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Effect of a Stable Magnetic Field on Silicon Properties

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The effect of a constant magnetic field (0.17 T) on microhardness, kinetics of photoconductivity decline and electro conductivity in silicon crystals is studied. The nature of changes of micromechanical and electrophysical characteristics in samples is investigated as a function of time elapsed after magnetic treatment. The results obtained are discussed in terms of magnetic field stimulated processes occurring in a subsystem of structural defects.

Keywords: Silicon, Structural defects, Magnetic field, Electrical properties.

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1. INTRODUCTION

One of the urgent problems of modern electronics is the creation of the reliable and predicted systems which could operate under extreme conditions: in the wide temperature ranges, under the influence of radiation, the atmosphere, magnetic field, etc. Influence of external factors stimulates changes of electrophysical and optical characteristics of crystals, including silicon and also the devices manufactured on their basis.

With consideration for the fact that silicon is a source of autonomous power consumption, even minor changes in mechanical and electrophysical properties of the specified material under the influence of various external factors become essential and their research is expedient. Recently effect of magnetic fields, including weak magnetic fields (induction $B < 1$ T), on physical characteristics of low-magnetic materials with various types of chemical bonds, is widely studied [1-3]. The specified scientific research on covalent crystals (for example, silicon) is rather scarce.

When silicon is alloyed with magnetic impurities creating deep energy levels in its forbidden band, its electrophysical and kinetic properties significantly change. Virtually, silicon becomes new material with improved properties. Use of the silicon alloyed with such impurities in combination with well-developed planar technology makes it a promising material for needs of a modern magnetoelectronics [4, 5].

2. EXPERIMANTAL DETAILS

In this work the investigation results of the influence of a weak constant magnetic field ($B \leq 0{,}5$ T) on micromechanical and electrophysical properties of single crystal silicon grown by the Chokhralsky (Cz) technique (KEF 0,5, KEF 4,5, KEF 7,5) and crucibleless melting (Fz) and which is also alloyed with various impurities are presented.

Samples were put in a magnetic field for 7-60 days. Micromechanical characteristics, specifically microhardness and electric characteristics, namely change of magnetosensitivity, specific resistance and lifetime of non- basic charge carriers depending on time of exposure in the constant magnetic field and also photoconductivity relaxation time were as indicators of changes caused by the magnetic field.

Measurements of microhardness were taken on the automatic Tukon-2100 microhardness gage with the use of Knup's indenter. Non-alloyed samples (KDB and BZP) were located in a constant magnetic field $B = 0{,}5$ T for 7 days at room temperature, and the alloyed samples of Si <Gd + Ge>, Si <Al>, Si <Gd + Mn> were maintained 14 days in a magnetic field.

3. RESULTS AND DISCUSSION

It is found at a measurement of microhardness that after magnetic processing micro fragility of material most clearly manifests itself. The results of microhardness measurement before and after magnetic processing (MP) are presented in Table 1.

Table 1 – Values of microhardness before and after magnetic processing

№	Sample	Microhardness (Hk), kg/mm^2	
		Before MP	After MP
1	KDB 10	1049,90	1031,70
2	BZP	989,52	982,30
3	Si <Gd + Ge>	1015,50	1010,33
4	Si <Al>	1021,86	1073,00
5	Si <Gd + Mn>	1041,24	1120,31

Measurements of sample specific resistance were taken on the VICK-WES computing and measuring complex 15A, a four-probe method.

The convenient characteristic of specific resistance change after magnetic processing is the relative amount of change of specific resistance – magnetosensitivity of specific resistance: $\Delta\rho/\rho = (\rho - \rho_0)/\rho_0$, where ρ_0 – the initial value of specific resistance before magnetic processing, Ω·cm; ρ-value of specific resistance certain time after magnetic processing, Ω·cm.

Values of magnetosensitivity of specific resistance depending on the time of exposure in a magnetic field are presented in Fig. 1 ($B = 0{,}5$ T).

The analysis of the experimental data obtained revealed that the influence of magnetic field within 40 days led to an increase $\Delta\rho/\rho$ for the samples of silicon grown by the Cz method by 1,5-2 times, samples of Si <Gd + Mn> by 50 times. On other samples, considerable change of magnetosensitivity is not revealed. Further influence of MT leads to the beginning of relaxation process, i.e. magnetosensitivity reduction.

Measurement of lifetime of non-basic charge carriers was taken by contactless microwave technique on photoconductivity decline with the apparatus - program complex TAUMETR.

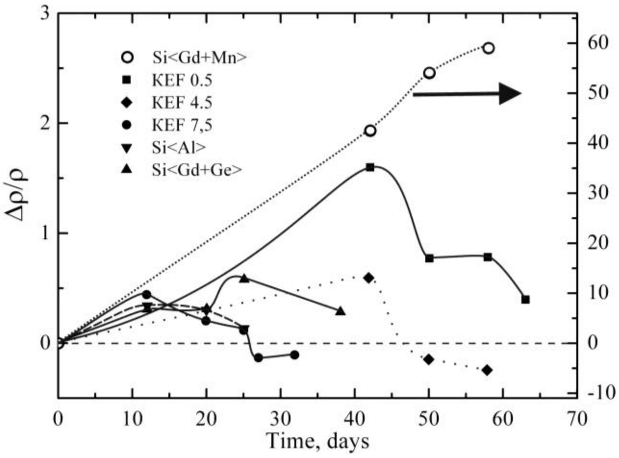

Fig. 1 – Dependence of magnetosensitivity of specific resistance on time of exposure in a stable magnetic field (B = 0,5 T)

For measurement of the lifetime of non-basic charge carriers depending on the time of exposure in a constant magnetic field the samples grown by the Cz method were taken: KEF 0,5; KEF 4,5; KEF 7,5 (Table 2).

Table 2 – Dependence of the lifetime of non-basic charge carriers on the processing time in a constant magnetic field ($B \leq 0,5$ T)

Sample	Lifetime of non-basic charge carriers before MP(τ_0), μs	Processing, days		
		5	16	27
		Lifetime of non-basic charge carriers τ, μs		
		τ_1, μs	τ_2, μs	τ_3, μs
KEF 0,5	1.442	1.672	2,053	2.629
KEF 4,5	54.296	57.287	66.053	74.703
KEF 7,5	85.323	91.316	86.199	77.831

The convenient characteristic of change in lifetime after magnetic processing is the relative amount of change of lifetime $\Delta\tau = (\tau - \tau_0)/\tau$, where τ_0 is the original value of lifetime before magnetic processing, μs; τ is the value of lifetime certain time after magnetic processing, μs.

Dependences of the relative value of the lifetime (magnetosensitivity *τnbcc*) on the time of exposure in the magnetic field for KEF 0,5, KEF 4,5, KEF 7,5 are presented in Fig. 2. It is seen that magnetosensitivity of. KEF 0,5 and KEF 4,5 increased by 5-6 times.

To find the composition of impurities, the secondary ion mass spectrometry (SIMS) allowing one to estimate with high sensitivity (10^{-3}-10^{-6} %) structure and concentration of impurities in near-surface layers was used.

Histograms of secondary ions distribution were recorded histograms of secondary ions distribution were

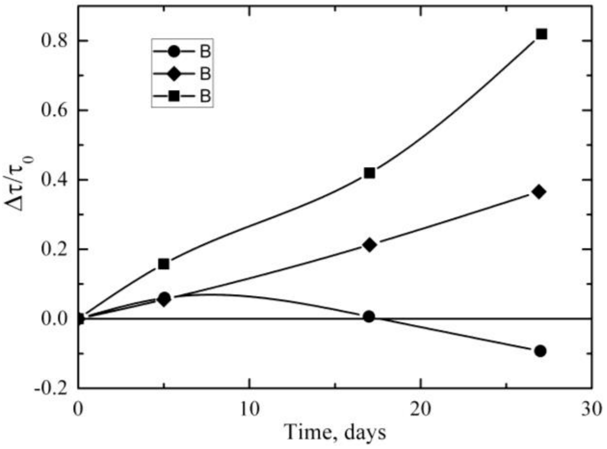

Fig. 2 – Dependence of magnetosensitivity of non-basic charge carrier lifetime on time of exposure in a constant magnetic field

recorded right after the completion of magnetic processing and placement of samples in a vacuum chamber of SIMS. Besides, changes in VIMS spectra at the endurance of samples in a vacuum for 7 days were recorded. Thus, the samples studied underwent magnetic processing and a peculiar additional vacuum processing (VP).

In view of the proofs [1-5], it is possible to make assumptions concerning the influence of the magnetic field on change of micromechanical and electrophysical properties of silicon. The reason for the observed, practically very small change of microhardness consists in the following. Firstly, the surface of silicon adsorbs hydroxyl groups, the hydrated ions from the surrounding atmosphere. Secondly, the chemical elements and groups of elements adsorbed by the surface react with A-like defects whose formation is connected with the action of a magnetic field. Change of microhardness under the influence of the magnetic field was practically not observed, because of binding of metastable A-like defects by the hydroxyl groups OH, hydrated ions and ions of other chemical impurities adsorbed by the silicon sample surface during its long magnetic processing from the surrounding atmosphere or from sample volume.

We measured the current of secondary ions recorded by the VIMS-spectrometer for each of the masses studied before and after magnetic processing.

It was established that after magnetic processing, the concentration of ions of alkaline metals (K^+, Na^+, Ca^+) and concentration of ions of aluminum increases by 2-4 times in near-surface layers. The SIMS technique revealed the existence in the samples under study of the hydroactive $SiOH^+$ complexes whose concentration after MP increased, and also availability of Si isotopes (^{28}Si, ^{29}Si, ^{30}Si) and the complexes Si^{+2}, SiO^+ whose concentration decreased after magnetic processing.

In the course of saturation of the surface broken valence bonds, selective adsorption of oxygen (as most active component) stimulated by magnetic field with a strong acceptor binding with the surface causes the appearance of local negatively charged sites of the surface. The existence of a local electric field, which is produced by a negative charge, can be the cause of gettering by the surface of positive ions of alkaline metals and aluminum, which arrive from the volume. The special activity of surface states at adsorption processes manifests itself in gettering impurities both from crystal volume and the environment. It is probable that the hydro active $SiOH^+$ complexes arise in near-surface layers thanks to adsorption by the torn-off superficial conditions of Si hydroxyl groups from the environment.

The results obtained allow one to conclude that on activated surface at first by a magnetic field, and then in VP adsorption turns even more intensified. It is established that concentration of impurities in the near-surface layers of silicon activated by a magnetic field and vacuum processing increases, which also finds reflection in research of sample conductivity.

The results of measurement of photoconductivity make it possible to assume that special activity of surface states of silicon stimulated by magnetic influence manifests itself both in gettering by the activated surface of impurities from the crystal volume and at adsorption of impurities from the environment. Charged impurities adsorbed and gettered by the magneto- active surface lead to an increase in a macroscopic recombination barrier and by doing so cause a change in the bend of bands, which causes an increase in the relaxation time of photoconductivity. In the electric field of the potential barrier produced by ions of impurities adsorbed and gettered by the surface, nonequilibrium electrons and holes s are spatially divided, and their recombination time increases considerably according to expression $\tau = \tau_0 \cdot \exp(\varphi T/k)$ where τ_0 is the recombination time in a uniform crystal, φ is the height of the potential barrier, T is temperature, k is Boltzmann's constant.

Growth of τ in silicon crystals after magnetic processing is caused by the emergence of the macroscopic recombination barrier connected with a strong bend of a band near Si surface. Some time after completion of magnetic processing in the course of relaxation τ gradually comes back to initial values. It testifies to a gradual relaxation of the macroscopic recombination barrier which appeared under the influence of a strong bend of bands. Therefore, the charge condition of the centers responsible for parameter τ, is unstable and over time begins to relax. Ions of impurities of alkaline metals and aluminum which are gettered from the material volume under the influence of magnetic field act as such centers. Over time after MP, the specified centers enter the interdefect reactions stimulated by the magnetic field, for example, with the hydroxyl groups adsorbed by the magneto activated surface from the surrounding atmosphere at the expense of which their charge is neutralized. Therefore, the parameter τ changed as a result of a magnetic influence relaxes over time.

The action of a magnetic field on samples is explained by the change of a surface condition of silicon. At the beginning of the magnetic field effect A-like defects (oxygen containing complexes of point defects) of type oxygen – vacancy are formed, which causes an increase in ρ. Further action of the magnetic field leads to the binding of A-defects by hydroxyl groups OH or other ions. Due to the adsorbed processes, charged sites appear at the surface, which also reduces ρ. When samples are in a not magnetic field, the process of relaxation continues.

It is established that the constant magnetic field does not cause a change of microhardness in silicon but leads to micro- fragility manifestation. It is shown that the constant magnetic field causes the effect of a change of conductivity and magnetosensitivity in silicon. The effects revealed in silicon are explained from the point of view of the magnetic field- stimulated processes of interdefect transformations.

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