Growth and characterization of magnetite based artificial multiferroic heterostructures

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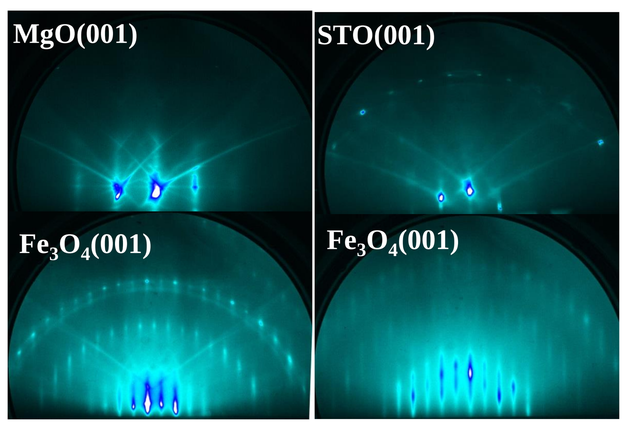
Motivation

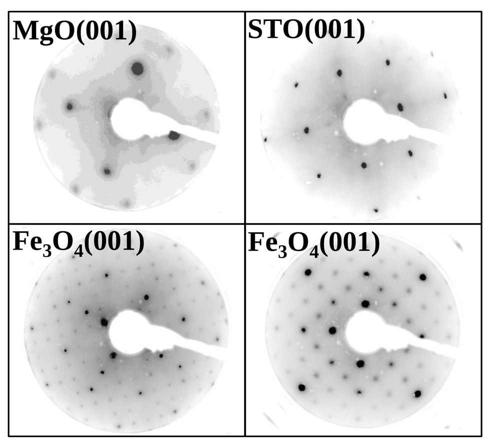
- Strain mediated magneto-elastic heterostructure device providing modulation of magnetic properties (magnetization, anisotropy, exchange bias, etc.) and spin-transport by electric field.
- Exotic properties of Fe_3O_4: half-metallic characteristics, metal-to-insulator transition (Verwey transition) at 120 K, ferrimagnetic with a Curie temperature of 850 K and multiferroicity at low temperature. Promising candidate for applications in spintronics devices.

Materials and Sample Preparation

- Film: Fe_3O_4
- Substrate: a. MgO(001), b. $SrTiO_3$(001) → STO(001) , and c. $(0.7)[Pb(Mg_{1/3}Nb_{2/3})O_3]-(0.3)PbTiO_3(011)$ → PMN-PT(011)
- Growth Techniques: a. Oxide Molecular Beam Epitaxy (OMBE) and b. Pulsed Laser Deposition (PLD)



RHEED

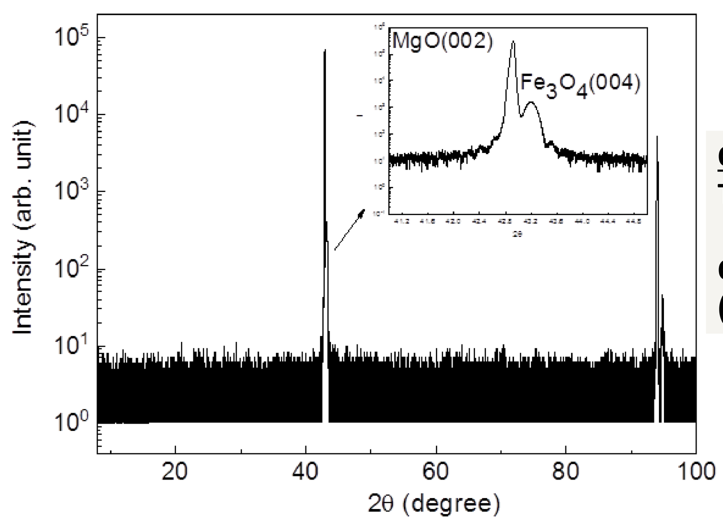


LEED

Structural Characterizations

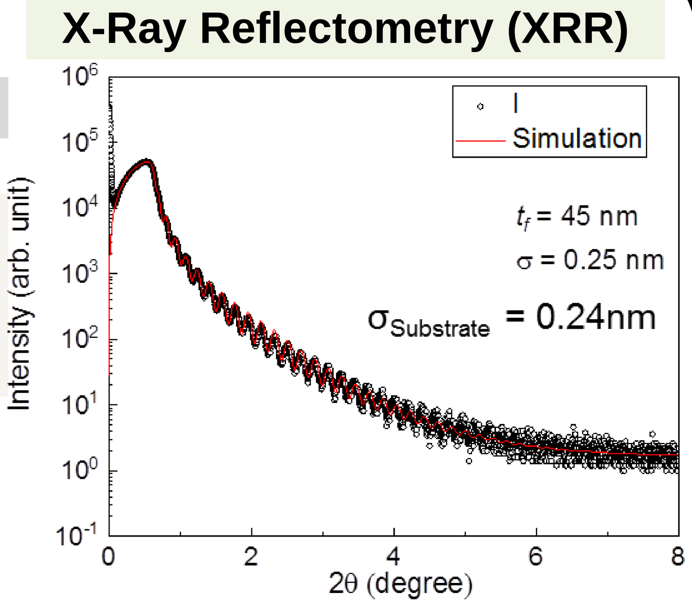
X-Ray Diffraction (XRD)

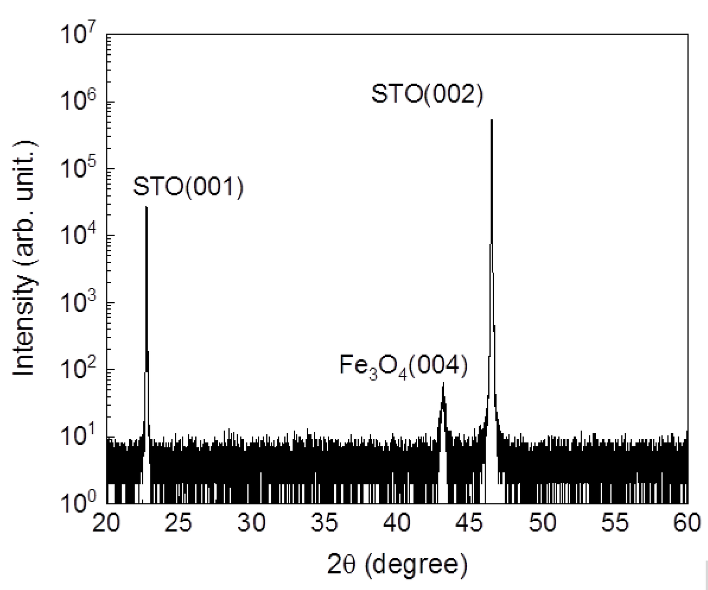
X-Ray Reflectometry (XRR)



Fe_3O_4/MgO(001)

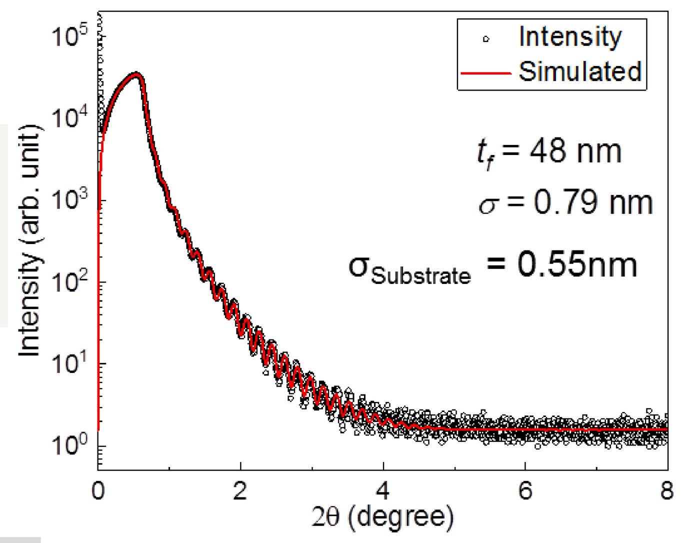
OMBE Grown
T_G = 350 °C
Oxygen = 0.15 SCCM (2×10^{-6} mbar)

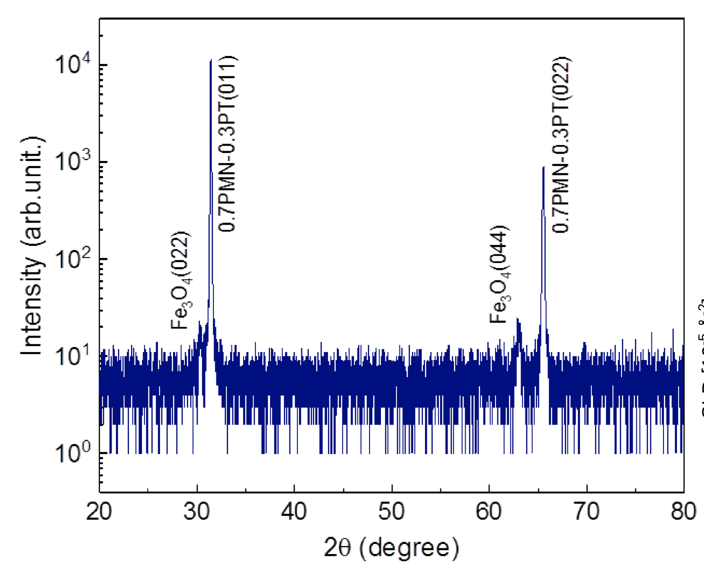




Fe_3O_4/STO(001)

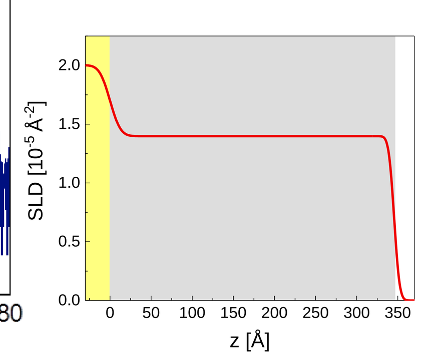
OMBE Grown
T_G = 450 °C
Oxygen = 0.15 SCCM (2×10^{-6} mbar)

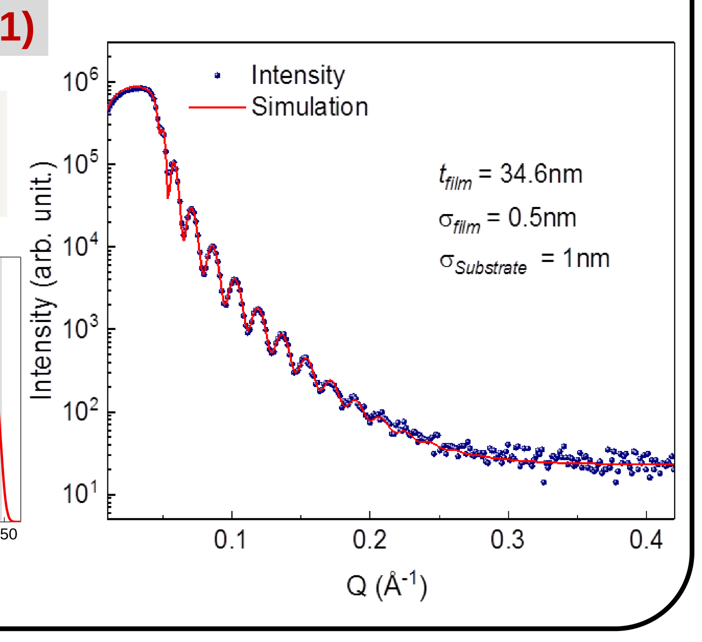




Fe_3O_4/PMN-PT(001)

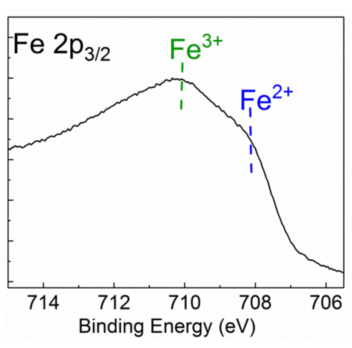
PLD Grown
T_G = 500 °C
Oxygen = 2×10^{-6} mbar

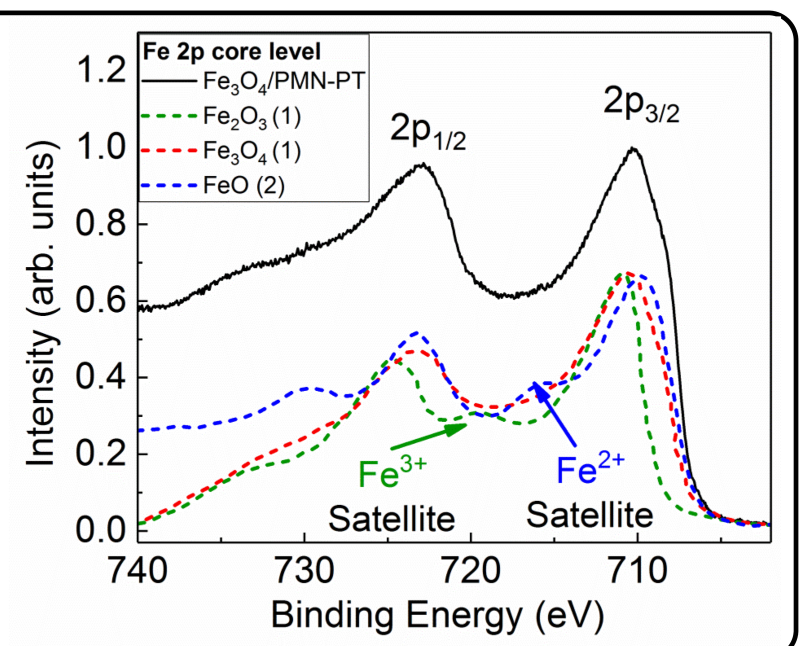




XPS Study

- Fe binding energy (B.E) peaks: $2p_{3/2}$ = 724 eV and $2p_{1/2}$ = 711 eV.
- No satellite peaks of FeO at 715.5 eV and Fe_2O_3 at 719 eV, observed.
- Absence of 706.6 eV peak of metallic Fe- $2p_{3/2}$ reveals that there is no cluster of Fe.

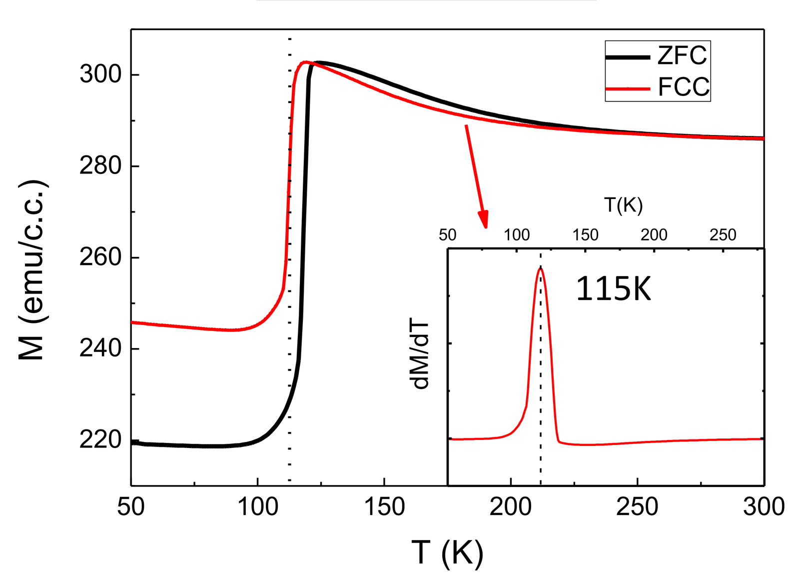


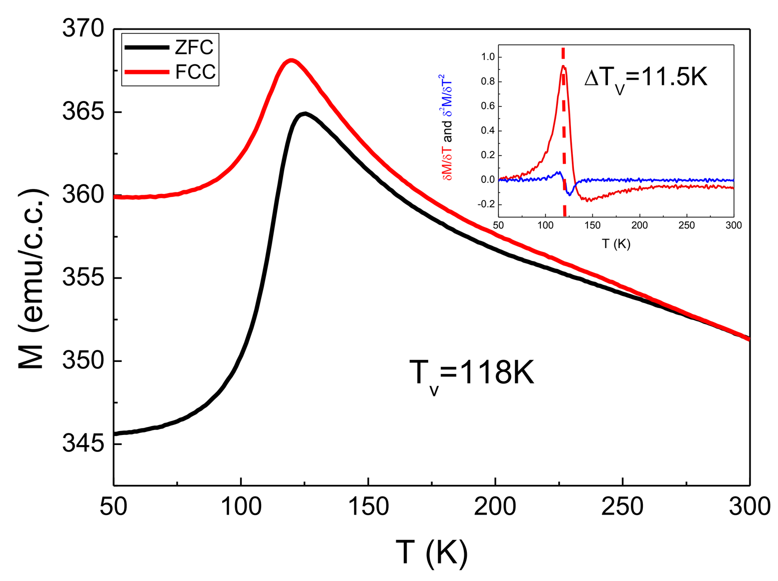


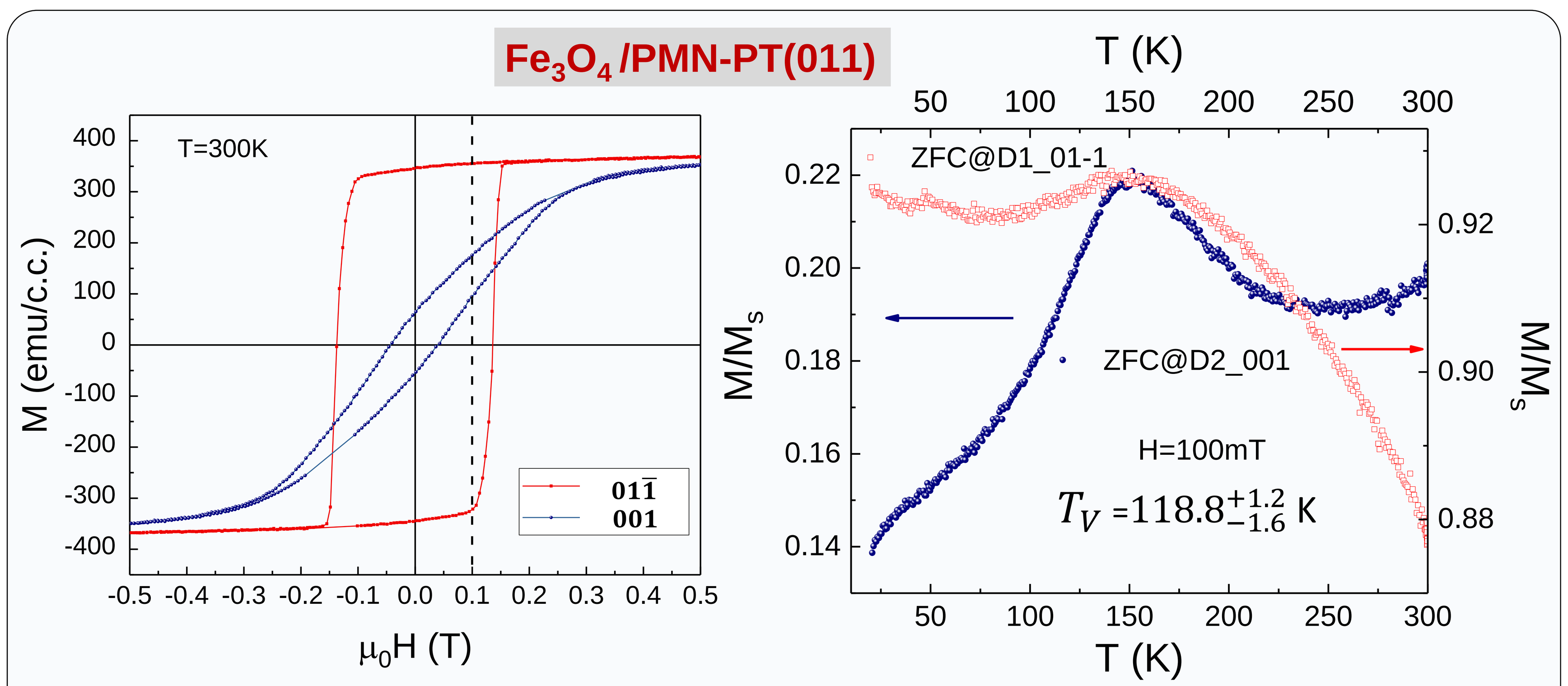
References

[1] Zhang et. al., APL 110, 082602 (2017).
[2] Liu et. al., Scientific reports 3, 1876, (2013)

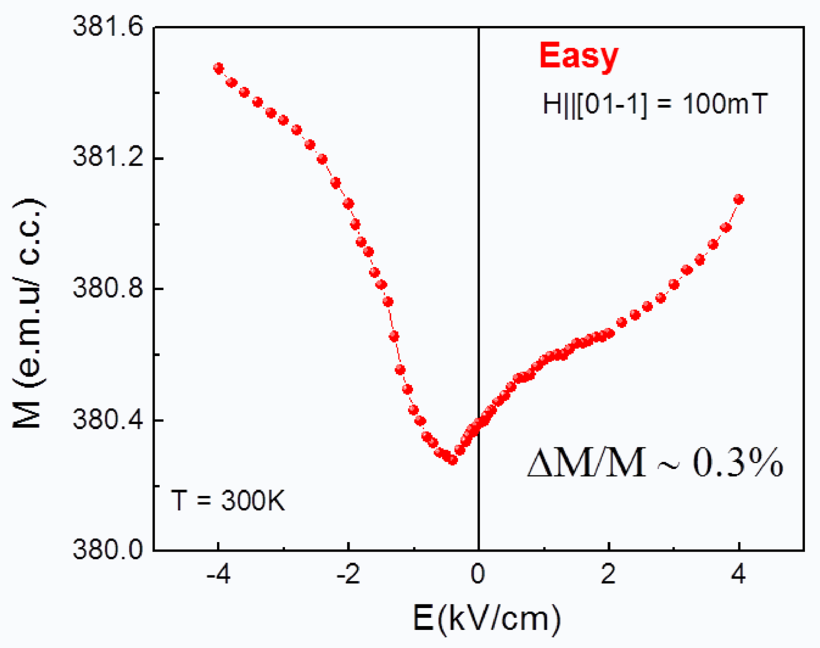
Magnetization Measurements

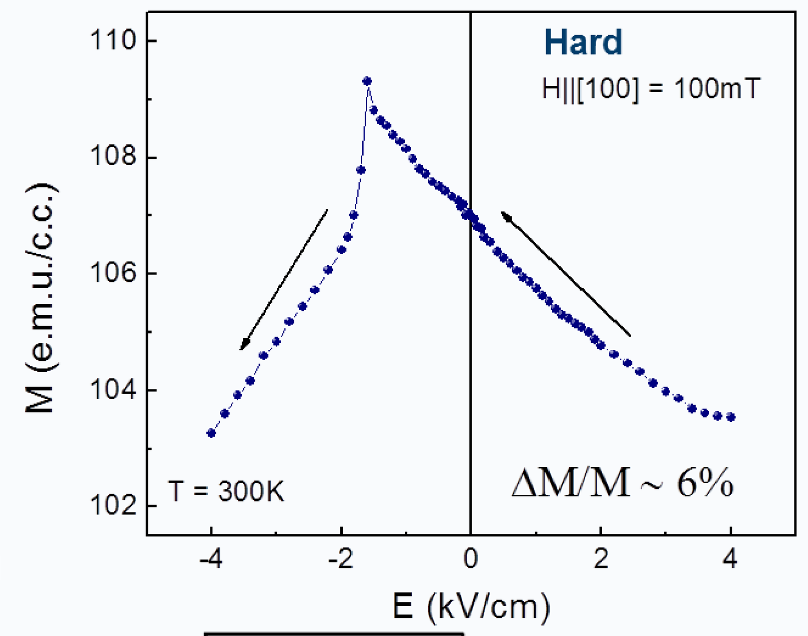






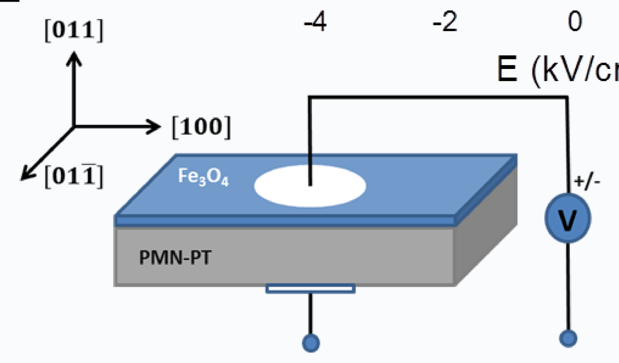
Magnetization (M) Tuning with Electric field (E)

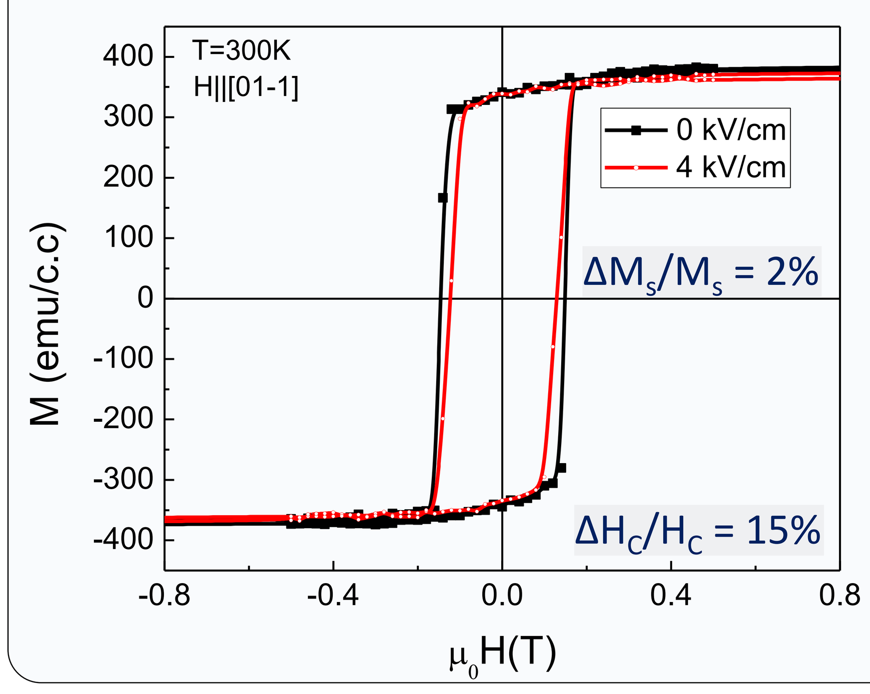


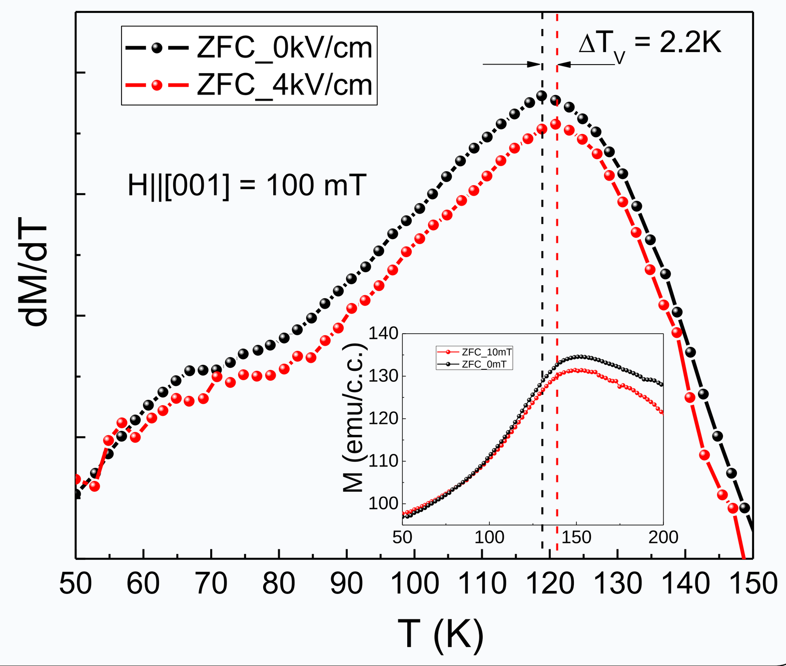


Hard d_{31}= -3100 pC/N [100]

Easy d_{32} = 1400 pC/N [01$\bar{1}$]







Materials →	MgO(001)	Fe_3O_4	STO(001)	PMN-PT(011)
a (Å)	4.20	8.39	3.90	4.02
Misfit(%) $\frac{a_s - a_f}{a_f}\times 100\%$	0.07% ⟷	0	⟷ - 7%	- 4.2%
T_v (K)	115 ⟷	xx	⟷ 118	118 + 2.2K

Summary and Outlook

- Compressive strain tends to shift the Verwey transition towards the bulk value.
- Large change in the magnetization due to application of the electric field ~6% at room temperature could be realized in Fe_3O_4/PMN-PT(011) heterostructure for small magnetic field appled along (100) direction.
- It is still unclear if the shift of the magnetization is purely strain mediated, or if there is an influence of the PMN-PT polarization. Therefore, polarized neutron reflectometry will be used to investigate the magnetic depth profile across the heterostructure and to probe the substrate-film interface.

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