Transition-Metal-Doped Topological Insulators

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Topological insulators (TIs) are a new class of materials which has attracted great attention for upcoming technological applications for spintronic devices. The electronic structure of 3D TIs consists of two distinct topologically protected states. The surface states of TIs are gapless and protected by time-reversal symmetry (TRS) which makes them immune to surface impurities and backscattering, while they have an insulating energy gap in their bulk. However, if a time-reversal perturbation is introduced the TRS can be broken and the surface states of the TIs will become insulating. One way of breaking the TRS is by doping a TI with magnetic elements. Doping the TIs with transition metals such as Mn and Cr could break the TRS and enable the opening and control of their surface band gap, hence providing a material platform for the realization of the quantum anomalous Hall effect. [1] In this work we use scanning transmission electron microscopy (STEM) and electron energy loss spectroscopy (EELS) to systematically study the structure and chemical composition of Mn and Cr doped Bi_2Te_3 and Bi_2Se_3. For this purpose we have grown two Mn-doped Bi_2Te_3 thin films with different doping percentages as well as a Cr-doped Bi_2Se_3 sample, by molecular beam epitaxy on Al_2O_3 (0001) substrates. The STEM-EELS data from the Mn-doped Bi_2Te_3 film with the lower doping percentage show that Mn atoms are uniformly present in the bulk of the Bi_2Te_3 film, with only small amounts of interfacial segregation near the substrate (Fig. 1). Furthermore, we show that Mn atoms tend to substitute for Te in the Bi_2Te_3 lattice even in the areas with high Mn concentrations. In contrast to previously reported studies where Mn concentrations up to a 15% doping level were used, this work shows that Mn doping concentrations should be limited to much lower levels in order to avoid secondary phase formation. Similarly, the Cr distribution in Cr-doped Bi_2Se_3 films shows a uniform distribution (Fig. 2), with a tendency for Cr to substitute onto Bi sites in the film's bulk. Magnetisation measurements of both Mn- and Cr-doped films have shown that the films are ferromagnetic. Our atomistic study shows that Cr doping is more desirable than Mn, hence more promising for magnetically doped TIs for future applications.

[1] A. Ghasemi, D. Kepaptsoglou, et al, APL Mater. 4 (2016) 126103

[2] A. Ghasemi, D. Kepaptsoglou, et al Sci Rep 6 (2016)26549

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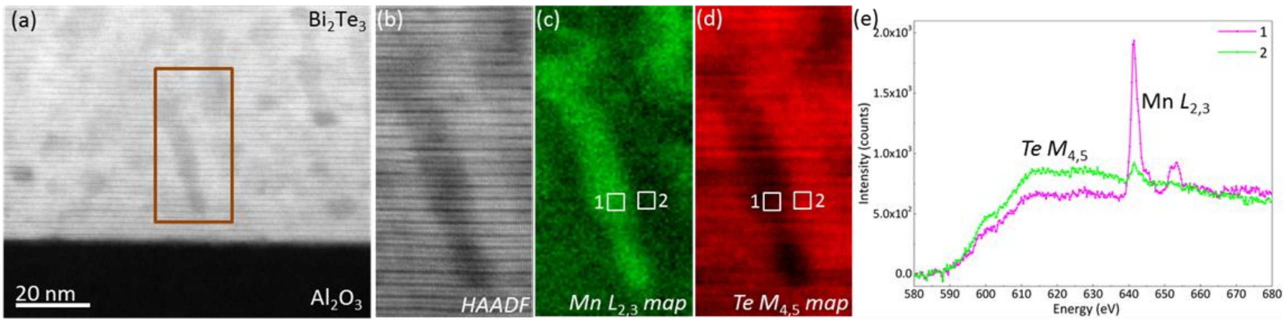

Fig.1 (a) HAADF-STEM survey image from the Bi_2Te_3. (b) HAADF-STEM from the region of in (a) acquired simultaneously with the Mn $L_{2,3}$ EELS signal (c) showing a higher concentration of Mn in the dark feature observed in the image. (d) The Te $M_{4,5}$ EELS signal shows a distribution anti-correlated to that of Mn. (e) Mn $L_{2,3}$ and Te $M_{4,5}$ edges obtained from the grain-boundary and off-boundary regions labelled as 1 and 2 in (c) and (d).

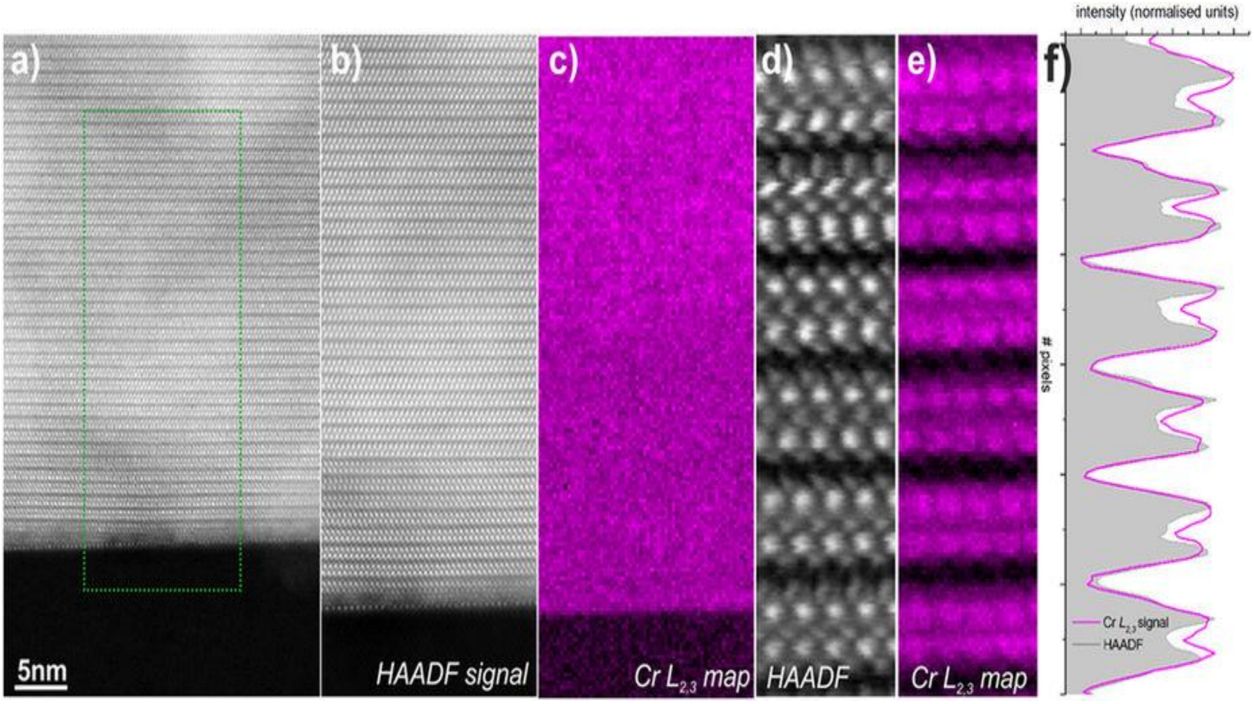

Fig. 2. (**a**) HAADF-STEM survey of Bi_2Se_3 /Al_2O_3 . (**b**) HAADF-STEM from the region of interest. Acquired simultaneously with the Cr $L_{2,3}$ EELS signal (**c**) showing uniform distribution of Cr. (**d**) Atomically resolved HAADF-STEM image from the film area recorded simultaneously with the EELS signal shown in (**e**). (**e**) Cr $L_{2,3}$ EELS showing substituting of Bi.