ESRF	**Experiment title:** Probing the Mn incorporation, polarization and magnetism to evidence magneto-electric coupling in multiferroic $Ge_{1-x}Mn_xTe$	**Experiment number**: HC-2970
Beamline: ID 12	**Date of experiment**: from: 12.07.2017 to: 18.07.2017	**Date of report**: 04.09.2017
Shifts: 18	**Local contact(s)**: A. Rogalev	*Received at ESRF:*

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Report:

The aim of the proposal was to study the structural, electric and magnetic properties of Mn in $Ge_{1-x}Mn_xTe$ by XANES, x-ray linear dichroism (XLD) and x-ray magnetic circular dichroism (XMCD) in external electric and magnetic fields in the concomitant ferromagnetic (FM) and ferroelectric (FE) phases to evidence magneto-electric coupling in this multiferroic material. For that a concentration series from 15% to 40% Mn was initially studied at the Mn (Fig. 1) and Ge (Fig. 2) K-edges using XLD at room temperature. At both edges a finite but small XLD evidences slight structural distortions. At the Ge K-edge a change of the local symmetry around 30% Mn is visible (Fig. 2, top) which is consistent with a change in the crystallographic structure known from X-ray diffraction studies; however, no influence of an applied voltage is found (bottom).

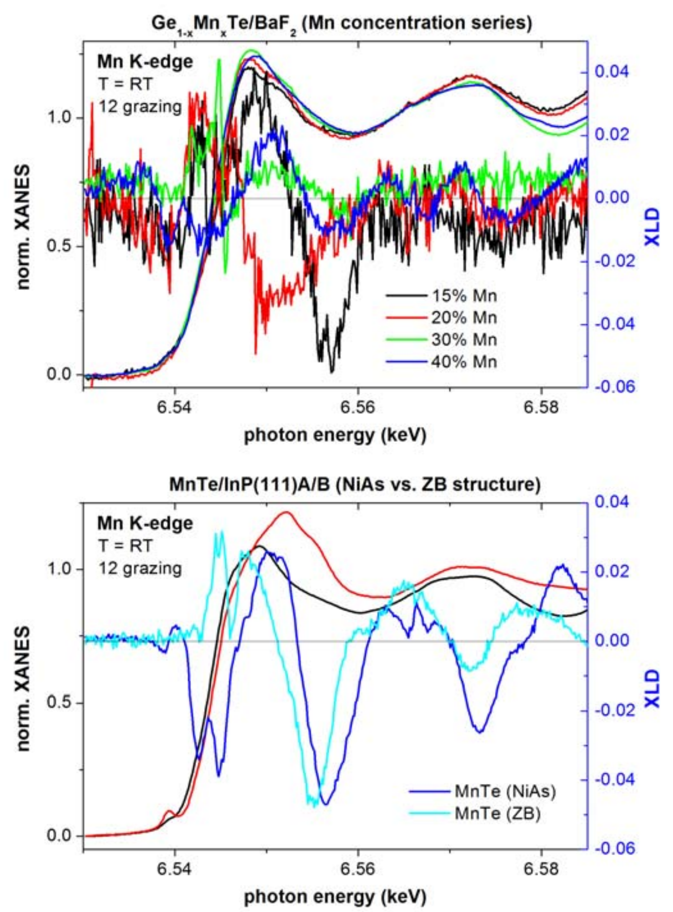

Figure 1: XANES/ XLD at the Mn K-edge for GeMnTe (top) and MnTe reference samples (bottom).

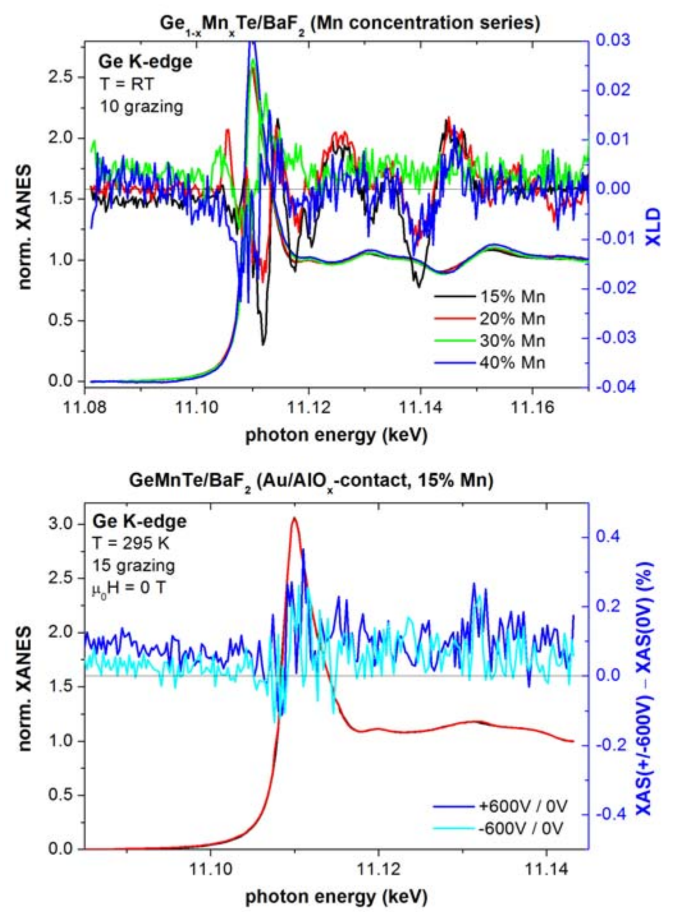

Figure 2: XANES/XLD at the Ge K-edge for the Mn concentration series (top) and E-field effect for 15% at RT (bottom)

In contrast, at the Mn K-edge the small XLD is different for each studied Mn concentration (Fig. 1, top). Comparing both XANES and XLD with two reference samples of MnTe grown in the NiAs and zincblende (ZB) structure (Fig. 1, bottom) demonstrate that in none of the GeMnTe films MnTe is present as secondary phase. Unfortunately, the noise at the Mn K-edge XANES which stems from the strong luminescence from the BaF_2 substrate made a reliable measurements of any E-field effect impossible (not shown). It was also not possible to measure any significant Mn K-edge XMCD although it was tried both at 20% and 40% Mn including XCMCD(H) curves up to 17 T (not shown).

Therefore, in the following only the Ge K-edge could be measured in greater detail. Figure 3 shows that for the 40% Mn sample measured at 2 K and zero magnetic field no influence of the voltage was present. Especially the dependence on the applied voltage (Fig. 3, bottom) underlines that up to the maximum voltage of 600 V no significant effect is observable. It should be noted that for both samples 15% and 40% Mn the experiments were done at 295K and 2K so that for the entire Mn concentration and temperature range the expected E-field effect could not be observed. The reason for this is so far unclear.

However, recording the XMCD at the Ge K-edge for the 40% sample at 2 K and 10 T demonstrates that a finite magnetic polarization of the Ge sublattice exists (Fig. 4, top). Recording the full XMCD (switch of circular polarization and magnetic field) with and without E-field indicates that the magnetic polarization seems to be influenced by the applied voltage. However, a close inspection of the individual raw XMCD scans (Fig. 4, bottom) reveals that for a fixed external voltage and magnetic field direction the individual XMCD scan derived from only the switch of circular polarization seems to switch direction with time. This is more pronounced for the positive magnetic field direction and it is also not observed if no voltage is applied. The reason for this behavior is so far unknown but other experiments at the Mn L-edges have also reveals an XMCD signal with appeared to reverse with time. This behavior will deserve further systematic investigations, e.g. with respect to light- or photo carrier-induced effects.

In summary, we were able to record a range of XANES, XLD and XMCD spectra for a Mn concentration series of $Ge_{1-x}Mn_xTe$ films. While the fluorescence of the substrate hindered a detailed study at the Mn K-edge, the expected E-field effect at eh Ge K-edge is absent which implies that the material is not polar, e.g. because of ferroelectric domain formation. A finite magnetic polarization of the Ge has been found as well as an unexpected spontaneous switching of the polarization which deserves further investigation.

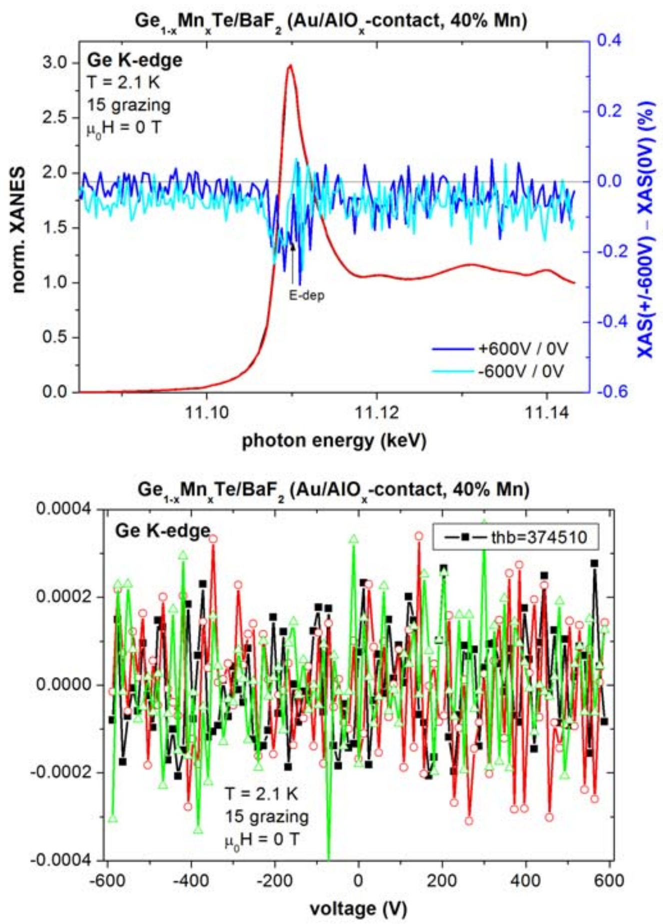

Figure 3: E field effect at the Ge K-edge at 2K (top) and the field-dependence (bottom) both without magnetic field.

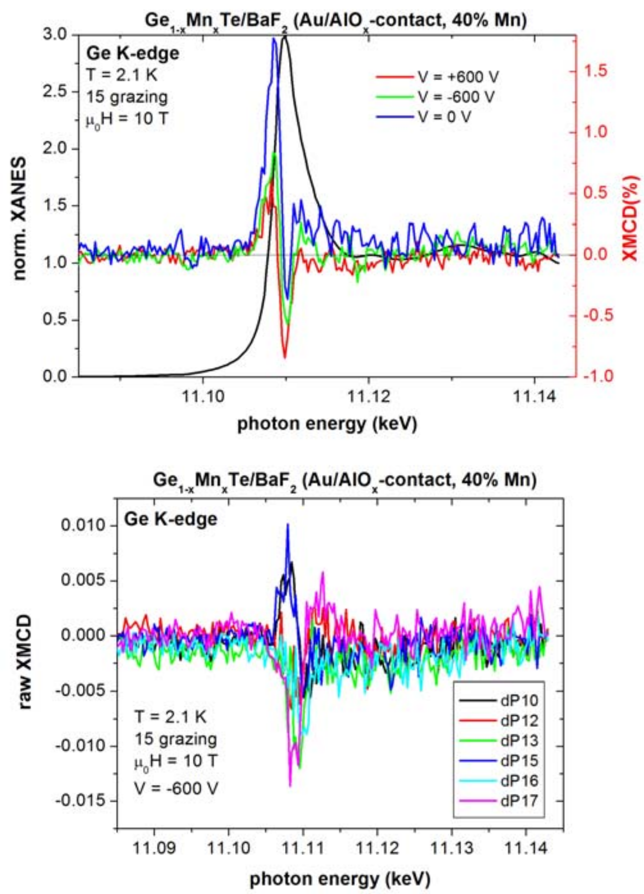

Figure 4: XANES, XMCD at 2K and 10T with and without E-field at the Ge K-edge (top) and individual XMCD for fixed B- and E-field (bottom).