

The relaxation of magnetomechanical effect in silicon crystals under cyclic magnetic treatment

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Received June 25, 2008

The experimental magnetic treatment conditions of silicon crystals in a weak (B = 0.17 T) magnetic field which provide a long-term stability of magnetomechanical effect (MME) have been investigated. It is established that at long-term and cyclic magnetic processing, the MME relaxation is slowed down. The correlation character between the magnetic processing duration of investigated samples and MME relaxation time is established to be linear. A possible reason of MME prolongation at long-term and cyclic magnetic processing is absorption processes and interdefect reactions on the magnetic-field-activated silicon surface.

Исследованы экспериментальные режимы магнитной обработки кристаллов кремния в слабом (B = 0,17 Тл) магнитном поле, которые обеспечивают длительную стабильность магнитомеханического эффекта (ММЭ). Обнаружено, что при длительной и циклической магнитной обработке релаксация ММЭ замедляется. Установлен линейный характер связи между временем магнитной обработки исследуемых образцов и временем релаксации ММЭ. Вероятной причиной пролонгации ММЭ при длительной и циклической магнитной обработке являются адсорбционные процессы и междефектные реакции на магнитоактивированной поверхности кремния.

Recent studies have revealed changes in the structure and the structure-dependent (micromechanical and electrophysical) properties of weak-magnetic silicon crystals after the treatment in a weak magnetic field (MF) [1–7]. Changes in Si crystal microhardness in constant magnetic field with induction $B = 0.17$ T were defined as the magnetomechanical effect (MME) [5–7]. The MME observed in Si crystals during short-time (7 days) magnetic treatment (MT) in constant magnetic field was found to be unstable and relaxed quickly (during a few days). The magnetic-field-induced changes in structure-dependent properties of Si crystals are based on several processes [1–9]. First, it is a spin-dependent breakage process of chemical bonds in point defect complexes (PDC), particularly, in Si–O complexes. Second, it is the process of "new" PDC formation consisting of oxygen released due to decay of Si–O complexes and vacancies present in Si crystals. The mentioned processes transform Si–O complexes into oxygen-vacancy (O–V) ones which are referred to as A-type defects [3]. Disappearance of compression zones associated with decrease in the concentration of free vacancies and their transition to bound state results in a decrease of internal microstresses and thereby of microhardness and thus in the MME appearance.

It should be noted that the nature of magnetosensitive centers (MC) in weak-magnetic materials, in particular in silicon, is not elucidated completely to date. The experimental data obtained in [5–7] allow us to suppose that MC are non-equilibrium metastable complexes with thermodynamic potential that can be lowered under magnetic

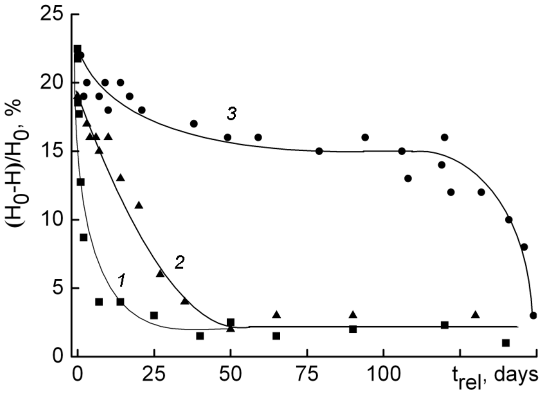

Fig. 1. Relative microhardness relaxation after termination of the action of magnetic field: duration of magnetic treatment t_{MT} = 7 days (*1*), t_{MT} = 124 days (*2*) and t_{MT} = 300 days (*3*).

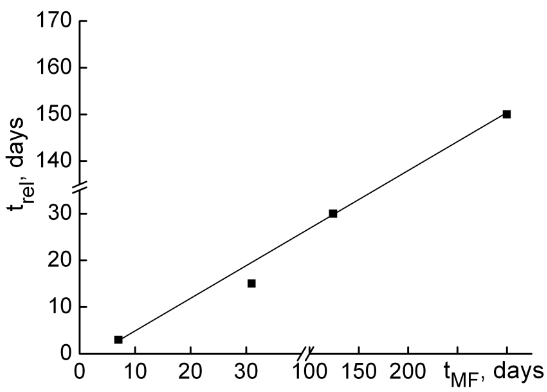

Fig. 2. The MME relaxation time t_{MR} the duration of exposition of Si samples to magnetic field t_{MT}.

field action. The MME relaxation is likely to be due to the formation of A-like defects due to the MF action that are metastable. As a result, the initial structure in the near-surface layers of Si crystals is restored and the microhardness comes back to the initial value. In our opinion, of certain scientific interest is the question how the changes in structure-dependent properties observed in Si crystals as a result of magnetic treatment can be made irreversible. This question requires a specal experimental verification. We suppose that the main point of this verification is to change the experimental conditions under which the MME was observed before [5–7]. A considerable prolongation of MT as well as the use of cyclic, that is, a repeated (multiple) MT would allow to control experimentally the irreversibility of changes in the structural defect subsystem and thus the point about irreversible changes in microhardness under MF action. In this connection, the aim of this work was to reveal the peculiarities in the MME behaviour at prolongation of MT and at the use of a cyclic MT.

Czochralski-grown *n*–Si (111) single crystals were studied. The samples were divided into three groups. Duration of magnetic treatment, that is, exposure duration of Si samples to a weak (B = 0.17 T) constant magnetic field was t_{MT} = 7 days (for the first group of samples), 124 days (second group), and 300 days (third group). The experimental procedure for investigation of relaxation processes was as follows. The Si samples were subjected to the first cycle of MT and just after withdrawal of the samples from the magnetic field their microhardness was measured using a PMT-3 microhardness meter. Further measurements of microhardness H were carried out as the delay between the MT and the moment of microhardness measurement increased. The period of time when the microhardness changed due to MT was restored to the value close to the reference one was considered to be the magnetic relaxation time t_{MR}. The reference microhardness value was assumed to be the value for the initial Si samples which were not exposed to MF. As the microhardness relaxation process was over, the second MT cycle was carried out. In the second cycle, the Si sample was again exposed to magnetic field for 7 days. After repeated MT, the microhardness measurements were carried out again during a prolonged time (about 60 days). The relative experimental error for microhardness measurements did not exceed 4 %.

It has been found that when the MT duration is raised from 7 days to 124 and even 300 days (some 10 months), the MME relaxation time rises (Fig. 1). It is to note that an increase in the magnetic treatment duration from 7 to 300 days practically did not affect the MME magnitude being measured just after MT termination, whereas it changed the MME relaxation time after removal of the Si samples from magnetic field. The dependence of the MME relaxation time on the MT duration has turned out to be linear (Fig. 2). We suppose that the MME prolongation mechanism at long magnetic treatment durations may be due to two processes: (i) the impurity adsorption and generation occurring at the magnetic-field-activated Si surface, and (ii) by magnetic-treatment-activated interdefect reactions.

Experimental results related to the cyclic mode of magnetic treatment have been also

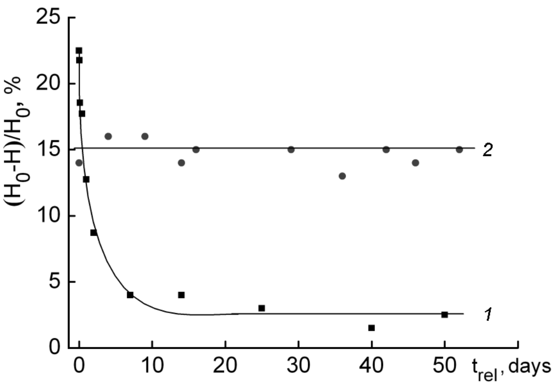

Fig. 3. Dependence of the MME magnitude for Si samples on time that passed after termination of magnetic treatment: *1* – first cycle of magnetic treatment, *2* – second cycle of magnetic treatment. Parameters of magnetic treatment: B = 0.17 T, t_{MT} = 7 days.

obtained. As is seen from Fig. 3, which illustrates the above-mentioned results after the first MT cycle, the MME was relaxed quite quickly (the relaxation time t_{MR} = 5 days). After the first MT cycle, the MME magnitude dropped from 25 % to 15 % and the MME relaxation behavior changed, that is, the MME remained constant for a long time (about 60 days). The use of cyclic magnetic treatment mode, that is, carrying out the second MT cycle after the MME relaxation, made it possible to clear up the question about both preservation of MC after the first MT cycle and the possibility to effect the MC state in the case of their survival. Our experimental results have shown that after the first MT cycle, the point defects still remained sensitive to MF, because the MME took place after the second MT cycle. The MME after the second cycle, unlike the first cycle, was more stable and not relaxing for a long time (about 60 days). The fast MME relaxation after the first MT cycle (dependence *1* in Fig. 3) indicates that a short-term action of a weak MF produces reversible changes in the point defect subsystem. After the second MT cycle, the PDC stability rises.

It is not improbable that certain interactions occur between non-equilibrium structural defects being existed in Si crystals prior to the second cycle and the defects that were formed as a result of spin-dependent reactions during the second MT cycle. It is these interactions that resulted in irreversible structural changes and to the fact that after the second cycle the MME becomes irreversible. Thus, the micromechanical properties of silicon, in particular, its microhardness, changes in different manners both at different MT durations and after different MT cycles. In our opinion, in both cases — under both long-term and cyclic MT — the most probable mechanism of the MME existence prolongation and its stabilization is the occurrence of interdefect solid-state reactions at the magnetic-field-activated silicon surface.

References

1. V.N.Buzykin, O.I.Dacko, S.N.Postnikov, in: Electronic Treatment of Materials, issued by Academy of Sciences of Moldova Rep., No.2, 16 (1993).
2. A.L.Danilyuk, A.I.Nareyko, *Poverkhnost*, **9**, 27 (1996).
3. B.A.Zon, *Zh.Eksp.Teor.Fiz.*, **111**, 1373 (1997).
4. M.N.Levin, A.V.Tatarincev, O.A.Kostsov, A.M.Kostsov, *Zh.Tekhn.Fiz.*, **73**, 85 (2003).
5. V.A.Makara, L.P.Steblenko, Yu.L.Kolchenko et al., *Solid State Phenom.*, **108–109**, 339 (2005).
6. V.A.Makara, M.A.Vasilev, L.P.Steblenko et al., *Fiz.Techn.Poluprov.*, **42**, 1061 (2008).
7. V.A.Makara, M.A.Vasilev, L.P.Steblenko et al., *Fiz.Khim.Tverd.Tila*, **10**,193, (2009).
8. A.L.Buchachenko, *Zh.Eksp.Teor.Fiz.*, **132**, 673 (2007).
9. A.L.Buchachenko, *Zh.Eksp.Teor.Fiz.*, **132**, 827 (2007).

Релаксація магнітомеханічного ефекту у кристалах кремнію в умовах циклічної магнітної обробки

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Досліджено експериментальні режими магнітної обробки кристалів кремнію у слабкому (B = 0,17 Тл) магнітному полі, які забезпечують тривалу стабільність магнітомеханічного ефекту (ММЕ). Виявлено, що при тривалій та циклічній магнітній обробці релаксація ММЕ сповільнюється. Встановлено лінійний характер зв'язку між часом магнітної обробкиб що досліджуються, зразків і часом релаксації ММЕ. Імовірною причиною пролонгації ММЕ при тривалій і циклічній магнітній обробці є адсорбційні процеси та міждефектні реакції на магнітоактивованій поверхні кремнію.