Study of \textit{Ar}^{+} and \textit{He}^{+} implanted SOS-structures

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Abstract. In the work Silicon – on - insulator nanostructures after implantation by various doses of ions \textit{He}^{+} and \textit{Ar}^{+} are investigated. Researches were carried out by measurement of optical reflection spectrum and magnitude of work function of an electron. It is shown that ions \textit{Ar}^{+} in Silicon – on - insulator nanostructures, providing high efficiency of gettering influence, incorporate the neutral divacancy responsible for an observable minimum in ranges of reflection 0.73-0.75\textit{eV}. As a result of implanted by ions \textit{He}^{+} the gettering doesn't occur and the entered defects are divacancies with one negative charge, responsible for an observable maximum in reflection ranges 0.73-0.75\textit{eV}.The received results indicate possibility of purposeful updating of Silicon – on - insulator nanostructures for improvement of their optical characteristics.

1. Introduction
The transition of modern semiconductor electronics to nanoscale systems, resulting in quantum size limitations, revealed new physical properties in traditional materials that open up broad prospects for this industry. Silicon – on - insulator for modern micro - and nanoelectronics is one of the most promising materials, which determined its choice as the object of research in this work[1].

Recently, serious efforts have been directed to the development of technology for fabrication and study of optical properties of so - called photonic crystals. One of the essential reasons explaining the great interest in photonic crystals is that photonic crystals can be used to create elements for processing electromagnetic signals in the X-ray optical and microwave ranges that perform the same functions as microelectronic components for electric signals (addition, decomposition, filtering, gain, etc.). At the same time, it is obvious that photonic crystals elements will surpass their microelectronic counterparts in terms of speed, and such reliability indices as resistance to radiation, operability at elevated temperatures, intrinsic heat generation, resistance to crosstalk noise, etc. [2].

With the current trend towards miniaturization of electronic equipment and the preservation of silicon as a predominant material in nanoelectronics for the next 30 years, it is advisable to create corresponding elements of the optical range (from ultraviolet to near - infrared). The great importance of silicon nanostructures makes the development and study of methods for their creation and
modification very urgent. To date, research is aimed at developing the scientific foundations of the technology for fabrication of micro- and nanoscale elements that ensure the generation of light radiation and its propagation. As an object for the manufacture of such elements, multilayer structures based on silicon characteristic of modern nanoelectronics will be used, and as a method of their manufacture - ionic synthesis of semiconductor and dielectric phases in the components of the mentioned multilayer systems. At that, silicon-on-insulator structures will be used as the basic layered structures, since their silicon and dielectric components facilitate the creation of fibers for ultraviolet, visible and near-infrared radiation, and ion implantation makes it possible to synthesize regions of various chemical compositions, which is a necessary condition for the creation of optical fibers, nanoscale light emitters based on photonic crystals elements [2]. However, as is known, during ion implantation, radiation defects are an undesirable factor, which can be eliminated by various stimulating methods: annealing in a furnace at high temperatures [3]; photon pulse annealing at lower temperatures [4,5]; etc..

2. Experiment and Results

In this work, we investigated the effect of bombardment with inert gas ions on Silicon–on-insulator structures obtained using the SMARTCUT technology [6,7]. The hidden insulator in these structures is the SiO₂ layer (Figure 1).

![Figure 1. Silicon–on-insulator structure obtained using SMARTCUT technology](image)

The resulting Silicon–on-insulator structures were irradiated with ions in such a way that as a result, 3 batches of samples were obtained: a) irradiated with helium (4He⁺), energy of 40 keV (doses \(D = 1.10^{14}-1.10^{16}\) cm⁻²) at a temperature \(T = 22^0\)C; b) irradiated with argon (40Ar⁺), energy of 400 keV (doses \(D = 1.10^{13}-1.10^{14}\) cm⁻²) at a temperature \(T = 22^0\)C and c) irradiated with argon (40Ar⁺), energy of 400 keV (doses \(D = 1.10^{13}-1.10^{15}\) cm⁻²) at a temperature \(T = 220^0\)C. The irradiating ions, energies and doses were selected in such a way that the energy transferred by the ions fell mainly on the thin surface layer of silicon up to the interface with the hidden dielectric.

The studies were carried out by measuring the optical reflection spectra and the value of the electron work function at room temperature.

Figure 2 shows the reflection spectra of Silicon–on-insulator structures irradiated with argon and helium ions. As can be seen from the figure, the reflection spectrum of Silicon–on-insulator structures (1) irradiated with argon ions (\(T_{\text{reg}} = 22^0\)C, \(D = 3.10^{13}\)ion/cm²) exhibits two clearly degenerate minima in the spectral region of 0.73-0.75 eV and near the edge of the band-gap - 1.04 eV, whereas in the spectrum of the Silicon–on-insulator structures (2) irradiated with argon ions (\(T_{\text{reg}} = 220^0\)C, \(D = 3.10^{13}\)ion/cm²), in the range of 0.73-0.75 eV, not only the minimum is absent, but, on the contrary, an increase in the reflection value is observed. Qualitatively, the same picture can be seen upon irradiation with helium ions (\(T_{\text{reg}} = = 22^0\)C, \(D = 10^{14}\)ion/cm²) (curve 3).
Figure 2. Reflection spectra of the irradiated Silicon – on - insulator structures: (1) \(^{4}\text{He}^+\) ions (batch a); (2) \(^{40}\text{Ar}^+\) ions (batch b); (3) \(^{40}\text{Ar}^+\) ions (batch c).

Figure 3 shows the dependence of the work function of the electron (\(\phi\)) from the surface of the Silicon – on - insulator structures on the dose of argon ions of the batch b) and c). As can be seen from Figure 3, the initial doses of argon ions suppress the value of the work function of the electron, while an increase in the dose of ions leads to an increase in its value.

It is known [3] that the implantation of argon ions in silicon provides a high efficiency of the gettering effect, while the gettering efficiency increases with increasing doses of implantation to improve the light-emitting properties of Silicon – on - insulator nanostructures. In the experiment, this is expressed in an increase in the value of the work function of an electron with an increase in the doses of argon implantation in silicon (Figure 3). The experimentally observed decrease in the value of \(\phi\) at the initial doses of implantation, in comparison with the initial sample, is caused by the fact that at low doses the creation of radiation defects prevails over the gettering effect, which leads to the observed decrease in the value of \(\phi\).

Figure 3. Dependence of the work function of an electron on the surface of Silicon – on - insulator structures on the dose of argon ions: (1) - batch b); (2) - batch c).
As for the Silicon – on - insulator structures doped with helium, in this case, the gettering effect is not observed at all [3], but radiation defects are created that cause suppression of the electron work function, in so much that it cannot be measured experimentally.

3. Discussions
As is known [3,8], the main radiation defects created by ion implantation in silicon at room temperature are A-centers, divacancies and tetravacancies in various charge states. When bombarded with helium ions - divacancies with one negative charge, and with argon ions - neutral divacancies. This leads to the difference in the optical reflection spectra, which corresponds to the data on optical absorption known from the literature [9,10] - neutral divacancies in silicon absorb quanta with an energy of ~ 0.73 eV (~ 1.7 μm), and divacancies with a negative charge - in the region of lower energy 0.32-0.38 eV. At high implantation temperatures, significantly higher radiation doses are required for the formation of the same number of defects as at room temperature [3]. This is associated with the annealing of defects during the implantation process due to the high mobility of defects. This reasoning is confirmed by experiments on measuring the work function of an electron (Figure 3).

At the same time, high implantation temperatures increase the probability of the formation of defect - impurity atom complexes in different charge states. For example, E – center complexes, a vacancy with two neighboring substituted atoms, a negatively charged vacancy with positively charged atoms of the implant [3].

Thus, it becomes clear that there is a qualitative difference in the optical reflection spectra in the Silicon – on - insulator samples implanted with 40Ar+ ions at different temperatures associated with the formation of various complexes of defects.

4. Conclusions
To establish the relationship between the nature, properties and mechanisms of the formation of defects in Silicon – on - insulator structures and the role of the dielectric in this process, further studies of optical absorption spectra will be carried out using thermal and photon pulse annealing. The results obtained will make it possible to perform a targeted modification of Silicon – on - insulator nanostructures to improve their optical characteristics.

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