Magnetoelectric couplings in heterostructures

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Prof. Xu's group meeting

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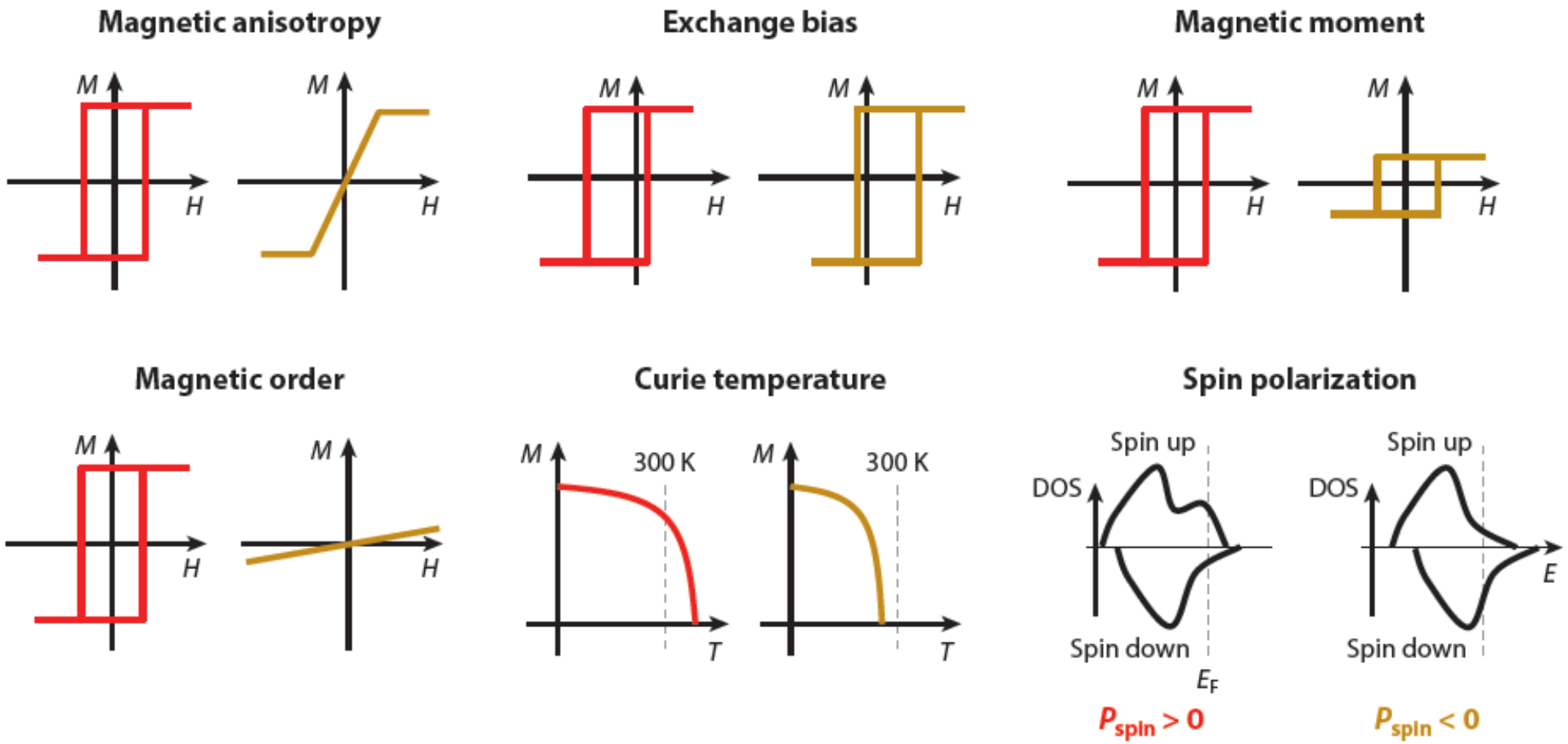
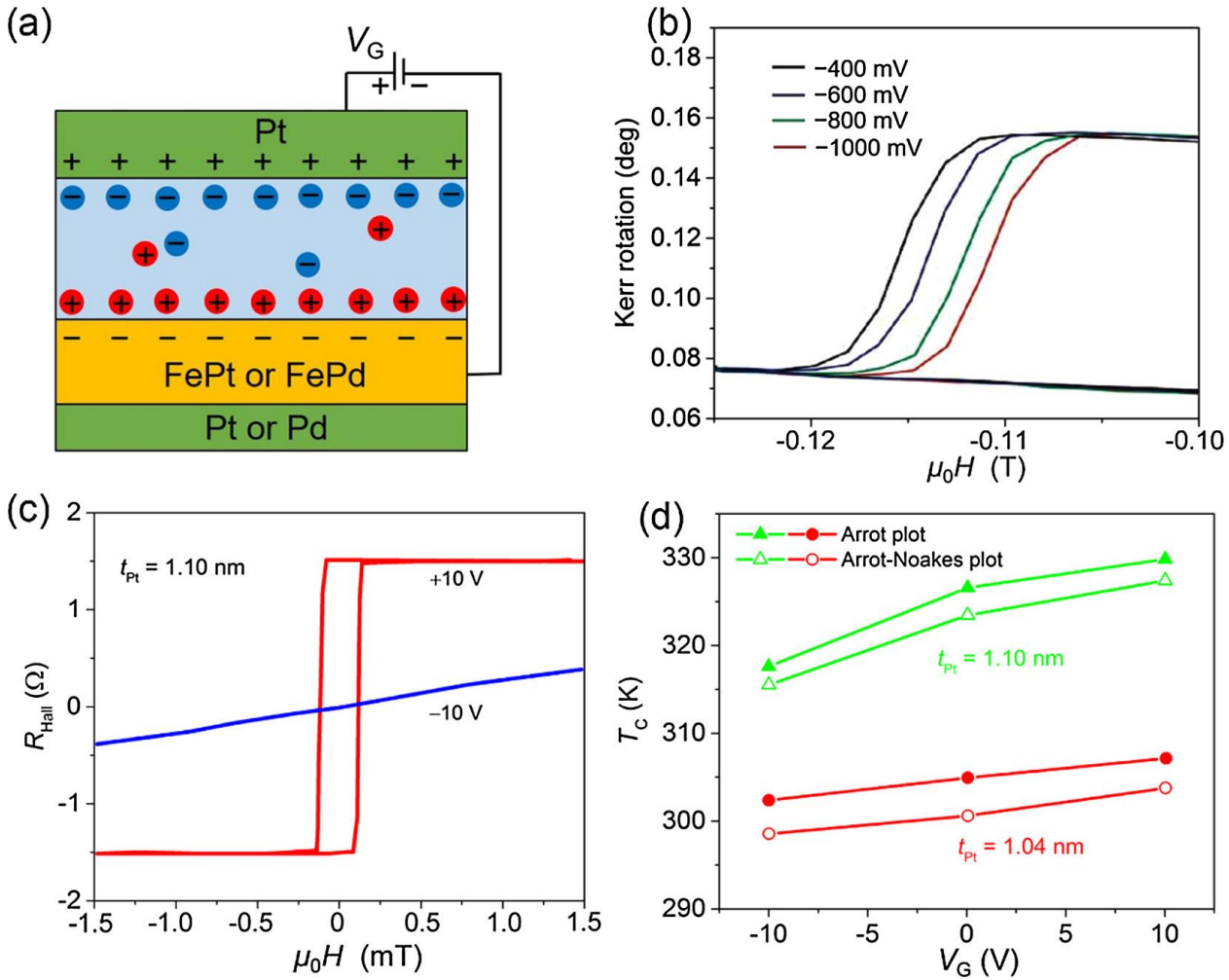
Magnetic properties to be changed



Different mechanisms

- 1. Charge – field effect;
- 2. Lattice – strain effect;
- 3. Spin – exchange coupling
- 4. Orbit –ionic displacement
- 5. Structure/composition – electrochemical reaction

Charge modulation in ferromagnetic metals



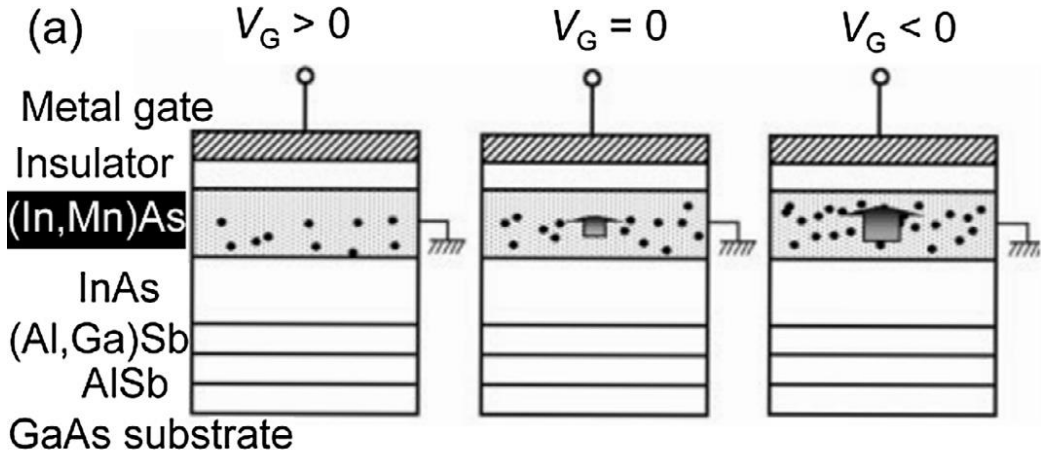
A large electric field can be used to modulate the carrier density and electron occupancy in ultrathin metal systems, which have a high surface-to-volume ratio. The application of voltage could affect the energy of the 3z2–r2 orbital and the corresponding electron occupancy in 3z2–r2, xy, and x2–y2 orbitals. Then the magnetic anisotropy is tuned owing to the spin–orbit coupling.

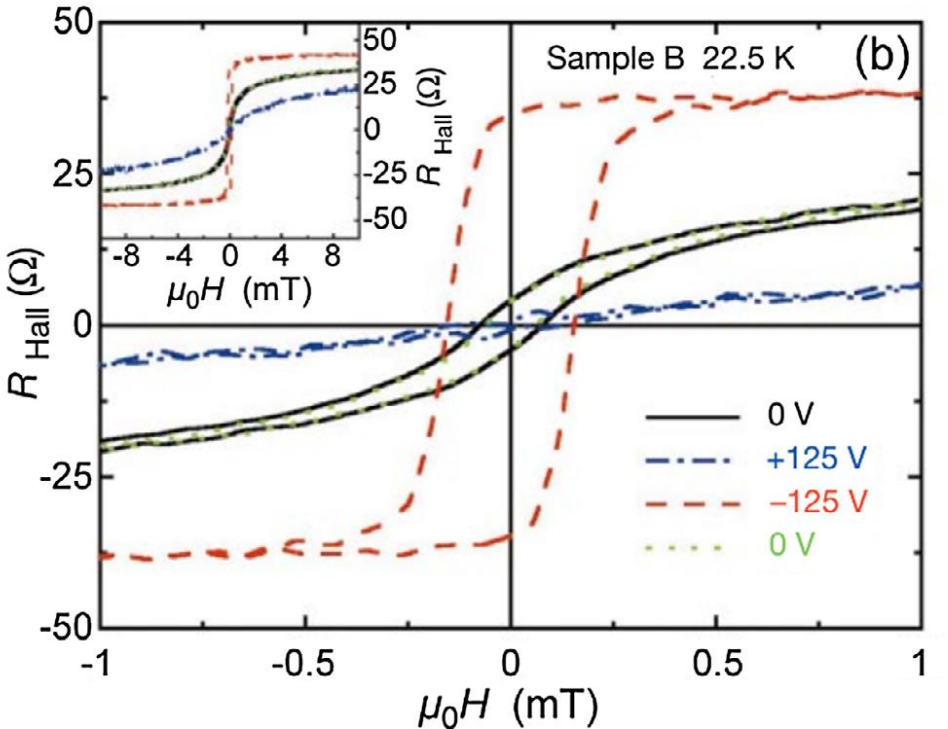
Science 2007;315:349–51

Nat Mater 2011;10:853–6

Charge modulation in diluted magnetic semiconductors

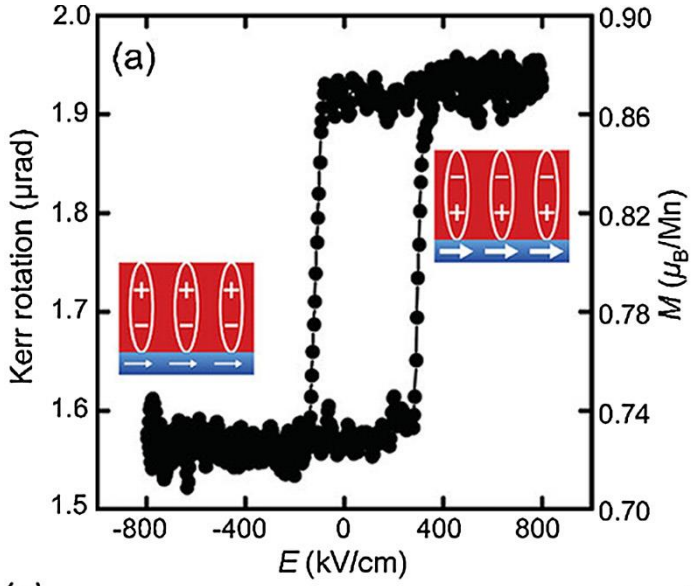
The most prominent feature for a diluted ferromagnetic semiconductor is that its ferromagnetism is correlated to carrier mediated magnetic interaction, as described by the p–d Zener model. This intrinsic feature makes it possible for the DMS to be used as an outstanding model for VCM, based on the FET configuration. Consequently, the pioneering work on the observation of VCM is realized in (In,Mn)As. A negative gate voltage enhances the hole density and leads to an increase in the FM interaction among Mn ions, accompanied by enhanced magnetic moments and Curie temperature, whereas a positive counterpart does the opposite.

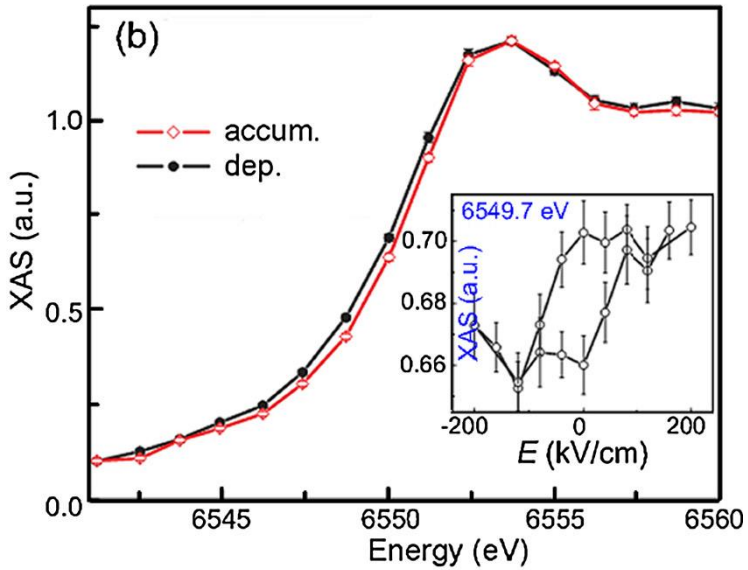


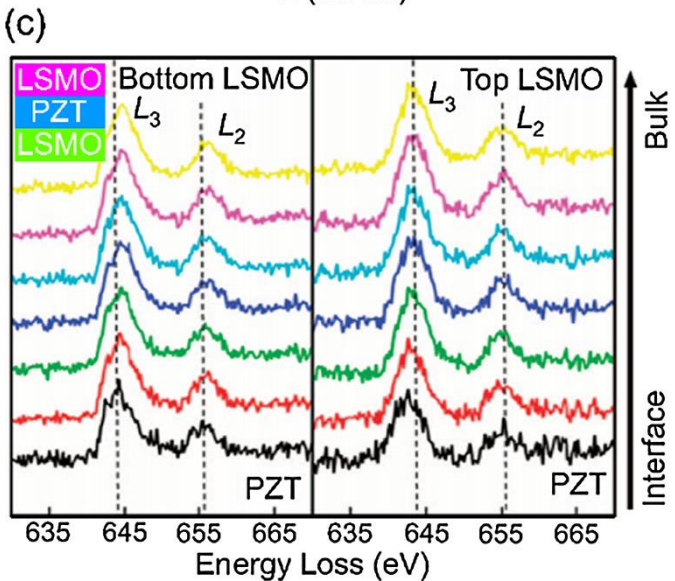


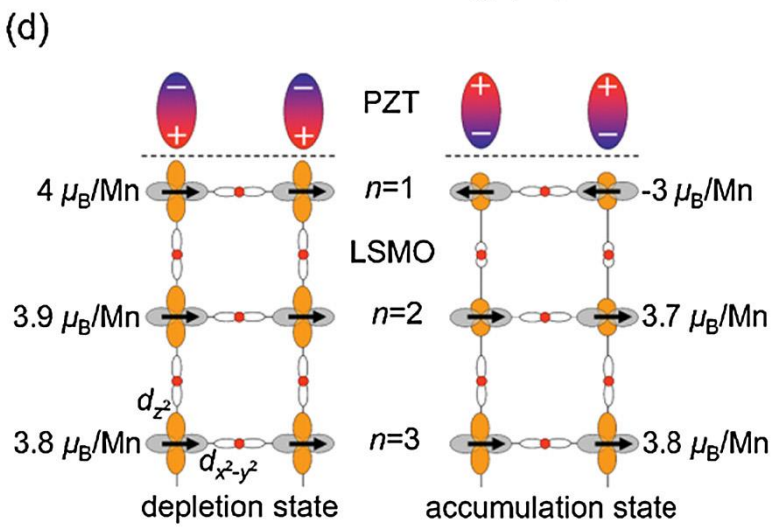
Nature 2000; 408:944–6

Charge modulation in ferromagnetic oxides









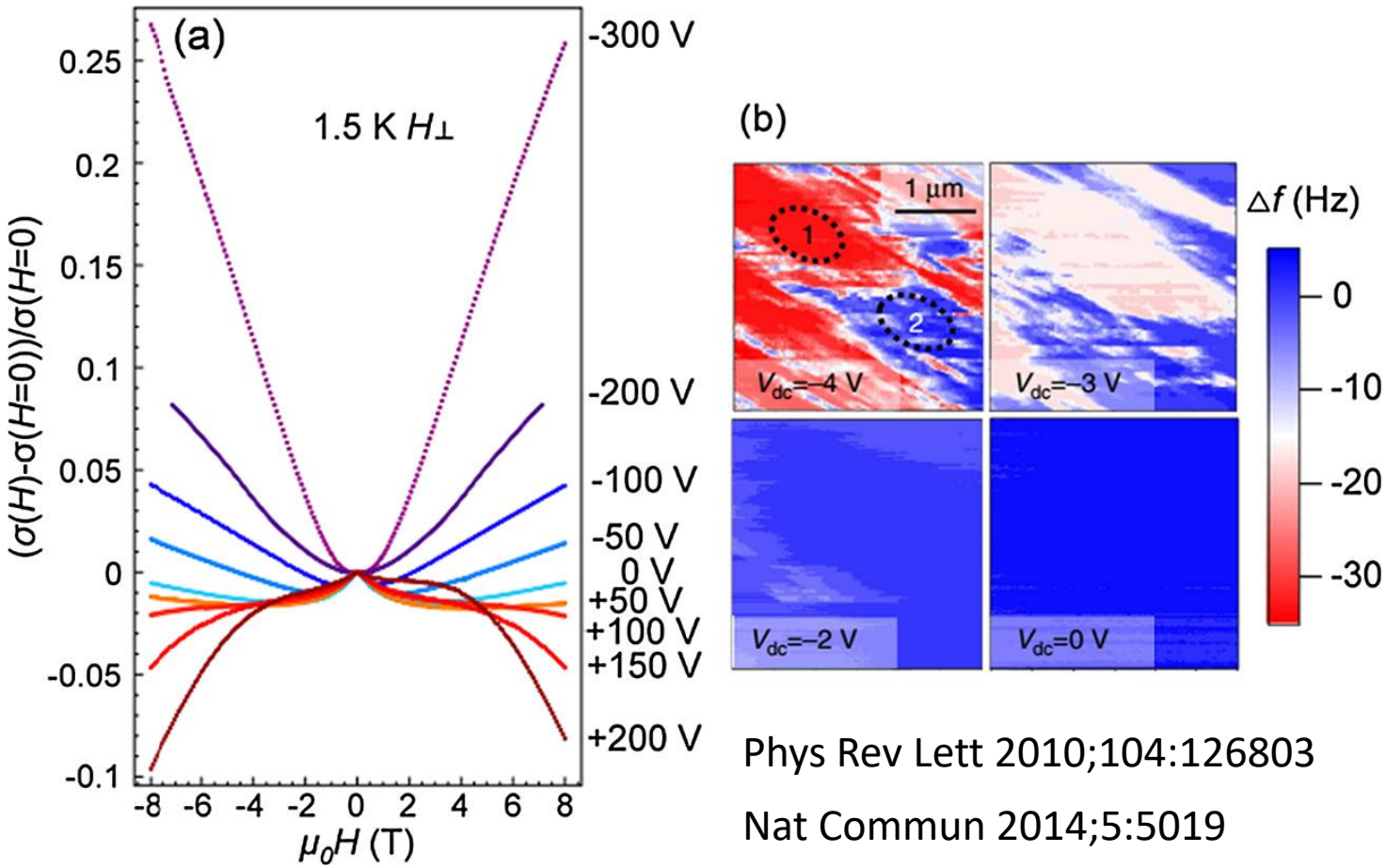
The doped manganite supplies an ideal arena for VCM because of its rich electronic phase for different chemical doping levels. MOKE: The reversal of magnetic moment in LSMO is relevant to the switching of FE polarization in PZT. XAS: an energy shift in the Mn XANES upon reversing the PZT polarization. EELS: the EELS peak position shifts between two interfaces.

Adv Mater 2009;21:3470–4

Phys Rev Lett 2010;104:127202

Nat Commun 2015;6:6735

Charge modulation in non-magnetic oxides



Phys Rev Lett 2010;104:126803

Nat Commun 2014;5:5019

The novel magnetic state and 2-DEG is closely related to the interfacial charge transfer from LAO to STO. The significant perpendicular magnetoresistance in this system can be switched from positive to negative as the voltages change
from negative to positive. The dependence of interfacial magnetism on the carrier
density was characterized by MFM. As the external voltage gradually changes from -4 V to 0 V, the perpendicular magnetic domain structure is weakened and spin aligns in plane.