

Sn influence on MBE growth of GeSiSn/Si MQW

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Abstract. Temperature and composition dependencies of the critical thickness of transition from two-dimensional to three-dimensional growth for GeSiSn films on Si(100) with a lattice mismatch of 1 – 5% were experimentally determined. To understand the Sn influence on growth of SiGeSn/Si multi-quantum wells, the phase diagram of surface superstructures during the growth of pure Sn on Si(100) was created. A possibility of synthesizing multilayer structures by molecular beam epitaxy was shown, and the crystal lattice constants were determined using high-resolution transmission electron microscopy. We obtained GeSiSn/Si MQW structures which demonstrated photoluminescence for the Sn content in GeSiSn layers of up to 6%.

1. Introduction

The interest in GeSiSn materials is associated with the ability to create a direct bandgap semiconductor, as a double compound GeSn [1], and a ternary compound GeSiSn [2]. These compounds can be grown directly on a silicon wafer, providing the ability to create silicon photonics and optoelectronics devices operating in the IR spectrum. In recent years, a lot of articles on the creation of emitting devices and photodetectors, based on GeSiSn materials, have been published [3–6]. The structures, which were obtained in these studies, were grown on a silicon wafer using a 1 μm thick Ge buffer layer.

In the present work, we suggest to use pseudomorphic elastic-strained GeSiSn films grown directly on Si rather than relaxed layers. The principal advantage of pseudomorphic films against thick relaxed layers is that they are free of dislocations and coherent to the substrate. GeSiSn films are more thermostable than GeSn [7], their lattice constant and bandgap can be individually controlled as dependent on the composition.

In this work, GeSiSn multi-quantum wells (MQW) structures were grown directly on Si(100) substrates by molecular-beam epitaxy (MBE). The data about the initial growth stages of ternary compounds Ge-Si-Sn on Si(100) have been earlier obtained [8]. Using the reflection high-energy electron diffraction (RHEED) method [9], the kinetic diagrams of growth of $\text{Ge}_{1-x-y}\text{Si}_x\text{Sn}_y$ on Si(100) in a wide temperature range (150 – 500°C) and at different lattice mismatch (1 – 5%) between a GeSiSn film and a Si substrate were determined (figure 1). Based on the temperature dependencies of 2D-3D transition, the growth temperature and thickness of GeSiSn layers were chosen to achieve a pseudomorphic growth. The GeSiSn layer thickness was 2 – 3 nm and the growth temperature of GeSiSn layers was 150 – 200°C. GeSiSn layers act as quantum wells which are covered by a Si layer



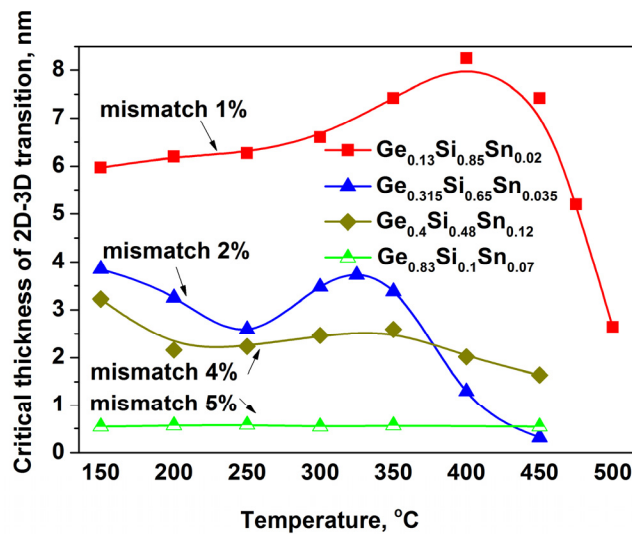


Figure 1. Kinetic diagram of GeSiSn film growth at different lattice mismatch. Generally, an increase in the critical thickness of 2D-3D transition is observed with a decrease of the lattice mismatch. Sn content is varied from 2 to 12%.

at higher growth temperatures (400 – 500°C) for smoothing the surface and also to create a potential barrier. The number of periods of a GeSiSn/Si heterostructure ranged up to 15 repetitions.

2. Results and discussion

Using the *in situ* RHEED technique during the growth of GeSiSn/Si MQW, a variety of superstructures such as (2x1), (2xN), (4x4), (6x4), (5x1) were observed on the growth surface. Similar surface structures were observed during the growth of pure Sn on Si(100) [10]. Thus, the appearance of various surface structures demonstrates the Sn surface segregation.

To prove the Sn segregation and to study the Sn influence on growth of GeSiSn/Si MQW, the phase diagram of surface superstructures during the growth of pure Sn on Si(100) was created (figure 2). Sn films were grown at a temperature of 100°C and then structures were annealed at a higher temperature up to 800°C. The Sn layer thickness reached 1.7 monolayer (MN). Different

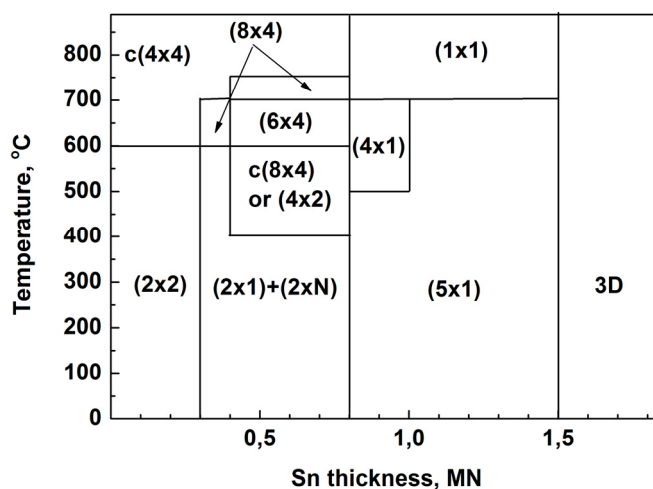


Figure 2. Phase diagram of surface superstructures during the growth of pure Sn on Si(100).

superstructures were observed at various annealing temperatures and growth thicknesses. It is clear that the appearance of (5x1) superstructure indicates a higher Sn content on the surface. Therefore, the appearance and disappearance of various surface reconstructions during the growth of SiGeSn/Si MQW show the surface quality and can assist in selecting the optimal growth parameters such as the growth temperature, a composition of the ternary compound and the number of periods of MQW structure.

High-resolution transmission electron microscopy (TEM) was used to characterize the crystal structure of the obtained samples (figure 3(a)). Inspection of the TEM data allows to conclude that the structures are free of threading dislocations or their concentration is negligible. The crystal lattice distortion and deformation fields were visualized and measured in TEM images of the multilayer GeSiSn/Si structure using the method of geometric phase [11] (figure 3(b)). The experimentally measured interplanar spacing ($d_{002} = 0.29$ nm, $d_{111} = 0.32$ nm, $d_{220} = 0.192$ nm), with the sample presented in figure 3 (c), are to show that the tetragonal lattice with constants $a = 0.543$ nm and $c = 0.58$ nm is characteristic of GeSiSn layers. This implies that GeSiSn layers feature either a non-strained strained tetragonal or a cubic crystal lattice that is elastically deformed and coherently conjugated with the silicon crystal lattice at the heteroboundary, i.e. a pseudomorphic GeSiSn film is formed.

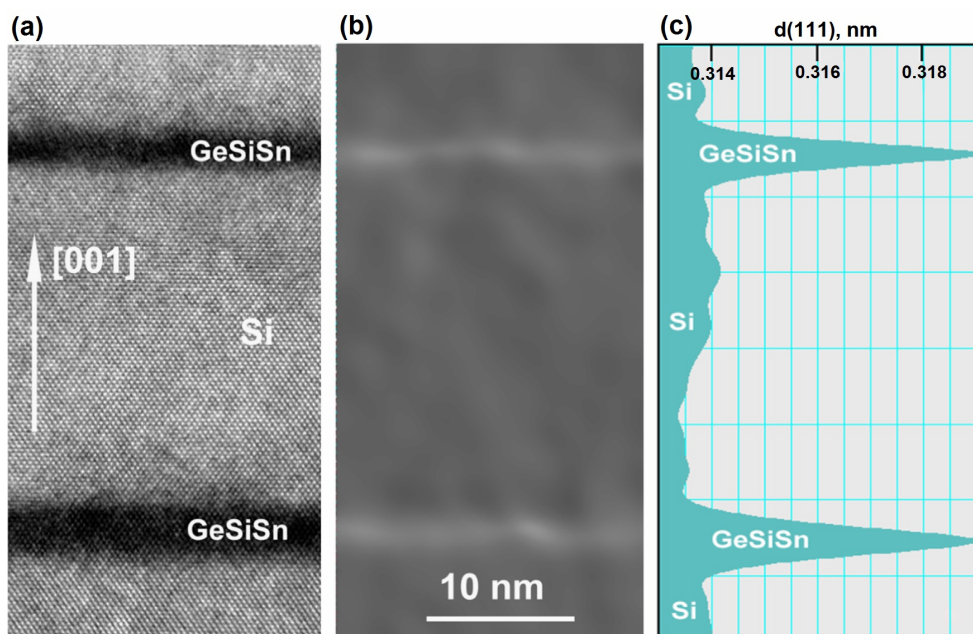


Figure 3. (a) Fragment of a high-resolution multilayer structure including Si-covered GeSiSn layers; (b) the map of interplanar (111) distances; (c) the profile of interplanar (111) distances versus the thickness of the film.

The optical properties of multilayer structures were studied using photoluminescence (PL). The PL signal was excited by a Nd:YAG laser (532 nm). Figure 4 shows the spectra of PL at a temperature of 77 K. PL is observed in the range of 0.6 eV to 0.85 eV. With increasing Sn concentration in the composition of a ternary compound GeSiSn, the maximum of PL intensity decreases from 0.77 eV to 0.65 eV for $\text{Ge}_{0.315}\text{Si}_{0.65}\text{Sn}_{0.035}$ and $\text{Ge}_{0.4}\text{Si}_{0.54}\text{Sn}_{0.06}$, respectively. With decreasing growth temperature, and by increasing the thickness of the GeSiSn layer, PL signal reduces, which may be caused by an increase in point defects in the crystal structure. Progress to wavelengths longer than 2 μm requires an increase in the Sn content in GeSiSn layers higher than 10%.

3. Conclusion

Regularities of the MBE formation of multilayer structures on quantum wells comprising pseudomorphic GeSiSn layers without relaxed buffer layers but creating the structures directly on Si were studied for the first time. The obtained TEM data proved the crystal perfection of the samples under study. To investigate the Sn influence on growth of SiGeSn/Si MQW, the phase diagram of surface superstructures during the growth of pure Sn on Si(100) was created. The appearance and disappearance of various surface reconstructions during the growth of SiGeSn/Si MQW show the surface quality and can assist in selecting the optimal growth parameters. Nanostructures based on GeSiSn layers have demonstrated the photoluminescence at 0.6-0.85 eV. With increasing Sn content in the GeSiSn composition, the maximum of PL signal appears in the long-wave IR region.

Acknowledgments

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