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THE GROWTH OF SiGe NANOSTRUCTURES BY MOLECULAR BEAM EPITAXY[1]

In the paper the method of molecular beam epitaxy (MBE) is considered. MBE allows to receive nanoheterostructures on the basis of SiGe with Ge quantum dots. Also the results of experiments on synthesis of nanoheterostructures SiGe with Ge quantum dots by growth on the installation MBE «Katun-100» are presented.

Keywords: *quantum dots, molecular beam epitaxy, germanium, silicon.*

In recent years, creation of semiconductor structures with new physical properties is the main task of nanotechnology, with the aim to expand the application of semiconductor materials. Special attention is paid to the structures on the basis of silicon, as silicon is the basic material of electronics. Low-dimensional semiconductor heterostructures attract more attention. Spatial localization of charge carriers leads to a substantial difference between the electrical and optical properties of low-dimensional structures in comparison with the bulk semiconductors. Among a wide class of semiconductor heterostructures it is possible to allocate the structure of Si/Ge, which are compatible with the modern silicon technology. This allows to use them both for the improvement of the traditional elements of silicon nano - and microelectronics, and for creation of new electronic and optoelectronic devices. The most promising method of formation of quantum dots (QDs) is based on the effects of self-organization of semiconductor nanostructures in heteroepitaxy systems. There are developed modes of growth of structures, providing sufficiently homogeneous in the size of the islands of nanometric scale. For many applications it is necessary to create heterostructures with quantum dots with different properties, which are determined by such parameters QDs, as their form and lateral size (the size of the plane of the substrate) [1–3].

The main method of obtaining Ge/Si nanostructures is a molecular-beam epitaxy. In this case the formation of Ge islands occurs by the Stranski – Krastanov mechanism due to the effects of self-organization at the expense of a mismatch in the permanent crystal lattices (4,2 %). Since during the process of growth the islands are formed spontaneously, you can control their morphology only by changing the conditions of synthesis: the temperature of the substrate, the speed of deposition, the amount of deposited material. In addition, the characteristics of arrays of germanium clusters grown on surfaces with different crystallographic orientation, at the pre-oxidized silicon surface differ significantly.

Compared with other technologies used for the synthesis of nanostructures MBE is characterized, first of all, by low growth rate and a relatively low temperature of growth. The advantages of this method should include the possibility of sharp interruptions and subsequent renewal of the process of deposition of different materials, which is the most important for the formation of multilayer structures with sharp boundaries between the layers. Receiving perfect nanostructures is promoted by the possibility of the analysis of the structure, composition and morphology of grown layers in the process of their formation by the method of high energy electron diffraction and electron Auger-spectroscopy [4].

The main parameter of the synthesis of nanoheterostructures Si/Ge with Ge quantum dots is the temperature of the silicon substrate, on which germanium is deposited. In [5] it is shown that during the process of formation of structures of Ge/Si (001) by the method of MBE high density of self-organizing clusters can be achieved during the deposition of germanium on the silicon substrate preheated to the moderate temperature (< 550 °C). Decrease of the temperature of formation of the array to the values lower than 450 °C is required to ensure that the process of growth of heterostructures Ge/Si(001) is compatible with silicon microelectronic devices production technology. This is another reason to decrease the temperature of all technological processes starting with the stage of preparation of the silicon surface. In this case, the lower the temperature of the silicon substrate during the deposition of germanium, the higher the density of the clusters with the same amount of Ge deposited. So, for example, at a temperature of substrate of $T_{\text{gr}} = 360$ °C during the deposition and effective thickness Ge layer $h_{\text{Ge}} = 8$ Å the density of clusters of Ge in the array reaches $6{\cdot}10^{11}$ cm^{-2}, while at $T_{\text{gr}} = 530$ °C and the same value of h_{Ge} the density of clusters obtained made up only about $2{\cdot}10^{11}$ cm^{-2}.

The MBE installation «Katun-100» is a complex automated complex with a large number of controlled parameters. «Technology» software program, installed on the computer is designed for the process

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control and operational control of the basic technological parameters: channels, valves and stepper motors.

The presence of high vacuum in the chamber of the growth during MBE allows to use analytical methods of the control of the parameters of the surfaces, in particular, the high energy electron diffraction. High energy electron diffraction is a method of study of surface structure, speed of growth, the control of changes of the upper atomic layers (formation of 3D-islands), observation of the topography of the surface directly during the process of growth.

The MBE installation is also equipped with a mass spectrometer, which allows to determine the chemical composition of external atomic layers of solid body and determine the pressure of residual gases during the epitaxy. The pressure of residual gases in vacuum chamber with the enabled sources of material is maintained at a level not higher than the ~ 10^{-8} Torr. Figure 1 shows diagrams of pressure of residual gases detected with the use of mass spectrometer.

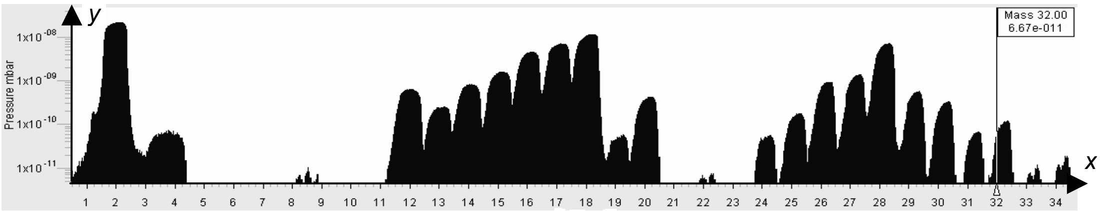

Fig. 1. Pressure of residual gases in the epitaxy in searching for leaks. The axes are: *y* – pressure (mbar), the *x* – axis the atomic mass.

Experimental samples were grown by the method of MBE on the device «Katun-100» on the substrate of Si(100). After a preliminary standard chemical treatment the substrate were placed in the growth chamber, where annealing at a temperature of 800 ºC in a weak stream Si within 15 minutes was performed. Then buffer layer Si a thickness of the order of 100 monolayers at a substrate temperature of 500 ºC was grown. The deposition of Ge was carried out at temperatures of substrates 350 and 450 ºC, the growth rate v = 3,84 nm/min. The pressure in the growths experiments were not above $5 \cdot 10^{-8}$ Torr. Figures 2 and 3 show the experimental samples of Ge/Si quantum dots Ge. The parameters of the experiments are given in Table 1.

Table 1

Parameters of growth of the samples

Pattern No.	Temperature of deposition of Si, °C	Rate of deposition of Si, nm/min	Thickness of the deposited layer of Si, nm	Temperature of deposition Ge, °C	Rate of deposited Ge, nm/min	Thickness of the deposited layer of Ge, nm
1	500	1,5	90	350	3,84	0,83
2	500	1,2	72	450	3,84	0,83

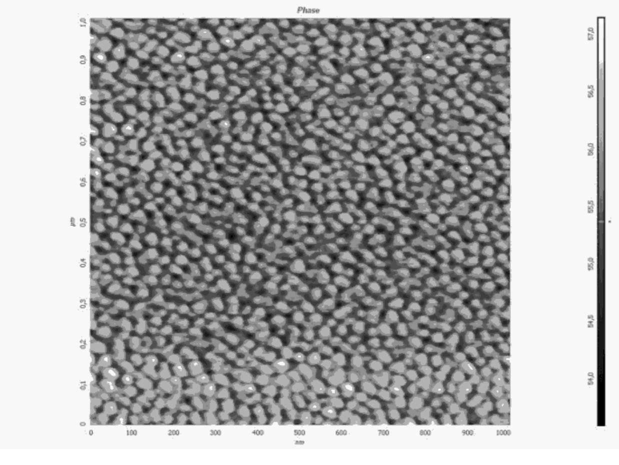

Fig. 2. AFM image of the sample No. 1.

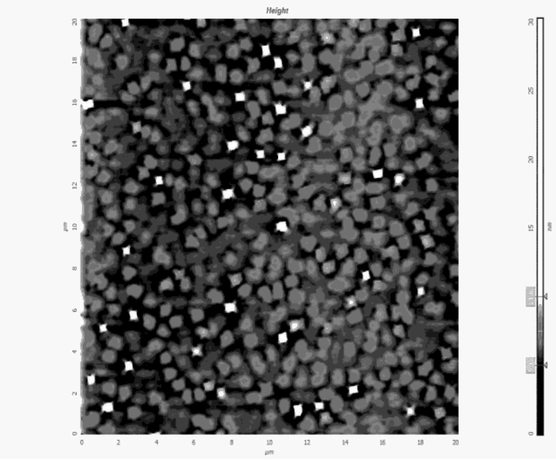

Fig. 3. AFM image of the sample No. 2.

From Table 1 and Figs. 1, 2 you can see that the surface density of Ge nanoislands and their lateral dimensions depend very much on the conditions of synthesis.

REFERENCES

1. Шкляев А.А., Ичикава М. // УФН. – 2008. – Т. 178. – № 2. – С. 139–169
2. Болховитянов Ю.Б., Пчеляков О.П. // УФН. – 2008. – Т. 178. – № 5. – С. 459–480
3. Новиков А.В., Яблонский А.Н., Платонов В.В., et al. // ФТП. – 2010. – Т. 44. – № 3. – С. 346–351
4. Дубровский В.Г. Теоретические основы технологии полупроводниковых наноструктур. – СПб.: СПБГУ, 2006. – 347 с.
5. Арапкина Л.В., Юрьев В.А. // УФН. – 2010. – Т. 180. – № 3. – С. 289–302

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