Study of premature quench fields of Nitrogen-doped Niobium cavities
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

High N₂ concentration due to NbN phases, before 5 μm EP

After 5 μm EP
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 $E_{\text{acc}} = 16 \text{MV/m}$:

- **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

LCLS 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 $E_{\text{acc}} = 16\text{MV/m}$:

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

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

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.
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 $E_{\text{acc}} = 16\text{MV/m}$:

- $Q_0 = 4.4 \cdot 10^{10}$ 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 $E_{\text{acc}}$. 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

RDTNX002: equator, region of quench (B3.4.5;T8)

Bump on the equator (Board 3-4), visible on all three sides of the welding.
Bump height: 150 μm
Bump length: 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
- $E_{\text{Quench}} = 27$ MV/m
- Tmap shows pre-heating
- Region of quench: equator
- Optical inspection shows morphological defects, in agreement with Laser confocal microscopy

Tokyo Denkai
- $E_{\text{Quench}} = 20$ 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