The ordering of Ge islands on a stepped Si(100) surface

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Abstract. In the paper we investigate the Ge island nucleation on a Si(100) surface which was annealed to obtain the diatomic steps. It was observed that the islands tend to nucleate at the step edges.

1. Introduction

The self-organization in the Ge–Si system allows to obtain the nanometric size quantum dots with a density of 10^{10} – 10^{11} cm^{-2} [1]. The quantum dots system represents a great potential for nanoelectronics and photonics applications. The basic requirements of quantum dots are the following: the high island density, the size homogeneity and the nanoisland size providing manifestation of the dimensional quantization effect [2].

The past decade has seen rapid progress in research into high-performance Ge-on-Si photodetectors. Owing to their unique optoelectronic properties, which include high responsivity at near-infrared wavelengths, high bandwidths and compatibility with silicon complementary metal–oxide–semiconductor circuits, these devices can be monolithically integrated with silicon-based read-out circuits for applications such as high-performance photonic data links and IR detectors at low cost and low power consumption [3].

In paper [4], the clusters were found to preferably decorate the step edges in the form of a «necklace» indicating the possibility of ordered quantum dots creating. In paper [4], the author does not focus attention on the surface preparation for growth, the substrate disorientation specific characteristics and the step characteristics, that is necessary to know for studying the step influence on the Ge island growth. It is seen that dimer vacancy lines on the steps are directed perpendicularly to each other indicating that the surface has two-domains and, hence, the steps are monatomic.

At a certain temperature, the change in the two dimensional growth mechanism occurs. If the terrace width is larger than the average length of adatom migration, the film growth occurs due to the two-dimensional islands nucleation. If the terrace width is smaller than the average length of adatom migration, the film growth occurs due to the step movement. This is shown experimentally in [5] by the damping of specular beam intensity oscillations of reflection highenergy electron diffraction (RHEED). Also, the results of investigations of Ge island nucleation on the Si(100) surface are presented in [6, 7], where it was found that the temperature of growth mechanisms change is equal to 600 °C. Under heating of the surface in a Si flux, the steps transform from monoatomic to diatomic.
The control method consists in observation of disappearance of the reflexes belonging to one of two domains of the structure in the reflection high-energy electron diffraction (RHEED) pattern.

The goal of this work is to study the effect of Ge islands ordering on a Si(100) surface depending on the conditions of growth and surface preparation.

2. Experimental technique

The studies were carried out on a Si(100) substrate. Initially, chemical oxide SiO$_2$ was on the Si surface, meant for the surface protection from atmospheric contamination. Before the layer deposition, the Si substrate was annealed at a temperature of 800°C for SiO$_2$ layers desorption. The structures were obtained by molecular beam epitaxy (MBE). The investigations were carried out by reflection high-energy electron diffraction and atomic force microscopy (AFM). The AFM images were obtained in the contact mode.

3. Results and discussions

The samples with Ge islands on the Si(100) surface were obtained. In sample 1, the surface was annealed for 2 hours at a temperature of 600°C, then for 30 minutes at 700°C and for 10 minutes at 800°C. Upon the annealing, the Ge film with an effective thickness of 10 angstroms was grown at a temperature of 450°C. In sample 2, the silicon surface was annealed at a temperature of 1000°C during 10 minutes in a low Si flux of $10^{13}$ at.cm$^{-2}$s$^{-1}$. Upon the annealing, the Ge film with an effective thickness of 9 angstroms was grown at a temperature of 400°C.

Figure 1 shows the RHEED pattern in the azimuthal [100] direction from the Si(100) surface, where the surface was annealed for 2 hours at a temperature of 600°C, then for 30 minutes at 700°C and for 10 minutes at 800°C.

![RHEED pattern from the Si(100) 2×1+1×2 surface in the [100] direction in sample 1.](image)

Figure 2 shows the RHEED pattern in the azimuthal [100] direction from the Si(100) surface in sample 2.
Figure 2. The RHEED pattern from the Si(100) 2×1+1×2 surface in sample 2.

Figure 3 shows the RHEED pattern in the azimuthal [110] direction from the Si(100) surface in sample 1.

Figure 3. The RHEED pattern from the Si(100) 2×1+1×2 surface in the [110] direction in sample 1.

Figure 4 shows the RHEED pattern in the azimuthal [110] direction from the Si(100) surface in sample 2.
Figure 4. The RHEED pattern from the Si(100) 2\times 1+1\times 2 surface in the [110] direction in sample 2.

Figure 5 shows the profiles taken along the white line in figures 1 and 2.

Azimuthal [100] direction

- 1/2 Laue zone
- Annealing 120 min. 600° C
- 30 min. 700° C
- 10 min. 800° C
- Annealing 10 min. 1000° C
In the profile obtained from the RHEED patterns, it is seen that at higher annealing temperatures the reflex intensity from one sublattice of the two-domain surface becomes larger. Besides, the reflexes intensity generally falls and the background level decreases. This can be explained by the fact that the terrace length of one sublattice of the two-domain surface becomes wider. The reflex intensity decreasing can generally be related to the partial decay of the 2×1 reconstruction. The background decreasing can be related to the fact that the surface becomes less defective and atomically smoother.

Figure 6 shows the profile taken along the white line in figures 3 and 4.
Figure 6. The profile taken along the white line on the RHEED pattern in figures 3 and 4.

The pattern analysis in the azimuthal [110] direction shows that the intensity from the fractional order reflex increases with temperature increasing. This also indicates that the system departs from the equilibrium state and the terrace length for the two-domain surface changes.

Figure 7 shows the AFM image of the Ge island on the Si(100) surface of sample 1.

Figure 7. The Ge islands grown on the Si(100) surface of sample 1.

It is seen from the AFM image (figure 7) that some fraction of the island nucleates in parallel to the [110] direction. As it is known from the substrate characteristics, the steps are parallel to the [110] direction and the disorientation angle is 0.5°. The terrace widths approximately equal 16 nm and 31 nm for the monatomic and diatomic steps, respectively.

Figure 8 shows the AFM image of the Ge islands of sample 2.
Figure 8. The Ge islands grown on the Si(100) surface of sample 2.

Analogously, it is seen from figure 8, that some fraction of the island nucleates is parallel to the [110] direction. But unlike sample 1, it is seen from the RHEED picture of sample 2 that the reflex intensities of superstructure on the zero-order Laue zone and the fractional-order Laue zone are not equal to each other. This indicates that the surface tends to a single-domain structure and, hence, to the diatomic steps.

Conclusions
As can be seen from the represented results, the diatomic steps have not been formed. However, it is seen from the RHEED picture that the reflexes from 2x1 and 1x2 domains of the reconstruction become not equal to each other. That is due to the different terrace widths. As it was observed on two such surfaces, the islands tend to nucleate on the step edges.

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