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EFFECT OF ION IMPLANTATION ON THE COMPOSITION, STRUCTURE AND OPTICAL PROPERTIES OF SILICON

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ABSTRACT

In this work, comparative studies of the effect of bombardment with Ar+ and Ni+ ions on the composition, structure, and light transmission coefficient of single-crystal Si are carried out. In both cases, implantation leads to disordering of the surface layers and a decrease in K. After heating at T = 900 K of Si implanted with Ni+ ions, epitaxial phases are formed in the surface region of Si, depending on the dose of ions (at $D < 5 \cdot 10^{15}$ $см^{-2}$) and films (at $D = 6 \cdot 10^{16}$ $см^{-2}$) $NiSi_2$.

Keywords: heterostructure, nanophase, band gap, nanolayer, nanocrystalline phases, ion implantation, morphology, silicide, transition layer.

АННОТАЦИЯ

В данной работе проведены сравнительные исследования влияния бомбардировки ионами Ar+ и Ni+ на состав, структуру и коэффициент прохождения света монокристаллического Si. В обоих случаях имплантация приводит к разупорядочению поверхностных слоев и уменьшению К. После прогрева при Т = 900 К Si, имплантированного ионами Ni+, в поверхностной области Si в зависимости от дозы ионов формируются эпитаксиальные фазы (при D < 5·1015 см-2) и пленки (при D = 6·1016 см-2) NiSi2.

Ключевые слова: гетероструктура, нанофаза, запрещенная зона, нанослой, нанокристаллические фазы, ионная имплантация, морфология, силицид, переходный слой.

ANNOTATSIYA

Ushbu ishda Ar^+ va Ni^+ ionlari bilan bombardimon qilishning natijasida monokristal Si ning tarkibi, tuzilishi va yorug‘lik o‘tkazuvchanlik koeffitsientiga ta’sirini qiyosiy tadqiqotlari olib borildi. Ar^+ va Ni^+ ionlari bilan bombardimon qilinganda implantatsiya sirt qatlamlarining tartibsizlanishiga va K ning kamayishiga olib keladi. Ni^+ ionlari bilan bombardimon qilingan Si ning T = 900 K da qizdirilgandan so‘ng, ion dozasiga qarab, Si sirt mintaqasida yuza va yuz osti qatlamlarida epitaksial fazalar hosil bo‘ladi. Doza $D < 5 \cdot 10^{15}$ sm^{-2}) dan yuqori miqdorda olingan, $NiSi_2$ plyonkalar hosil bo‘lish dozasi $D = 6 \cdot 10^{16}$ sm^{-2} da.

Kalit so‘zlar: geterotuzilish, nanofaza, tarmoqli bo‘shliq, nanotuzilish, nanokristal qatlam, ion implantatsiyasi, yuza tuzilishi, silisid, o‘tish qatlami.

At present, much attention is paid to the study of the optical and electronic properties of semiconductors with nanophases and nanofilms on the surface layers. Of particular interest are studies related to the change in the properties of silicon with a decrease in its size to several nanometers, as well as studies aimed at changing the properties of Si nanofilms under various influences (atomic adsorption, ion and electron bombardment, oxidation). It was shown in [1–3] that an increase in porosity and, therefore, a decrease in the size and change in the shape of silicon nanophases leads to an increase in the light absorption edge towards higher energies, which is explained by an increase in the band gap Eg. The largest increase in Eg (up to 1.7 eV) is observed when the size of Si nanocrystalline phases is ≤ 3–4 nm [2, 5]. An increase in Eg to 1.9 eV is also observed in the case of the formation of thin amorphous silicon films [5]. Therefore, the amorphous silicon/nanocrystalline silicon system is a promising material for the development of high efficiency solar cells [6-8].

It is shown that the band gap E_g of nanoscale phases of the $MeSi_2$/Si and GaMeAs types is noticeably larger than E_g of bulk $MeSi_2$ and GaMeAs films. The sizes of nanostructures at which quantum-size effects begin to appear are estimated. When monatomic single-crystal semiconductors (Si, Ge) are bombarded under conditions of ultrahigh vacuum with ions of inert gases, the composition of ion-bombarded layers practically does not change, and all changes in properties are determined only by disordering of the near-surface layers. However, the influence of the formation of disordered phases and layers on the band structure has not yet been practically studied, and the electrophysical and optical properties of Si have been practically not studied. The results of such studies are of practical and scientific interest.

Therefore, the main purpose of this work is to study the effect of the formation of nanosized phases in the near-surface region of Si (111) single crystals upon bombardment with Ar^+ and Ni^+ ions with $E_0 = 0.5 – 2$ keV, energy band parameters, electrical and optical properties.

Single-crystal samples of Si (111) with dimensions of 10×10×0.5 mm were used as the object of study. Thermal treatment, bombardment with Ar+ and Ni+ ions and studies using the methods of Auger electron spectroscopy (OES), ultraviolet photoelectron spectroscopy (UVES), measurements of the energy and quantum yields of photoelectrons were carried out in the same experimental device at vacuum $P \leq 10^{-7}$ Pa. The energy of Ar^+ and Ni^+ ions varied within $E_0 = 0.5 – 2$ keV, and their dose was $D = 10^{14} – 10^{17}$ cm^{-2}. Before ion bombardment, the Si surface was degassed at T = 1200 K for 4–5 hours in combination with short-term heating up to T = 1500 K at a vacuum no worse than 10^{-7} Pa. The dependence of the intensity I passing through the sample (light transmission coefficient K) on the photon energy was measured using a UV-1280 spectrophotometer, and fast electron diffraction patterns were recorded using an ЭМР -2 device.

Disordering of the Si (111) near-surface layer leads to a decrease in the light transmittance K in the entire studied photon energy range (hν = 0.4 – 1.5 eV) (Fig. 1). From fig. 1 shows that in the case of pure Si (111) in the region hν = 0.6 – 0.9 eV, the value of K does not noticeably change; hν = 1.0 – 1.1 eV K sharply, almost linearly, with a large steepness decreases to zero. This indicates a good single crystallinity of the Si(111) sample. It is known that the presence of disorder at the atomic level in crystals leads to the appearance of exponential sections in the dependence of the absorption coefficient on $(h\nu)^2$. Ion bombardment leads to a noticeable decrease in the absorption coefficient in the entire studied region hν, an increase in the exponential section and, consequently, a decrease in the steepness of the linear section of the I(hν) curve (Fig. 1).

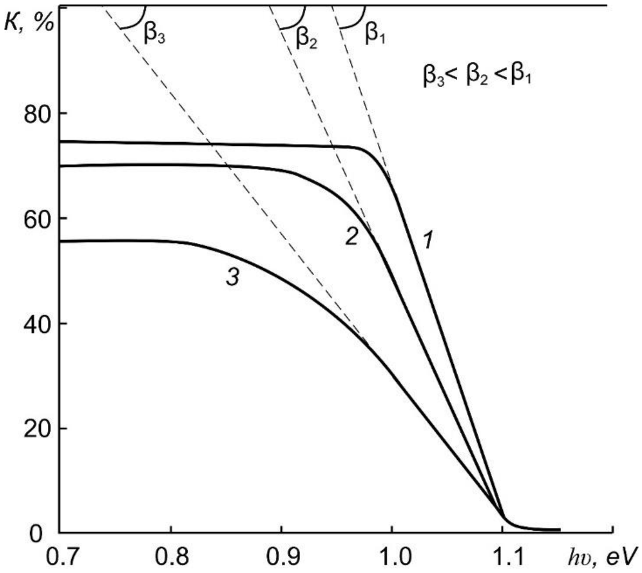

Fig. 1. Dependences of the light transmittance K on the photon energy for a Si(111) film bombarded with Ar+ ions with $E_0 = 1$ keV at doses D, см$^{-2}$: 1 – 0; 2 – $5\cdot10^{15}$; 3 – $5\cdot10^{16}$.

These changes occur up to a dose of $D = 5\cdot10^{16}$ cm^{-2}, which corresponds to the complete amorphization of the near-surface layer. In the case of light absorption for the exponential region, the dependence of the absorption coefficient on the photon energy can be estimated from the formula given in [8] for a CdSeS crystal:

$$\alpha = \alpha_0 e^{\frac{-(E_g - h\nu)}{E_0}}$$

where E_0 is the characteristic energy, which determines the edge steepness and provides information on fluctuations in the interatomic distances [8]. In [8], to determine the value of E_0, the dependence K(hν) was constructed and those sections were selected where these dependences become linear, and the value of E0 was determined by the reciprocal of the steepness of the linear sections.

Taking into account the fact that for single-crystal and amorphous Si films, the light reflection coefficients in the study area hν differ little from each other and its value does not exceed 4–6%, it can be assumed that for these films, the dependences K(hν) and α(hν) are inversely proportional. Therefore, the degree of surface disorder can be estimated from the steepness of the linear sections of the curves K(hν). In this case, in contrast to K(hν), the slopes of the curves K(hν) are defined relative to the axis K = 100%. It can be seen that with an increase in the dose of ions, the value of β, respectively, the steepness of the curves tgβ decreases, and the value increases, which leads to an increase in light absorption and a decrease in the intensity of transmitted light $E_0 \sim \frac{1}{tg\beta}$ [8-15]. It should be noted that during ion bombardment, regardless of the ion dose, the value of hν at which K decreases to approximately zero does not change and lies within 1.1 – 1.15 eV, i.e. during amorphization, the band gap does not decrease. Our further studies showed that Eg for an amorphized Si layer is ~1.2 eV.

This, in this work, comparative studies of the effect of bombardment with Ar+ and Ni^+ ions on the composition, structure, and light transmission coefficient of single-crystal Si were carried out. In both cases, implantation leads to disordering of the surface layers and a decrease in K. After heating at T = 900 K of Si implanted with Ni^+ ions, epitaxial phases are formed in the surface region of Si, depending on the dose of ions (at $D < 5{\cdot}10^{15}$ cm^{-2}) and films (at $D = 6{\cdot}10^{16}$ cm^{-2}) $NiSi_2$. The thickness of the amorphized layers, the degree of surface disorder, and the degree of surface coverage by amorphized Si (111) phases bombarded by low-energy ions (E_0 = 0.5 – 2 keV) were determined for the first time.

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