NONLINEARITY OF CURRENT IN GERMANIUM FILMS IN A MAGNETIC FIELD

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1. It is known that Ohm's law is satisfied in bulky semiconductors in a weak electric field, and that the presence of a magnetic field does not lead to nonlinearity of the current. However, in thin semiconducting films of thickness 2d commensurate with the energy mean free path ℓ_e, the magnetic field can destroy the linearity of the current as a function of the electric field, even if the latter is weak [1 - 3]. This was first pointed out by the authors of [1], who predicted the appearance of a term linear in the electric and magnetic fields in the magnetoresistance. We report in this communication experimental observation of the current nonlinearity in a weak electric field in semiconducting p-Ge films grown on sapphire.

2. We measured the magnetoresistance in a magnetic field parallel to the film plane and perpendicular to the electric field at a temperature of 77° K. The initial films (2d ~ 100μ) had a hole concentration ~ 3 x 10^{15} cm^{-3} and a Hall-effect mobility 2.5 x 10^4 cm^2/V-sec at 77° K. The measurements were made by a null method in constant electric and magnetic fields. According to [3], the signal proportional to the conductivity can be written in the form

$$V = V_0(E) + \Delta V(E^3) + \Delta V(E, H^2) + \Delta V(E^2, H), \qquad (1)$$

where $V_0(E) + \Delta V(E^3)$ is the voltage on the potential contacts in the absence of the magnetic field, $\Delta V(E, H^2)$ is the usual term quadratic in the magnetic field and linear in the electric field, $\Delta V(E^2, H)$ is the term quadratic in the electric field and linear in the magnetic field, and $\Delta V(E^3)$ is the term cubic in the electric field, which appears when the electron (hole) gas becomes heated; we disregarded this term, for no deviations from Ohm's law were observed in the absence of a magnetic field. By varying the directions of E and H we could easily separate in the experiment each term of the expression (1). Figure 1 shows a plot of $\Delta V(E^2, H)$ against the electric field for three films of different thickness. Figure 2 shows for one of the samples the magnetoresistance $\Delta\rho/\rho_0 = (V - V_0)/V_0$ as a function of the magnetic field for two opposite current directions. We see that for one of them $\Delta\rho/\rho_0$ reverses sign with increasing H. Thus, in thin semiconducting films, under definite conditions, the term linear in the magnetic field can prevail over the quadratic term, and if their signs are opposite, a negative magnetoresistance can occur.

3. Let us discuss in greater detail the nonlinear term $\Delta V(E^2, H)$. An analysis of the experiment has shown that it is actually well approximated by a quadratic dependence on E (Fig. 1) and a linear dependence on H. Physically, the occurrence of the term $\Delta V(E^2, H)$ is connected with the deviation of the hole temperature T_e averaged over the film cross section from the phonon temperature T_0. However, since the relaxation time depends on the energy, it will also differ (with a corresponding difference in the conductivity) from the relaxation time in the case when $T_e = T_0$. In turn, the inequality of the hole and lattice temperatures occurs when the rates of energy loss by the carriers are different on opposite surfaces of

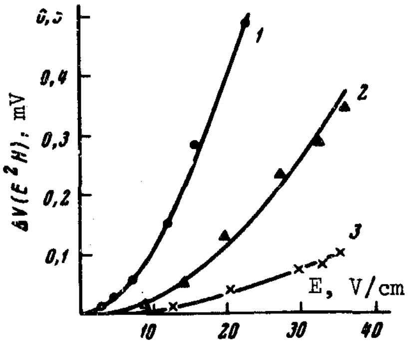

Fig. 1. Nonlinear term vs. electric field for three samples of thickness 5 (1), 3 (1) and 0.8 (3) microns. All curves were obtained with a magnetic field H = 0.35 kOe.

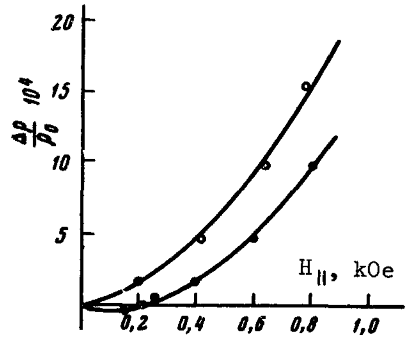

Fig. 2. Magnetoresistance vs. magnetic field for two opposite current directions. The curves correspond to a 0.08 micron sample and were plotted for E = 30 V/cm.

the film. In the investigated films, this condition is apparently satisfied as the result of the fact that one surface is free and the other is the interface between the germanium and the sapphire. It is seen from Fig. 1 that $\Delta V(E^2, H)$ decreases when the thickness changes from 5 to 0.8μ, this being in agreement with the theory [1, 3] if $d/\ell_e < 1$.

In conclusion it should be noted that the observed nonlinearity is not connected with the magnetoconcentration effect [4], which takes place in nearly-intrinsic semiconductors, since the hole concentration in the investigated films was larger by four orders of magnitude than the electron concentration.

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CONCERNING A GAS OF ULTRACOLD NEUTRONS IN A TRAP

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The possibility of storing a neutron gas in traps was first pointed out by Zel'dovich [1] and by Vladimirskii [2], but the detailed behavior os such a gas in a trap was not examined. In this paper we investigate several factors that influence the duration of the storage of a gas of ultracold neutrons (UCN) in traps, we determine the requirements imposed on the traps, and propose a method of obtained UCN directly in a trap [3]. The first to observe UCN experimentally was F. L. Shapiro and co-workers [4].

We consider first the effect UCN absorption. Assume that in a trap of volume Ω there is a "black" absorber, for example a neutron counter of area S. Then, at a coefficient of