The Ge island ordering on a stepped Si(100) surface

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Abstract. In the paper the investigations were carried out by the Ge island nucleation on Si(100) surface which was annealed to obtain the diatomic step. It was observed that the islands tend to nucleate on the step edges.

1. Introduction

Manifestation of the self-organization in the Ge – Si system allowed to obtain the nanometric size quantum dots with the density 10^{10} – 10^{11} cm^{-2} [1]. The quantum dots system represents great potential in the nanoelectronic and photonic applications. The basic requirements by the quantum dots are following: high island density, homogeneity by the size and the nanoisland size providing the dimensional quantization effect manifestation [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 in wavelength near-infrared field, 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 the paper [4] the results were represented in which clusters preferably decorate the step edges in the form of «necklace» indicating the possibility of ordered quantum dots creating. In the paper [5] the author does not focuses attention on the surface preparation to growth, on the substrate disorientation specific characteristics and on the step characteristics that is necessary to know for the step influence studying on the Ge island growth. It is seen that dimer vacancy lines on the steps is directed perpendicularly to each other indicating the surface is two domain and, hence, the steps is monatomic.

The Ge island growth of the this paper [4] occurred on the Si(100) surface under temperature 690 K. There is a provision [5] that under some temperature dominated the growth mechanism over mechanism on account of the two-dimensional island formation is growth on account of the step moving and under temperature 690 K the Ge atom migration length is close to transition these mechanisms, as evidenced by the intensity oscillation damping depending on the substrate temperature [6, 7].

Under certain conditions the surface transits from monatomic to step diatomic. The conditions are to consist under heating of the surface at Si atom flux the steps transform from monatomic to diatomic.

The control method is to consist in observation on the reflection high-energy electron diffraction (RHEED) pattern of the reflex disappearance belonging one from two-domain structure.

The goals and objectives of this work is the Ge island nucleation effect study on Si(100) surface depending on the growth conditions and the surface preparation conditions.

2. Experimental technique

The studies were carried out on the Si(100) substrate. Initially, chemical oxide SiO_2 was on the Si surface, meant for the surface protection from atmospheric contamination. Before the layers deposition the Si substrate is annealed at temperature 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 (RHEED) and atomic force microscopy (AFM). The AFM images were obtained in contact mode.

3. Results and discussions

The samples were obtained with the Ge islands on Si(100) surface. In the sample №1 the surface were annealed 2 hours under temperature 600°C, then 30 minutes under 700°C and 800°C during 10 minutes. Upon completion of the annealing the Ge film was grown with the angstrom 10 effective thickness and temperature 450°C. In sample №2 the silicon surface was annealed under temperature 1000°C during 10 minutes in the low Si flux 10^{13} at.cm^{-2}s^{-1}. Upon completion of the annealing the Ge film was grown with the angstrom 9 effective thickness and temperature 400°C.

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

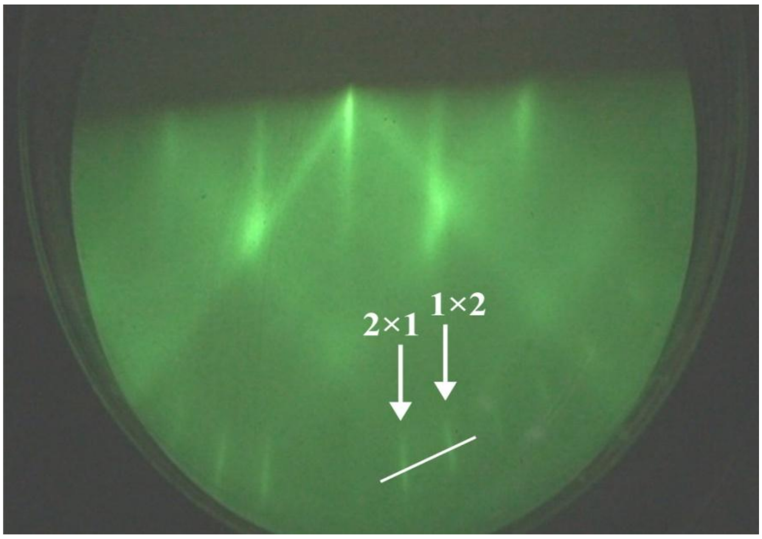

Figure 1. RHEED pattern from Si(100) 2×1+1×2 surface in [100] direction which was annealed 2 hours under temperature 600°C, then 30 minutes under 700°C and 800°C during 10 minutes.

Figure 2 shows the RHEED pattern in the azimuthal [100] direction from Si(100) surface, where the silicon surface was annealed under temperature 1000°C during 10 minutes in the low Si flux 10^{13} at.cm^{-2}s^{-1}.

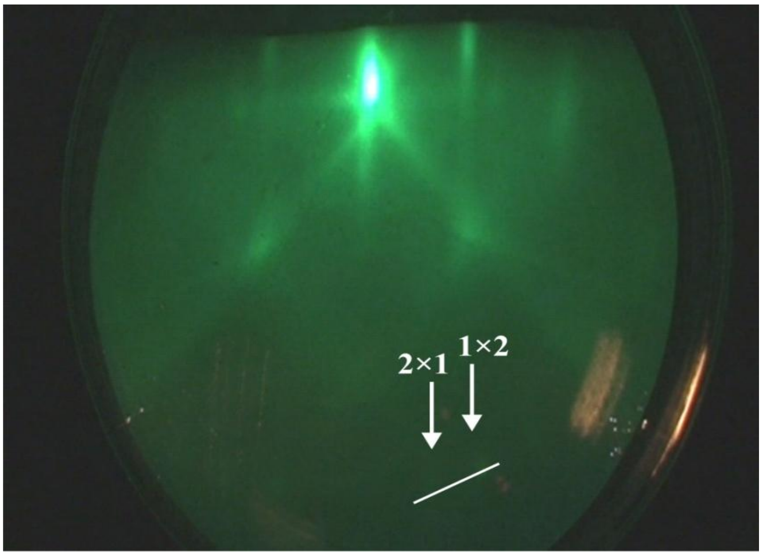

Figure 2. RHEED pattern from Si(100) 2×1+1×2 surface in [100] direction which was annealed under temperature 1000^{o}C during 10 minutes in the low Si flux 10^{13} at.cm^{-2}s^{-1}.

Figure 3 shows the RHEED pattern in the azimuthal [110] direction from Si(100) surface, where the surface was annealed 2 hours under temperature 600^{o}C, then 30 minutes under 700^{o}C and 800^{o}C during 10 minutes.

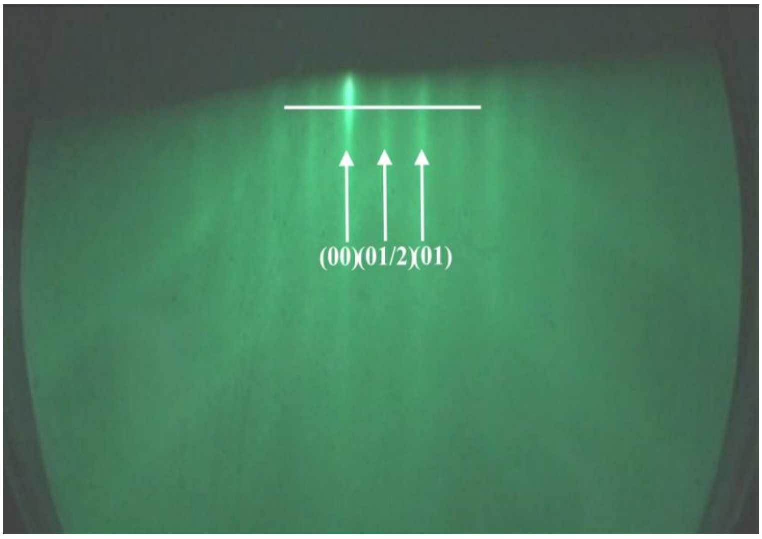

Figure 3. RHEED pattern from Si(100) 2×1+1×2 surface in [110] direction which was annealed 2 hours under temperature 600^{o}C, then 30 minutes under 700^{o}C and 800^{o}C during 10 minutes.

Figure 4 shows the RHEED pattern in the azimuthal [110] direction from Si(100) surface, where the silicon surface was annealed under temperature 1000^{o}C during 10 minutes in the low Si flux 10^{13} at.cm^{-2}s^{-1}.

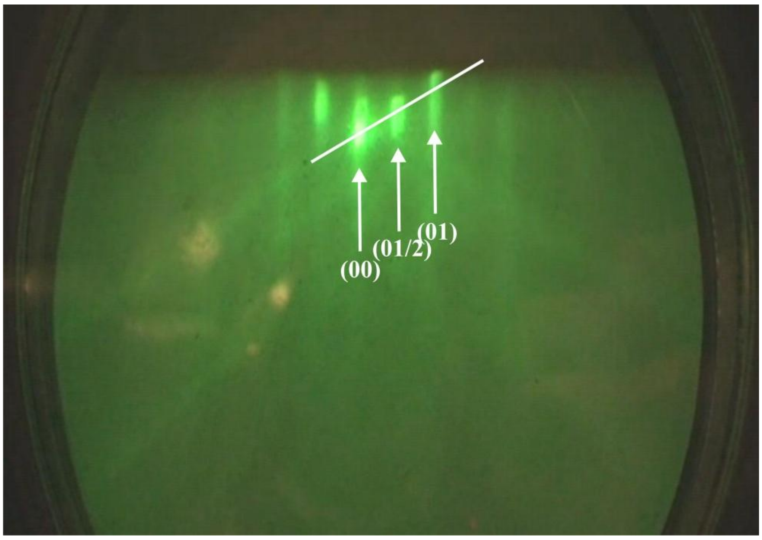

Figure 4. RHEED pattern from Si(100) 2×1+1×2 surface in [110] direction which was annealed under temperature 1000^{o}C during 10 minutes in the low Si flux 10^{13} at.cm^{-2}s^{-1}.

Figure 5 shows the profile made along white line on the figures 1 and 2.

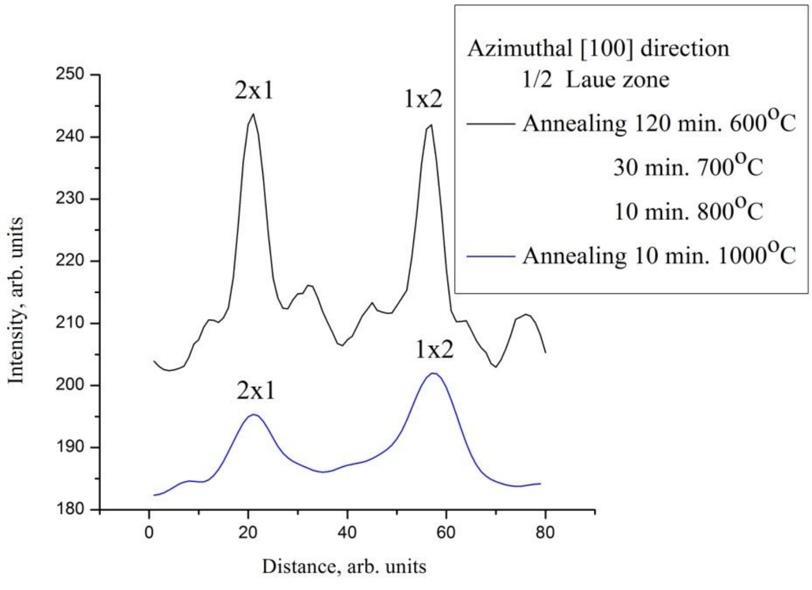

Figure 5. Profile along white line on RHEED pattern of the figure 1 and 2.

Profiles obtained from of the RHEED patterns it is seen that under more high temperature of the annealing the reflex intensity from one of sublattice from the two-domain surface become larger. As well as the reflexes intensity generally falls and background decreases. This can explain by that terrace length of one from sublattice from the two-domain surface becomes more width. The reflex intensity decreasing can generally be related with the 2×1 reconstruction partial destruction. The background decreasing can be related with that the surface becomes less defective and more atomically smooth.

Figure 6 shows the profile made along white line on the figures 3 and 4.

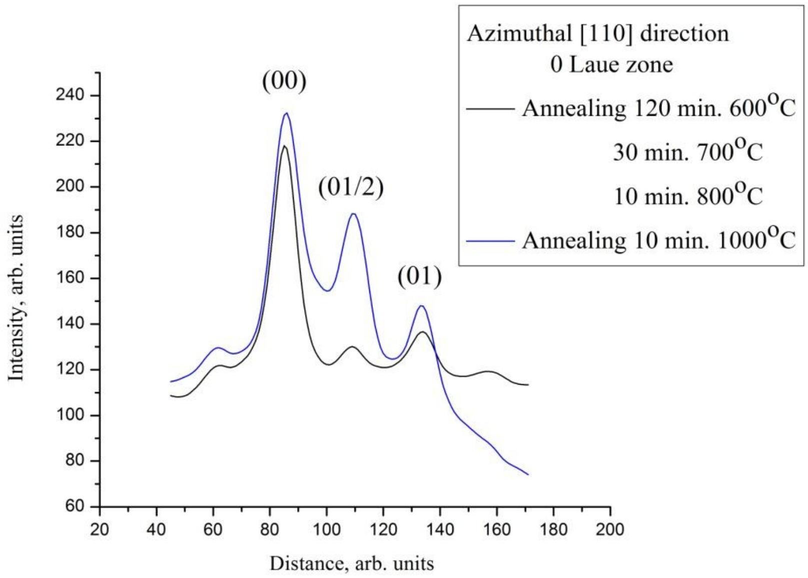

Figure 6. Profile along white line on RHEED pattern of the figure 3 and 4.

The pattern analysis in azimutal [110] direction is carried out, where it was observed that the intensity from the fractional order reflex increases under temperature increasing, this also indicates the system exit from the equilibrium state and the terrace length change of the two-domain surface.

Figure 7 shows the Ge island image AFM on Si(100) surface which was annealed 2 hours under temperature 600^{o}C, then 30 minutes under 700^{o}C and 800^{o}C during 10 minutes.

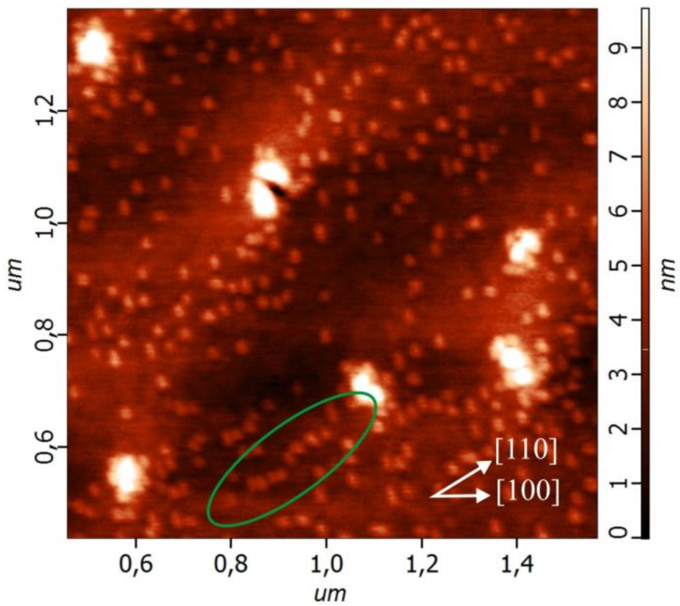

Figure 7. The Ge islands grown on Si(100) surface which was annealed 2 hours under temperature 600^{o}C, then 30 minutes under 700^{o}C and 800^{o}C during 10 minutes.

It is seen from the AFM image (figure 7) that the island some fraction nucleates in parallel [110] direction. It is know from the substrate characteristics that plate disorientation is such that the steps dispose parallely [110] direction and under in 0,5° the terrace width for the monatomic steps approximately equals 16 nm, and for the diatomic steps approximately equals 31 nm.

Figure 8 shows the Ge island image AFM on Si(100) surface which was annealed under temperature 1000°C during 10 minutes in the low Si flux 10^{13} at.cm^{-2}s^{-1}.

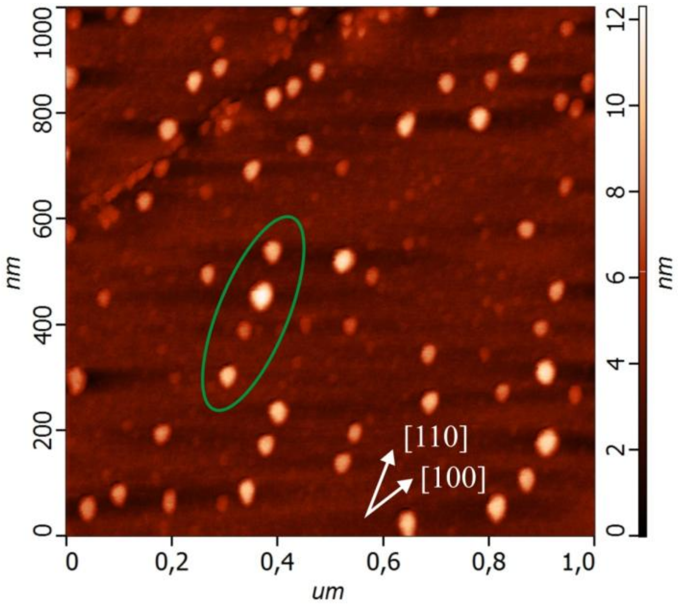

Figure 8. The Ge islands grown on Si(100) surface which was annealed under temperature 1000°C during 10 minutes in the low Si flux 10^{13} at.cm^{-2}s^{-1}.

It is seen analogously and for AFM image (figure 8) that the island some fraction nucleates in parallel [110] direction, but unlike the sample №1 of the figure 7, it was seen on the diffraction from the sample №2 of the figure 8 that fractional order reflex intensities on the zeroth zone Laue, and also 1/2 did not equal each other indicating the surface seeks to single-domain surface and hence to the diatomic steps.

4. Conclusions

As can be seen from the represented results on the sample №1 of the figure 7 the diatomic steps were not formed. On the sample №2 of the figure 8 it was seen on reflection high-energy electron diffraction that reflexes from the two sublattices become not equal to each other that appears due to the different terrace widths belonging these sublattices. It was observed on the two such surfaces that the islands tend to nucleate on the step edges.

Acknowledgments

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