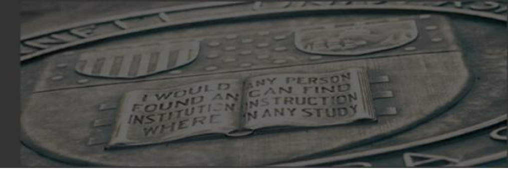


Crystalline Microstructure Role in a High Field Q-slope

Alexander Romanenko

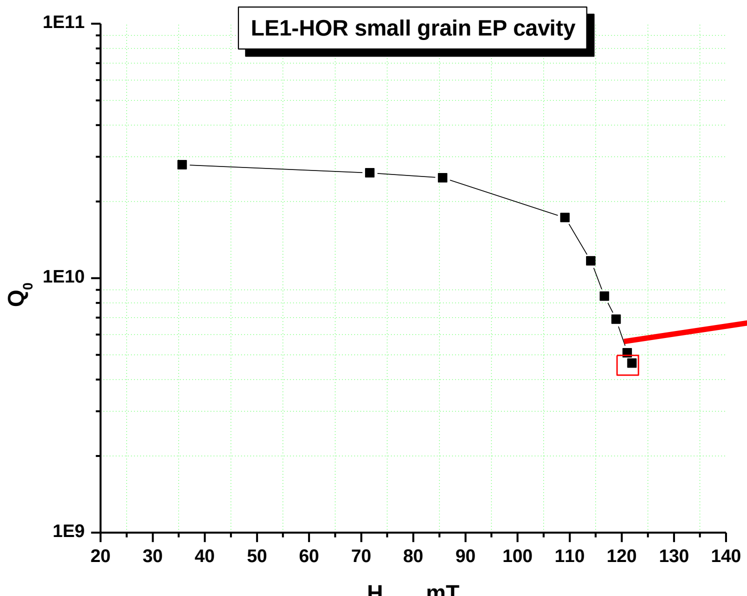
Cornell University

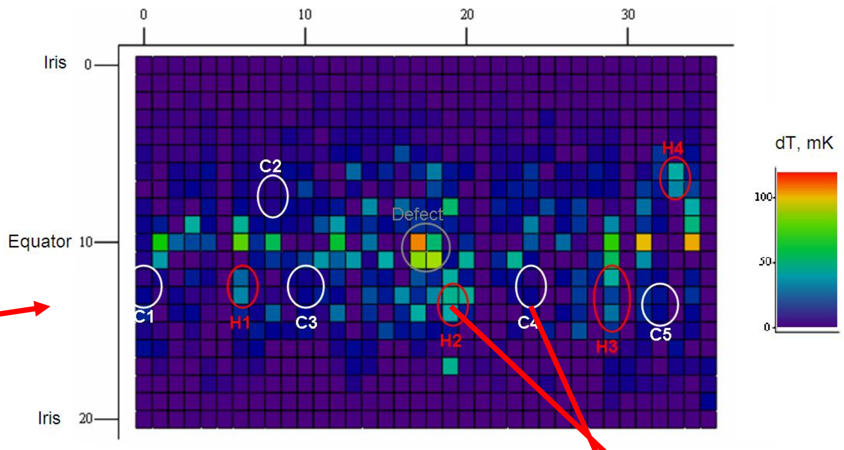
CLASSE

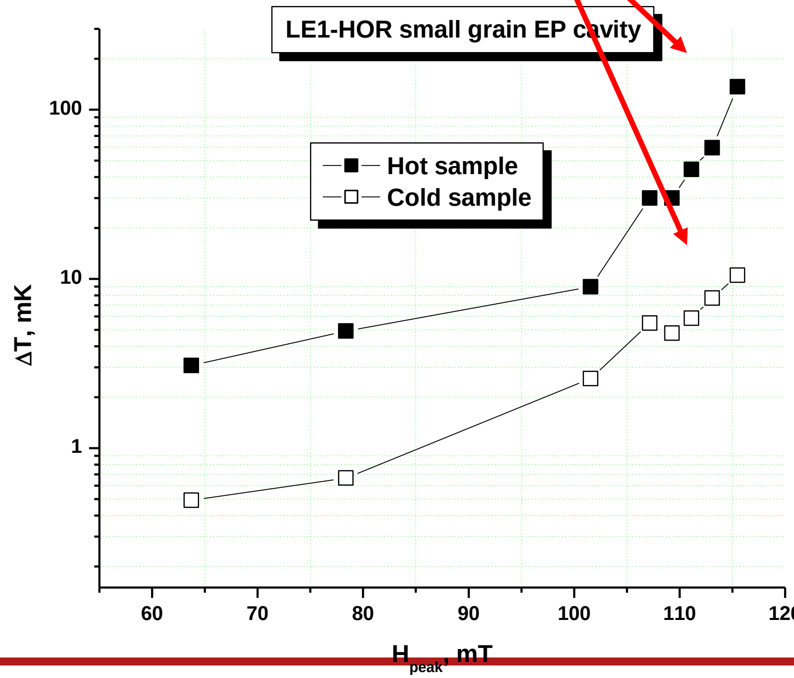
Outline

- Background
- Samples used
  - “Hot” and “cold” areas from small and large grain EP and BCP cavities
  - Further baking at 100-120C applied to samples
- EBSD data analysis
  - Local misorientation
  - Calculation of dislocation density from raw data
- Possible cause of the HFQS
- Model for baking mechanism
  - Vacancies-assisted dislocation climb
- FIB/TEM and EELS analysis of cavity samples
  - No oxygen diffusion observed
  - Interface structure similar
- Conclusions

Typical small grain EP cavity test results

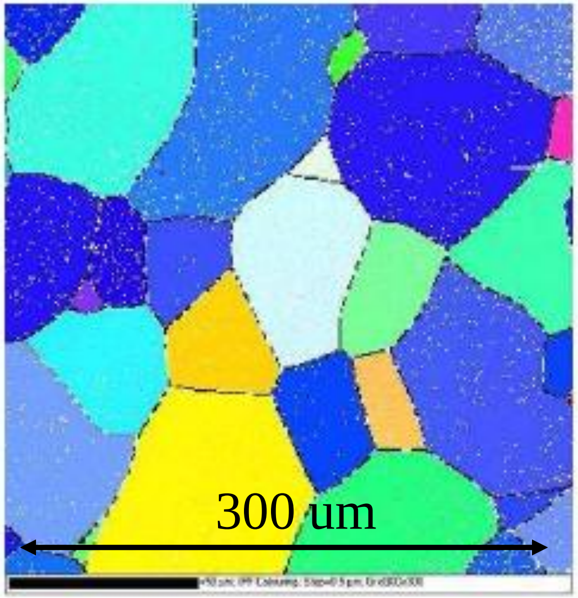


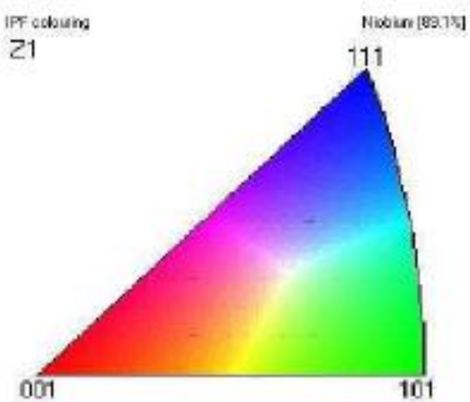




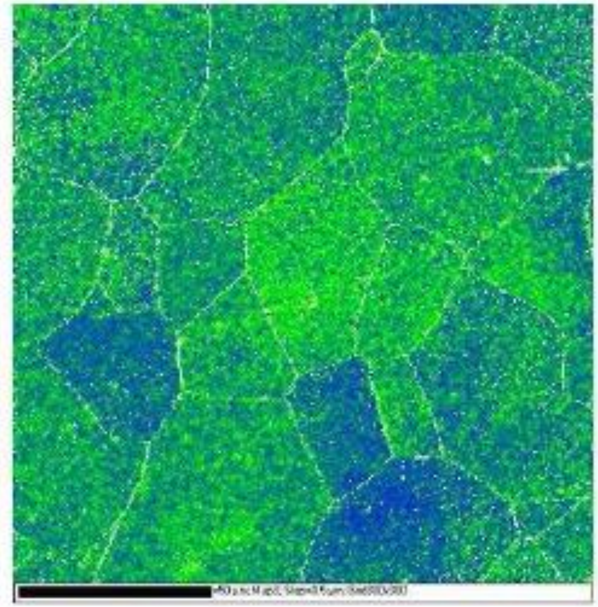
EBSD characterization of samples

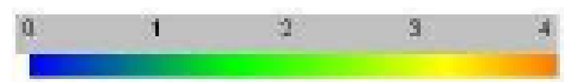
EBSD raw data:
crystalline orientation map

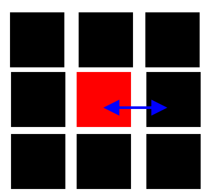




Local misorientation map







$\Delta\alpha_i$ – angle to rotate the unit cell to make orientations equal

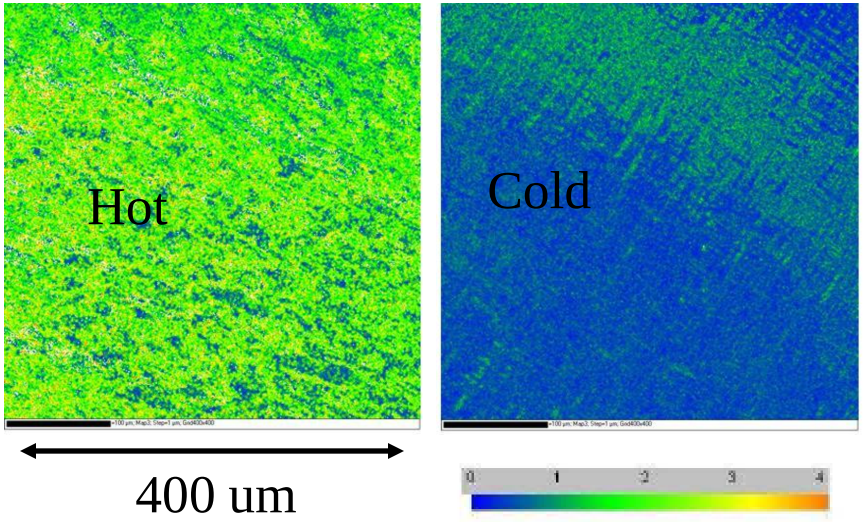
Local misorientation = $1/8 * \Sigma(\Delta\alpha_i)$

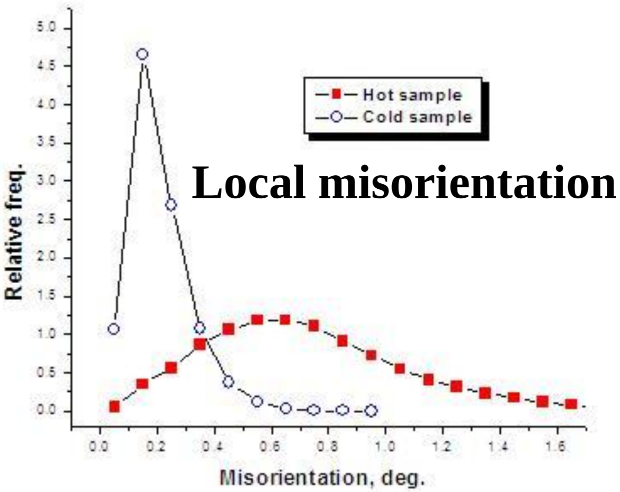
Obtaining dislocation density from crystalline orientation maps

- Lattice curvature tensor – directly measured by EBSD (change of orientation from pixel to pixel)
- From curvature tensor under assumption of no elastic stresses => dislocation density tensor
- More details:
  - [W. Pantleon, Scripta Materialia 58 (2008) 994–997]
  - [D.P. Field et al., Ultramicroscopy 103 (2005) 33–39]

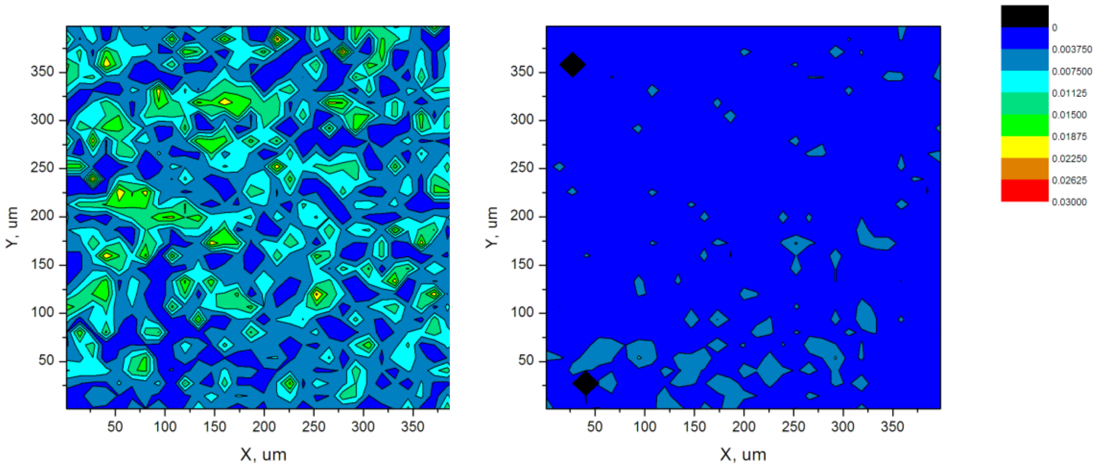
Dislocation density and local misorientation – extreme case

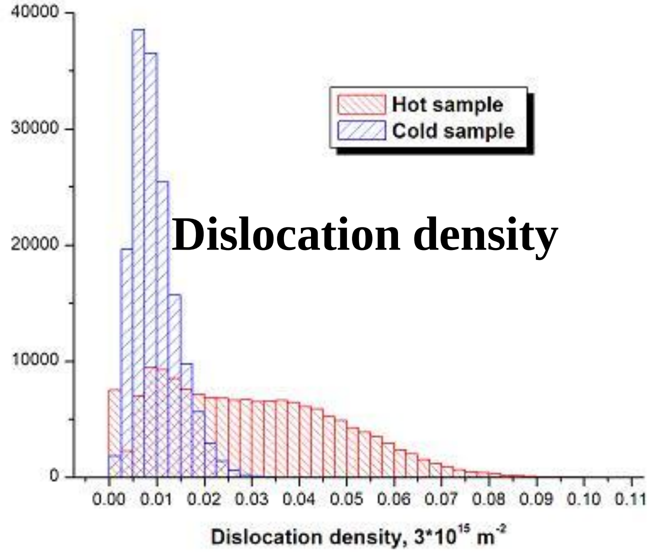
Local misorientation



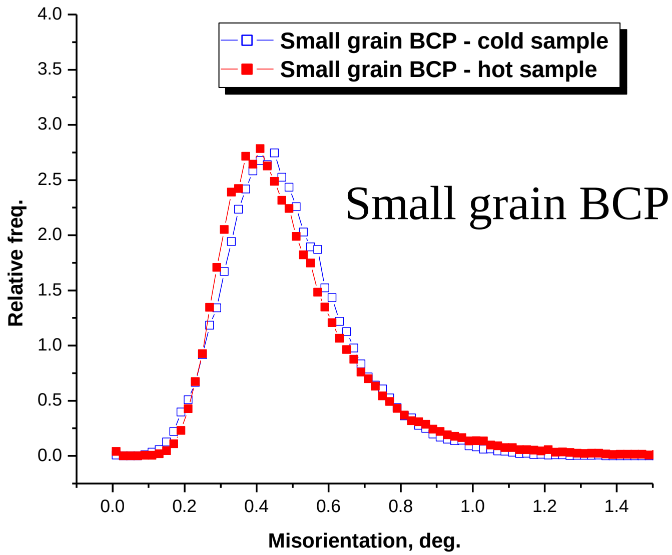


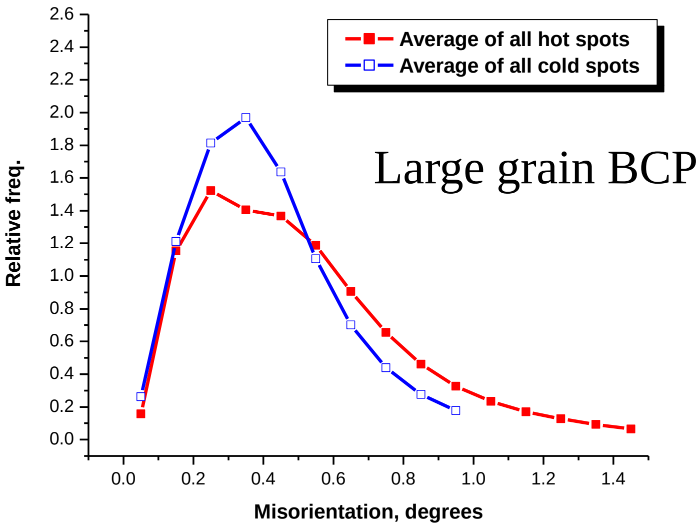
Dislocation density

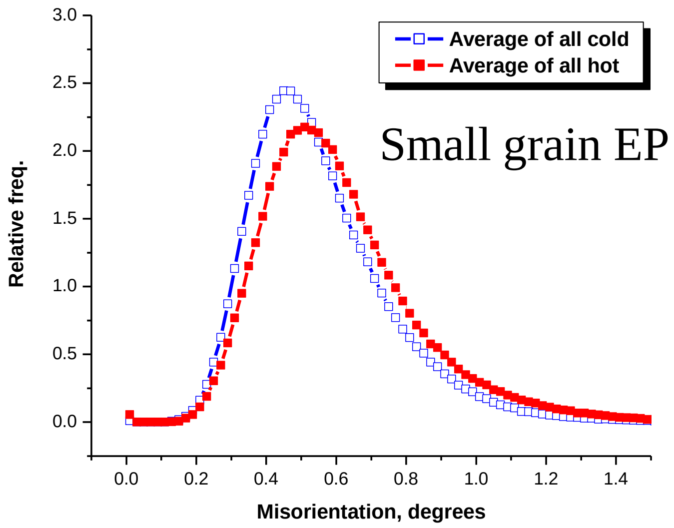




Hot/cold EBSD summary

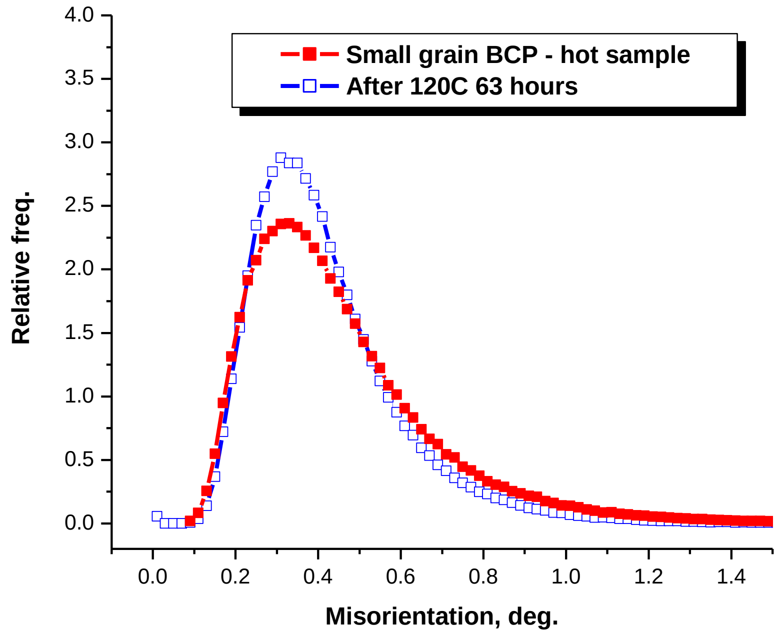


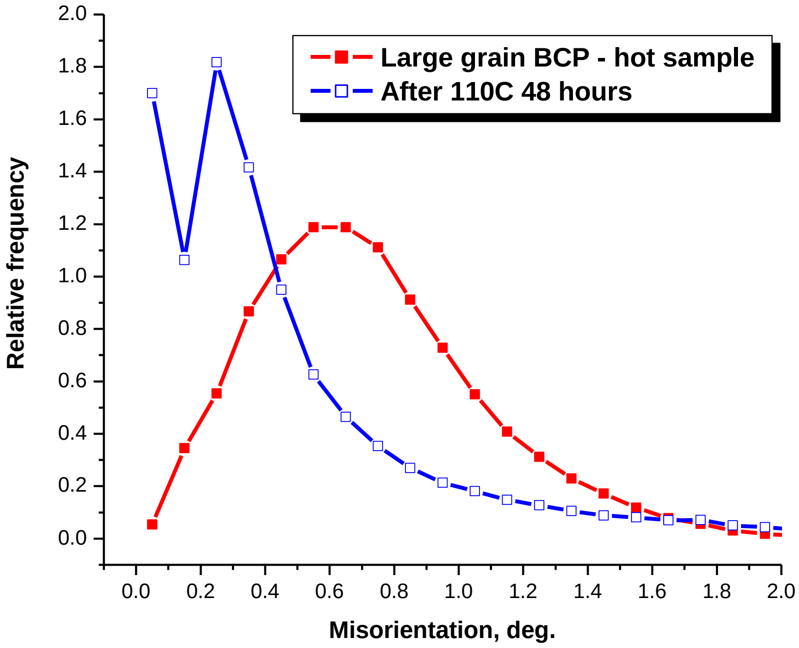




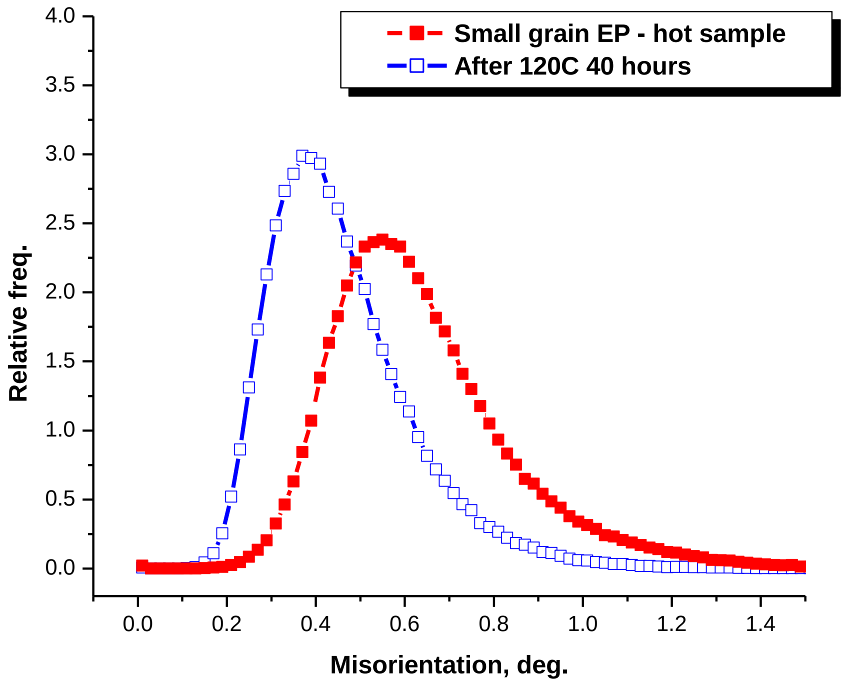
- Hot areas on average have misorientations shifted toward higher angles
- Difference hot/cold is largest in the case of large grain BCP, which is consistent with thermometry
- Motivated annealing of the samples at 100-120C and subsequent EBSD analysis

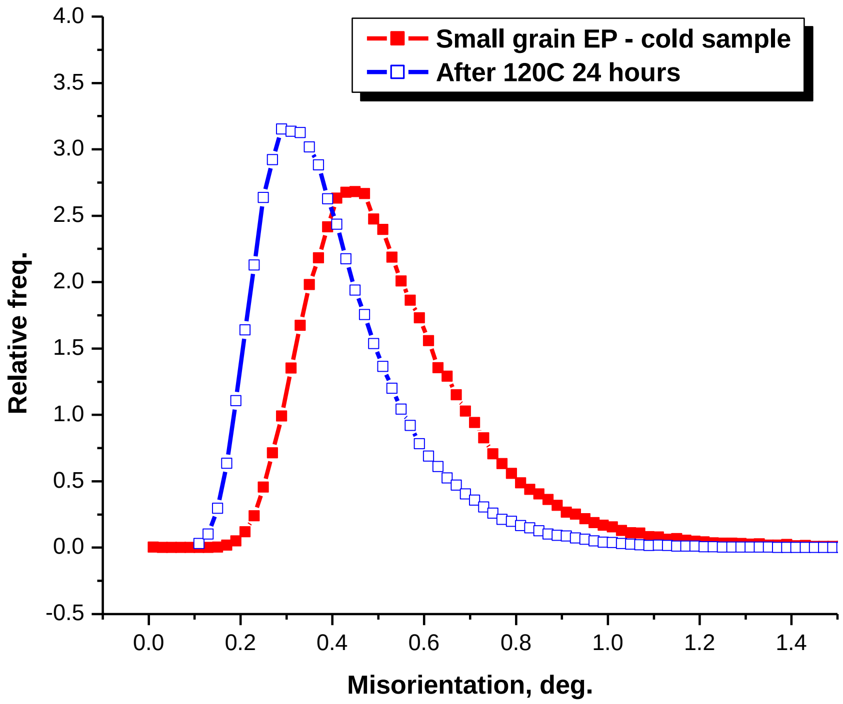
Small/large grain BCP - baking





Small grain EP - baking





- Strong shift due to baking is observed in local misorientation distributions of both hot and cold samples
- Dislocation density maps were obtained to confirm and to get more info on distribution

Average screw dislocation density maps

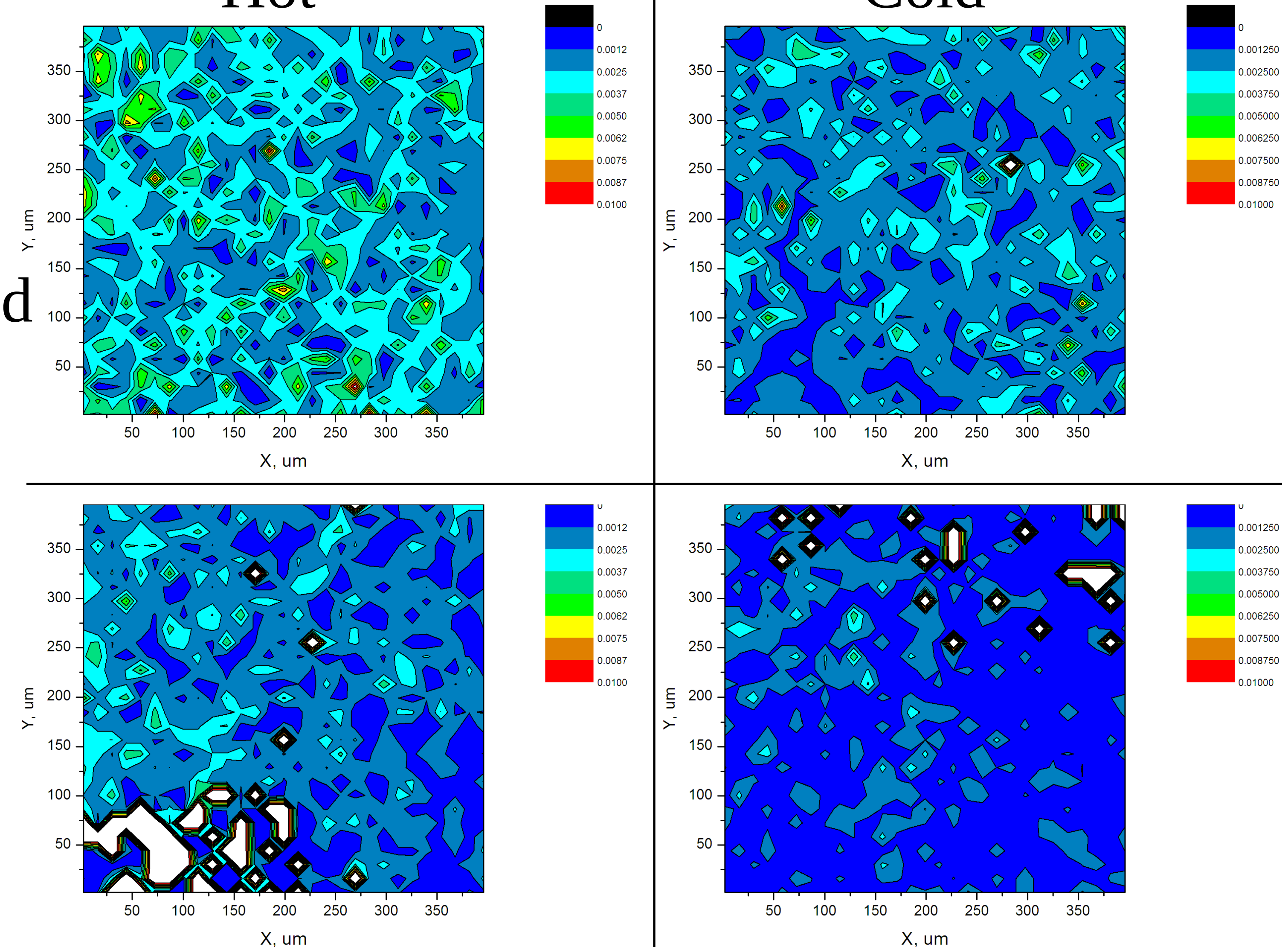
Hot

Cold

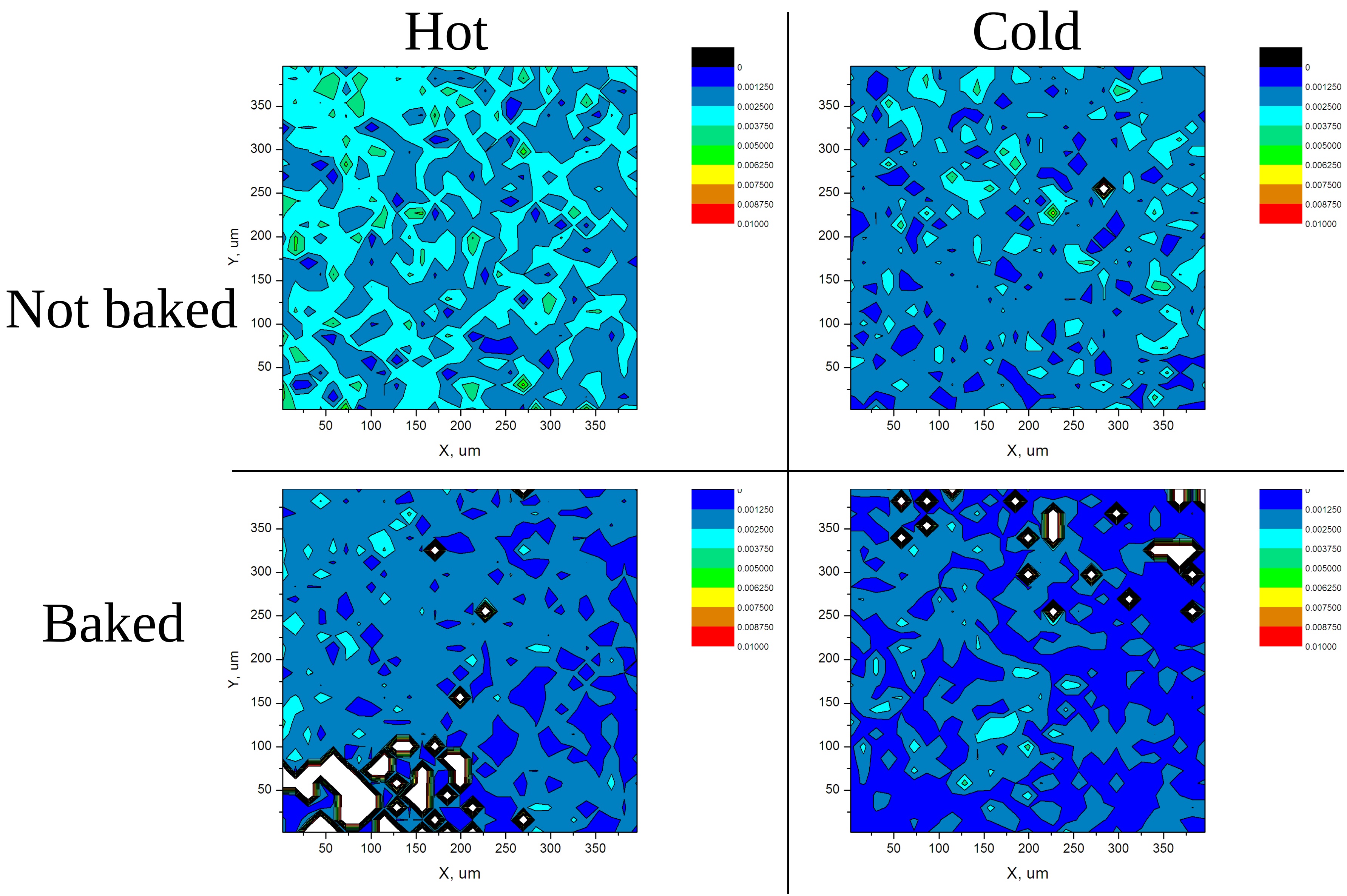
Notice cell structure

Not baked

Baked



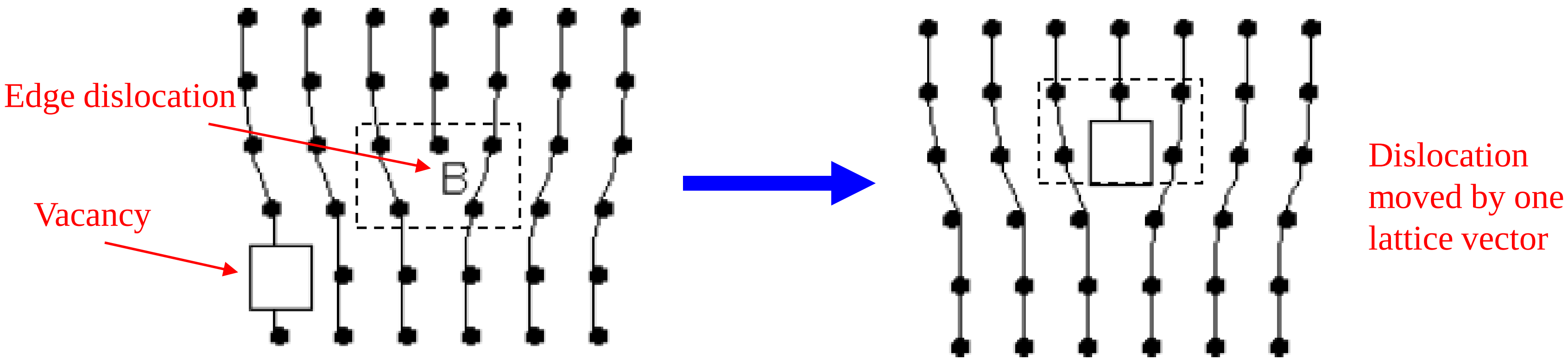
Average screw dislocation density maps



Baking summary (EBSD)

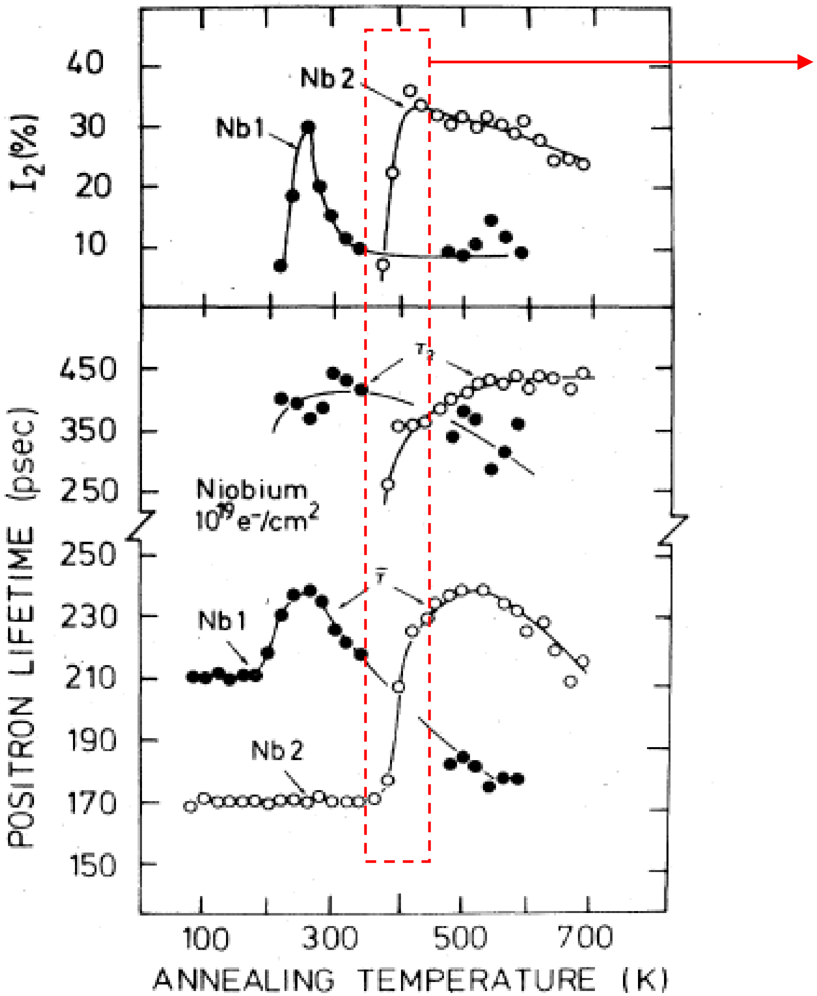
- Significantly reduced dislocation density in small grain EP and large grain BCP samples after 120C baking
  - Consistent with the strong baking benefit on EP and large grain BCP cavities
- Almost no change in the small grain BCP sample due to baking
  - Consistent with the lack of baking effect on the small grain BCP cavities

Baking mechanism – dislocation climb



- Dislocation climb
  - Vacancies are necessary for the climb to occur
  - Vacancies in Nb become mobile around 100C due to Vacancy-H complexes dissociation – see next slide for positron annihilation studies [*Phys. Rev. B*, 32(7):4326–4331, 1985]
- Possibly - reduction in the dislocation density near the surface due to climb and annihilation of dislocations

Vacancy-H complexes dissociation



- Vac-H complexes in niobium containing some H (Nb2 in plots) dissociate at ~380K (107C) – compare to baking temperatures
- Mobile vacancies => dislocation climb becomes possible

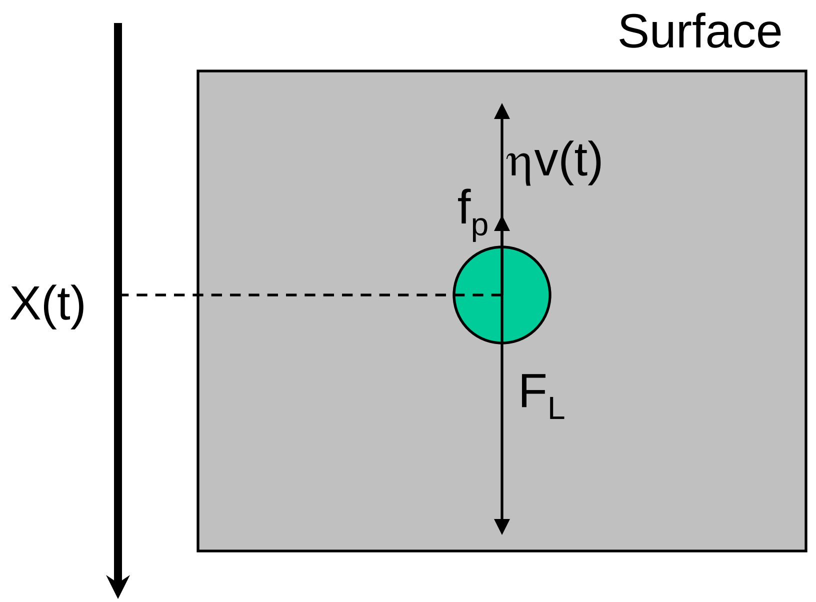
[P. Hautojarvi et al., Phys. Rev. B., Vol.35, Num.7, 1985]

Dislocations and RF superconductivity

- Dislocation tangles, dislocation cell walls might serve as sites for magnetic flux penetration at lower fields due to
  - Lower surface barrier
  - Higher κ => lower H_{c1}
- After flux penetrates – losses due to oscillatory flux motion

Estimates from Rabinowitz's model

- Assumptions for the fluxoid:
  - Image force negligible
  - Effective mass negligible
- Results
  - Effective surface resistance $R_{eff} = 4$ mOhm
  - Interfluxoid spacing for Q to decrease by a factor of 2 at 100 mT is $d_{flux} = 45$ um – comparable to the size of the "cells" seen in dislocation density maps



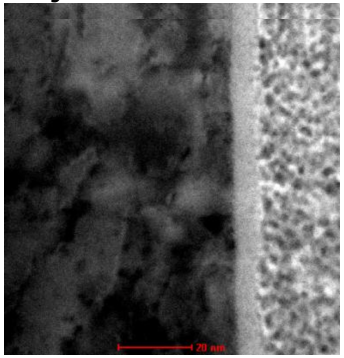
Effective resistivity

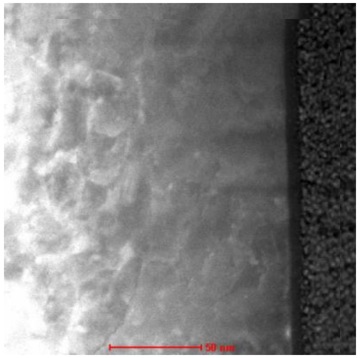
$$\boxed{\rho = \{\omega^2\phi^2 H H_0 \mu^2 / [\rho_n^2(\omega^2 M - p)^2 + \omega^2\phi^2 H_0^2\mu^2]\}\rho_n}$$

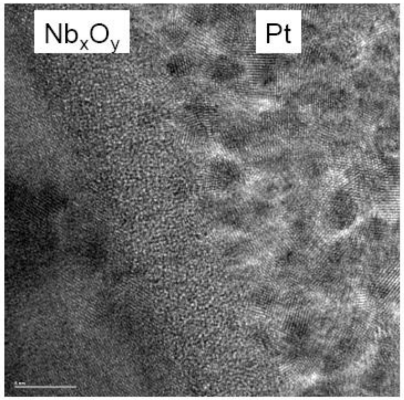
TEM + EELS

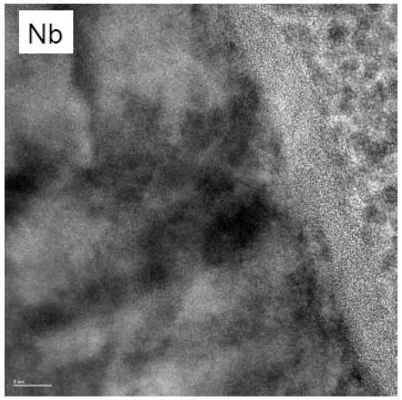
A. Romanenko, J. Mundy, P. Ercius, J. Grazul – details eslewhere

- FIB prepared samples from “hot” spot before and after 120C baking
- EELS elemental analysis with atomic scale resolution
- **No oxygen-enriched layer**
- **No oxygen diffusion**
- **No oxide modification**
- **No cracks or suboxide clusters – very nice and uniform oxide**

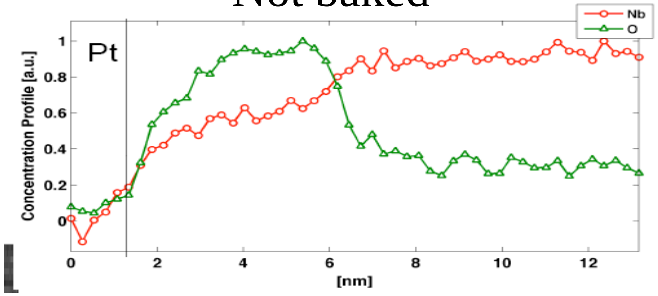




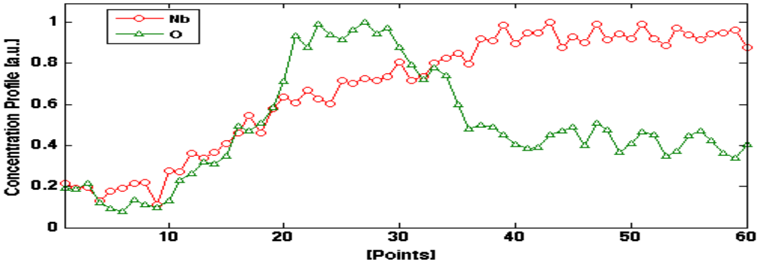




Not baked



Baked



Conclusions

- Lattice defects (i.e. dislocations) may be the cause of the HFQS based on:
  - Difference between hot and cold samples
  - Change with 100-120C baking
- Dislocation climb as a possible mechanism
  - Vacations immobilized by H up to ~ 100C
- FIB/TEM + EELS disqualify oxygen diffusion-related and/or oxide modification baking mechanisms

Thank you!