Towards the Universal Quantum Electrical Standard

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Quantum standards are the backbone of the international system of units (SI). Already since the end of previous century, all electrical units are based on magnetic flux quantization in the units of $h/2e$ utilizing the superconducting Josephson effect, and conductance quantization in the units of e^2/h realized with the use of the quantum Hall effect. With the recent revision of the SI system also the realizations of the units of mass (kilogram) and temperature (Kelvin) depend on electric quantum standards, realizing the vision of James Clerk Maxwell and Max Planck of a truly universal system of units.

Both electrical quantum standards recently require cryogenic temperatures of about $T = 4.2K$ or lower to operate, but since the quantum Hall effect in addition requires application of high external magnetic field, it is practically impossible to combine both in a single system (for example a Kibble balance), given that the induced superconductivity, the phenomena behind the Josephson effect requires external magnetic field to be zero. However, in ferromagnetic topological insulators such as V (or Cr)-doped $(Bi, Sb)_2Te_3$, the recently discovered quantum anomalous Hall effect [1,2] exhibits conductance quantization without any external magnetic field, providing a realistic path for a future quantum standard where all units based on h and e can be realized in one measurement setup.

Here we present a first metrologically comprehensive measurement of the zero field conductance quantization in one of our samples patterned from MBE grown $9nm$ thick layer of V-doped $(Bi, Sb)_2Te_3$ ferromagnetic topological insulator, previously demonstrated to exhibit the quantum anomalous Hall related phenomena [3,4,5]. Excellent agreement with the von-Klitzing constant $R_k = h/e^2$ was found. For the deviation of the quantized anomalous Hall resistance from R_k, we determined a value of $0.17 \pm 0.25ppm$ [6], the smallest and most precise value reported to date. This is a step towards the realization of a practical zero-field quantum resistance standard which in combination with the Josephson effect could provide a universal quantum electrical standard in the future.

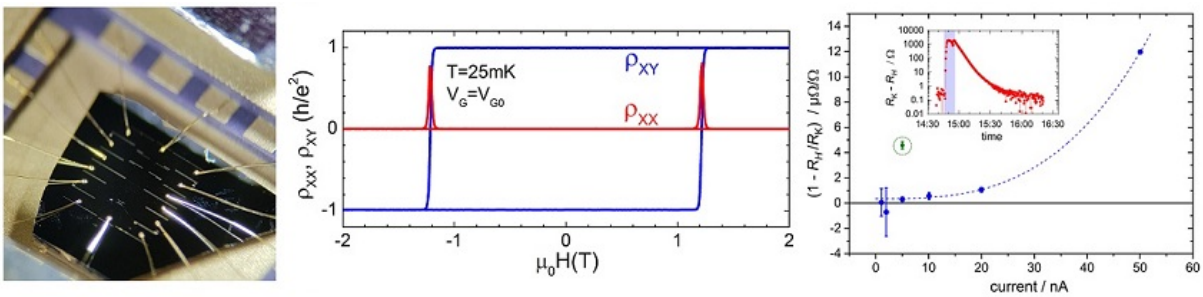

Figure 1: (left) Photo of one of the ferromagnetic topological insulator samples, glued and electrically connected to a chip carrier, (middle) external magnetic field sweep demonstrating the hysteresis loop of longitudinal resistivity (ρ_{XX}, red line) and Hall resistivity (ρ_{XY}, blue line) demonstrating the quantum anomalous Hall effect, (right) metrologically comprehensive measurement as a function of the bias current, tracing the zero-field Hall resistance value to the von-Klitzing constant $R_k = h/e^2$.

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