Search for room-temperature multiferroics: Ferroelectric-ferromagnet interfaces

Interface-induced room-temperature multiferroicity in $BaTiO_3$, S. Valencia, A. Crassous, L. Bocher, V. Garcia, X. Moya, R. O. Cherifi, C. Deranlot, K. Bouzehouane, S. Fusil, A. Zobelli, A. Gloter, N. D. Mathur, A. Gaupp, R. Abrudan, F. Radu, A. Barthélémy, and M. Bibes, Nature Materials **10**, 753-758 (2011).

Recommended with a Commentary by Atsushi Fujimori, University of Tokyo

Multiferroic materials, in which two ferroic order parameters coexist, have attracted increased attention because of their possible applications to novel multifunctional devices and interesting physics behind them. If the coupling between the order parameters (in the present case of ferromagnetism and ferroelectricity, magnetoelectric coupling) is strong, one can control ferromagnetism by electric field, or control ferroelectricity by magnetic field. If the coupling is weak, they can be used as multiple-state memory elements. However, there are few multiferroics which are both ferromagnetic and ferroelectric at room temperature, and practical applications of multiferroics have been hampered. The distorted perovskite-type $BiFeO_3$ (BFO) is one of such few examples of room-temperature multiferroics and has been extensively studied, particularly in thin film forms [1]. However, bulk BFO is a canted antiferromagnet and to enhance its uniform magnetization has not been easy. Another approach is to search for a new class of materials. Recently, hexaferrites (such as $Sr_3Co_2Fe_{24}O_{41}$) were discovered to exhibit both ferrimagnetic and ferroelectric orderings and also magnetoelectric coupling at room temperature [2]. The third approach is to combine a ferroelectric (typically BTO) with a ferromagnetic (typically spinel-type oxides) material in composite forms such as embedded nano-pillars [3], nano-particles, and multilayers [4].

As for the third approach, several years ago, a first-principles calculation on an Fe/BTO/Fe magnetic tunnel junction (MTJ) by Duan *et al.* [5] predicted that the spin polarization at the Fermi level can be controlled by the electric polarization of the BTO tunnel barrier. This effect was experimentally confirmed by the observation of electric polarization dependent tunnel magneto-resistance (TMR) of an Fe/BTO/LSMO MTJ, where LSMO stands for the ferromagnetic metal $La_{1-x}Sr_xMnO_3$ [6]. In the title paper "Interface-induced room-temperature multiferroicity in BTO" by Valencia *et al.*, microscopic information at the Fe/BTO and Co/BTO interfaces of the Fe/BTO/LSMO and Co/BTO/LSMO MTJ's have been studied by the element-specific magnetic probes of x-ray magnetic circular dichroism (XMCD) and x-ray resonant magnetic scattering (XRMS) experiments combined with first-principles calculations. They have found that a sizeable amount of spin polarization is induced on the Ti and O atoms at the Fe(Co)/BTO interfaces; Most remarkably, Ti has a spin magnetic moment as large as $\sim 0.1\mu_B$/Ti atom antiparallel to that of Fe (Co). This spin moment results from not only charge transfer, i.e., the formation of Ti^{3+} (d^1) components, but also covalency between atomic orbitals without net charge transfer. Since the ferromagnetic Fe (Co) thus induces spin polarization in the ferroelectric BTO, the ferroelectric polarization of BTO conversely affects the spin polarization of Fe (Co) at E_F and hence TMR.

The room-temperature magnetoelectric coupling realized at the Fe(Co)/BTO interfaces is remarkable not only for making the electrical control of magneto-transport realistic, but also for opening up the possibility to fabricate practical devices utilizing the toroidal order at the interfaces. If the toroidal moment defined by $\vec{T} = \vec{P} \times \vec{M}$, where $\vec{P}$ is the ferroelectric polarization and $\vec{M}$ is the ferromagnetic moment, is finite at the interface, which is the case if the electric and magnetic polarizations of different directions coexist on a microscopic scale as in the present case, optical spectra will show non-reciprocal directional dichorism (NDD) [7]. That is, the spectra depend on the propagation direction of light either parallel or antiparallel to $\vec{T}$, and therefore depend on both the electric and magnetic polarization directions. In order to predict more precise behaviors of magnetoelectric coupling and magneto-optical properties, spin-orbit coupling at the Ti and Fe (Co) sites will have to be taken into account in theoretical studies.

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