Optically induced dichroism in a magnetic semiconductor

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We observed optically induced circular dichroism by pumping the ferromagnetic semiconductor europium sulfide with circularly polarized light. The observed decrease of the effect in a transverse magnetic field is well approximated by a Lorentz curve. A procedure for observing optically induced circular dichroism is presented.

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Research on optical orientation of electron and nuclear spins in semiconductors (see, e.g., the reviews[1,2]) has been carried out so far on nonmagnetic semiconductors (Li, GaSb, GaAs, etc.). The principal method used in these investigations was the study of the polarization of luminescence excited by circularly polarized light.

It is of interest to investigate optical pumping in magnetic semiconductors, where one can expect the optical orientation of the spins to influence the magnetic properties. We present below results of an investigation of this pumping in a ferromagnetic semiconductor by the method of optically induced circular dichroism.

The experimental object was chosen to be EuS, which is a ferromagnetic semiconductor with a Curie temperature 16 °K. Light of wavelength 0.63 μ, which is at the edge of the absorption band, excites in the conduction band electrons from deep donor centers with concentration 10^{22} cm^{-3}, corresponding to the europium $4f$ levels located in the forbidden band. According to[3], the resultant transitions are

$$4f^7(^8S_{7/2}) \rightarrow 4f^6(^7F_J)5d(t_{2g}).$$

When the transitions are excited by circularly-polarized light, there is a large probability of excitation of electrons from levels for which the projection of the total angular momentum is opposite in sign to the photon momentum. The electron excited into the conduction band should apparently lose its orientation rapidly, ow-

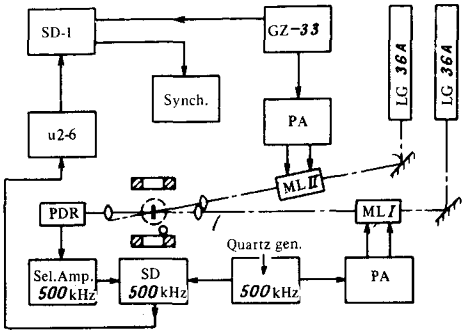

FIG. 1. *Simplified diagram of the experiment.*

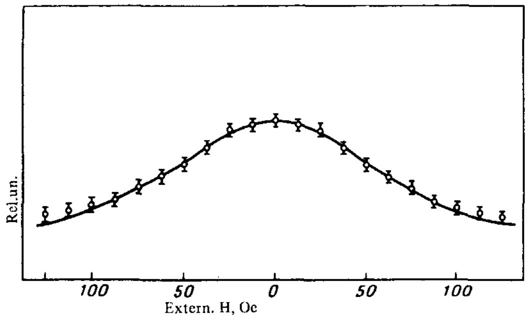

FIG. 2. Depolarization in an external transverse magnetic field. *Points—experiment, solid curve—approximating Lorentz* contour with half-width 75 Oe.

ing to the strong spin-orbit interaction in the conduction band made up of *s* and *d* states. The center, which remains without an electron, has in the ground state a zero total angular momentum, and therefore "does not remember" its prior orientation. As a result of recombination, there is an equal probability of production of centers with total angular momentum projections of opposite sign. The most probable absorption of circularly-polarized light by centers with definite orientation, in the absence of a preferred direction in the recombination, should lead to accumulation of centers with angular momentum oriented parallel to the photon spin (optical pumping of the ground state is realized). Within the framework of this approximation, the search for the orientation by analyzing the degree of polarization of the recombination radiation may turn out to be unpromising. The resultant predominant orientation of the absorbing centers should lead to different absorption coefficients for the left- and right-hand circularly polarized light, i.e., to circular dichroism induced in the center by the pumping light.

In the experiment, the europium-sulfide sample was a film grown on a sapphire substrate and was placed on the cold finger of a cryostat (*O* in Fig. 1). The pumping was by an He-Ne laser. The initial polarization of the laser light was modulated from right- to left-circular polarization by means of an ML-3 electro-optical light modulator with the polarization prism removed (ML I in Fig. 1). Voltage from generator GZ-33, with a frequency f_1 of several dozen Hz, was applied to the modulator to an additional power amplifier (PA). The dichroism induced in this manner was measured by using a beam of a second similar laser of somewhat smaller power, polarization-modulated in the same manner (ML II), but at a frequency $f_2 = 500$ kHz set by a stabilized piezoelectric quartz oscillator. The probing laser beam passing through the sample was received by a cascade photodiode (PDR). The dichroism in the sample produced at the receiver output a signal of frequency f_2, having the same phase as the modulation of the circular polarization of this beam. To separate the dichroism induced by the light from the dichroism due to the spontaneous magnetization and to the external magnetic fields, the signal was again electrically amplified and synchronously detected at the frequency f_1 at which the polarization of the pumping beam was modulated.

The signal observed in this manner offered evidence of the appearance of optically modulated dichroism in the sample. The proof that the observed phenomenon is connected with an orientation caused by the circularly polarized light is the following test. At 100% modulation of the pumping-beam intensity at the same frequency f_1, the effect disappeared in the absence of circular polarization.

To estimate the value of the effect, the sample as placed in an alternating external magnetic field parallel to the light beam and in phase with the pump; the pumping beam was blocked in this case. Without a change in tuning, the setup registered the magnetic circular dichroism signals. The field that produced the same signal as optical pumping has made it possible to estimate the magnitude of the effect. The value of H_{eq} under our conditions, at a laser power ≈25–40 mW and at a light-spot diameter on the sample ≈0.2 mm, was 0.1 Oe.

Application of an external magnetic field transverse to the light beam decreases the effect of induced dichroism, with a dependence that is quite well approximated by a Lorentz curve (Fig. 2). The plot shown in Fig. 2 is similar to the luminescence depolarization curves (the Hanle effect) usually observed in the case of optical orientation. It remains unclear how this relatively weak external field becomes observable against the background of the internal field of the paramagnetic samples.

The described effect was observed on samples prepared by methods of explosive evaporation and vacuum sputtering.

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[1]B. P. Zacharchenya, Proceedings of the 11th Int. Conf. on Phys. of Semiconductors, Warsaw (1972), p. 1315.
[2]G. Lampel, Proceedings of the 12th Int. Conf. on Phys. of Semiconductors, Stuttgart, 1974, p. 743.
[3]G. Busch, P. Wachter, and Z. Angew, Phys. 26, 1 (1968).