Influence of the weak magnetic field on nanostructure and physical properties of the single crystal Si(111)

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Abstract. The possibility to modify nanostructure of silicon by applying of the weak (B-0.2T) constant magnetic field is proposed. It has been shown that structure and structure sensitive properties of Si undergo essential changes due to the action of a magnetic field. It has been found that relaxation of investigated experimental characteristics after magnetic treatment correlates with a relaxation of metastable states of nanoclusters, which commonly consist in structural defects and restoration of initial structure. Observed changes of physical characteristics are supposed to be connected with occurrence of structure relaxation processes.

1. Introduction
Silicon, as a basic material for microelectronics, is well studied, but taking into account new demands of more high technologies, caused by various reasons and first of all due to the transition of planar production of higher level, its further investigation, especially in single crystal state is needed. On that reason an actual problem is a study of the structure and physical properties of Si/SiO₂ system in order to control their properties by various external influences, in particularly, by weak magnetic field . Unfortunately there are available only few works [1-4] devoted to studies of a weak magnetic field influence on various physical properties of the diamagnetic crystals, in spite of suggestion that magnetic fields of B~1T can have effects just by an order of magnitude (μ₀/kT)~10⁻³. Especially, it should be noted that a little of publications consist results on changes of the structurally-dependent properties in semiconductors effected by external magnetic field [5]. On that reason the studies of Si structure and structure-dependent properties changed by an applied magnetic field are important both from fundamental and practical use viewpoints.
2. Experimental
The n-Si(111) samples under investigation have been doped by P in order to reach the specific resistance $\rho=4.5\Omega\cdot\text{cm}$. The surface of sample was covered with SiO$_2$ oxide layer, of the tick $\sim$2nm. Magnetic treatment (MT) was performed in the weak magnetic field ($B\sim0.2T$) at room temperature during 7-10 days.

For diagnostics of the crystal structural changes the several methods were used: the X-ray diffraction (CuK$\alpha$ - radiation) measuring the lattice parameter of near surface region: the physical-chemical state of the Si surface was investigated by laser ellipsometry and X-ray photoelectron spectroscopy (XPS) method. Measuring of the energy and intensity of photoelectrons was carried out with using of EC-2402 electron spectrometer, equipped with energy analyzer PHOIBOS-100SPECS (Germany). For excitation of photoelectrons the MgK$\alpha$ X-ray radiation was used ($E=1252.6$ eV).

3. Results and discussion
The magnetic treatment of n-Si(111) causes the non-monotone changes of the inter layers distances $d$, and significant changes of the diffraction peak intensities (Fig.1).

![Figure 1. Diffraction peak profile in n-Si(111)](image)

As it can be seen from this figure, the diffraction peaks shift to the less diffraction angel values with increasing magnetic treatment duration. While the magnetic treatment is completed, the considerable increasing of the diffraction peak intensities and corresponding shift of their angular positions to large angle values, i.e. returning to their initial positions. The experimental result is the evidence of the change of resiliently strained state of the near surface layers in Si single crystal. On Fig.2 the dependence of Si relative deformation change as function of magnetic field treatment duration is shown.

![Figure 2. Change of relative deformation $\Delta d/d$ as function of magnetic treatment duration](image)
Magnetic treatment results in the decreasing of the relative deformation value (3%). After finishing of the magnetic field influencing the relaxation of interplanar distance \( \Delta d/d \) was denoted. This fact indicates that structural changes causing the changing of the relative deformations, and as a result the internal tensions, are reversible. In this work a changing of the lattice parameters when magnetic field treatment duration varies, was also observed. It is important to note, that after finishing of the magnetic field influence, the lattice parameter shows the non-monotone relaxation returning nearly to the initial value. We suppose that changing of the resiliently strained state in the near surface layers of Si due to magnetic treatment is directly related to the modification of the imperfectly-structural subsystem in the SiO\(_2\) oxides as well as in Si/SiO\(_2\) interface.

The analysis of the experimental data, obtained by means of X-ray diffraction method, reveals the structural changes of the Si crystal in near surface region under act of the weak magnetic field, and on that reason it is of interest to study in more details the physical-chemical state of the Si surface modified by MT.

Using the XPS method the change of native oxide layer thickness was observed. These results allowed us to establish the following experimental facts (Table 1): the oxide layer thickness of the samples which were not under MT (reference samples) had the size of 0.89 nm. After MT during 10 days the SiO\(_2\) layer thickness grew and attained 3.48 nm. Similar results were obtained in [6], where it was shown by means of laser ellipsometry, that action of the impulsive magnetic field results the increasing of the oxide layer thickness.

| Si crystal          | (Si) \( E_B/I \) | (SiO\(_2\)) \( E_B/I \) | Thickness of oxide, d (nm) |
|---------------------|------------------|-------------------------|--------------------------|
| n-Si(111) initial   | 99.8 eV/86.8%    | 103.5 eV/13.2%          | 0.89                     |
| n-Si(111) \( t_{\text{mt}}=10 \) days | 99.5 eV/50.8%    | 103.2 eV/49.2%          | 3.48                     |
| n-Si(111) \( t_{\text{relax}}=12 \) days | 99.6 eV/82.1%    | 103.4 eV/17.9%          | 1.11                     |

Twelve days later, since the magnetic field treatment was finished, there was decrease of the oxidized layer thickness to the size 1.17 nm. These experimental results show that magnetic treatment activates the Si-surface, increasing the surface chemical activity.

It is known that main factor, responsible for the increasing of magnetic chemical activity is the forming of more defect Si surface. Influence of the weak magnetic field on the real crystal structure can be explained using the ideas [7-9], where authors assume that at such small value energy of the magnetic field (\(B \sim 1\) T) existence of magnetic sensitivity effects can be related not to the magnetic field energy but to the electronic spins which are managed by magnetic field. Using the results obtained in [7-9] one can conclude that spin conversion in the nanoclusters as complexes of point defects (CPD) is responsible for the change of diamagnetic crystal properties under act of weak magnetic field. Weakening and break of chemical bonds is the final result of spin conversion in the nanoclusters on the base of point defects, existing in real crystal structure.

Induced the magnetic field decomposition of the Si-O complexes and “vacancy-O” ones promote the migration of the free vacancies to the surface and forming the more relief surface. Due to such mechanism an amount of chemically active centers increases. Further growth of oxide film can be induced by, in our view, the molecular oxygen taken from surrounding atmosphere, diffused to the Si/SiO\(_2\) interface, as well as the atomic one, created after disintegration of the indicated complexes. Significant growth of the oxide layer thickness is the main reason of the mechanical stress changes. The removal of such stress according to [10], take place due to migration of silicon atoms to the Si/SiO\(_2\) interface. Laser ellipsometry analysis of the oxide thickness for three investigated states confirmed the results, obtained by means of XPS method.
4. Conclusion
Observed in the present work effects, induced by MT, can be attributed to influence of the weak magnetic field on the stability of the chemical bonds in nanoclusters formed by structural defects. This mechanism provides modification of the structure and properties of Si single crystal.

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