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OMICS Group International is a pioneer and leading science event organizer, which publishes around 400 open access journals and conducts over 300 Medical, Clinical, Engineering, Life Sciences, Phrama scientific conferences all over the globe annually with the support of more than 1000 scientific associations and 30,000 editorial board members and 3.5 million followers to its credit.

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Atomically-resolved imaging of surfaces of complex oxide thin films grown by laser-MBE

Alexander Tselev

Oak Ridge National Laboratory,

Oak Ridge, TN, USA

OAK RIDGE National Laboratory | CENTER FOR NANOPHASE MATERIALS SCIENCES

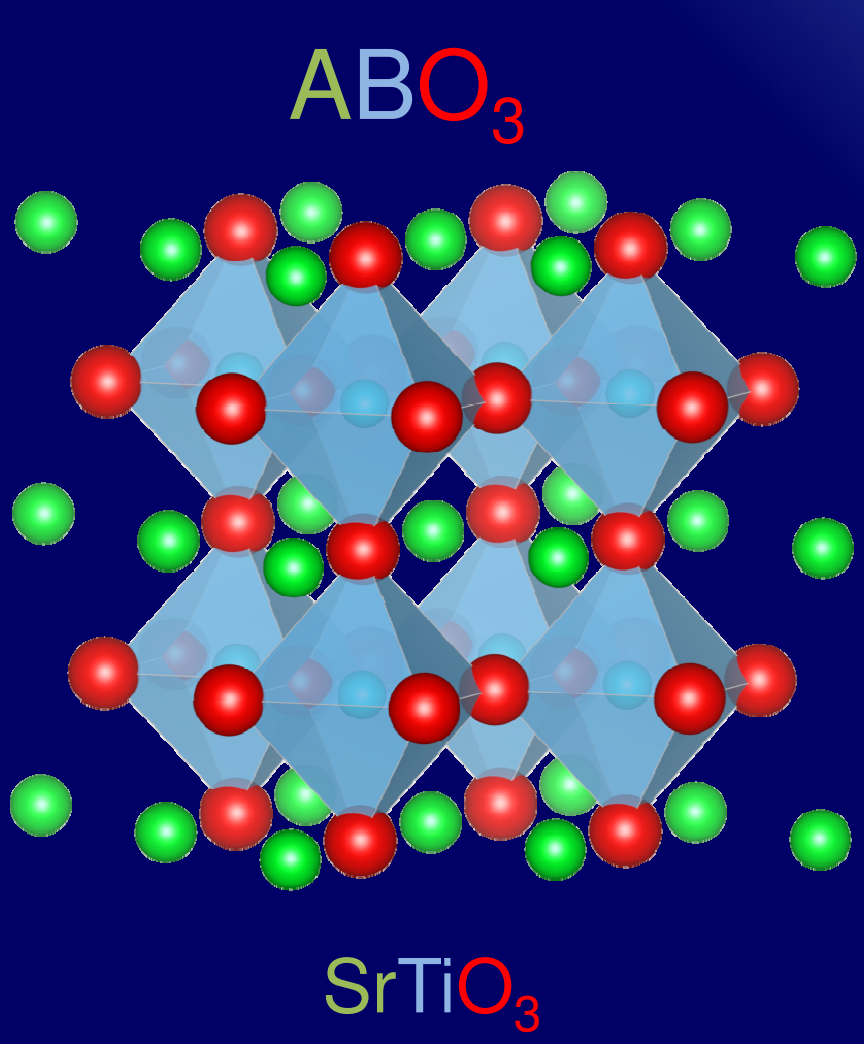
What complex oxides offer

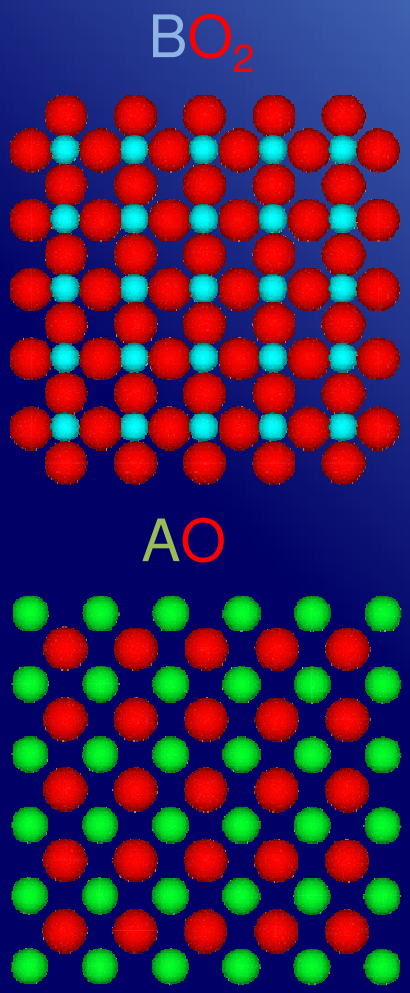
- Superconductivity
- Colossal magnetoresistance
- Ferromagnetism (spintronics)
- Ferroelectricity
- Multiferroism
- Metal-insulator transitions
- Tunability by strain
- Memristive bahavior

Can be integrated with existing Si-based technologies

- Use in electrochemical energy storage and conversion systems

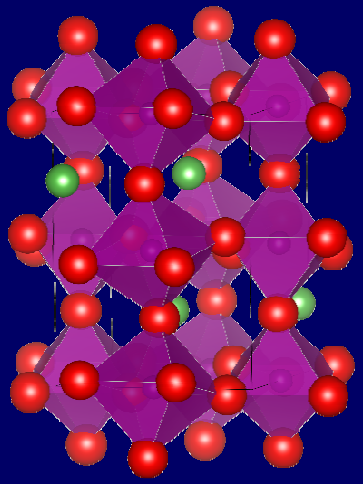
Perovskite structure



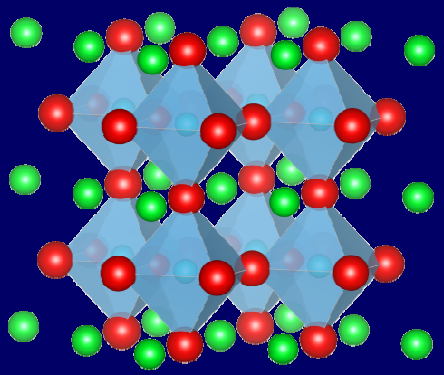


Epitaxial film growth

$LaMnO_3$



$SrTiO_3$

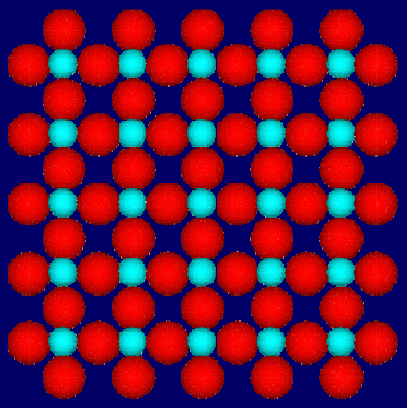


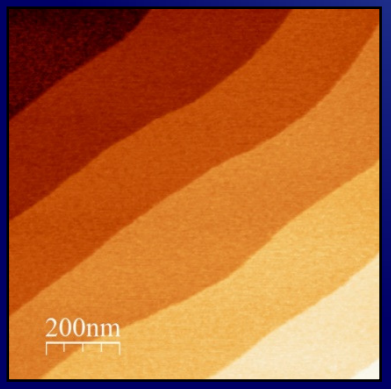
substrate

Growth at:
elevated substrate temperatures
650-850 °C &
in oxygen atmosphere 1-300 mTorr

B-terminated single-crystalline substrate

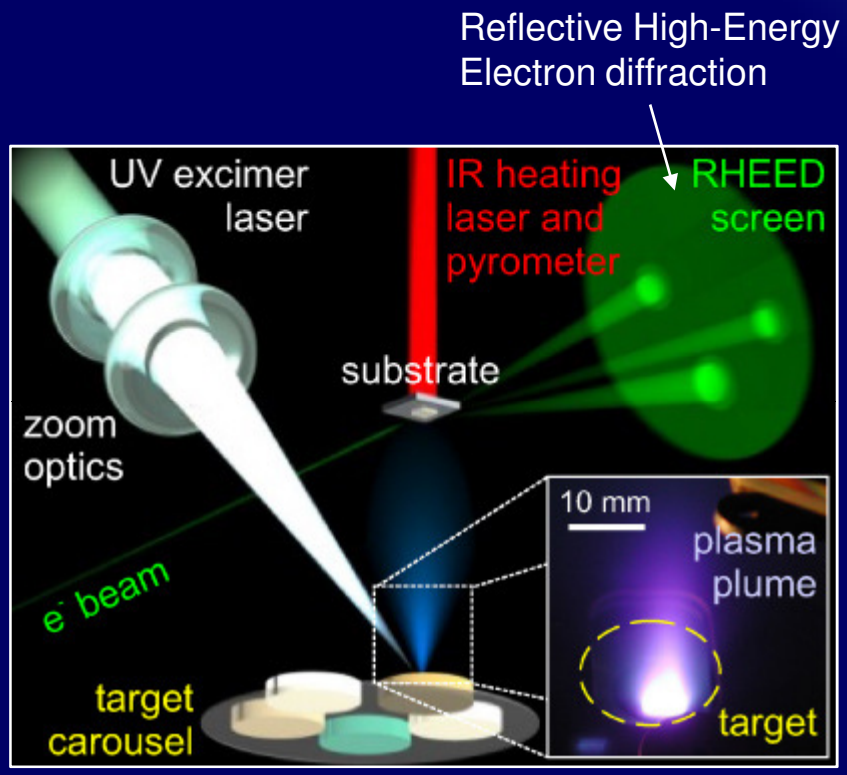
BO_2



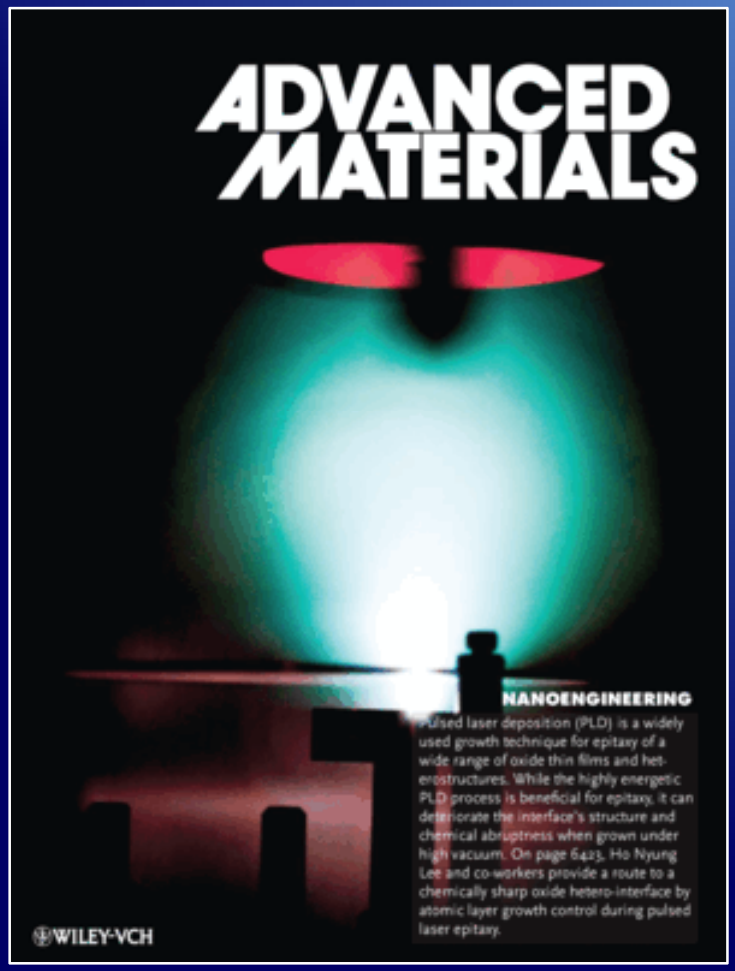


Atomic force
microscopy image

Pulsed Laser Deposition

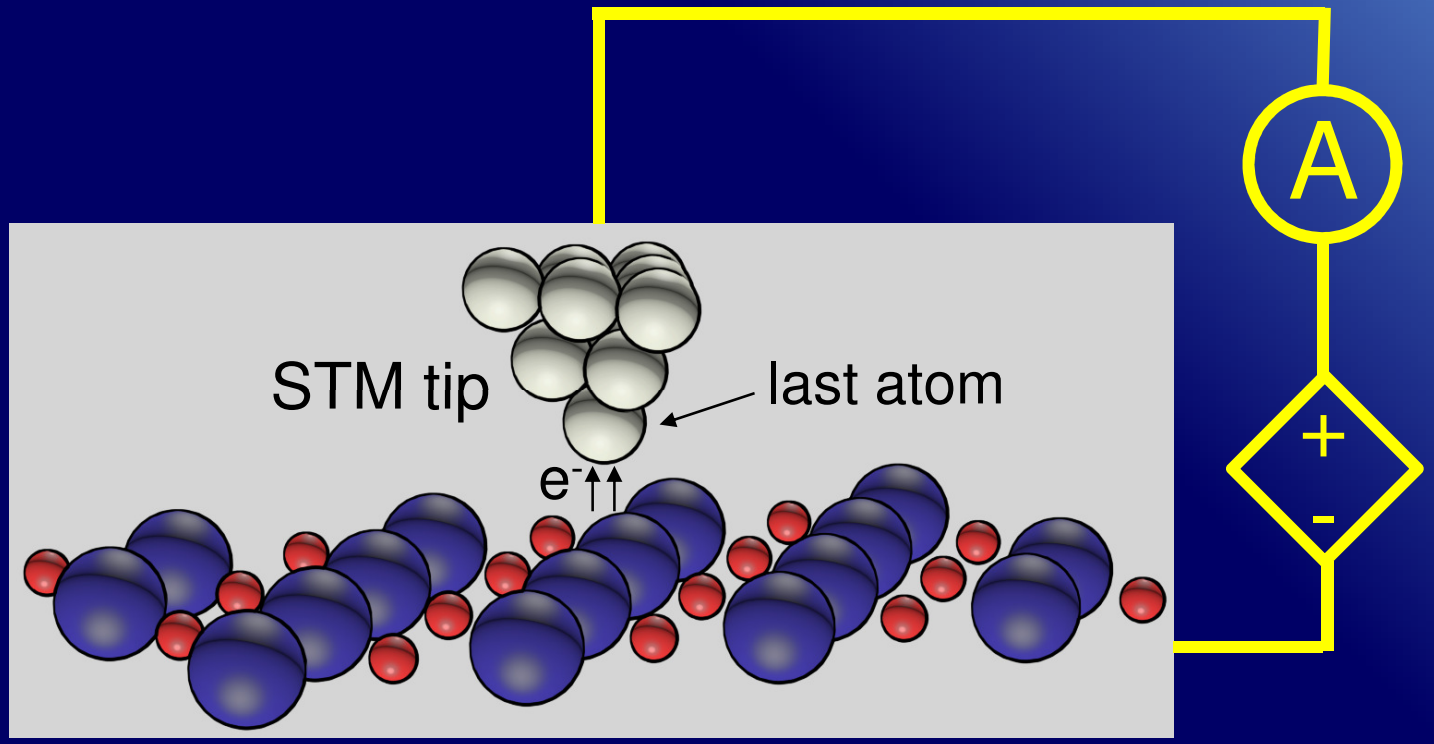


The schematic is from: M. Opel, J. Phys. D 45, 033001 (2012)



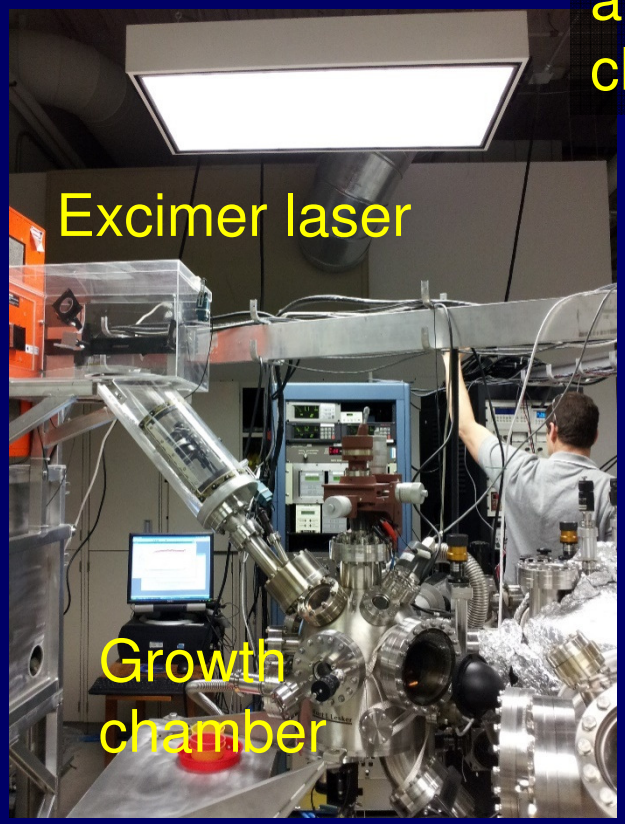
Adv. Mat. cover Dec 2012, connected to a paper from an ORNL group

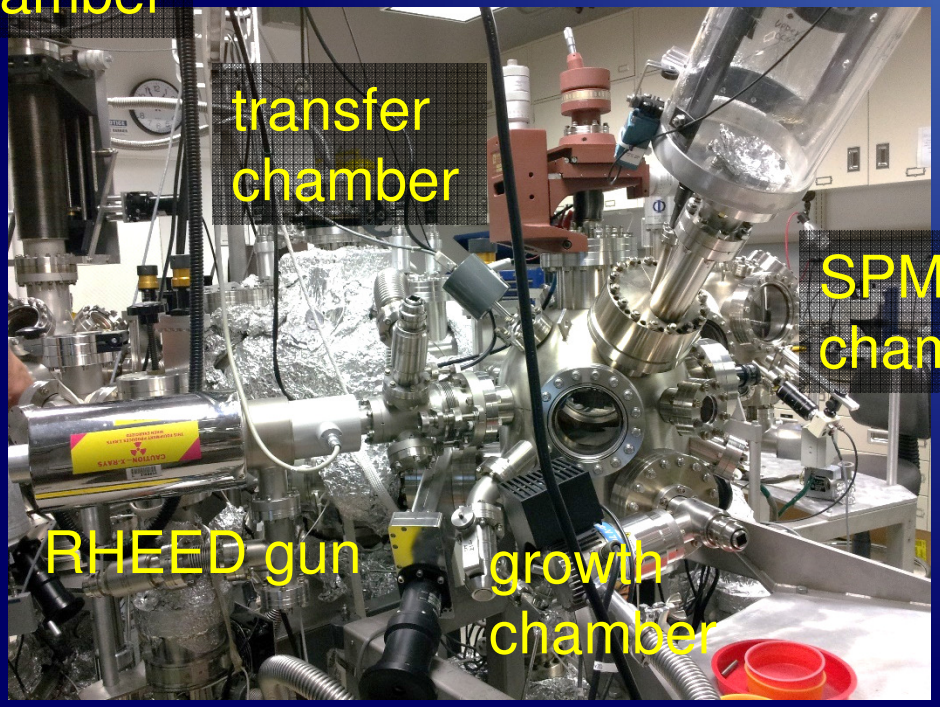
Scanning tunneling microscopy



- *Atomic* resolution is generally *very difficult* to achieve on PLD-grown films

NanoTransport system at CNMS





http://www.cnms.ornl.gov

STM
AFM
in
UHV

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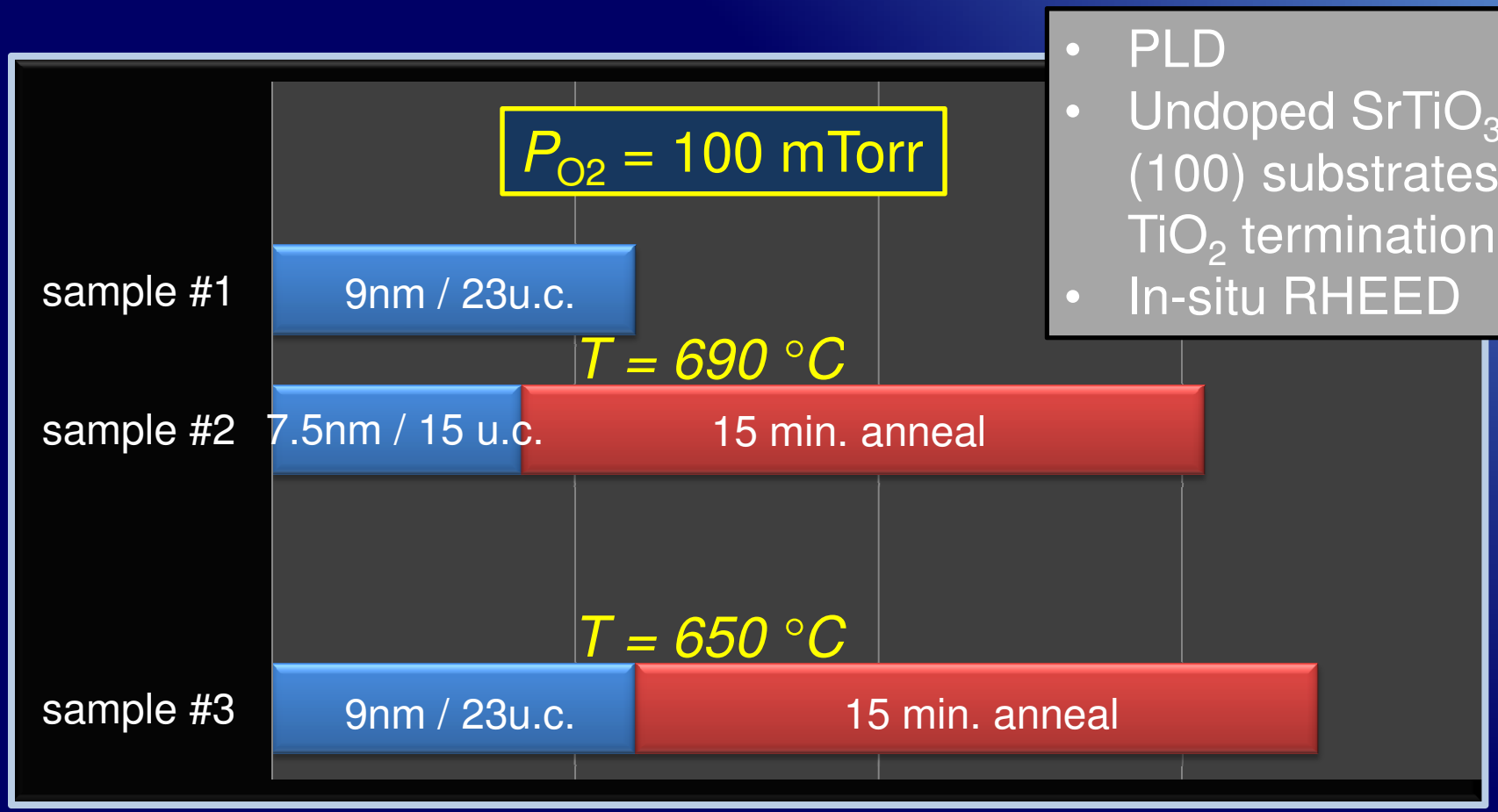
$SrRuO_3$

Widely used as a metal electrode

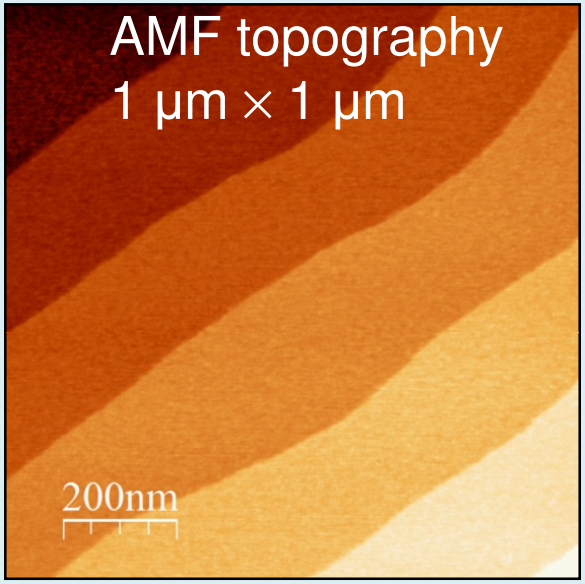
Samples



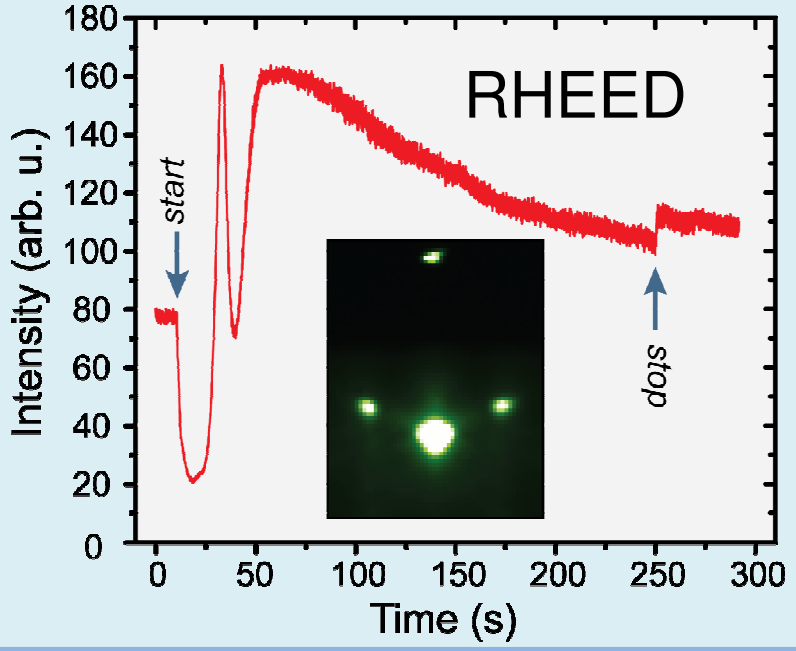
- PLD
- Undoped $SrTiO_3$ (100) substrates / TiO_2 termination
- In-situ RHEED

Transfer to the STM chamber right after film growth

Film growth



RMS Roughness = 55 pm



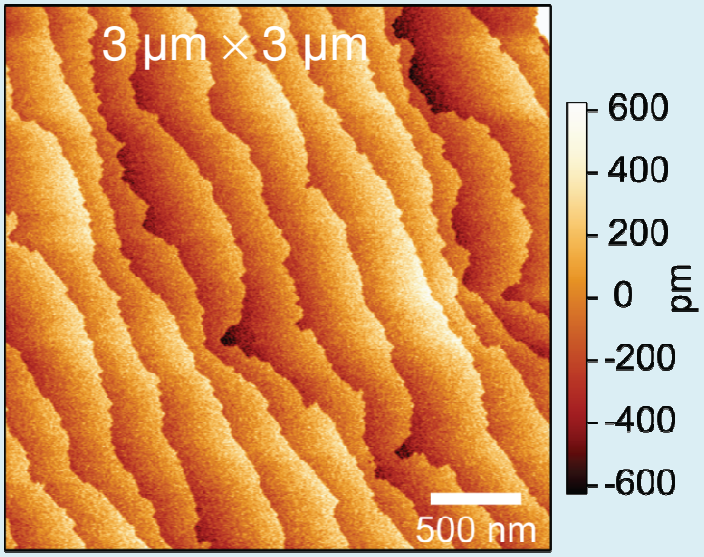
Substrate selection:
RMS roughness < 70 pm

Growth modes:

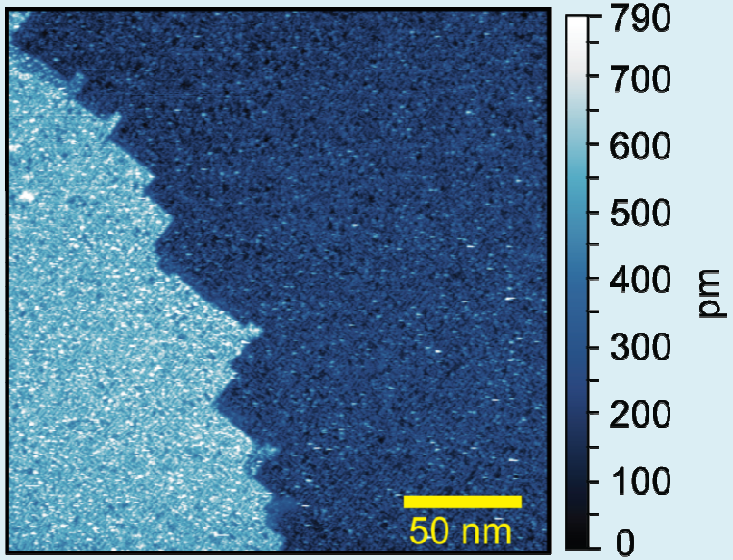
- 690 ℃ – step-flow
- 650 ℃ – step-flow/island-formation

Film surface: larger scale

ex-situ AFM (topography)

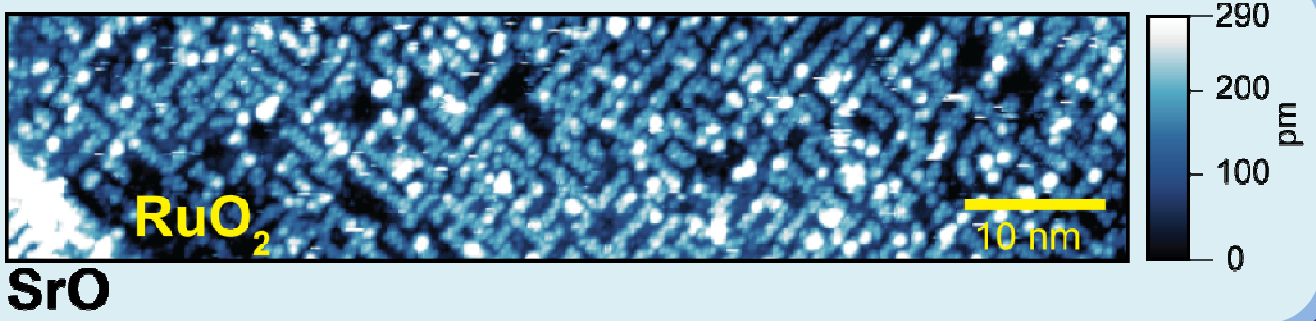


in-situ STM

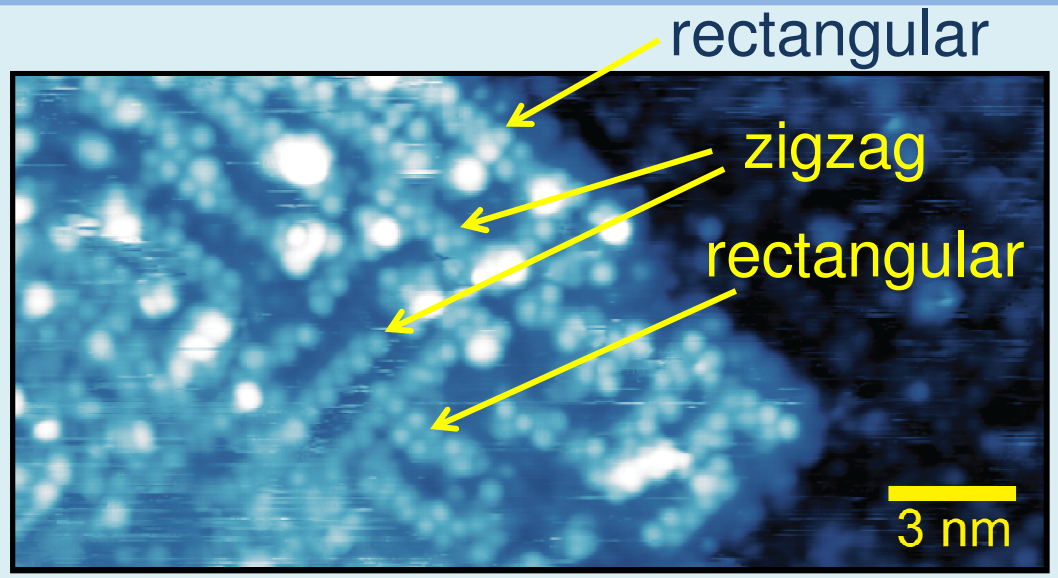


690 °C, no anneal

Competing surface patterns

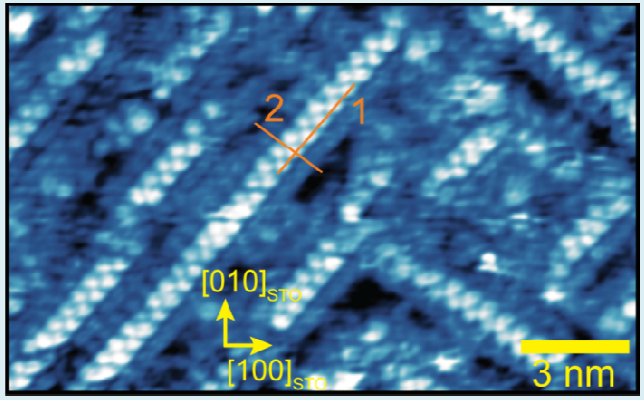


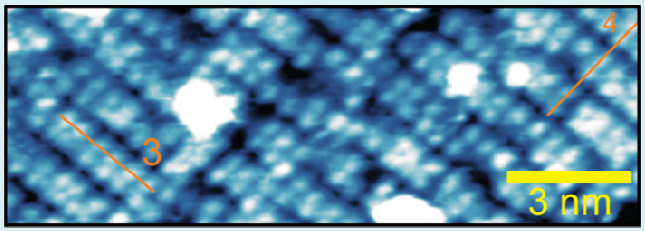
690 °C,
no ann.



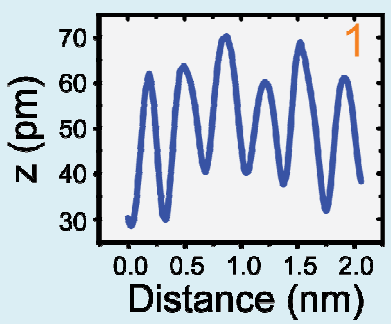
Zigzag and rectangular patterns

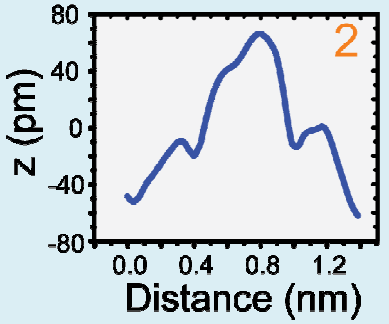
650 °C, ann.

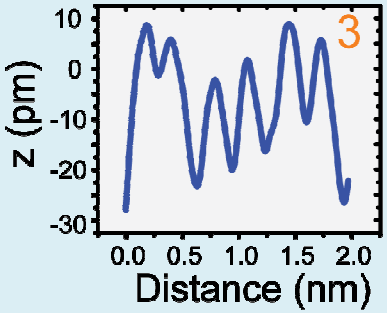


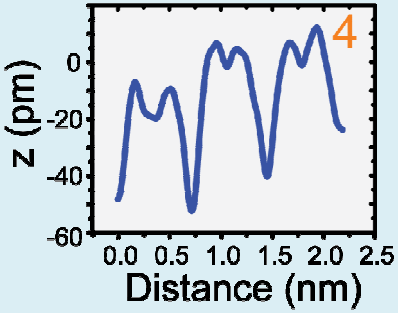


690 °C, ann.

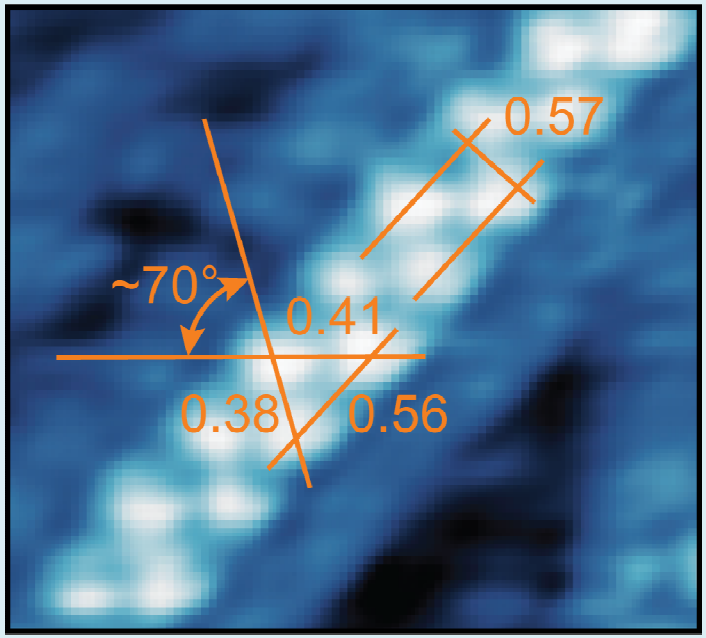




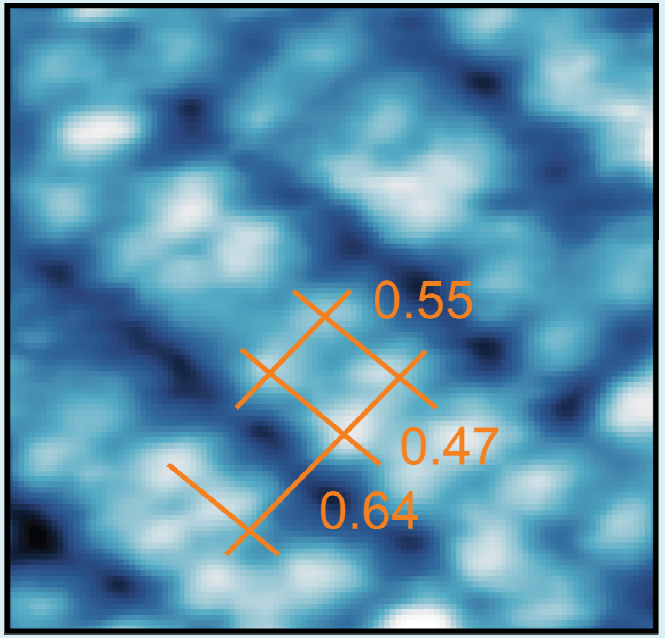




Zigzag and rectangular patterns

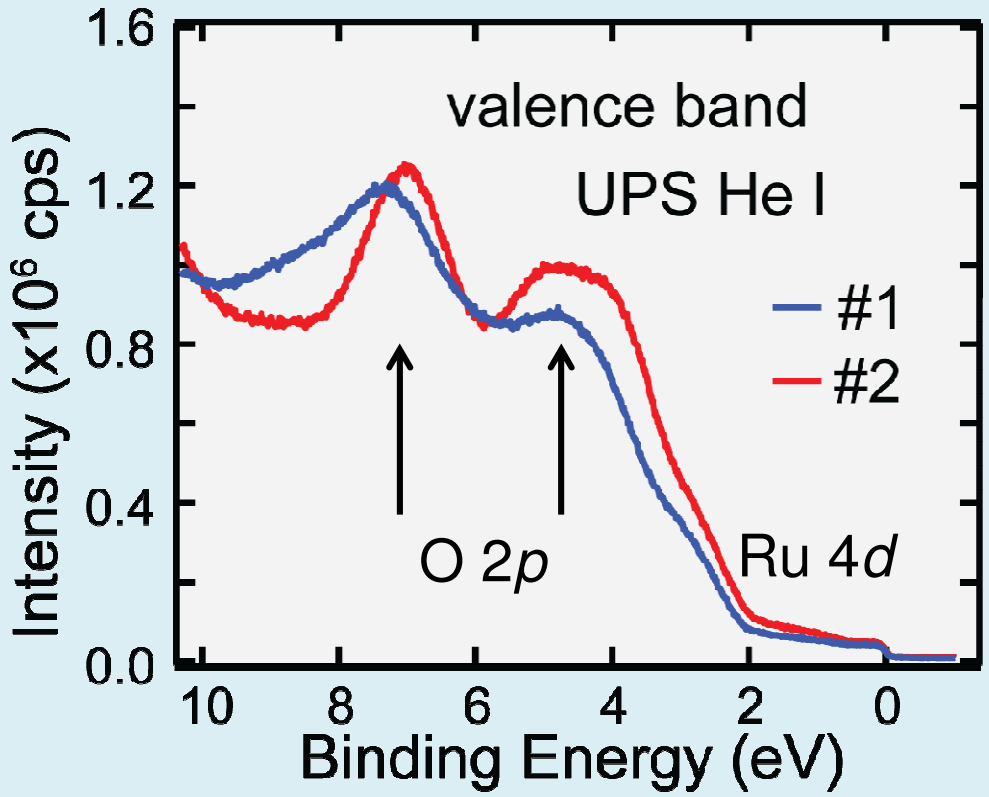


zigzag



rectangular

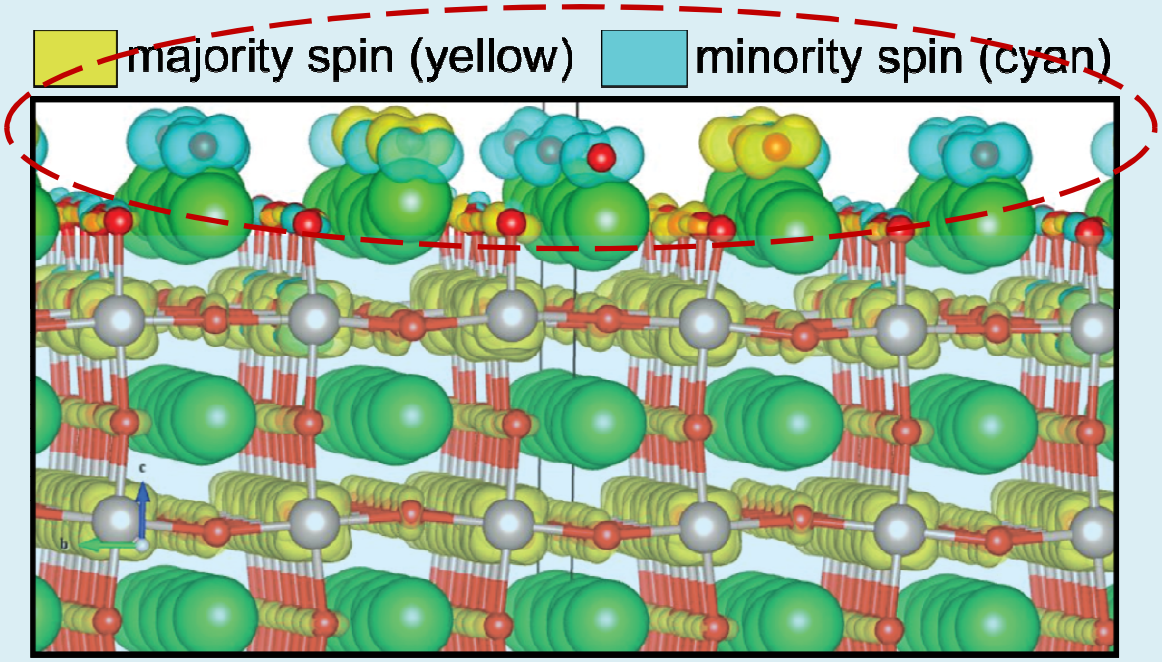
In-situ UPS



#2: rectangular

#1: zigzag

Surface spin-glass behavior



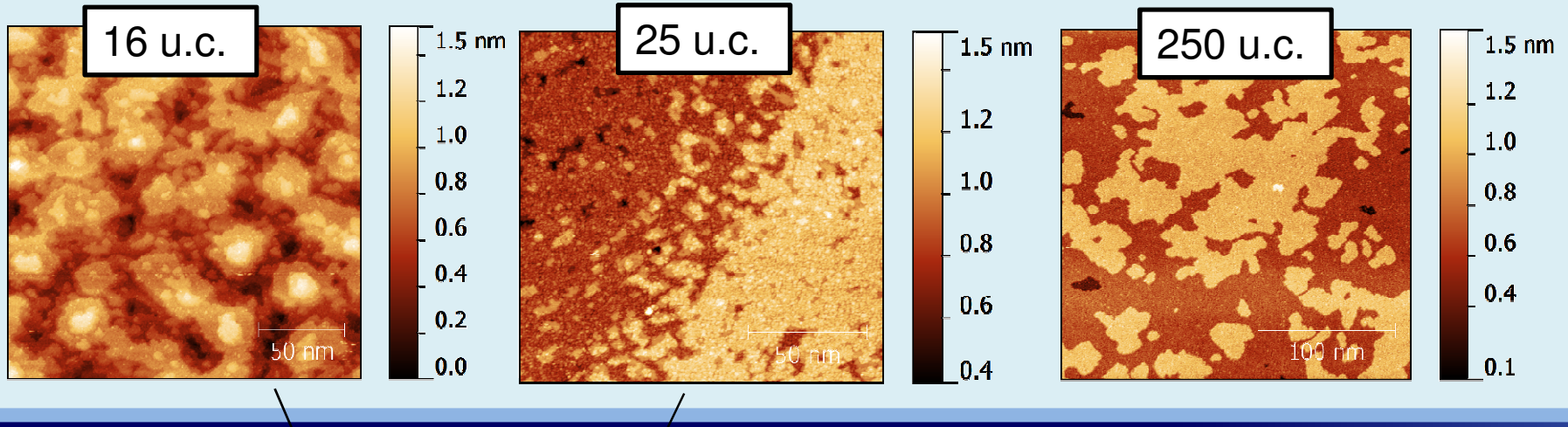
Isosurfaces of magnetization densities

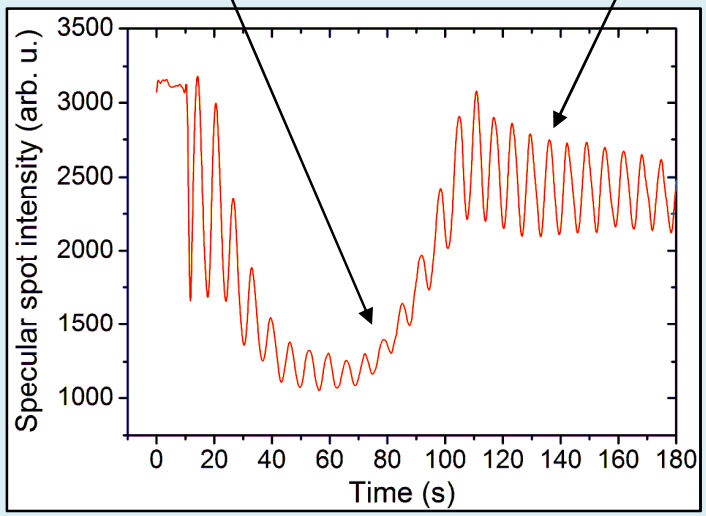
- Randomly oriented local spins from O_{ad} *p*-orbitals

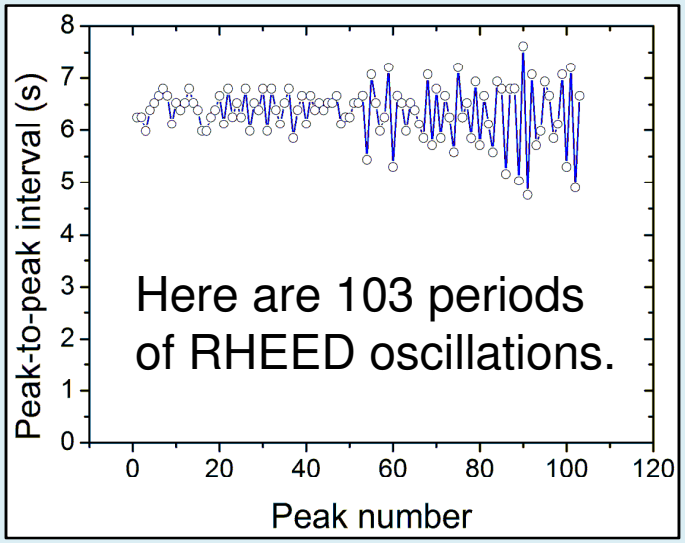
$La_{5/8}Ca_{3/8}MnO_3$

Classical *Colossal magnetoresistance* material

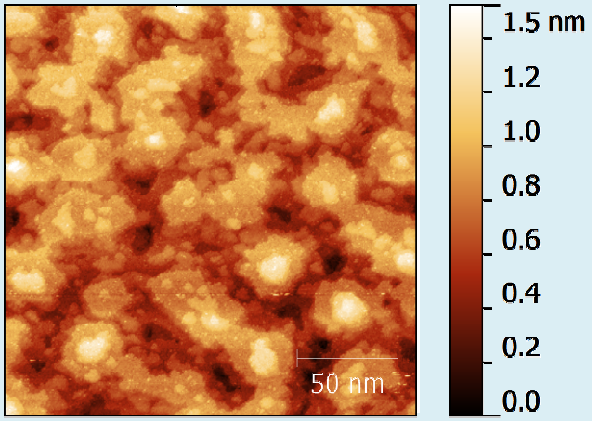
Evolution of surface morphology

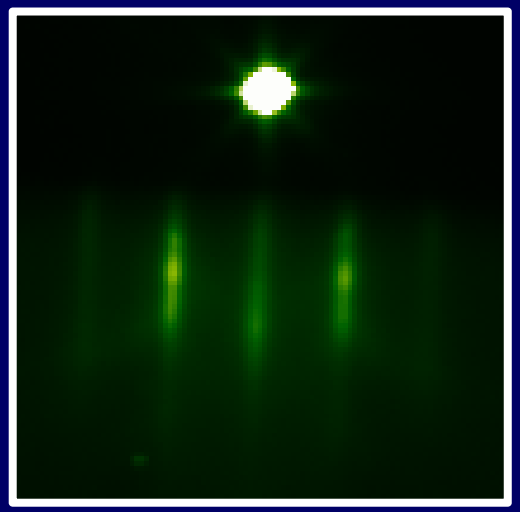


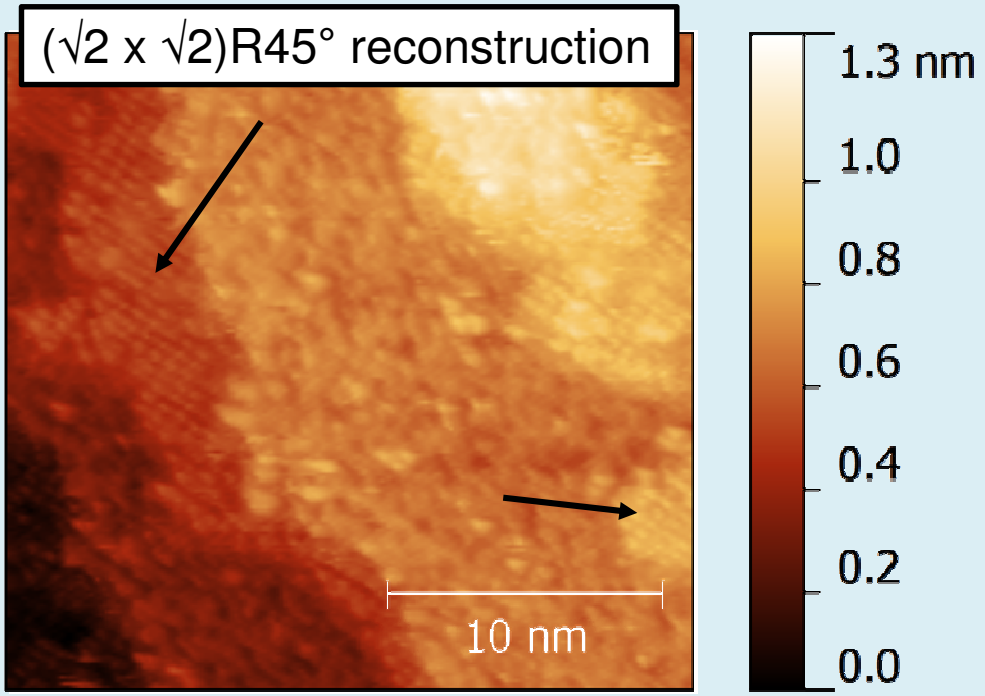




16 u.c. on $SrTiO_3$



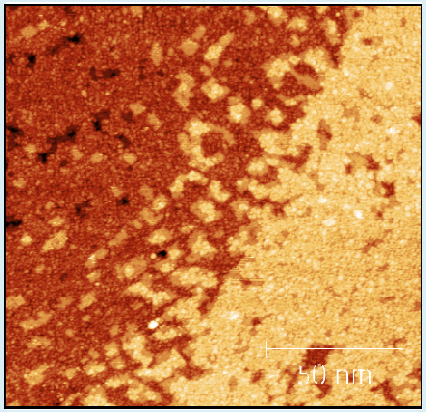


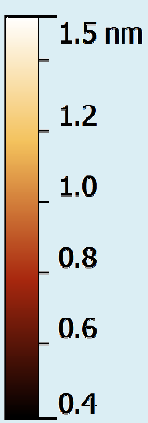


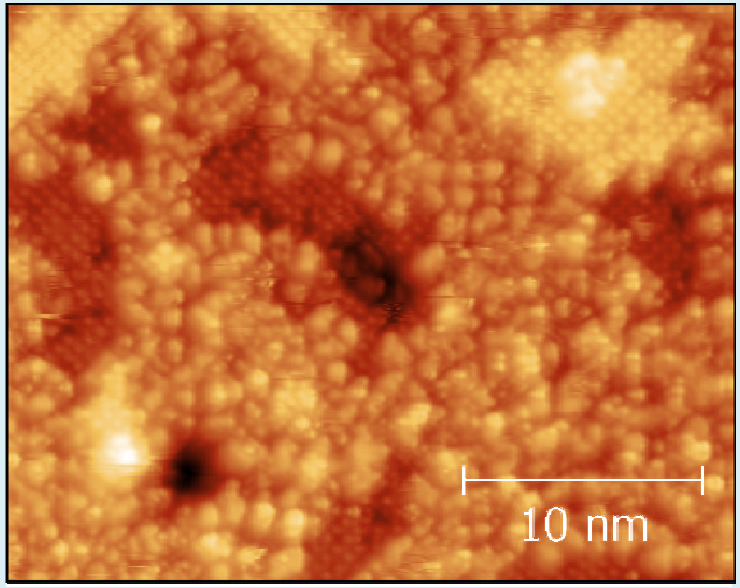
- Up to 7 u.c. layers can be seen.
- Two terminations: *ordered* and *disordered*.

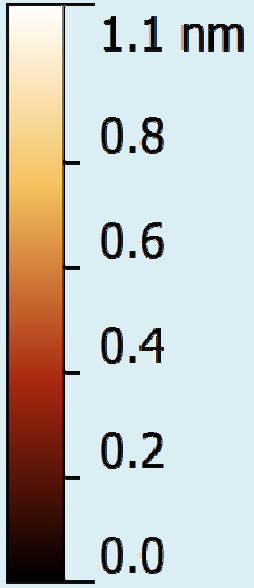
V_t = -1.8 V, I_t = 40-90 pA, T = 297 K

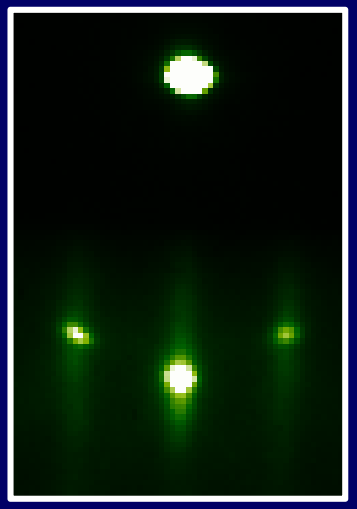
25 u.c. on $SrTiO_3$





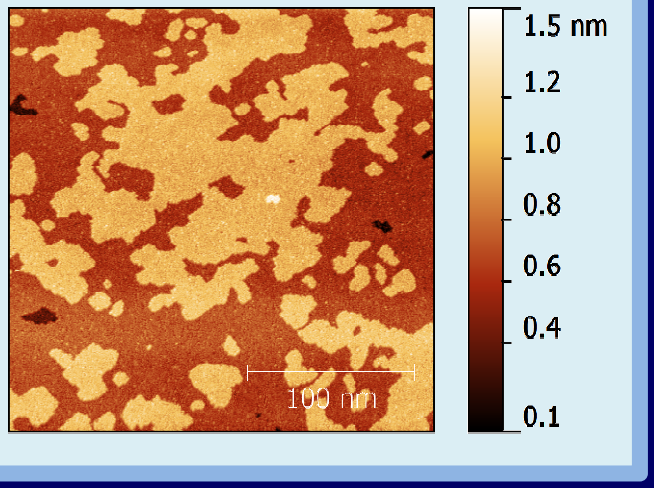


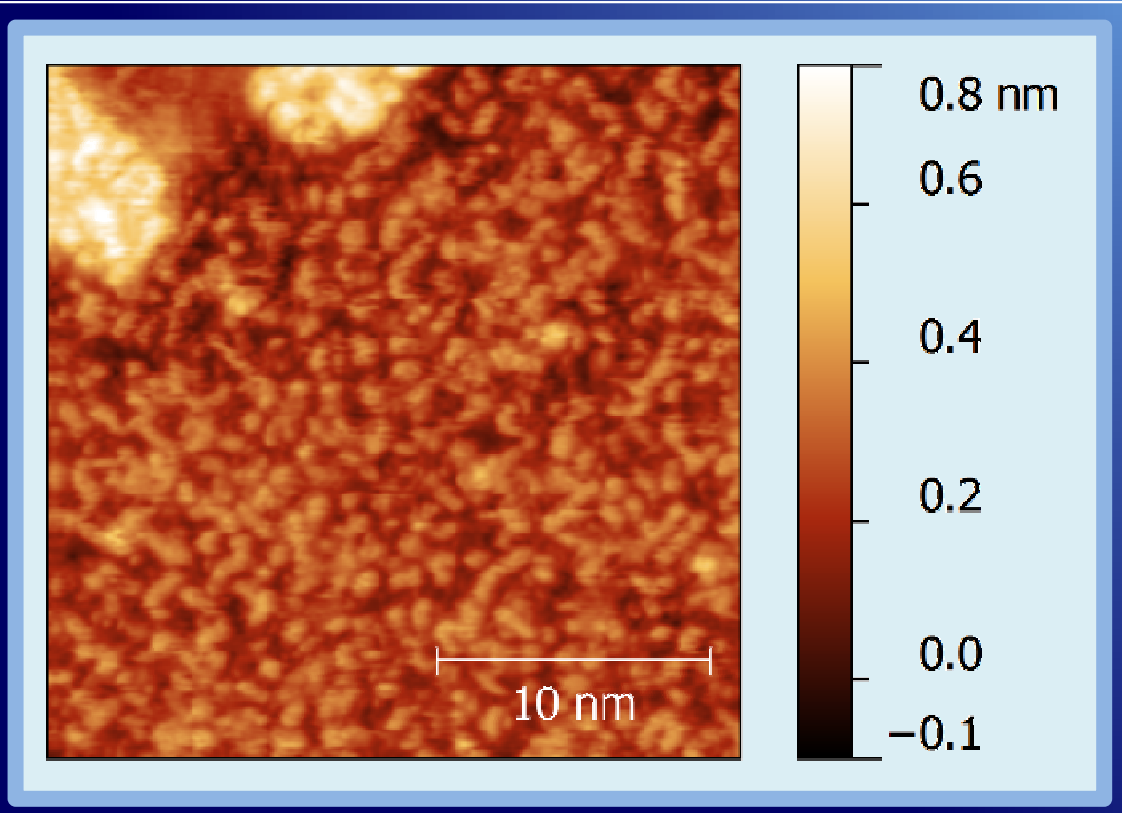


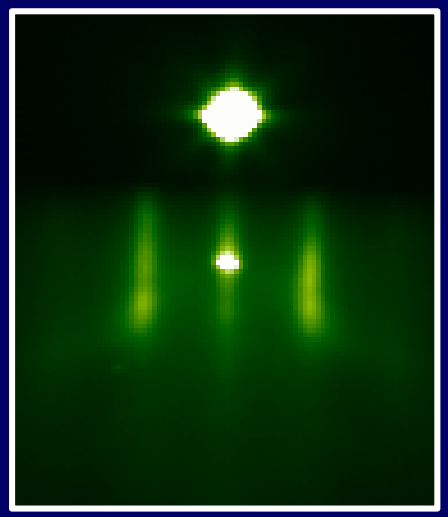


- Appear after anneals in oxygen (at 400 °C for 30 min.) as well as after fast cooling (150 °C/min.) to room temperature.
- No significant change after anneals in vacuum at 450 ° C for 30 min.

250 u.c. on $SrTiO_3$



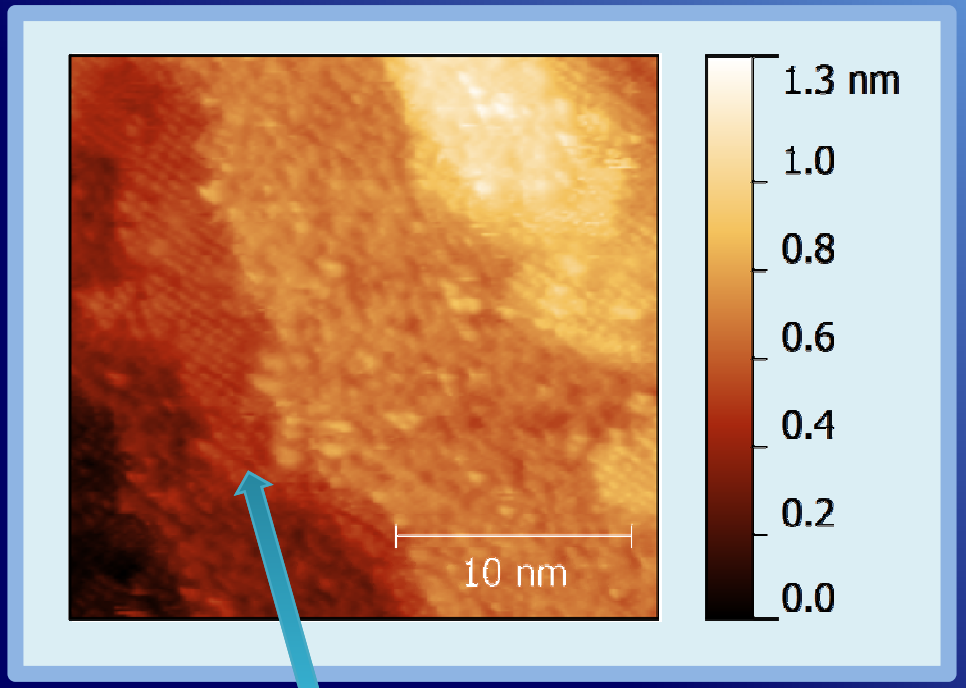




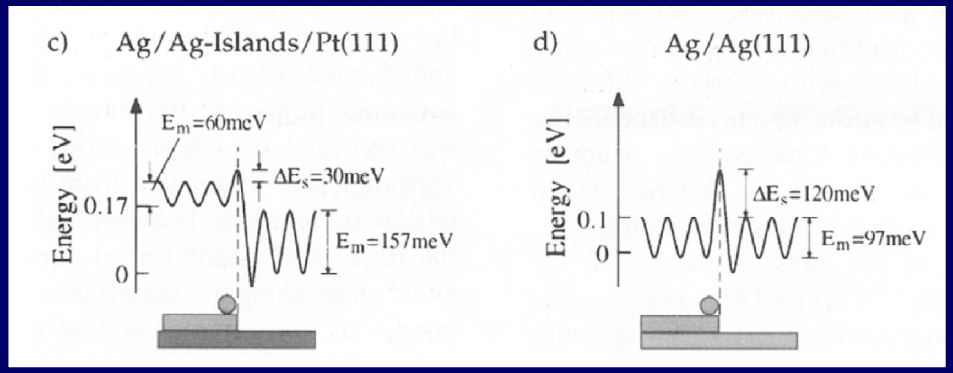
- Up to 3 u.c. layers can be seen.
- One termination: *disordered*.
- Nearly perfects layer-by-layer growth.
- X-ray: film is coherently strained to STO.

Interpretation of the growth evolution

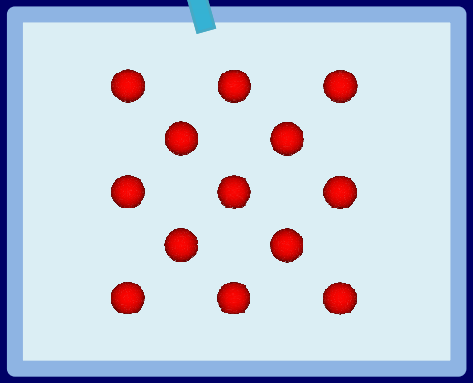
- Dependence of the barrier for interlayer adatom transport (Ehrlich-Schwoebel barrier) on strain.
- Tensile strain increases the barrier.



Ag-on-Pt (111) as an example

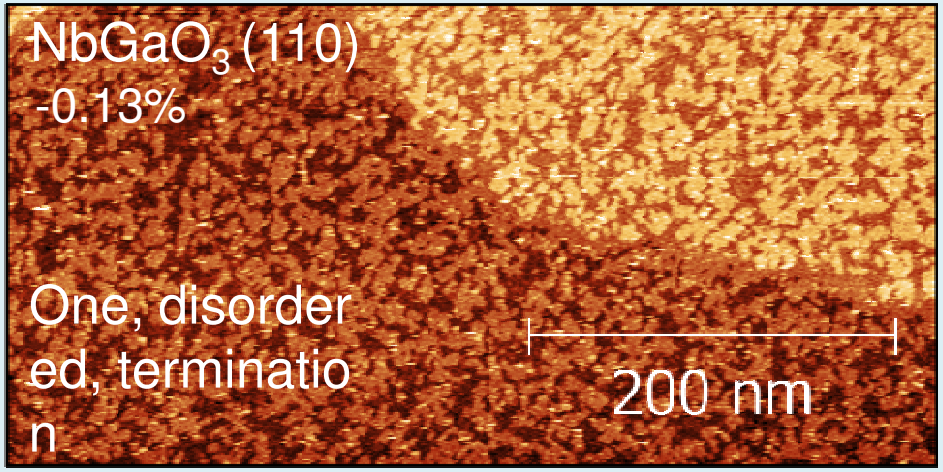


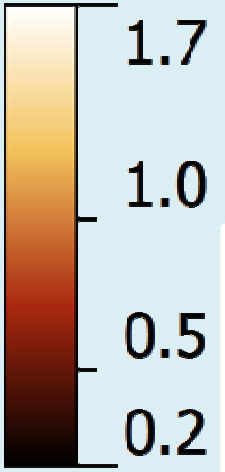
K. Bromann et al., PRL 75, 677 (1995)

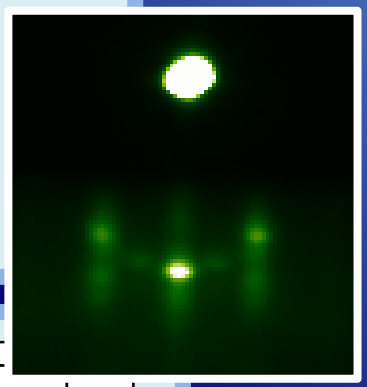


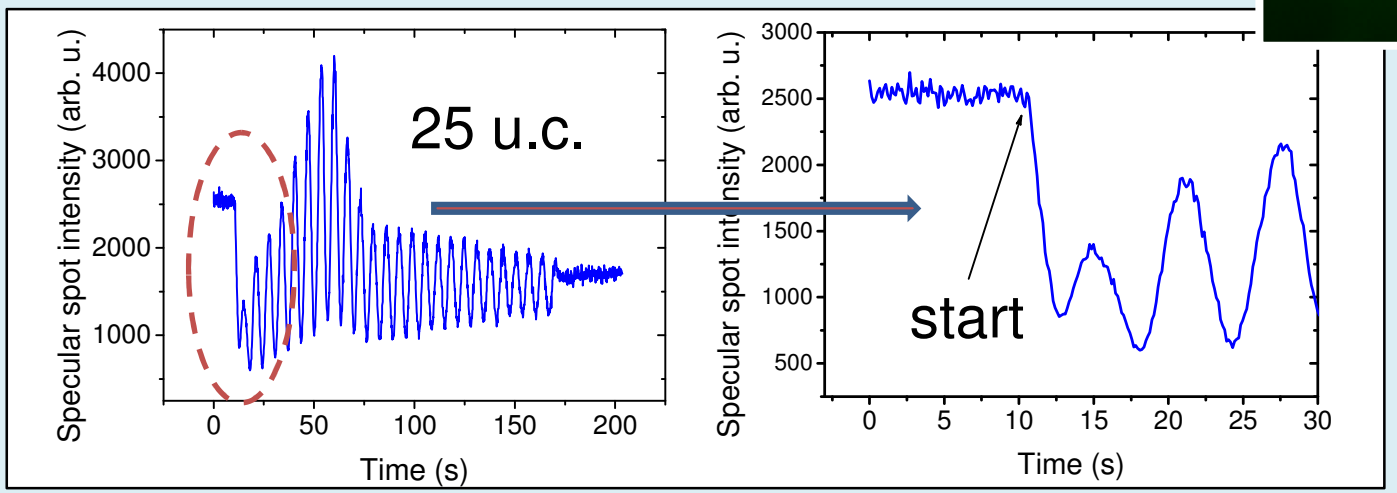
½ of oxygen atoms is visible on A-termination

25 u.c. on B-terminated $NbGaO_3$ – single termination









Acknowledgement

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- Division of Materials Sciences and Engineering, Office of Basic Energy Sciences, U.S. DOE
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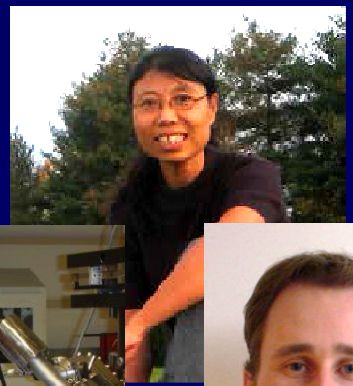
P. Ganesh

Lian Qiao

Zhen Gai



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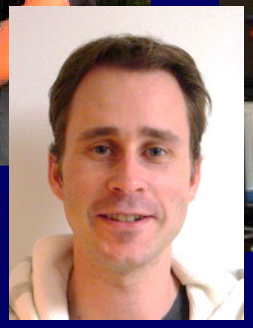

Wolter Siemons

Rama Vasudevan

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