Structural and electrical properties in superconducting $Sr_{0.85}La_{0.15}CuO_2$-based nanostructures

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Outline

1. Experimental motivation of the work - the electron-doped infinite-layer type $Sr_{1-x}La_xCuO_2$ high T_c superconductors

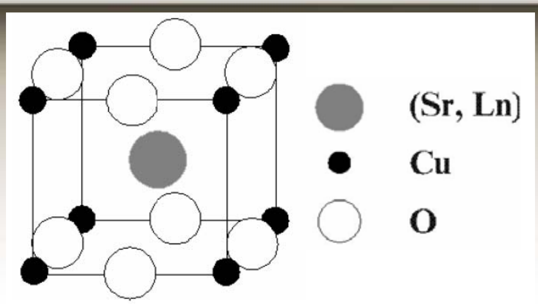
2. $Sr_{1-x}La_xCuO_2$ (x=0.10-0.20) thin films: PLD growth by the reduction method and characterization

3. Grain boundary $Sr_{1-x}La_xCuO_2$ (x=0.15) Josephson junctions

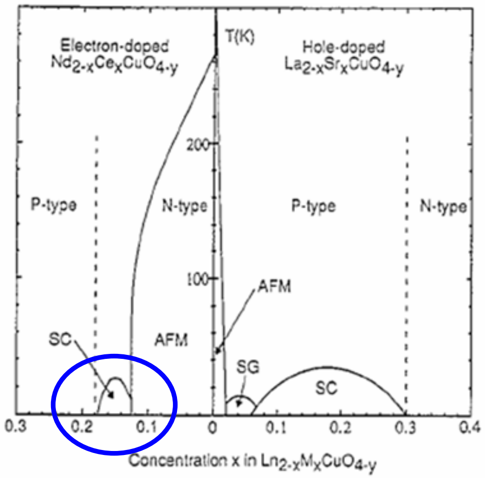
4. Preliminary results on the $Sr_{1-x}La_xCuO_2$/Au/Nb ramp-type junctions

5. Conclusions

The $Sr_{1-x}La_xCuO_2$ (SLCO) compounds

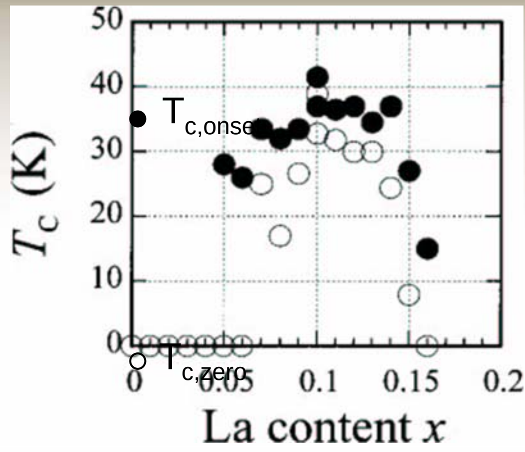


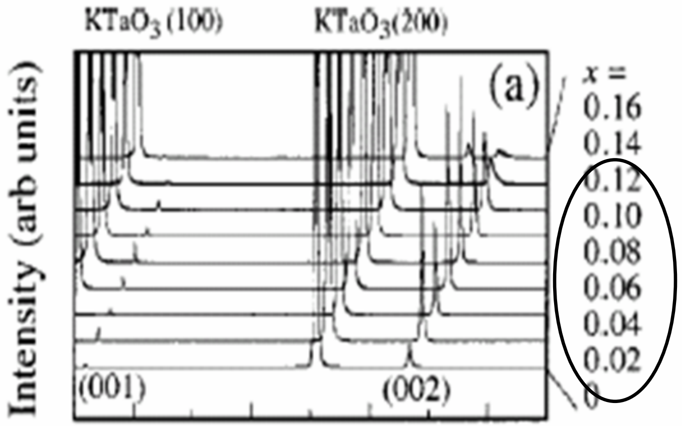
$Sr_{1-x}La_xCuO_2$
-infinite-layer type structure
- $T_{c,max}$ = 43 K



T_c vs. dopant concentration phase diagram for T'-$Ln_{2-x}Me_xCuO_4$

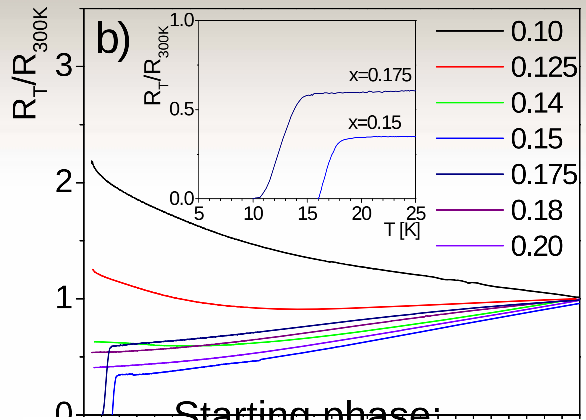
MBE growth on (001) $KTaO_3$
(reduction method)





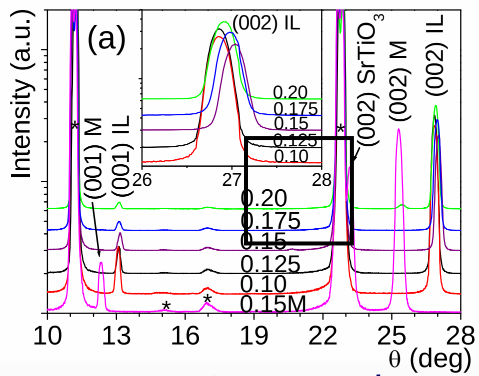
Karimoto et al.
Appl. Phys. Lett. 79 (2001)

PLD growth on (001) $KTaO_3$
(oxidation method)



Starting phase:

$$2\sqrt{2}a_p \times 2\sqrt{2}a_p \times c \text{ (super)structure}$$

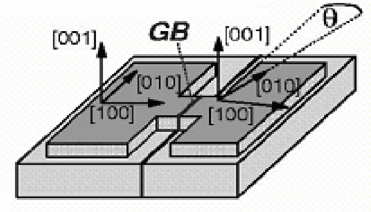


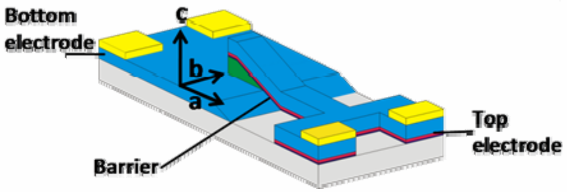
Leca et al.
Appl. Phys. Lett. 89 (2006)

Motivation of the work

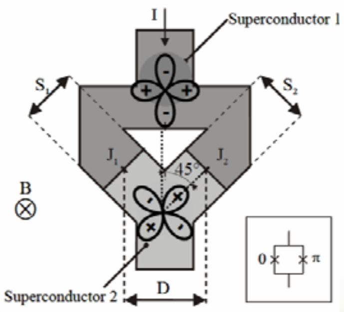
1. *Studies on the $Sr_{1-x}La_xCuO_2$ (x=0.10-0.175) thin films: growth and characterization; PLD growth of SLCO thin films on different substrates: (001) $SrTiO_3$, (001) $KTaO_3$, and (110) $DyScO_3$ – role of the epitaxial strain on structural and transport properties*

2. *Fabrication of the grain-boundary Josephson junctions on $BaTiO_3$ buffered $SrTiO_3$ and studies of their transport properties (for x=0.125-0.15)*





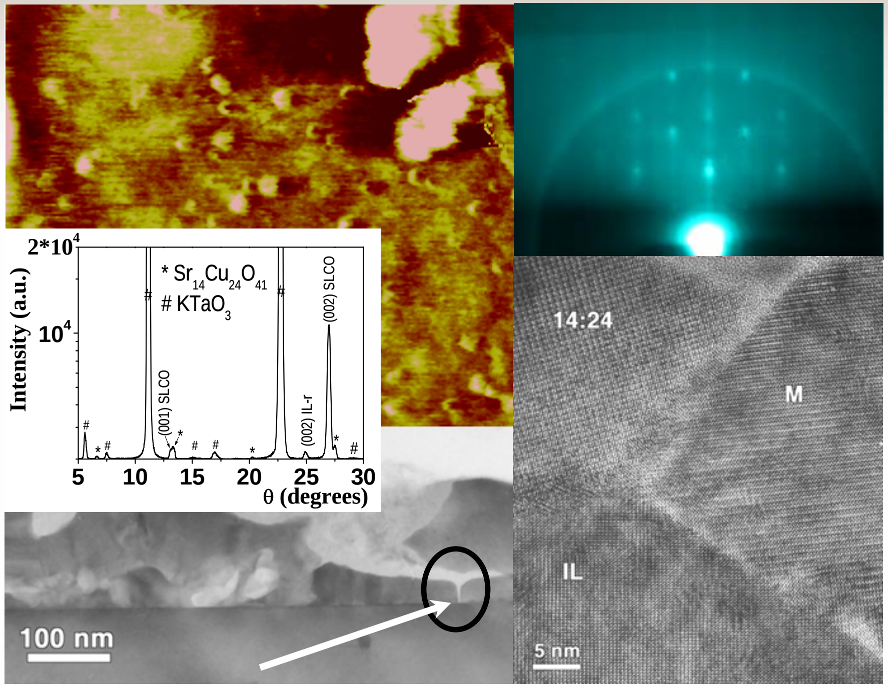
3. *Development of the ramp-type $Sr_{1-x}La_xCuO_2$/Me/Nb (Me=Ag, Au) Josephson junction technology and studies on junctions transport properties (for x>0.15)*



4. *Studies on the order parameter symmetry – based on GB (tetracrystal) or ramp-type Josephson junctions for different La doping levels (x=0.10-0.175) and temperatures (2 K-T_c)*

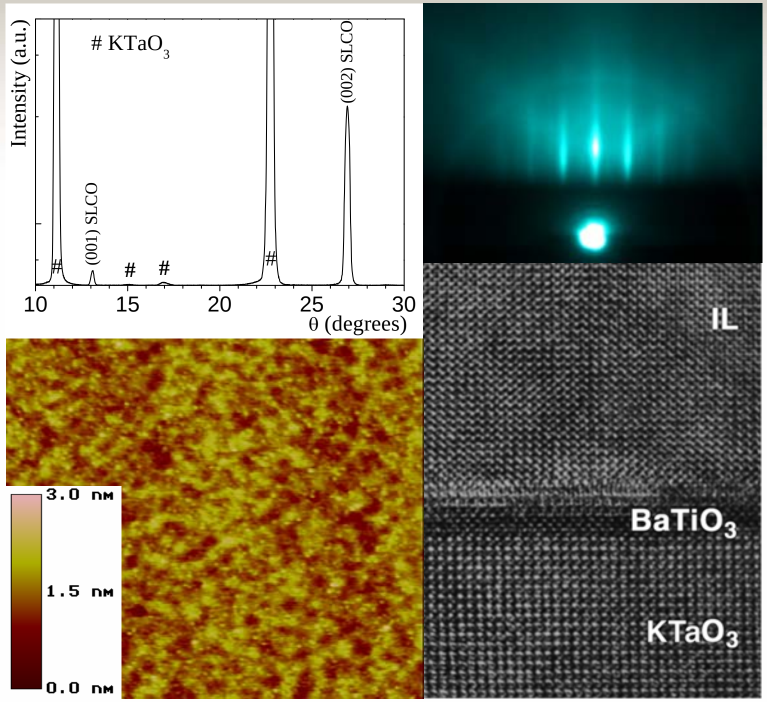
Role of the substrate-film interface

$Sr_{1-x}La_xCuO_2$ grown on as-received (001) $KTaO_3$



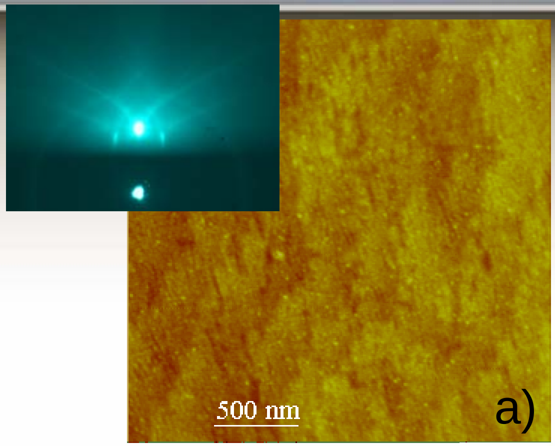
XRD, HRTEM: Structural defects/secondary phases developing at the substrate-film interface
RHEED, AFM: 3D growth mode induced by the high interface roughness

$Sr_{1-x}La_xCuO_2$ grown on $BaTiO_3$-buffered (001) $KTaO_3$

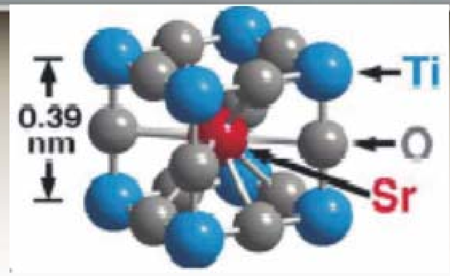


XRD, HRTEM, AFM: single-phase, lower density of structural defects, improved morphology
RHEED, AFM: 2D growth mode

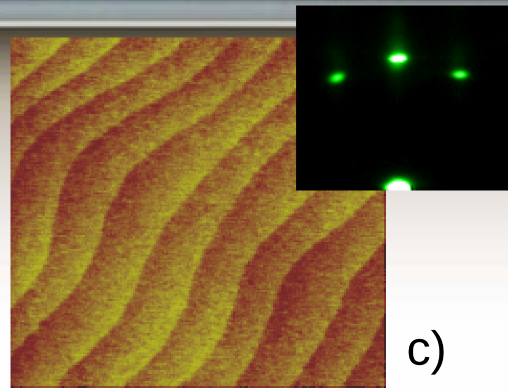
Substrate morphology – $SrTiO_3$

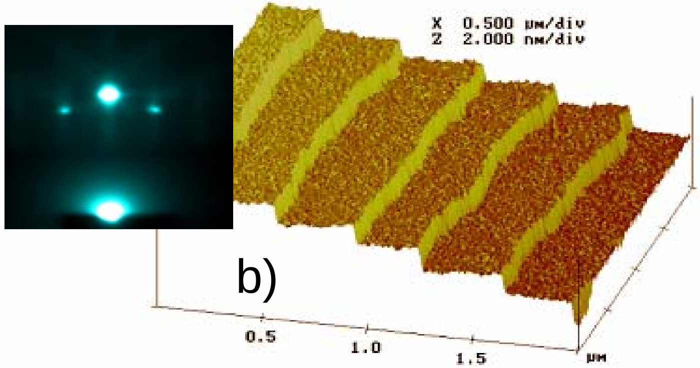


a)

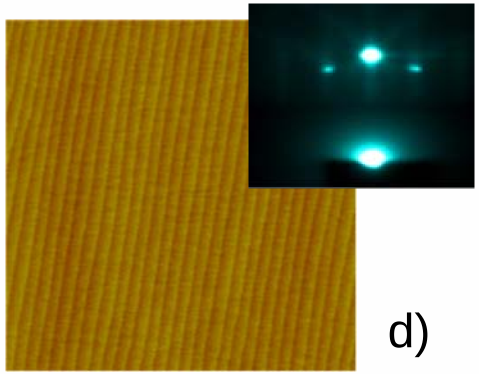


$SrTiO_3$ structure


c)



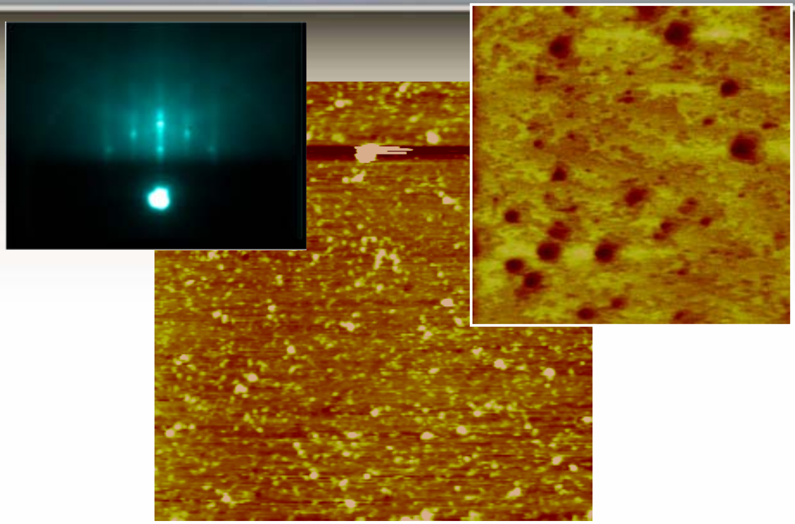
b)


d)

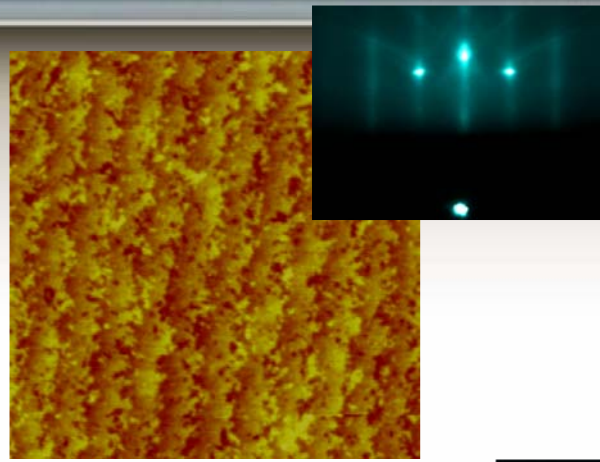
a) as-received substrate
b) after chemical treatment (BHF) and annealing ($950^oC/1h/O_2$) - TiO_2 termination
c) after annealing ($950^oC/1h/O_2$) - SrO termination
d) after chemical treatment (BHCl) and annealing ($950^oC/1h/O_2$)-TiO_2 termination (high miscut angle case)

Kawasaki et al. Science 226 (1994)
Koster et al. Appl. Phys. Lett 73 (1998)
Leca, PhD thesis (2003)

Substrate morphology – $KTaO_3$

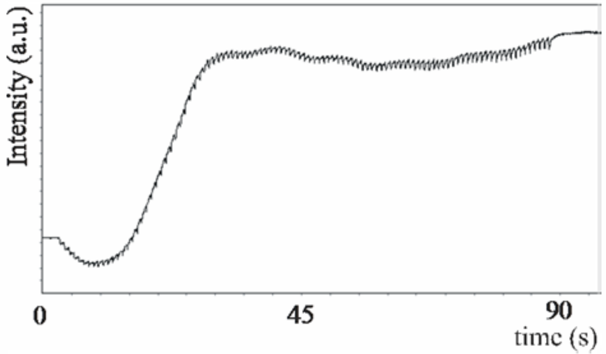


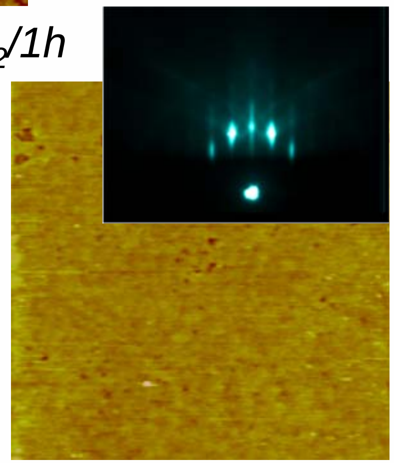
as-received substrate



after annealing at 750^{o}C/O_2/1h

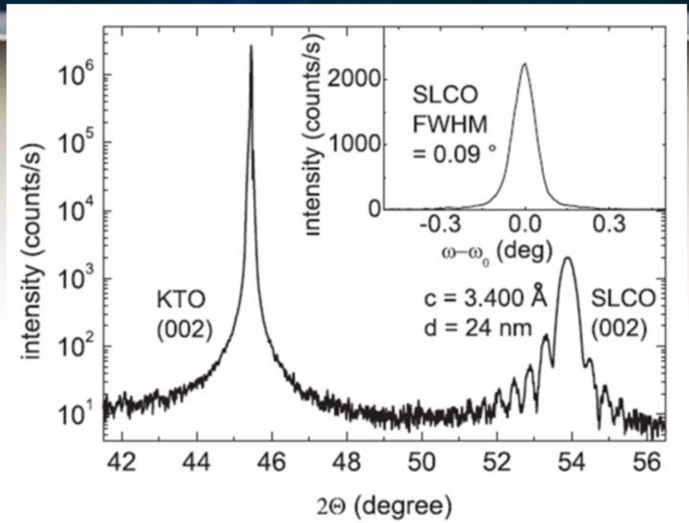
$KTaO_3$: new methods required



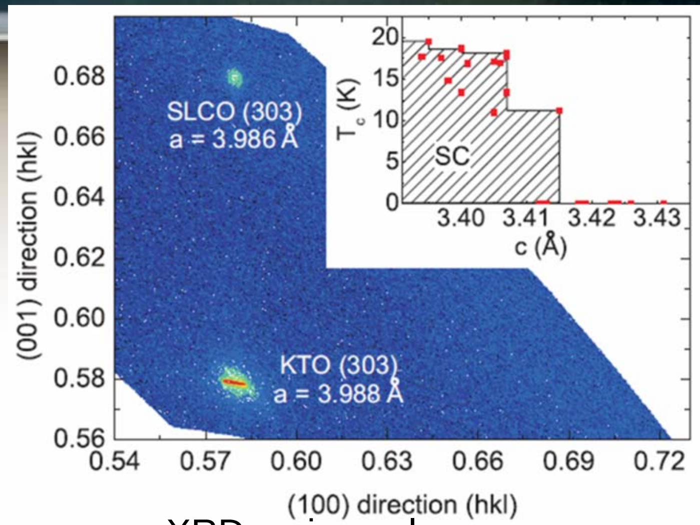


"surface healing": $BaTiO_3$ on $KTaO_3$ –
RHEED intensity evolution and AFM of the resulted surface

$Sr_{1-x}La_xCuO_2$ (x=0.15) grown on $KTaO_3$ (001)

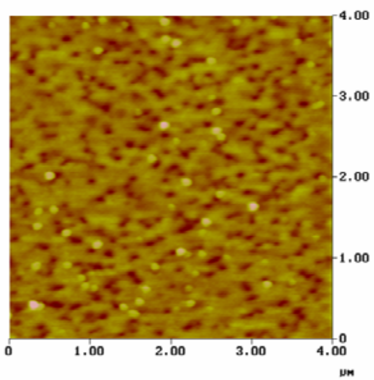


2θ/ω XRD scan of (002) SLCO/KTO

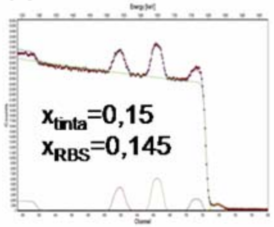


XRD reciprocal space map

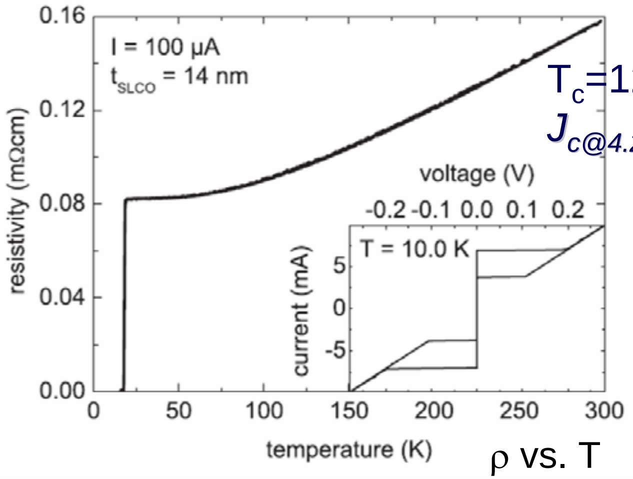
a_{SLCO}~3.978-3.988 Å
c_{SLCO}~3.395-3.405 Å



AFM image



RBS



ρ vs. T

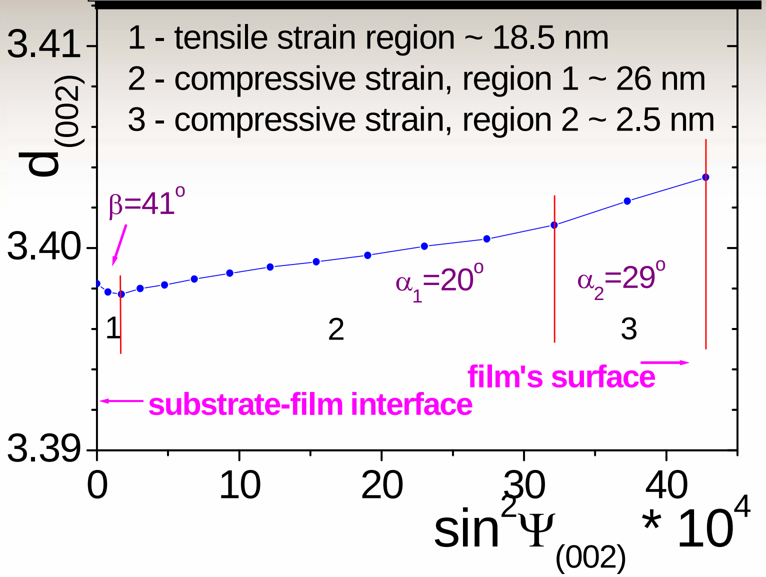
T_c=12-25 K;
$J_{c@4.2K}$~2.2×10^6 A/cm^2

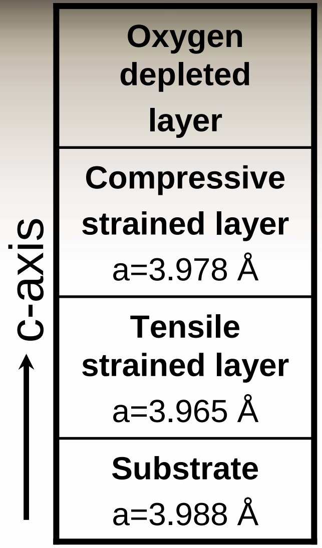
Growth parameters:
$Sr_{0.85}La_{0.15}CuO_2$ (SLCO): T_d=575°C, P_d=0.30 mbar O_2; E_d=2 J/cm^2; 20 min/550°C/10^{-7} mbar
films thickness: 15-50 nm;

Tomaschko, Leca, Selistrovski, Diebold, Jochum, Kleiner, Koelle, Physical Review B 85 (2012)

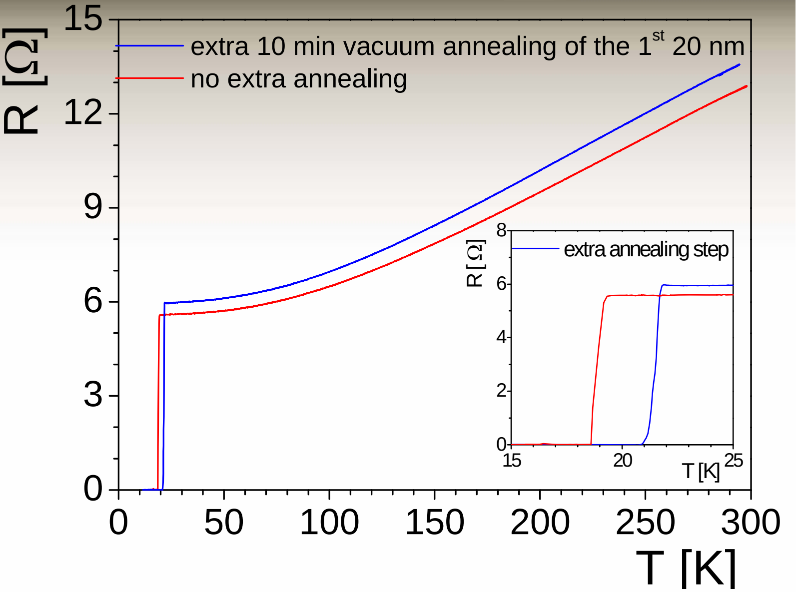
Role of the epitaxial strain

strain evolution in c-axis direction





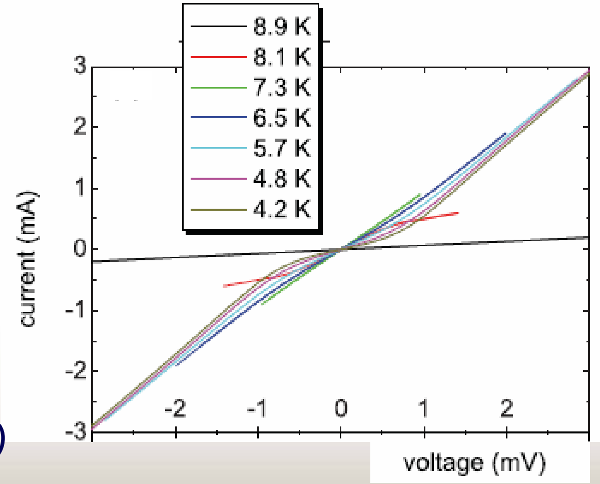
SLCO on $KTaO_3$



Strain dependence of R vs. T

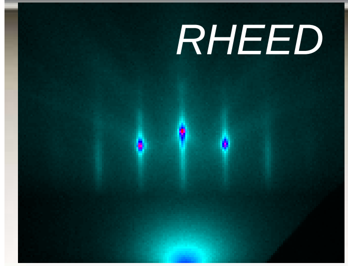
***XRD and XPS**: existence of an oxygen depleted top layer;*
- implications: no Copper pair tunneling in planar SLCO/Au/Nb junctions

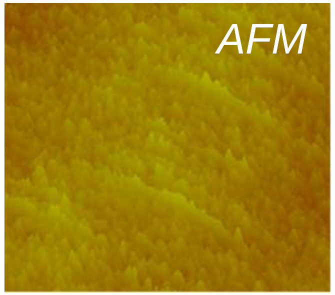
***XRD**: two types of strain: tensile (@ substrate-film interface) and compressive, on top*

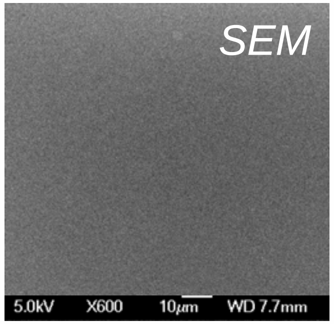


Tomaschko et al., PRB 84 (2011)

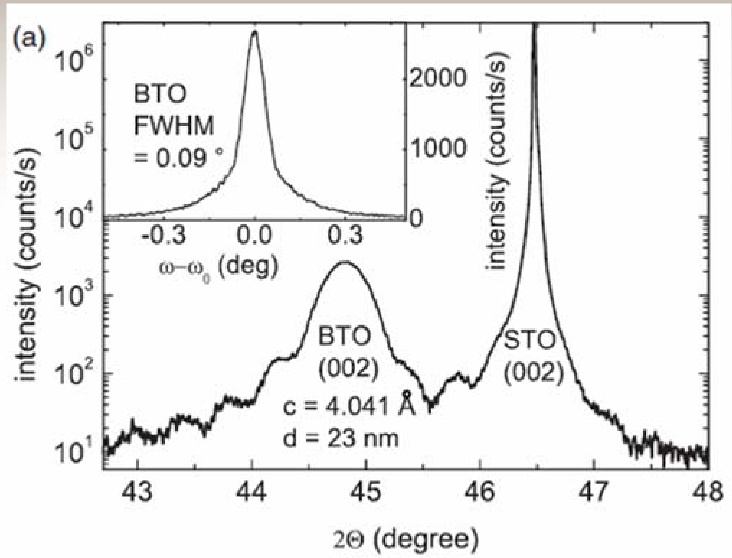
$Sr_{1-x}La_xCuO_2$ (x=0.15) grown on $BaTiO_3/SrTiO_3$ (001)



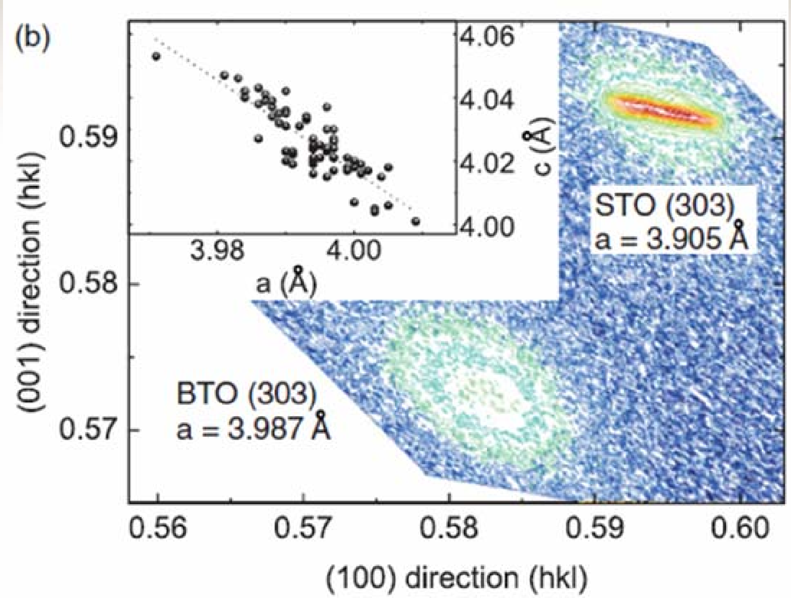




The $BaTiO_3$ buffer layer



$2\theta/\omega$ XRD scan of (002) BTO/STO

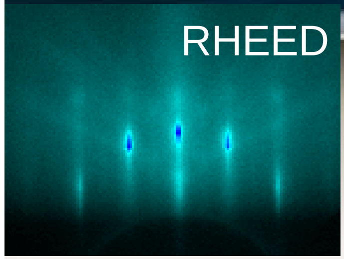


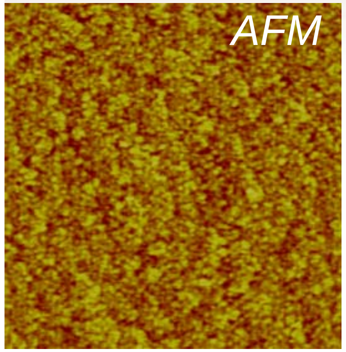
XRD rsm of (303) BTO/STO

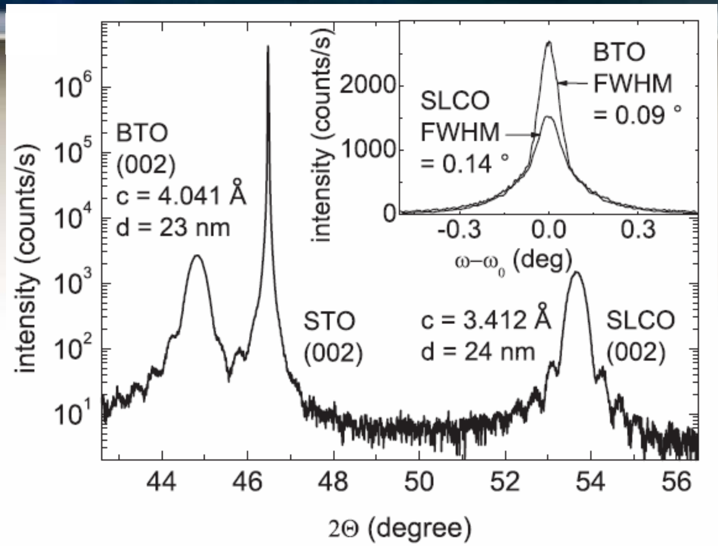
Deposition conditions for $BaTiO_3$:
T_d=750°C, P_d=0.10 mbar O_2, E_d=1.75 J/cm²; 30 min/950°C/10^{-7} mbar

Tomaschko, Leca, Selistrovski, Diebold, Jochum, Kleiner, Koelle, Phys. Rev. B 85 (2012)

$Sr_{1-x}La_xCuO_2$ (x=0.15) grown on $BaTiO_3/SrTiO_3$ (001)

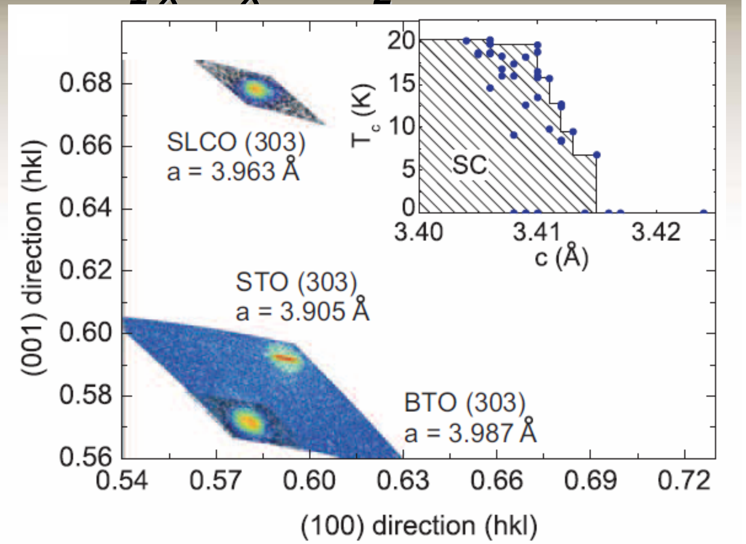




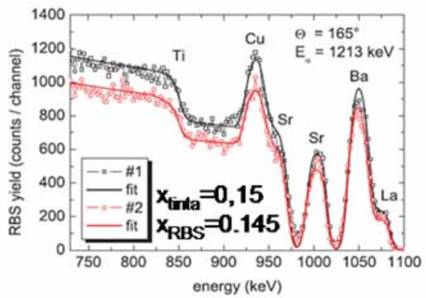


2θ/ω XRD scan of (002) planes

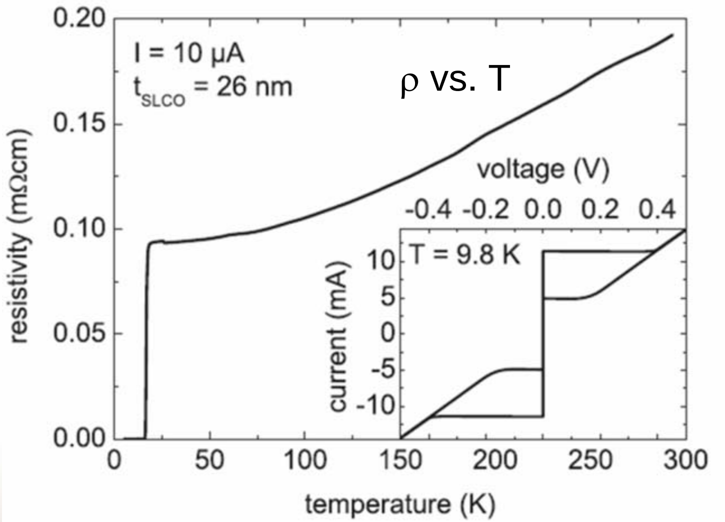
$Sr_{1-x}La_xCuO_2$ films



XRD rsm of (303) SLCO/BTO/STO



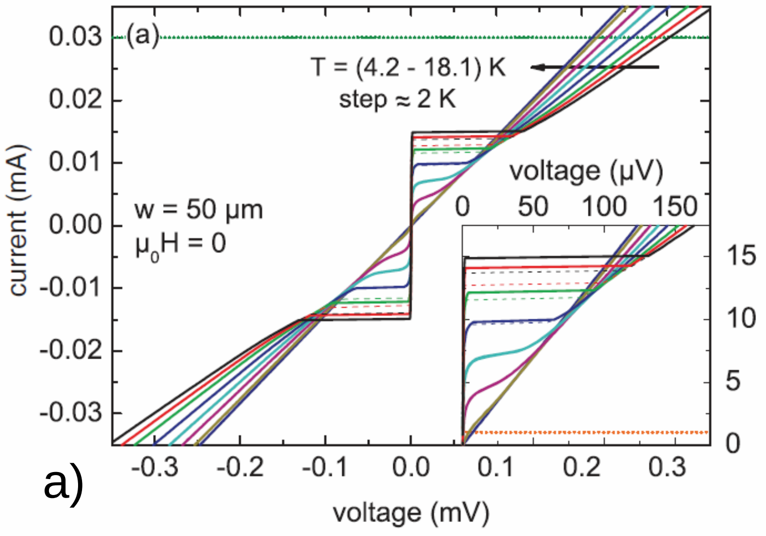
RBS

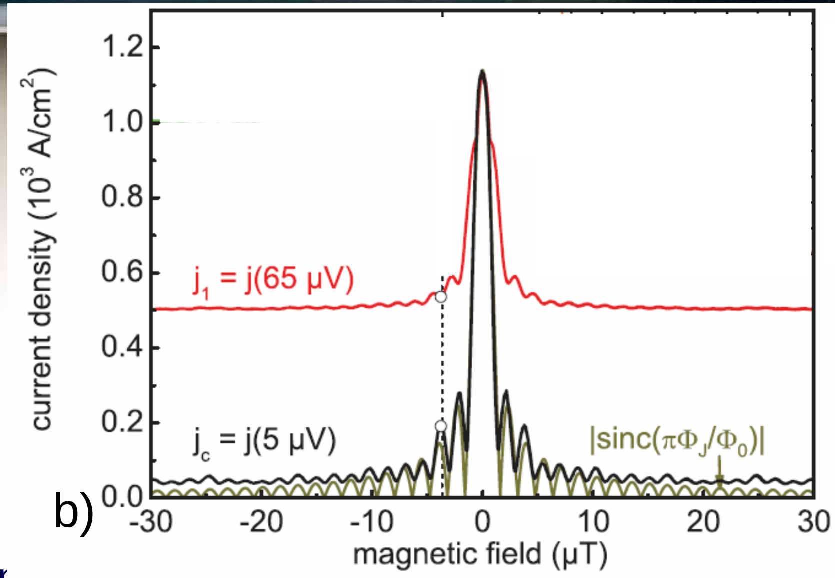


Deposition conditions:
T_d=550°C, 0.40 mbar O_2;
50 min/550°C/10^{-7} mbar
$T_{c,0}$=12-21 K
$J_{c@4.2K}=2.1\times10^6$ A/cm²

Tomaschko, Leca, Selistrovski, Diebold, Jochum, Kleiner, Koelle, Phys. Rev. B 85 (2012)

$Sr_{1-x}La_xCuO_2$ 24^o symmetric grain boundary junctions

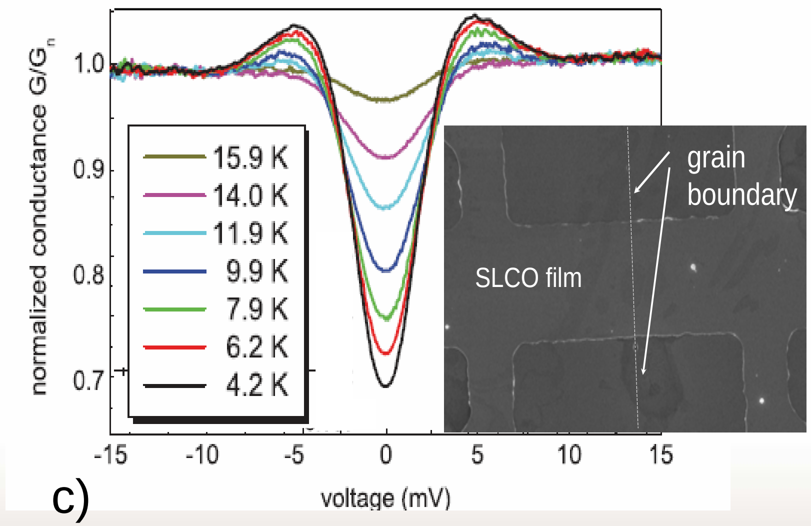




a) ICVs: resistively and capacitively shunted junction (RCSJ)-like, with no significant excess current;
- J_c (@ 4.2 K) ~ 1.2 kA/cm^2 – 1-2 orders of magnitude above J_c of 24^o GB based on NCCO and LCCO

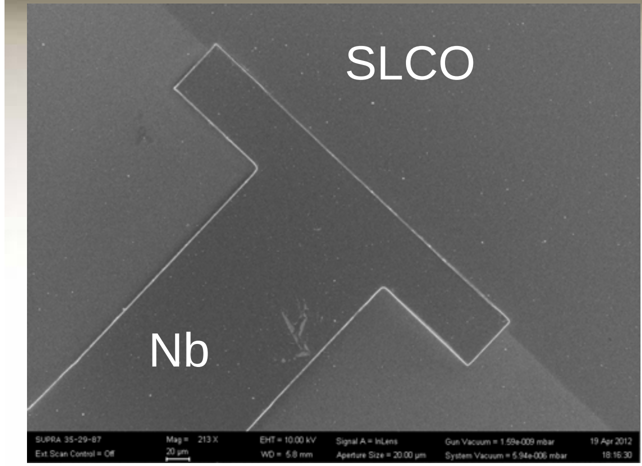
b) highly regular Fraunhofer-like patterns for different voltage criterion

c) conductance spectra did not show a zero-bias conductance peak. s-wave symmetry?
but the V-shaped of the spectra in the subgap regime may indicate an order parameter with nodes

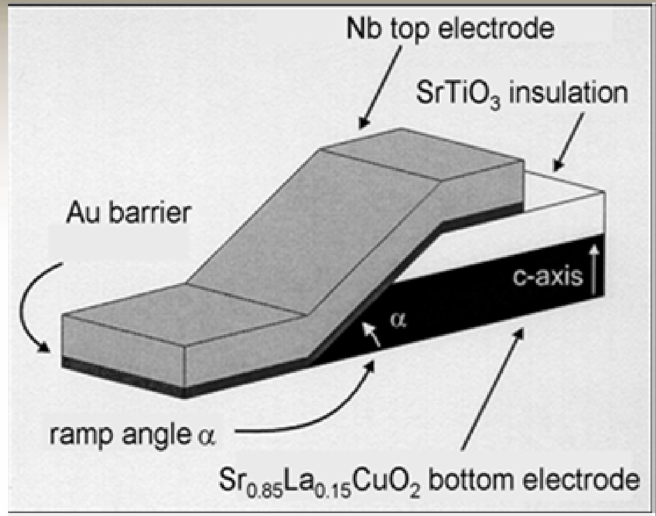


Tomaschko, Leca, Selistrovski, Kleiner, Koelle, Phys. Rev. B 84 (2011)

$Sr_{1-x}La_xCuO_2$ ramp-type junctions – preliminary data

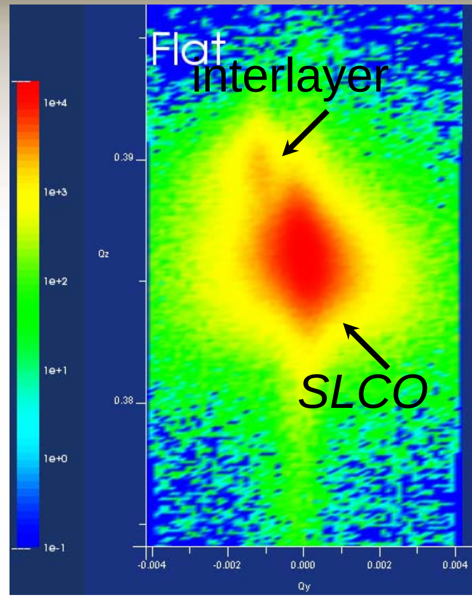


SEM image of a 200μm wide SLCO/Au/Nb ramp-type junction

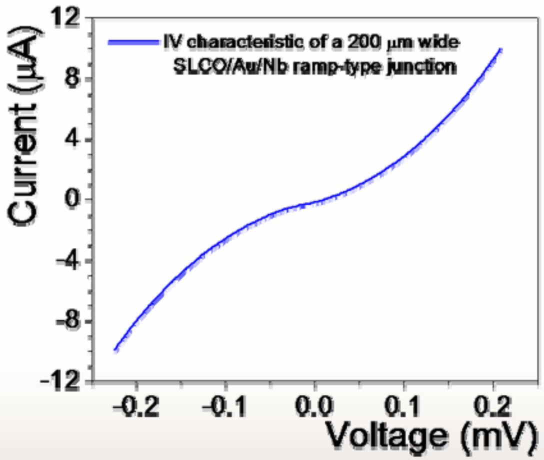


Schematic representation of the SLCO/Au/Nb ramp-type junction

(Smilde et al., APL 80)



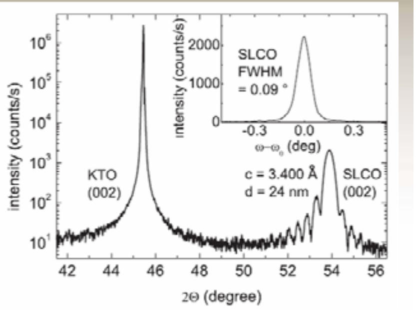
XRD rsm scan of (101) showing the separation of the SLCO and interlayer peaks



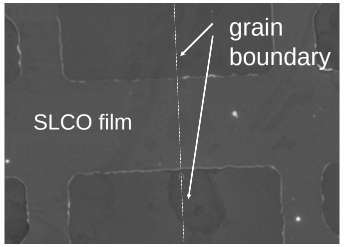
No Cooper pair tunneling observed
- rough SLCO/Au interface

Conclusions

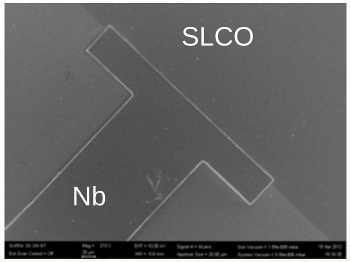
- single-crystal like thin films of the electron-doped $Sr_{1-x}La_xCuO_2$ compounds could be grown by PLD for x=0.15, but their superconducting properties (highest T_c of 25 K) are still far of those of the bulk or of the MBE grown films, but with better structural characteristics than the MBE films ⟹ improving T_c



- epitaxial strain controls the final structural and transport properties of the films grown on $BaTiO_3$/$SrTiO_3$ or $KTaO_3$ ⟹ new substrates (like $MeScO_3$)?



- first 24° [001] tilt grain boundary junctions were fabricated and their transport properties studied



- no transparency of the $Sr_{1-x}La_xCuO_2$/Au interface – no technology yet for the fabrication of the ramp-type $Sr_{1-x}La_xCuO_2$ based junctions