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Composition of the “GaAs” quantum dot, grown by droplet epitaxy

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ABSTRACT

Self-assembled strain-free quantum dot (QD) structures were grown on AlGaAs surface by the droplet epitaxal method. The QDs were developed from pure Ga droplets under As pressure. The QDs were investigated by atomic force microscopy (AFM) and transmission electron microscopy (TEM). Both techniques show that the QDs are very uniform in size and their distribution on the surface is also homogeneous. The high resolution cross-sectional TEM investigation shows perfect lattice matching between the QD and the substrate, and also the faceting of the side walls of QD can be identified exactly by lattice planes. Analytical TEM (elemental mapping by EELS) unambiguously identifies the presence of Al in the QD.

1. Introduction

Recently, the growth of self-assembled quantum structures has been intensively investigated for basic physics and device applications. It is very important to understand their growth process and to know their particular shape. The archetypal system of these nanostructures is the lattice-mismatched system such as InAs on GaAs, where the strain-induced process leads to the formation of quantum dot (QD) [1,2]. Detailed electronic structure of QD, which governs electronic and optical properties, depends on the shape [3,4]. It is generally accepted, that one of the essential

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driving forces, for coherent lattice mismatched QD formation, is strain relaxation [5]. In this field, the self-assembled lattice matched quantum structures, employing droplet epitaxy, is an interesting and novel alternative for the the estabilished technology of strain-driven QD formation [6,7]. Today, no theoretical description is available for the underlaying growth mechanism, the development of the facetting, in the case of droplet epitaxy. It is very important to understand the growth kinetics. In this paper, we focus on the composition and evolution of the dropletepitaxial QDs, investigated by the transmission electron microscopy (TEM). We compare the corresponding atomic force microscopy (AFM) results with TEM images.

2. Experimental

We studied the process responsible for the droplet epitaxial formation of GaAs QDs on AlGaAs by various experimental techniques. The growth experiments were performed in a solid source molecular beam epitaxy (MBE) system equipped with effusion cells for Ga and Al evaporation and a valved cracker cell for As. The evolution of the growth front was monitored with reflection high-energy electron diffraction (RHEED). The substrate material was an exactly oriented GaAs(001) wafer with a diameter of 50 mm. On the substrate, at first, a pure GaAs layer was grown, followed by an $Al_{0.3}Ga_{0.7}As$ layer, with a thickness of 180 nm.

The droplet-epitaxial QDs were prepared in the following manner. After the growth of the $Al_{0.3}Ga_{0.7}As$ layer, the sample was cooled down to 200 °C. The $\theta = 3.75$ ML Ga was deposited with a flux of 0.19 ML/s without As flux. After the deposition of Ga we waited 60 s still without As ambient pressure, that was followed by a 120 s processing under an As pressure of 6.4×10^{-5} Torr. The process of annealing, at 350 °C, was carried out under the same As pressure for 10 min. The formation of the quantum objects was tracked continuously in the direction of the [1–10] with the help of RHEED.

Immediately after the growth process the samples were characterized by atomic force microscopy (AFM). The AFM measurement was carried out in the tapping mode on the middle part of the wafer. After the AFM study, the surface was covered with photoresistant lacquer (product of Shipley) to protect the quantum objects. Thinned cross sectional specimens were prepared for TEM by the usual way (cutting, embedding into a special holder, mechanical grinding and polishing and finally ion beam milling with 10 keV Ar ions). A conventional TEM study of the samples was performed with a Philips CM20 electron microscope working at 200 kV. The high resolution images and the elemental maps were taken by a 300 kV JEOL 3010 dedicated high resolution microscope, equipped with an imaging filter (GATAN Tridem model).

3. Discussion

The formation of the QDs on AlGaAs (001) surface were observed by in situ RHEED. At the start of the process, the RHEED pattern of the surface shows sharp streaks. After the Ga deposition, the pattern becomes diffused on the RHEED screen (stage A). Almost at the same time with the opening of As cell (pressure of 6.4×10^{-5} Torr), the RHEED pattern changed from diffused to spotty (stage B). During the annealing phase, the pattern has changed slowly (some minutes) from spotty to spots with chevron tails [8].

Fig. 1 shows the quantum dots as observed on the AlGaAs surface by AFM (A) and by TEM (B). To make the latter image, the cross sectional TEM specimen was tilted by 30°. Both images show, that the QDs have uniform shapes and the sizes were distributed homogeneously on the surface. A part of the region of 1 μm $\times$ 1 μm is recorded in perspective and shown in Fig. 1(A) (upper insert). The mean dimensions of QDs (60 nm base width and 7.5 nm height) were determined from individual line scans of the height. An example of one of these scans (from the marked QD at the middle of the image) is shown on the lower insert of Fig. 1(A). The surface density of QDs was determined from AFM pictures as 1.5×10^{10} cm^{-2}. The TEM image of the tilted sample (Fig. 1(B)) confirms the presence of the homogeneously distributed QDs of uniform size. Their density (calculated from the TEM image taking into account the tilt angle) was found 2.5×10^{10} cm^{-2}, slightly different from the value measured by AFM. This small deviation may come from the little macroscopic inhomogeneity of the sample (the