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Optical Properties of Ge_xSi_{1-x} Binary Compounds in Silicon

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The use of alternative and renewable sources of energy supply in energy supply around the world is attracting great and practical interest. The growing interest in them is caused by environmental considerations, on the one hand, and the limited nature of traditional hydrocarbon energy sources, on the other. A special place among alternative and renewable energy sources is occupied by photoelectric solar energy converters, the study of physics, which has become a separate scientific direction of photovoltaics. The development and creation of photocells based on silicon by binary compounds of germanium atoms Ge_xSi_{1-x} in volume is also of particular interest to scientists and specialists. Since the production of silicon with binary compounds of silicon-germanium with certain electrical parameters and structure allows you to significantly expand the spectral region of the sensitivity of photodetectors and the efficiency of photocells based on such materials.

Keywords: Renewable sources, Energy, Photovoltaic properties, Heterojunction, Graded-gap structure, Diffusion, Solar cell, Silicon, Germanium.

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1. INTRODUCTION

At present, increasing the efficiency of silicon-based photovoltaic cells (PV) is a very important and urgent problem that requires a vigorous study of electrical parameters in order to increase the efficiency of photovoltaic stations. It seems to us that one of the ways to solve this problem is the stabilization of the parameters of photocells to external influences, such as temperature and radiation, which leads to an increase in their service life by additional doping with impurity atoms of the original (base) material [1-4].

In this regard, of great interest is the study of additional doping of silicon with isovalent and rare-earth impurity atoms. As is known, from the analysis of literature data, it has been established that silicon doped with these impurity atoms not only manages to maintain the initial electrophysical parameters of the PV, it is also possible to significantly increase the lifetime of minority charge carriers, which serve to increase the efficiency of the PV.

2. METHODOLOGY

Although the diffusion technology for the production of Ge_xSi_{1-x} binary compounds is of great interest, the preparation of such compounds based on silicon has not been crowned with success so far. This is mainly due to the very small diffusion coefficient of germanium atoms in silicon ($D \sim 10^{-14}$ cm²/s), which requires a long diffusion time. The developed two-stage low-temperature diffusion technology for doping germanium atoms into silicon makes it possible to suppress the formation of various thermal defects and the formation of nanoclusters of binary compounds of the Ge_xSi_{1-x} type [5]. On the basis of the developed technology, diffusion of germanium impurity atoms into single-crystal silicon from the gas phase was carried out for t = 20 hours, while the vapor pressure of the diffusant was P = 1 atm, at a temperature of T = 1250 °C.

3. RESULTS AND ITS DISCUSSION

Studies of the spectral dependence of the photosensitivity of the obtained silicon samples doped with germanium atoms were carried out on IKS-12 spectrometers at a temperature of T = 300 K. Figure 1 shows the results of a study of the spectral dependence of silicon samples in which the surface and near the surface region was enriched with impurity germanium atoms.

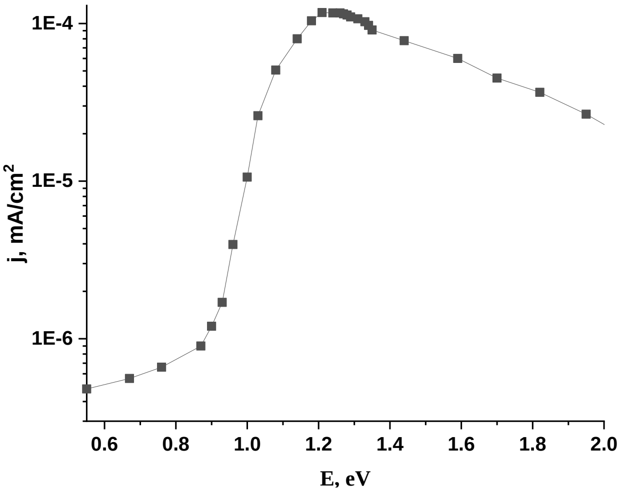

Fig. 1 – Spectral dependence of the photoconductivity of Ge_xSi_{1-x} samples, T = 300 K

The analysis of the obtained measurement results showed that, in the first region of the spectral dependence in the interval of the wavelength range λ = 2÷1 μm ($h\nu$ = 0.6÷1.2 eV), the value of the photocurrent increases by almost 150 times. Such a rapid increase in the photocurrent means that in this range of IR radiation there is a strong generation of charge carriers based on a double optical transition [6, 7]. These research results show that it is indeed possible to create sensitive photodetectors and more efficient photocells operating in a wide IR spectral region based on silicon with Ge_xSi_{1-x} binary unit cells.

Figure 2 shows the results of a study of the absorption spectra of the obtained silicon samples doped with germanium atoms on a Lambda 950 UV/Vis/NIR spectrometer at $T = 300$ K.

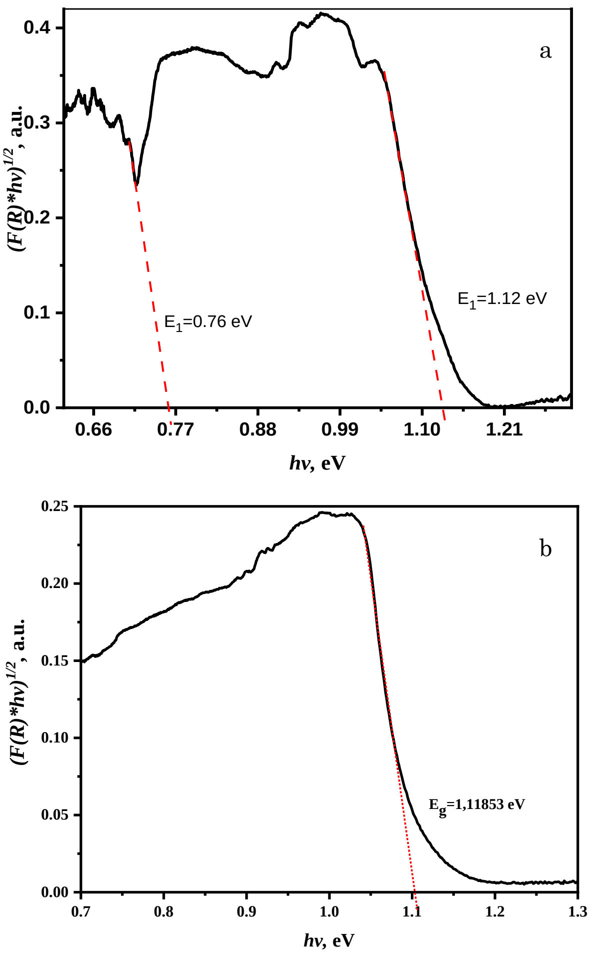

Fig. 2 – a) Absorption spectrum of a silicon crystal doped with germanium impurity atoms, at $T = 300$ K. b) Absorption spectrum of the original single-crystal silicon, at $T = 300$ K

Based on the solutions of the Kubelka-Munk function, the band gap of the obtained samples was determined based on the spectra of reflected light (form 1). The calculation results show that the band gap of the initial single-crystal silicon sample was equal to $E_{Si} = 1.2$ eV, the band gap of the silicon sample with binary silicon-germanium compounds was $E = 0.76$ eV.

$$F_{KM} = \frac{(1-R)^2}{2R}$$
$$h\nu \cdot F_{KM}^{1/n} = A(h\nu - E_g)$$

An analysis of the results of measurement of absorption spectra on Lambda 950 UV/Vis/NIR spectrometers has established that the absorption spectrum of silicon by doped germanium atoms differs from the initial single-crystal silicon [8-10].

From the results obtained, it was established that impurity germanium atoms form binary compounds of the Ge_xSi_{1-x} type on the surface and near-surface region of silicon. The formation of such compounds with high concentrations on the surface and near the surface regions leads to a change in the band gap of silicon. This, in turn, leads to the formation of heterostructures based on binary compounds of the Ge_xSi_{1-x} type, which, in turn, lead to a significant increase in the photoconductivity value, as well as an increase in the spectral sensitivity range relative to the initial silicon material. These results of the study indicate that the resulting heterostructure based on the Ge_xSi_{1-x} binary compound can be used as a promising material for the development and fabrication of efficient silicon-based photocells.

The composition and optical properties of the resulting binary compounds Ge_xSi_{1-x} in silicon were studied using an infrared Fourier spectrometer brand FSM-1202. Before studying the optical properties of the obtained silicon samples, two opposite surfaces were polished with diamond paste on a polishing device, and the remaining four sides of the silicon samples were ground to ~ 100 µm in order to remove the near-surface enriched layer. These studies made it possible to accurately measure the composition of the elements of the formed Ge_xSi_{1-x} binary compounds on the surface and near-surface silicon layer. The measurement results are shown in Fig. 3.

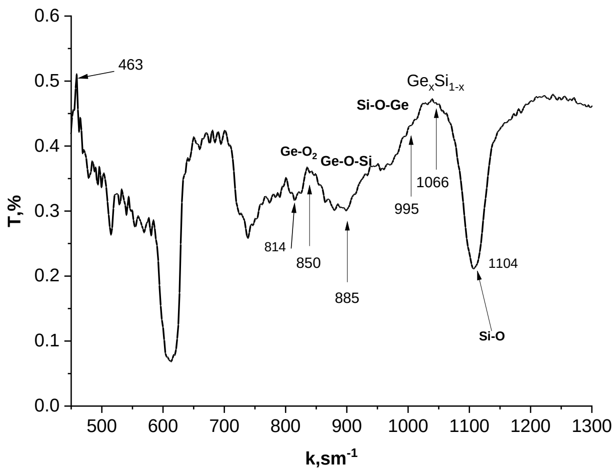

Fig. 3 – Elemental composition of the silicon surface doped with impurity germanium atoms. The study was carried out by a spectrometer brand FSM 1202, at $T = 300$ K

An analysis of the obtained results showed that the formation of binary compounds of impurity germanium atoms with atoms of the original silicon leads to the appearance of a peak associated with the absorption of a frequency of 1066 cm^{-1}. The peaks observed at 885 cm^{-1} and 850 cm^{-1} correspond to germanium oxide (GeO_2), the peak at 1104 cm^{-1} is associated with the formation of oxygen compound silicon (Si-O). Considering the intensity of other peaks at 463 cm^{-1}, 814 cm^{-1}, and 1104 cm^{-1} showed the presence of silicon oxide (SiO_2). The transmittance at a peak of 1066 cm^{-1} showed the presence of binary compounds of the Ge_xSi_{1-x} type in silicon. In other words, the choice of the annealing temperature at $T = 850$ °C was appropriate, because at this temperature the minimum oxidation thickness of the Si substrate is formed. Two dips in transmittance (absorption peaks) at 850 cm^{-1} and 885 cm^{-1} are shown in Fig. 3, indicating a significant thickness of the germanium oxide O-Ge-O (GeO_2) layer formed on the silicon

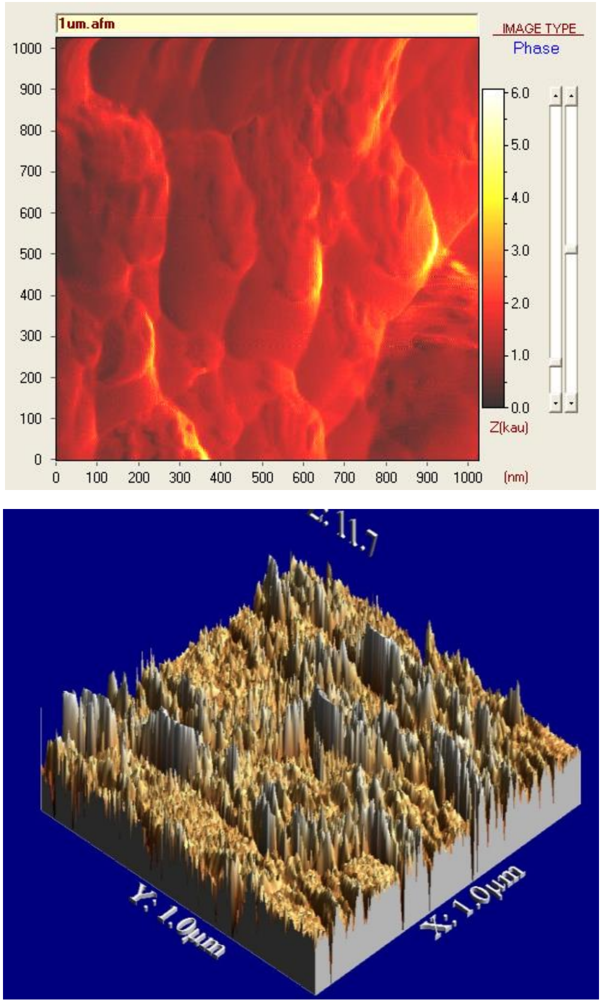

Fig. 4 – AFM images of a silicon surface doped with impurity germanium atoms

surface. These data were confirmed by the results obtained by other authors [11, 12].

On Fig. 4 shows the surface morphology of silicon samples doped with germanium atoms, obtained on a Core AFM atomic force microscope. As can be seen from the figure, the surface morphology of silicon samples doped with germanium atoms is characterized by relief irregularities, which is associated with the concentration of binary compounds of impurity atoms of germanium and silicon (Ge_xSi_{1-x}).

As can be seen from Fig. 4, the formation of islands on the silicon surface doped with germanium impurity atoms leads to an increase in the average roughness size. This indicates the formation on the silicon surface of Ge_xSi_{1-x} binary compounds, the electric potential of which is greater than that of the initial silicon.

4. CONCLUSIONS

Thus, it has been established that the developed two-stage low-temperature diffusion technology makes it possible to control the penetration depth (x) of impurity germanium atoms in silicon, which form binary compounds of the Ge_xSi_{1-x} type. It follows from the analysis of the experimental results that, by improving the diffusion technology of doping germanium atoms in silicon, it is possible to obtain binary compounds with different concentrations of impurity germanium atoms, which lead to the expansion of the spectral range of photoconductivity and leads to high photosensitivity in the IR region of the radiation spectrum with a wavelength $\lambda = 1 \div 3$ μm [13-15]. These research results show the possibility of creating sensitive photodetectors of IR radiation and efficient photocells based on silicon doped with germanium impurity atoms.

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Оптичні властивості бінарних сполук Ge_xSi_{1-x} в кремнії

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Використання альтернативних і відновлюваних джерел енергії в енергозабезпеченні в усьому світі викликає великий практичний інтерес. Зростання інтересу до них зумовлене екологічними міркуваннями, з одного боку, та обмеженістю традиційних вуглеводневих джерел енергії, з іншого. Особливе місце серед альтернативних і відновлюваних джерел енергії займають фотоелектричні перетворювачі сонячної енергії, вивчення фізики, що стало окремим науковим напрямком фотовольтаїки. Розробка та створення фотоелементів на основі кремнію бінарними сполуками атомів германію Ge_xSi_{1-x} в об'ємі також становить особливий інтерес для вчених і спеціалістів. Оскільки виробництво кремнію з бінарними сполуками кремній-германій з певними електричними параметрами і структурою дозволяє значно розширити спектральну область чутливості фотоприймачів і ефективність фотоелементів на основі таких матеріалів.

Ключові слова: Відновлювані джерела енергії, Фотоелектричні властивості, Гетероперехід, Варизонна структура, Дифузія, Сонячний елемент, Кремній, Германій.