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HIGHT-FIELD SUBMILLIMETER MAGNETO-SPECTROSCOPY ON Hg(Fe)Se

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Magnetooptical phenomena in the zero-gap semimagnetic semiconductor Hg(Fe)Se are studied by various techniques in pulsed magnetic fields up to 150 T. Microscopical parameters are estimated in combination with results obtained from transport and magnetization measurements.

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1. Introduction

In the semimagnetic semiconductor Hg(Fe)Se the location of the Fe^{2+}-$3d^6$-level high in the conduction-band leads to carrier concentrations as high as 5×10^{18} cm^{-3} [1]. The usual way of determining microscopical parameters by magnetooptical methods therefore becomes rather troublesome — in the FIR-region resonant intraband transitions are obscured by strong magneto-plasma effects both in transmission and reflection experiments.

On the other hand the reliability of information deduced from transport measurements is limited since the scattering processes in Hg(Fe)Se are not yet totally understood [2]. Also the large number of fitting parameters especially in the case of spin-related quantities leads to a certain degree of arbitrariness in the evaluation of such data. A straightforward approach to determine the magneto-quantization of the conduction-band is therefore favourable.

In the present paper we will discuss two possibilities how to overcome difficulties related to high carrier densities in magnetooptical measurements and present first evaluable results of high-field cyclotron resonance measurements.

2. Stripline measurements

A suitable method for the optical detection of intraband transitions in highly conductive materials is the stripline-technique [3]. In this set-up the sample is embedded into the surface of a waveguide, thus determining the wave propagation by the boundary conditions for the electric and magnetic-field quantities. Size and geometry of the stripline are usually adjusted to allow only a single well defined mode (i.e. the lowest quasi TM-mode) to propagate. In the case of the so-called parallel configuration (Fig. 1) this leads to an unambiguous coupling with the ordinary Voigt-mode in the sample. Therefore the stripline attenuation is related to the dielectric constant of the sample in a very simple way and hence depicts the desired quantum-structure.

The spectra taken for Hg(Fe)Se ($N_{\mathrm{Fe}} = 5 \times 10^{19}$ cm^{-3}) (Fig. 1) in the parallel configuration clearly exhibit a strong resonant absorption-effect. In the parallel configuration only the ordinary Voigt-mode is assumed to be dominant. Therefore the cyclotron resonance cannot be detected unless the effective mass tensor is non-diagonal. The resonance observed at 1.6 T was hence assumed to be spin-related. The resonance position was found to be shifted slightly to lower fields with increasing temperature, indicating a high-field combined spin-flip resonance (i.e. $n = +1$, $s = +1$ for negative g-factor).

First the exchange interaction part of the effective g-factor was estimated with the aid of SQUID magnetization data, yielding a Curie–Weiss-like behaviour. The corresponding g-factor was then fitted by using the resonance-positions from the outermost high and low temperature measurements. A temperature dependence of $g_{\mathrm{smsc}} = -31.7/(T[\mathrm{K}] + 4.7)$ was derived in that way. However, considerable deviations between the experimental values of the resonance positions and the best fit appeared in a temperature range between 30 and 50 K. This indicates that the exchange interaction may not be represented appropriately by the magnetization in the case of Hg(Fe)Se. A possible reason is the presence of both Fe^{2+}- and Fe^{3+}-ions which may contribute to the total exchange by different coupling-constants.

Since the exchange interaction becomes negligibly small at high temperatures and in low fields, data taken at temperatures between 60 and 80 K were used to determine the combination of the effective mass and the cyclotron-averaged g-factor to be $m_0/m_c + g_0/2 = 17.7$.

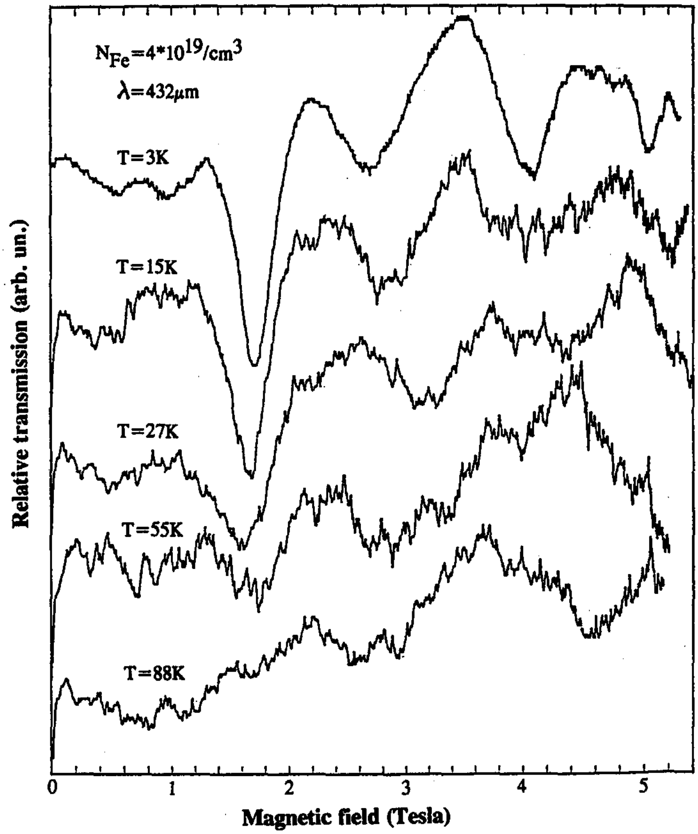

Fig.1. FIR-stripline spectra showing the temperature dependence of the combined spin-flip transition in Hg(Fe)Se. The exact resonance position is located at the turning point of the traces on the low field side of the absorption peak.

3. Transmission-measurements

In Hg(Fe)Se the carrier-concentration of $N_e = 5 \times 10^{18}$ cm^{-3} gives rise to a plasma-frequency of the order of 130 meV. Any successful transmission-experiment therefore requires radiation energies higher than this value, which in turn shifts the cyclotron resonance into a magnetic field-range of about 60 T. Fields in that order of magnitude, that is close to the mega-Gauss region, can only be generated by destructive coil techniques with a pulse-duration of some microseconds. Careful preparations are therefore necessary to prevent any damage of the samples caused by mechanical forces and eddy-current effects.

In our case the samples ($N_{Fe} = 1 \times 10^{20}$ cm^{-3}) were etched to thicknesses less than 2 μm to guaranty good transmission of the radiation. As a support against mechanical forces both sides were glued to thin BaF_2-wafers.

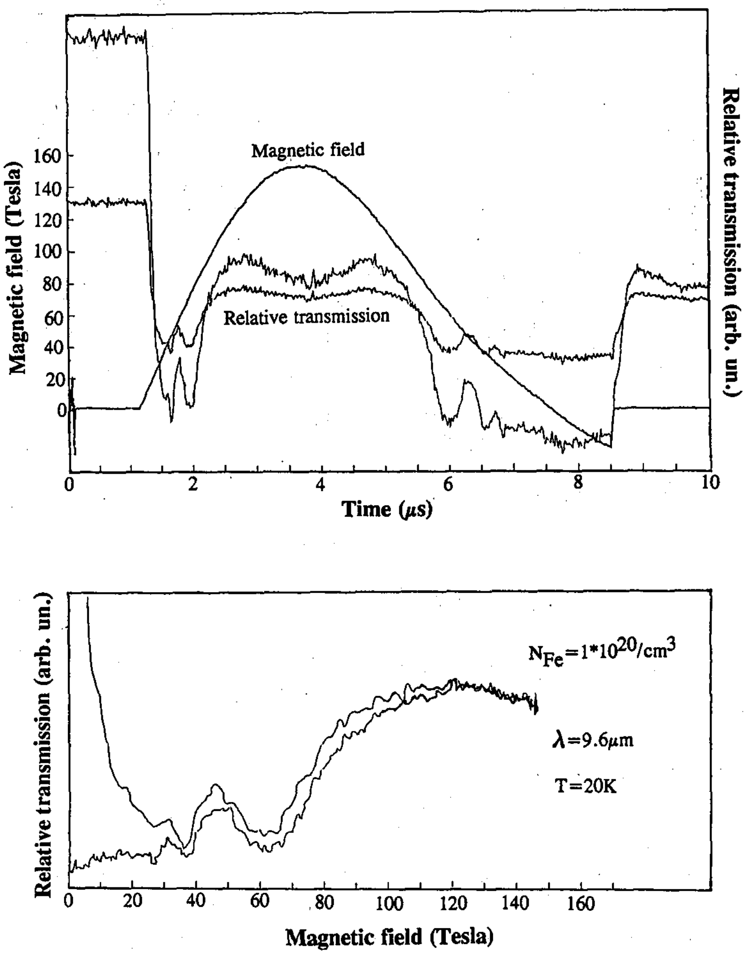

Fig. 2. IR-transmission experiments in pulsed magnetic fields exhibit a multiline structure including the cyclotron resonance at 62 T. The upper part shows the original recording of the transmitted radiation and the monitoring of the magnetic field pulse versus time. In lower part the transmission data is plotted with respect to the magnetic field.

The spectra taken in magnetic fields up to 150 T exhibit a pronounced multi-line structure and resolve clearly for the first time the cyclotron-resonance in Hg(Fe)Se. If one interprets the most pronounced line at 62 T as the cyclotron resonance a mass of $m_c/m_0 = 0.056$ can be obtained. The physical origin of the additional low-field lines is not yet completly clear. A spin-splitting of the cyclotron resonance, impurity transitions as well as 'hot carrier' effects due to the generation of eddy currents during the magnetic-field pulse are under consideration. It should be noted however, that the multi-line structure of the resonance spectrum is reproducible for different samples, although the resonance width depends strongly on the sample thickness.

4. Conclusion

We have measured the cyclotron mass of Hg(Fe)Se independently of any other parameter and obtained a value of $m_c/m_0 = 0.056$. This value can now be used to calculate spin-related quantities, that is the cyclotron-averaged g-factor and the effective exchange integral. Especially the quantum structure of the Shubnikov-de Haas effect is an appropriate tool for this purpose.

Under the assumption that the cyclotron mass is the same for all iron concentrations if only the Fermi level is pinned, we derive the values of $g_0 = -8.9$ and $xJ < S >= -3.1$ meV from magneto-transport data [5].

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