# Strain mediated magnetoelectric couplings in heterostructures

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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



## Volatile strain modulation of magnetization



Nat Mater 2014;13:345–51. Nat Commun 2015; 6:5959.

The Fe<sub>50</sub>Rh<sub>50</sub> shows a ferromagnetic to antiferromagnetic phase transition at 350 K. A voltage applied on the BTO backside of 21 V could clearly increase the T\* by around 25 K. The voltagecontrolled FeRh phase transition between FM and AFM phases also causes a significant electroresistance effect in FeRh/PMN-PT.

#### Non-volatile strain modulation



If electric field swept circularly from positive to negative but does not exceed the negative coercivity, the electric field dependence on the Ni/(011) PMN-PT strain shows a hysteresis. Appl. Phys. Lett. **98**, 012504 2011

#### Non-volatile strain modulation



A loop-like behavior in the magnetization dependence on the electric field can be seen clearly with an electric field reversal between +8 and 8 kV/cm. The nonvolatile electrical manipulation of magnetism depends strongly on the 109 domain switching of PMN-PT.



Phys Rev Lett 2012;108:137203

#### Strain modulation in ferromagnetic oxides



The magnetization intensity of LSMO (x = 0.3) displays a butterfly shape when sweeping the electric field, which just tracks the dependence of the piezoelectric strain along the [100] direction in PMN-PT on the electric field. This work attributes the enhanced magnetization at the polarized state to the ferromagnetic-to-paramagnetic phase transition induced by the piezoelectric strain during ferroelectric polarization switching.

### Strain modulation in epitaxial films



Due to reduced substrateclamping effect, the interfacial couplings can be effectively transferred, leading to the enhanced ME effects. The magnetization of the individual nanodots can be switched by properly applying a bias electric field to the nanodots.

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#### 0-3 nanocomposite heterostructures



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