# Effect of intense pulsed illumination on the Faraday effect in the ferromagnetic semiconductor $CdCr_2Se_4$

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Experiments reveal a substantial change in the Faraday rotation in the ferromagnetic semiconductor $CdCr_2Se_4$ as the illumination intensity is raised.

Sanford *et al.*[1] have reported a shift of the Faraday rotation spectrum of the ferromagnetic semiconductor $CdCr_2Se_4$ when subjected to cw optical pumping. The shift of the Faraday rotation spectrum corresponds to an increase in magnetization equivalent to a cooling of the sample by 5 K at a pump intensity of 1.6 W/cm$^2$. The magnetization increase was attributed to an indirect exchange through photoexcited electrons, produced in a high density by the intense optical pumping. In a cw experiment the substantial heating of the crystal reduces the magnetization. The photomag-

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netic effects associated with the indirect exchange should therefore be seen much more clearly under nonequilibrium conditions, with pumping by short light pulses. In the present letter we report experiments which show that the Faraday rotation in $CdCr_2Se_4$ changes significantly with increasing intensity of pulsed illumination. There is a simultaneous change in the absorption coefficient for circularly polarized light.

We measured the angle of the Faraday rotation of the beam from a neodymium laser ($\lambda = 1.06\ \mu$m) in $Q$-switched operation (pulse length of $1.5\times10^{-8}$ s, pulse repetition frequency of 12 Hz) at various illumination intensities over the temperature interval 20–140 K. The beam, attenuated by filters, was focused by a lens onto the $CdCr_2Se_4$ sample in flow-through optical cryostat. The sample, cut from a single crystal in the form of a plane-parallel wafer $1.5\times1.5$ mm$^2$ in area and 20 $\mu$m thick, was magnetized to saturation by a field of 4.8 kOe.

The Faraday rotation changes significantly as the light is intensified over the temperature range 20–120 K. Figure 1 shows the temperature dependence of the Faraday rotation for various incident light intensities. Over the temperature interval 60–90 K the rotation angle varies linearly with this intensity. The maximum change in the rotation angle is $1.6\times10^4$ deg/cm at $T = 75$ K and at an intensity of 300 kW/cm$^2$.

The relaxation time of the effect was determined by measuring the Faraday rotation angle of the laser beam in free-running operation. In this operating regime the output pulses, 1 $\mu$s long, repeat at intervals of 2–3 $\mu$s over essentially the entire pump pulse (50 $\mu$s). Figure 2a shows a typical oscilloscope trace of the light in free-running operation. Figure 2b shows an oscilloscope trace of the output signal from a photomultiplier when the analyzer is in the blocking position for low-intensity light. The amplitude of the photomultiplier signal is proportional to the deviation of the rotation angle from the blocking angle of the analyzer. The deviation of the rotation angle increases,

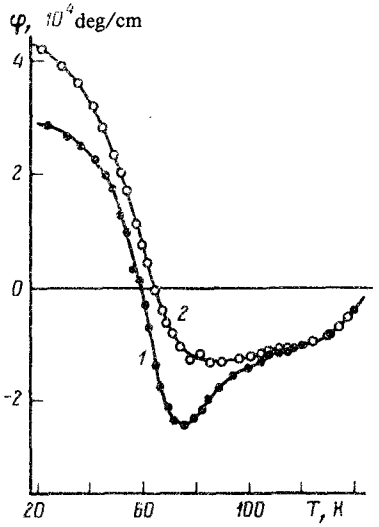


FIG. 1. Temperature dependence of the specific Faraday rotation at two light intensities: 1—300 kW/cm$^2$; 2—3 kW/cm$^2$.

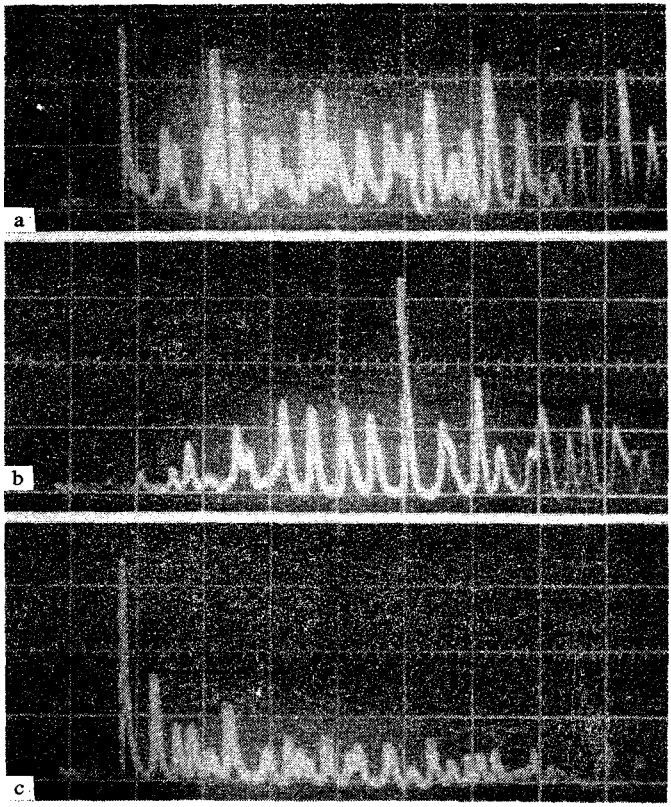


FIG. 2. Oscilloscope traces of the photomultiplier output signals. a—Beam from the laser in free-running operation; b—analyzer in the blocking position for low-intensity light; c—analyzer in the blocking position for the last of the light pulses.

and the increase is substantial even after two free-running pulses. Shown for comparison in Fig. 2c is an oscilloscope trace of the signal when the analyzer is in the blocking position for the last of the light pulses. The change in the Faraday rotation angle increases from pulse to pulse, so the relaxation time is considerably longer than the time interval between two successive free-running pulses (3 $\mu$s).

The absorption coefficients for circularly polarized light, which are related to the Faraday rotation by the dispersion relations, also change substantially as the light intensity is increased. Figure 3 shows the temperature dependence of the absorption of circularly polarized light over the temperature interval 20–140 K for various light intensities. The transmission of the sample is increased significantly by right-hand circularly polarized light, especially at low temperatures. The absorption of left-hand circularly polarized light decreases at high intensities at 75 K, but it increases at lower temperatures. To some extent the temperature dependence of the absorption coefficient and of the Faraday rotation in $CdCr_2Se_4$ is equivalent to an absorption spectrum because of the so-called red shift of the absorption edge, which amounts to about 1 nm/K. This temperature dependence thus gives us information about the dispersion and absorption spectra of the Faraday rotation.

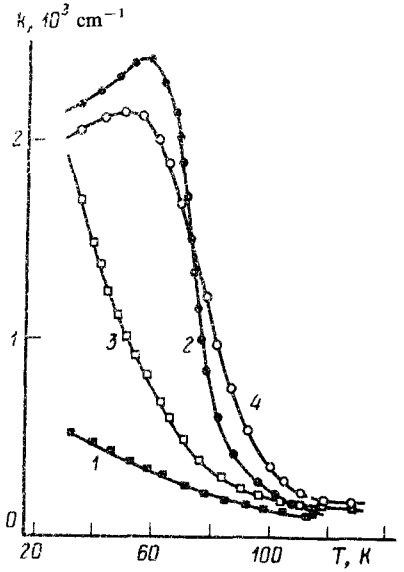


FIG. 3. Temperature dependence of the absorption coefficients for right- and left-hand circularly polarized light at two light intensities. 1—$k_r$, 300 kW/cm$^2$; 2—$k_L$, 300 kW/cm$^2$; 3—$k_r$, 3 kW/cm$^2$; 4—$k_L$, 3kW/cm$^2$.

There are several factors which could cause the absorption of circularly polarized light and the Faraday rotation angle to depend on the light intensity. At an intensity of 300 kW/cm$^2$ there may be a saturation of the absorption, which leads to a decrease in both the absorption coefficient and the absolute value of the Faraday rotation. The increase in the absolute value of the Faraday rotation may be due to an increase in the magnetization due to indirect exchange through photoexcited electrons. An increase in the magnetization should work through the red shift to increase the optical absorption. Just which of the mechanisms is responsible for the observed effects can be determined by carrying out experiments of this type over broad wavelength and temperature ranges.

[1]N. Sanford, R. W. Davies, A.Lempicki, W. J. Miniscalco, and S. J. Nettel, Phys. Rev. Lett. **50**, 1803 (1983).

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