MOI study of grain boundary transparency in [001] tilt $(Yb_{0.7}Ca_{0.3})Ba_2Cu_3O_{7-d}$ 6º and 9º bi-crystal thin films

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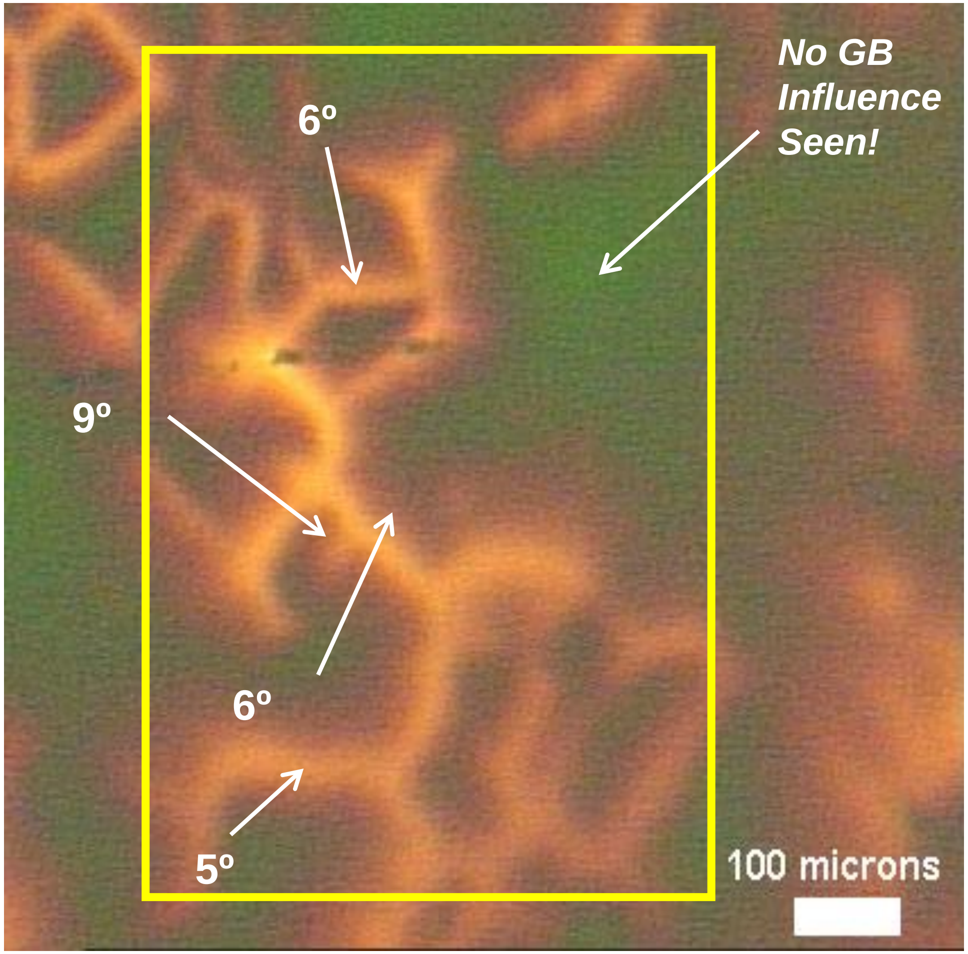
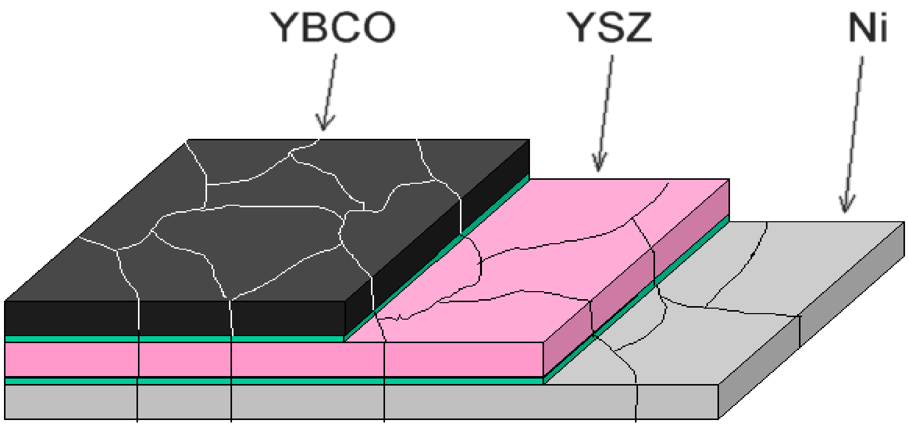
Outline

- Motivation: why do we study Ca-doped GBs again? Is Ca-doping still useful at low temperature?
- Thin film deposition and post annealing: Ca-doped films are different from pure films
- Use MOI to monitor the change of Jc^{GB}, J_c^{grain} and GB transparency: dependence on annealing condition and temperature
- Conclusion

MO evidence: grain boundaries (GBs) are a major problem for current flow in REBCO



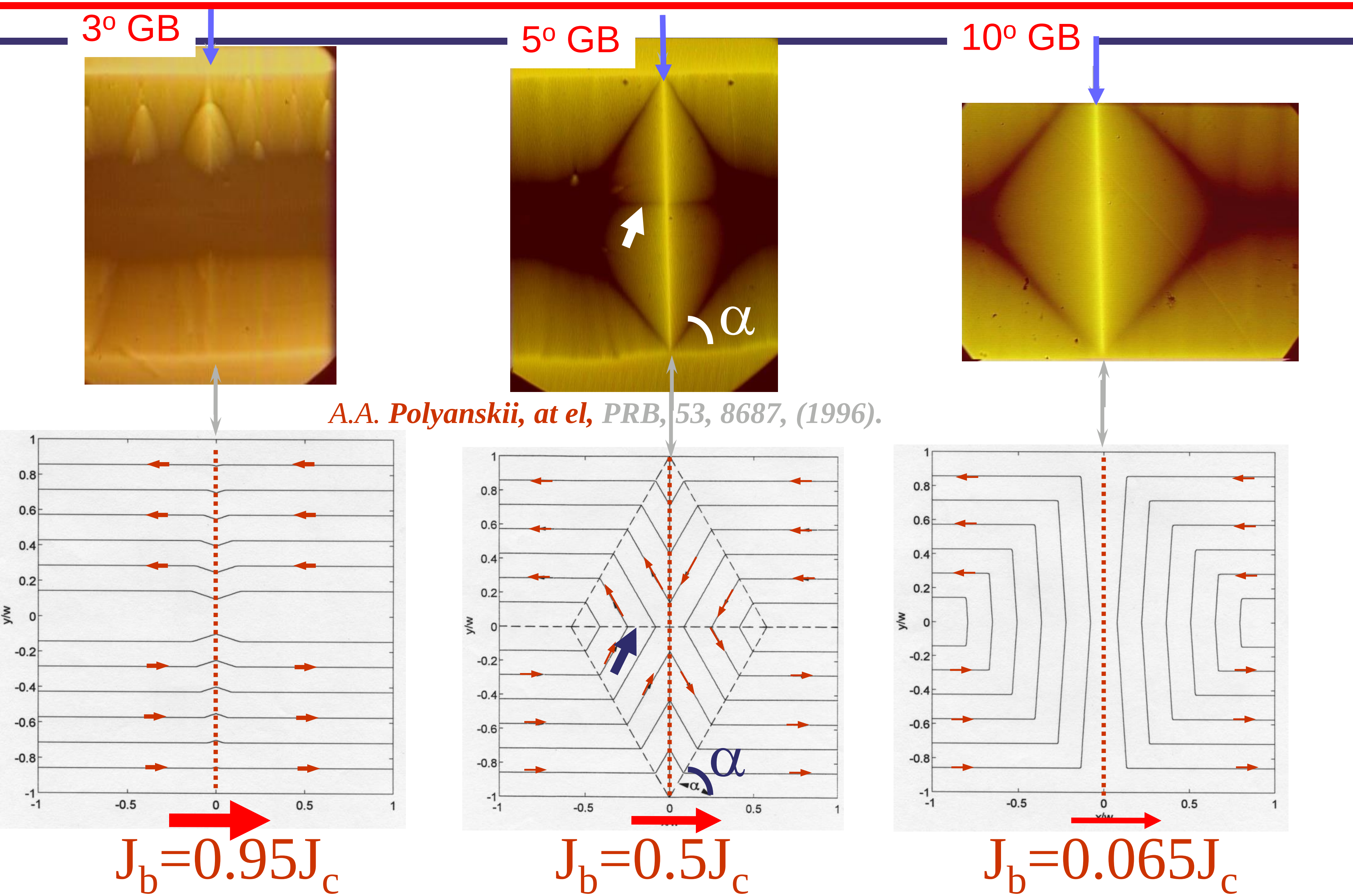


RABiTS: Rolling Assisted Biaxially Textured Ni Substrates

MOI: GBs > 4º are barriers to current flow.

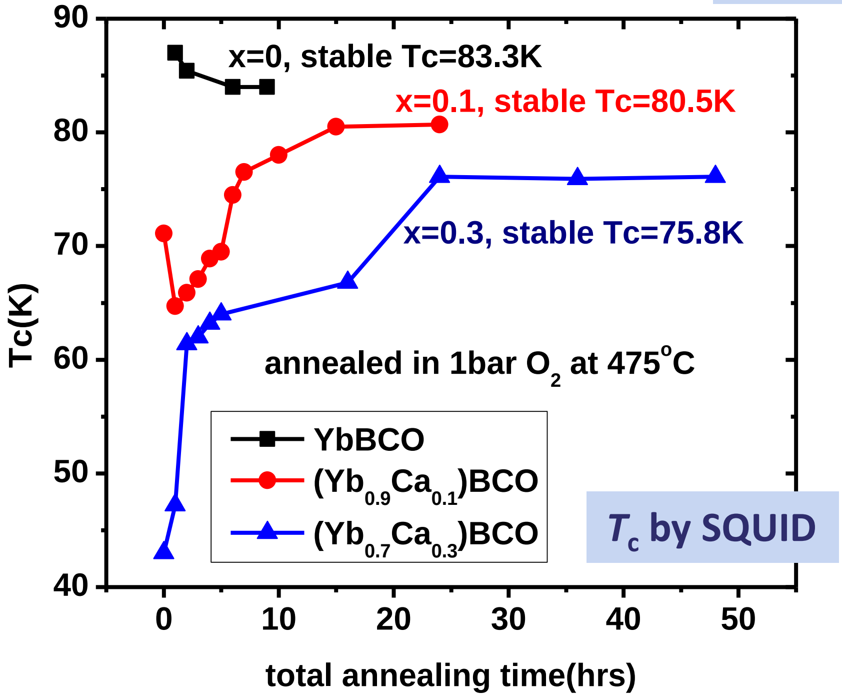
D. Larbalestier, A. Gurevich, D.M. Feldmann, A. Polyanskii. Nature, 2001, v15, p.368-377

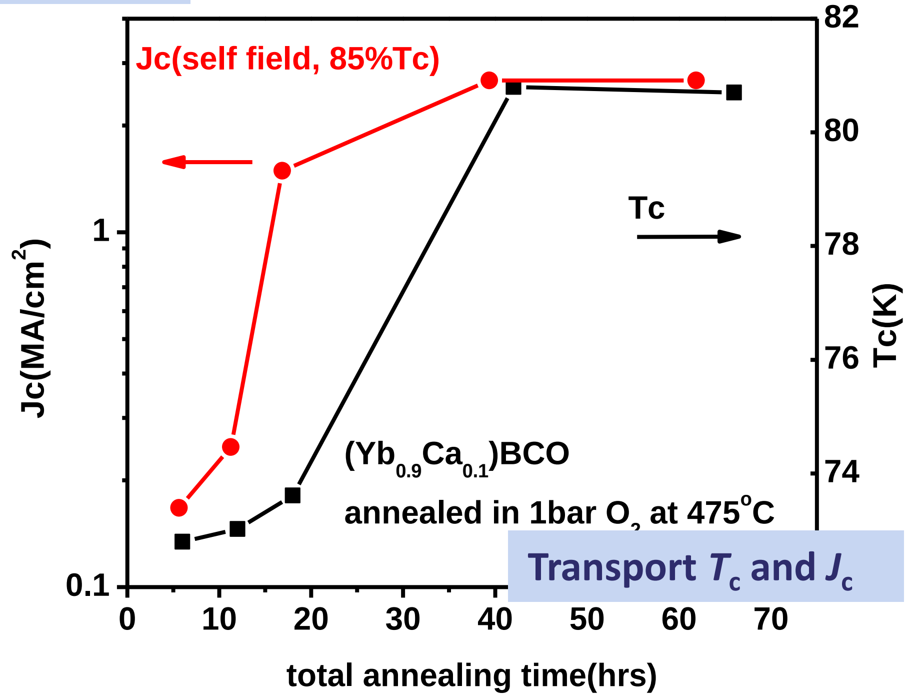
Magneto-Optical flux behavior and current distribution around GBs in pure YBCO bi-crystals at T=7 K and 40 mT



As-grown Ca-doped films: an unusual T_c and J_c dependence during annealing

single crystal film



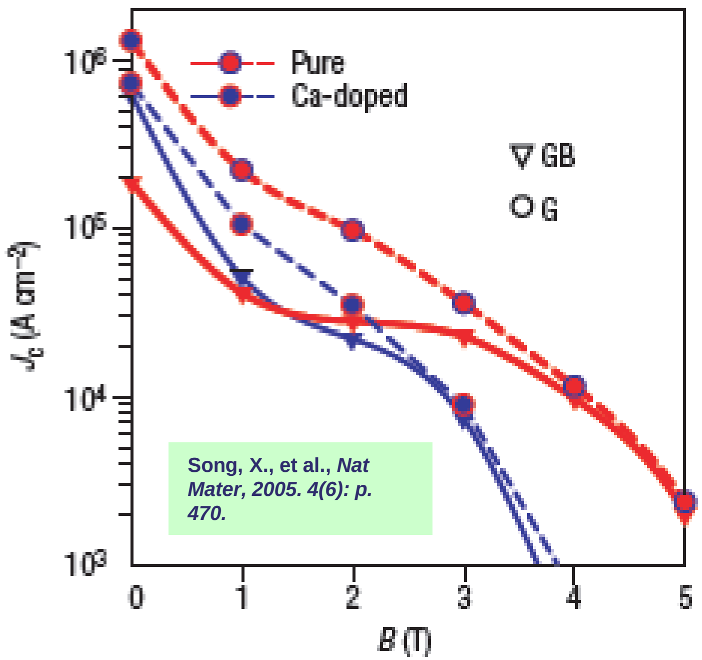


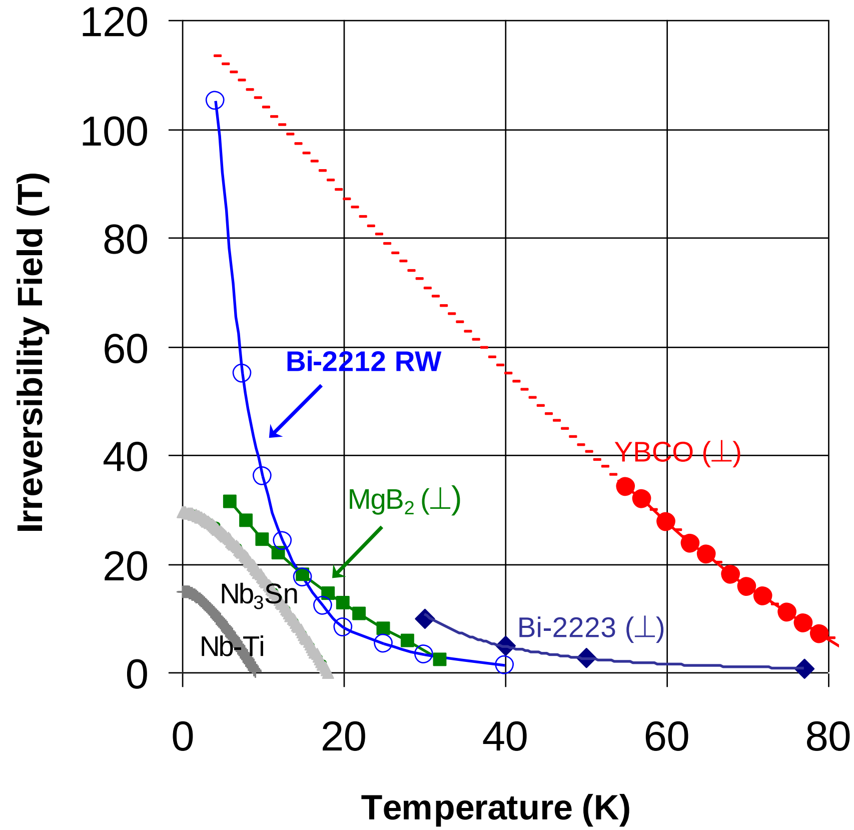
P. Li et al. PRB 91,104504 (2015)

During oxygen (1 bar=760 torr) annealing:

- **Pure film:**
  - **T_c slightly decreases & saturates within several (<5) hours.**
  - **Consistent with hole over-doping**
- **Ca-doped film:**
  - **T_c and Jc increases and needs much longer time to be stabilized.**
  - **Consistent with hole-doping only after stabilization.**

Ca-doping repairs GB at high temperature, what about low temperature?



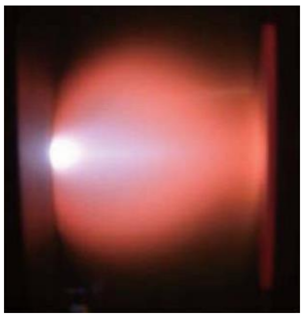


- Effect only confirmed at **high reduced temperature** ***$t=T/T_c$***, e.g. t=0.85=(77K/90K)
- Ca-doping reduces Tc, **high** ***$t \neq$* high *T*** !

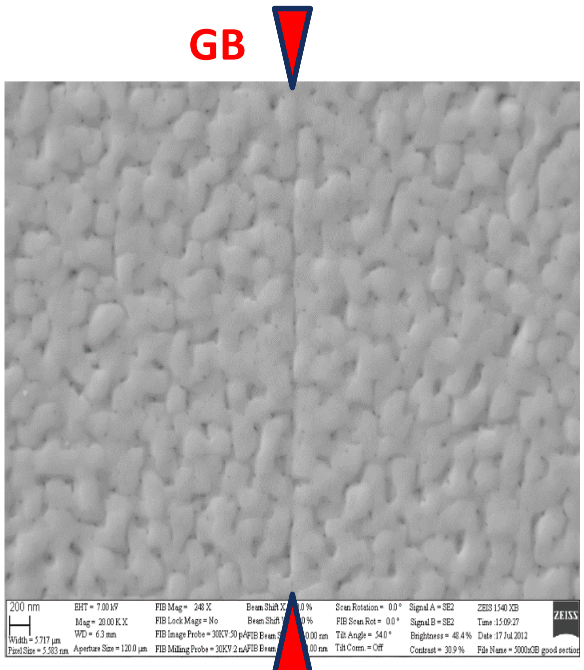
High field application of HTS: at low temperature to take advantage of the very high Irreversibility field H*

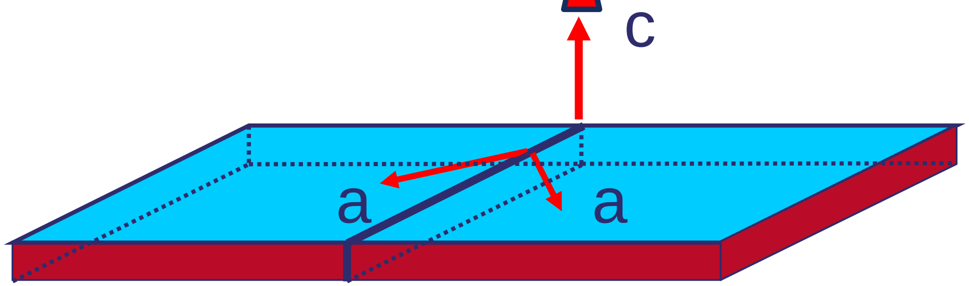
Experiments on Ytterbium-123 bi-crystals

- High quality 30% Ca doped YbBaCuO deposited on single crystal, 6º and 9º bi-crystals



810ºC
0.2torr O_2





Tilted bi-crystal: 4.77mm x 10 mm, t=300 nm

- **Superconducting properties evaluated on:**

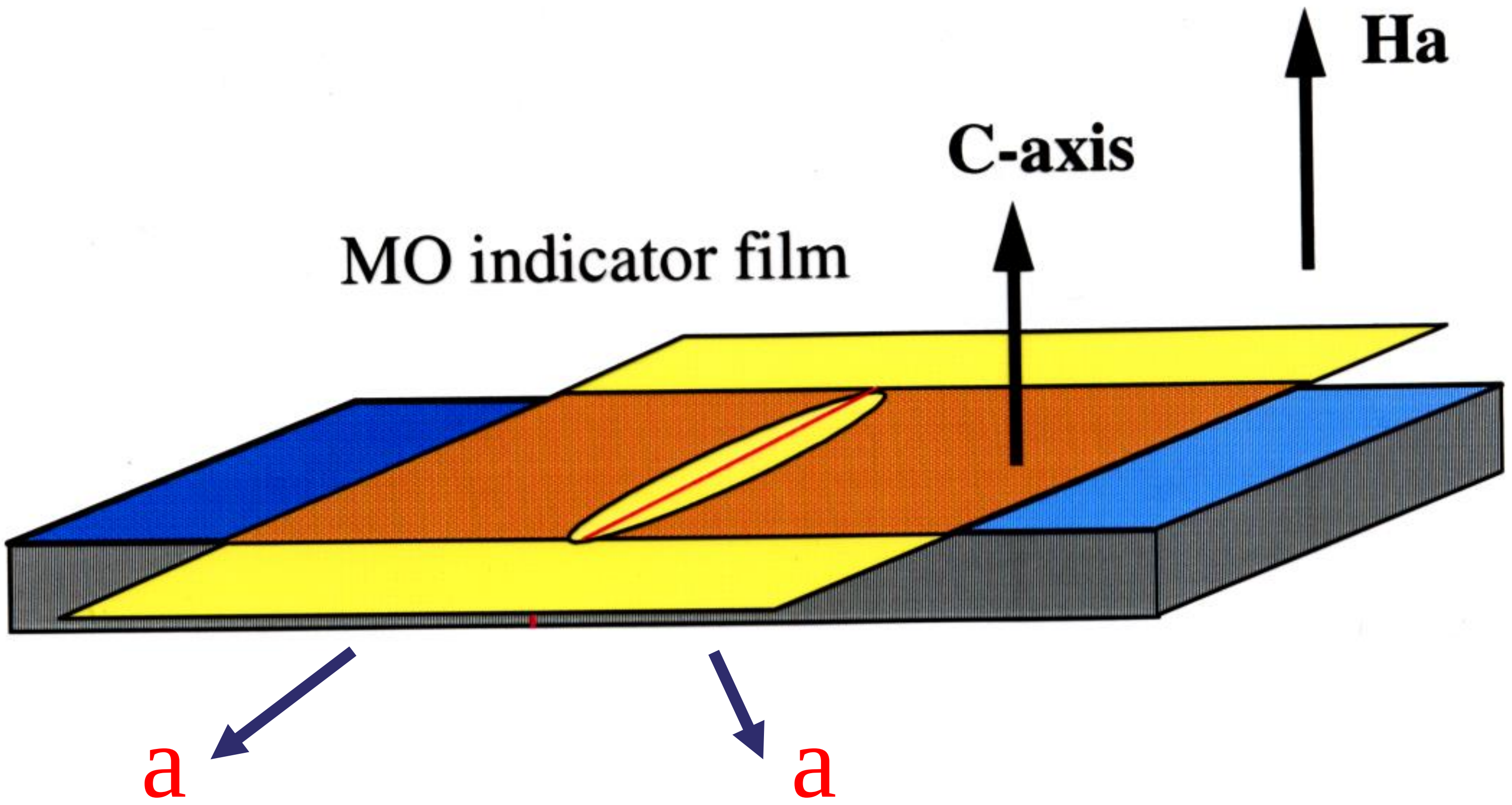
the same sample

at different stages of oxygen annealing

760 torr-0.2 torr, 0-96 hours

- **MOI**
- **PPMS**
- **SQUID**

Geometry of Magneto-Optical experiment on thin tilted film grown on bi-crystal STO substrate

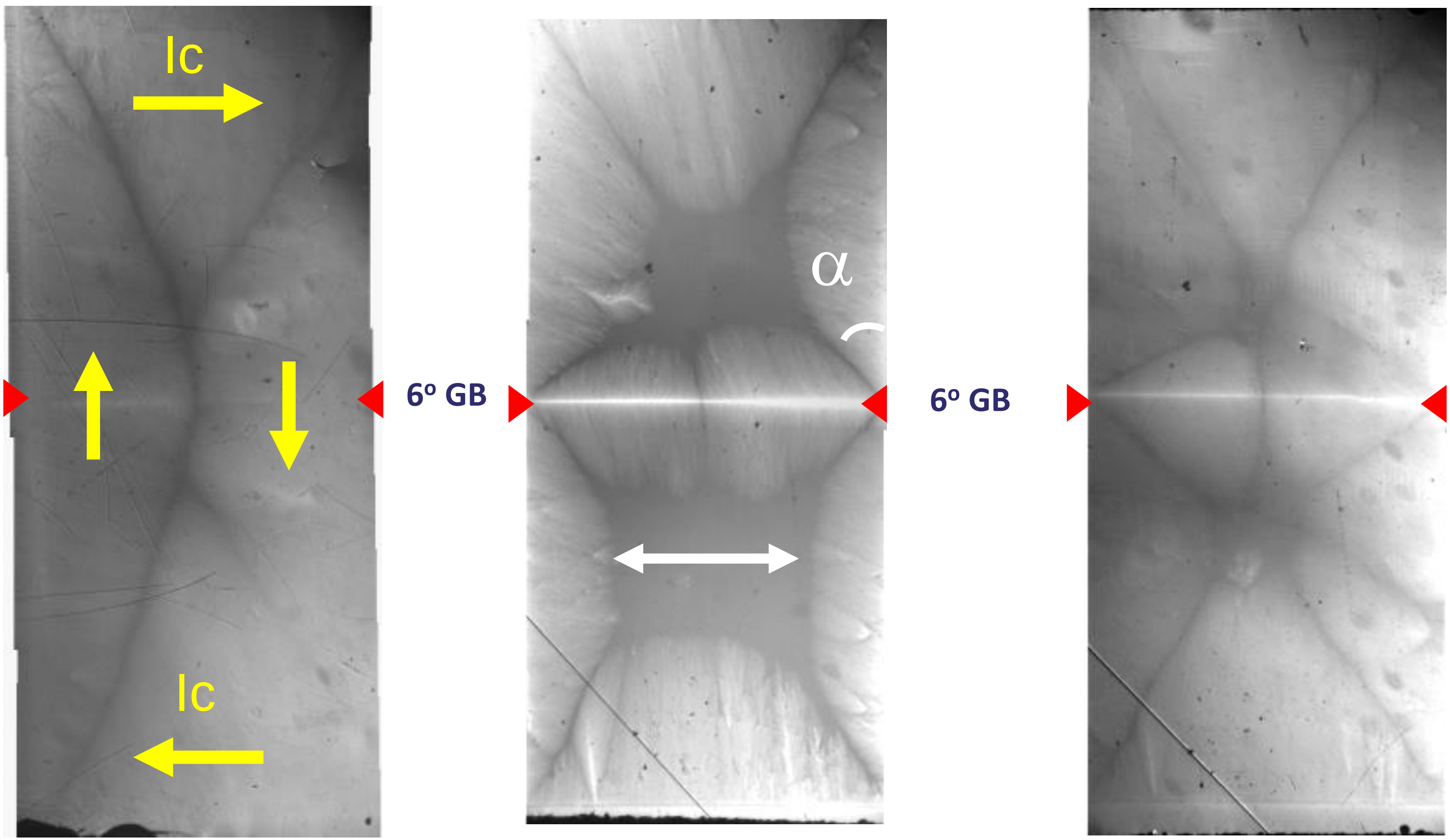


YBCO thin tilted film on bi-crystal STO substrate

6 ^{0} bi-crystal 30% Ca, at different HT, ZFC, T=10K. Calculation critical current in grains (J_c^{grain})

Bulk current, GB is not obstacle

GB is an obstacle to current flow after post-annealing



180 Oe,
HT-1
2h/750torr

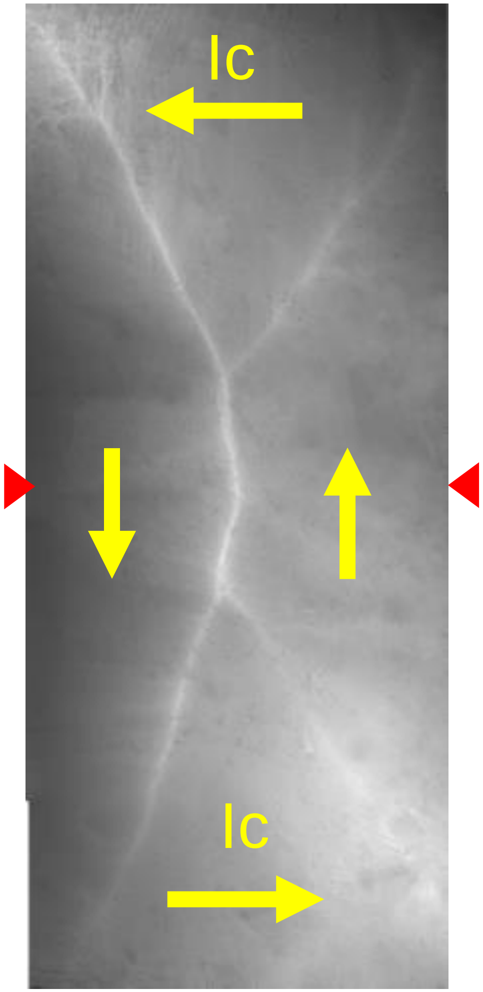
200 Oe
HT-4
36h/750torr

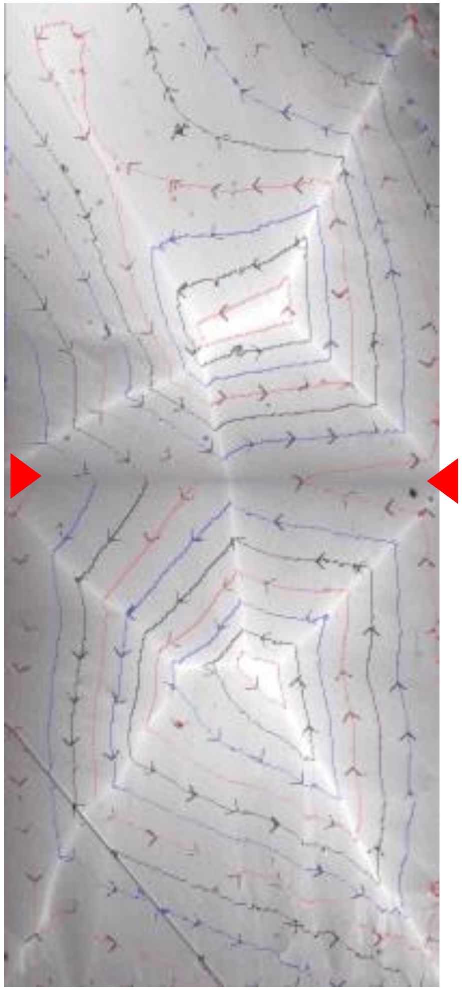
80 Oe
HT-7
24h/0.5torr

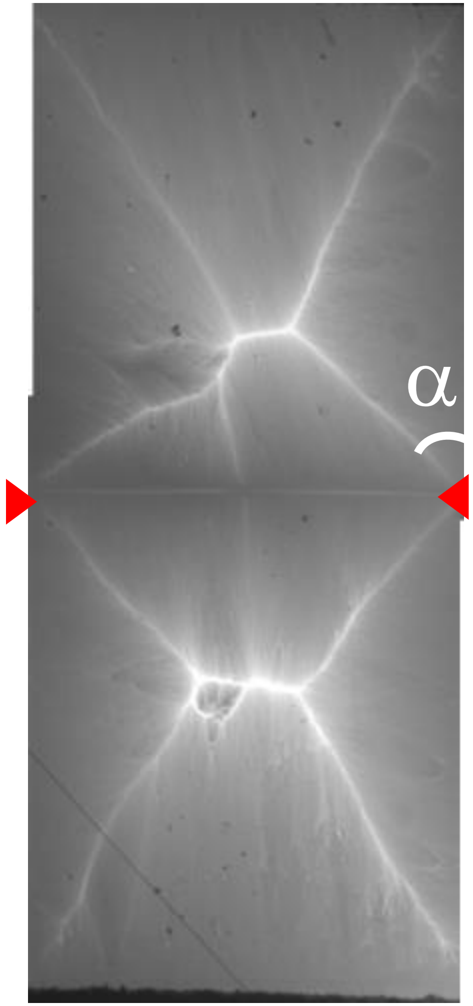
6 ^{0} bi-crystal 30% Ca, at different HT, FC, T=10K. Calculation transparency of GB ($r=J_c^{GB}/J_c^{grain}$)

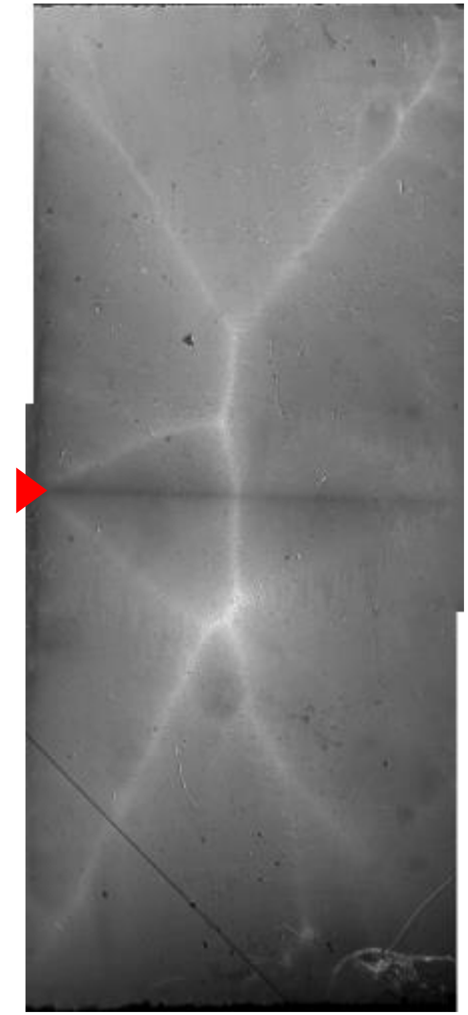
Bulk current, GB is not obstacle

GB is an obstacle to current flow after post-annealing in oxiden









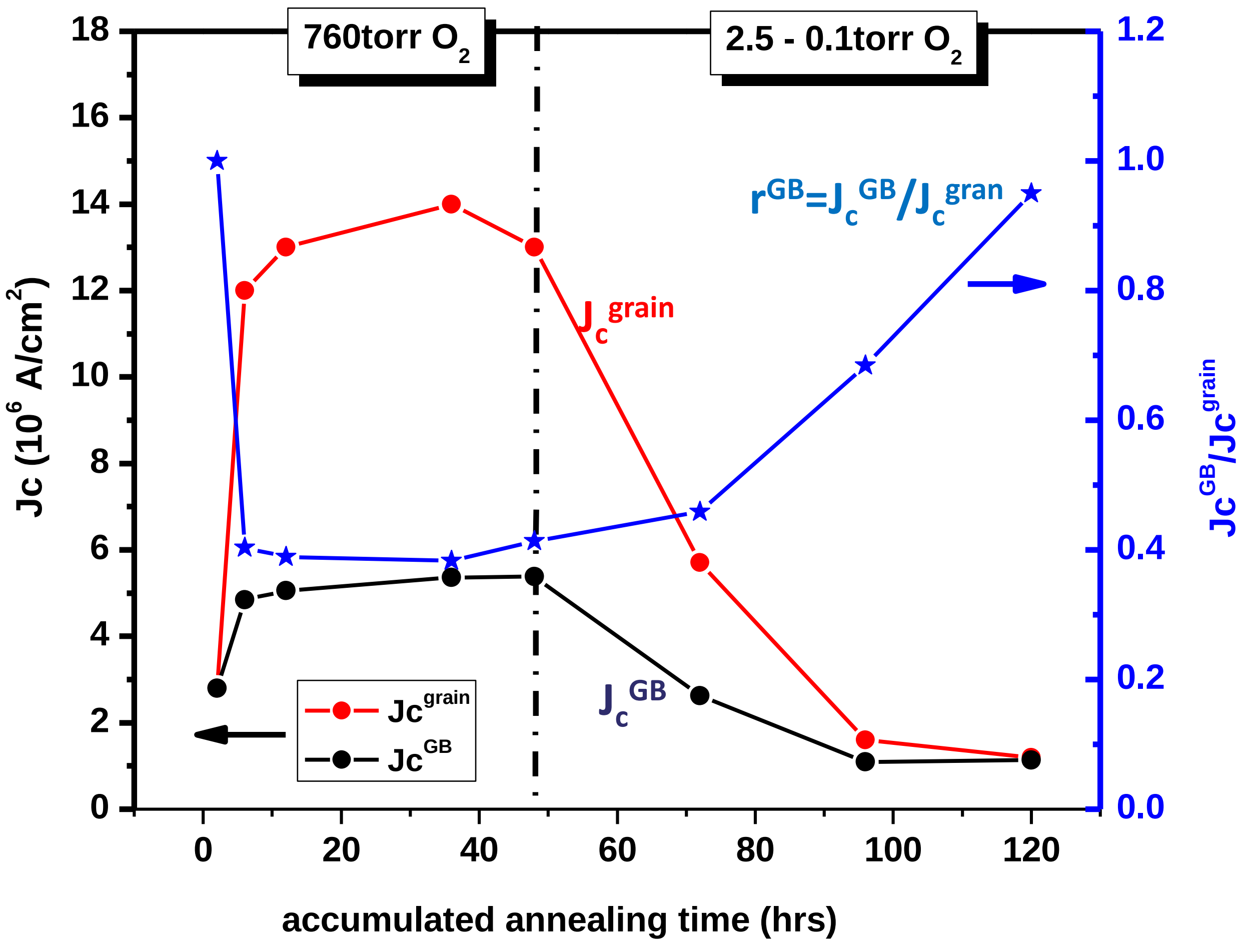
HT-1
2h/750torr

HT-2
6h/750torr

HT-4
36h/750torr

HT-8
24h/0.1torr

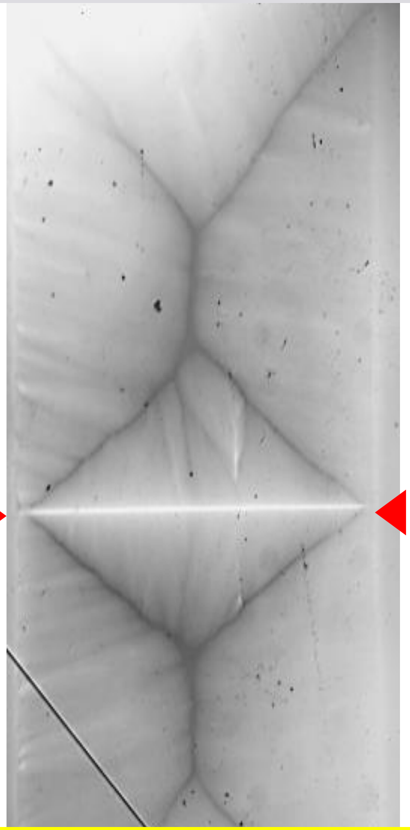
MOI: 6º $(Yb_{0.7}Ca_{0.3})BaCuO$. Jc in grains, across GB and GB transparency depends from annealing time



- As-grown film in metastable state has the highest GB transparency: **r^{GB}~1 at 10K !**
- Oxygenation increases Jc^{GB}, Jc^{grain} and their difference as well. Transparency r^{GB} decreases with oxygenation.
- Depressing Jc^{grain} by annealing in low oxygen partial pressure recovers transparency r^{GB}

MOI: 9^{o} $(Yb_{0.7}Ca_{0.3})BaCuO$ bi-crystal. J_c in grains, across GB and GB transparency depends from annealing time

2 hours annealing in 760 torr oxygen

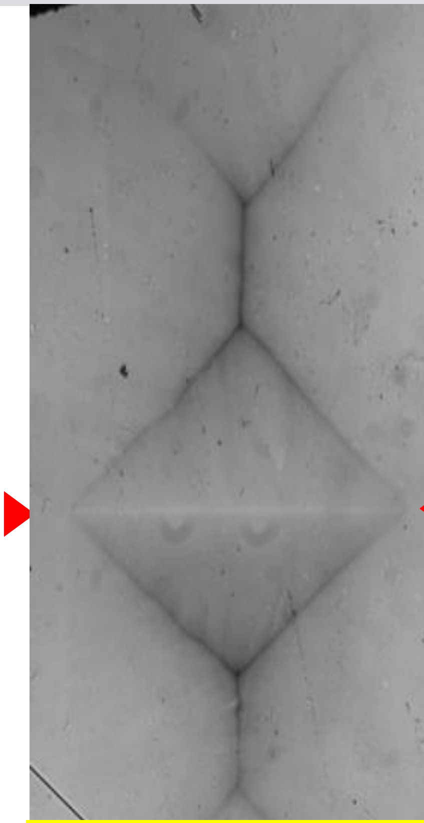


9º GB

Current flows across GB

ZFC, 10K,
Jc^{grain}~$5.3x10^{6}$ MA/cm^2
r^{GB}~0.37

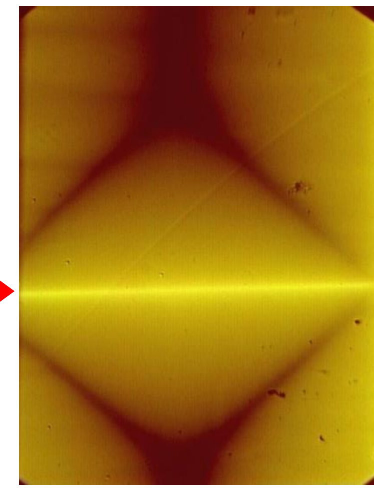
96 hours annealing in 760 torr oxygen



No current across GB

ZFC, 10K,
Jc^{grain}~$1.7x10^{7}$ MA/cm^2
r^{GB}~0.15

No current across GB



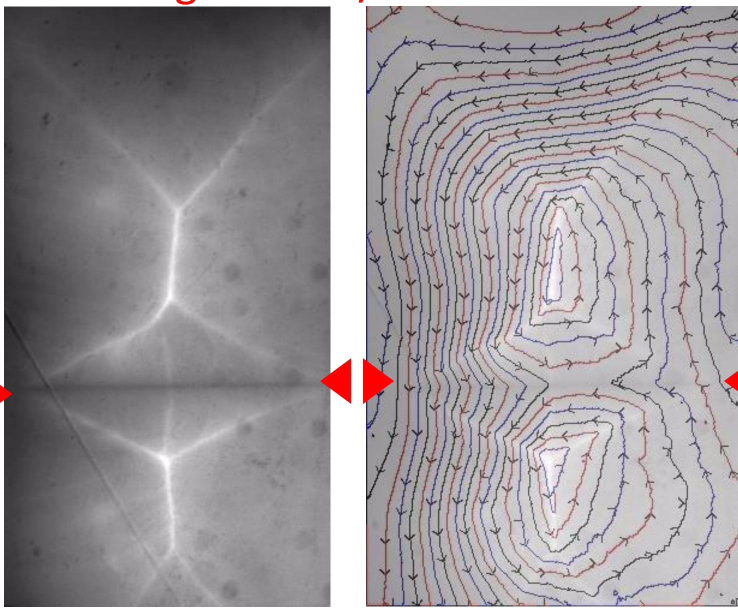
10º GB

10º GB, pure YBCO
A. Polyanskii,PRB, 53, 8687, (1996)

r^{GB}~0.06

MOI: 9° bi-crystal. Jc in grains, across GB and GB transparency depends from annealing time

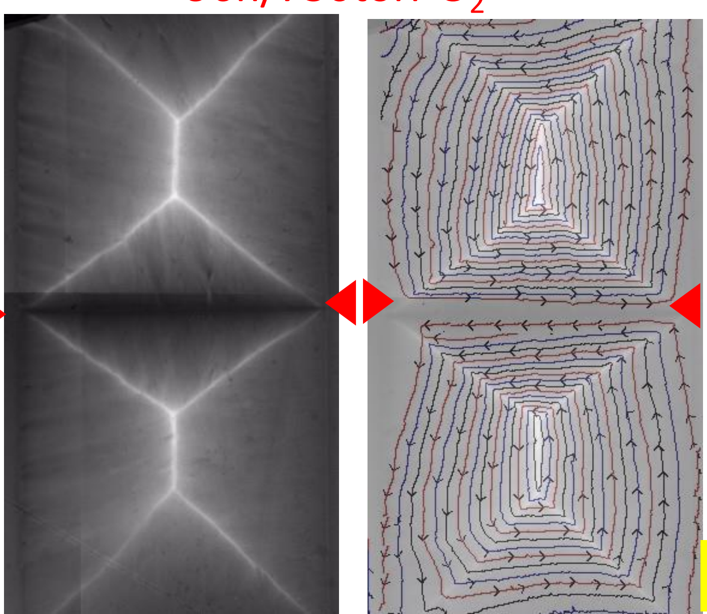
as grown 2h/750torr



Current flows across GB

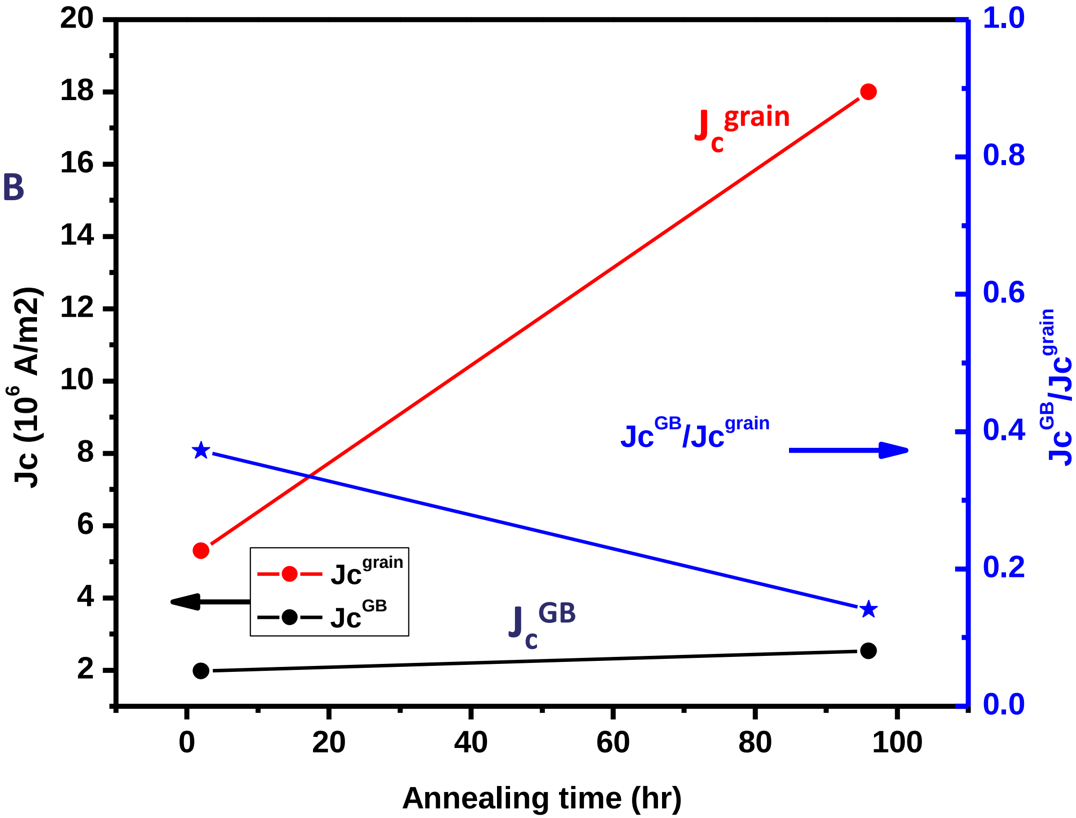
9° GB

96h/750torr O_2



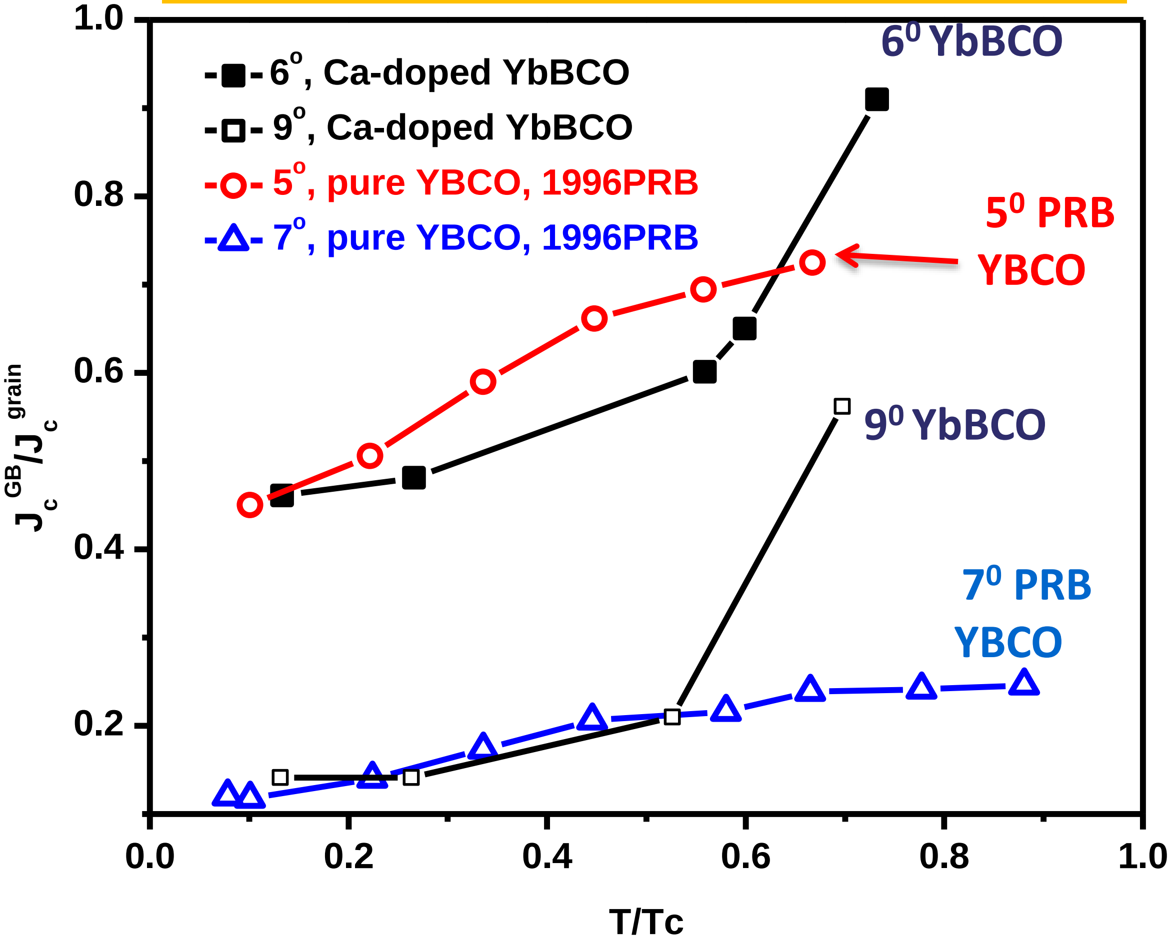
9° GB

No current across GB



MOI: GB transparency (r^{GB}) dependence vs temperature in Ca-doped and pure bi-crystals

Transparency of Ca-doped GB vs pure GB



With Ca-doping:

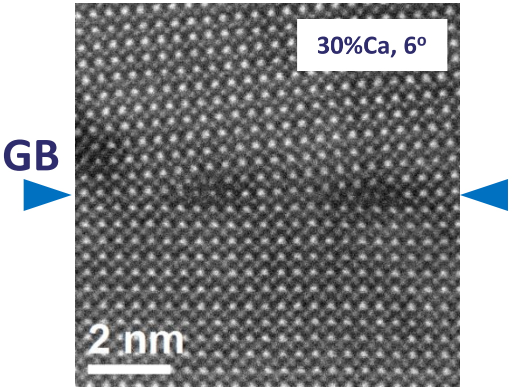
- GB transparency has an unusual boost at high temperatures.
- The beneficial effect of Ca-doping does not exist in low temperature.

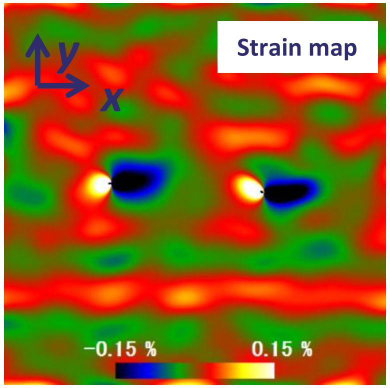
Reference: Polyanskii et al. PRB 53, 8687 (1996)

What has MOI found?

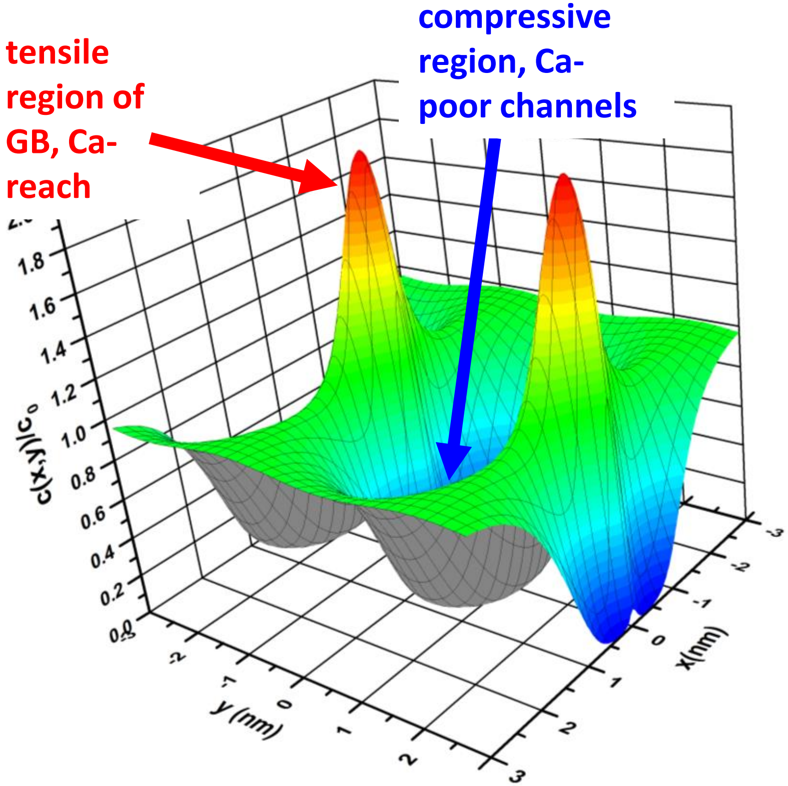
- J_c^{GB} and J_c^{grain} of the same sample is successfully monitored during oxygen annealing process
- J_c^{GB} and J_c^{grain} react differently to oxygen annealing. J_c^{grain} is less affected by annealing in low oxygen atmosphere.
- Ca-doping is especially (or only)effective at repairing GB transparency at high $t=T/T_c$.
- Why is the effectiveness of Ca-doping so strongly temperature-dependent?

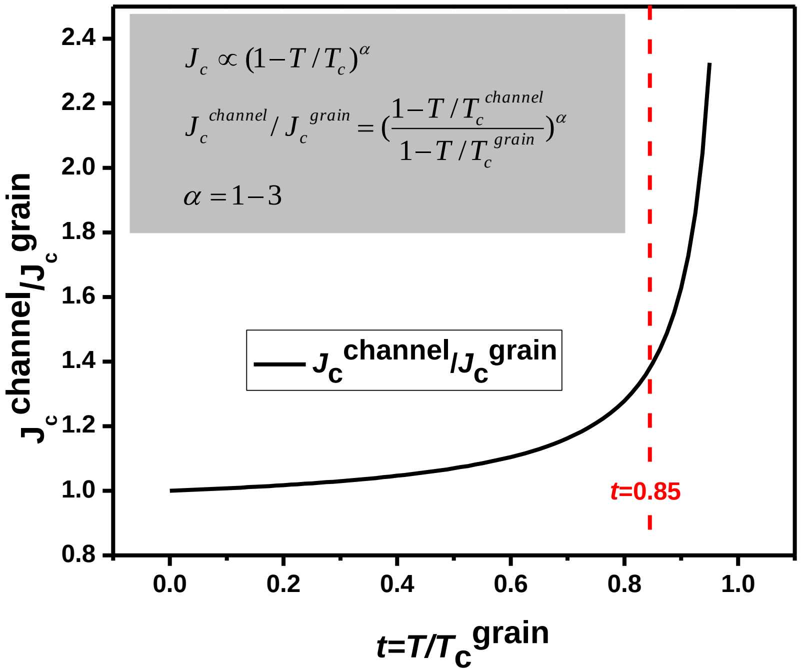
Segregation: a non-uniform Ca distribution is the key





- Ion radius, Ca^{2+}>Yb^{3+} (0.099nm vs 0.086nm)
- Driven by local strain and electrical fields, Ca^{2+} segregates to the tensile region of GBs
- The Ca-poor channel has $Tc^{channel}$>Tc^{grain}





- The unusual transparency dependence of GB Jc^{GB}/Jc^{grain} vs temperature is due to Ca-segregation and local Tc imbalance.

Kametani and Li

Conclusion

- MOI is used to monitor GB transparency of Ca-doped [001] tilt bi-crystal films over a broad temperature range and throughout the annealing history
- J_c^{GB} and J_c^{grain} respond to oxygen annealing differently. In Ca-doped films, Jc^{GB} is less affected by oxygen annealing.
- Surprisingly, high GB transparency r^{GB} **$=Jc^{GB}/Jc^{grain}$** is associated with low intra-grain Jc.
- With Ca-doping, GB transparency is boosted at high temperature, which is mainly a result of Ca-segregation and local Tc imbalance.

Thank You!

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