Multifractal conductance fluctuations of the helical edge states

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The theory suggests the presence of a unique category of solid-state materials defined by an energy gap in the electron bulk states and gapless helical edge states that exhibit strict spin-momentum coupling, known as two-dimensional (2D) topological insulators. Without interactions, helical edge transport is topologically protected by time reversal symmetry (TRS), leading to the anticipation of sample conductance being quantized in units of $G_0 = 2e^2/h$. However, in practice, these predicted universal conductance values are typically observed only in samples with short edge channel lengths [1]. The presence of unexpected elastic backscattering among helical edge states in two-dimensional topological insulators has sparked extensive debate and continues to be a highly discussed issue. Additionally, contradictory to theoretical predictions, reproducible mesoscopic fluctuations in both local and non-local resistance as a function of gate voltage have been observed in HgTe Quantum Wells (QWs) at millikelvin temperatures.

In the present work we analyse the scaling behaviour of the mesoscopic conductance fluctuations (MCF) in HgTe wells whith the helical edge transport and observe multifractality of the MCF as a function of the gate voltage. Multifractal structures of fluctuations are characterized by an infinite set of critical scaling exponents of the power law of the probability density. Multifractal analysis is a useful method to investigate various properties in many fields that has recently received more attention by scientists due to its ability to describe complexity and irregularity of the system behaviour. In condensed matter physics signatures of multifractality appear in Anderson transitions.

We observe a multifractality of the conductance fluctuation in 2D topological insulator based on HgTe quantum well in the regime of the helical edge states transport [2]. We employ the multifractal detrended fluctuation analysis (MF-DFA) which identifies the deviations within fictitious time period in fractal structure with large and small fluctuations. The large mesoscopic fluctuations (fig.1a) can be attributed to Anderson transition between localized and delocalized states similar to transitions between different quantum Hall states. Fig. 1b,c show fluctuation functions $F_q(s)$ and the multifractal singularity spectrum [2]. We attribute these effect to multifractality of the electron wave function or the local density of states are due to the strong coupling between the helical edge and the bulk states. It would be interesting to explore interplay between topology and interaction, which is expected for the spin quantum Hall symmetry class.

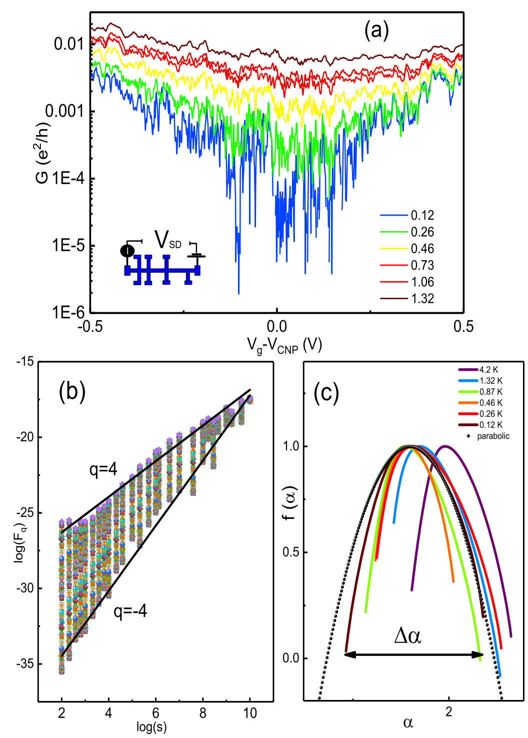

Fig. 1. (a) Conductance as a function of the gate voltage at different temperatures. (b) The multifractality of the helical edge states resistance fluctuations for sample . The MF-DFA fluctuation functions $F_q(s)$ are shown versus the scale s in log ˘ log plots, T=0.12 K. (c) The multifractal singularity spectrum of the resistance fluctuations. Dots-parabolic law.

References

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