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Volmer–Webber epitaxial growth of InAs nanoscale islands on Si(100)

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Abstract. InAs/Si(100) heteroepitaxial growth is studied with reflection high-energy electron diffraction and scanning electron microscopy methods. It is shown that under certain growth conditions the formation of InAs nanoscale islands on Si(100) surface occurs via Volmer Webber growth mechanism.

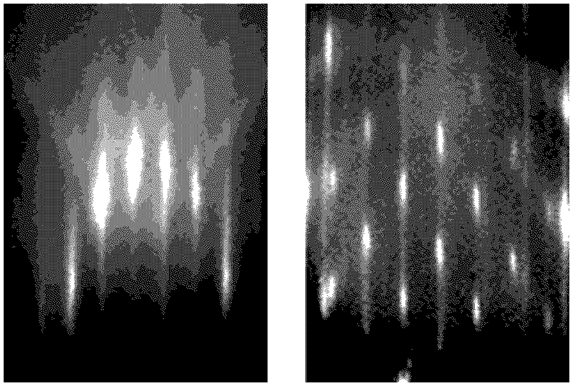
Recently we proposed to use coherent narrow gap InAs quantum dots in a silicon matrix for development of Si-based light-emitting devices. By now the possibility to form coherent nanoscale InAs islands on Si(100) surface directly during molecular beam epitaxial (MBE) growth is demonstrated. Photoluminescence (PL) signal was observed for InAs quantum dot array embedded in a silicon matrix up to room temperature. It is shown that the PL band originating from InAs quantum dots is in the 1.3–1.6 micron range depending on the observation temperature [1]. This wavelength range is important for various applications, *e.g.* fiber optics, medicine, biology *etc.*

However, the development of light emitting devices based on the nanoscale islands in the active region requires further basic and technological research. InAs/Si band alignment, the role of strain, size and shape of nanoscale island in designing the necessary bandgap profile is still unclear. In addition, the effect of growth regimes on size and shape of InAs islands is not yet studied in detail.

In this paper we report an effect of the growth conditions on realization of the epitaxial growth mode (Stranski–Krastanow or Volmer–Webber) during heteroepitaxy of InAs on Si(100).

The growth experiments are carried out using EP1203 MBE machine (Russia) or Riber 32 Supra (France) on exactly oriented Si(100) substrates. The Si(100) surface preparation is made in a way similar to that described in [2]. Thermal desorption of silicon native oxide layer is performed at substrate temperature of 800−820 °C during 15 min. After that, well resolved (2×1) or mixed (1×2) and (2×1) surface reconstructions typical for cleaved Si(100) surface has been observed. Then the substrate temperature is gradually decreased to the desired value and the InAs deposition is initiated in a conventional MBE mode. The InAs deposition rate is 0.1 monolayer (ML) per second. A calibration of the growth rate, III–V flux ratio, and monitoring of the surface morphology during growth has been performed using reflection high energy electron diffraction (RHEED) system composed of a high sensitivity video camera, a video tape recorder and a computer, all interconnected via a specially designed interface [3]. Pieces for scanning electron microscopy (SEM) studies are taken from the same wafers, but InAs nanostructures were previously capped with 30 nm silicon.

We have recently shown that the critical thickness T_c for the formation of InAs 3D islands on the Si(100) surface significantly depends on the growth conditions (*e.g.*, substrate temperature and fluxes ratio). We have found that T_c is in the range of 0.7–5.0 monolayers



(a) (b)

Fig. 1. RHEED patterns before (a) and after (b) deposition of InAs (2 monolayers) at 10 keV. Images are taken in [011] direction.

of InAs for the substrate temperature range 350–450 °C a fluxes ratio ~ 2–10 [4]. We could expect the realization of Volmer–Webber growth mechanism for a case of the critical thickness less then 1 ML. This growth mechanism was observed previously for different heteroepitaxial systems, *e.g.* GaAs/Si.

In Fig. 1(a,b) RHEED patterns for Si(100) surface just before the deposition of InAs (a) and after deposition of 2 ML of InAs at $T_s = 380°$ C and fluxes ratio = 10. For these particular growth conditions we observe a change of 2D to 3D growth mode at average InAs thickness ~ 0.7 ML.

For the pattern in Fig. 1(a) only streaky-like features responsible for a atomic-smooth Si surface are observed. In contrast, in Fig. 1(b) there is coexistence of the peculiarities from both silicon surface (elongated streaks) and nanoscale InAs islands (spots) which began to appear just after the critical thickness is exceeded. There is also evident the difference in lattice constants for substrate and deposited material.

We speculate that for the latter case the situation is the following. After initiation of InAs deposition, on the bare Si substrate the nuclei of InAs start to appear very rapidly. At the continuation of the growth, the island density remains the same with the increasing of their volume only. At the same time the part of Si surface is free from InAs deposit. This is typical for Volmer–Webber growth mechanism. Another situation was observed for Stranski–Krastanow growth mechanism, typical for, *e.g.* InAs/GaAs system or the same InAs/Si, but other growth conditions [5]. Here the formation of nanoscale islands occurs on the top of wetting layer, when first ~ 1.5 ML of deposited material grew via layer-by-layer growth mode. In Fig. 2 SEM image of the sample with the islands growing via Volmer–Webber growth mechanism realization is presented. The coexistence of relatively small (~ 20 nm) and high (~ 50 nm) islands pyramidal in shape and smooth silicon InAs-free space in between them is seen (real size of the islands is smaller due to presence of thin Si cap layer). The orientation of sides of the islands is [011] and [0$\bar{1}$1], opposite to the situation with the islands formed via Stranski–Krastanow mode [5], where dense array of the islands was observed with the preferential orientation along [011] and [001] directions. In conclusion, we have demonstrated the possibility of the formation of InAs nanoscale islands on Si(100) surface via Volmer–Webber growth mechanism that sheds more light in a heteroepitaxial growth processes in this system. This is also important for the tuning of

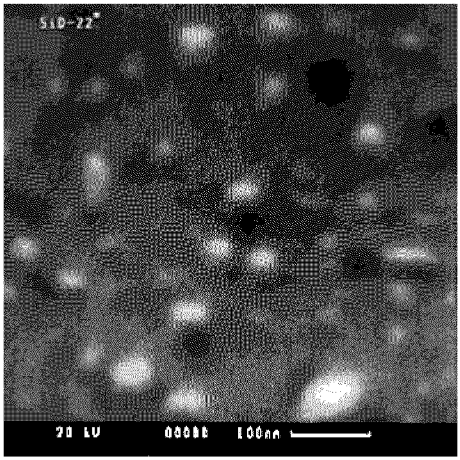


Fig. 2. SEM image of the surface after deposition of 2 ML InAs in a Volmer–Webber growth mode. Sides of the image are parallel to [011] and [0$\bar{1}$1] directions.

the lateral size in order to achieve appropriate geometry of the nanoscale islands.

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