Imaging Antiferromagnetic Domains in Nickel-oxide Thin Films by Magneto-optical Voigt Effect

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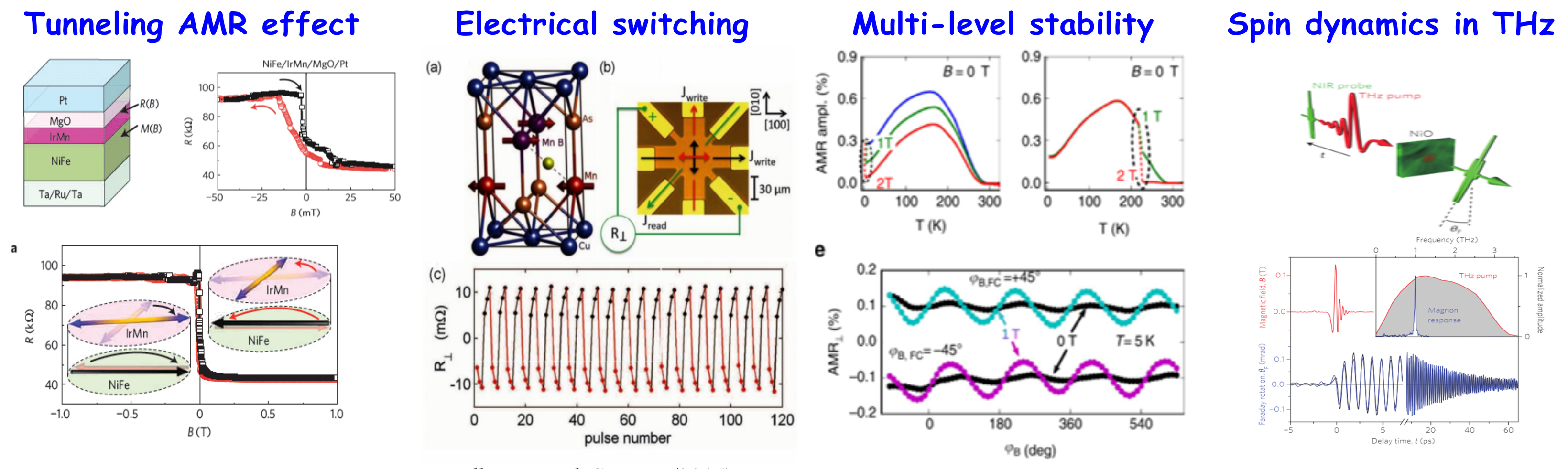
Introduction

Antiferromagnetic Spintronics

Tunneling AMR effect | Electrical switching | Multi-level stability | Spin dynamics in THz

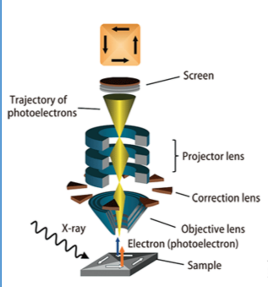


B. G. Park et al., Nat. Mat. (2011) | Wadley, P. et al. Science (2016) | D. Kriegner et al Nat. Commun. (2016) | K. Olejnik et al Nat. Commun. (2017)

It is a great challenge in accessing their magnetic properties especially at the microscopic scale.

Antiferromagnetic Domains

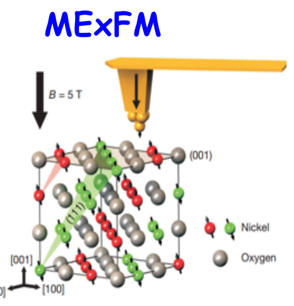
PEEM

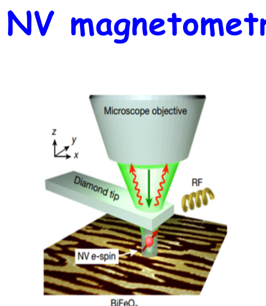


- Based on XMLD effect
- Most common technique
- Difficult to work with electric or magnetic field

Wadley, P.et al.Nat. Nanotechnol (2018)

MExFM | NV magnetometry



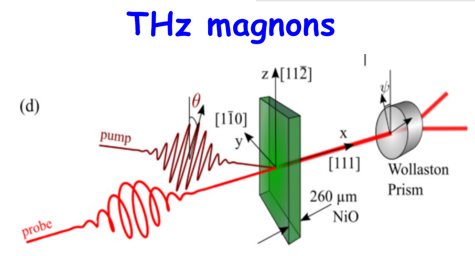


Uwe Kaiser et al. Nature (2007) | Gross, I et al. Nature (2017)

Require well-ordered, pristine sample surfaces.

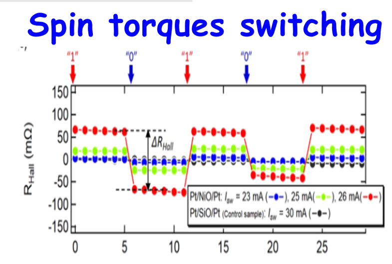
NiO in Spintronics

THz magnons



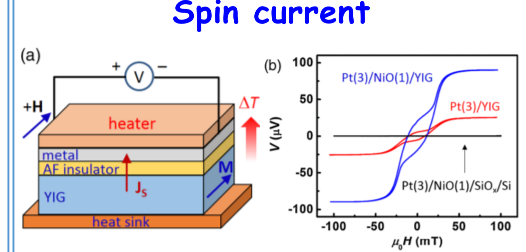
C. Tzschaschel et al Phys. Rev. B (2017)

Spin torques switching



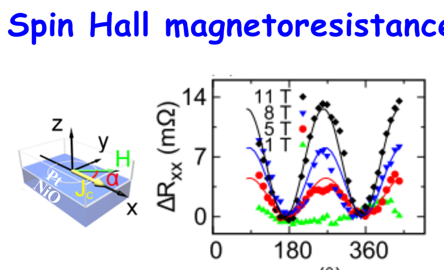
T. Moriyama Sci. Rep. (2018).

Spin current



W. Lin Phys. Rev. Lett. (2016)

Spin Hall magnetoresistance

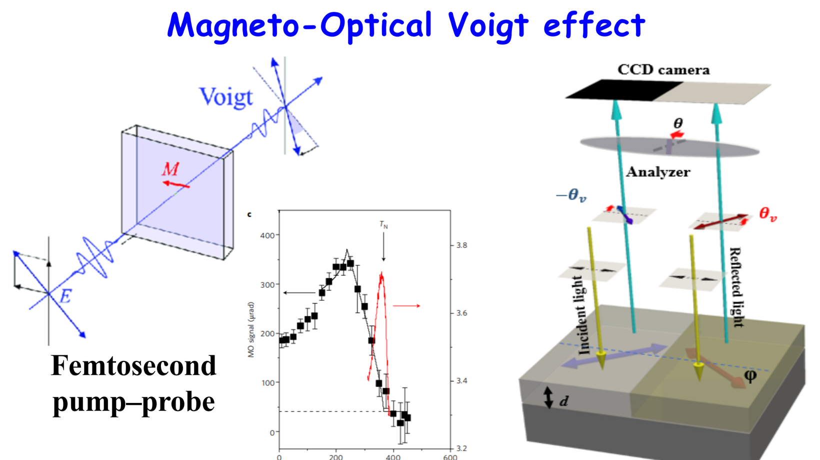


L. Baldrati, et al Phys. Rev. B (2017)

It is greatly needed to experimentally elucidate the behavior of AFM domains.

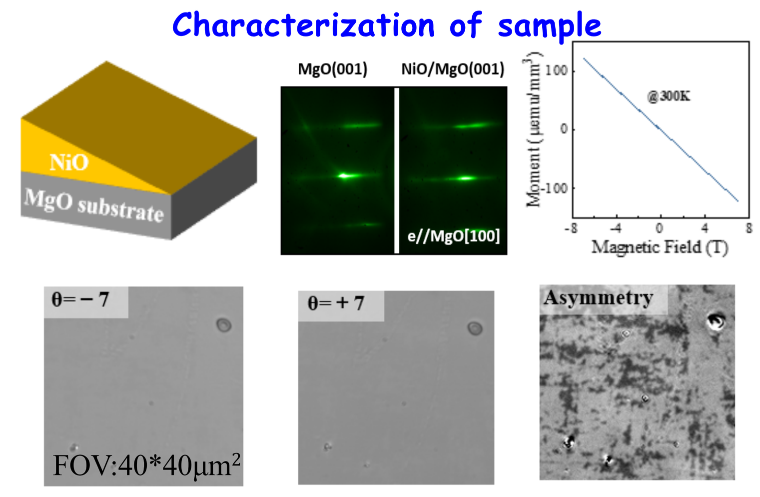
Methods

Magneto-Optical Voigt effect



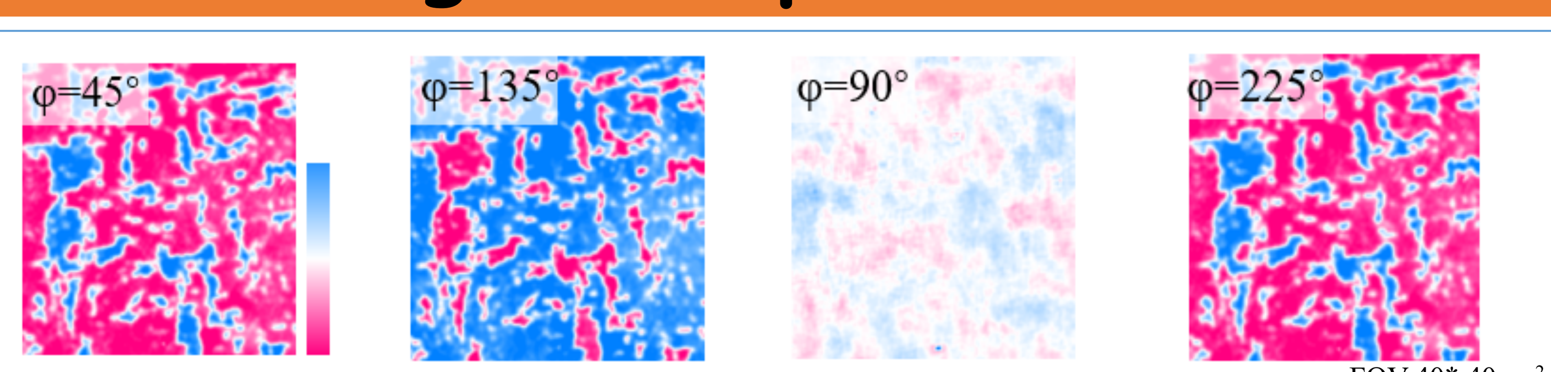
V. Saidl et al Nat. Photonics (2017).

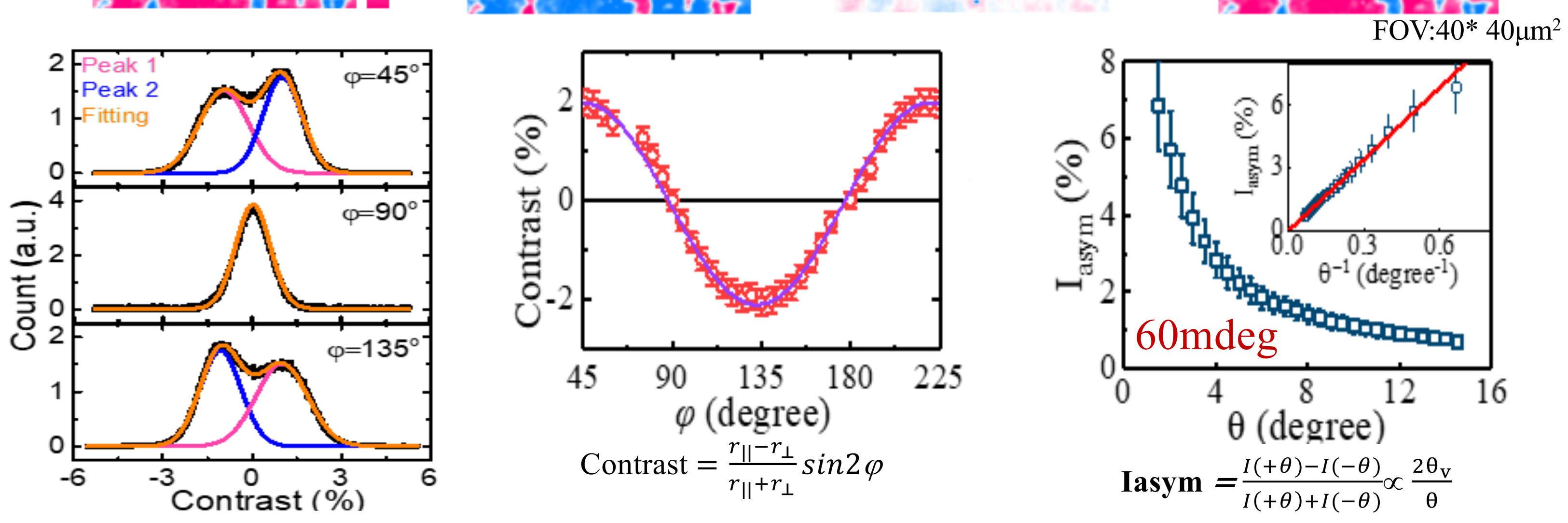
Characterization of sample



We can observe the magnetic contrasts induced by the Voigt effect.

Angular dependence



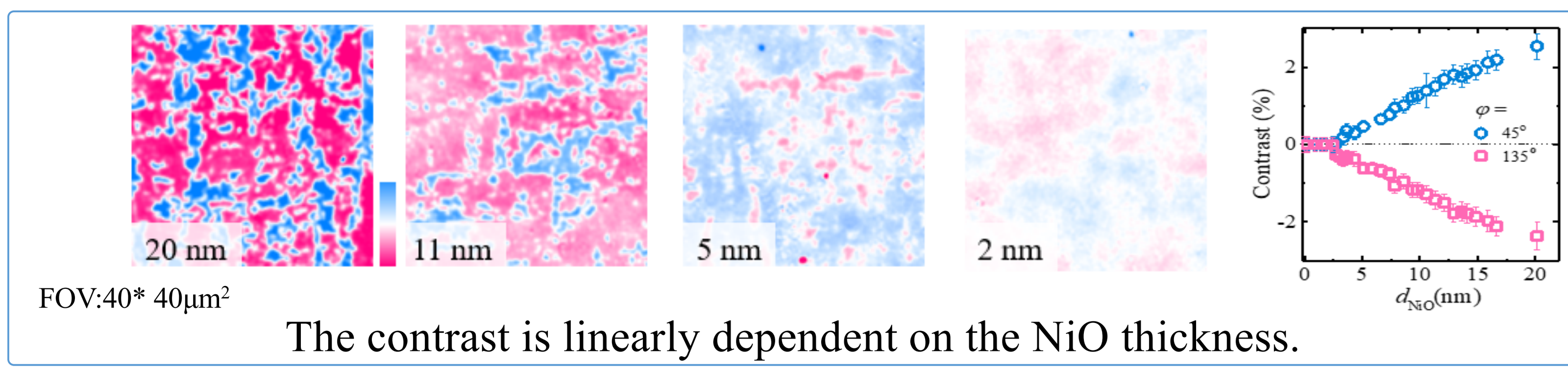


$$\text{Contrast} = \frac{r_{||} - r_{\perp}}{r_{||} + r_{\perp}} \sin 2\varphi$$

$$\text{Iasym} = \frac{I(+\theta) - I(-\theta)}{I(+\theta) + I(-\theta)} \propto \frac{2\theta_V}{\theta}$$

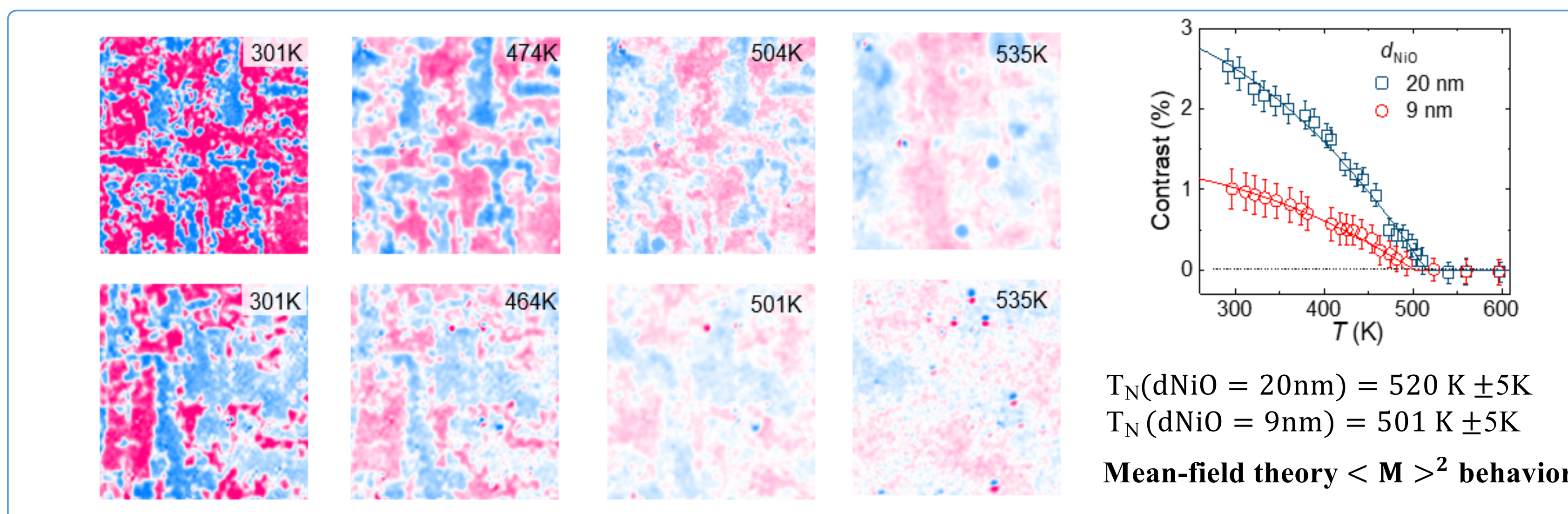
It is in good agreement with the expected polarization-dependence of the Voigt effect.

Thickness dependence



The contrast is linearly dependent on the NiO thickness.

Temperature dependence



T_N(dNiO = 20nm) = 520 K ±5K

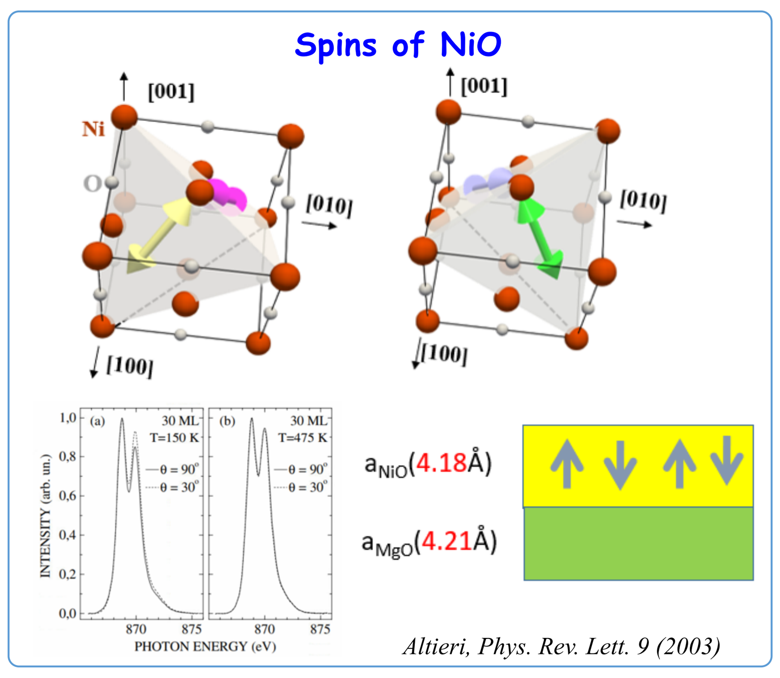
T_N (dNiO = 9nm) = 501 K ±5K

Mean-field theory < M >^{2} behavior

The origin of the observed contrast is the antiferromagnetic order.

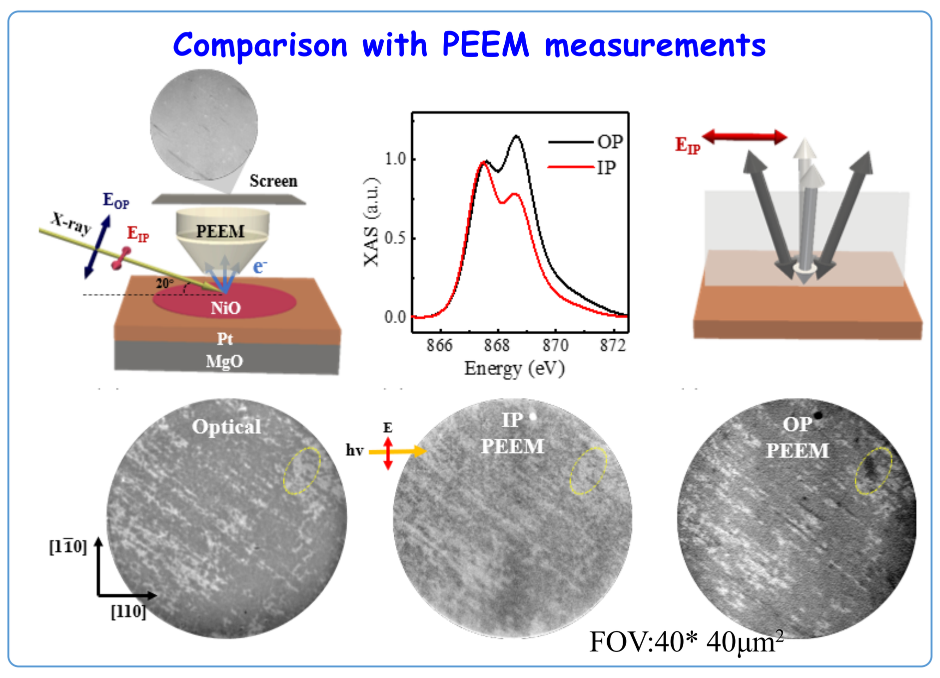
Structure of spins

Spins of NiO



Altieri, Phys. Rev. Lett. 9 (2003)

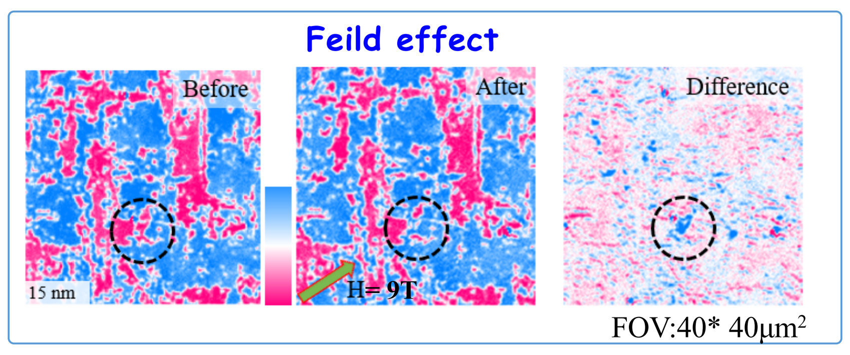
Comparison with PEEM measurements



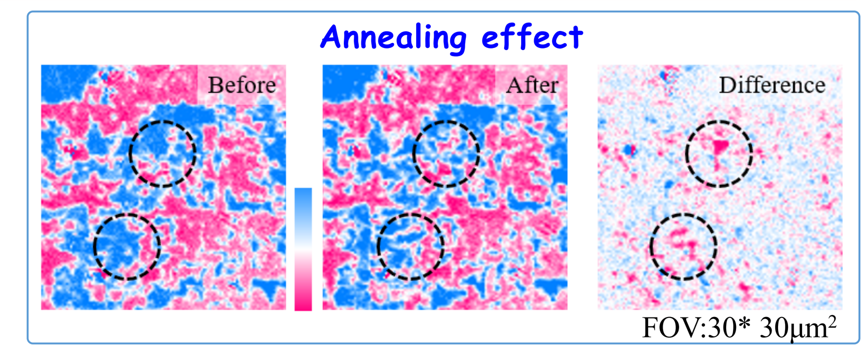
Both PEEM and Voigt measurements show that the spin structure of NiO on MgO(001) partially tilts outward from the surface, rather than perpendicular as previously claimed

Switching of AFM domains

Feild effect



Annealing effect



Only a few percent of domain area can be changed. The formation of AFM domains is determined by the strongly locked AFM spins due to local strains.

Summary

1.Here we report a significant Voigt rotation up to 60 mdeg in thin NiO(001) films at room temperature.

2.Such large Voigt rotation allows us to directly observe AFM domains in thin-film NiO by utilizing a wide-field optical microscope.

3. We elucidated on the surface spin-canting structure of NiO on MgO(001).

4. Magneto-optic Voigt effect can also be made adaptable with external magnetic fields or electric currents which are extremely important in future experiments involving electric- and magnetic-field driven AFM dynamics and switching.