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Strained Multilayer Structures with Pseudomorphic GeSiSn Layers

V. A. Timofeev[a]*, A. I. Nikiforov[a, b], A. R. Tuktamyshev[a], M. Yu. Yesin[a], V. I. Mashanov[a], A. K. Gutakovskii[a], and N. A. Baidakova[c]

[a] *Rzhanov Institute of Semiconductor Physics, Siberian Branch, Russian Academy of Sciences, Novosibirsk, 630090 Russia*

[b] *National Research Tomsk Polytechnic University, Tomsk, 634050 Russia*

[c] *Institute for Physics of Microstructures, Russian Academy of Sciences, Nizhny Novgorod, 607680 Russia*

**e-mail: Vyacheslav.t@isp.nsc.ru*

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Abstract—The temperature and composition dependences of the critical thickness of the 2D–3D transition for a GeSiSn film on Si(100) have been studied. The regularities of the formation of multilayer structures with pseudomorphic GeSiSn layers directly on a Si substrate, without relaxed buffer layers, were investigated for the first time. The possibility of forming multilayer structures based on pseudomorphic GeSiSn layers has been shown and the lattice parameters have been determined using transmission electron microscopy. The grown structures demonstrate photoluminescence for Sn contents from 3.5 to 5% in GeSiSn layers.

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1. INTRODUCTION

In recent years, researchers have paid much attention to compounds based on Ge–Si–Sn materials in view of their potential for application in integrated silicon photonics, micro- and nanoelectronics, photovoltaics, thermophotovoltaics, telecommunications, and IR (infrared) detection [1–6]. By incorporating Sn into Ge, one can control the lattice constant, strain, energy diagram, carrier mobility and effective mass, and defects. In addition, the minimum of the conduction band for the L and Γ valleys decreases with an increase in the Sn content (with a higher rate at the Γ point). As a result, GeSn can become a direct-gap semiconductor at a Sn content of 10% for relaxed layers and 6% for tensile-strained films [7, 8]. Advances in the growth of GeSn and GeSiSn epitaxial layers [9–11] are opening up ways of modifying their energy-band structure by controlling strains in them and their composition. Along with a change in the electronic and optical properties, the presence of Sn on the surface enhances the surface diffusion of adatoms [12] and leads to the formation of a series of superstructures, which are not observed in the GeSi system [13]. The main problems in the synthesis of GeSn and GeSiSn epitaxial films, i.e., the low equilibrium solubility of tin in Ge and Si (< 1%), segregation, and precipitation, are solved using nonequilibrium growth techniques: molecular-beam epitaxy (MBE), magnetron sputtering, solid-phase epitaxy, recrystallization, and vapor-phase epitaxy (VPE) [14–16]. Epitaxial layers based on Ge–Si–Sn materials containing up to 25% Sn have been obtained by reducing the growth temperature and controlling the lattice mismatch and strained state [17]. In most studies devoted to the growth of GeSn and GeSiSn compounds, structures with thick relaxed Ge, GeSn, or GeSiSn layers were described. The main drawback of these structures is the presence of threading dislocations, which worsen the structural and optical properties of material.

In this paper, we suggest that relaxed layers be replaced with pseudomorphic elastically strained GeSiSn films grown directly on Si. The main advantage of pseudomorphic films over thick layers is that they do not contain dislocations and are coherent with the substrate. GeSiSn films are thermally more stable than GeSn [18], and their lattice parameter and band gap can be independently controlled. We obtain strained multilayer structures with pseudomorphic GeSiSn layers, exhibiting photoluminescence at Sn contents from 3.5 to 5% in GeSiSn layers.

2. EXPERIMENTAL

Multilayer structures containing pseudomorphic GeSiSn layers of different compositions (with a Sn content ranging from 0 to 10%) and thickness (in the range of 2–3.5 nm) were grown by MBE in ultrahigh vacuum conditions. The temperature and growth rate of GeSiSn layers in the multilayer structures were varied, respectively, in the ranges of 100–150°C and 0.075–0.43 monolayers/s (the thickness of one Sn monolayer on the surface of Si(100) is 0.184 nm). A Si layer was grown on GeSiSn layers at a temperature of