Angle-dependent XMCD as a Probe of Anisotropic Spin-density Distribution

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Magnetic thin films often exhibit magnetic anisotropy due to epitaxial strain, surface and interfacial effects, lowered dimensionality, and so on. In general, magnetic anisotropy arises from the combined effects of anisotropic electronic structure and spin-orbit interaction (SOI). Understanding the detailed mechanism of the magnetic anisotropy in ferromagnetic thin films and controlling it have been one of the major research issues both from scientific and technological points of view. Since the electronic structure of magnetic thin films can be highly anisotropic, soft x-ray spectroscopy, including, x-ray absorption spectroscopy (XAS) and x-ray magnetic circular/linear dichroism (XMCD/XMLD), with varying incident angles and magnetic-field angles will give new insights into the magnetic anisotropy of thin films.

We have developed the 'vector-magnet' apparatus for XMCD and XMLD measurements, in which the direction of the magnetic field can be varied two-dimensionally [1]. It has been theoretically predicted that the "magnetic dipole moment" M_{T} or "electric quadrupole moment" Q_{zz}, which represent the anisotropy of spin/charge density distribution (i.e. elongation or shrinkage of electron orbitals of magnetic ions), can be deduced through such angle-dependent XMCD and XMCD measurements [2,3]. In this talk, I will introduce our recent studies on the magnetic anisotropy of $La_{1-x}Sr_xMnO_3$ (LSMO) thin films via the angle-dependent XMCD and XMLD measurements [4,5]. LSMO is a material which shows ferromagnetic metallicity in the widest ranges of hole concentration x and has highest Curie temperature above the room temperature among colossal-magnetoresistive perovskite manganites. From the angle-dependent XMCD experiments [4], it has been demonstrated that the anisotropy of the spin-density distribution of Mn 3*d* electrons changes depending on the epitaxial strain and that it is correlated with the change of strain-induced magnetic anisotropy [6]. From the XMLD experiments [5], changes in the charge-density anisotropy of Mn 3*d* electrons induced by the spin polarization has been observed, which can be understood as the inverse process of the strain-induced magnetic anisotropy. These angle-dependent XMCD and XMLD measurements will pave a new way for elucidating the origin of magnetic anisotropy in various transition-metal thin films by directly probing the anisotropic electronic structure.

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