Arrangement, Structure and Magnetisation of epitaxially grown Iron Oxide Nano Islands on $SrTiO_3$

S. Tober, M. H. Hamed, Y. Xu, A. Qdemat, C. Bednarski-Meinke, U. Rücker, E. Kentzinger and T. Brückel

Jülich Centre for Neutron Science (JCNS) and Peter Grünberg Institut (PGI), JARA-FIT, Forschungszentrum Jülich GmbH

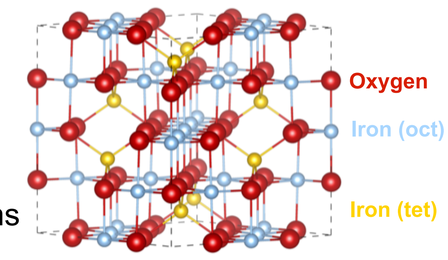
JÜLICH Forschungszentrum

s.tober@fz-juelich.de

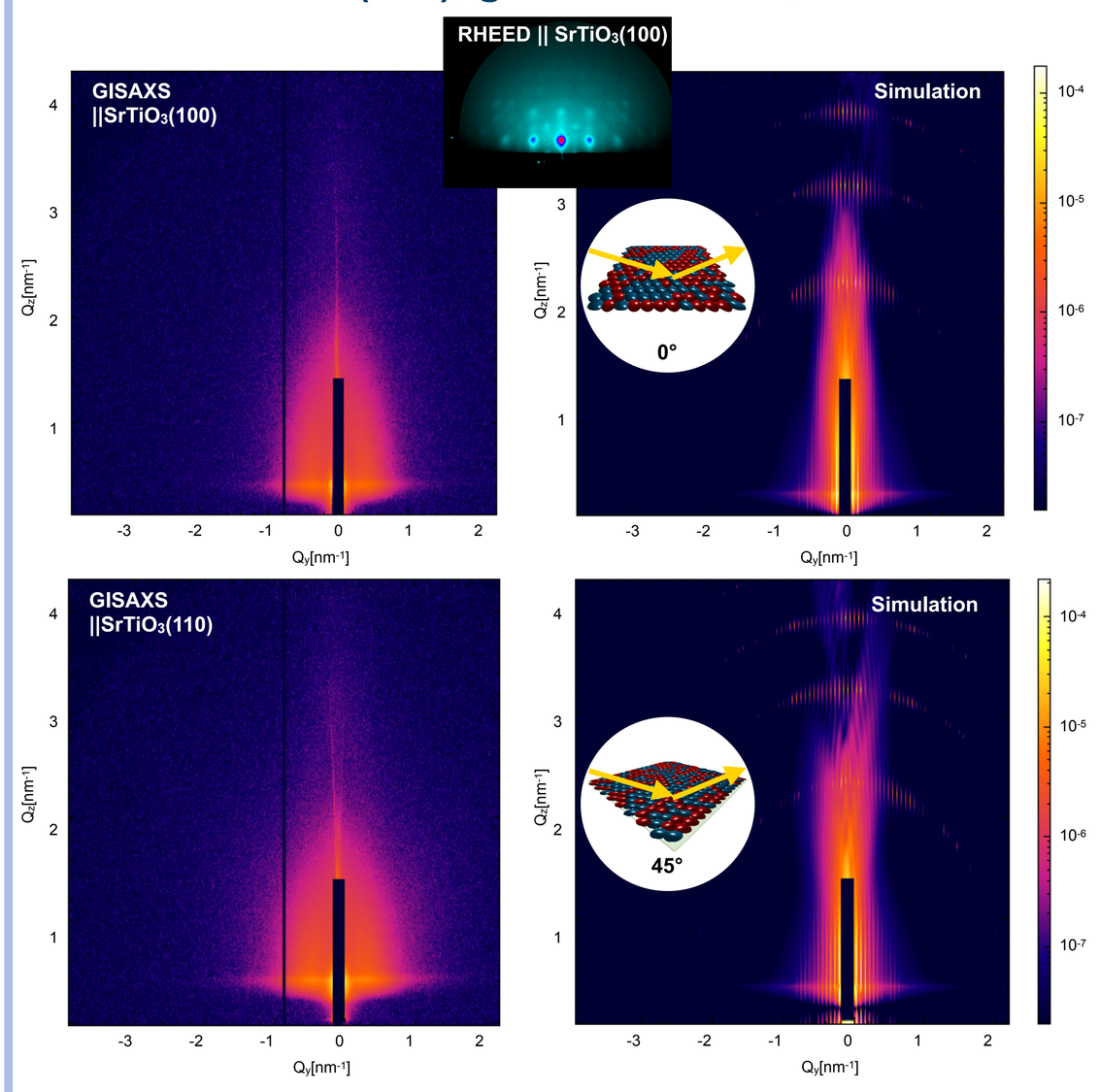
Fe_3O_4 - Properties and Applications

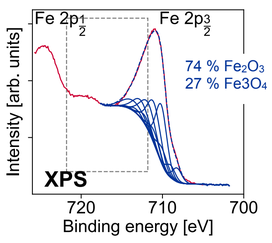
- Ferrimagnetic spinel type oxide used in catalysts (Haber Bosch, water gas shift), hyperthermia and nanoscale building blocks [1,2,3,4]
- Magnetic and electronic properties strongly depend on size, shape, composition and crystal structure [5,6]
- Chemical interaction and electronic/magnetic coupling between Fe_3O_4 structures and $SrTiO_3$ substrates expected [6,7]
- Large lattice mismatch (-7%) of Fe_3O_4 and $SrTiO_3$ causes distorted structures and the formation of antiphase boundaries

➡Epitaxial nano islands enable studying the electronic and magnetic interactions at the $Fe_3O_4/SrTiO_3$ interface in confined systems without effects caused by structural distortions



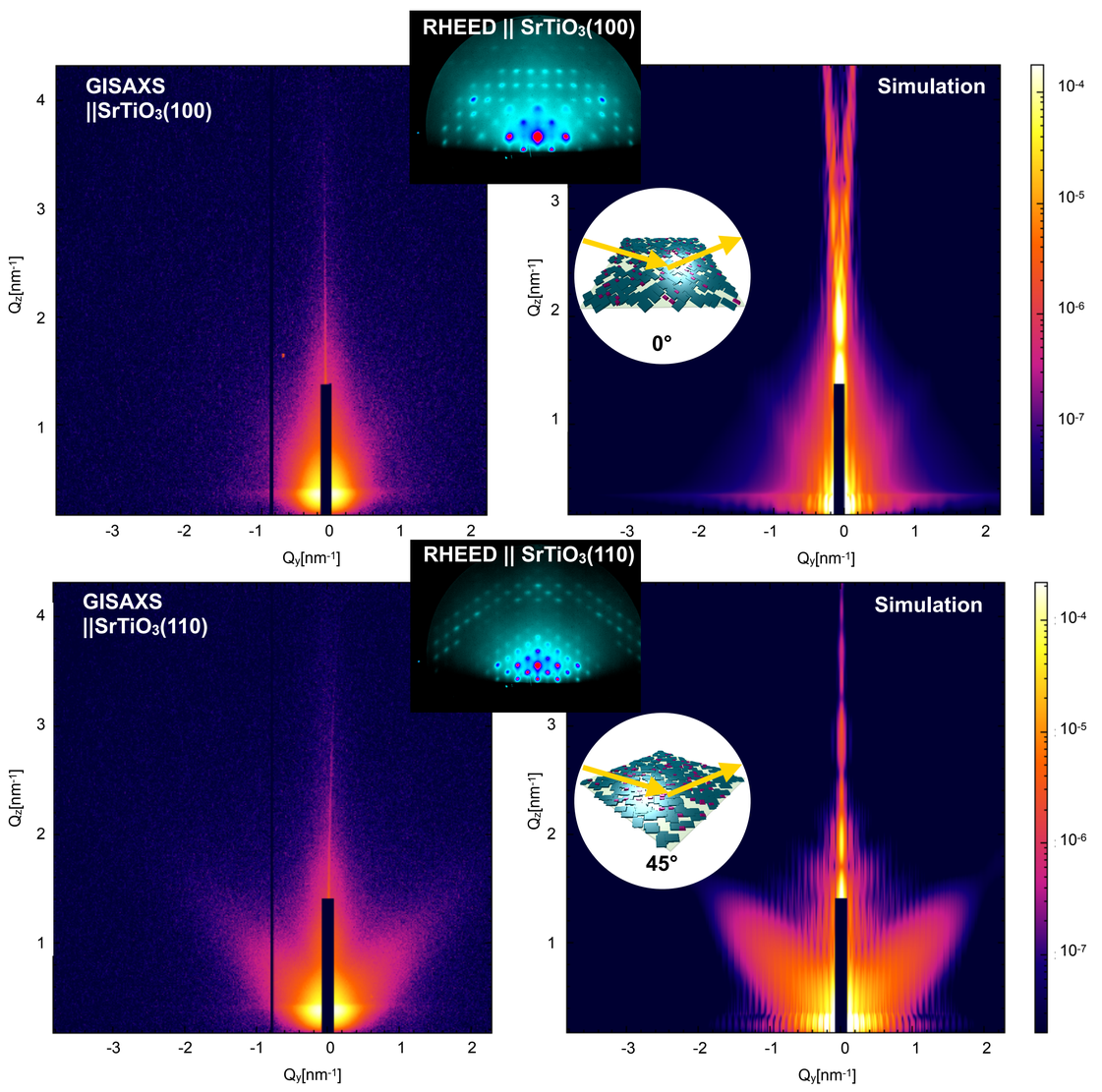
$Fe_{3-\delta}O_4$ on $SrTiO_3$(001), growth at 420 K, $1 \cdot 10^{-6}$ mbar O_2

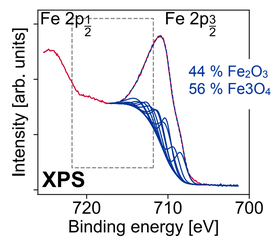




- Island growth with small cubic crystalline domains
- Mixture of mainly Fe_2O_3 and Fe_3O_4
- Grazing-incidence small angle scattering (GISAXS) along $SrTiO_3$ (100) and (110) at the GALAXI instrument [8]
- Simulations using BornAgain [9]
- Island heights of ~10 nm, edge length 60-100 nm
- No well-defined island shape but weak ordering

$Fe_{3-\delta}O_4$ on $SrTiO_3$(001), growth 620 K, $1 \cdot 10^{-6}$ mbar O_2





- Epitaxial island growth of cubic $Fe_{3-\delta}O_4$(100) with high cation deficit along STO(100)
- Well-aligned faceted islands with rectangular basis, heights ~10 nm, edge length 40-120 nm
- Side facets of islands tilted along STO (110)
- No ordered arrangement between islands

Structural Characterisation

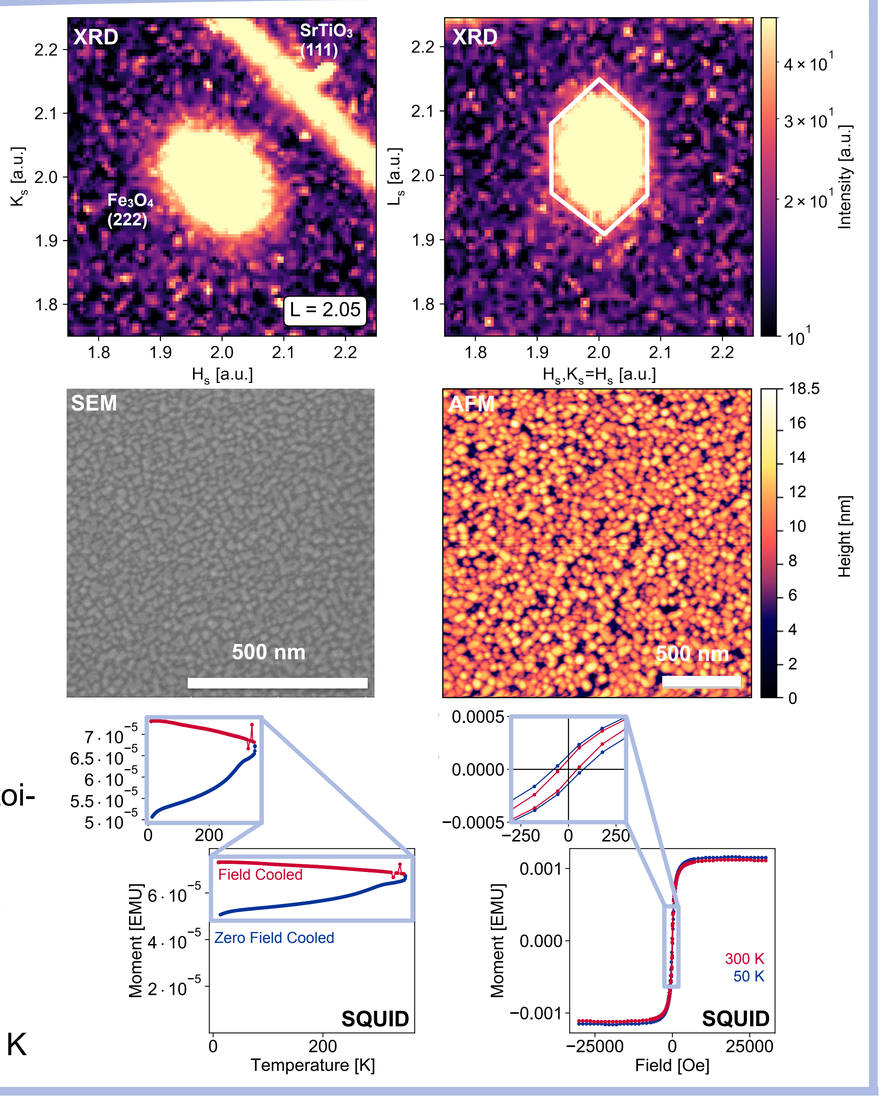
- Cube-on-cube epitaxy of $Fe_{3-\delta}O_4$ on $SrTiO_3$ despite lattice mismatch of -7%
- Weak facet signal for Fe_3O_4(100) and Fe_3O_4(111), no Fe_3O_4(110) facets
- Crystalline particle diameter ~14 nm, height 8 nm

Real Space Characterisation

- Aligned but unordered rectangular islands form percolating lattice
- Surface coverage 70-80 %
- Height profiles indicate nucleation and growth of islands on top of islands
- Average island height of 15 nm, diameters 30-250 nm

Magnetic Properties

- No Verwey transition in zero field cooled/ field cooled (ZFC/FC) curves due to nonstoichiometry of the $Fe_{3-\delta}O_4$ nano islands
- ZFC/FC curves could result from ferrimagnet or superparamagnet with high blocking temperature
- Open hysteresis indicates ferro-/ ferrimagnetic component
- Nearly identical coercivities at 50 and 300 K



Conclusion and Outlook

- $Fe_{3-\delta}O_4$ island growth with cube-on-cube epitaxy on $SrTiO_3$(100)
- Improved crystallinity and reduced nonstoichiometry δ for growth at higher substrate temperatures
- Island shape indicates preferential formation of (100)- and (111)-like facets
- Islands merge forming percolating system with structures larger than crystalline structure size
- Weak ferromagnetism, no Verwey transition as in $Fe_{3-\delta}O_4$

➡Further optimisation of growth procedure to obtain well-separated islands

➡Investigation of the electronic and magnetic coupling of $Fe_{3-\delta}O_4$ and $SrTiO_3$ by angular resolved photoelectron spectroscopy and grazing-incidence nuclear resonant small angle scattering

Acknowledgment

AFM supported by V. A. de Oliveira Lima
Magnetometry supported by O. Petracic
XPS by H. Hartmann and U. Breuer, ZEA-3, FZ Jülich
Reciprocal space mapping at DESY NanoLab supported by E. E. Beck, J. C. Schober, S. Chung, M. Tehrani, V. Vonk and A. Stierle

References

[1] Parkinson, Surf. Sc. Rep. **71** 272 (2016); [2] Muhich et al., Chem. Mater., **28** 214 (2016); [3] Nandakumaran et al., Adv. Mater., **33** 2008683 (2021); [4] Dreyer et al. Nat. Mat., **15** 522 (2016); [5] Keavney et al., J. Vac. Sci. Technol. B. **25** 1389 (2007); [6] Lak et. al., Nanoscale **5** 12286 (2013); [7] Hamed et al., Appl. Mater. Interfaces, **11** 7576 (2019); [8] Kentzinger et al., JLSRF **2** A61 (2016); [9] Pospelov et al., J. Appl. Cryst. **53** 262 (2020)