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Effect of alloying on growth of GeSi self-assembled islands

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Abstract. The effect of alloying on growth and parameters of GeSi self-assembled islands has been investigated at different growth temperatures by the atomic force microscopy and X-ray diffraction. The correlation between the sizes and composition of islands has been obtained. The Ostwald ripening and alloying significantly broaden the islands sizes distribution at growth temperature 750°C.

Introduction

Heterostructures of consisting GeSi strain-induced self-assembled islands provide a promising material to realise Si-based optoelectronic devises operating at $1.2-2\ \mu$m. This range is particularly important for telecommunication industry. High crystal quality of structures is critical to the success of such applications. In general, rather high growth temperatures ($500-800$°C) are used for fabrication of GeSi structures with good crystal quality. The diffusion and alloying process largely affect growth and parameters of structures at these temperatures. In case of islands growth the non-uniform elastic strain fields arise which result in additional flow of atoms [1].

In this paper, we present the results of investigation of self-assembled GeSi islands growth on Si (001) at various temperatures. The effect of alloying on the size and shape of GeSi self-assembled islands is investigated by X-ray diffraction, atomic force and electron microscopy.

1. Results and discussion

The samples under investigation were grown by molecular beam epitaxy from a solid source (SSMBE) (BALZERS UMS 500P) and a gas source (GSMBE) (Daido-Hoxan VCE S2020) on Si (001) substrates at growth temperatures $T_g = 600$°C, 700°C and 750°C. Further details of the growth process are presented elsewhere [2, 3]. After substrate cleaning and growth of Si buffer layer a Ge layer with the equivalent thickness from 3 monolayers (ML) to 11 ML was deposited. Sample morphology was determined by *ex situ* atomic force microscopy (AFM) (NT-MDT "Solver-P4" and Digital Instruments Nanoscope IIIa). The electron microscopy measurements were performed on "JEOL EM-200EX". The X-ray diffraction measurements were performed at room temperature using a "DRON-4" double crystal X-ray diffractometer.

The parameters (sizes, surface density, composition and elastic strain) of GeSi islands grown from a gas source at 700°C coincided with the parameters of the islands, grown from a solid source and investigated earlier [3, 4]. The structures with a narrow size distribution of dome-islands (dispersions of lateral sizes and height less than 10%) were obtained at

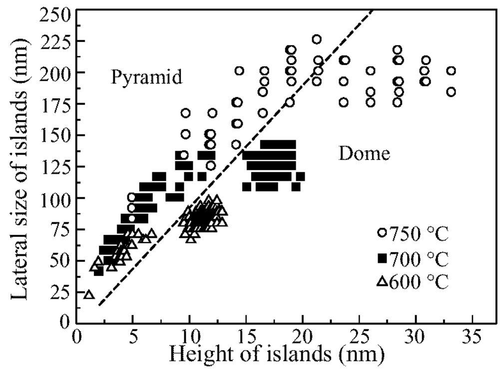

Fig. 1. The dependence of the island lateral size on its height obtained from AFM images. The dashed line separates the regions of different island shape.

this growth temperature by both deposition techniques. Average composition and elastic strain of dome-islands were defined from X-ray diffraction investigation using a strained layer approximation. In the framework of this model the content of Si in dome-islands is about 50% regardless of a deposition technique. Such a high value of Si content is related to strain-driven surface and volume diffusion of Si from the region of maximum elastic strain near the islands bases [4, 5].

A decrease of growth temperature to 600°C inhibits the surface and volume diffusion of Si and Ge. As a result of reduction of Ge adatom surface diffusion, the surface density of islands at T_g = 600°C increases four times in comparison with that T_g = 700°C. Besides, the critical sizes of islands with pyramid-like shape ("pyramid"-islands), at which they transform to a dome shape, decrease about 2 times (Fig. 1). One reason of this change of size is reduction of Si content in islands with a decrease of T_g. Modification of island composition with a change of growth temperature was confirmed by X-ray analysis. Figure 2 displays the $\Theta/2\Theta$ scans of samples grown at different temperature near the symmetric (004) Si reflection. It is seen that the small peak from the islands shifts from the Si substrate peak to the region of diffraction from a pure Ge layer. The Ge concentration in islands obtained by analysis of the symmetric (004) and asymmetric (224) X-ray reflections changes from 50% at T_g = 700°C to 75% at T_g = 600°C. The increase of Ge content results in an increased elastic strain in islands and, according to the model suggested by Tersoff *et al*[6], a decreased critical pyramid-islands volume.

The increase of islands surface density is another reason for changes in the pyramid and dome islands size. The high surface density of the islands gives rise to elastic interactions between them and can significantly reduce the equilibrium transition volume [7].

The effect of alloying on growth of GeSi islands is most pronounced at T_g = 750°C. Besides the increase of pyramid and dome size (Fig. 1), the high diffusion rate of Si into islands at this growth temperature initiates a reverse transformation of islands from dome to pyramid shape during deposition. As a result, the islands of an intermediate shape (with pyramid-like base and dome-like apex) were seen on AFM image. Similar changes of the islands shape were observed during a post-growth annealing of structures grown at T_g < 700°C and connected with a decrease of elastic strain in dome islands with an increase of Si content in the islands during annealing [4, 8].

The Ostwald ripening mechanism also affects islands growth at T_g = 750°C. During Ostwald ripening some islands build up at the expense of other islands that shrink and

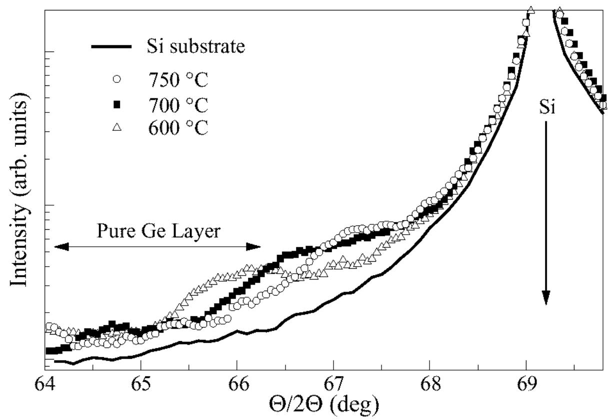

Fig. 2. The Θ/2Θ X-ray scans of samples grown at different temperature near (004) Si reflection. The arrows mark angle region of diffraction from pure Ge layer at different strain and peak position from Si substrate.

dissipate completely. This results in the spread of the islands sizes distribution. The surface of samples grown at $T_g = 750°C$ keeps traces of the dissociated islands as circumference-like grooves. Here the situation is also similar to annealing of structures grown at $T_g <$ 700°C [4].

In summary, we investigated the effect of alloying on growth and parameters of GeSi self-assembled islands. The change of maximum pyramid-islands sizes with an increase of growth temperature is related to enhancement of alloying in GeSi islands. The Ostwald ripening and alloying broaden the islands sizes distribution at $T_g = 750°C$.

Acknowledgements

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