Resonant photoemission study of Mn/GeEuTe

M.A. Pietrzyk¹, B.J. Kowalski¹, W.Knoff¹, T. Story¹, B. Taliashvili¹, R.L. Johnson²

¹Institute of Physics, PAS, Al. Lotników 32/46, 02-668 Warsaw, Poland
²Institute of Experimental Physics, University of Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany

GeEuTe belongs to IV-VI-based diluted magnetic semiconductors in which the presence of magnetic ions and their exchange interaction with carriers in the conduction and valence bands result in unusually strong magneto-transport and magneto-optic phenomena. IV-VI crystals form diluted magnetic semiconductors (DMS) not only with transition metal ions (like Mn), but also with the rare earth elements (Eu, Gd, Ce, Yb) [1]. These elements are characterized by the partially filled 4f (RE) or 3d shells (TM). In Eu-doped IV-VI crystals, Eu ions interact ferromagnetically via the RKKY mechanism. The substitutional europium ions occur as Eu²⁺, however, sometimes Eu³⁺ can also be detected, especially at disordered surfaces. Presence of Eu³⁺ related spectra features indicates a deviation from stochiometry.

The Ge₀.₉₈Eu₀.₀₂Te layers were grown on BaF₂ (111) substrates by an MBE method with use of effusion cells as GeTe, Te₂ and Eu sources. The substrate temperature was 400-450 °C. The contents of Eu in the layer was checked by energy dispersive X-ray fluorescence analysis. The photoemission experiment was performed at the FLIPPER II beamline (E1) in HASYLAB.

![Image](https://via.placeholder.com/150)

Fig. 1. The valence band spectra of Ge₀.₉₈Eu₀.₀₂Te measured after deposition of 2 ML Mn, for photon energies near the Mn 3p-3d excitation threshold.

![Image](https://via.placeholder.com/150)

Fig. 2. Set of photoemission spectra of Ge₀.₉₈Eu₀.₀₂Te, after deposition of 2 ML Mn, taken for the photon energies close to the Eu 4d→4f resonance.
For photoemission measurements, the clean crystal surface was prepared *in situ* by sputtering with Ar\(^+\) ions and annealing under UHV condition. The Mn overlayers were deposited *in situ* on the substrate kept at room temperature. The amount of deposited manganese was measured using a quartz microbalance. After each stage of the sample treatment (deposition or annealing) the sample was transferred (under UHV conditions) to the analysis chamber and the photoemission experiments were carried out. The spectra were normalized to the photon flux and the secondary electron background has been subtracted by means of the Shirley method. The overall energy resolution was kept at 250 meV. The origin of the energy axis was set at the Fermi energy as measured for a reference metallic sample.

The goal of this work was determination of the electronic structure of Ge\(_{0.98}\)Eu\(_{0.02}\)Te - clean and doped, in the subsurface layer, with manganese. It was previously shown for Mn/GeMnTe system that deposition of monolayer amount of Mn and annealing the sample under UHV conditions at 200\(^\circ\)C led to efficient Mn doping of the subsurface layer of the crystal [2]. The same method was applied in this study.

In order to reveal a contribution of Mn 3d states to the valence band of the Mn/Ge\(_{0.98}\)Eu\(_{0.02}\)Te system we applied resonant photoemission spectroscopy for photon energies in the range 45-60 eV (corresponding to Mn 3p\(\rightarrow\)3d transition). The spectra (photoelectron energy distribution curves) covered the range of electron binding energy from the valence band edge to 15 eV. Fig. 1 shows a typical set of energy distribution curves taken at several photon energies near to the Mn 3p-3d resonance after deposition of 2 ML Mn. A strong resonant enhancement of the emission from the valence band and appearance of a maximum at 4.6 eV below the Fermi energy was observed at the photon energy of 51 eV. The antiresonance behaviour (suppression of the Mn 3d-related emission) was observed at h\(\nu\)=47 eV. The contribution of Mn 3d states to the valence band structure has been derived by subtraction of the anti-resonance spectrum from the resonance one.

Fig. 2 shows the photoelectron energy distribution curves in the photon energy range corresponding to the Eu 4d\(\rightarrow\)4f absorption edge, the valence band as well as the Ge 3d (at 30.5 eV) and Te 4d (at about 41 eV) core level peaks can be discerned. The Eu\(^{2+}\) feature occurs just below the valence band edge. The analysis of Mn 3d and Eu 4f contributions to the electronic structure of Mn/Ge\(_{0.98}\)Eu\(_{0.02}\)Te during its *in situ* formation enables us to reveal interactions between them in GeTe co-doped with both elements.

**Acknowledgements**

The authors acknowledge support by MSHE (Poland) grants: DESY/68/2007, N202 101 31/0749, 0992/T02/2007/32 as well as by the European Community under Contract RII3-CT-2004-506008 (IA-SFS) (via DESY/HASYLAB).

**References**
