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MORPHOLOGY OF THE SURFACE OF SILICON DOPED WITH LUTETIUM

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In this paper, using a scanning electron microscope (SEM) and atomic analysis, the location map of microcomposites formed on the surface of n-Si, p-Si, n-Si<Lu> and p-Si<Lu> samples was studied. Force microscope (AFM) research devices. The atomic fractions of inclusions of carbon, oxygen and lutetium formed on the surface of the samples were studied. Also, using the ASM device, the sizes, relief and topographic appearance of defects formed on the surface of the samples were determined. In silicon samples doped with Lu, a decrease in the size of surface defects and the formation of nano-sized structures were found, which makes it possible to obtain materials with a more perfect crystal structure. Using a ZEISS GeminiSEM 300 scanning electron microscope, the structural structure, chemical composition and images of their arrangement of n-Si, p-Si, n-Si<Lu> and p-Si<Lu> samples were obtained. In this case, the electron accelerating voltage was 20 kV, and the pressure in the sample chamber was (10^{-3} mmHg). Research results show that the structural structure of micro- and nanocomposites formed in silicon mainly depends on the diffusion time and cooling rate of the samples after diffusion annealing.
Keywords: *Silicon; Lutetium; Access; Doping; Defect; Diffusion; Oxygen; Carbon; SEM; AFM*
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INTRODUCTION

As you know, silicon is the main semiconductor material used in electronics [1,17]. These are micro-nano compounds important optical, electrophysical and photoelectric to the properties of k e. Therefore, the study of the structure, size and surface morphology of such compounds is one of the urgent problems of modern physics.

Silicon-based microstructures have a wide range of potential properties that can enhance the capabilities of micro-nanoelectronic devices. Many scientific works note that of particular importance is the study of processes occurring as a result of the interaction of alloying and technological impurities of atoms of their sizes, as well as specific defects, and the determination of the stages of their formation. impurity atoms during the diffusion of various impurity atoms into a silicon single crystal at high temperatures [3,6,9,13,15]. In the photoconductivity region, they can increase light absorption and reduce recombination losses. Silicon single crystals can also serve as an active element in LEDs and other optoelectronic devices [10,11, 14,16]. By analyzing changes in surface topography, researchers have conducted a number of studies to develop new technologies in areas such as microelectronics, optoelectronics and photovoltaics [9,12,16].

Electronic processes in semiconductor materials are determined mainly by volumetric and surface defects of the semiconductor. Studying these defects and reducing their formation is one of the main tasks of modern semiconductor electronics. In recent years, interest in the development of methods for monitoring defects in silicon single crystals and their interaction by doping with rare earth elements (REEs) has increased significantly [2,5,8].

MATERIALS AND METHODS

In the manufacture of silicon structures based on rare earth elements (REE), the diffusion method was used [7,15]. In the research work, n-type (ρ=0.3÷150 Ω×cm) and p-type (ρ =0.3÷20 Ω×cm) silicon single crystals grown by the Czochralski method were used. At the input, the element lutetium with a purity of 99.999% was obtained.

Before diffusion, silicon single crystals were subjected to mechanical and chemical treatment. Using a VUP-4 setup, lutetium atoms were deposited onto the surface of a silicon sample under high vacuum conditions (10^{-6} mm Hg). A high-vacuum ampoule was prepared using quartz glass. Diffusion was carried out in a SUOL oven at a temperature of 1250°C for 30 hours. After diffusion, the samples were quickly cooled. After diffusion annealing, the samples were quickly cooled. Before measurements, 10 μm was removed from the surface of the prepared samples using micropowder. After mechanical and chemical treatment, the morphology of the samples was measured using SEM, and the surface composition structure was measured using SEM.

RESULTS AND DISCUSSION

Using a ZEISS GeminiSEM 300 scanning electron microscope, the structural structure, chemical composition and images of their arrangement of n-Si, p-Si, n-Si<Lu> and p-Si<Lu> samples were obtained.

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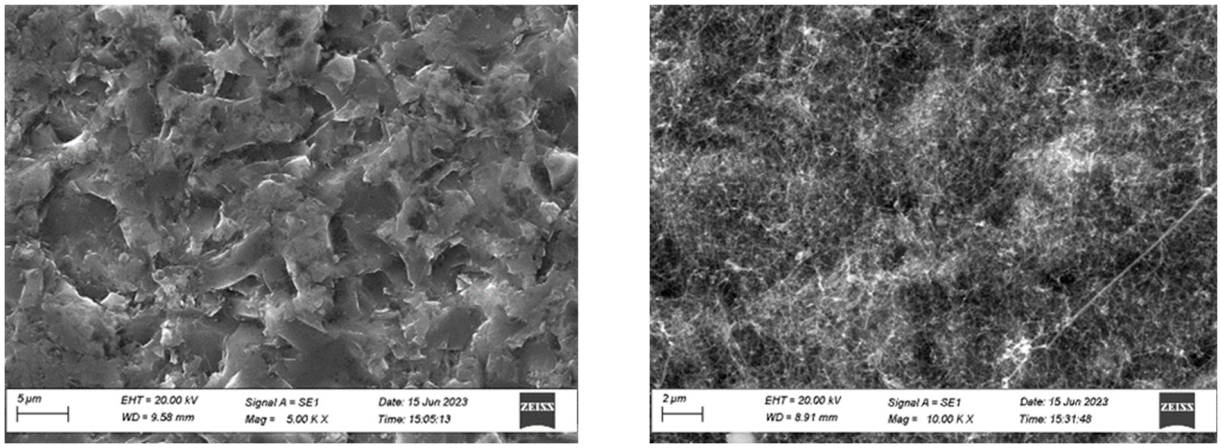


Figure 1. p – Si (control) and SEM image of samples p - Si <Lu>

In Figure 1 shows an SEM image of lutetium-doped silicon. As can be seen in the figure, for the first time the fibrous arrangement of lutetium atoms on the surface of single-crystalline silicon doped with lutetium has been experimentally established. As a result of the research, quantitative indicators of atoms of technological raw materials, such as O and C, as well as Si and Lu atoms in this microcomposite were determined.

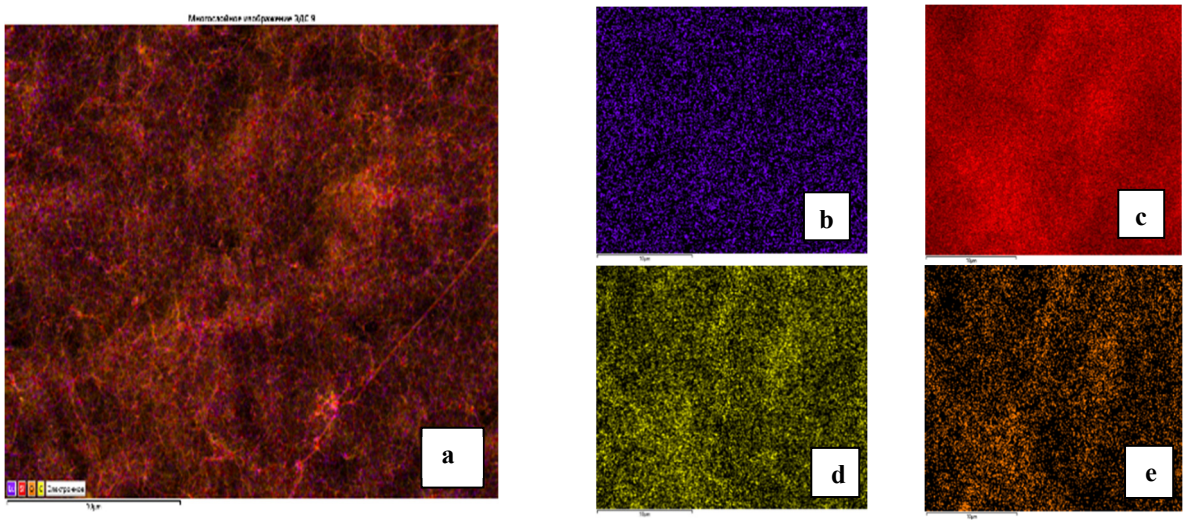


Figure 2. Arrangement of elemental atoms in a lutetium-doped silicon sample (p-Si<Lu>).
a) p- Si<Lu>, b) Lu, c) Si, e) C, d) O

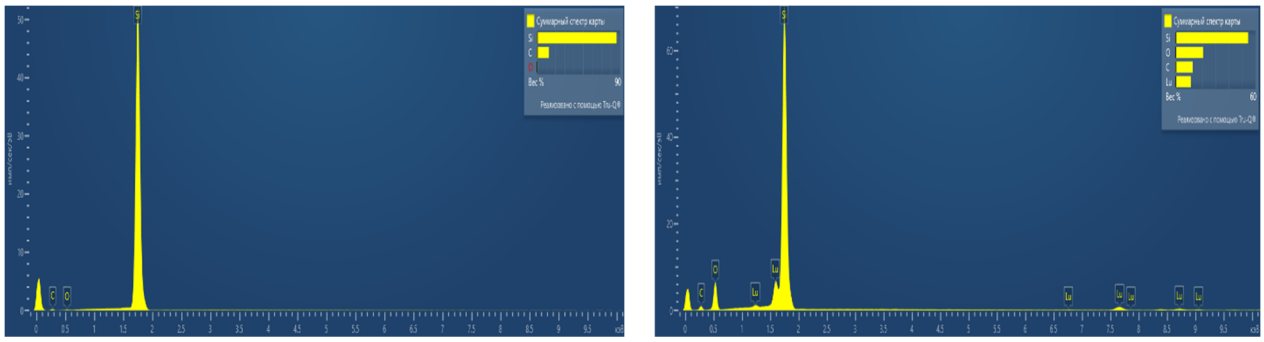
Figure 2 with lutetium doped in silicon elements concentration for elemental spectrum mapping shown. In the mapping image, the elements Si, Lu, O and C (red, violet, green and yellow) are arranged correctly without any gaps, and the atomic percentages of the sample are 25.24%, 0.96%, 7.08% and 66 .72% respectively. These quantitative values were obtained from SEM analysis. The results of the analysis of the chemical composition of these microgranules in their central part are presented in the Table below.

Table. Total spectrum of the card

Element	Line type	Conditional concentration	Weight. %	Atom %
		n-Si		
C	series K	9.51	44.74	66.72
O	series K	5.03	6.32	7.08
Si	series K	65.99	39.57	25.24
p-S<Lu>				
C	series K	9.51	44.74	66.72
O	series K	5.03	6.32	7.08
Si	series K	65.99	39.57	25.24

Element	Line type	Conditional concentration	Weight. %	Atom %
Lu	L series	10.89	9.36	0.96
n-S<Lu>				
C	series K	1.55	13.07	24.75
O	series K	17.26	20.79	29.56
Si	series K	65.56	54.59	44.19
Lu	L series	10.34	11.55	1.50

When the finished samples are measured, no peaks are observed. The Si peak obtained at 1.8 keV confirms the correctness of the technological process in the prepared samples. Figure 3-a, b confirm the absence of any impurities other than natural additives. Works [1,5,7] confirm the formation of additional growing technological impurities (defects) formed during sample preparation.An unknown Si peak obtained at an energy of 1.8 keV confirms the correctness of the technological process in the prepared samples. The results obtained confirm the absence of any additions other than preformed defects. Works [1,5,7] confirm the formation of additional growing technological impurities (defects) formed during sample preparation.



a) b)

Figure 3. SEM spectrum of n-Si(a) and n-Si<Lu>(b) samples

A single crystal of silicon is an optional element with doping its surface morphology changes [3-5]. In our studies, changes in surface properties can be seen when doped with lutetium. However, these surface changes may be associated not with the concentration of lutetium atoms, but with technological factors of sample preparation. In general, in a number of works it was believed that the addition of a foreign substance to a silicon single crystal leads to a change in the surface topography [11,12,15].

Changes in surface morphology may depend on the sputtering time during the deposition process, the heating temperature of the crucible and the diffusion time during the diffusion process in the VUP-4 installation.

The AFM image was obtained at different points on the sample surface. On the surface of the sample there are pits in the form of protrusions up to 1 μm wide, the appearance of which is directly related to mechanical processing. Small rounded peaks were observed on the surface of the silicon single crystal; a transverse peak height profile with a diameter of 2 to 14 nm is shown (Fig. 3). The surface relief heights of the silicon monolith differ from each other by 31.5 nm.

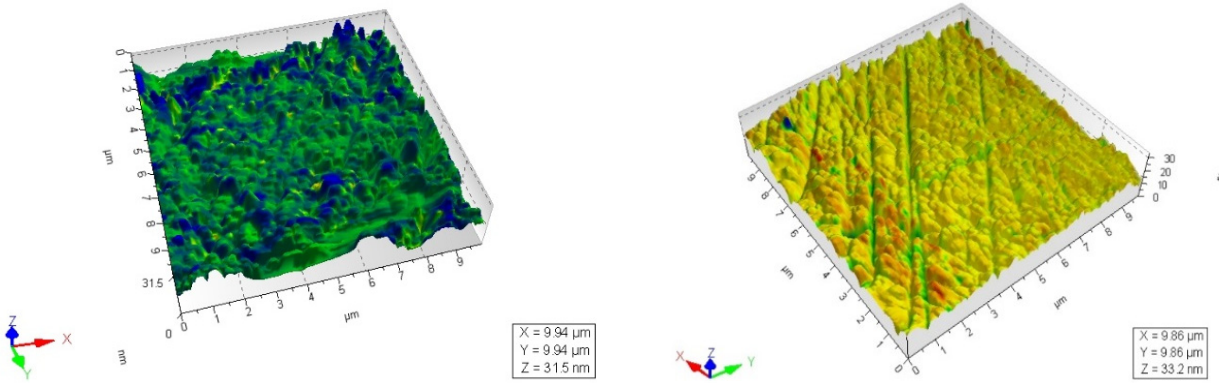


Figure 4. SEM images of n-Si and n-Si<Lu> samples

Doping single-crystal silicon with lutetium led to a significant change in the morphology of the sample surface (Fig. 5.1). But the relief height was 33.15 nm. If the initial relief height of a silicon single crystal was 31.15 nm, then the change in relief can be associated with the diffusion process. Grooves up to 1 μm wide were observed on the surface of samples in the initial state of a single crystal of silicon and on the surface of samples doped with lutetium. These pits are explained by the removal of a 10 μm thick layer from the surface of the sample after a diffusion process followed by mechanical processing.

Judging by the obtained image profiles, the dimensions of the resulting grooves can vary from hundreds of nanometers to several microns. Analysis of the 3D image shows that the overall structure (n-Si<Lu>) shows that the structure formed on the surface of the sample is very small. However, this is not visible in the cross-sectional profile of the AKM image of the surface (Fig. 5.2), which is due to the visualization of the gaps due to the nanometry and shape of its structural elements.

Several factors have been found to influence the surface morphology of lutetium-doped silicon.

1. Firstly, it fills the irregularities on the surface of the silicon single crystal, that is, the voids, and reduces lumps on the surface.

2. Secondly, the protrusions in the glaze led to a decrease in the growth of crystalline phases.

As a result of the diffusion of lutetium atoms onto the surface of a single crystal of silicon, the morphology of the silicon surface changes; probably, the collision of lutetium ions with the surface of the crystal during diffusion at 1250°C leads to the formation of structural defects on the silicon surface. sample. This, in turn, leads to an increase in the number of quantum islands on the surface of the sample.

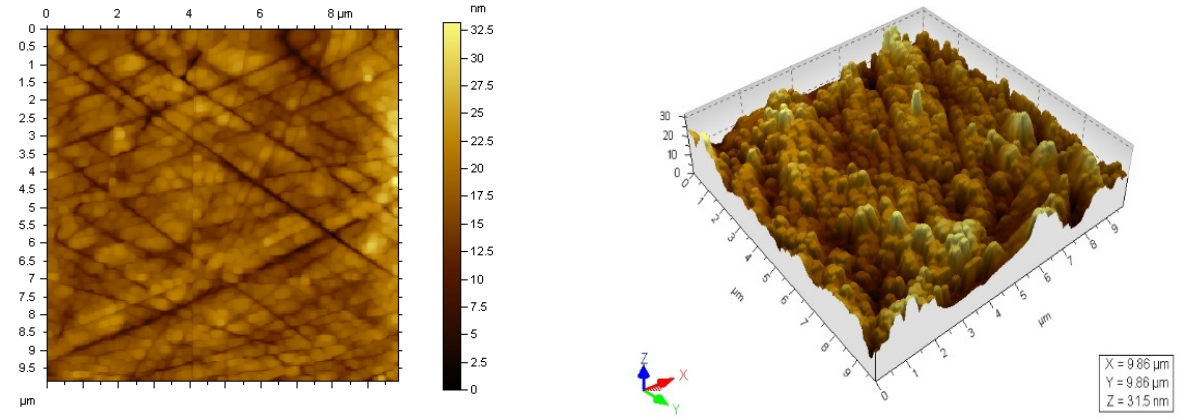


Figure 5.1 Raw monocrystalline silicon (n - Si) state AKM received description

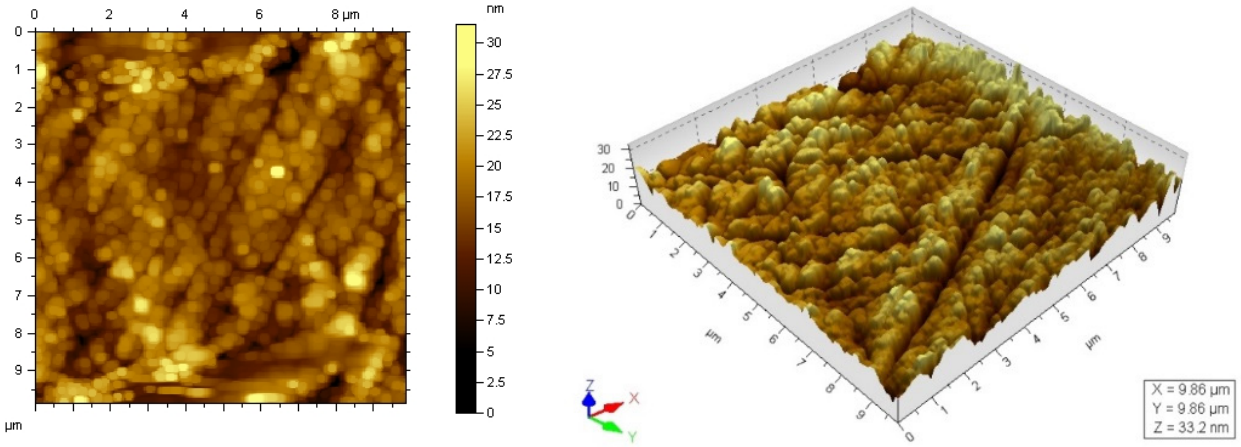


Figure 5.2 Lutetium with An AFM of doped silicon single crystal was obtained. description

CONCLUSION

Based on the results of the experiments, the following conclusions were made. The structural structure, chemical composition and their description of n-Si, p-Si, p-Si<Lu> and nS<Lu> samples were studied for the first time. Research results have shown that the structural structure of micro- and nanocompounds formed in silicon mainly depends on the diffusion time and cooling rate of the samples after diffusion annealing. For the first time, the fibrous arrangement of lutetium atoms on the surface of single-crystalline silicon doped with lutetium has been experimentally established. As a result of the studies carried out, the quantitative indicators of atoms of technological raw materials, such as O and C, as well as Si and Lu atoms, were determined in this microcomposite. In our studies, a significant change in the morphology of the sample surface was observed when single-crystal silicon was doped with lutetium. Grooves up to 1 µm wide were observed on the surface of samples in the initial state of a single crystal of silicon and on the surface of samples doped with lutetium. It was concluded that the grooves formed on the surface are associated with mechanical processing. If the initial relief height of a silicon single crystal was 31.15 nm, then the change in relief can be associated with the diffusion process. Grooves up to 1 µm wide were observed on the surface of samples in the initial state of a single crystal of silicon and on the surface of samples doped with lutetium.

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МОРФОЛОГІЯ ПОВЕРХНІ КРЕМНІЮ, ЛЕГОВАНОГО ЛЮТЕЦІЄМ

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У цій роботі за допомогою скануючого електронного мікроскопа (SEM) та атомного аналізу досліджено карту розташування мікрокомпозитів, сформованих на поверхні зразків n-Si, p-Si, n-Si<Lu> та p-Si<Lu>. Дослідницькі прилади силового мікроскопа (АСМ). Досліджено атомні частки включень вуглецю, кисню та лютецію, що утворюються на поверхні зразків. Також за допомогою приладу АСМ визначали розміри, рельєф і топографічний вигляд дефектів, утворених на поверхні зразків. У зразках кремнію, легованих Lu, виявлено зменшення розмірів поверхневих дефектів і утворення нанорозмірних структур, що дозволяє отримувати матеріали з більш досконалою кристалічною структурою. За допомогою скануючого електронного мікроскопа ZEISS GeminiSEM 300 отримано структурну будову, хімічний склад та зображення їх розташування зразків n-Si, p-Si, n-Si<Lu> та p-Si<Lu>. У цьому випадку прискорювальна напруга електронів становила 20 кВ, а тиск у камері зразка становив (10-3 мм рт. ст.). Результати досліджень показують, що структурна структура мікро- та нанокомпозитів, сформованих у кремнії, в основному залежить від часу дифузії та швидкості охолодження зразків після дифузійного відпалу.
Ключові слова: *кремній; лютецій; доступ; допінг; дефект; дифузія; кисень; карбон; SEM; АСМ*