Voltage control of magnetism in La$_{0.67}$Sr$_{0.33}$MnO$_3$/PMN-PT heterostructures

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**Motivation**

- Current information devices based on spin and charge
- Complex oxides - strong coupling between lattice, charge, spin & orbital degrees of freedom
- Ferromagnetic/Ferroelectric heterostructures (FM/FE)
- Quest for higher data density without need of magnetic field to manipulate magnetization
- Voltage control of magnetism
- Magnetolectric coupling

**System**

- La$_{0.67}$Sr$_{0.33}$MnO$_3$
- PMN-PT (Substrate)

**FM layer -** La$_{0.66}$Sr$_{0.34}$MnO$_3$ (LSMO-30nm)
- Piezoelectric substrate – PMN-PT (0.7Pb (Mg$_{0.33}$Nb$_{2/3}$)O$_3$ - 0.3PbTiO$_3$ (001)

**Magnetoelectric SQUID measurements**

- Strain-mediated magnetoelectric coupling
- Rich correlation between magnetization and applied voltage
- Low temperature magnetoelectric coupling

**Polarized Neutron Reflectometry**

- The magnetic depth profile deduced from PNR datasets indicate the presence of interlayer between LSMO/PMN-PT.
- Spin-flip signal indicates presence of canting magnetic moments due to the strain imparted by the substrate.

**Transmission Electron Microscopy**

- Darker contrast regions show La- deficiency at the interface.
- LSMO has grown epitaxially on PMNPT and is strained at the interface.

**Conclusions and outlook**

- Clear proof of strain-mediated magnetoelectric coupling.
- Possible indication of charge-mediated magnetoelectric coupling due different magnetization values for opposite polarity of applied voltage.
- Presence of interlayer with reduced SLD and La-deficiency at the interface.
- Analysis of PNR curves with voltages is in progress.
- Further structural investigation will be done using TEM.

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