Electric field-induced changes in the magnetic properties in doped semiconductors with lack of inversion symmetry

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Absorption spectroscopy under an applied electric field has a longstanding history. Classical examples are the quadratic and the linear Stark effect. More recently the x-ray variant of the linear Stark effect has been reported in polar materials where the entire x-ray absorption near edge spectrum (XANES) was found to shift in energy in the presence of an electric field to polar materials [1]. Applying an electrical field to magnetically doped wide-band-gap semiconductors with lack of inversion symmetry bares the potential to directly study magneto-electric coupling effects. For example, based on integral magnetometry an electrical field induced magnetization has been reported in Mn-doped GaN [2].

Recording x-ray magnetic circular dichroism (XMCD) with and without electric field at the Co and Mn K-edges of Co-doped ZnO and Mn-doped GaN, respectively, offers a direct and element selective spectroscopic probe of electric field induced changes of the magnetic properties. The experimental findings can be compared with *ab initio* simulations of the respective XANES and XMCD spectra with and without an applied electric field.

In this study XANES and XMCD spectra as well as XMCD(H) curves are recorded in applied electric field at low temperatures of 2 K where Mn-doped GaN is still paramagnetic while the uncompensated antiferromagnet Co-doped ZnO is already magnetically ordered. In agreement with the theoretical calculations, the XMCD at the pre-edge feature of the Mn K-edge can be increased or decreased depending on the polarity of the electric field pointing at electrical manipulation of the magnetic moment. In contrast, at the Co K-edge only slight changes of the XMCD at the main absorption are observed while the pre-edge feature remains unaffected [3]. The difference in the response of magnetically doped GaN and ZnO can be explained by the energetic position of the impurity level of the magnetic dopant. Specifically, Mn introduces states close to the Fermi level, which can be shifted by the electric field thus altering the magnetic moment. In contrast, no Co states are found close to the Fermi level so that the influence of the electric field on the magnetic properties of the system is less pronounced.

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[1] V. Ney *et al.*, Phys. Rev. B **93**, 035136 (2016).

[2] D. Sztenkiel et al. Nat. Comm. **7**, 13232 (2016).

[3] V. Ney *et al.*, in preparation (2018).