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MAGNETIZATION STEPS IN $Cd_{1-x}Mn_xTe$ OBSERVED IN COHERENT TRANSPORT

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Magnetoconductance measurements on submicron wires of n^+-$Cd_{1-x}Mn_xTe$ were carried out up to 27 T and down to 100 mK. The inverse correlation field of the universal conductance fluctuations is found to increase abruptly in the vicinity of the magnetization steps due to Mn pairs in CdMnTe. No such effect is observed in similar wires of CdTe. These findings support a recent model, according to which the correlation field of the universal conductance fluctuations in magnetic systems is inversely proportional to the magnetic susceptibility of the localized spins.

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When the linear size of a conductor, L, becomes comparable to the phase breaking length, $L\varphi$, electron waves preserve their phase coherence. In this regime quantum interference of transition amplitudes corresponding to various possible electron trajectories through the sample leads to random but reproducible fluctuations of the conductance G as a function of those external parameters which can affect the interference. The best known parameter is the magnetic field, which, via the Aharonov–Bohm [1] mechanism, changes the electron phase. The phenomenon is known under the name of universal conductance fluctuations (UCFs) [1, 2], as their mean amplitude is remarkably insensitive to the system properties, and for $L < L\varphi$ is $\mathrm{rms}(\Delta G) \approx 0.5e^2/h$.

It has recently been demonstrated that the field-induced redistribution of the carriers between the spin subbands constitutes an efficient driving mechanism of UCFs in diluted magnetic semiconductors (DMS) [3]. This is because the giant spin-splitting specific to DMS changes the electron wavelength, thus modifying strongly the interference term. The faster are the changes of the spin-splitting as a function of the magnetic field, the greater number of the fluctuations will appear in a given field range. Since the spin-splitting is proportional to the magnetization, the fluctuations density $d_{\mathrm{UCF}}(B)$ (per unit magnetic field) is proportional to the magnetic susceptibility of the localized spins, $d_{\mathrm{UCF}}(B) \propto \chi(B) = \alpha M/\partial B$. This opens the door for quantitative studies of the subsystem of magnetic ions by means of coherent transport phenomena in mesoscopic systems.

The influence of the spin-splitting upon the fluctuations density has been so far observed in weak magnetic fields [3]. In intermediately strong magnetic fields ($B > 1$ T at low temperatures), this influence tends to vanish, because the magnetization saturates and $\chi \to 0$. The purpose of the present work is to extend previous measurements to very strong magnetic field, in which the magnetization shows an abrupt increase due to the so-called magnetization steps [4] (MSTs). MSTs occur due to the field-induced alignment of the antiferromagnetically coupled clusters (pairs, triangles etc.) of the magnetic ions. Because in the region of MST the magnetic susceptibility is nonzero, an increase in the fluctuation density is to be expected.

We are carrying out an experimental study of magnetoresistance up to 27 T and down to 100 mK for free standing wires of CdTe and $Cd_{1-x}Mn_xTe$ ($x = 0.01$ and 0.07) doped with either indium or iodine up to the electron concentrations $n \approx 10^{18}$ cm^{-3}, greater than that corresponding to the metal–insulator transition. The wires in the form of Hall bridge structures with the thickness and line width of 0.3 μm were fabricated by means of the electron beam lithography followed by wet etching from the films grown by molecular beam epitaxy [5].

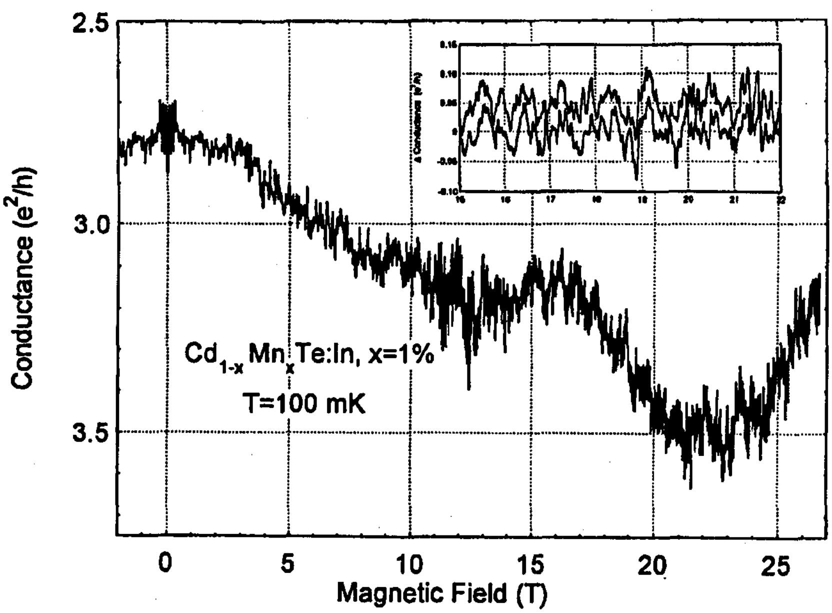

Fig. 1. Magnetoconductance trace taken on $Cd_{0.99}Mn_{0.01}Te$:In wire at $T = 100$ mK. The inset shows reproducibility of the fluctuations.

As seen in Fig. 1, high field magnetoresistance reveals the simultaneous presence of the Shubnikov–de Haas oscillations and aperiodic conductance fluctuations. The inset shows a good reproducibility of the fluctuations, even in the strongest magnetic fields, where the mechanic and electromagnetic noise coming from the hybrid magnet was rather strong. These raw data were digitally filtered and averaged over a few field sweeps.

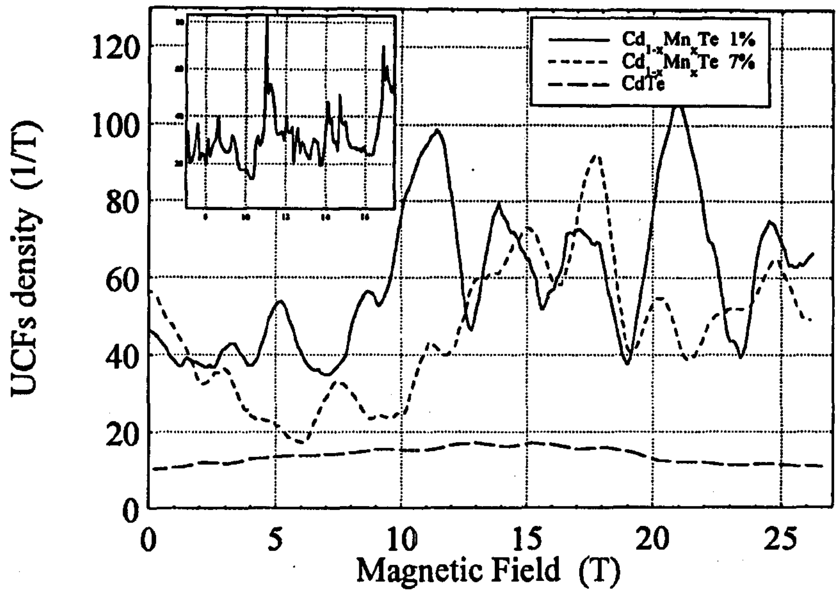

Fig. 2. Fluctuations density d_{UCF} for $Cd_{0.99}Mn_{0.01}Te$:In (solid line), $Cd_{0.93}Mn_{0.07}Te$:I (short dashes' line) and CdTe:In (long dashes' line) wires. The inset shows d_{UCF} for $Cd_{0.99}Mn_{0.01}Te$:In wire in the vicinity of the first MST.

Figure 2 shows the fluctuation density $d_{UCF}(B)$ for the wires of 1% and 7% CdMnTe as well as of CdTe. The fluctuation density d_{UCF} is inversely proportional to the correlation field $\Delta B_{corr}(B)$, which denotes the field range, for which the Lee–Stone correlation function [2]

$$F_{corr}^{L-S}[\Delta B(B)] = \int_{B-0.5W_B}^{B+0.5W_B} \delta G(B')\delta G(B'+\Delta B)\mathrm{d}B'$$

drops to one-half of its value at $\Delta B = 0$. Here δG is the UCF's amplitude and $W_B = 2$ T is the window adopted to obtain the data in Fig. 2.

One sees that for 1% sample the fluctuation density increases in the vicinity of 11 and 20 T. This anomaly can be assigned to the magnetization steps coming from the nearest neighbor (NN) pairs of the Mn ions. This conclusion is supported by previous optical and magnetization measurements [6–8]. It is also seen that the actual spectrum of the fluctuations density is rather complex. In particular, in the vicinity of 17 T an additional anomaly is visible, which — guided by previous experiments and theory [8] — could be attributed to cluster consisting of open triangles. For 7% sample, the presence of higher order clusters is more probable, which is responsible presumably for a decrease in the peaks coming from NN pairs. At the same time the peak at 17 T corresponding to the triangles is seen to dominate. Moreover, at appropriately low temperatures, we observe additional features. It is tempting to attribute them to *distant-neighbor* exchange interactions. The inset to Fig. 2 shows the density of the fluctuations for 1% wire in the vicinity of the first MST, evaluated by adopting a narrower window, $W_B = 1$ T, so that the features appear sharper. A fine structure of the peaks is found to decrease with increasing temperature. Such behavior is indeed expected for distant pairs [8], such as next near neighbors (NNN) and next-NNN (NNNN), for which exchange constants $J_{\rm NNN}$ and $J_{\rm NNNN}$ are evaluated to be 1.8 K and 0.4 K, respectively [8].

By contrast, in the case of nonmagnetic CdTe, we observe a smooth decrease in the correlation field below 12 T and its increase in higher magnetic fields. The latter is in accord with theoretical predictions for the universal conductance fluctuations in the presence of the Landau quantization [9]. In our sample $\mu B \rightarrow 1$ at *ca.* 20 T.

In summary, we have observed an increase in the fluctuation density in the vicinity of the magnetization steps in CdMnTe. At the same time, the density varies smoothly in the case of the nonmagnetic CdTe. These findings provide a new support for the conjecture that the UCFs in the magnetic systems are driven by the spin-splitting of the carrier states.

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