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MEGAGAUSS SPECTRA OF SEMICONDUCTORS: MERCURYSELENIDE LOW-DIMENSIONAL STRUCTURES IN MAGNETIC FIELDS UP TO 1000 T

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Abstract: Mercuryselenide is a zero-gap semiconductor of Ⅱ-Ⅵ-family. The iron-doped modification HgSe:Fe has a "Fermi-level pinning" beyond the electron concentration of 5×10^{18} cm^{-3}. Due to the short-range correlation of Fe^{++}/Fe^{+++}-system, a dramatic increase of carrier mobility is observed, so that any quantum effect in 3D, 2D, 1D, and 0D is well detected. Applying molecular-beam epitaxy for the sample preparation, we present magnetospectral data of selected samples of this compound demonstrating various features in magnetic fields up to 1000 T by applying different field generators. The resulting data are explained in connection with suitable theoretical concepts basing on the k·p-method as well as on the tight-binding approximation.

Key words: iron-doped mercuryselenide HgSe: Fe; infrared magnetotransmission; magnetospectrum; magnetoresistance; magnetic fields up to 1000 T
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Introduction

Mercuryselenide is a n-type zero-gap semiconductor in zincblende structure. The modification HgSe:Fe with an iron doping $n_{Fe} > 5\times10^{18}$ cm^{-3} leads to a mixed-valence regime of Fe^{++}/Fe^{+++} system and a pinning of the Fermi-energy to the energy of iron donor about 210 meV above the band edge [1]. Pronounced short-range correlation effects in Fe^{++}/Fe^{+++}-system give rise to a drastic mobility increase, so that HgSe:Fe as a host material for nano-structured systems ensures the observability of any quantum effect [2].

1 Recent experiments on HgSe:Fe in magnetospectra:

Magnetospectrum is a powerful tool for the investigation of electronic energy levels in any semiconductor structure. Both non-resonant and resonant magnetospectrums take advantage of the tunability of electronic energy levels by an external magnetic field. The higher the tuning magnetic field is, the more detailed information on the electronic system can be obtained. In this report we concentrate on three selected new experiments: a) inter-dot conductivity of Hg:Se quantum dots in fields up to 12 T, b) magnetotransmission of bulk HgSe in fields up to 140 T, and c) magnetotransmission of HgSe:Fe in fields up to 1000 T.

2 Inter-dot magnetoconductivity in HgSe: Fe quantum-dot systems:

We succeeded in growing HgSe. Fe quantum-dot systems of different density depending on the interface strain with respect to the ZnSe(Te) buffer layer. The HgSe:Fe layer formed strained quantum dots of about 10-100 nm diameter and a height of the order 10 nm as shown by the AFM images in fig. 1 [3]. The Fe-doping ensures a "bulk" carrier concentration of $n_e = 5\times10^{18}$ cm^{-3} in the Fermi-level pinned system, so that in each quantum dot, 5-500 electronic states are occupied depending on its size. To characterize these states with respect to "inter dot"-transitions, we measured the transversal DC-magnetoresistance up to 12 T in Hall-bar geometry at liquid-He-temperatures. All soldered Au-contacts were carefully checked with re-

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spect to ohmic behaviour. The principal objective of the investigation was, however, to find some analogy between impurity hopping in semiconductors and inter-dot transitions. As a matter of fact, both energies and orbital dimensions are of the same order of magnitude, so that similar features in the experimental data are expected. Depending on the different manifestations of the dot system, different features of the magneto-transport properties became predominant indicating Shubnikov-de Haas oscillations, positive, or negative differential magnetoresistance as shown in fig. 2. The low density sample B shows a strong positive magnetoresistance with small SdH-oscillations referring to a carrier concentration of 4×10^{18} cm^{-3}. For the more dense sample C the positive differential magnetoresistance is limited to the magnetic field range below 1 T and followed by a pronounced negative differential magnetoresistance. This behaviour is similar to the results for hopping conductivity in impurity bands of semiconductors. As a matter of fact our high density quantum dot sample is in many features similar to an ordinary hopping system. For the interpretation of the experimental results, we have therefore applied a nearest neighbour hopping approach considering spin-flip scattering as established by Movaghar and Schweitzer and successfully applied to ordinary impurity hopping systems [4]. For sample D we have included the corresponding theoretical result by thin line.

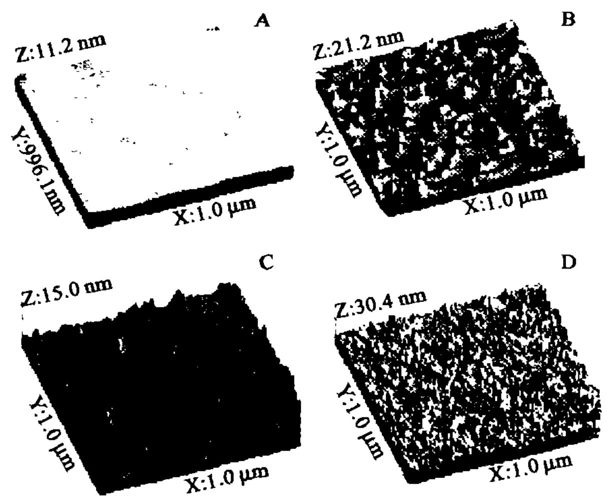

Fig. 1 A flat HgSe: Fe-surface in A in comparison with quantum-dot systems of increasing density in B-D of the same material

3 Magnetotransmission of bulk HgSe

Using the semi-destructive single-turn coil as field generator, we have investigated the IR-magnetotransmission of low-concentration HgSe epitaxial layers applying 10.6 μm wavelength in magnetic fields up to 140 T for different temperatures as shown in fig. 3 for different temperatures[5]. The arrows indicate up-and down-sweep of the magnetic field pulse. Whereas the low-temperature data exhibit a multi-line structure due to inter-band transitions (IBTs) and a minor cyclotron resonance (CR) with negligible hysteresis effects, these effects get more pronounced with increasing temperatures. As a matter of fact, with increasing temperatures the IBTs fade and the CR is tremendously increased in intensity. The spin-splitting of the CR is clearly visible for $T = 300$ K. The most exciting manifestation is, however, the pronounced hysteresis in the cyclotron absorptions for up-and down sweep. This phenomenon can be explained by the transient character of the magnetic field pulse: the magnetic field is changed so rapidly that thermal equilibrium in population of the energy levels cannot be achieved due to the finite spin-lattice relaxation time. Detailed evaluation of the experiment reveals that this relaxation time $\tau_{SL} = 1$ μsec is of the same order of magnitude as the characteristic time parameter of the field pulse of $\tau_B = 6$ μsec pulse length.

4 Magnetotransmission of HgSe: Fe in fields up to 1000 T

Recently the question of a possible hybridisation of quasi-free conduction-band states and bound Fe-states has been raised, so that a direct investigation of the overlapping of the states involved became desirable[6]. The corresponding experiments aim at the magnitude of the transition matrix element between quasi-free band states and the localized Fe-state to be measured by direct optical absorption intensity. To obtain an unambiguous result it is necessary that no other transitions obscure the expected transitions. In fig. 4, we have plotted the scheme of Landau levels for HgSe for magnetic fields up to 1000 T. The horizontal line indicates the iron level and hence also the Fermi energy of the system. The arrows indicate possible transi-

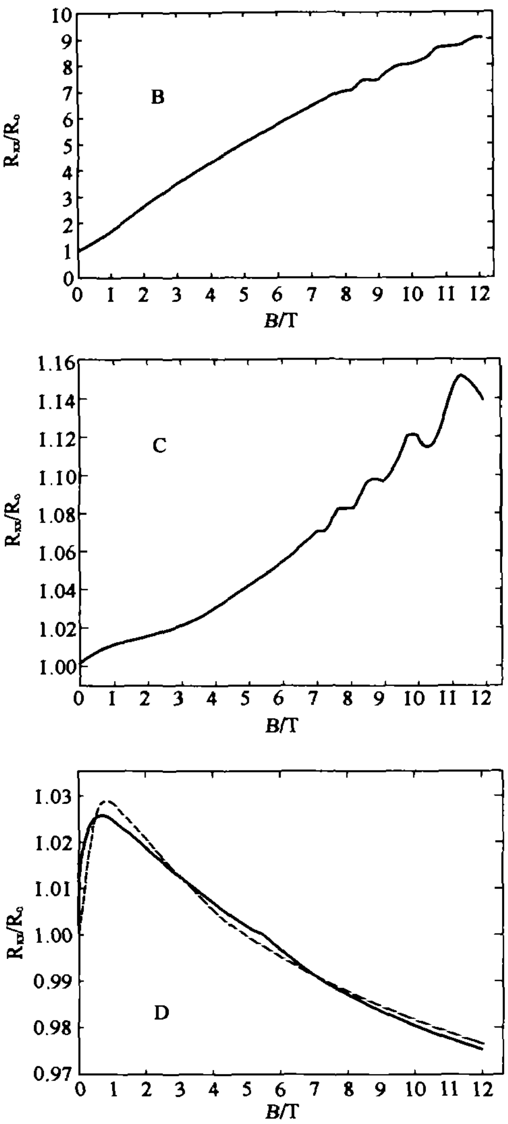

Fig. 2　Magnetoresistance curves for the samples B, C, and D show a decrease of positive magnetoresistance with increasing dot density, so that sample D with the highest dot density has a well pronounced negative magnetoresistance. The thin grey curve for sample D is theoretical fit to ref[4].

tions between the lowest Landau level and the iron level. Whereas the low-field transitions are within the range of the CR, beyond the level-crossing at about 250 T two transitions without any perturbations of other transitions are expected. The necessary field range above 250 T is, however, an extreme challenge for the experimentalist. Magnetic fields higher than 300 T can be generated only in a destructive way by flux compression. The range above 600 T is accessible only by the explosive flux compression, so that the actual experiment has to be performed inside a concentric violent detonation of about 16 kg TNT corresponding to 64 M-

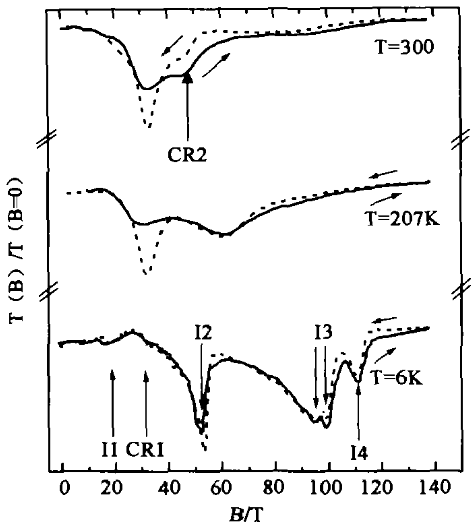

Fig. 3　Experimental data of the relative magnetotransmission T(B)/T(B = 0) of 117.2 meV-radiation through low-concentration HgSe for different temperatures in up-and down-sweep

Joule. This violent environment requires very sophisticated experimental arrangements. For the data recording EMP-proven electronics has to be applied. In fig. 5 we have plotted the corresponding of the magnetotransmission of 10.6 μm radiation through HgSe: Fe [6]. The strong absorption below 100 T originates from the CR of quasi-free electrons. In the range beyond about 200 T, rather broad but weeks absorptions are detected. From fig. 4 it is quite evident that these absorption can be assigned to the transition from the bound Fe-state to the quasi-free Landau states. The matrix element seems to be rather week, but non-vanishing. As a consequence we can state that there is a small, non-zero coupling and hence hybridisation of the bound Fe-state and the quasi-free electrons, at least in intense magnetic fields. This coupling, however, is only small, so that the proposed FRIEDEL-mechanism of resonance scattering[7] to explain the dramatic mobility increase in HgSe: Fe is not very probable, so that the MYCIELSKI/WILAMOWSKI model of charge correlation seems to be much more realistic[8,9].

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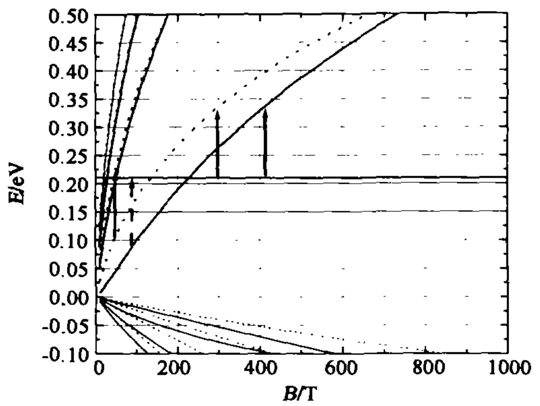

Fig. 4 Scheme of Landau levels in the conduction band of HgSe for magnetic fields B up to 1000 T. The horizontal line indicates the Fermi level pinned to the Fe^{++}-state, the arrows are the possible transitions into and out of the bound Fe-state with respect to quasi-free states of the conduction band

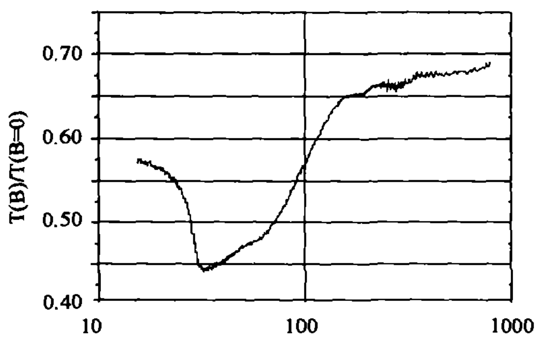

Fig. 5 The experimental data of the relative transmission of 10.6 μm-radiation T(B)/T(B=0) show below 100 T the strong cyclotron resonances, whereas the week absorptions above 150 T may be interpreted as transitions from the bound Fe^{++}-level into the lowest Landau levels

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