which are essential for QDs device applications.

KEYWORDS: underlying layer, quantum dots, AFM, MOCVD

I. INTRODUCTION

Recently, $In_xGa_{1-x}As$ QDs fabricated on GaAs substrate by MBE or MOCVD using the Stranski-Krastanow (S-K) growth mode have been widely studied. Many of these investigations focused on the evolution of surface morphology and optical properties of self-assembled $In_xGa_{1x}As$ QDs. However, $In_xGa_{1-x}As$ QDs grown using Stranski-Krastanow growth mode are not sufficiently uniform in size and distribution to achieve high-performance optoelectronic devices [1]. High quality self-assembled QDs via Stranski-Krastanow growth mode using MOCVD or MBE still need more works to improve the size, shape, uniformity and density of the dots.

Several studies were conducted to improve the quality of self-assembled QDs using underlying layer. Deposition of underlying layer before QDs layer is believed to have strong effects on the formation of wetting layer followed by QDs formation. Several studies on the effect of underlying layer on InGaAs QDs were previously carried out using InGaAlAs [2] and AlGaAs [3,4] as the underlying layer. These studies show that the QDs interconnection via the underlying layer has strong influence on the structural and optical properties of $In_xGa_{1-x}As$/GaAs or InAs/GaAs QDs. The presence of an underlying layer between QDs layer and buffer layer also influences the carrier kinetic of the QDs [5]. This paper investigates the effect of indium composition in the thin InxGa1 xAs underlying layer on the structural of the $In-0.5Ga_{0.5}As$/GaAs QDs using Stranski-Krastanow growth mode by MOCVD. The result shows significant difference in size, uniformity and density of the dots.

II. EXPERIMENTAL PROCEDURE

Single layer $In_{0.5}Ga_{0.5}As$ QDs were grown by Stranski-Krastanow growth mode in the vertical chamber "Nanoepi Versatility 2×1" MOCVD system. Schematic illustration of the cross-section of the samples with single layer $In_{0.5}Ga_{0.5}As$ QDs grown on a thin $In_xGa_{1-x}As$ underlying layer is shown in Figure 1.

The precursors used for the growth of GaAs layer and $In_{0.5}Ga_{0.5}As$ QDs were trimethylgallium (TMGa), trimethylindium (TMIn) and arsine (AsH3). Prior to growth, substrate was heated to 750°C for 10 minutes under arsine flow to remove oxides on the its surface. The growth began with 200 nm GaAs buffer layer followed by a 10 nm thin $In_xGa_{1-x}As$ underlying layer at temperature of 650°C. The nominal composition of the InxGa1 xAs underlying layer was

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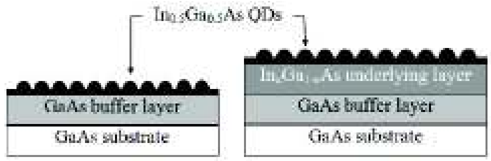
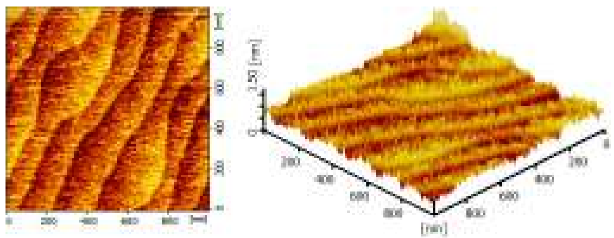
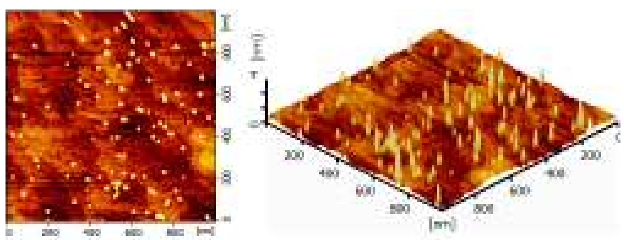


FIG. 1: Schematic cross-section of the samples QD



(a)



(b)

FIG. 2: AFM images of (a) surface morphology of 200 nm GaAs buffer layer and (b) 4.7 ML $In_{0.5}Ga_{0.5}As$ QDs grown on GaAs buffer layer

varied between x = 0.1, x = 0.15, and x = 0.2 by changing the In/Ga flux ratio. After deposition of the buffer layer and underlying layer, growth temperature was lowered to 550°C and 4.7 ML $In_{0.5}Ga_{0.5}As$ QDs were grown. The growth rate of In0.5Ga0.5As was estimated to be 1.1 μm/hour at 76 Torr. The pressure reactor and growth parameters were fixed during deposition process. Finally, the samples were cooled down to 400°C under group-V precursor to limit desorption of As (arsenic) from the surface. The size, uniformity and density of the dots were investigated using SII AFM system.

III. RESULTS AND DISCUSSION

Figure 2 shows the AFM images of GaAs buffer layer surface and the $In_{0.5}Ga_{0.5}As$ QDs grown on GaAs buffer layer. The surface morphology of 200 nm GaAs buffer layer is shown in Figure 2(a). These AFM images show the multi-atomic steps were formed on the surface of the buffer layer. The formation of this steps was along [$\bar{1}$ 10] direction as determined by Ishihara *et al.* [1] and Kitamura *et al.* [6]. GaAs multi-atomic steps naturally formed on GaAs (100) substrate during epiatxial growth using MOCVD. The terraces were atomically flat with the width of the terraces between 100 to 250 nm. Non-uniform terrace-width due to a surface diffusion length of reacting species smaller than the terrace-width, leads to an aggregation of adatoms forming 2D islands as reported by Dumont *et al.* [7]. From AFM measurement, the height of the step on the surface was between 0.3 to 0.5 nm and the average step width was 10 nm. In another study by Ishihara *et al.* [1], the misoriented substrate causes the formation of the multi-atomic steps on the surface of the buffer layer. The formation of multi-atomic steps from GaAs buffer layer affects the formation of QDs on the surface.

AFM images of the $In_{0.5}Ga_{0.5}As$ QDs that were grown on 200 nm GaAs buffer layer are shown in Figure 2(b). Transition from two-dimensional to three-dimensional growth clearly occurs in this sample, where the dots are spontaneously formed on the surface of GaAs buffer layer. Results of AFM measurements reveal that the average height, diameter, and density of the QDs are approximately 4 nm, 18 nm and 1.04 $\times$ 10^{10} cm^{-2}, respectively. From the AFM images, it can be seen that $In_{0.5}Ga_{0.5}As$ step edges were formed on the buffer layer and most of the QDs were formed on these steps edges. The $In_{0.5}Ga_{0.5}As$ steps edges were influenced by the GaAs step edges in the process of this growth mode. The QDs grew randomly on the surface but are most likely to grow near the step edges compared to the terrace centre. This result is similar to the results obtained by Kitamura *et al.*, [6] where there were no QDs at the terrace centre of the surface with increasing growth time of QDs. In this work the step width is almost similar to the diameter of the dots, so it is impossible for nucleation sites of the dots to be distributed widely over the steps area. Only one of the dots could be successively grown on the steps edges and the dots were randomly distributed as shown in AFM images.

The influence of a thin $In_xGa_{1-x}As$ underlying layer on the growth of self-assembled $In_{0.5}Ga_{0.5}As$ QDs is shown in Figure 3. The evolution of size, uniformity, and density of self-assembled $In_{0.5}Ga_{0.5}As$ dots can be seen in the AFM images. The dots are small elliptical shaped where quantitative result of the AFM measurement. The dots density of the samples changes with different composition of indium in the underlying layer. The dots density of samples (a), (b), and (c) are 1.62 $\times 10^{10} cm^{-2}$; 3.39 $\times 10^{10} cm^{-2}$; and 2.42 $\times 10^{10} cm^{-2}$, respectively. The density of self-assembled $In_{0.5}Ga_{0.5}As$ QDs increases as the effect of $In_xGa_{1-x}As$ underlying layer. As reported by He *et al.*, [8] density of InAs QDs is increased by the growth a thin $In_{0.15}Ga_{0.85}As$ underlying layer between the QDs and the buffer layer. The increment of the indium content from 0.10 to 0.15 in the $In_xGa_{1-x}As$ underlying layer causes the dots to become smaller in size and higher in density. In contrast, the size of dot is constant but the dots density decreases when indium content is increased from 0.15 to 0.20. Several large dots can also be seen formed on the surface when the indium content of underlying layer is increased as shown in Figure 3(b) and (c).

The changes of size and shape of self-assembled $In_{0.5}Ga_{0.5}As$ QDs formation can clearly be seen in AFM images. Formation of larger dots is increased when indium content of the underlying layer is increased. Coalescence of

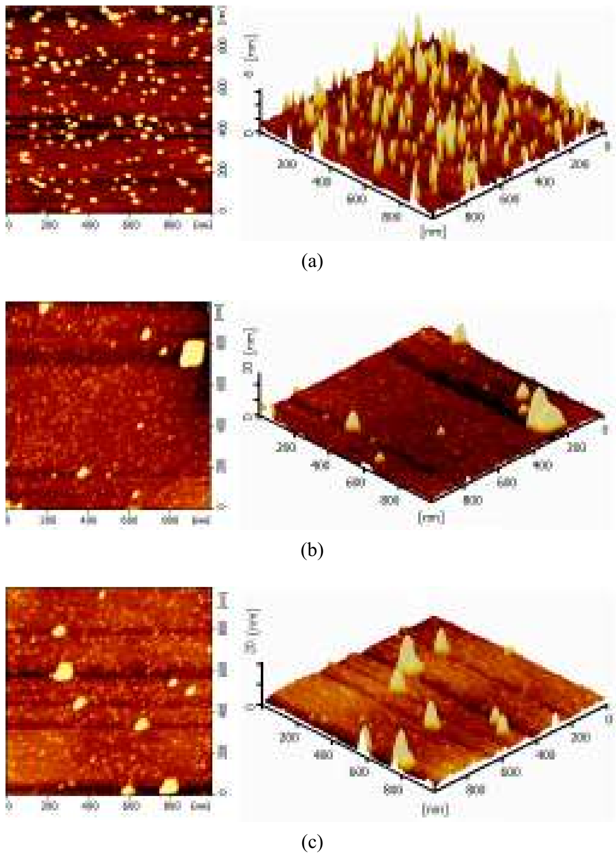


FIG. 3: AFM images of $In_{0.5}Ga_{0.5}As$ QDs grown on GaAs (100) substrate using InxGa1-xAs underlying layer (a) x=0.10; (b) x=0.15; and (c) x=0.20, respectively.

the dots was due to the increasing diffusion energy of the dots as an effect of the increasing indium content in the underlying layer. It was also caused by the decreasing of critical layer thickness of QDs due to presence of $In_xGa_{1-x}As$ underlying layer. When the thickness reached over a critical thickness, two or more dots generally merged into one larger dots and the strain energy is relaxed as dislocation were incorporated in the dots [9]. The indium diffusion atom from InxGa1-xAs underlying layer to $In_xGa_{1-x}As$ QDs is believed to supply in the formation of the larger dots.

The evolution of size and density of the dots on the top most is affected by the structural surface of $In_xGa_{1-x}As$ underlying layer with different composition. The relief of strain on the surface of underlying layer is influenced by carrier kinetics [5], which contributes to the transition from the 2D to the 3D growth mode. The growth of $In_xGa_{1-x}As$ underlying layer between $In_{0.5}Ga_{0.5}As$ and GaAs reduces the lattice mismatch. In Stranski-Krastanow mode, the dots/islands formed on the surface as a result of elastic strain relaxation of a lattice-mismatched system. Transition from layer-by-layer to island growth occurs at the critical layer thickness, which is it important depends on the surface energy, strain energy [10] and lattice-mismatch systems [9,11]. As shown by Jiang *et al.* [2], the underlying layer has significant contribution in the formation of the dots. This is due to the inhomogeneous strain in the surface of underlying layer which controls the nucleation and growth of the dots on the surface. The fundamental surface properties such as steps, reconstructions, facets, defects and strain state of the matrix materials are also found to affect the QDs size uniformity.

IV. CONCLUSION

The structural of single layer $In_{0.5}Ga_{0.5}As$ QDs grown on $In_xGa_{1-x}As$ underlying layer were investigated. Formation and evolution of the dots occurs on the surface as a result of different indium composition in the $In_xGa_{1-x}As$ underlying layer. With different indium contents, the strain energy on the surface also changes thus affecting the formation of the QDs. Increasing indium composition in the $InxGa1-xAs$ underlying layer causes lattice mismatch to reduce and decreases critical layer thickness of the dots. This causes several larger dots to form on the surface. However, the dots density was improved by growing a thin $In_xGa_{1-x}As$ underlying layer between the $In_{0.5}Ga_{0.5}As$ QDs and GaAs layer. In the growth studies of $In_{0.5}Ga_{0.5}As$/GaAs QDs, the interaction between the underlying layer and the QDs is considered to be important.

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