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Magnetic order in topological insulator thin films: transition metal vs rare earth doping

Topological insulators (TIs) are one of the most important recent discoveries in condensed matter physics. They have a gapless topological surface state which exhibits robust spin-momentum-locking protected by time-reversal symmetry (TRS). The Dirac-cone-shaped surface state can become gapped if TRS is broken, which gives rise to quantum phenomena such as the quantum anomalous Hall effect. The most common route to controlled TRS breaking in TIs is to introduce magnetic order through doping with magnetic impurities. However, the nature of the ordering in magnetically doped TIs remains poorly understood. In particular, the homogeneity and disorder has been under debate, and various types of magnetic order have been proposed to play a role [1-4].
Here we contrast the microscopic magnetic order in two magnetically doped topological insulator thin films: transition metal doped Cr:Sb2Te3 and rare earth doped Dy:Bi2Te3.

Our combined polarized neutron reflectometry, muon spin spectroscopy, x-ray magnetic circular dichroism, and x-ray resonant photoemission studies show that long range magnetic order in Cr:Sb2Te3 [5] is accompanied by significant amounts of inhomogeneity and dynamics – even in films whose magnetic volume fraction tends to 100%. In contrast, Dy:Bi2Te3 [6] does not order ferromagnetically, but instead displays similar, inhomogeneous islands of more static magnetism embedded in a paramagnetic environment [7]. These islands are highly susceptible to moderate magnetic fields. In Cr:Sb2Te3, ferromagnetic order is mediated by charge carriers [8], as shown by the presence of magnetic polarization on the anion sites. Crucially, this is absent in Dy:Bi2Te3. In both materials the presence of dopant-induced charge carriers cannot be excluded, however, in Dy:Bi2Te3 these do not appear to contribute to the magnetic order of the dopants. Most recently, we were able to combine these two materials into heterostructures leading to new physical properties as demonstrated using XMCD and polarized neutron reflectometry measurements.

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