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NANOSTRUCTURE DEVICES

Magnetoimpedance Effect in a SOI-Based Structure

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Abstract—This paper presents the results of the study the transport properties of the SOI-based structure. Measurements were carried out on an alternating current with an external magnetic field in a wide temperature range. The influence of the magnetic field was found. We associate this effect with the influence on the surface states located at the interface, this appears as a change of the energy of their levels. This effect is enhanced by the nanoscale of the silicon channel.

Keywords: magnetoimpedance, spintronics, silicone on insulator, nanosized semiconductors, interface states

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In the modern world, silicon-based materials are the main components of the most devices, circuits, and microarrays [1]. Therefore, using the silicon-based structures is promising in terms of the effective introduction of new devices into modern electronics. One of these structures is silicon on insulator (SOI). The perspective way is use SOI technology to build spintronic devices because they will be compatible with modern CMOS electronics. Also, the advantage of silicon-on-insulator (SOI) in the manufacture of integrated circuits because of its high speed and low power requirements [2], SOI is an ideal platform in photonic applications [3] and even as biosensors [4]. Due to the above, SOI structures have sufficient interest for research, and, moreover, is a logical continuation of our research as part of silicon-based structures.

We have previously written about the study of silicon-based metal-insulator-semiconductor (MIS) structures. We have observed effect of the magnetic field on the structures [5], and the magnitude of the magnetoresistance for some structures reached values of $10^{8\%}$ [6]. Further studies have shown that even for structures with nonmagnetic metals films, the same effect is observed [7]. This showed that the appearance of the magnetoimpedance (MI) effect is more influenced by the interface and the silicon, but not the magnetic state of the metal film. In our opinion, the magnetic field affects on the impurity centers and surface states at the dielectric/semiconductor interface, which are involved in the recharging process. That is why it was very interesting for us to see what will happen to the MI effect in a thin layer of silicon.

To study the phenomenon of magnetic impedance, we have specially prepared structures using SOI. The Fe polycrystalline film was deposited on the boron-doped silicon (100) on insulator (SOI) wafer (with resistivity of 18 Ω cm) by thermal evaporation. Substrates were chemically cleared before placing into the growth chamber [8]. Further, the plates were annealed in an ultra-high vacuum (10^{-8} Pa) at the temperature of 400C for 30 min to remove the natural oxide from the silicon surface. Figure 1 shows the cross-sectional transmission electron microscopy (TEM) of the. The final structure consists of handle Si, buried oxide (BOX) layer with thickness 200, 100 nm silicon on insulator and 14 nm iron film. One can see that the structure layers are fairly smooth, with well-defined borders without interdiffusion.

The impedance measurements were performed by a two-probe method. Ohmic contacts were formed on the metallic film using silver epoxy and at the bottom of the Si substrate by indium alloying. The contact pad areas were 1 mm^2. The device is schematically illustrated in Fig. 2. The studies were held on alternating current, using an Agilent E4980A LCR-meter. The ac current frequency ranged from 20 Hz to 2 MHz. An external magnetic field H up to 0.8 T was applied parallel to the sample plane. The measurements were conducted in temperature range of 4.2–350 K using helium cryostat.

Measuring temperature dependences, below 30 K an intense peak was detected for the real part of the impedance $R(T)$ (Fig. 3). Appearance of such a peak were caused solely by a delay in recharging of the inter-

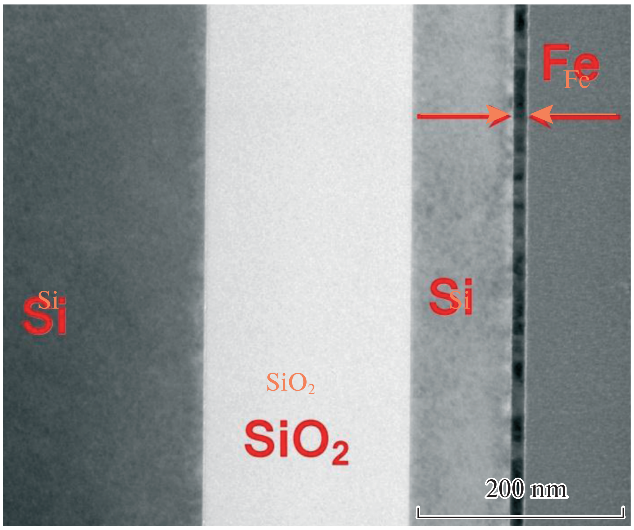

Fig. 1. Cross-sectional TEM images of the structure interfaces.

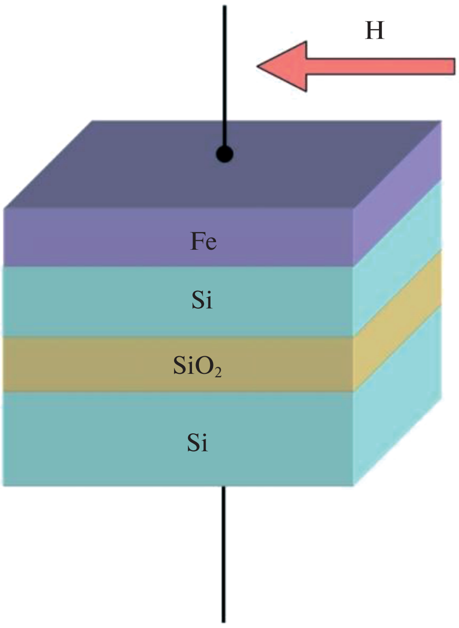

Fig. 2. Schematic representation of the device.

face states localized near the insulator/semiconductor interface. Those recharging processes may be affected by the ac-measurements since as the voltage Vac was applied to the MIS structure it swept the Fermi level through the interface center energy levels. The $R(T)$ peaks are caused by the delays of recharging processes. Earlier, such peaks were found for a MIS structures. Under the influence of the magnetic field H, this peak shifts to higher temperatures region. This shift is due to the influence of the magnetic field on the energy spectrum of the localized states at/or near the interface.

Magnetic field shifts the energy levels of interface states relative to the semiconductor band edges toward higher energies (to the band gap center). In this case, the Fermi level crosses the energy levels of the interface states at higher temperatures than it would do without field [5].

We calculated the energy of the interface states in zero and non-zero magnetic field using relation $\ln(\omega) = \ln(1/\tau_0) - E_s/(k_B T_p)$ [9]. T_p is a peak position on $R(T)$ curve at fixed ω. By making a linear fit of the experimental $\ln(\omega)$ vs. $1/T_p$ dependence, from the slope of the fitting line, we estimated the energy of the interface states. Such fitting is presented in Fig. 4 at $H = 0.8$ T and $H = 0$.

As can be seen, without the influence of the magnetic field the energy levels of the surface states is 41.8 meV. When the magnetic field H is applied, the energy changes to 44.9 meV. Thus, the energy has changed about 3 meV. This is several times more than was observed for structures with bulk silicon. It is logical to assume that the increase of the effect is connected with the nanoscale layer of silicon, which in our case is 100 nm. It should be noted that the recharge effect is directly related to the band banding in the silicon due to the formation of a space charge region and a Schottky barrier. In silicon with doping of the order of 10^{15} cm^{-3}, the width of the space charge region is about 300 nm [10], and in our structure the thickness of silicon is 100 nm. Consequently, a limited thickness can play an important role in the energy structure of the energy levels of the interface states, charge exchange processes, and the magnetic field effect.

In this paper we presented the results of investigations of the SOI structure. It was shown that the ac transport properties of the structure are sensitive to external magnetic fields at low temperatures. The shift of the peaks in the temperature dependence of the real

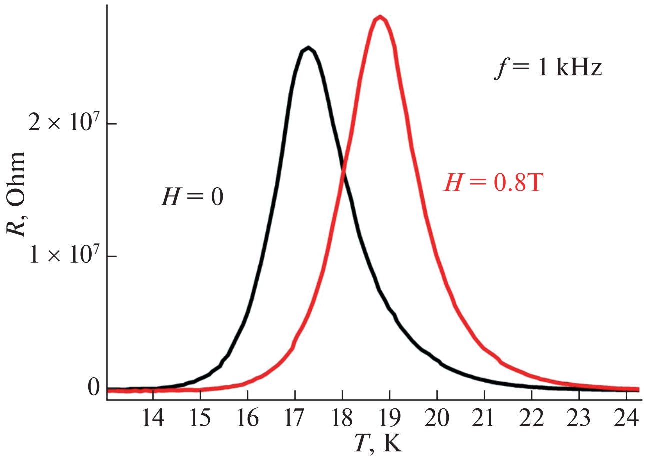

Fig. 3. Temperature dependence of the real part of the impedance at $H = 0$ and $H = 0.8$ T.

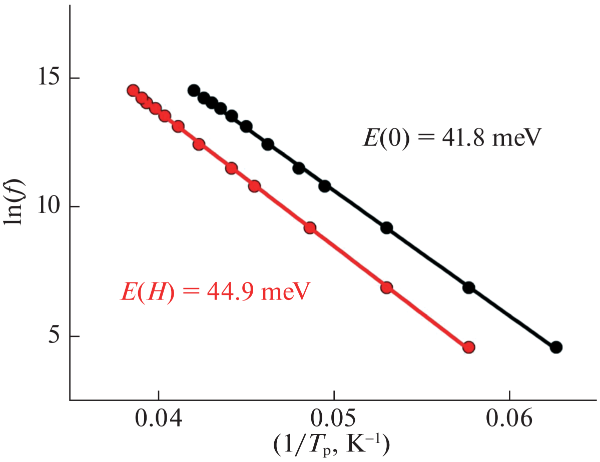

Fig. 4. ln(ω) vs. reciprocal temperature peak for determining the energy levels of the interface states.

part of the impedance was observed. It is due to, the magnetic field affects the surface states located at the interface. The surface state levels shift to the high-energy region in a magnetic field, which affects their recharging and, consequently, leads to the magneto-impedance effect. The nanoscale of the channel increases this effect several times.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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