ESRF	**Experiment title:** Magnetic dopants and adatoms in and on Bi_2Se_3 and Bi_2Te_3 single crystals studied with XMCD	**Experiment number**: HE 3658
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Names and affiliations of applicants (* indicates experimentalists):

T. Eelbo[1](*), M. Sikora[2](*), M. Dobrzanski[2](*), A. Kozlowski[2](*), M. Wasniowska[1](*), R. Wiesendanger[1]

[1)] Institute of Applied Physics, University of Hamburg, Germany

[2)] Department of Solid State Physics & Applied Computer Science, University of Science & Technology – AGH, Krakow, Poland

Report:

The aim of the experiments was to study the electronic and magnetic properties of 3*d* transition metal impurities, e.g. Fe and Mn adatoms on topological insulators (TI) Bi_2Te_3, Bi_2Se_3, also doped with Fe and Mn. The surface of TIs reveals unique properties compared to TI bulk : although the bulk is insulating, metallic states are present on the surface. For this reason, we wanted to check whether the TI surface modifies the magnetic and electronic properties of adsorbed atoms and confirm theoretically predicted out-of-plane easy-axis for adsorbed atoms. To this end, the impurities were either adsorbed on the TI surface or diluted in the TI's bulk.

Before XMCD experiments, samples were cleaved *in-situ* in the ID08's preparation chamber at room temperature. The deposition rate of 3*d* transition metals were calibrated on a W(110) surface by means of STM. The impurities were deposited on the TIs at 10K before the XAS spectra were taken. Measurements were performed with and without magnetic fields, at angles of 0° and 70° with respect to the surface normal, while temperatures were varied between 10K and 300K.

We select in the following two sets of samples as a summary to show that we could address the points mentioned above. Firstly, we discuss Mn adatoms adsorbed on Bi_2Te_3 and compared them to diluted Mn atoms in a Bi_2Te_3 crystal.

Comparison between diluted and adsorbed Mn atoms on Bi_2Te_3:

XAS and XMCD spectra of Mn adatoms on Bi_2Te_3 in comparison with diluted Mn atoms in $Bi_{1.9}Mn_{0.1}Te_3$ are summarized in Fig. 1. We found that for single Mn adatoms deposited on Bi_2Te_3 long-range ferromagnetic order is absent. Furthermore, the magnetization curves are not saturated in a magnetic field of B = 5 T. In contrast, in case of doped Mn in $Bi_{1.9}Mn_{0.1}Te_3$ the magnetization curve can be saturated at 5T. Furthermore, our data disclose an unusual extra effect for Mn adatoms on the Bi_2Te_3 surface, i.e. the strongest magnetic response is found in the direction pointing out of the plane. The magnitude of the XMCD relative to the XAS intensity measured for B = 5 T applied out-of-plane and close to in- plane differs by more than 40%. Moreover, a closer look at the magnetic curves of doped Mn atoms in $Bi_{1.9}Mn_{0.1}Te_3$ reveals out-of-plane anisotropy for the dopants as well, in line with previous SQUID measurements [1]. The dependence of the Mn dopants' magnetization on temperature confirms the transition from a ferromagnetic to a paramagnetic phase with the Curie temperature T_C = 15 K (see Fig.1c). Further data analysis is needed to extrapolate quantitatively spin and angular moments of the Mn atoms in these different samples.

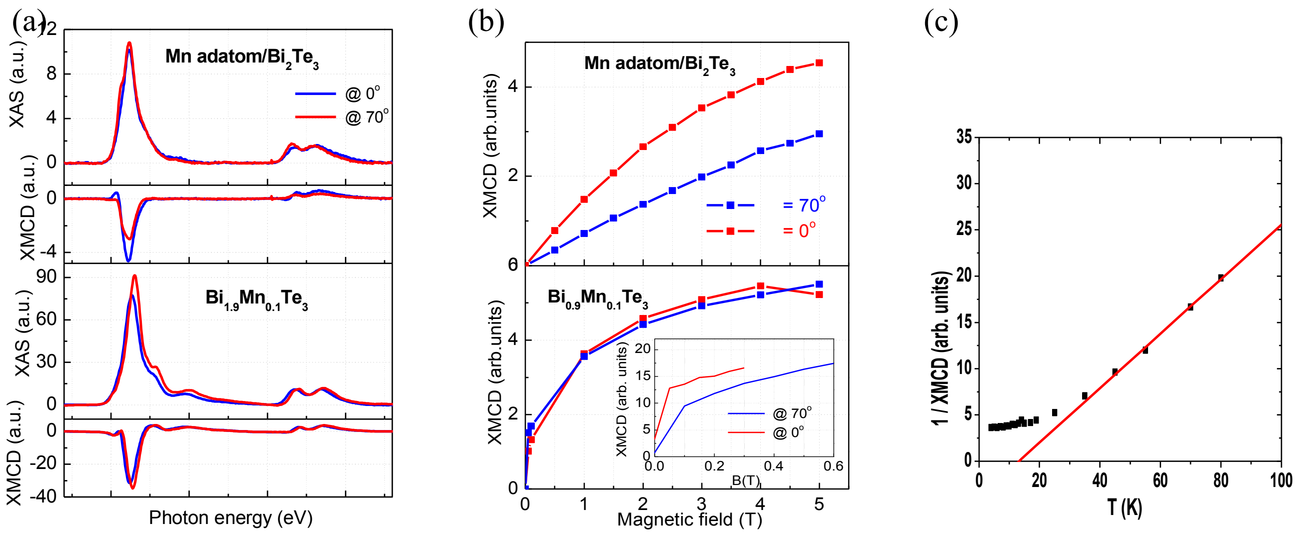

Fig. 1(a) XAS and XMCD spectra taken for 0.01 monolayer equivalent (MLE) Mn/Bi_2Te_3 and $Bi_{1.9}Mn_{0.1}Te_3$ at T = 10 K and μ_0H = 5 T with right and left circularly polarized light. After background subtraction the spectra were normalized with respect to the incident beam intensity and the pre-edge intensity at the L_3 edge. (b) Magnetization curves of the Mn atoms for normal and grazing incident angle. The data points represent the Mn XMCD intensity taken at theL_3-edge. (c) The inverse XMCD signal as a function of the temperature revealing the Curie temperature for $Bi_{1.9}Mn_{0.1}Te_3$.

Fe adatoms adsorbed on Bi_2Se_3:

The electronic and magnetic properties of Fe adatoms were investigated as a function of the magnetic field up to 5T as well. The measurements were performed for three different coverages, i.e. 1%, 8% and 25% of a ML that allows us to monitor how the magnetic properties of adatoms change upon the cluster density. Figure 2b and c display Fe impurities' $L_{2,3}$-edges of the XAS and XMCD spectra taken for the lowest and highest coverage of Fe deposited on Bi_2Se_3. For all coverages, we found the easy-axis in the plane. Moreover, by increasing the coverage a gradual increase of the ratio between the orbital and spin moment is observed, see Fig.2a. The phenomenon is yet not fully understood and a more detailed analysis is under progress.

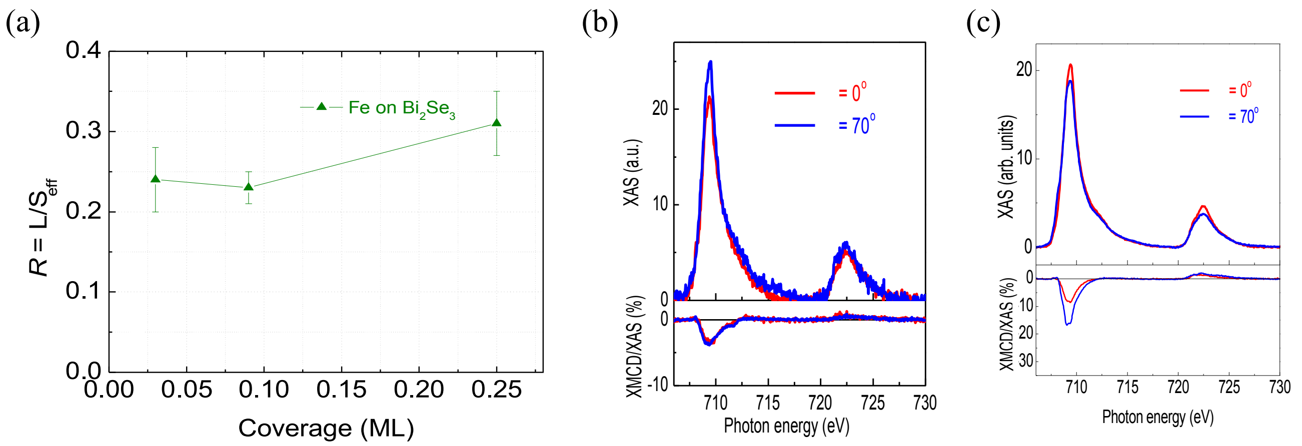

Fig. 2. (a) Experimental ratios of orbital to spin moments estimated from XMCD spectra acquired at B = 5T depending on the coverage for Fe deposited on Bi_2Se_3. (b) and (c) present circularly polarized X-ray absorption spectra of Fe adatoms on Bi_2Se_3 for two different coverages and orientations. The XMCD signal is shown for each orientation. The background was subtracted for all XAS spectra.

[1] Y. Hor *et al*,. *Phys. Rev. B*. **81**, 195203 (2009)