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# The structure, mechanical and electrophysical properties of monocrystalline silicon after exposition in constant magnetic fields with differentmagnetic induction

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Abstract
The influence of constant magnetic field with different induction on the structure, phase composition, and properties of silicon was observed. Itwas noted that increase the induction of external magnetic field causes a significant increase in resistivity samples. Thus, increasing the exposure time significantly increases the value of micro hardness. An increase in the induction of the external magnetic field greatly activates the sample surface, resulting in saturation of oxygen electroactive ions that are able to capture carriers and cause increased resistivity. Increase exposure time samples helps to generate more structural defects and, consequently, increases the microhardness of samples.
Keywords: MONOCRYSTALLINE SILICON, MICROSTRUCTURE, MICROHARDNESS, ELECTROPHYSICAL PROPERTIES, MAGNETO-STIMULATED EFFECTS

**Introduction**

Investigation of the influence of the magnetic field on solids has recently attracted considerable interest. Several effects that are associated with the influence of a weak magnetic field on various physical processes in paramagnetic crystals have been observed. Theoretically, it is assumed that the magnetic field affects the crystals, mainly causing the formation and destruction of chemical bonds. A growing number of scientific publications on this topic have caused the emergence of a new direction in physics – spin-micromechanics, aimed at studying micromechanical spin-dependent processes that affect the mechanical properties of solids.

At present time, in the scientific literature there are very few publications devoted to the effect of the magnetic field on the mechanical and electrophysical properties of elementary semiconductors, crystalline silicon in particular. A generalization of the results of previous studies has shown that magnetic treatment causes the evolution and modification of structural defects in paramagnetic silicon. This, in turn, indicates the possibility of changing the structural-sensitive properties of silicon (mechanical and electrophysical) as a result of magnetic treatment.

In this paper, we investigated the micromechanical (microhardness) and electrophysical (specific resistivity) properties of silicon, as well as their interrelation, under the influence of constant magnetic fields with different magnetic induction.

**Materials and methods**

The influence of constant magnetic fields (magnetic induction B = 0.4 and 1.2 T) on the structure, mechanical and electrical properties of doped silicon was investigated in the work.

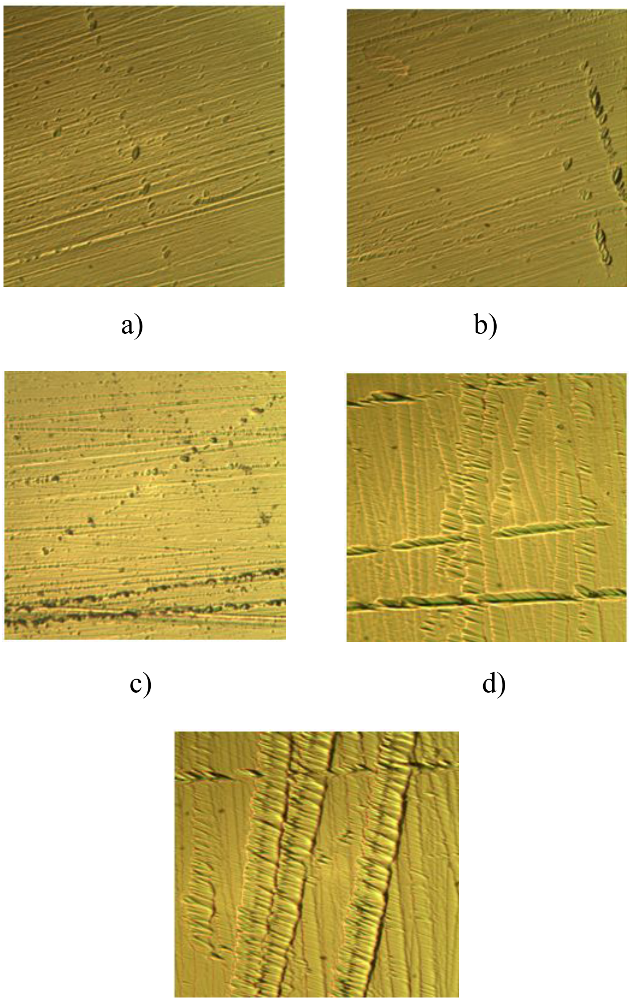
As initial materials, specimens of single-crystal semiconductor silicon that have been grown by the Czochralski method (Cz-Si) were chosen.

The specimens were processed in constant magnetic fields with inductions of 0.4 and 1.2 Tesla. Exposure of specimens was 10 and 30 days. To reveal the general structure of silicon, the specimens were etched in a solution of HF: $H_2O$: $CrO_3$ in a ratio of 3: 3: 1 for 30-60 minutes followed by washing in running water. The microstructure of the specimens was studied using an optical microscope “Neophot-21”. The microhardness was measured by a PMT-3 device at a load of 20 g. 25-60 samples were taken on each specimen. Measurement of the resistivity of the specimens was carried out by a four-contact method.

**Results and discussion**

The results of previous studies have shown that a weak magnetic field with an induction of 0.07 T is able to cause a change in the mechanical and electrophysical properties, as well as induce the evolution of defects in the structure of Cz-Si single crystals. Constant magnetic fields with inductions of 0.4 and 1.2T also cause an increase in the number of structural defects in silicon single crystals (Fig. 1b, c). At the same time, an increase in the exposure time of the specimens, as well as induction of the magnetic field, causes the formation of a larger number of structural defects, which is confirmed by microhardness measurements (Fig. 1 d, e).

The results of measurements of the microhardness of silicon specimens that were exposed in magnetic fields with inductions of 0.4 and 1.2 T (Figure 2) showed that an increase in the induction of an external magnetic field causes a more significant change in the microhardness of the specimens, and is nonlinear in nature. It was also noted that increasing the exposure time has a more significant effect on the mechanical properties of silicon specimens than an increase in the induction of an external magnetic field.



a) b) c) d) e)

**Figure 1.** Microstructure of silicon specimens after exposition in constant magnetic fields

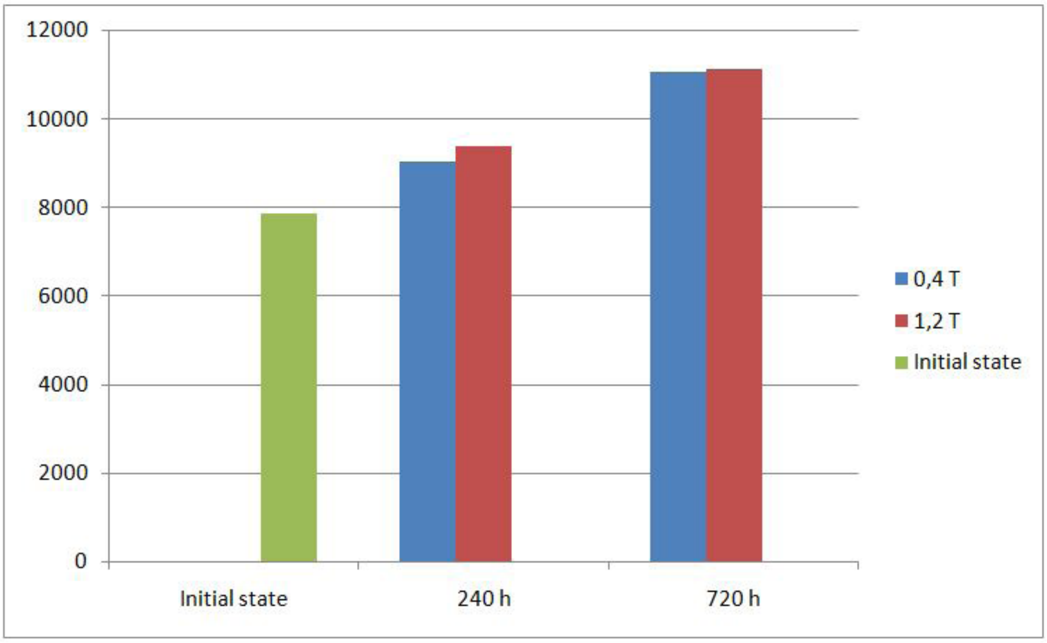



**Figure 2.** Microhardness of silicon specimens before and after treatment in a constant magnetic field

It has been shown experimentally that magnetic processing of silicon specimens causes an increase in the concentration of oxygen on the surface of silicon samples. Oxygen, adsorbed on the surface, can form chemical compounds, with both silicon and any of the adsorbed elements, and also cause the appearance of various kinds of structural defects, such as vacancy-oxygen complexes, A-defects, interstitial atoms and simple vacancies, by interaction with silicon atoms in the crystalline lattice. Structural defects are often electroactive they; influence the density of electronic states near the Fermi level, by creating additional energy levels in the band gap of silicon crystals, and also act as efficient recombination centers, reducing the mean free path of minority charge carriers and their lifetime.

The change in the electrical characteristics of silicon crystals after magnetic treatment was studied by measuring the electrical resistivity by a four-contact method.

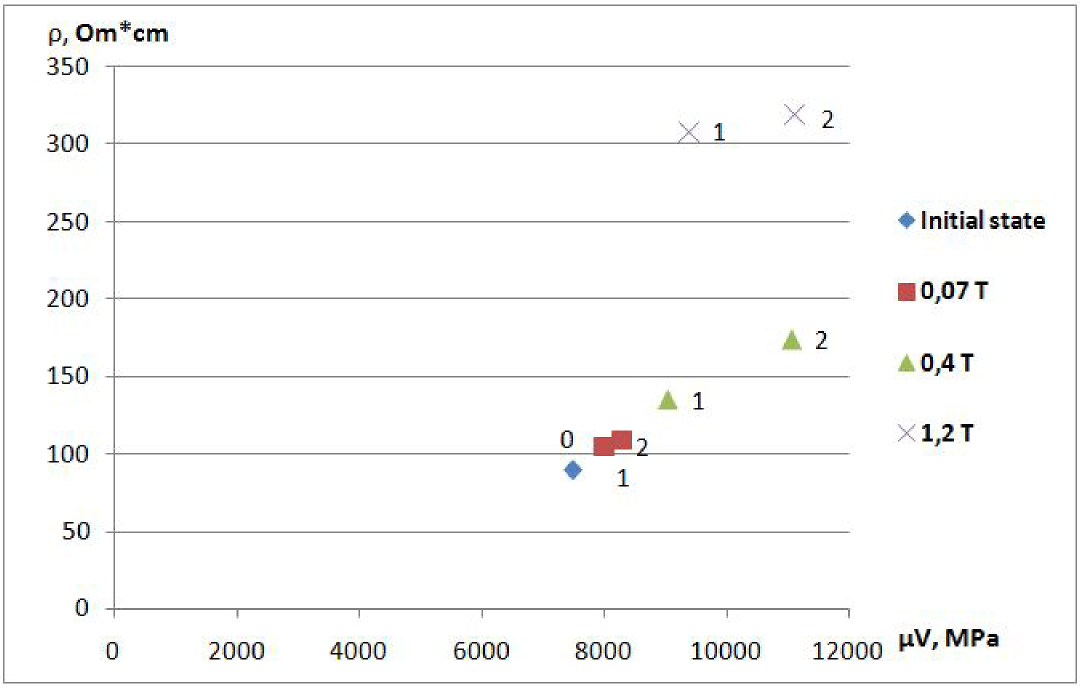
**Table 1.** Electrophysicalpropertiesofsiliconspecimensaftertheexposurein a constant magnetic field (B = 1.2 T)

| Specimen | Magnetic induction/specific resistanceρ | | |
|---|---|---|---|
| | Initial state | 240 h | 720h |
| Cz- Si | 90-105 | 0.4/130-142<br>1.2/308-324 | 0.4/166-181<br>1.2/320-326 |

The results of measurements of the electrophy- sical properties of single-crystal silicon specimens before and after exposure in constant magnetic fields with magnetic inductions of 0.4 and 1.2 T are shown in Table 1. An analysis of the data shows that exposure of specimen sin constant magnetic fields leads to an increase in the resistivity, and an increase in the exposure time of the samples in magnetic fields has a significantly smaller effect than an increase in the induction of the magnetic field. The increase in the resistivity after aging has confirmed the fact that a constant magnetic field initiates the evolution of the defect structure of paramagnetic silicon, which leads to the formation of new scattering centers and charge carriers. Also, magnetic treatment promotes the activation of the surface, its saturation with oxygen and other electroactive ions, which increases the resistance of the samples.

Figure 3 shows the values of the electrical resistivity of specimens in relation to their mechanical properties (microhardnessμV, MPa) and induction of an external magnetic field (B, T). A certain correlation was observed between the values of microhardnessand their resistivity, as well as the very strong dependence of the resistivity on the induction of the magnetic field. Exposure of samples in a strong magnetic field (1.2 T) caused a significant degradation of electrophysical properties with a slight increase in microhardness compared with the influence of the magnetic field of medium induction (0.4 T). It should also be noted that increasing the exposure time of specimens from 240 to 720 hours has a more significant effect on microhardness than on the values of the electrical resistivity of the specimens.

Thus, an increase in the induction of an external magnetic field causes a significant increase in the resistivity of the specimens, while an increase in the exposure time substantially increases the value of the microhardness.




0-initial state; 1- 240h; 2-720h

**Figure 3.**The values of the electrical resistivity of thespecimensin relation to their mechanical properties (microhardness μV, MPa) and the induction of an external magnetic field (B, T)

It can be assumed that an increase in the induction of an external magnetic field activates the surface of the specimens to a large extent, which leads to saturation with electric-active oxygen ions, which are capable to capture the charge carriers, and as a result, cause an increase in the resistivity.

The increase in the exposure time of the specimens promotes the generation of more structural defects and, as a consequence, has a significant effect on the microhardness of the specimens.

**Conclusions**

- Increase in the induction of external magnetic field causes a significant increase in resistivity samples, thus increasing the exposure time significantly increases the value of micro hardness;

- an increase in the induction of the external magnetic field greatly activates the sample surface, resulting in saturation of oxygen electroactive ions that are able to capture carriers and cause increased resistivity;

- increase exposure time samples helps to generate more structural defects and, consequently, increases the microhardness of samples.

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