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Influence of elastic strains and growth temperature on synthesis of self-assembled GeSi nanoscale structures

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Abstract. Nanoscale structures such as quantum wells, quantum wires, quantum dots and quantum fortresses are obtained by molecular beam epitaxy (MBE) technique. Various surface morphology was controlled by changing of growth parameters. Formation of Ge quantum dots in hut-island form is observed during deposition of Ge on Si film or GeSi solid solution layer in temperature range between 300 and 500 °C. Density of Ge islands without use of surfactant reaches 3.5×10^{11} cm^{-2} at lateral size of 12 nm. Lowering growth temperature up to 300 °C emergence of quantum fortress array takes place at deposition of Ge on GeSi solid solution layer. By depositing a Ge wetting layer at thickness of 3–5 monolayers and subsequent continuous annealing we have obtained nanostructures in form of wires. The results of these studies can be useful in the field of infrared photodetectors, light-emitting diodes and ultrafast transistors.

Introduction

At present, nanostructures are particularly important objects in the nano- and optoelectronics. Based on structures including the quantum dots, quantum wires and quantum wells with the carrier charge confinement in three, two or one directions, respectively, can be designed devices with the new electronic and optical properties. A large number of papers published on the subject focus on to improve the technology of the synthesis of nanoheterostructures and study of phenomena associated with growth such as strain relaxation in systems with lattice mismatch, segregation, bulk diffusion and the effects related to the presence of the surfactant on the surface. The basic materials investigations have focused on the modification of the material to improve its optical and electronic properties in order to realize the efficient light emitting or absorption. The structures with the Ge quantum dots and wells are applied for mid-infrared (3–5 μm) and (8–12 μm) photodetectors, fiber-optic communications (1.3–1.55 μm) as well as Ge quantum dot light-emitting diodes [1,2].

1. Experimental

The experiments have been carried out by a molecular beam epitaxy (MBE) installation Katun C equipped with two electron beam evaporators for Si and Ge sources. The analytical equipment consisted of a quadrupole mass spectrometer, a quartz thickness monitor and a high energy electron diffractometer (20–24 kV). The RHEED patterns were monitored during the growth with the use of a CCD camera. The software allowed us to identify the superstructure and morphological transitions. The Ge and Si growth rate defined by quartz thickness monitors. The substrates for Ge/Si(100) and Ge/GeSi/Si(100) growth were p-type Si(100) wafers with a miscut of 0.5°. After chemical pretreatment the substrates loaded in the growth chamber and cleared in a low Si flow at 800 °C for 3–10 min. The appearance of the clear Si(100)-(2 × 1) superstructure was determined by the RHEED pattern. Ex situ scanning tunnel microscopy (STM) with an ultrahigh vacuum instrument Omicron-Riber was used for the observation of the surface morphology.

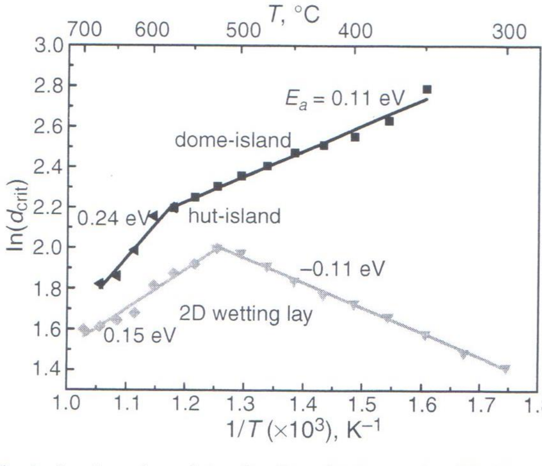

Fig. 1. Arrhenius plot of the Ge film thickness for 2D-3D and hut-dome transition at the Ge growth rate of 4 ML/min.

2. Results and discussion

Fig. 1 demonstrates the kinetic growth diagram of Ge on the Si surface in the temperature range of 300–700 °C. The curve corresponding to the 2D-3D transition has two areas which obey the Arrhenius law and relate to the different mechanisms of the two-dimensional growth: two-dimensional island mode in the temperature range of 300–525 °C and the step flow in the range of 525–700 °C. The activation energies are — 0.11 and 0.15 eV, respectively. The activation energy of the 2D-3D transition is determined on the base of the Arrhenius equation by the ratio between $\Delta \ln(d_{\text{crit}})$ and $\Delta(1/T)$ using Fig. 1. We also observed the transitions from hut-islands to dome-islands. The curve constructed for the hut-dome transition is approximated by two exponentials. The activation energy of the hut-dome transition is equal to 0.11 and 0.24 eV in the temperature ranges of 350–550 °C and 550–700 °C, respectively. The appearance of dome-islands is completely determined by the kinetic growth diagram of Ge on the Si surface (Fig. 1). The negative value of the activation energy for the hut-islands may be related to the roughness which increases with the decrease of the temperature and promotes the 2D-3D transition.

Based on the growth of Ge film on the Si surface we have obtained the kinetic growth diagram of Ge on the Ge$_x$Si$_{1-x}$ solid solution layer and compared the experimental results with the theory. The comparison is carried out from the consideration of the balance equation [3]. The analysis of changes of the surface