Effect of magnetic field on microhardness of germanium

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Microhardness variations in germanium crystals caused by a weak constant magnetic field have been studied. It is found that the magnetomechanical effect, that is relative change in microhardness, becomes relaxed in time. The results obtained indicate that the effect physical nature is related to spin-dependent reactions in the subsystem of point defects.

Исследовано изменение микротвердости кристаллов германия в результате действия слабого постоянного магнитного поля. Установлено, что магнитомеханический эффект, т.е. относительное изменение микротвердости, со временем релаксирует. Полученные результаты указывают на то, что физическая природа эффекта связана со спин-зависимыми реакциями в подсистеме структурных дефектов.

A unique ability of weak magnetic fields ($B < 1$ T) to affect the real structure of solids and the processes occurring therein was reported repeatedly in literature [1–3]. It has been found that weak magnetic fields are capable of changing irreversibly the impurity-defect structure of $A^{II}B^{V}$, Cz–Si, and $A^{II}B^{VI}$ semiconductor crystals. In particular, short-duration magnetic field pulses have been found to initiate a long-term low-temperature decay of oxygen solid solutions in Czochralski-grown silicon crystals (Cz–Si), resulting in a drastic modification of the whole crystal microstructure [4]. The problem of the weak magnetic field influence on solids gains ever-growing importance nowadays, since that influence results in a considerable changes not only in microstructure, but also in various structure-sensitive properties of solids [3]. Of extreme importance is now the problem of the influence of electron spins localized at the lattice defects on the plastic and other properties of crystals [3]. Intensely developed are the fundamental concepts on control of the elementary physical and chemical processes in solids by reorientation of particle spins in magnetic field.

Although various processes of breakage and formation of new chemical bonds during plastic straining of solid bodies have been known for a long time, the ability of electron spins localized at structure defects to influence the mechanical properties of crystals has not been taken into account until recently. This is caused by the fact the processes in the defect spin system have long been considered a priori as equilibrium ones and, therefore, it has been believed that they contribute very little to plasticity as compared to elastic and electrostatic interactions in the structural defect subsystem. The obtained experimental evidences for the influence of spin-dependent processes on the plastic straining of ionic and covalent crystals in magnetic field as well as the increasing number of publications on the subject in the last few years have defined the appearance of a new trend in the plasticity physics, namely, of the spin micromechanics, aimed at acquiring knowledge on microscopic spin-dependent processes, which affect the mechanical properties of solids.

In our previous works [5, 6], it was shown that the action of a weak constant magnetic field on silicon crystals results in considerable changes in microhardness and thus stimulates the occurrence of the magneto-mechanical effect (MME) in the crystals in question.

The above-mentioned circumstances have defined the interest in the elucidation of the appearance possibility of spin-dependent effects in germanium crystals resulting from action of a weak magnetic field. It should be noted that to date, there are no data on studies of magnetic field influence on the structural relaxation and relaxation-induced physical properties of Ge crystals. The aim of this work was to study changes in micromechanical properties of germanium crystals under action of a weak constant magnetic field. The microhardness was used as an indicator of a change in micromechanical properties. For microhardness measurements, a PMT-3 microhardness meter was used with an indenter shaped as a diamond pyramid with a square base and the apex angle between the opposite sides of 136°. The indenter load P was 10 to 50 g. To evaluate the microhardness, the diagonal of an imprint reduced due to elastic aftereffect was measured after the load removal for a specific indentation duration (10 s). To raise the accuracy and the validity of the results obtained, at least 10 microhardness imprints were made for each indentation regime on the germanium crystal surface, and the microhardness was calculated using the averaged diagonal value. For the Vickers pyramid (as in our case), the microhardness was calculated by the following standard formula:

$$H = \frac{1854.4 \cdot P}{d^2}, \quad (1)$$

where $P(g)$ is the load on the indenter; d, the imprint diameter (diagonal); 1854.4, the numerical coefficient dependent on the indentor geometry that converts the microhardness values H from g/μm^2 to kg/mm^2 or GPa. The relative experimental error for the microhardness measurements did not exceed 4 %.

The initial Ge crystals with the {111} surface orientation as well as the crystals treated by magnetic field were examined. The Ge samples were exposed to a constant magnetic field with an induction of $B = 0.17$ T at $T = 300$ K for 14 days. The microhardness of Ge samples subjected to the magnetic treatment was measured after the samples were removed out of the magnetic field. Then the obtained microhardness values were compared with the reference ones measured on the initial Ge samples not exposed to magnetic field. Then the relative change in microhardness was calculated, being considered as a characteristic of MME. The error in the MME value measurements was about 4 %.

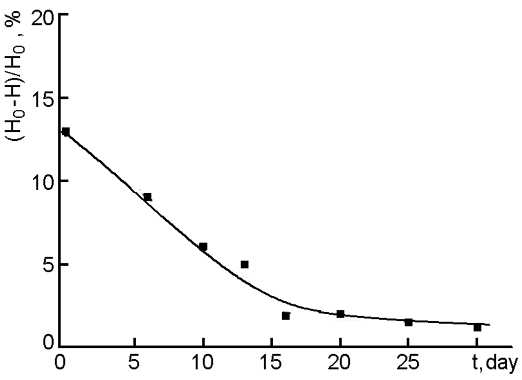

Fig. 1. Relaxation of relative microhardness in Ge crystals subjected to magnetic treatment. H_0, microhardess of initial (control) Ge samples; H, that of those treated in magnetic field.

The microhardness changes revealed in Ge crystals after magnetic field treatment indicate what follows. First, the MME, which just after the magnetic treatment was over reached about 13 %, relaxes in time and disappears in about 14 days (Fig. 1). Thus, the MME is a reversible effect. Second, our studies have shown that the MME is almost independent of the indenter load. According to modern model concepts, weak magnetic fields ($B \leq 1$ T) influence the processes of breakage and formation of chemical bonds and these magnetic-field-induced processes are spin-related ones [4]. The spin-dependent reactions occurring in point defect complexes give rise to long-term structural relaxation. In our opinion, the basis for the structural relaxation is the breakage process of chemical bonds in germanium-oxygen complexes and formation of chemical bonds between oxygen formed due to Ge–O complex decay, and vacancies existing in Ge crystals. Thus, the Ge–O complexes are transformed under magnetic field to O–V complexes, known as the A-type defects. Disappearance of compression zones related to a decrease in the concentration of free vacancies and to their transition into the bound state, that is, into the O–V point defect complexes, decreases internal microstresses and, therefore, the microhardness. Thus, the structural evolution stimulated by magnetic field changes microhardness and gives rise to the MME. The modification of defect-impurity subsystem caused by the magnetic field in Ge crystals and long-term structural transformations are likely to be metastable processes, which relax in time, as our experimental studies carried out in this work has shown. The latter results in a gradual temporal relaxation of the MME. The absence of any MME dependence on the indenter load and, consequently, on the indentation depth, is an indirect evidence for the uniformity of microhardness changes in subsurface layers of the material different in the occurrence depth.

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Вплив магнітного поля на мікротвердість германію

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Досліджено зміну мікротвердості кристалів германію в результаті дії слабкого постійного магнітного поля. Встановлено, що магнітомеханічний ефект, тобто відносна зміна мікротвердості, з часом релаксує. Одержані результати вказують на те, що фізична природа ефекту пов'язана з спін-залежними реакціями у підсистемі точкових дефектів.