Inducing High-Temperature Magnetic Order in Topological Insulator - Ferromagnetic Insulator Heterostructures

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Generating proximity-induced magnetism on a topological insulator (TI) surface with a ferromagnetic insulator (FMI) provides a clean approach for realizing many potential device applications exhibiting novel quantum functionality. Here we demonstrate a fundamental step towards realization of a high temperature magnetization in a TI-FMI heterostructure. We have successfully induced uniform long-range ferromagnetic order onto the surface of epitaxial Bi_2Se_3 films employing strong exchange coupling between TI and FMI. Polarized Neutron Reflectometry enables us to efficiently discriminate the magnetism at the surface of TI from the magnetization distribution in the FMI layer, as well as to probe the depth scale of the magnetism in the TI. Deeply penetrating into materials, neutrons are able to resolve simultaneously the chemical profile of structure and vectorial profile of magnetic induction with accuracy of a fraction of Oersted over a fraction of a nanometer. This unique tool provides direct evidence that Bi_2Se_3-EuS heterostructures exhibit proximity-induced interfacial magnetism in the top 2 QL (~2 nm) layer of Bi_2Se_3 that is generated by the short-range exchange interaction. The Bi_2Se_3 spin polarized surface, accompanied by magnetic order, appears in the immediate region of the interface and decays into the TI layer. This interfacial spin polarized state persists up to room temperature, above the Curie temperature of the FMI (EuS). The induced magnetism at the interface resulting from the large spin-orbit interaction and spin-momentum locking property of the TI surface is found to greatly enhance the magnetic ordering temperature. Due to the short-range nature of the ferromagnetic exchange interaction, the time-reversal symmetry is broken only near the surface of the TI, while leaving its bulk states unaffected [1]. The TI ferromagnetism is observed reproducibly in a variety of bi-layer samples with different combinations of thicknesses, providing a mechanism to control this effect. The analysis of polarized neutron off-specular scattering (OSS) that arises from lateral in-plane inhomogeneities, magnetic and non-magnetic, probes correlations of lateral inhomogeneity with a length scale of ~0.1-100μm. Grazing incidence neutron scattering (GINS) (specular reflection and OSS) establishes a direct and precise correlation between local interfacial characteristics and global physical properties and delivers the most exhaustive and detailed information on the 3-dimensional structure of thin films and hidden interfaces on enormous length scale. These findings of locally-induced ferromagnetic order on the TI surface extending over macroscopic areas without impurity doping open the door for an energy efficient topological control mechanism for future spin-based technologies.

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