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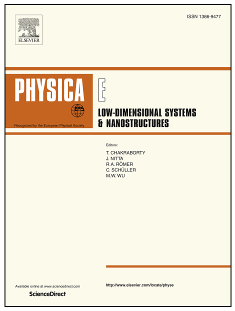

Two dimensional topological insulator in quantizing magnetic fields

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Two dimensional topological insulator in quantizing magnetic fields

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The effect of quantizing magnetic field on the electron transport is investigated in a two dimensional topological insulator (2D TI) based on a 8 nm (013) HgTe quantum well (QW). The local resistance behavior is indicative of a metal-insulator transition at $B \approx 6$ T. On the whole the experimental data agrees with the theory according to which the helical edge states transport in a 2D TI persists from zero up to a critical magnetic field B_c after which a gap opens up in the 2D TI spectrum.

Introduction

2D TI is characterized by the absence of bulk conductivity and the presence of two gapless edge current states with a linear dispersion and an opposite spin polarization that counter-propagate along the sample perimeter[1,2]. Such edge current states are called helical as opposed to the chiral edge states of the quantum Hall regime that circulate in the same direction independent of spin polarization. The described property of the 2D TI results from the energy spectrum inversion caused by a strong spin-orbit interaction. Up to date the presence of the 2D TI state has been established in HgTe QWs with an inverted energy spectrum[3,4]. The observation of a 2D TI has also been reported in InAs/GaSb heterostructure[5]. The later, however, require further verification since edge transport has also been reported in InAs/GaSb heterostructure with a non-inverted spectrum[6].

The effect of a perpendicular magnetic field on the properties of a 2D TI has two distinct and important aspects. On the one hand, even a weak magnetic field breaks down the time reversal symmetry protection of the topological edge states against backscattering. This effect is expected to manifest itself as a positive magnetoresistance (PMR) of a 2D TI in the vicinity of B=0. Such PMR has indeed been observed experimentally in diffusive and quasiballistic samples of 2D TI based on HgTe QWs[3,7–9] and is found to be in qualitative agreement with the existing theoretical models[10,11].

The other aspect of a perpendicular magnetic field is related to the transformation of the edge current states spectrum under the influence of quantized magnetic fields and, eventually, to the transition of the 2D TI system to the quantum Hall effect regime. The goal of the present work is an experimental investigation of the effect of a strong quantizing magnetic field on the transport properties a quasiballistic sample of 2D TI. In the beginning a few words about the existing theoretical and experimental results related to this problem. Theoretically this problem has been investigated in[12–15] but the conclusions at which the authors of these works arrive are quite controversial. Indeed, Tkachev et al[12] come to the conclusion that the gapless helical edge states of a 2D TI persist in strong quantizing magnetic fields but are no longer characterized by a linear energy spectrum. Similarly, Chen et al[13] suggest that the gapless helical states of a 2D TI survive up to 10 T, but there will also emerge several new phases with unusual edge states properties. By varying the Fermi energy one should be able to observe transitions between these phases accompanied by plateaux in the longitudinal and Hall resistivity. The results of the work[14] by Scharf et al also attest a certain robustness of the helical edge states with respect to the quantizing magnetic fields. However, according to[14] the edge states persist only up to a critical field B_c while at higher fields a gap proportional to B opens up in the energy spectrum. Finally, a mention should be made of the results obtained by Durnev et al in[15] that strongly differ from those cited above. The authors of[15] consider the effect of a perpendicular magnetic field on the properties of a 2D TI taking into account the strong interface inversion asymmetry inherent in HgTe QW. The key conclusion of this study is that the spectrum of the 2D TI helical edge states becomes gapped at arbitrary small magnetic fields. The size of this gap depends on the width of the gap separating the bulk energy bands and grows monotonically with magnetic field reaching, on average, a noticeable value of several meVs already in fields of the order of 0.5 T.

As for the experimental investigation of the effect of quantizing magnetic fields on the 2D TI, there are lacking at present direct transport measurements in the most interesting quasiballistic transport regime. In[16,17] far-infrared magnetospectroscopy has been used to probe the behavior of two peculiar "zero" Landau levels that split from the conduction and valence bands in an inverted HgTe QW and approach each other with magnetic field increasing. Instead of the anticipated crossing of these levels the authors have established that these levels anticross which is equivalent to the existence of a gap in the spectrum. In[18] a microwave impedance microscopy has been employed to visualize the edge states in a 2D TI sample. The authors come to the conclusion that there is no noticeable change in the character of the edge states up to 9 T.