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Self-assembled strained GeSiSn nanoscale structures grown by MBE on Si(100)

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ABSTRACT

Gradual relaxation of elastic deformations in a silicon layer at the growth of a covering layer on strained layers was established. The dependence of the thickness of a silicon film, where full elastic strain relaxation occurs, on the germanium layer thickness was determined. The dependence of the critical thickness of 2D–3D transition of temperature and composition of the GeSiSn film on Si(100) was studied. Regularities of the formation of multilayer structures on quantum wells comprising pseudomorphous GeSiSn layers without relaxed buffer layers but creating the structures directly on Si. A possibility of synthesizing multilayer structures by molecular beam epitaxy was shown, and the crystal lattice constants using the high-resolution transmission electron microscopy were determined. Based on multilayer GeSiSn/Si structures the p-i-n-diodes, which demonstrated the photoresponse increasing by several orders of magnitude compared to the Sn-free structures at an increase in the Sn content, were created.

1. Introduction

Nanostructures are extremely important objects for nano- and opto-electronics. The studies in the field are mainly focused on modifying the materials to improve their optical and electronic properties in order to provide the efficient light emission or absorption [1–3].

MBE multilayer Ge-based heterostructures can comprise various strained pseudomorphous layers with the lattice constants conjugated to the silicon substrate. Different morphological states are characteristic of the layers: These may be atomic-smooth wetting layers and 3D islands of different size – from hut-clusters to quantum stretching threads [4]. Coherent islands can have vertical correlation due to elastic strains propagating from built-in strained Ge layers to the Si layer that grows over it. The vertical ordering of quantum-size objects gives rise to changing the band diagram as compared to that of single and disordered nanoobjects. As a result, the optical properties of these heterostructures change considerably: e.g., the photoluminescence intensity increases remarkably [5]. The strained state of epitaxial layers is varied by adding various materials, for instance, C or Sn, to change the band structure of the material.

For recent years, Ge–Si–Sn-based materials have become of special focus due to their potential applications in integrated silicon photonics, micro- and nanoelectronics, photovoltaics [6–11]. Addition of Sn to Ge makes it possible to control the lattice constant, energy diagram, charge-carriers mobility, efficient mass and defects. Besides, the minimum of the conductivity band for the L and Γ-valley decreases with an increase in the Sn content, the decrease at the Γ-point becomes faster. As a result, GeSn may behave as a direct band semiconductor at the 10% Sn content in relaxed layers and 6% in the films with stretching deformations [12,13]. The progress in the field of GeSn, GeSiSn [14–16] layer growth opens the way to modifying the band structure by controlling the voltage and composition. Besides changes in the electron and optical properties, the surface Sn favors the adatom surface diffusion [17] and the appearance of a series of superstructures unobserved in the GeSi [18] system. The main problems in synthesis of epitaxial GeSn and GeSiSn film are the low equilibrium solubility of Sn in Ge and Si ($<1\%$), segregation and precipitation; they are solved using nonequilibrium growth techniques such as MBE, magnetron sputtering, solid phase epitaxy, recrystallization and gas phase epitaxy (GPE) [19–21]. Ge–Si–Sn-based epitaxial layers containing up to 25% of Sn were obtained by reducing the growth temperature, controlling lattice misfits and

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