Magnetic circular dichroism in photoelectron emission from partially compensated ferrimagnetic \( \text{Mn}_{3-x}\text{Ga} \) thin films

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The interaction of polarized light with magnetic matter shows a rather pronounced dependence of resulted effect on the orientation of polarization or the helicity vector of electromagnetic wave relative to the direction of sample magnetization. The features of magnetic dichroism phenomena are revealed in particular for the processes of x-ray absorption [1, 2] and in the photoelectron emission [3, 4]. The cross section of x-ray absorption involving core level electrons shows the dependence on core electron spin and relative orientation of photon polarization (helicity) to the sample magnetization. Present studies are devoted to the magnetic circular dichroism in photoelectron emission, where the dichroism effect is revealed due to i) a preferential interaction of circularly polarized x-ray quanta with the electrons of particular spin defined by helicity vector orientation and ii) splitting of excited state level upon exchange interaction of the core hole with the valence electrons.

The experiment was performed using the facility of a HArbd X-ray Photoelectron Emission Spectroscopy (HAXPES) endstation at Beamline P09 (PETRA III, DESY Hamburg). The distribution of photoelectrons according to their kinetic energy was analyzed with a “Phoibos 225 HV” hemispherical electron analyzer from SPECS GmbH (Berlin). The energy of excitation x-ray quanta was fixed at 6 keV. With 50 eV pass energy and 3x30 mm accepting slit of the electron analyzer, the total resolution of 350 meV was estimated from the profile of the Au Fermi edge. Beamline P09 is equipped with a phase retarder, which provides a possibility to change the polarization of x-ray quanta within a broad (3-8 keV) energy range. To vary the polarization of synchrotron radiation at 6 keV, one diamond [111] crystal of the phase retarder was employed. The studies were performed on a series of off-plane magnetized \( \text{Mn}_{3-x}\text{Ga} \) thin films grown using the dual magnetron co-sputtering technique to adjust the Mn/Ga ratio of the film composition. The experiment geometry with 45 deg. between the x-ray beam and the analyzer axis provided a 45 deg. angle of x-ray incidence at the sample surface with 90×7 deg. take-off angle (TOA) for the analyzed photoelectrons. In this way, the angle of 45 deg. was provided between the sample magnetization and the x-ray helicity vectors.

The \( \text{Mn}_{3-x}\text{Ga} \) alloys were reported to exhibit the tetragonal structure of \( I4/mmm \) symmetry (space group 139) for \( x \) varying from 0 to 1 [5]. The structure of this type provides a ferrimagnetic order in \( \text{Mn}_{3-x}\text{Ga} \) caused by two different sites for Mn atoms (Mn I and Mn II, see Figure 1). The electronic structure calculation for \( \text{Mn}_{3}\text{Ga} \) gives the magnetic moments of \(-2.896 \mu_B\) (Mn I) and \(2.355 \mu_B\) (Mn II) resulting in a total magnetic moment of \(1.77 \mu_B\) per unit cell due to the partial compensation of magnetic moments from Mn atoms of different sites [6]. The experimental results show the total magnetic moment of tetragonal \( \text{Mn}_{3-x}\text{Ga} \) to be tunable by varying \( x \) [6]. The tunable magnetic moment, high (up to 88%) a spin polarization at the Fermi energy and the high Curie temperature (about 760 K) revealed for \( \text{Mn}_{3}\text{Ga} \) make this material a promising candidate for spin torque transfer applications, where the density of switching current has to be reduced significantly.

![Figure 1: Crystal structure of \( \text{Mn}_{3}\text{Ga} \) in tetragonal phase of \( I4/mmm \) symmetry.](image-url)
Figure 2 presents a photoelectron emission peak reproducing the Mn 2p₃/₂ core states for the MnₓGa sample. Besides the main maximum at a kinetic energy of 5363.4 eV, the Mn 2p₃/₂ core shows a well pronounced satellite maximum around 5362.6 eV. The profile of the Mn 2p₃/₂ core peak was measured upon the excitation of the MnₓGa sample with circularly polarized x-ray quanta of opposite helicity. The asymmetry of about 2.5% is revealed due to the effect of magnetic circular dichroism (MCD) at the rise-up stage of the main Mn 2p₃/₂ photoelectron emission peak (5363.5-5364.2 eV) where the electron state with a well defined spin provides a major contribution. The asymmetry signal is not well pronounced in the range where the main maximum overlaps with the satellite. Thus, the satellite origin may not be attributed to the exchange splitting of Mn 2p₃/₂ core only but should also be considered taking into account a symmetry modification for Mn 2p orbitals of Mn atoms at different sites. 

The chemical shift of up to 0.1 eV was revealed in the Mn 2p core peak upon decrease of the Mn content in studied MnₓGa samples. The contributions and positions were estimated for main and satellite Mn 2p₃/₂ peaks after spectrum decomposition and background subtraction using the UniFit software. Besides the chemical shift, changes in the relative intensity were observed for the main and satellite Mn 2p₃/₂ peaks. The decrease of relative intensity in the main Mn 2p₃/₂ peak (as compared to the satellite peak) was observed upon reduction of the Mn content. Such behavior of the relative intensities is caused by a preferential Mn II site for Mn atom occupation in MnₓGa upon a reduction of the Mn content. The symmetry of Mn 2p orbitals may deviate between the Mn atoms occupying different crystallographic sites. The contribution of photoelectrons from the 2p₃/₂ core of the Mn atoms at different sites results in a smearing of the asymmetry signal and a reduction of the magnetic dichroism effect in the satellite Mn 2p₃/₂ peak. Thus, the MCD in photoelectron emission is an element specific technique and probes the local magnetic properties on an atomic scale showing the local symmetry and hybridization to influence the multiplet splitting and satellite structure in core level peaks.

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References