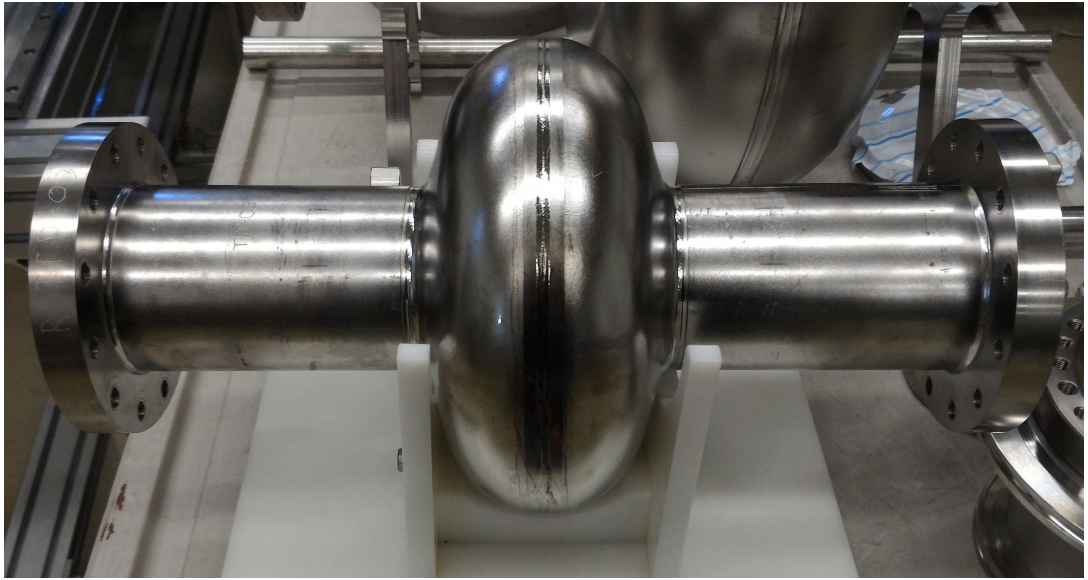
Study of premature quench fields of Nitrogen-doped Niobium cavities

Bianca Giaccone
Final Review
27th September 2017

Supervisor: Martina Martinello
Co-supervisor: Mattia Checchin

Outline

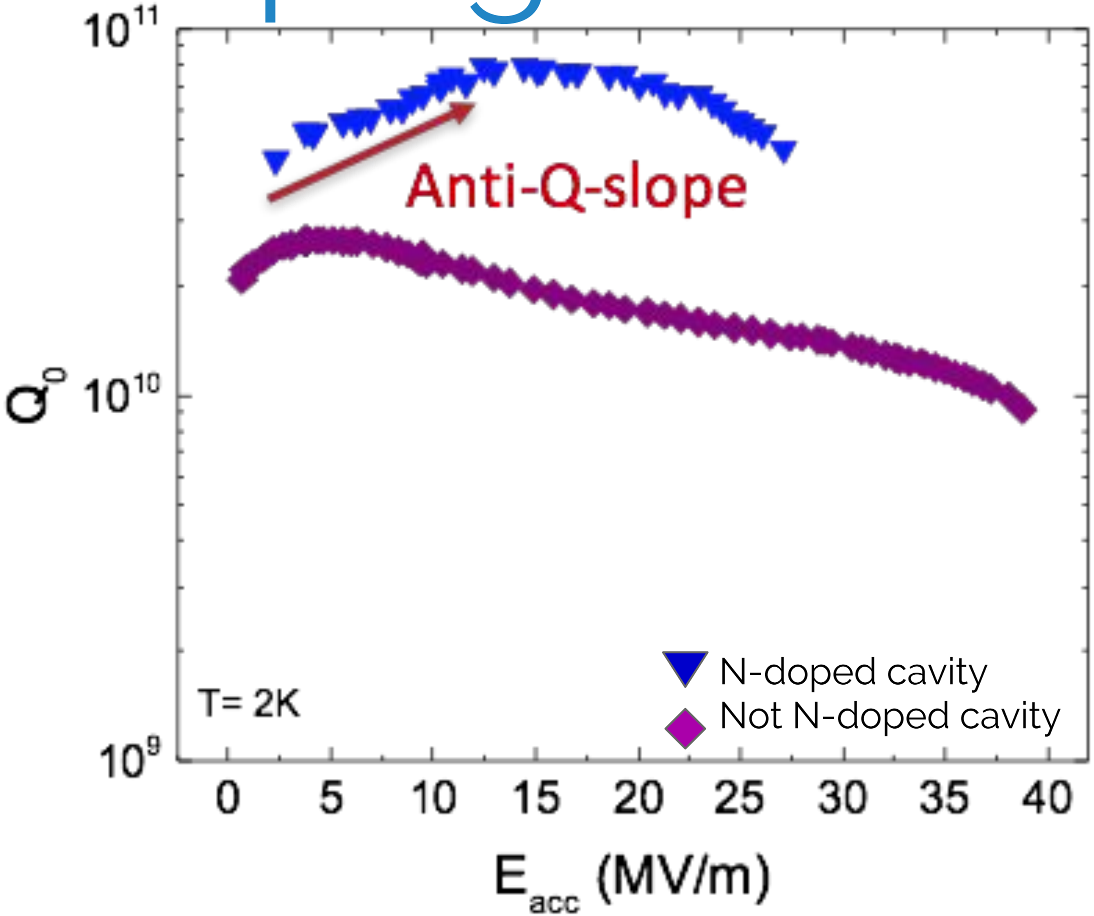
- Introduction
- Measurements
  - RF tests
  - Optical inspection
  - Laser confocal microscopy
  - SEM
- Conclusion



Introduction

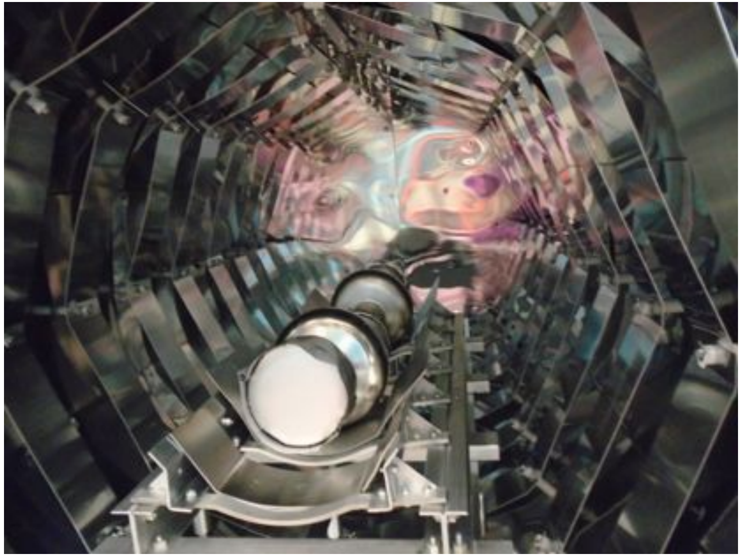
Nitrogen doping

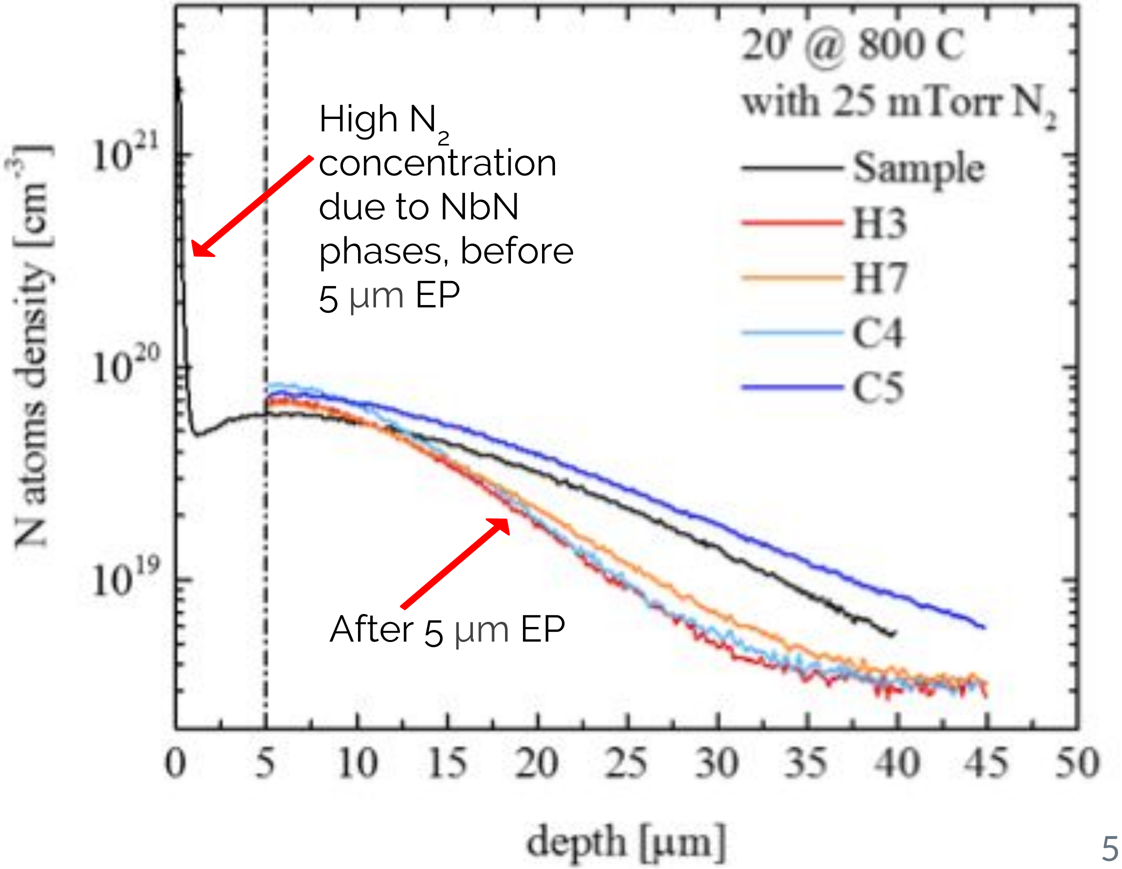
- Nitrogen treatment increases Q_0 compared to standard processing
- Anti-Q-slope
- LCLS II is using N-doping technology
- N-doped cavities present quench at medium values of E_{acc}



Nitrogen doping

- “2/6” recipe: at 800˚C, 2 min Nitrogen injection, 6 min anneal
- 5 µm EP to remove nitrides and have interstitial nitrogen only



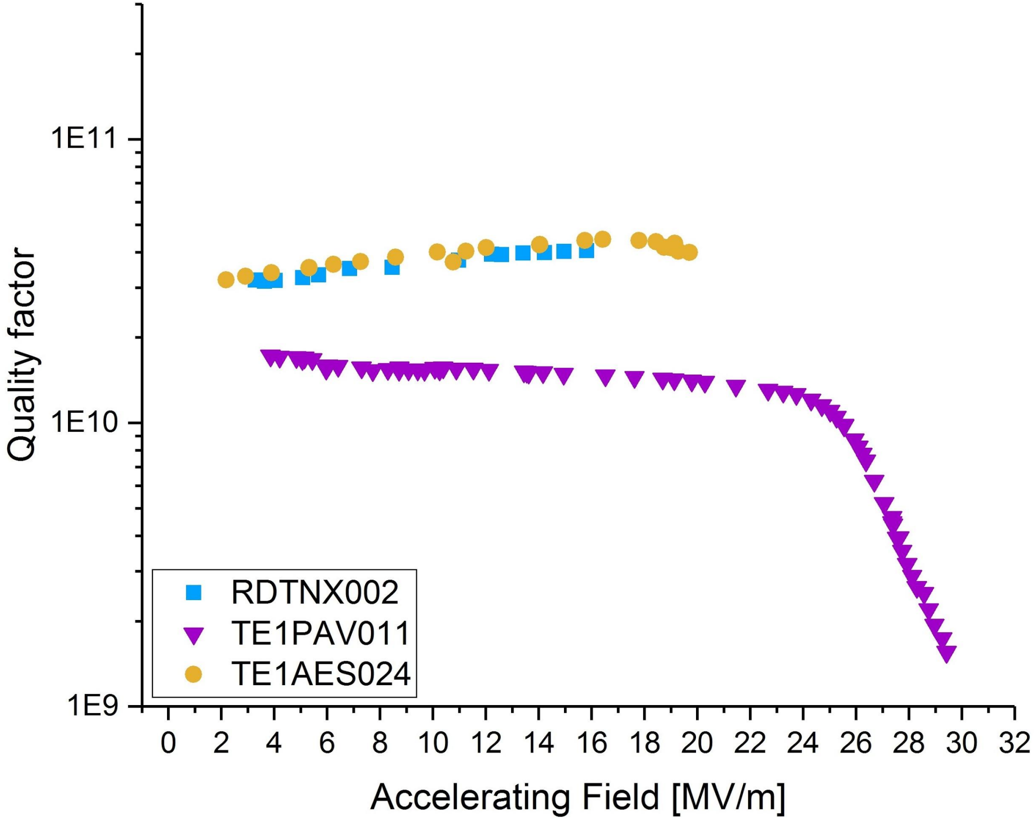


RF results from 3 cavities tested during the internship

- TE1PAV011: standard baked cavity, EP
- RDTNX002, TE1AES024: N-doped cavities, “2/6” recipe

At 2K at E_{acc}=16MV/m:

- TE1PAV011: $Q_0 = 1.6 \cdot 10^{10}$
- RDTNX002: $Q_0 = 4 \cdot 10^{10}$
- TE1AES024: $Q_0 = 4.4 \cdot 10^{10}$

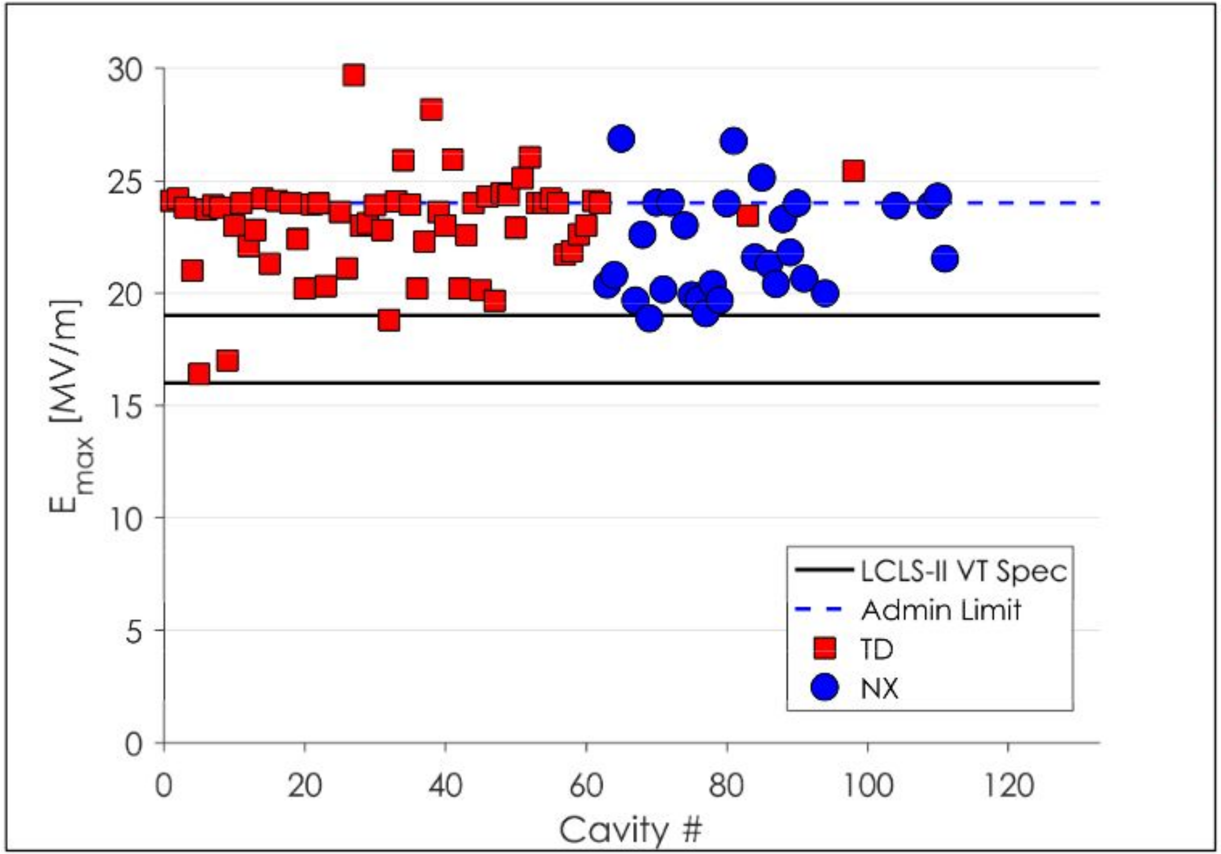


LCLS II: Ningxia vs Tokyo Denkai

LCSL II: cavities made with Nb from two different vendors:

- Ningxia
- Tokyo Denkai

NX and TD cavities statistically show different quench field



Measurements on two 1.3GHz single cell N-doped cavity:

- RDTNX002 → Ningxia
- TE1AES024 → Tokyo Denkai

Measurements on Nb N-doped samples of Ningxia and Tokyo Denkai, same recipe as the cavities.

Measurements

- 2 different 1.3GHz single cell cavities
  - RF tests:
    - 2K and 1.5 K power rise
    - T-map measurements
    - Fast thermometers analyses
  - Optical inspection
- Laser confocal microscopy on cavities' replicas
- SEM analyses on square sample of NX and TD

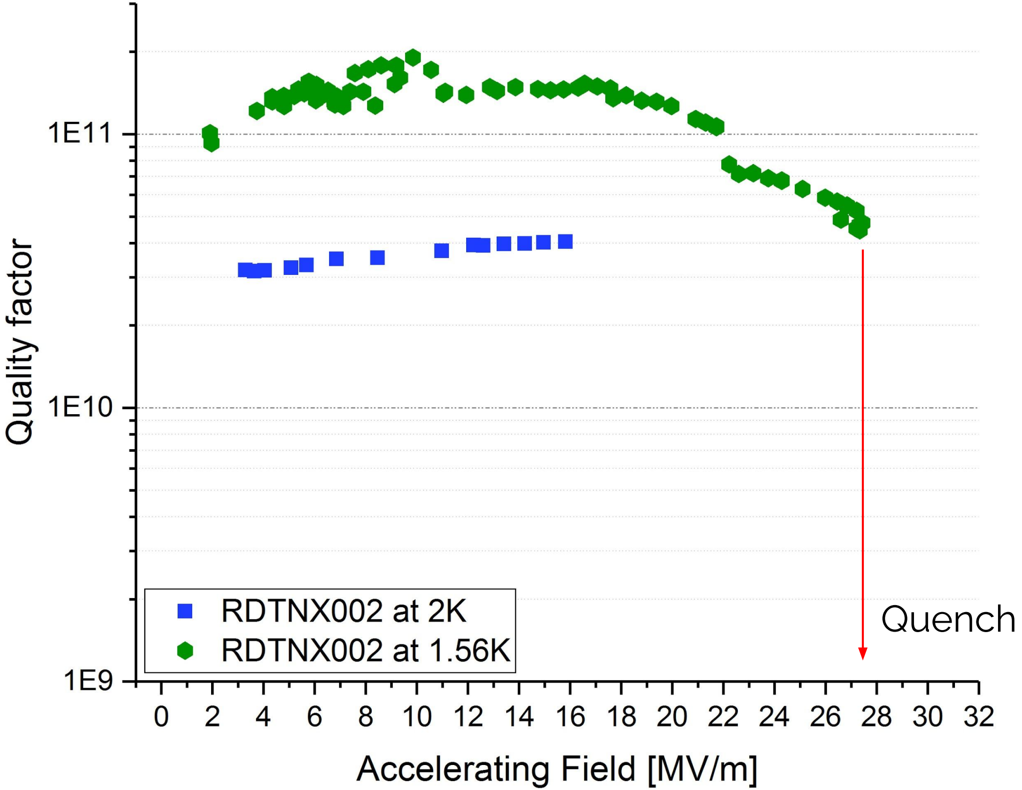
RF tests

RF tests results: RDTNX002

At E_{acc}= 16MV/m:

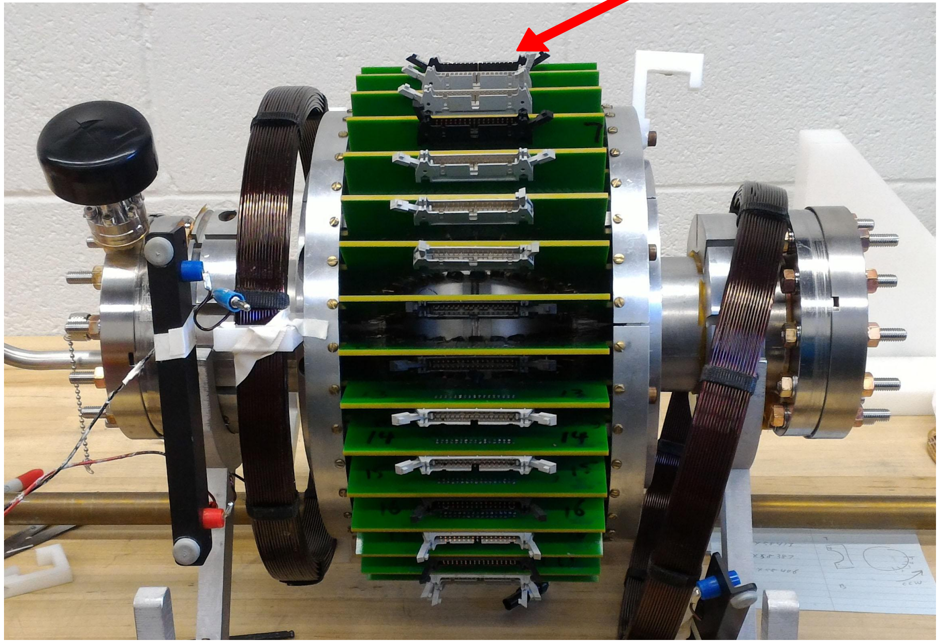
- $Q_0=4\cdot10^{10}$ at 2K
- $Q_0=1.5\cdot10^{11}$ at 1.56K

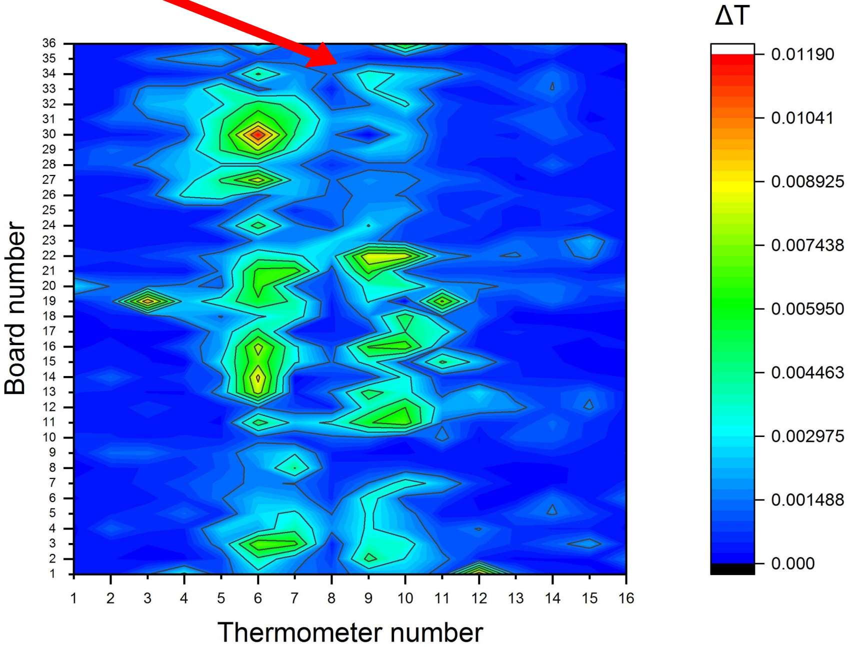
Power Rise at 2K: stopped at 16MV/m to avoid quench



Temperature Map

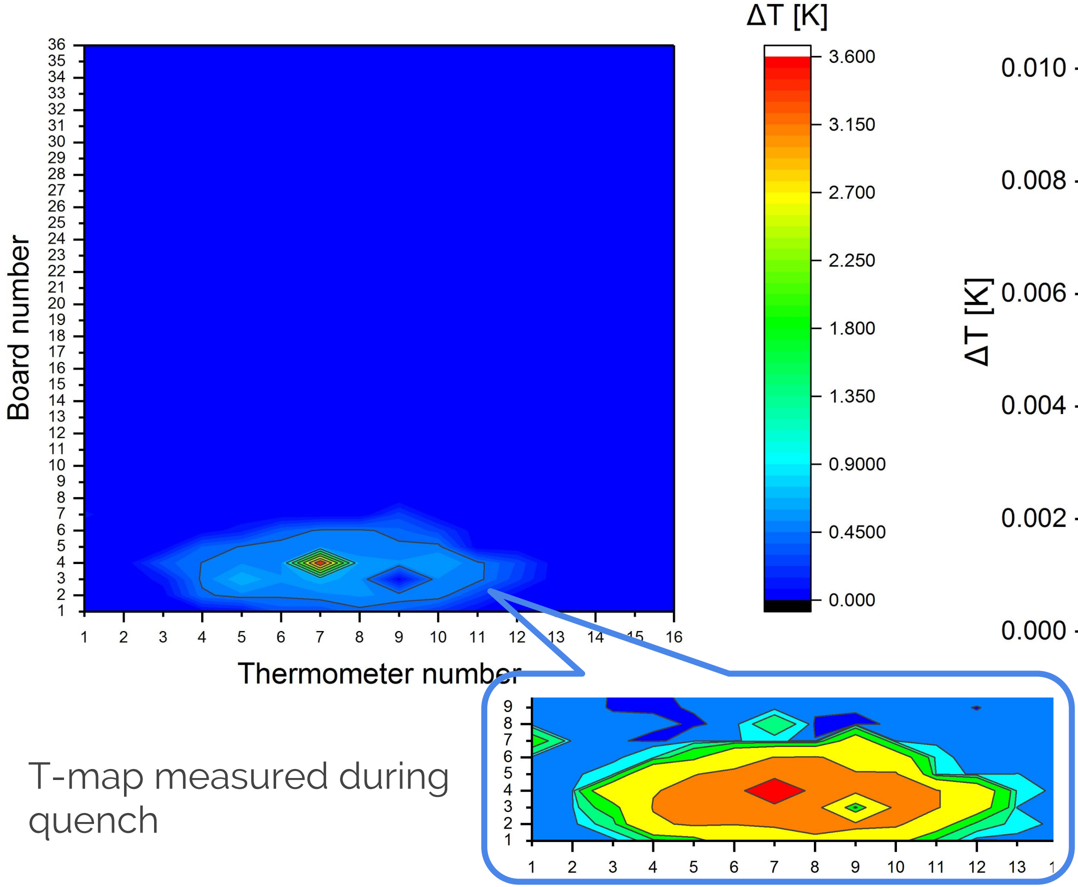
Cell equator



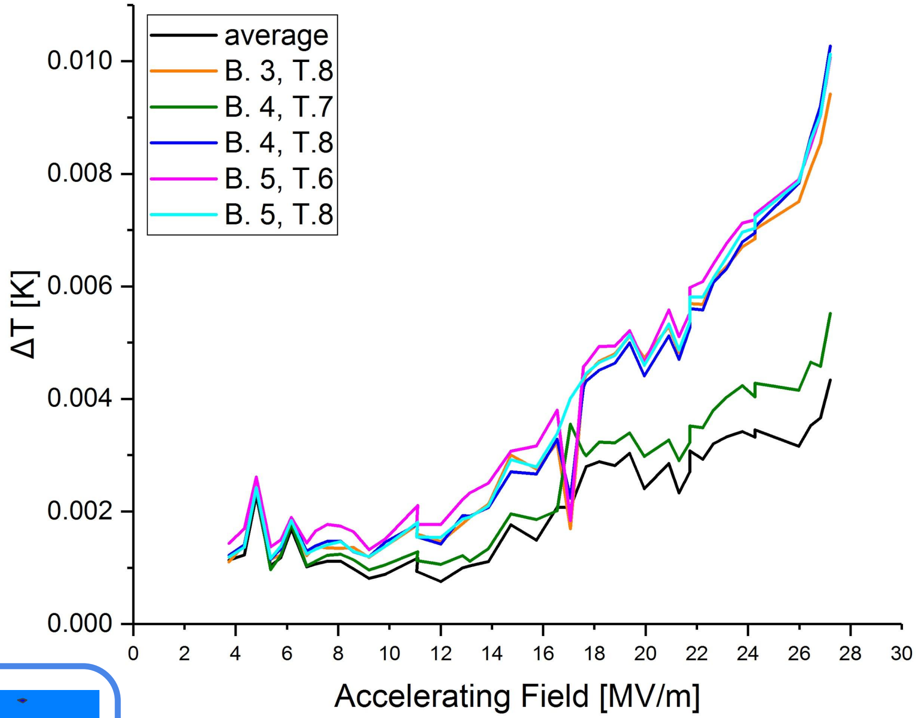


T-map installed on a 1.3 GHz single cell cavity

T-map: RDTNX002



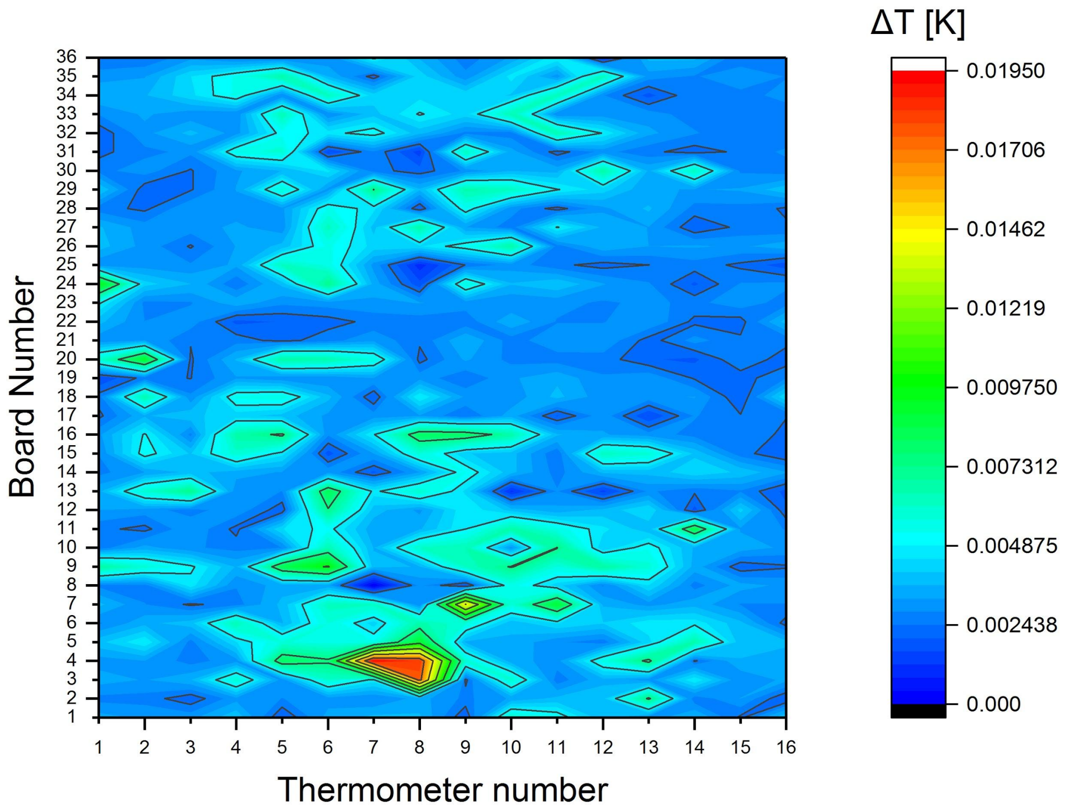
T-map measured during quench



Plot of T vs E_{acc}. Shows pre-heating of the thermometers involved in quench.

T-map: RDTNX002

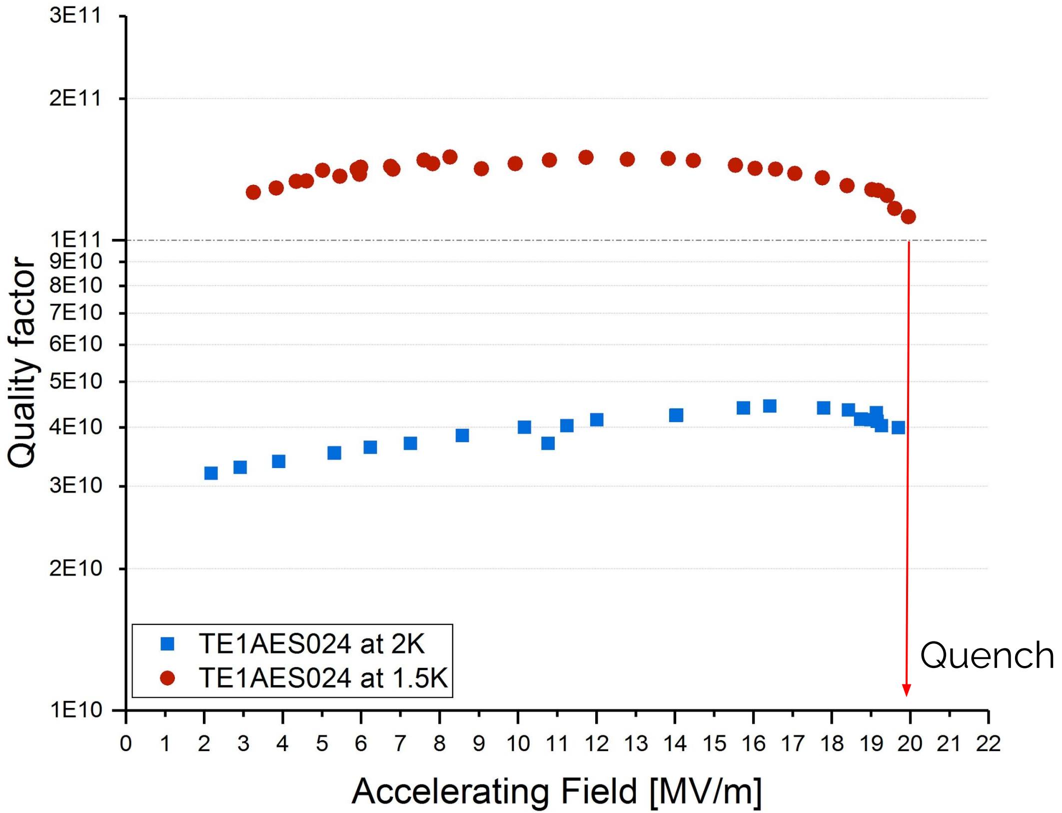
Second power rise at 2K, 27 MV/m.
Tmap acquired after quench, shows heating due to trapped field at the quench spot.



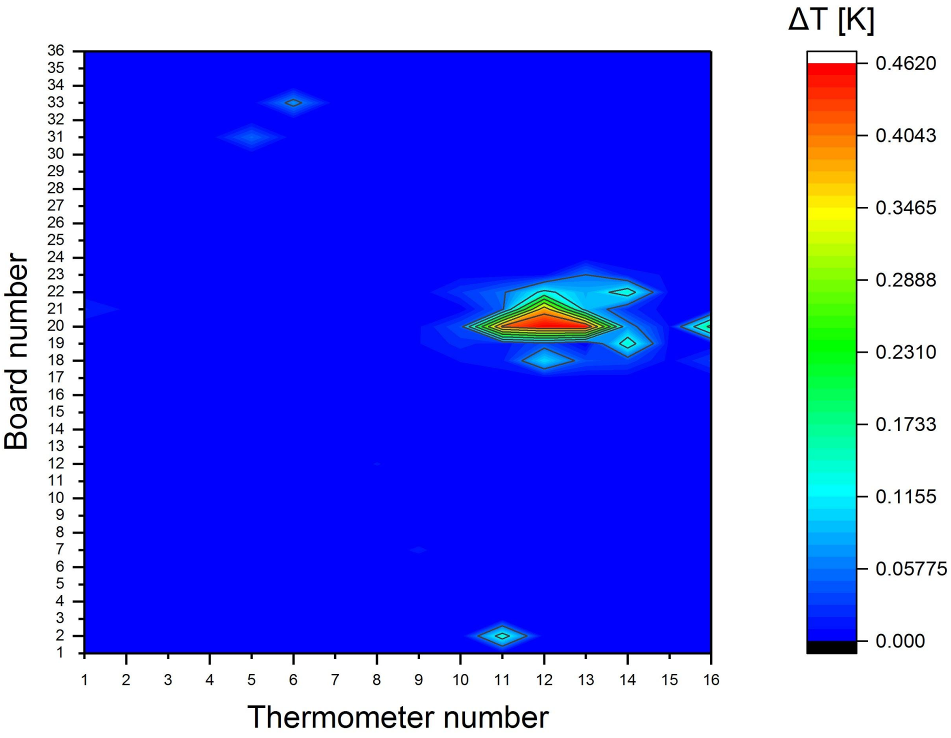
RF tests results: TE1AES024

At E_{acc} = 16MV/m:

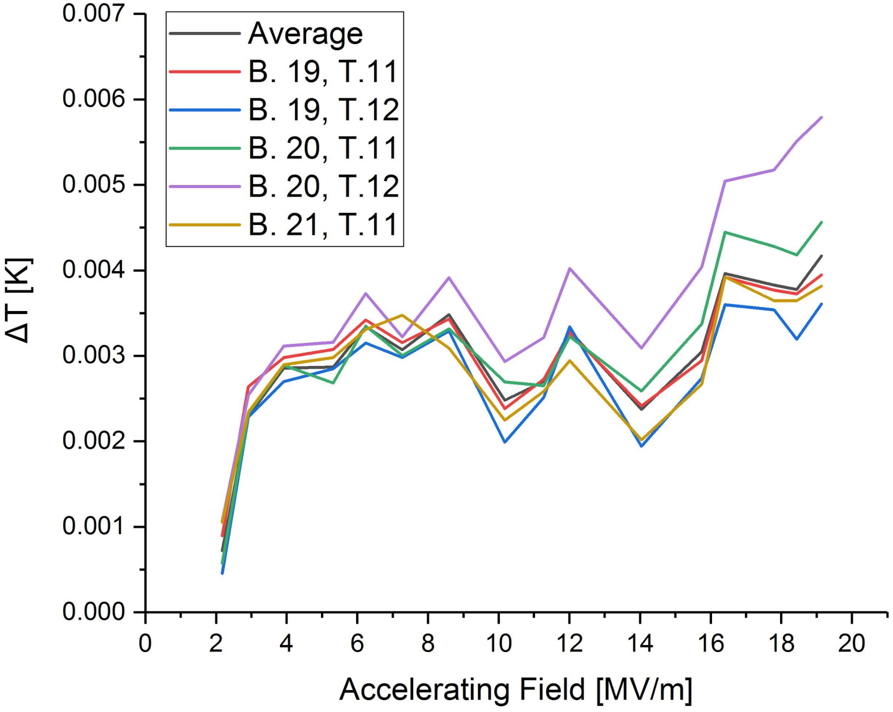
- $Q_0 = 4.4 \cdot 10^{10}$ at 2K
- $Q_0 = 1.4 \cdot 10^{11}$ at 1.56K



T-map: TE1AES024

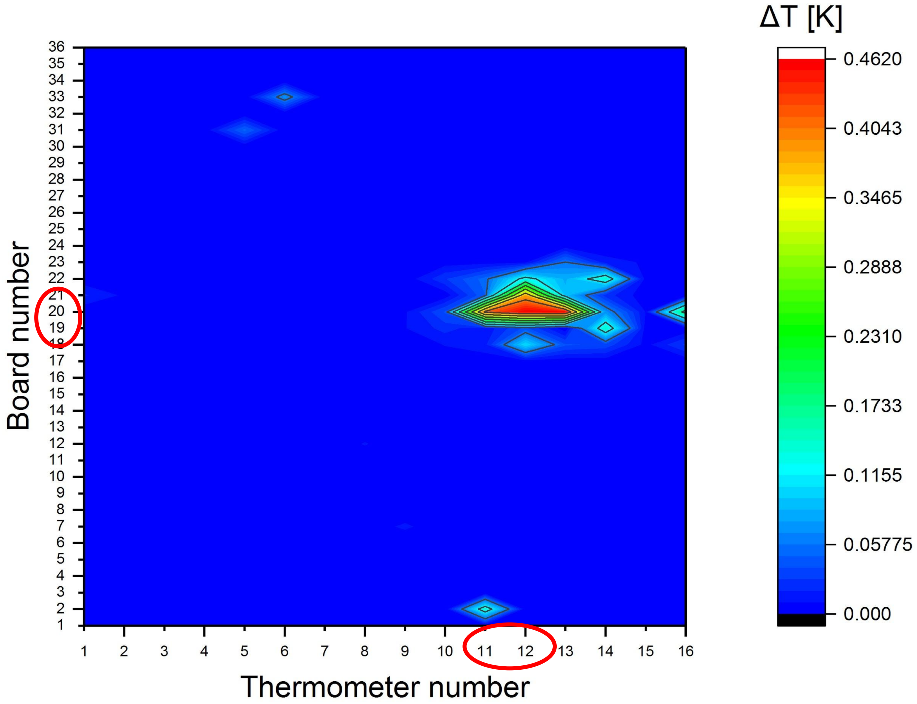


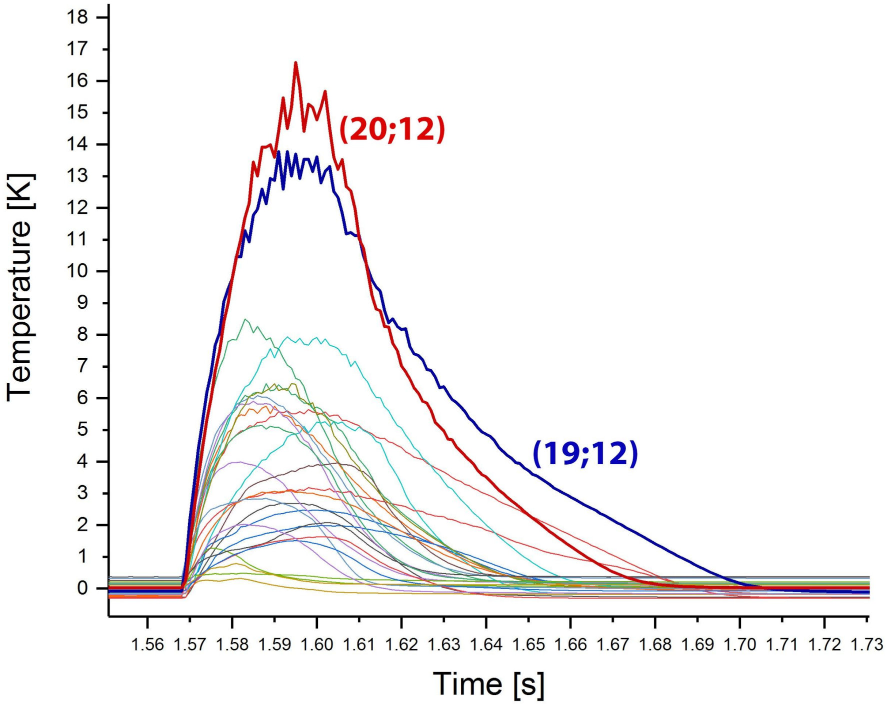
T-map of quench at 2K



Second power rise at 2K, plot of T vs E_{acc}. No pre-heating

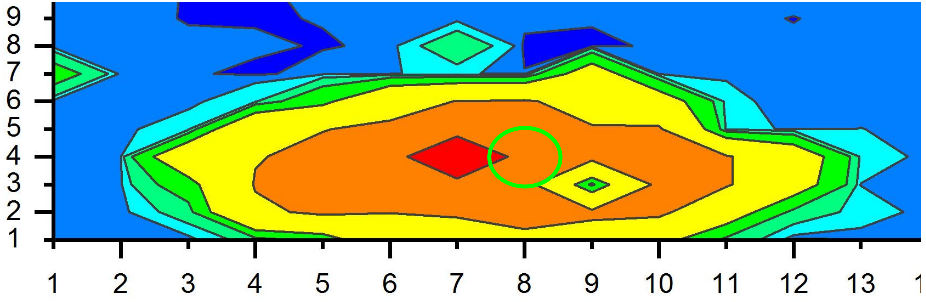
Fast T-map: TE1AES024

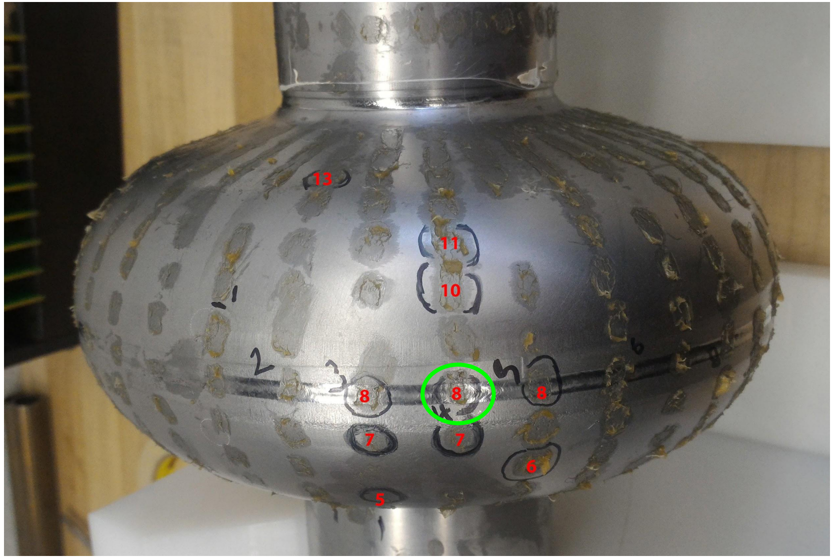




Optical Inspection and Replica analysis

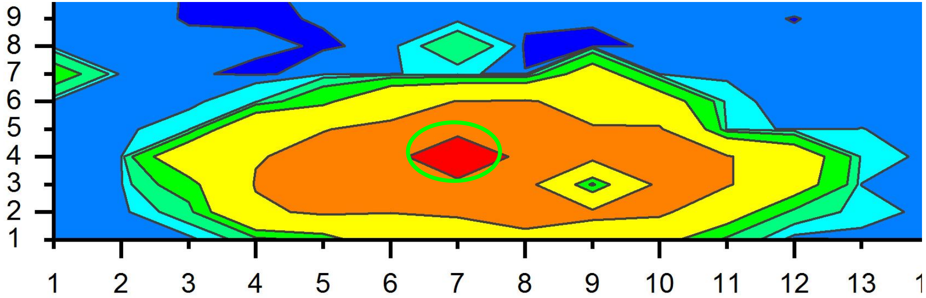
Optical Inspection: RDTNX002

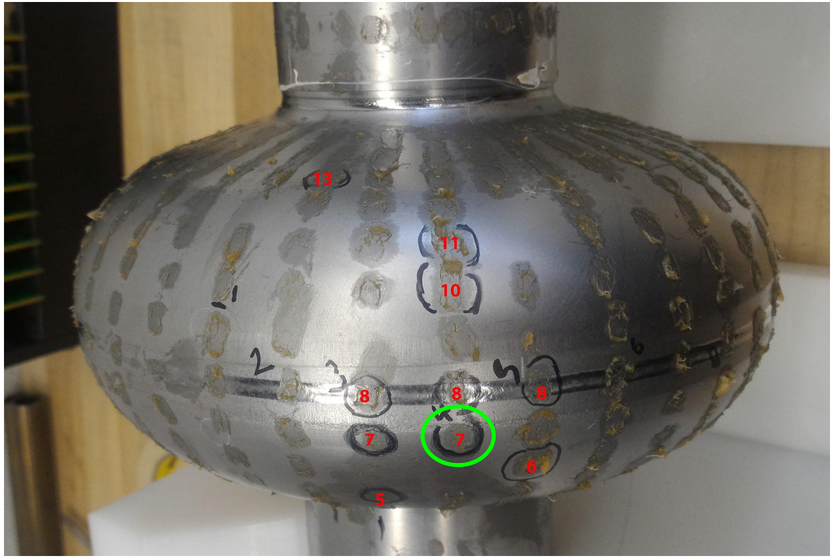




Surface of the cavity on the possible quench spot (B4-Th8)

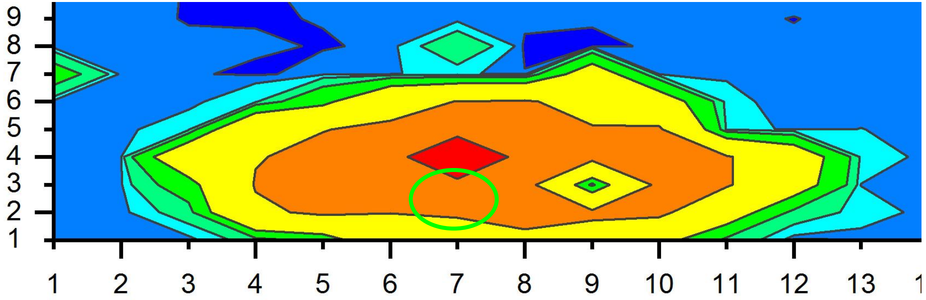
Optical Inspection: RDTNX002

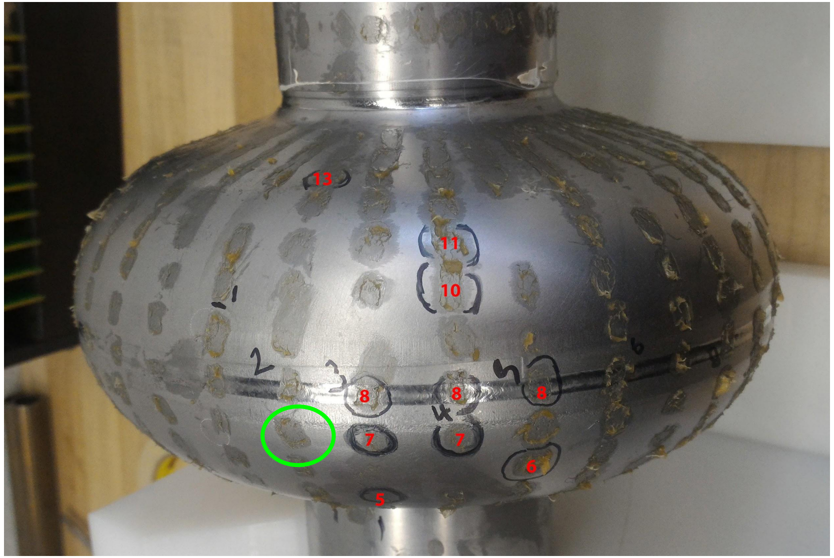




Surface of the cavity on a possible quench spot (B4-Th7)

Optical Inspection: RDTNX002

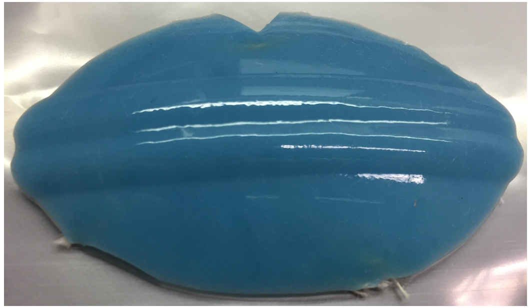


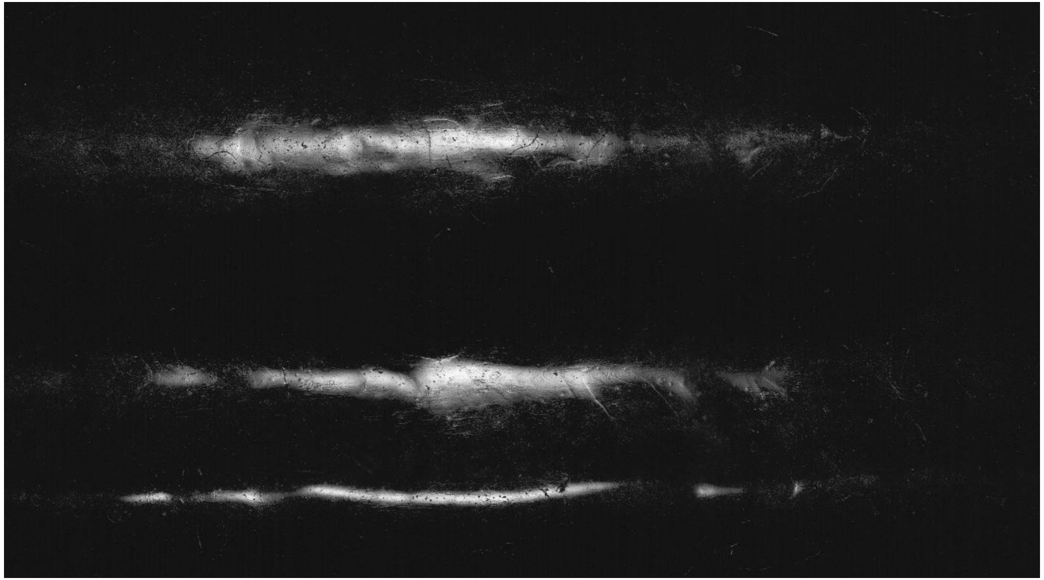


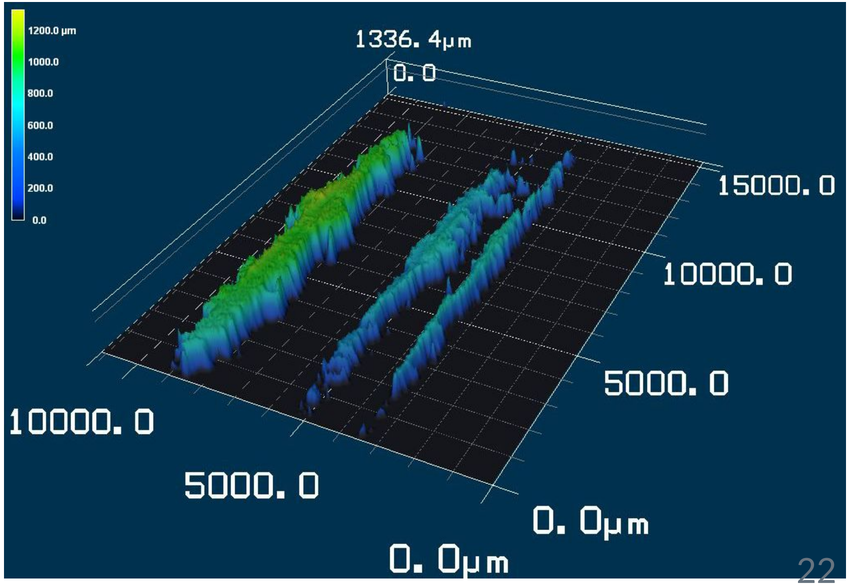
Bump on the surface of the cavity (B2-Th7)

Replica: Laser Confocal Microscopy

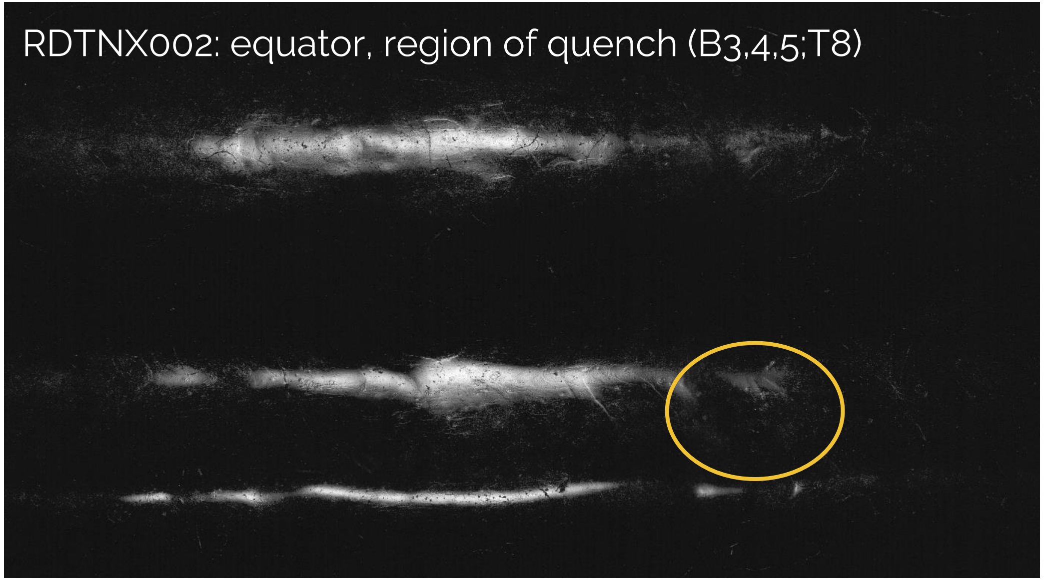
RDTNX002: equator, region of quench
(Board 3,4,5;Thermometer 8)

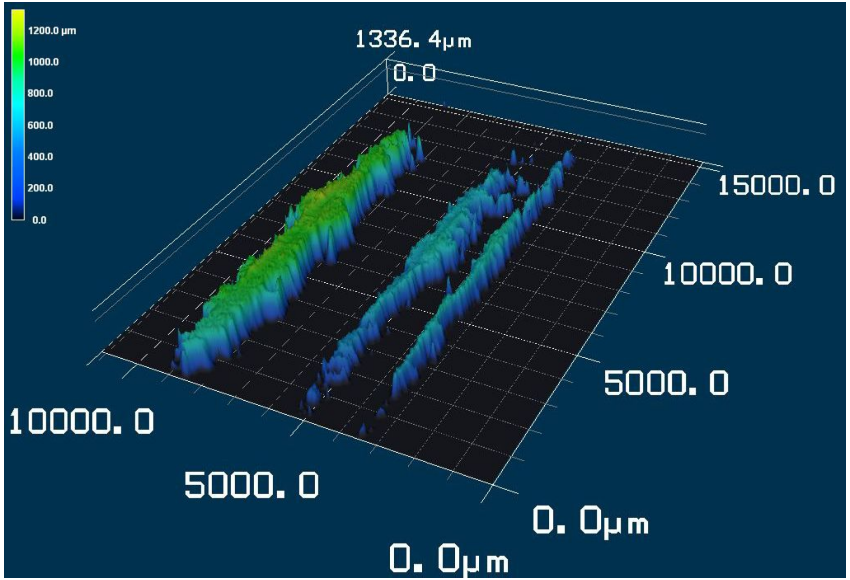


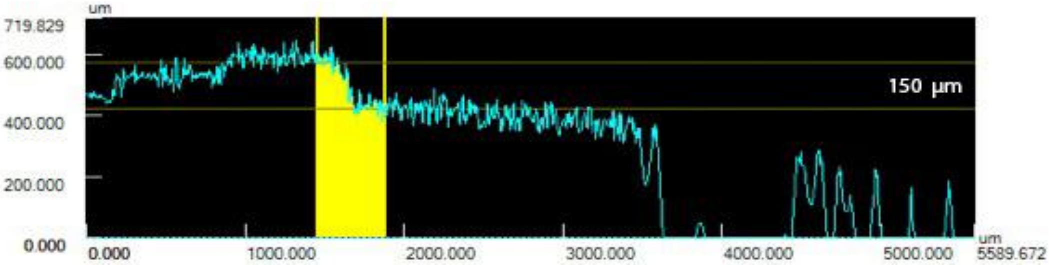




Replica: Laser Confocal Microscopy





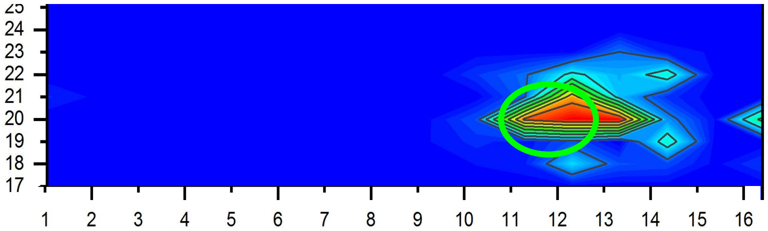


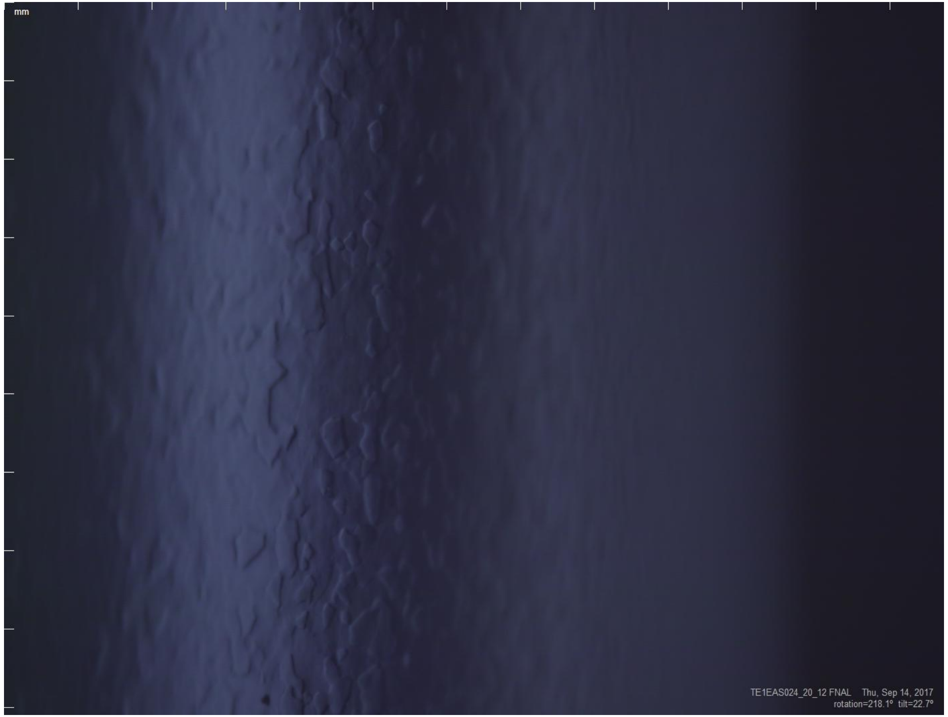
Bump on the equator (Board 3-4), visible on all three sides of the welding.
Bump height: 150 µm
Bump lenght: 10 mm

Optical Inspection: TE1AES024

Surface of the cavity on the possible quench spot (B20-Th12)

- No important defects
- Prominent grain boundaries → cause of quench may be the enhancement of local magnetic field on a grain boundary





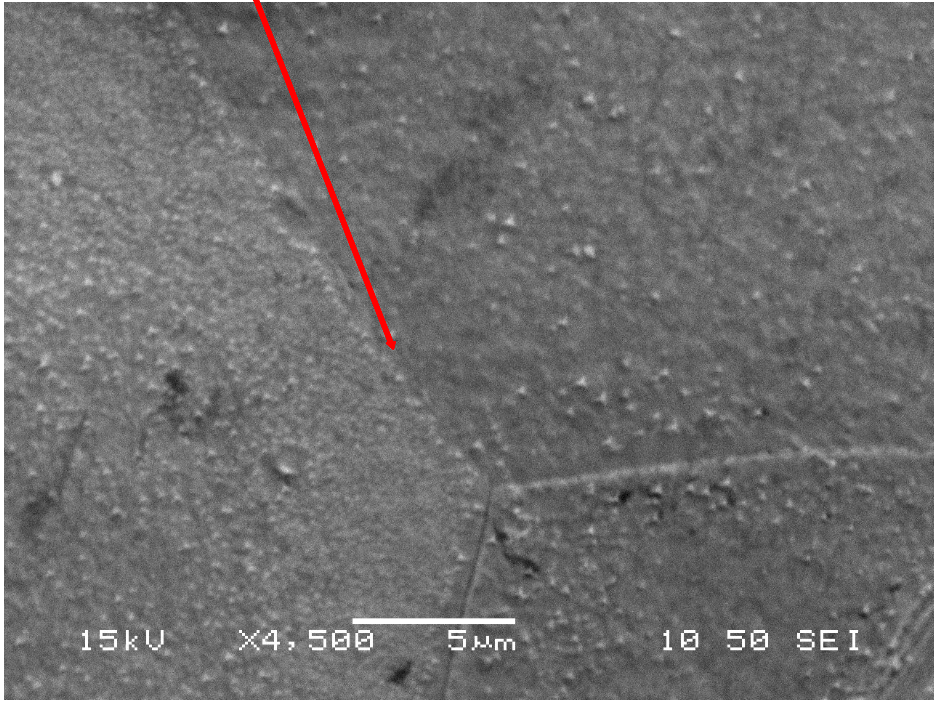
SEM

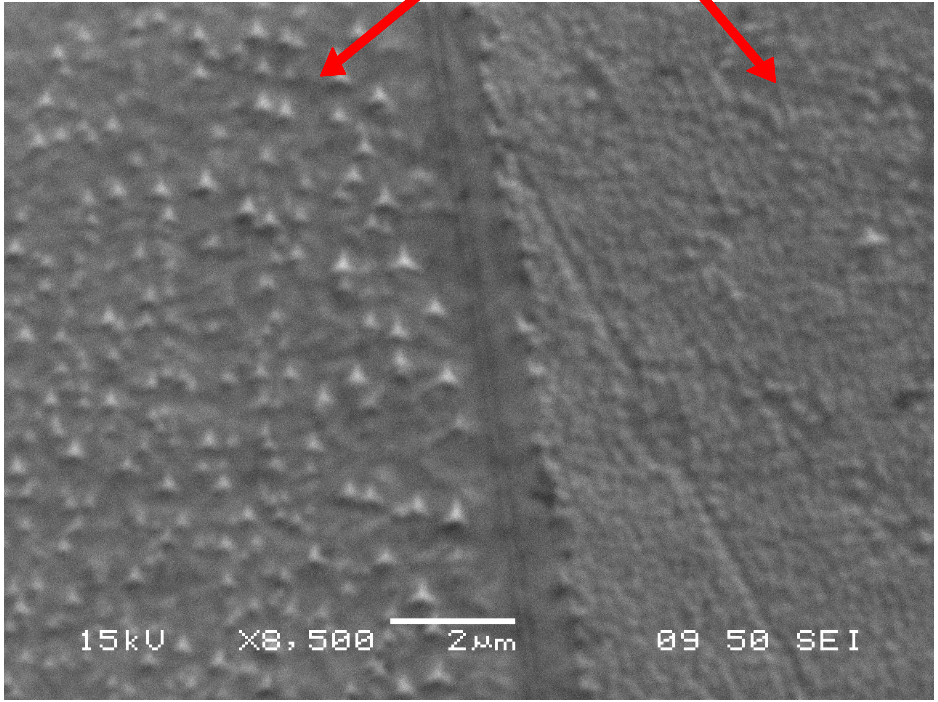
Scanning Electron Microscope

SEM: Ningxia Samples

Grain Boundaries

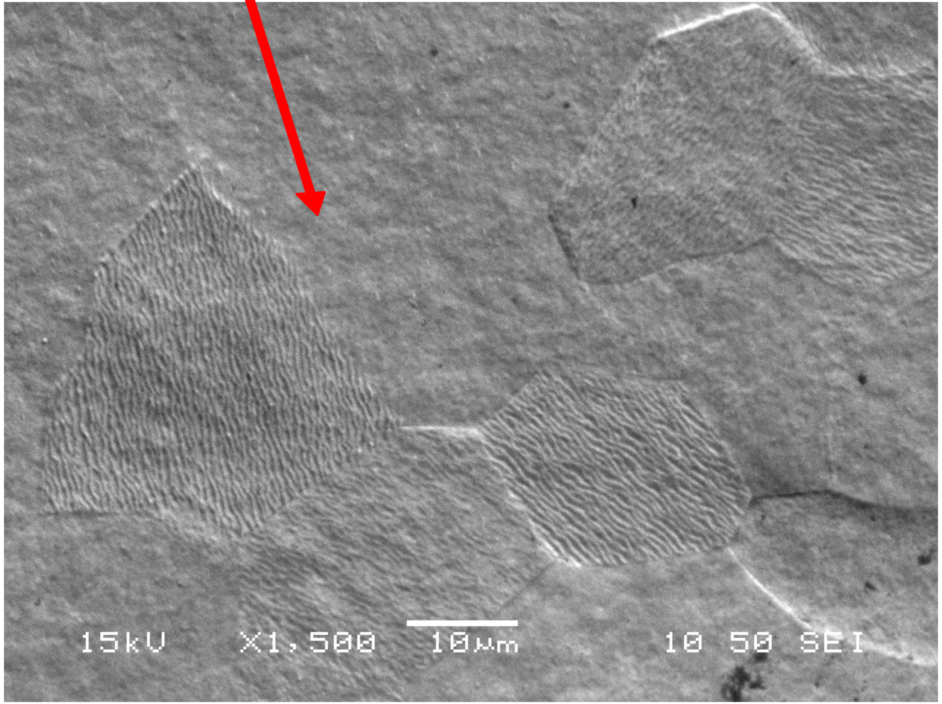
Different concentration of nitrides in different grains



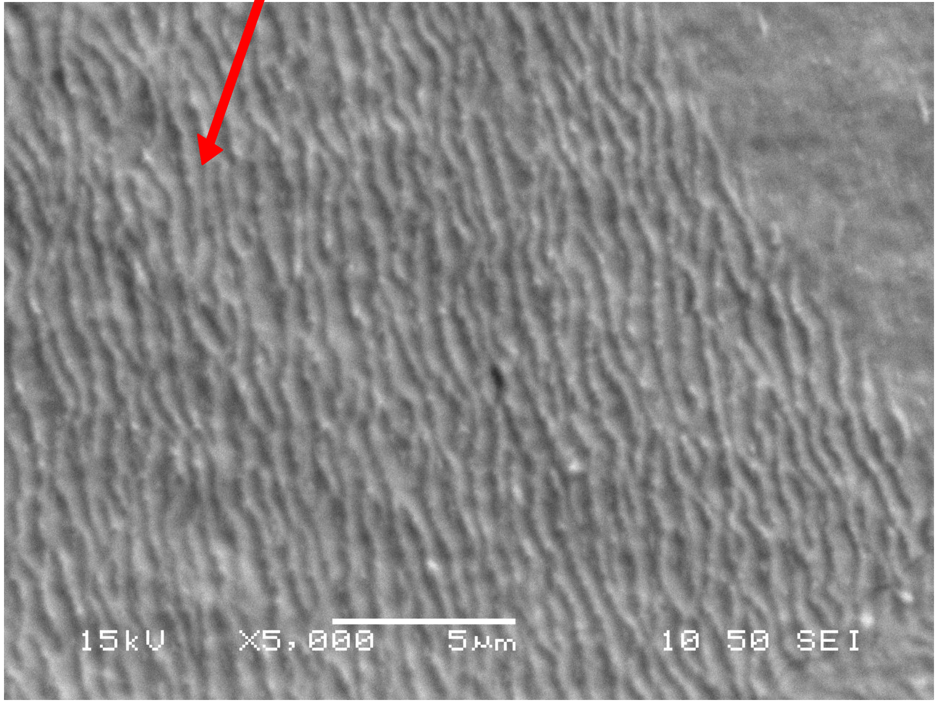


SEM: Tokyo Denkai Samples

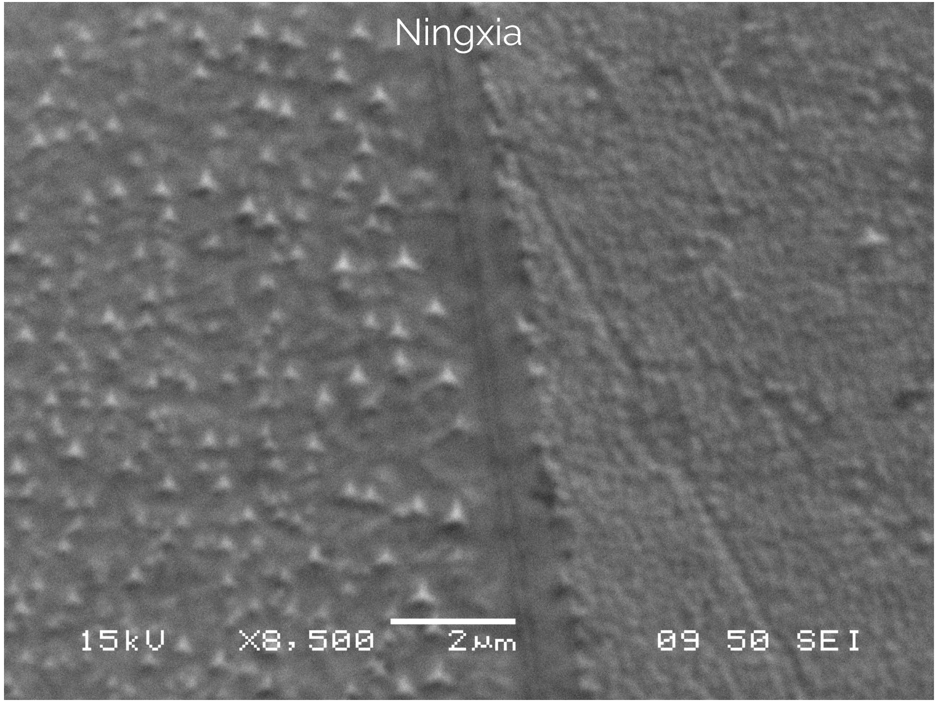
No nitrides

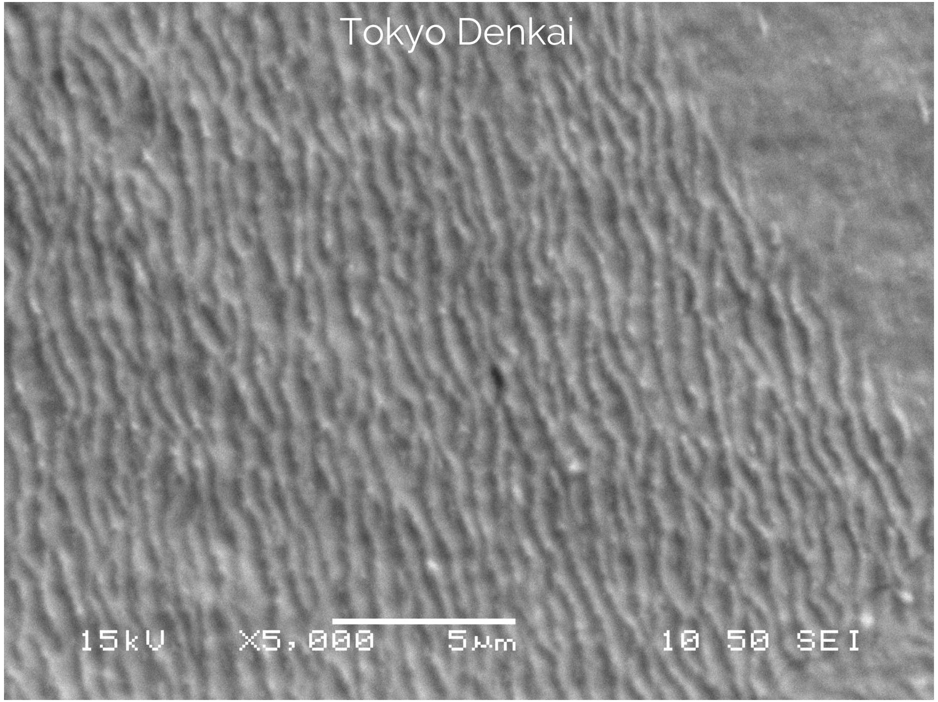


Different phase of nitrides compared to Ningxia



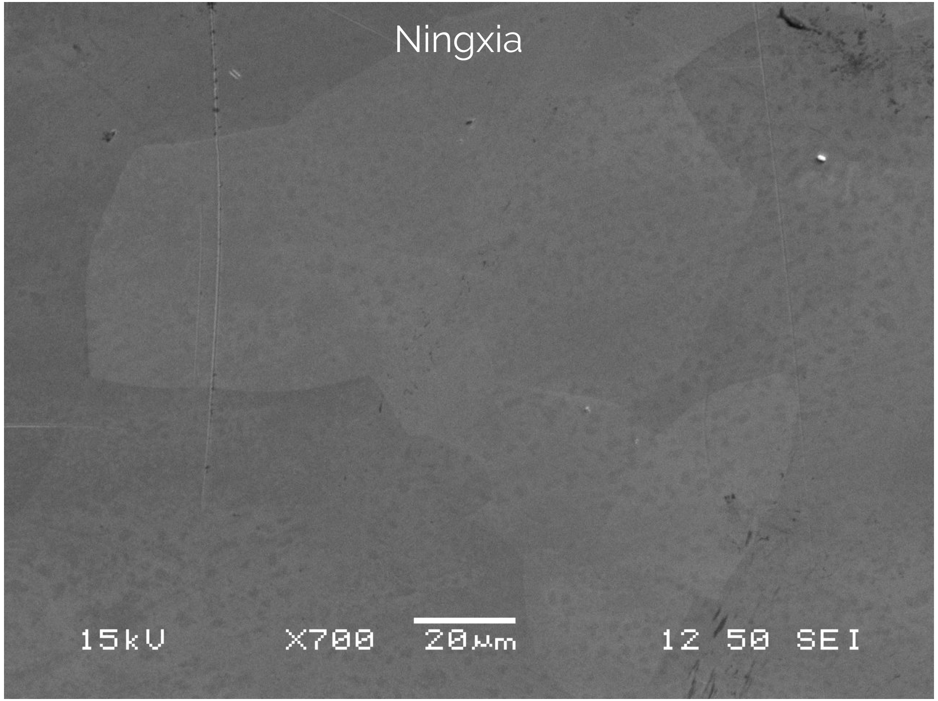
SEM: Ningxia vs Tokyo Denkai

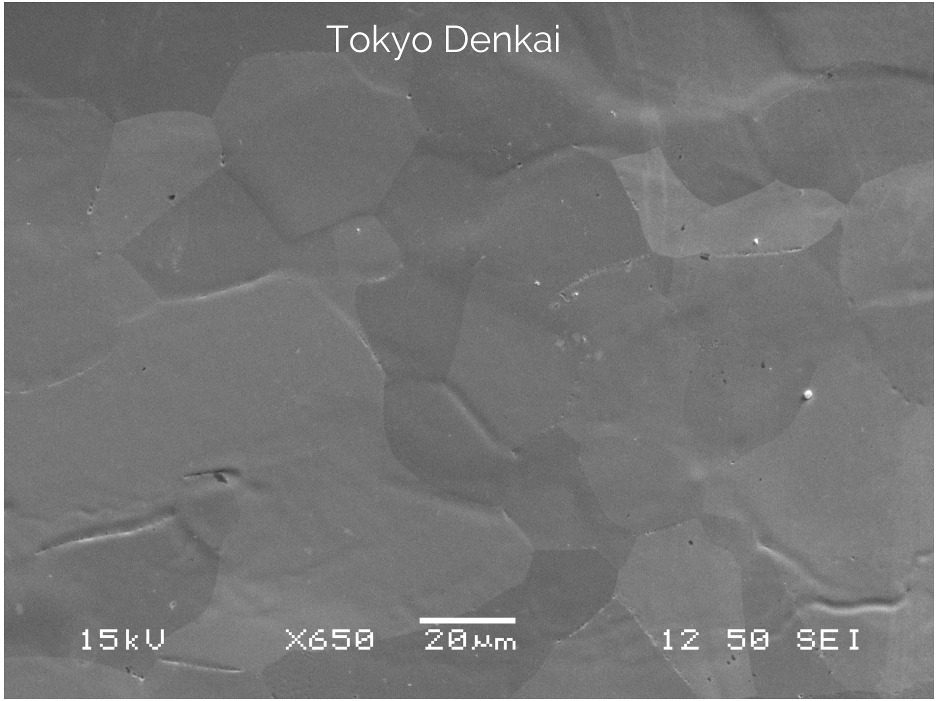




Ningxia and Tokyo Denkai react differently to Nitrogen-doping treatment

SEM: 5 µm EP N and T Samples





After EP the step at the grain boundaries are more pronounced in case of Tokyo Denkai material, in agreement with optical inspection images

Conclusion

RDTNX002 vs TE1AES024

Ningxia

- E_{Quench} = 27 MV/m
- Tmap shows pre-heating
- Region of quench: equator
- Optical inspection shows morphological defects, in agreement with Laser confocal microscopy

Tokyo Denkai

- E_{Quench} = 20 MV/m
- Tmap doesn't show pre-heating
- Region of quench: far from equator, where magnetic field is higher
- Optical inspection shows pronounced steps at grain boundaries

SEM analyses show different reaction of the two material to Nitrogen-doping treatment

Conclusion

Nitrogen doping treatment lowers critical magnetic field
Asperities increase local magnetic field

Ningxia

RDTNX002: morphological defects on the equator

↓

defects enhance local magnetic field but magnetic field is not maximum on the equator

↓

Cavity can sustain higher accelerating field before reaching critical magnetic field

Tokyo Denkai

TE1AES024: quench spot is shifted from equator, where magnetic field is maximum

↓

steps at grain boundaries cause enhancement of local magnetic field

↓

This enhancement causes magnetic field to overpass critical magnetic field

Thank you for your attention

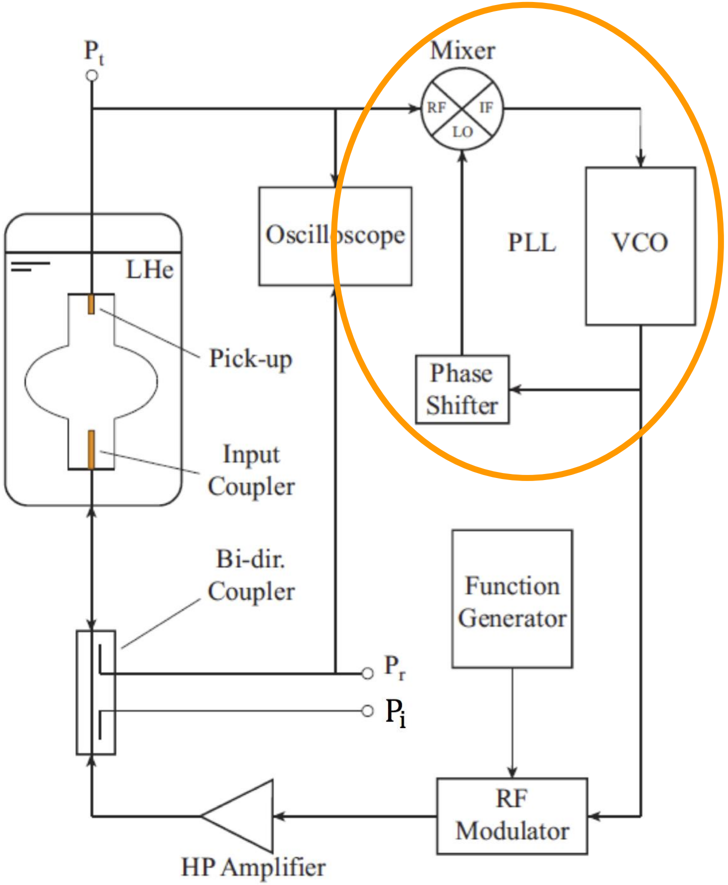
Preliminary measurements

Cryogenic tests of 2 single cell 1.3GHz N-doped cavities at 1.5 and 2 K:

- frequency measurements
- cables calibration

$$E = \frac{1}{L}\sqrt{\frac{R}{Q_L}Q_0P_c}$$

$$P_c = P_i - P_r - P_t$$



Optical Inspection: RDTNX002

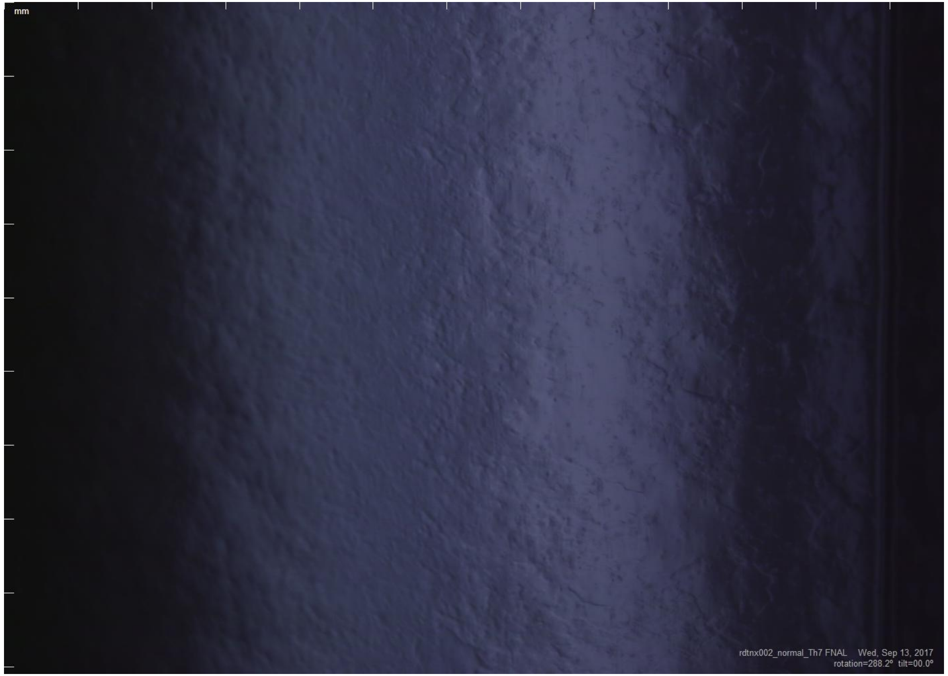
Surface of the cavity on the possible quench spot (B4-Th8)

Surface of the cavity on a different point of the equator (Th8)

Optical Inspection: RDTNX002

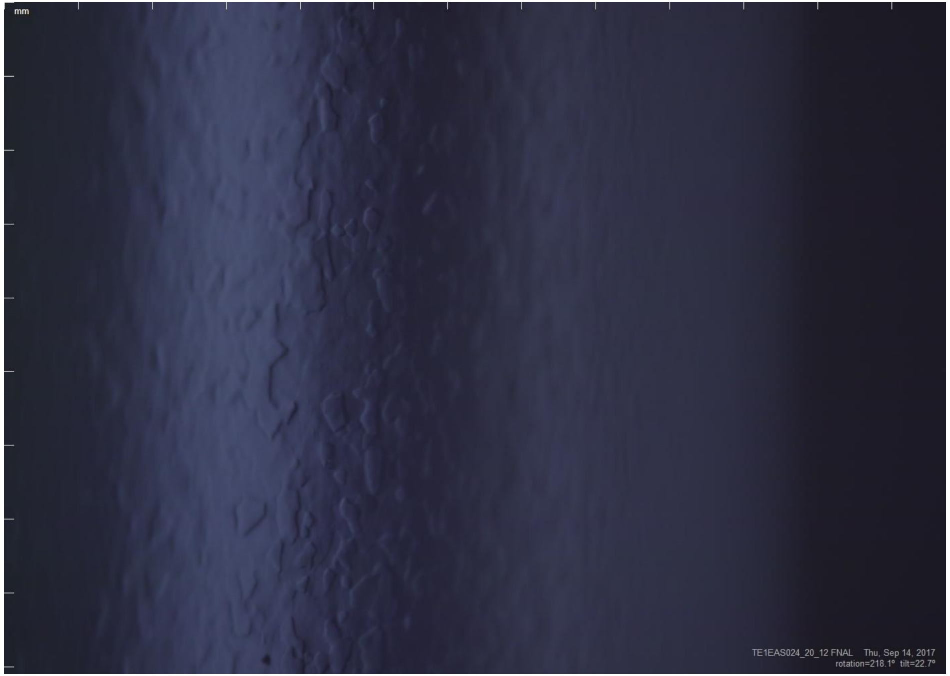
Surface of the cavity on a possible quench spot (B4-Th7)

Surface of the cavity on a different point of the cavity (Th7)



Optical Inspection: TE1AES024

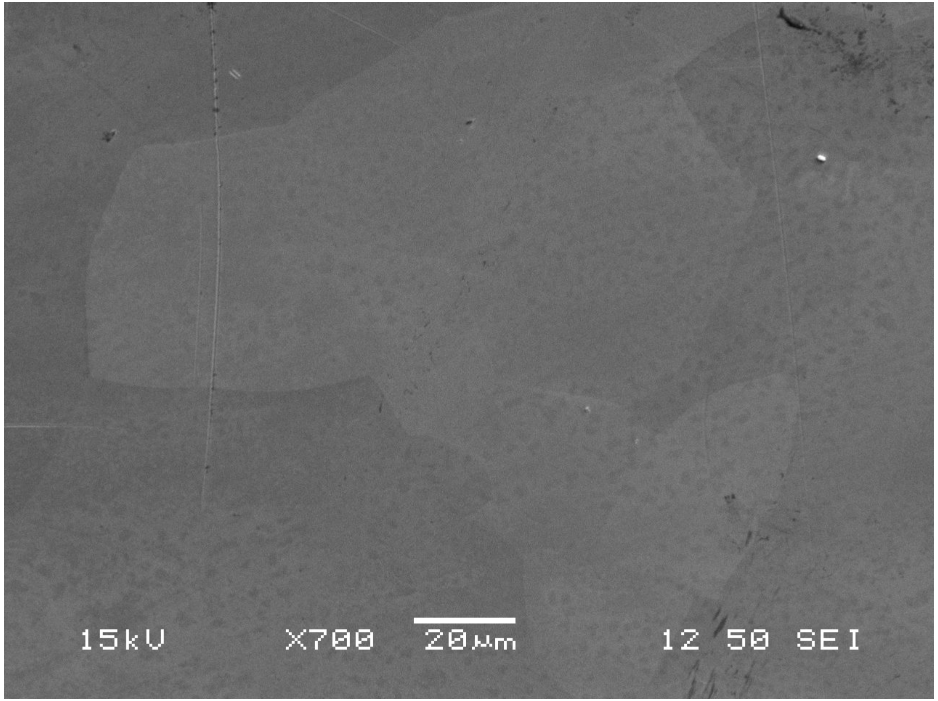
Surface of the cavity on the possible quench spot (B20-Th12)



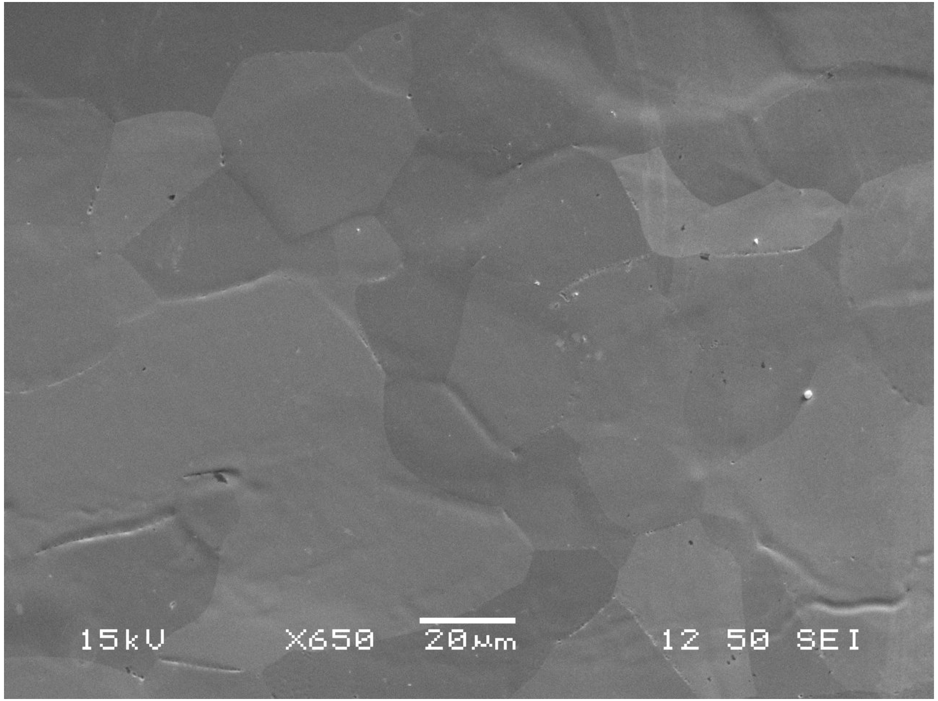
Surface of the cavity on a point of the equator

SEM: 5 µm EP N and T Samples

Nb N-doped samples treated at 800 ˚C, with "2/6" recipe, 5 µm EP



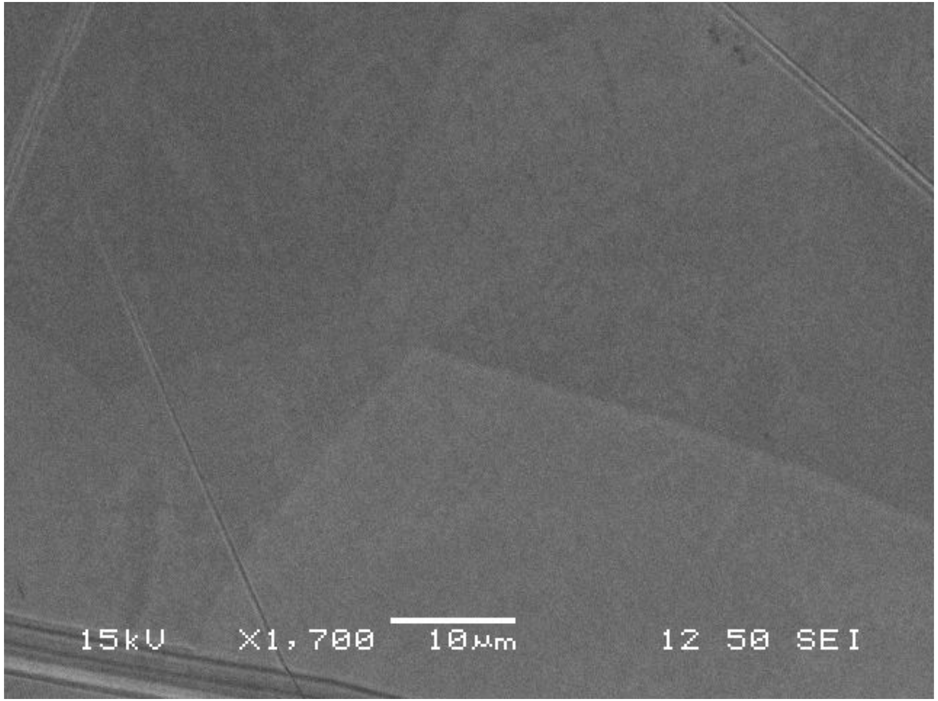
Ningxia sample



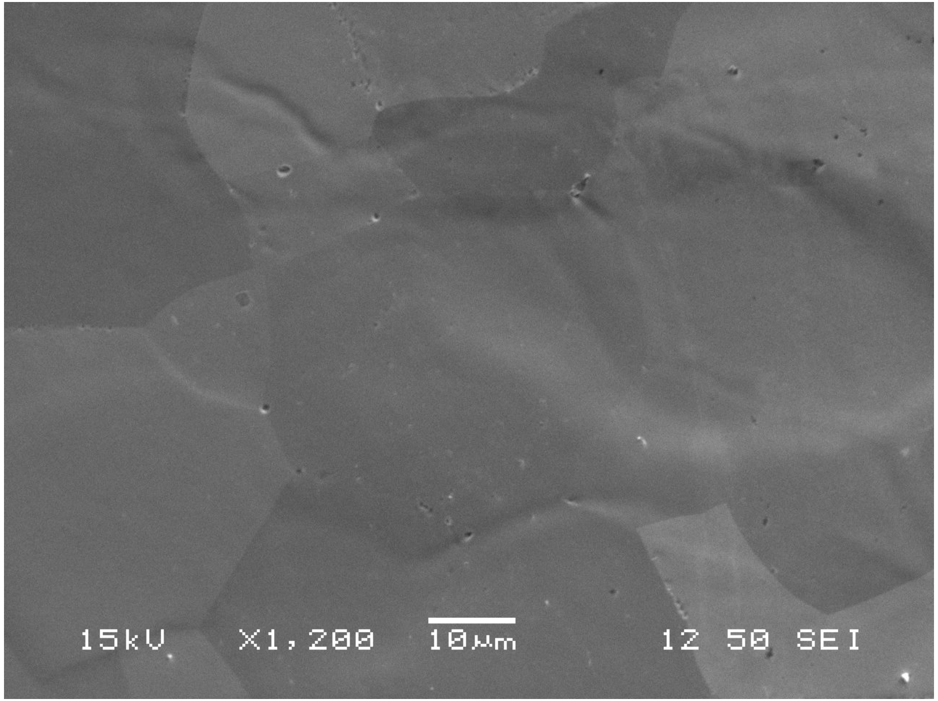
Tokyo Denkai sample

SEM: 5 µm EP N and T Samples

Nb N-doped samples treated at 800 °C, with "2/6" recipe, 5 µm EP



Ningxia sample



Tokyo Denkai sample