Effect of hot carriers on the Raman spectra of the magnetic semiconductors $CdCr_2Se_4$ and $HgCr_2Se_4$

A. A. Samokhvalov and Yu. P. Sukhorukov

Institute of the Physics of Metals, Academy of Sciences of the USSR, Ural Scientific Center

(Submitted 3 December 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **35**, No. 5, 212–214 (5 March 1982)

Measurements show that a static electric field affects the position of the Raman line in single crystals of the magnetic semiconductors $CdCr_2Se_4$ and $HgCr_2Se_4$. The line position is shown to be affected by an interaction of phonons with magnons excited by hot charge carriers.

PACS numbers: 78.30.Gt, 78.20.Jq

Previous studies[1,2] of the magnetic and electrical properties of magnetic semiconductors in strong electric fields have shown that the independent excitation of magnons and phonons by hot charge carriers can give rise to new effects through an active electron-magnon interaction. More information along this line can be obtained by studying Raman scattering in magnetic semiconductors in a strong electric field.

The temperature dependence of the Raman-scattering parameters (the frequencies and intensities of the spectral lines of certain phonon modes) in magnetic semiconductors of the EuO and $CdCr_2Se_4$ types is similar to the temperature dependence of the spin-correlation function.[3-5] The changes caused by a strong electric field in the Raman parameters in magnetic semiconductors can thus serve as a source of information about the interaction of the phonon and magnon systems with hot carriers. To pursue this possibility, we studied the temperature dependence of the frequency of the Raman C line (Γ_{12}^{+}; 152.8 ± 0.3 cm^{-1}) in p-type magnetic semiconductors, $CdCr_2Se_4$ with a resistivity $\rho \sim 10^8$ Ω cm at 90 K and a Curie temperature $T_{Cur} = 130$ K, and $HgCr_2Se_4$, with $\rho \sim 10^3$ Ω cm and $T_{Cur} = 106$ K. The dimensions of the samples were $3 \times 4.55 \times 0.5$ cm; measurements were carried out over the temperature range from 90 to 293 K. The measurement geometry corresponded to backscattering from a natural face of the sample [a (111) plane]. The light source was a He-Ne laser with $\lambda_L = 632.8$ nm and a power ~10 mW. We used a DSF-24 differential spectrophotometer with a cooled photodetector. The sample was insulated from its substrate by a beryllium oxide plate. Electrical contacts were applied to the sample with an indium-gallium paste. The constant electric field was applied to the end faces of the sample, in the direction perpendicular to the incident laser beam. We simultaneously monitored the current and found the power applied to the sample.

As the temperature is lowered from 293 K to T_{Cur}, there is a linear shift of the C line (Fig. 1a), similar to that observed in Ref. 3. This shift can be attributed to a shift of the phonon frequency because of thermal contraction of the crystal. At $T \lesssim T_{Cur}$, there is a change in the slope of the $\omega_C(T)$ curve, and between 130 and 95 K (for $CdCr_2Se_4$) the frequency increases 2%. The change in the lattice constant over this frequency interval is only ~0.02%, so that thermal contraction of the lattice can-

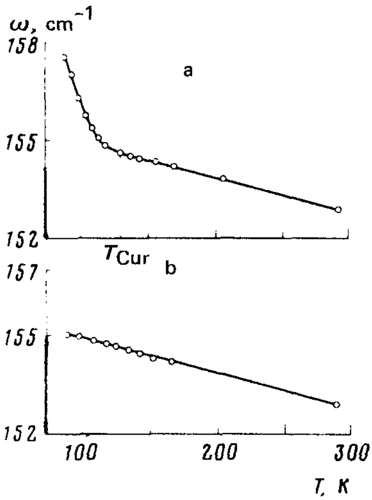

FIG. 1. Temperature dependence of the shift of the Raman line, ω_C, for $CdCr_2Se_4$. a–$E=0$; b–$E=420$ B/cm.

not explain the observed line shift. The imposition of an electric field on the $CdCr_2Se_4$ and $HgCr_2Se_4$ samples at $T=95$ K also reveals a significant shift of the C line, without any change in its intensity (Fig. 2). From Fig. 3 we see that at $T<T_{Cur}$ the C line shifts with increasing field, reaching $\omega_C=154.5$ cm^{-1} at $E=380$ V/cm for $CdCr_2Se_4$ and 156.5 cm^{-1} at $E=18$ V/cm for $HgCr_2Se_4$; these frequencies correspond to the frequency of the C line at the time in which T_{Cur} is reached in the samples in the absence of a field ($E=0$).

These results can be explained by assuming that an interaction of hot carriers with magnons[1] gives rise to a heating of a part of the spin system associated with phonons and thus to a decrease in that part of the light scattering which is determined by the coupling with magnons. In the present case, this part of the spin system is heated by the hot carriers to T_{Cur}. A further increase in the field causes no changes

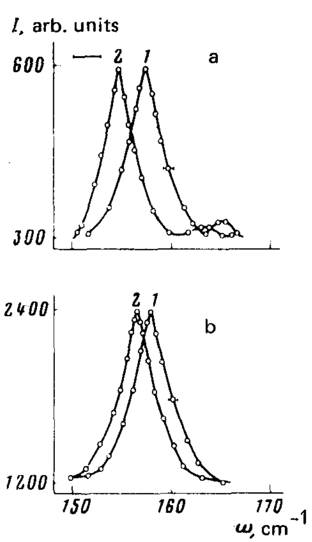

FIG. 2. Shift of the Raman C line in an electric field at $T=95$ K. a: $CdCr_2Se_4$. 1–$E=0$; 2–$E=420$ V/cm. b: $HgCr_2Se_4$. 1–$E=0$; 2–25 V/cm.

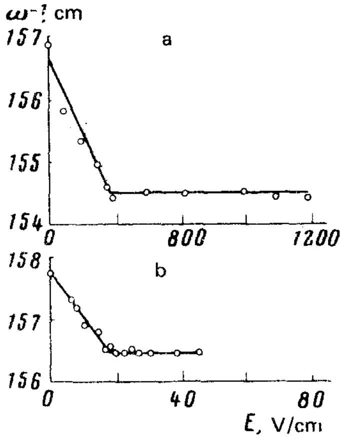

FIG. 3. Dependence of the shift of the Raman line, ω_C, on the electric field at $T = 95$ K. a–$CdCr_2Se_4$, $\rho \sim 10^8$ Ω cm; b–$HgCr_2Se_4$, $\rho \sim 10^3$ Ω cm.

in the line position, within the experimental errors. At $T \gtrsim T_{Cur}$, the applied electric field does not change the position of the C line, and we may accordingly conclude that the phonon system is heated only slightly. The change in the slope of the $\omega_C(E)$ curve for $HgCr_2Se_4$ occurs at a much weaker field than for $CdCr_2Se_4$, and this difference can be attributed to the much higher carrier mobility in $HgCr_2Se_4$ (Ref. 2). At the higher carrier mobility, the spin system is evidently heated more effectively.

Measurements of $\omega_C(T)$ for $CdCr_2Se_4$ at $E = 420$ V/cm show that even at 95 K the part of the spin system which is coupled with phonons is heated to temperatures above T_{Cur}, and no anomalous changes are observed when T_{Cur} is crossed for either $CdCr_2Se_4$ (Fig. 1b) or $HgCr_2Se_4$.

In summary, this study of Raman scattering in the magnetic semiconductors $CdCr_2Se_4$ and $HgCr_2Se_4$ in a strong electric field has revealed evidence of an independent heating of hot charge carriers by a part of the magnon system which affects the phonon spectrum.

We wish to thank N. G. Bebenin for a discussion of this work.

1. A. A. Samokhvalov, V. V. Osipov, A. T. Ivaev, V. T. Kalinnikov, and T. G. Aminov, Pis'ma Zh. Eksp. Teor. Fiz. **30**, 658 (1979) [JETP Lett. **30**, 623 (1979)].
2. A. A. Samokhalov, B. A. Gizhevskiĭ, N. N. Ooshkareva, T. I. Arbuzova, M. I. Simonova, and N. M. Chebotaev, Fiz. Tverd. Tela (Leningrad) **23**, 3469 (1981) [Sov. Phys. Solid State (to be published)].
3. E. F. Steigmeier and G. Harbeke, Phys. Kond. Mat. **12**, 1 (1970).
4. G. Gündtherodt, R. Merlin, and P. Grünberg, Phys. Rev. **B 20**, 2834 (1979).
5. W. Baltensperger and J. S. Helman, Helv. Phys. Acta **41**, 668 (1968); W. Baltensperger, J. Appl. Phys. **41**, 1052 (1970).

Translated by Dave Parsons
Edited by S. J. Amoretty