A. A. Samokhvalov and V. V. Osipov. *Electron-magnon interaction in magnetic semiconductors.* Since the discovery in the 1960s of the magnetic semiconductors—ferromagnetically ordered semiconducting compounds with a quite high charge-carrier mobility—europium oxide EuO and spinels of the type $CdCr_2Se_4$, the physics of magnetic semiconductors has been at the forefront of solid-state physics. Interest in magnetic semiconductors stems from the presence of electric and magnetic subsystems, which interact strongly with one another via Vonsovskiĭ's s-d exchange interaction.[1] This interaction leads to a number of unique phenomena observed in magnetic semiconductors[2]: a giant magnetoresistance, an insulator-metal transition with a very large change in the electrical conductivity, a giant shift of the optical absorption edge, formation of spin-polarized complexes—ferrons, etc. These phenomena, observed under equilibrium conditions, do not, however, exhaust the possibilities of magnetic semiconductors. A new and large group of physical phenomena is possible due to the interaction between elementary excitations—itinerant electrons, magnons, and phonons under nonequilibrium conditions.[3,4] For example, the interaction of hot charge carriers, drifting in a strong electric field, with spin wave (magnons) can lead to an amplification or Cherenkov generation of spin waves, heating of magnons, and a number of other electron-magnon interaction phenomena. Such excitation of spin waves (magnons) by hot charge carriers under favorable conditions must affect the macroscopic parameters of magnetic semiconductors. In particular, in this case, since each excited magnon decreases the magnetic moment by one Bohr magneton, the magnetization should decrease. Since in a magnetic semiconductor the electronic structure determining its physical properties depends, as a result of s-d exchange interaction, on the magnetization, other physical parameters will also change correspondingly: electrical, optical, and magnetooptical properties, magnetic and dielectric uhf properties, etc.

To observe experimentally the phenomena made possible by the strong electron-phonon interaction, quite large and perfect single-crystals of magnetic semiconductors based on EuO, $CdCr_2Se_4$, and $HgCr_2Se_4$ with a quite high charge-carrier mobility (up to $\sim 1000\ cm^2V^{-1}s^{-1}$), low damping of spin waves ($\Delta H_k \sim 1$ Oe), high saturation magnetization, and comparatively low Curie temperature, were grown. A complex of experimental techniques for studying the magnetic, electrical, optical, magnetooptical, and uhf properties of magnetic semiconductors in strong electric fields in the pulsed mode was developed in order to avoid Joule heating.

The magnetization, electrical conductivity, uhf absorption, and the optical, magnetooptical, and other parameters of magnetic semiconductors as a function of the intensity of the electric and magnetic fields as well as their relaxation characteristics during and after the pulse were studied in the temperature range 4.2–300 K. The measurements were performed on single-crystals of the magnetic semiconductors n-type EuO, p-type $Cd_{1-x}Ag_xCr_2Se_4$, and n- and p-type $HgCr_2Se_4$ with different concentration and mobility of charge carriers.

The results indicate the substantial effect of a strong electric field (up to $10\ kV \cdot cm^{-1}$) on the physical properties of magnetic semiconductors. Thus anomalies were observed in the dependence of the electrical conductivity on the electric-field intensity in the region of magnetic ordering, indicating Cherenkov generation of magnons by charge carriers, in the high-resistance magnetic semiconductors $Cd_{1-x}Ag_xCr_2Se_4$ with p-type conductivity.[5] More distinct effects were observed in magnetic semiconductors with a high concentration of mobile charge carriers.[6,7] In this case, the decrease in the electrical conductivity due to excitation of magnons by hot charge carriers reached 50%, indicating a significant transfer of energy from the charge-carrier system to the magnetic system. A drop in the magnetization in a strong electric field (up to 10%), resulting from the excitation of magnons by charge carriers, was also observed in the same samples. The drop in the electrical conductivity and in the magnetization in a strong electric field were studied as a function of the conditions (electric and magnetic field intensities and the temperature) and parameters of the magnetic semiconductors (electrical conductivity and the concentration and mobility of charge carriers). It was found that the indicated effects occur only in the presence of a quite high concentration of mobile charge carriers. The relaxation characteristics of the magnetization and electrical conductivity were studied. During the electric pulse the magnetization drops; after the pulse, depending on the experimental conditions and the parameters of the magnetic semiconductor, the magnetization either continues to decrease (though $E = 0$) or it increases, returning in both cases to the starting value within 10^{-3} s. This, at first glance, strange result was explained under the assumption of independent and different, with respect to intensity, excitation (heating) of magnons and phonons by charge carriers. According to the theory,[4] this possibility arises as a result of the weak coupling between the magnon and phonon subsystems in magnetic semiconductors with a low Curie temperature (lower than the Debye temperature).

To estimate the efficiency of excitation of magnons by hot charge carriers, the parameter $\gamma = \Delta T_{\mathrm{m}} / \Delta T_{\mathrm{p}}$, equal to the ratio of the increment to the magnon temperature during the pulse and the increment to the phonon temperature, is introduced. The increments ΔT_{m} and ΔT_{p} are determined experimentally from the magnetization relaxation curves. A set of studies of the parameter γ was performed as a function of the intensity of the electric and magnetic fields, temperature, and concentration and mobility of charge carriers in the magnetic semiconductor. The results of these studies agree with the theory.[4]

The results obtained on the excitation of magnons by hot charge carriers were confirmed by independent studies of the temperatures of hot charge carriers and magnons based on the uhf noise temperature.[8] These studies showed that under typical experimental conditions the charge carriers are heated by several tens to several hundreds of Kelvins. Heating of magnons up to several tens of Kelvins has also been observed.

The results obtained on the excitation of magnons by charge carriers have a number of consequences for other physical properties of magnetic semiconductors. These consequences are determined, first of all, by the effect of the drop in magnetization (due to excitation of magnons) on the electronic energy spectrum of the magnetic semiconductor and, second, by the possibility of a controllable transfer of energy from the charge carriers to the magnons. This can be illustrated by the results of experiments on the effect of a strong electric field on uhf absorption,[9] as well as on the optical and magnetooptical parameters[10] of magnetic semiconductors.

On the whole, it may be concluded that the results presented are the first but very hopeful steps in a new area of applied solid state physics—semiconducting magnetoelectronics, an area with important new possibilities for technology.

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