Effect of illumination on the galvanomagnetic characteristics of a 2*D* electron gas in a strong magnetic field

V. B. Anzin, V. G. Veselago, V. N. Zavaritskiĭ, and A. M. Prokhorov
Institute of General Physics, Academy of Sciences of the USSR

(Submitted 18 July 1984)
Pis'ma Zh. Eksp. Teor. Fiz. **40**, No. 6, 231–233 (25 September 1984)

Light with a photon energy $\cong 1.9$ eV strongly affects the galvanomagnetic characteristics of silicon metal-insulator-semiconductor structures under conditions corresponding to the quantum Hall effect. The light increases the density of 2*D* carriers by an amount ΔN_S (to 9×10^{10} cm^{-2}). The effect is linked with a decrease in the space charge density near the surface of the structure. The observed long-term relaxation of photoexcited carriers (lasting as long as 10^4 s) can be shortened (to 10 s) by illumination with infrared light.

An important problem in the physics of 2*D* electron systems is to determine how external agents affect their characteristics, in particular, the quantum Hall effect. The influence of agents such as the temperature of the sample[1,2] and an electric current[2–4] have now been studied in detail. Information on the effects of external radiation, in particular, light, is considerably sparser. Most of the work has dealt with the direct effect of illumination on the properties of 2*D* electron systems in strong magnetic fields (see Refs. 1, 5, and 6, for example), in which case the photon energy (0.7–10.5 meV) is on the order of the energy gap between Landau levels, which can reach 15–20 meV. Since the 2*D* system is generally realized at an interface between two media, e.g., between a semiconductor and an insulator or between two semiconductors (as in the case of heterostructures), the photoinduced changes in the volume properties of the regions adjoining the 2*D* electron system may influence the characteristics of the 2*D* system. This question, however, has remained open.

In the present experiments we studied the effect of changes in the volume properties of a system on the characteristics of a 2*D* electron system by using light with a photon energy $\cong 1.9$ eV, which corresponds to band-band transitions of the semiconductor and which is substantially larger than all the characteristic energies of the 2*D* system.

We studied *n*-channel metal-insulator-semiconductor structures with a Hall contact geometry. The contacts were on the (100) face of *p*-type silicon. The mobility of the 2*D* carriers at 4.2 K was $(8\text{–}20)\times 10^3$ cm^2/(V s). Potentiometric measurements were carried out at a direct current of 4×10^{-7} A; an x, y chart recorder was used to measure the voltage versus the magnetic field B or versus the gate voltage V_G. The structures were illuminated on the gate side; the area of the illumination spot was greater than the dimensions of the structure. The light was coupled into the device by lightguides. The measurements were taken at temperatures of 1.3–1.5 K in fields up to 14.5 T. To avoid an influence of the prolonged relaxation to an equilibrium carrier

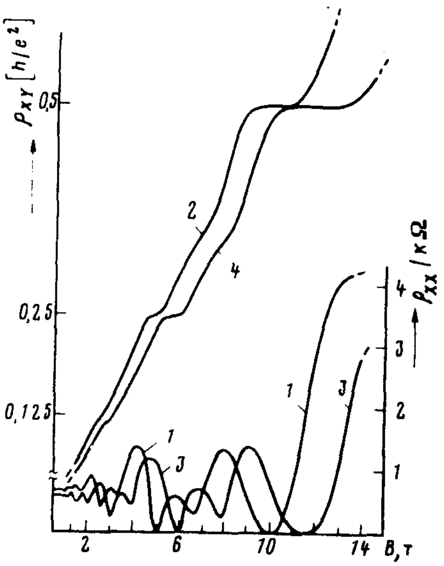

FIG. 1.

density in the channel of the structure upon a change in the gate voltage, we carried out most of the measurements under the condition V_G = const.

Illumination of the structure with visible light leads after some transients to changes in the behavior of the longitudinal (ρ_{xx}) and Hall (ρ_{xy}) resistivities as functions of the magnetic field B. Figure 1 is a reproduction of a typical experimental chart recording. The initial curves of $\rho_{xx}(B)$ and $\rho_{xy}(B)$ (before the illumination) are curves 1 and 2. Curves 3 and 4 are the magnetoresistance and Hall resistance of the structure during illumination. We see from these curves that the basic effect of the light is to stretch out the curves along the B axis; the effect is equivalent to increasing the density of 2D carriers, N_S. In the present experiments the increment ΔN_S ranged from 10^{10} to 9×10^{10} cm^{-2} for the various structures studied. The increment depends slightly on the initial density of 2D carriers, which ranged from 2×10^{11} to 10^{12} cm^{-2}. This photoinduced change ΔN_S is established over a time which depends on the nature and intensity of the illumination, reaching 15 min in some experiments. A discussion of the particular features of this transient process is beyond the scope of the present letter.

After the light is turned off, the system relaxes to its original state over a time which varies from 10^0 to 10^4 s, depending on the particular structure (these figures are based on the six samples studied). The long-term relaxation is illustrated by Fig. 2, which shows the measurements of ΔN_S for one of the samples versus the time which has elapsed since the light was turned off (curve 1). Similar (long-term) curves of $\Delta N_S(t)$ were observed for half of the samples studied. Since we observed no correlation between the mobility of the electrons of the 2D electron system and the relaxation time in these experiments, and since the relaxation time was insensitive to changes of any sort in the 2D electron system proper (insensitive, for example, to a variation of the gate voltage over a broad range), the observed effect is most likely due to relaxation in the metal-insulator-semiconductor structure, rather than in the 2D electron system. The relaxation time can be substantially reduced (to $\cong 10$ s) by illuminating the struc-

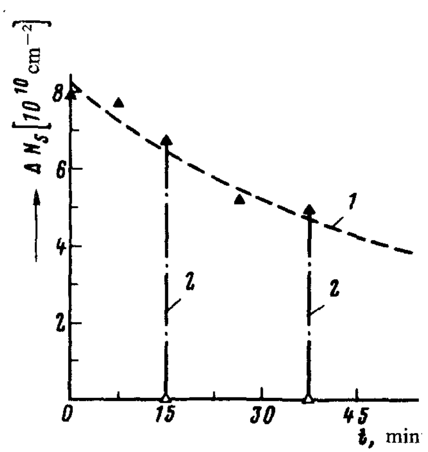

FIG. 2.

ture with infrared light with a photon energy $\cong 120$ meV. The effect of infrared light is shown by curves 2 in Fig. 2. The decrease in the relaxation time caused by the infrared light does not seem to be linked with the heating of the system, since in the relaxed state the infrared light has no effect (within an error of 5×10^{-3}) on the characteristics of the system [$\rho_{xx}(B)$ and $\rho_{xy}(B)$]. An infrared-induced decrease in relaxation time, which has been observed in experiments on the "frozen" conductivity in binary semiconductors, has been termed "infrared annealing."[7]

We know[8] that the density of $2D$ carriers, N_S, in a metal-insulator-semiconductor structure is determined by the gate field only if the distribution of space charge localized near the surface of the structure remains constant. This circumstance can serve as the basis for the following qualitative explanation of the observed effects: The increase in the density of $2D$ carriers upon illumination is apparently caused by a redistribution of charge among the quasisteady surface levels—a redistribution equivalent to a decrease in the resultant "frozen" charge at the Si/SiO_2 interface. This change evidently leads to a corresponding increase in the density of $2D$ carriers in the channel. The long-term relaxation to the original state, after the light is turned off, is determined by the height of the potential barriers of these quasisteady levels. The appearance of the barriers may be due to a nonuniformity in the distribution of charged impurities, capture centers, and structural defects of the crystal.[9] The infrared light imparts to the electrons an energy sufficient to overcome the barrier. An upper estimate of the barrier height can be found from the energy of a photon which causes a significant acceleration of the relaxation: no more than 100 meV, according to our data. This question requires further study, however.

We wish to thank V. G. Artyushenko, L. I. Butvina,and V. V. Voĭtsekhovskiĭ for cooperation and N. A. Nikitin for assistance in the experiments.

[1] K. Von Klitzing, B. Tausenfreund, H. Obloh, and T. Herzog, Lecture Notes Phys. **177,** 1 (1983).
[2] T. Englert, Lecture Notes Phys. **177,** 87 (1983).
[3] V. N. Zavaritskiĭ and V. B. Anzin, Pis'ma Zh. Eksp. Teor. Fiz. **38,** 249 (1983) [JETP Lett. **38,** 294 (1983)].
[4] H. Sakaki, K. Hirakawa, J. Yoshih, S. P. Svensson, Y. Sekiguchi, T. Hoffa, S. Nishi, and N. Miura, EP2DSV, 1983, 666.

[5] C. F. Kavine, R. J. Wagner, and D. C. Tsui, Surf. Sci. **113**, 112 (1982).
[6] D. Stein, G. Ebert, K. Von Klitzing, and C. Weimann, EP2DSV, 1983, 414.
[7] B. M. Vul, I. D. Voronova, G. A. Kalyuzhnaya, T. S. Mamedov, and T. Sh. Ragimova, Pis'ma Zh. Eksp. Teor. Fiz. **29**, 21 (1979) [JETP Lett. **29**, 23 (1984)].
[8] T. Ando, A. B. Fowler, and F. Stern, Rev. Mod. Phys. **54**, 487 (1982).
[9] B. A. Volkov and O. A. Pankratov, Preprint No. 127, P. N. Lebedev Physics Institute, Academy of Sciences of the USSR, Moscow, 1980.

Translated by Dave Parsons
Edited by S. J. Amoretty