High-Q/High-G activities at KEK

7th IHEP-KEK SCRF Collaboration meeting

2017/July/15

Kensei Umemori(KEK)

on behalf of KEK SCRF group, JAEA vacuum group, MHI-MS

Contents

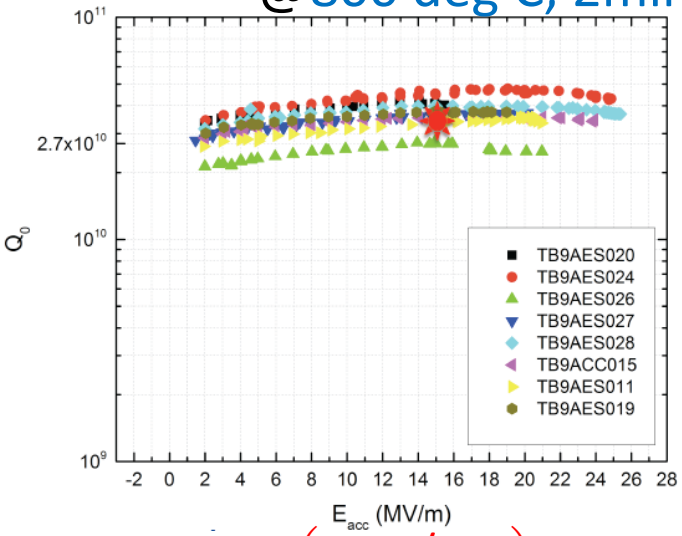
- Introduction
- KEK furnace and N-doping
- N-doping at FNAL
- J-PARC furnace
- N-doping / N-infusion at J-PARC
- Conclusion

High-Q for CW linac (ex. CW XFEL)

High-Q & high-G for pulse linac (ex. ILC)

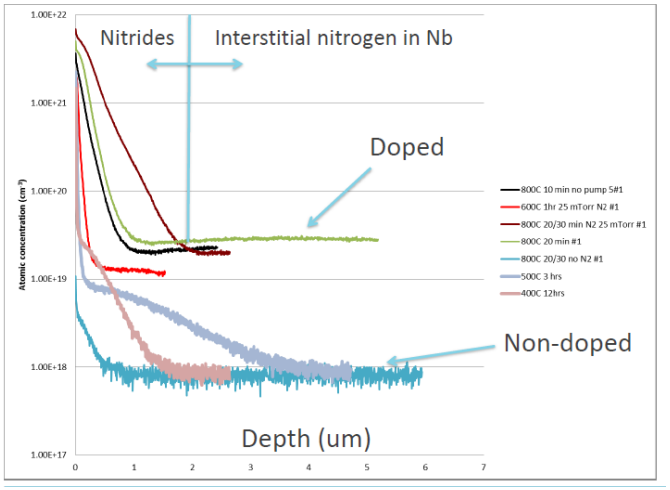
N-dope

25mTorr N2
@800 deg C, 2min



High-Q

TTC meeting（2014/Dec） A. Melnychuk
「Update on N doping at Fermilab」

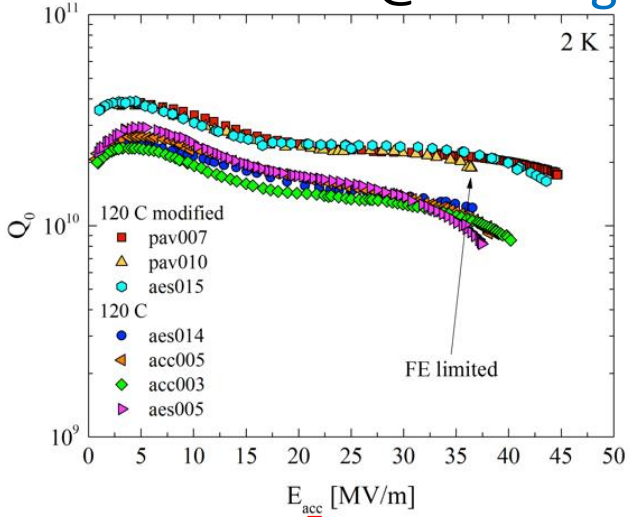


N goes to several tens um

A. Romanenco (Linac14)

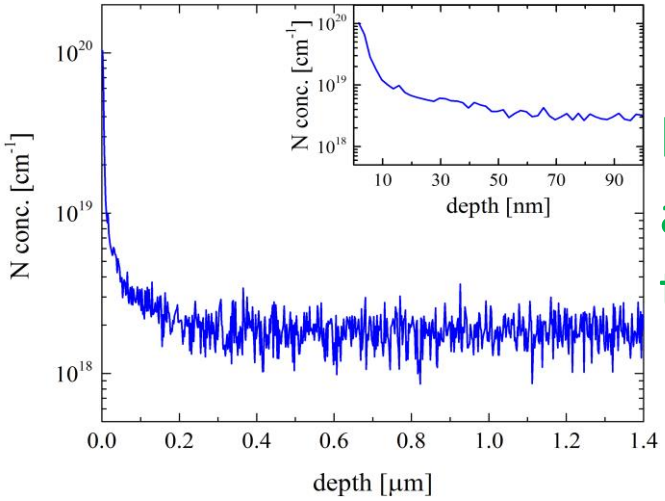
N-infusion

25mTorr N2
@120 deg C, 48hours



High-Q &
High-G

A. Grassellino 「High grad/high Q via N infusion」(LCWS2016)



N goes to around ten nm

S. Aderhold / A. Grassellino (TTC@Saclay)

History of N-doping / N-infusion at KEK

【Start N-dope at KEK】

- 2015/Feb: First N-dope trial at KEK small furnace
- 2015/Apr: Second N-dope trial at KEK small furnace
  (different N-dope parameter)
- 2015/May: Third N-dope trial at KEK large furnace

【Study at FNAL】

- 2016～: VT and N-dope at FNAL furnace

【Start N-dope/N-infusion at J-PARC】

- 2017～: N-dope and N-infusion trial at J-PARC furnace

KEK furnace for N-doping

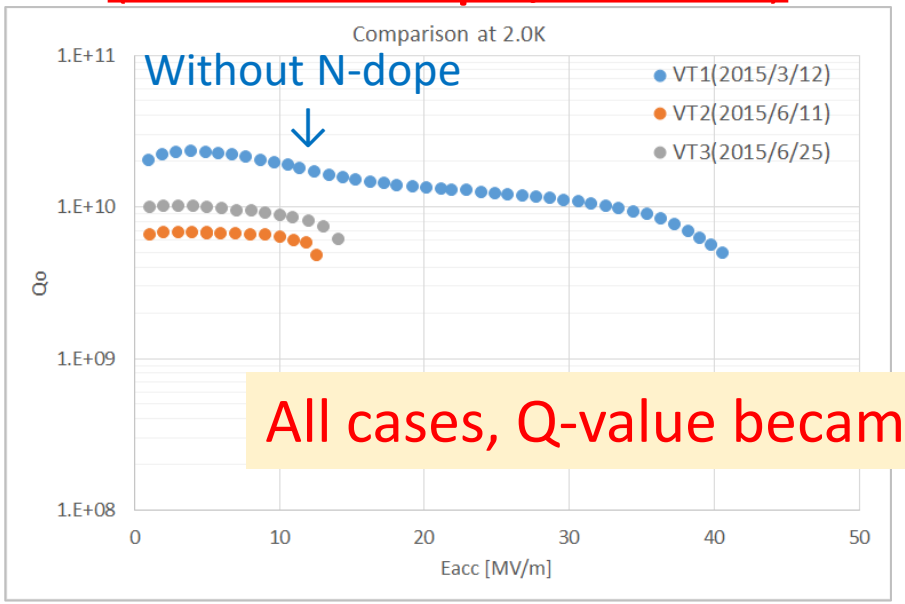
Large furnace for 9-cell cavity

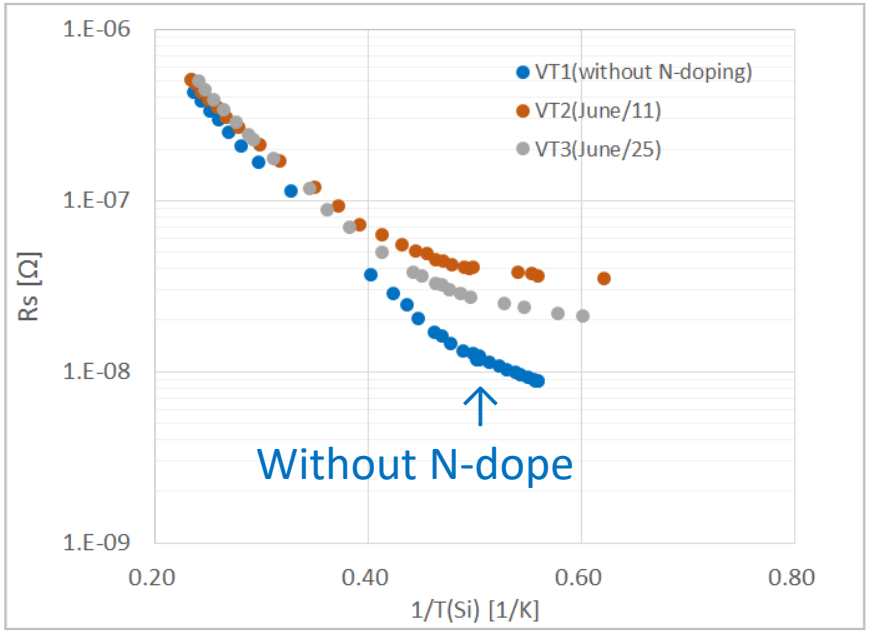
Diffusion pump without N-trap

Small furnace for single-cell cavity

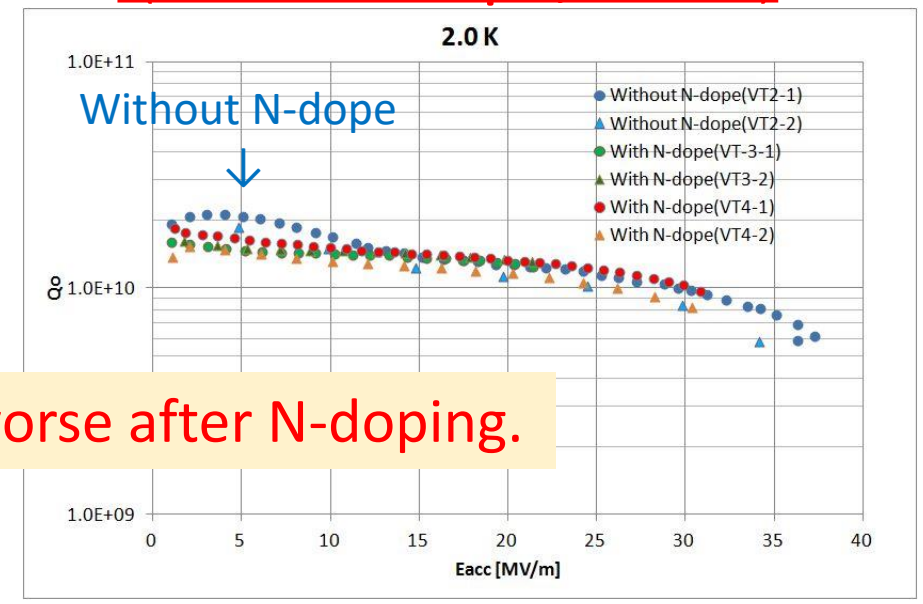
Diffusion pump with N-trap

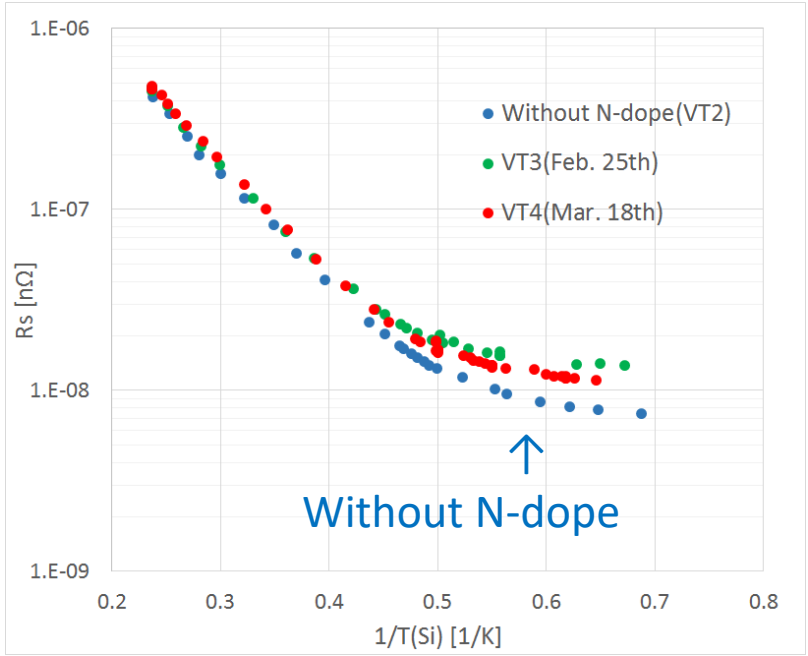
Results for large furnace (2.7Pa N-dope, 20min)





Results for small furnace (3.3Pa N-dope, 2min)

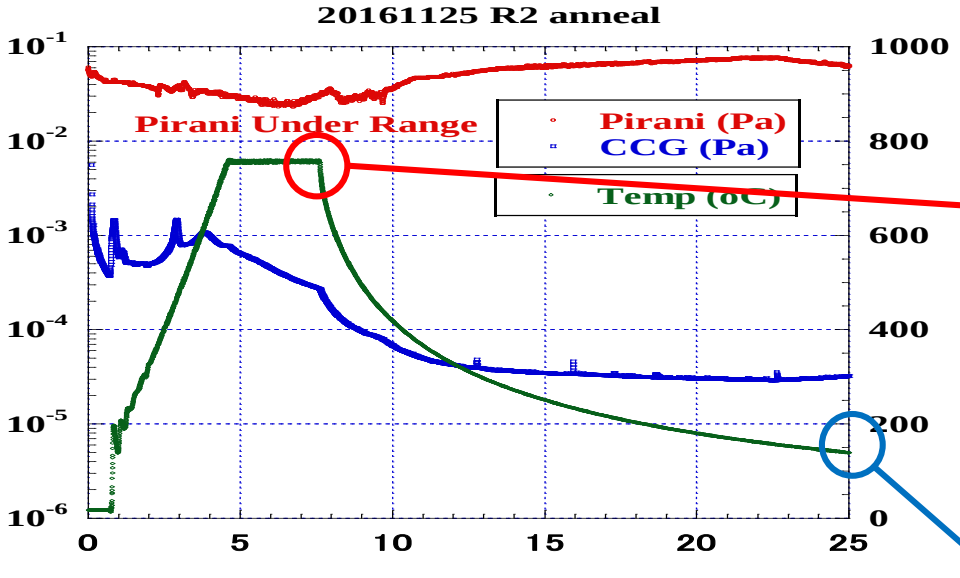


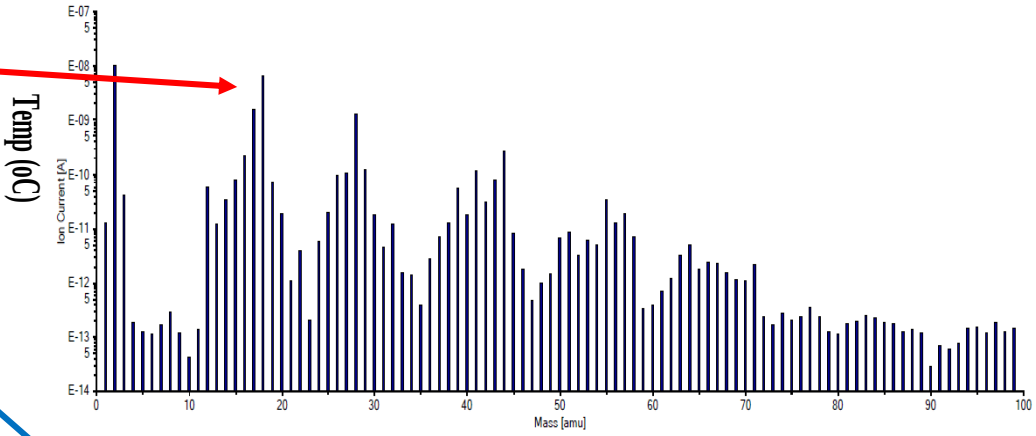


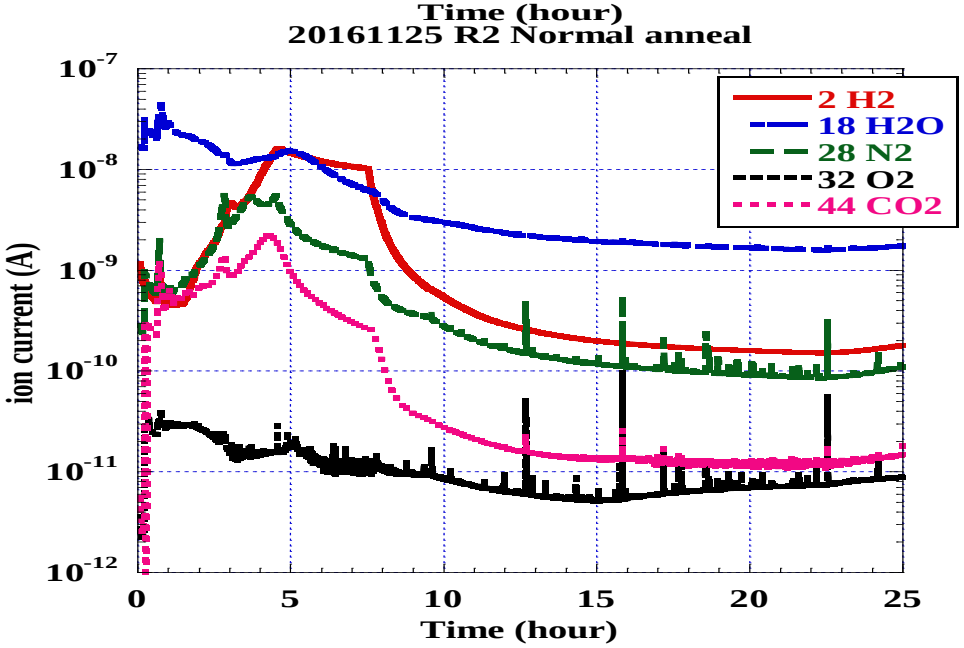
All cases, Q-value became worse after N-doping.

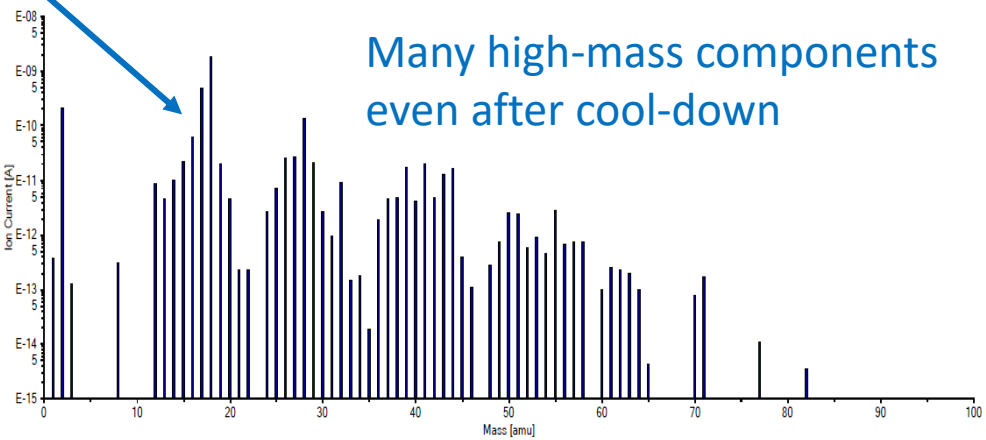
RGA spectrum of KEK big furnace

No RGA data for KEK small furnace





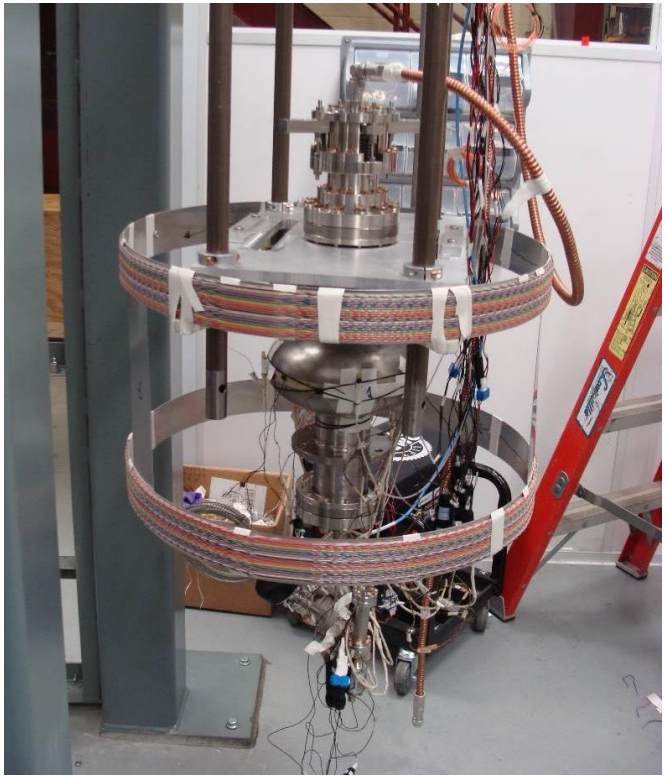


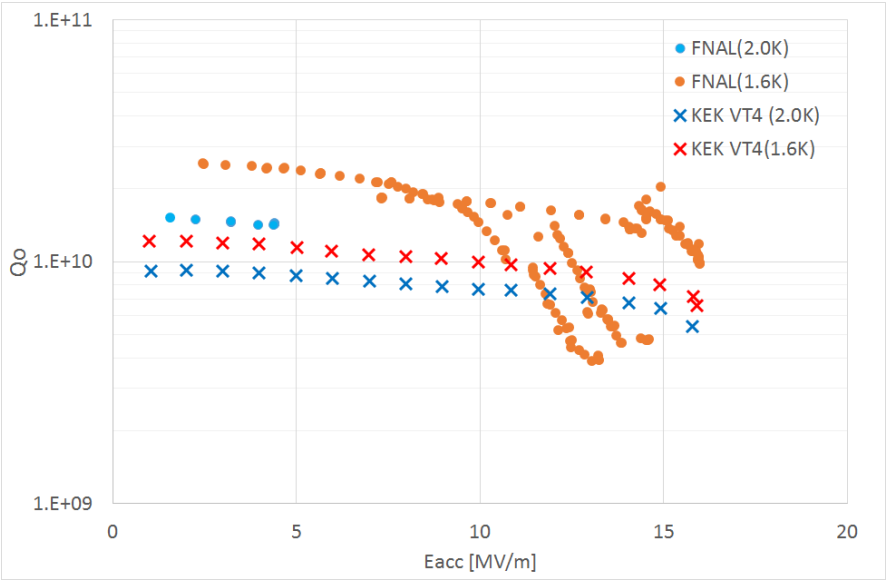


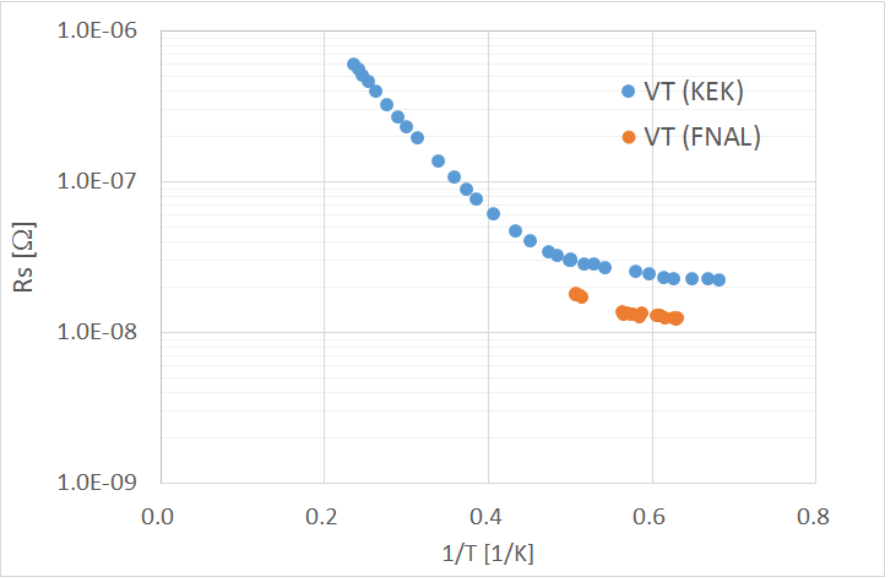
Many high-mass components even after cool-down

Vertical test and N-dope at FNAL

Vertical test of KEK doped cavity at FNAL







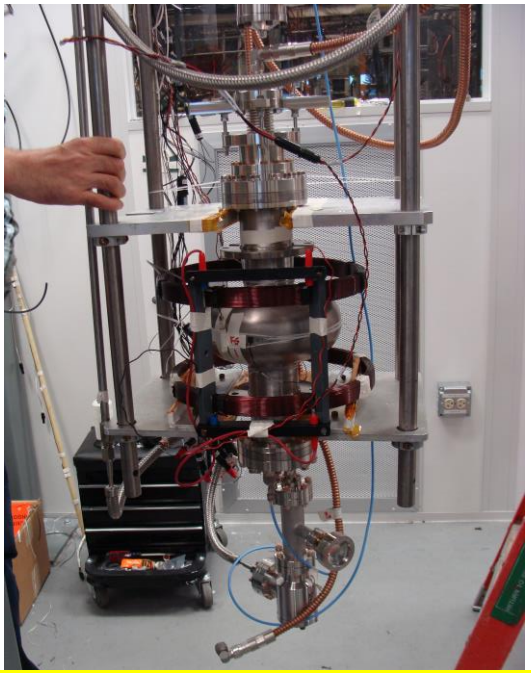
- Vertical test of KEK N-doped cavity was carried out at FNAL, where magnetic field inside VT dewar is very small.
- However, Q-value was not good as nominal N-doping cavity.

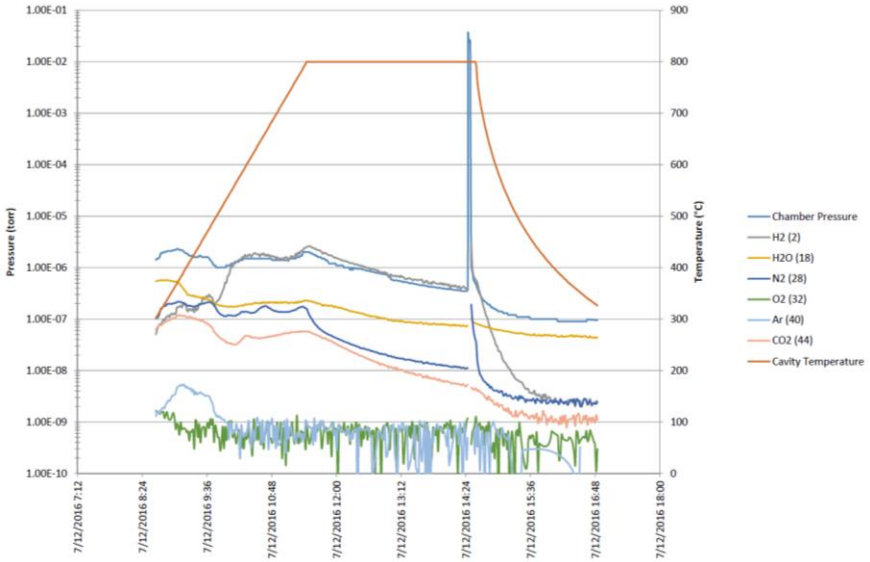
Even in zero magnetics field, still Rres was too large.

N-dope and VT of KEK cavity @FNAL

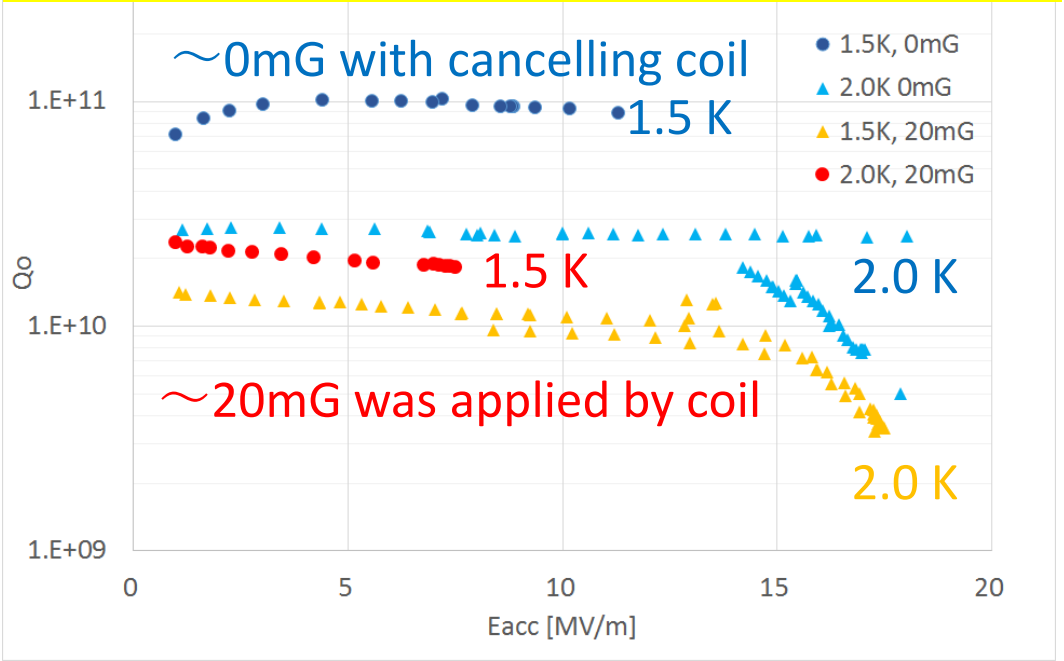
- 2016/7/9 EP 60um
- 2016/7/12 N-doping (FNAL standard recipe 2/6)
- 2016/9/13 EP 6um
- 2016/10/25, 26 VT

- KEK cavity was doped at FNAL and also tested.
- It showed successful doped performance.



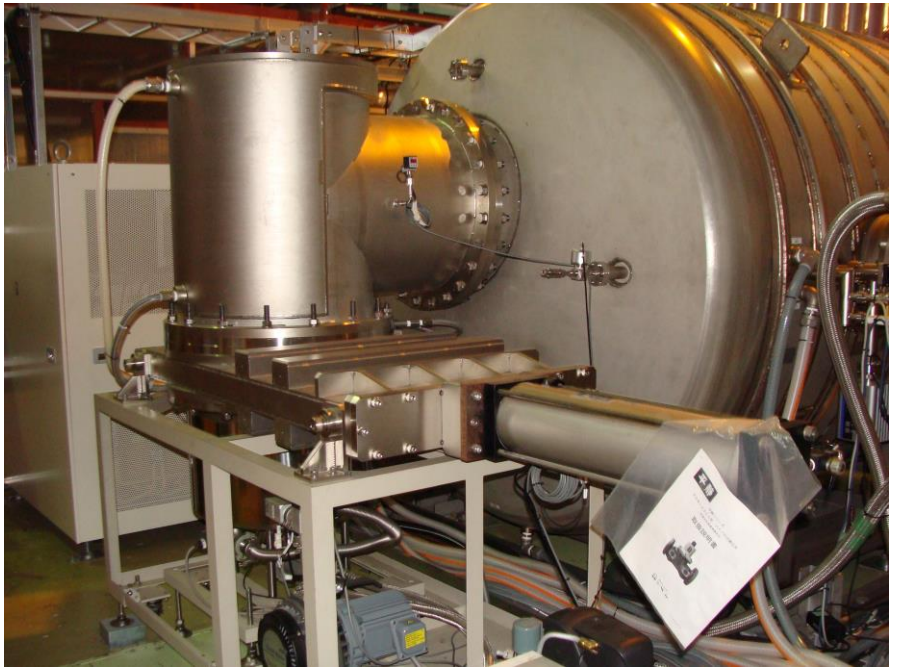


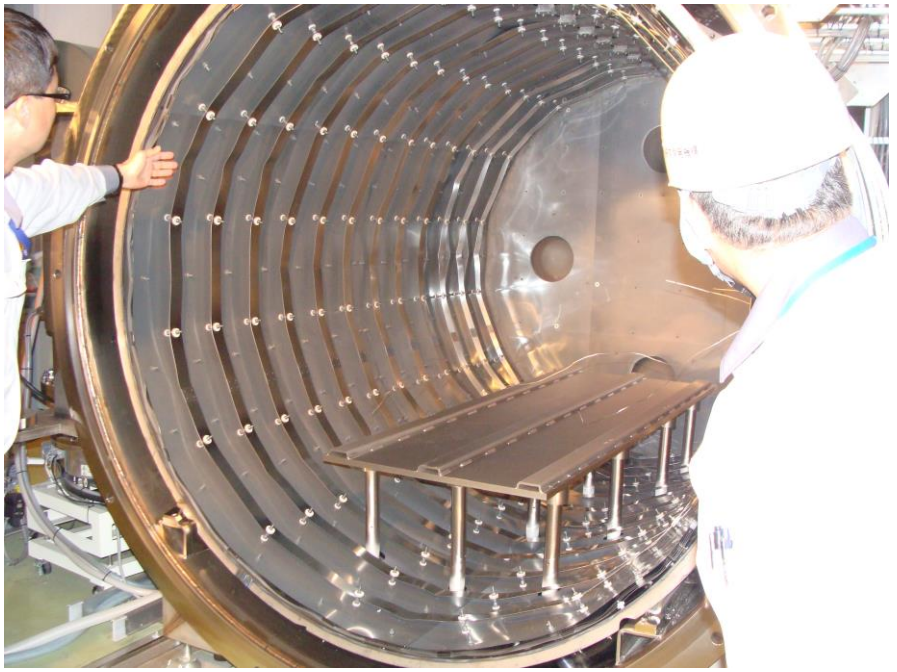
N-doping successful !! Thanks for FNAL-SRF group!!



N-dope & N-infusion using J-PARC furnace

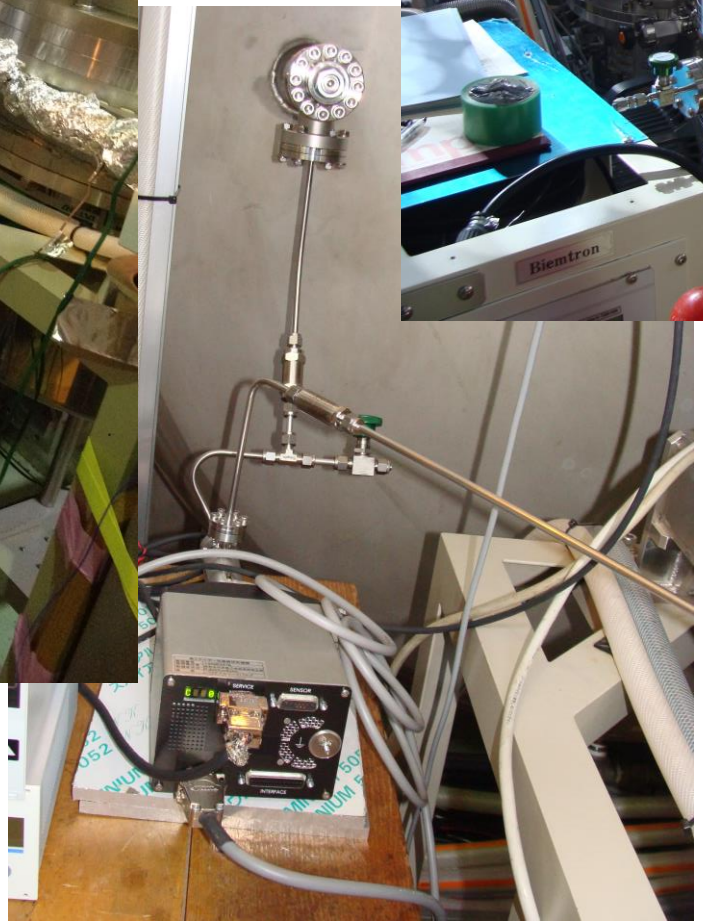
N-dope/N-infusion trial using J-PARC furnace





- J-PARC has oil-free furnace with cryo-pump(10,000 litter/sec) and three TMPs(3,000 litter/sec x 3).
- Vacuum level reached to ~1e-6 Pa.
- Normally used for degassing of beam-duct and components.

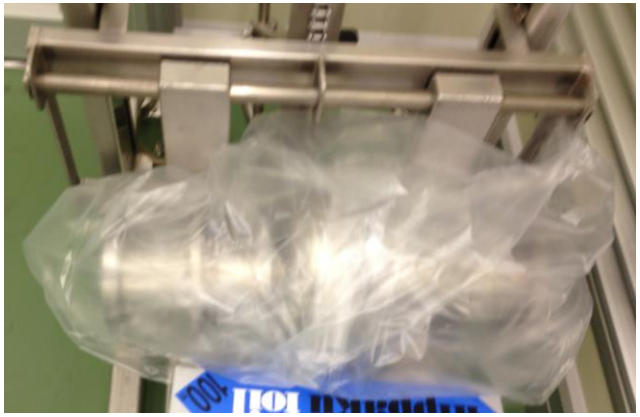
N-injection system

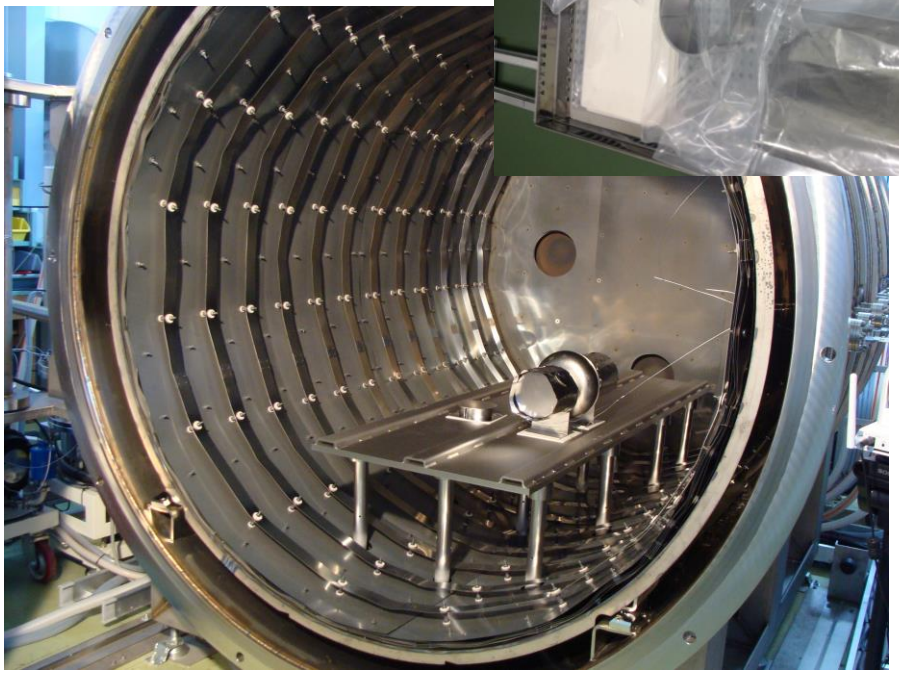


- Nitrogen pressure is controlled by variable leak valve
- Cryo-pump is closed and TMPs are off during N-injection. Small pump set, TMP and scroll, pump the furnace.

Cavity preparation for heat treatment

- HPR (flange open) 2 hours, drying one night
- Cavity was double-packed inside class-1000
- Nb cap & foil was ultrasonic cleaned with degreasing, drying inside class-10, packed inside class-1000
- Transport to J-PARC
- Setup into J-PARC furnace

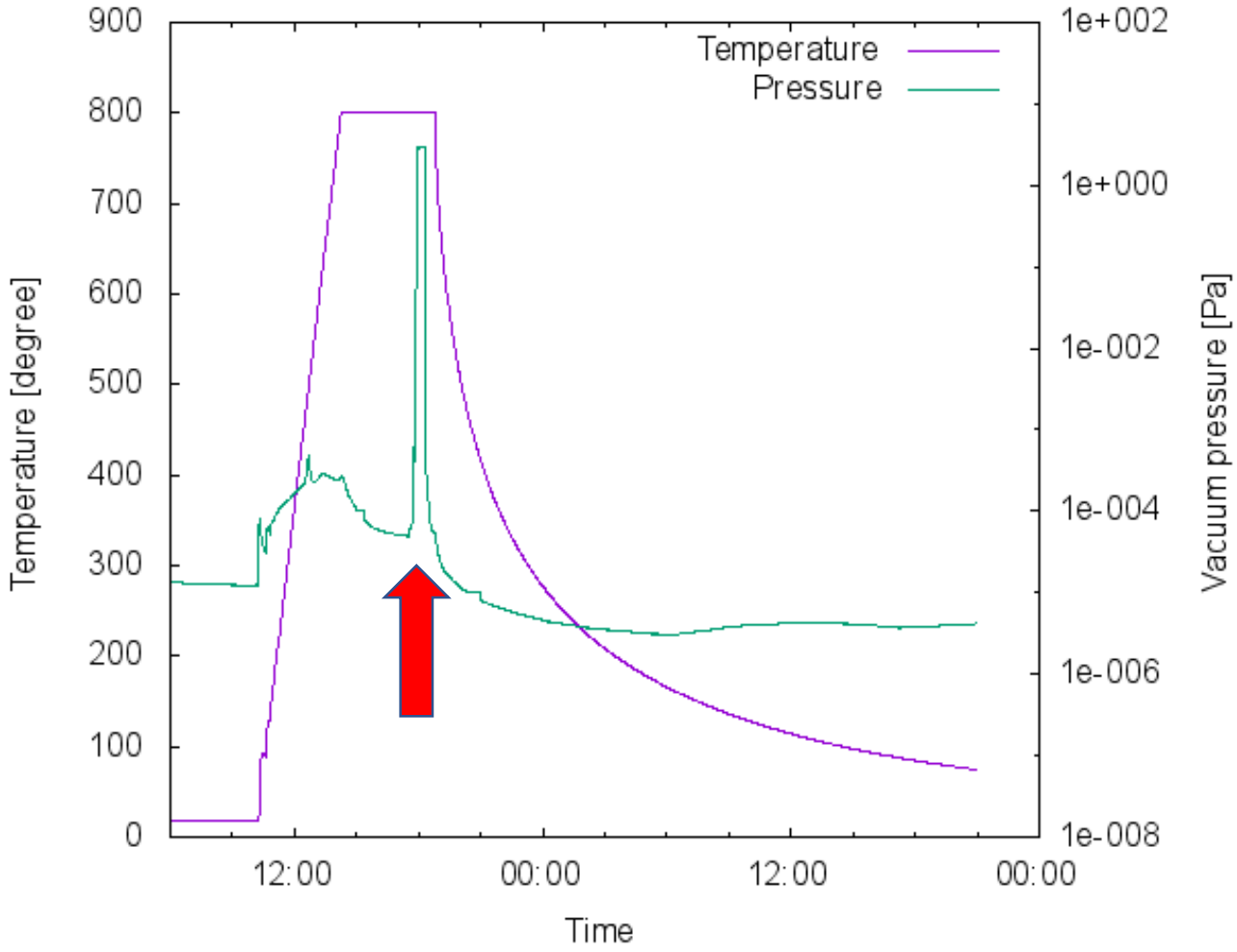




N-dope

N-dope (J-lab parameter)

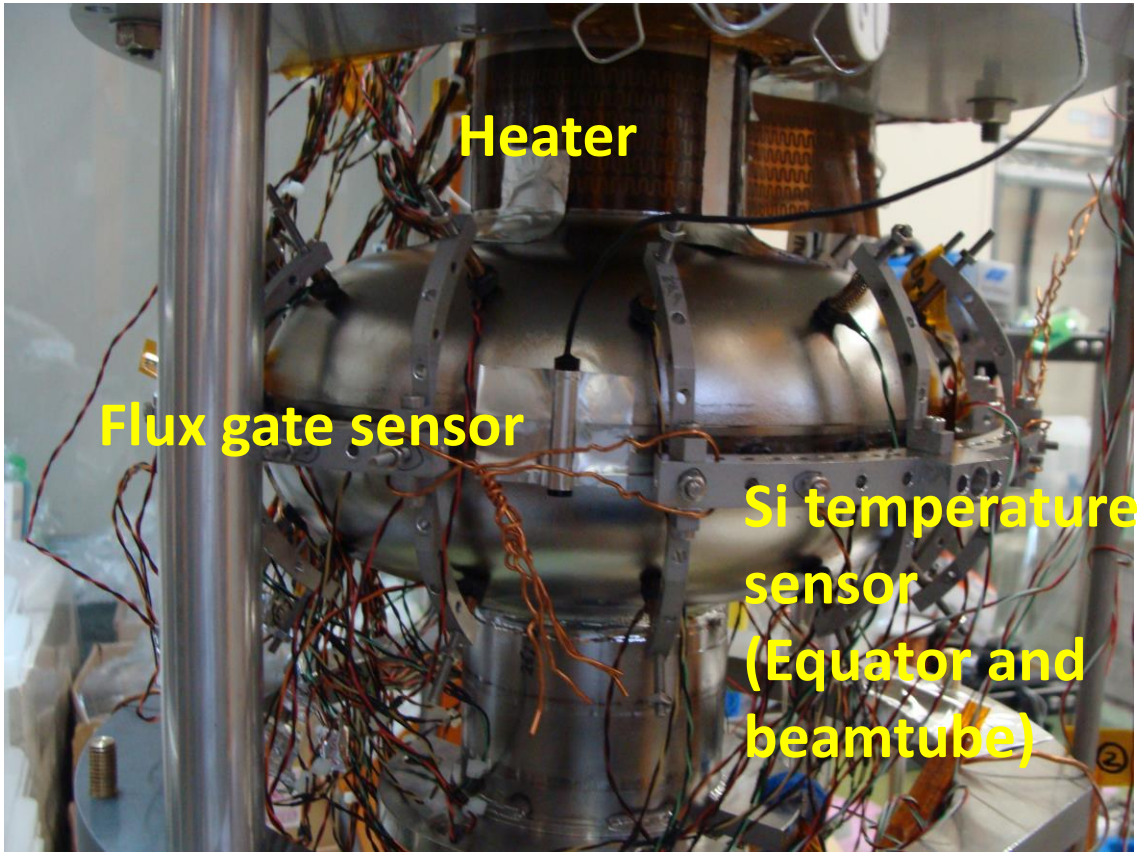
800 deg, 3 hours
800 deg, 20 min, N 2.7Pa
800 deg, 30 min
Cooldown



KEK tried J-lab N-doping parameter.

Typical vertical test setup

※ Pictures are for different measurement.
※ But setup of sensors and coil are same.

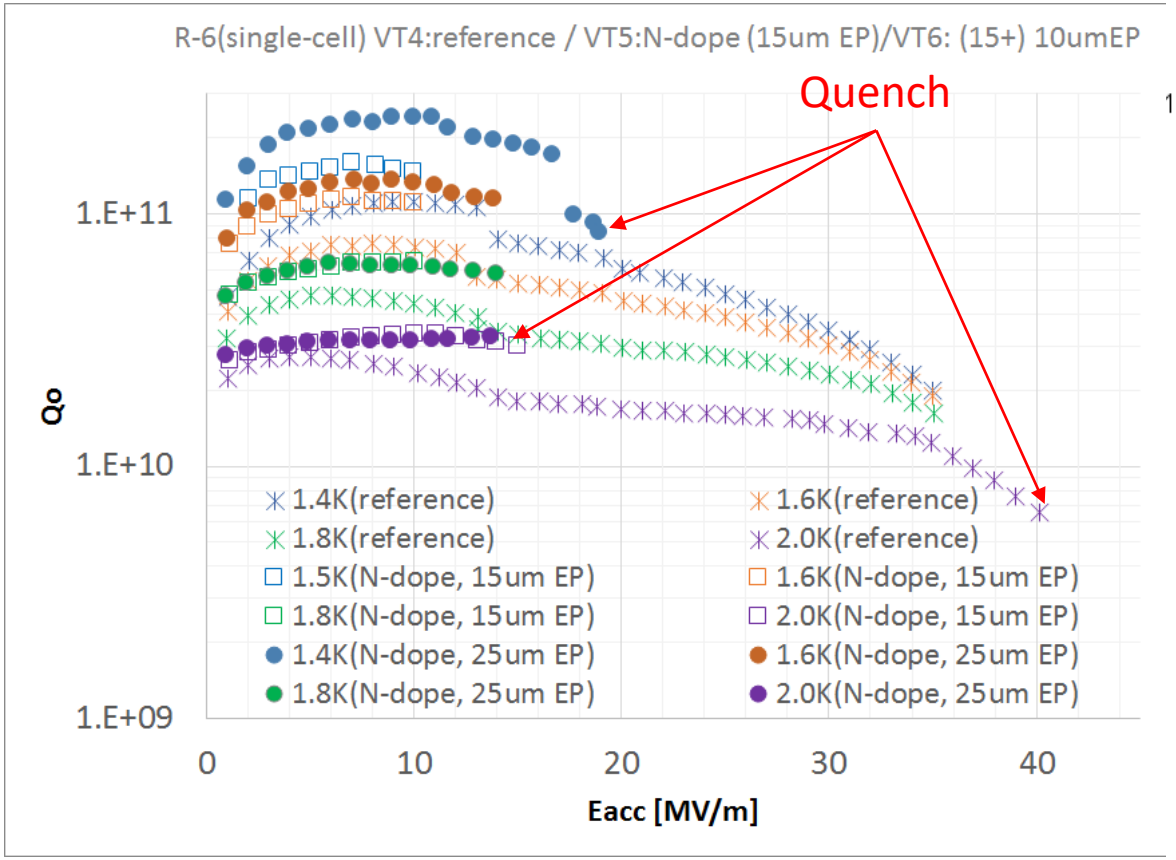


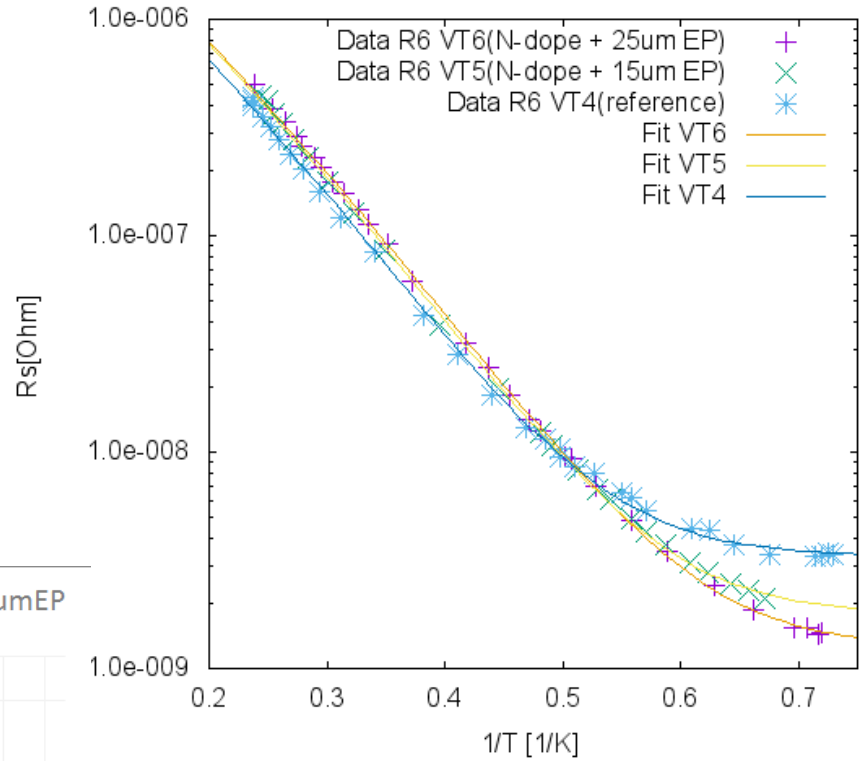
Flux gate sensor, Si temperature sensor, heater and solenoid coil were used.

VT results of N-doping

VT4(reference measurement)
N-doping
15um EP → VT5
Additional 10um EP →VT6

- Magnetic field canceled. (< 1mG)
- Cooled down with thermal gradient





VT4(reference) Rs=3.3nΩ
VT5(N-dope) Rs=1.8nΩ
VT6(add EP) Rs=1.2nΩ

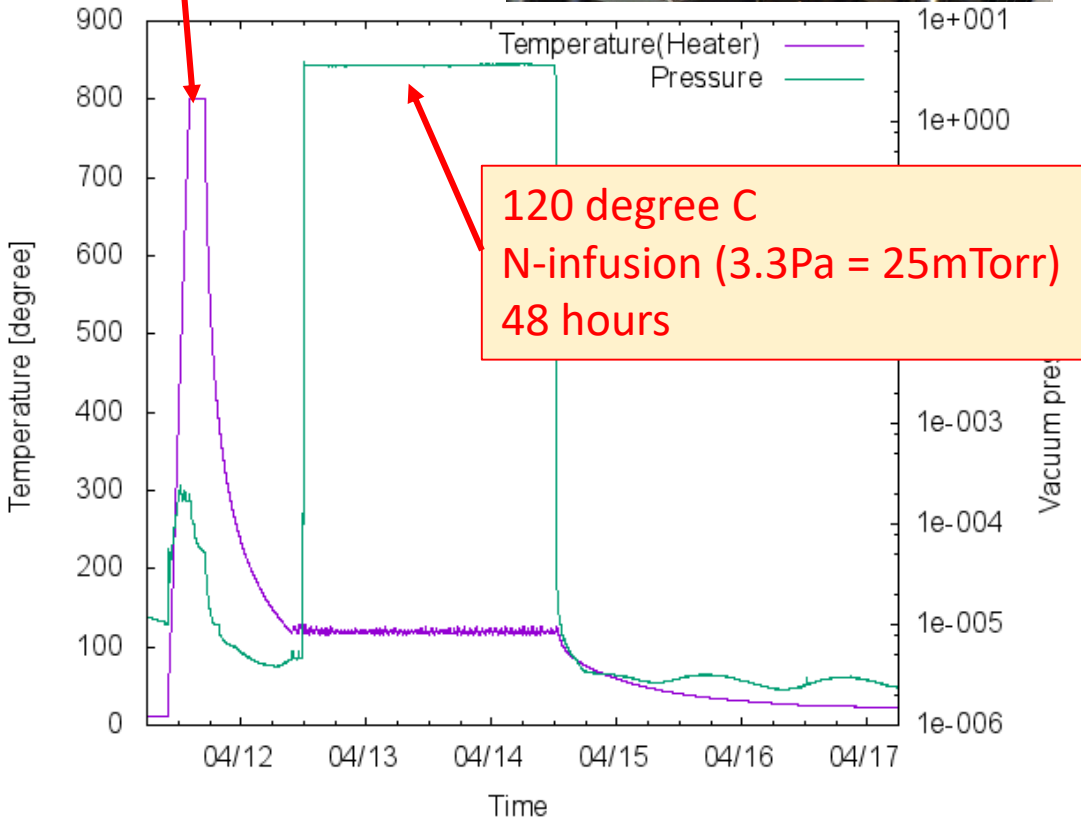
- Very high Q up to high field
- Q = 2.4e11@11MV/m, 1.4K
- Q = 3.3e10@14MV/m, 2.0K
- Quench at 19MV/m
- No field emission
- First success in Japan

N-infusion

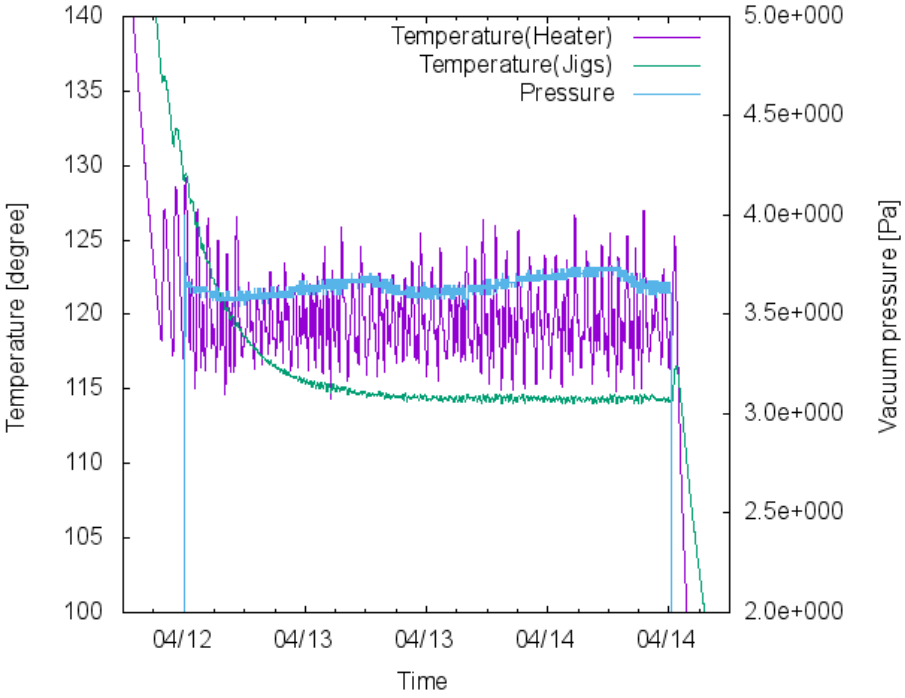
N-infusion(FNAL parameter)

800 degree C
3 hours

120 degree C
N-infusion (3.3Pa = 25mTorr)
48 hours



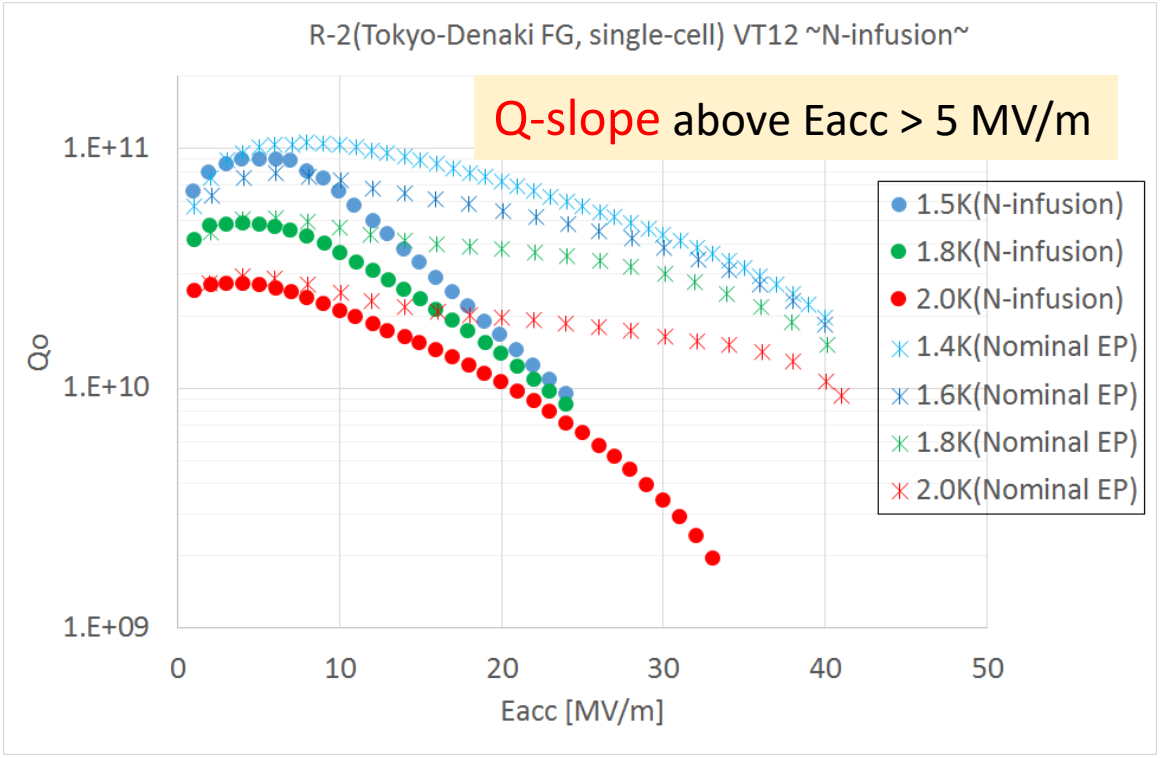
- Pressure is stabilized less than 0.1Pa
- Different vacuum gauges at different positions show around 0.3 Pa offset.
- Temperature is stabilized with +/- 5 degree.
- Temp. offset ~ 5 degree between furnace and jigs.

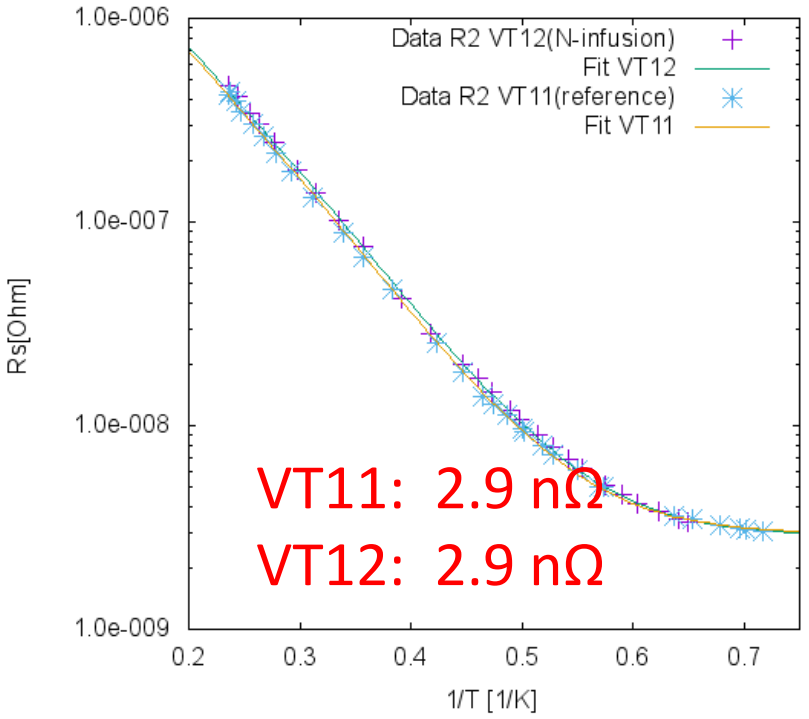


VT results for N-infusion

- Transfer to KEK
- HPR (No EP applied)
- Assembly

- Magnetic field canceled. (< 1mG)
- Cooled down with thermal gradient

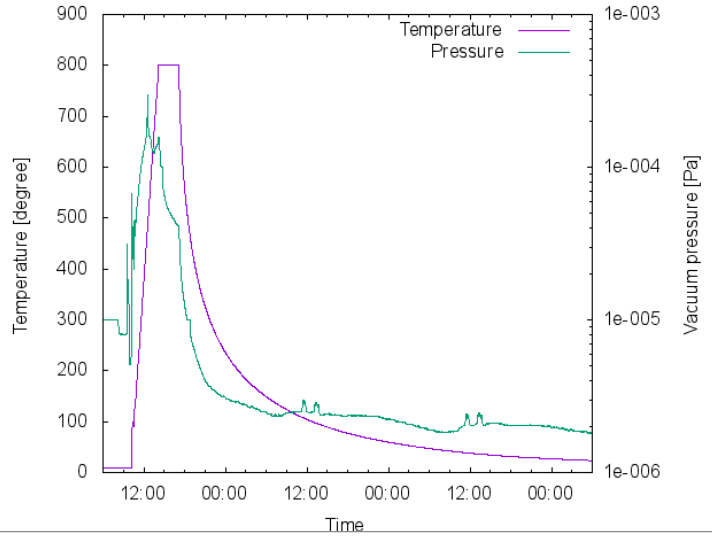




- Degradation was observed for > 5 MV/m
- Eacc was limited at 33MV/m by quench at 225 degree equator
- No field emission

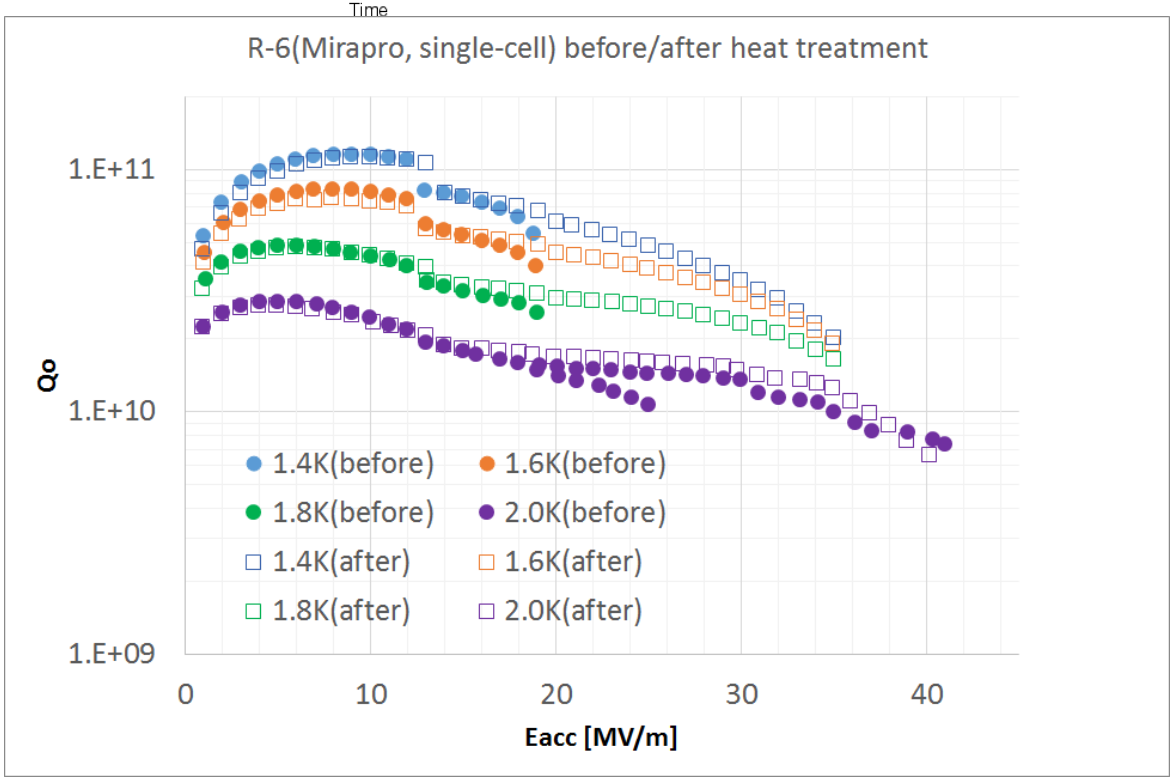
Test for furnace
(Heat treatment without EP)

Heat treatment (800 C, 3h) and VT



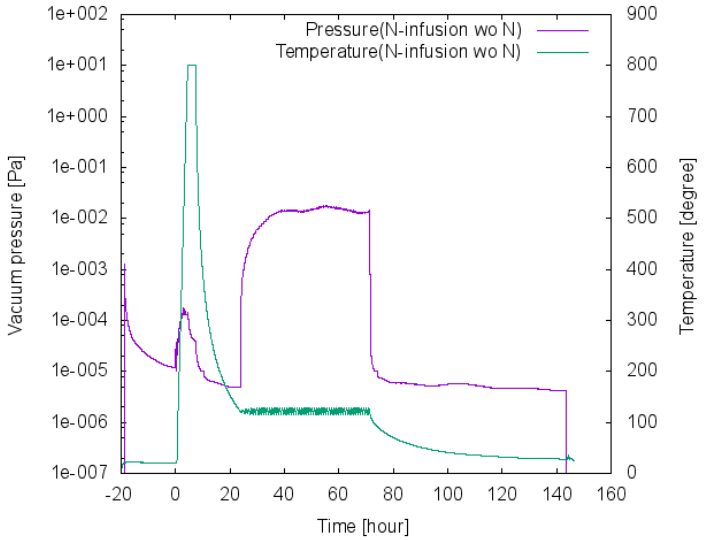
- 800℃, 3hours heat treatment at J-PARC furnace
- Transfer to KEK with double-packed
- HPR
- Assembly
- 120℃ baking
- Vertical test

No EP was applied!



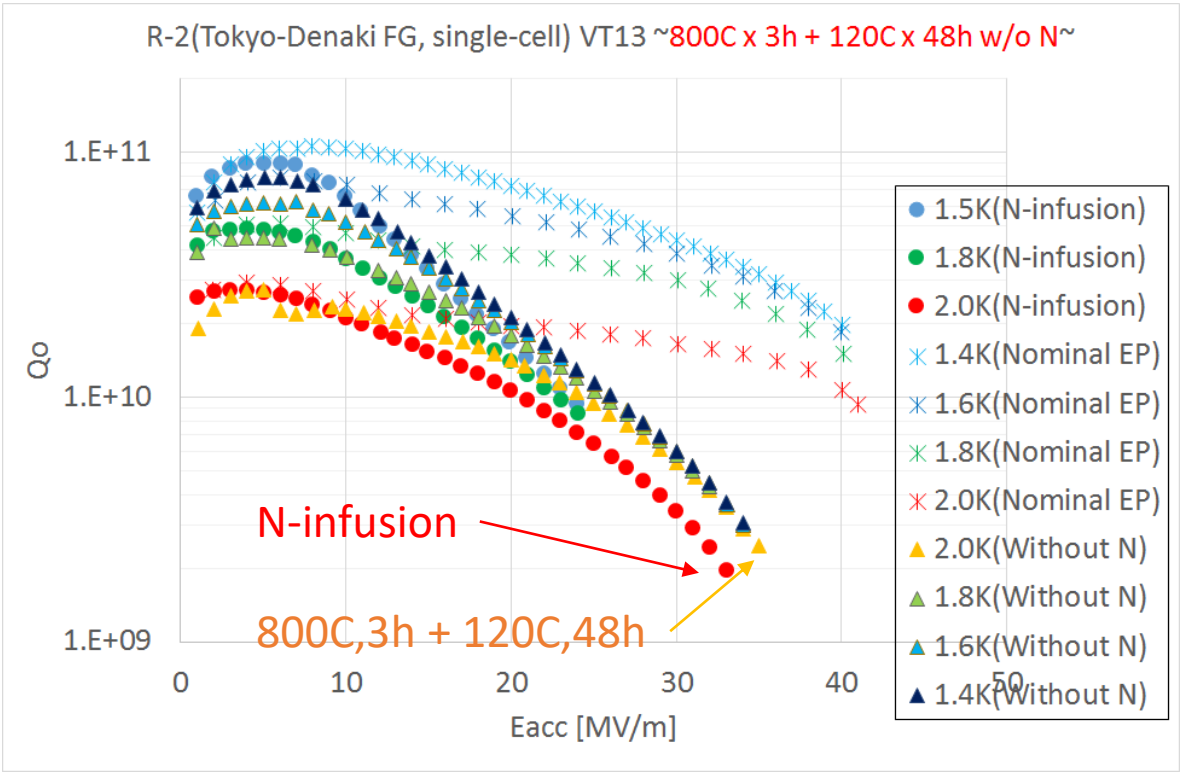
No degradation!!
Cavity performance was reproduced.

800℃, 3hours + 120℃, 48 hours w/o Nitrogen



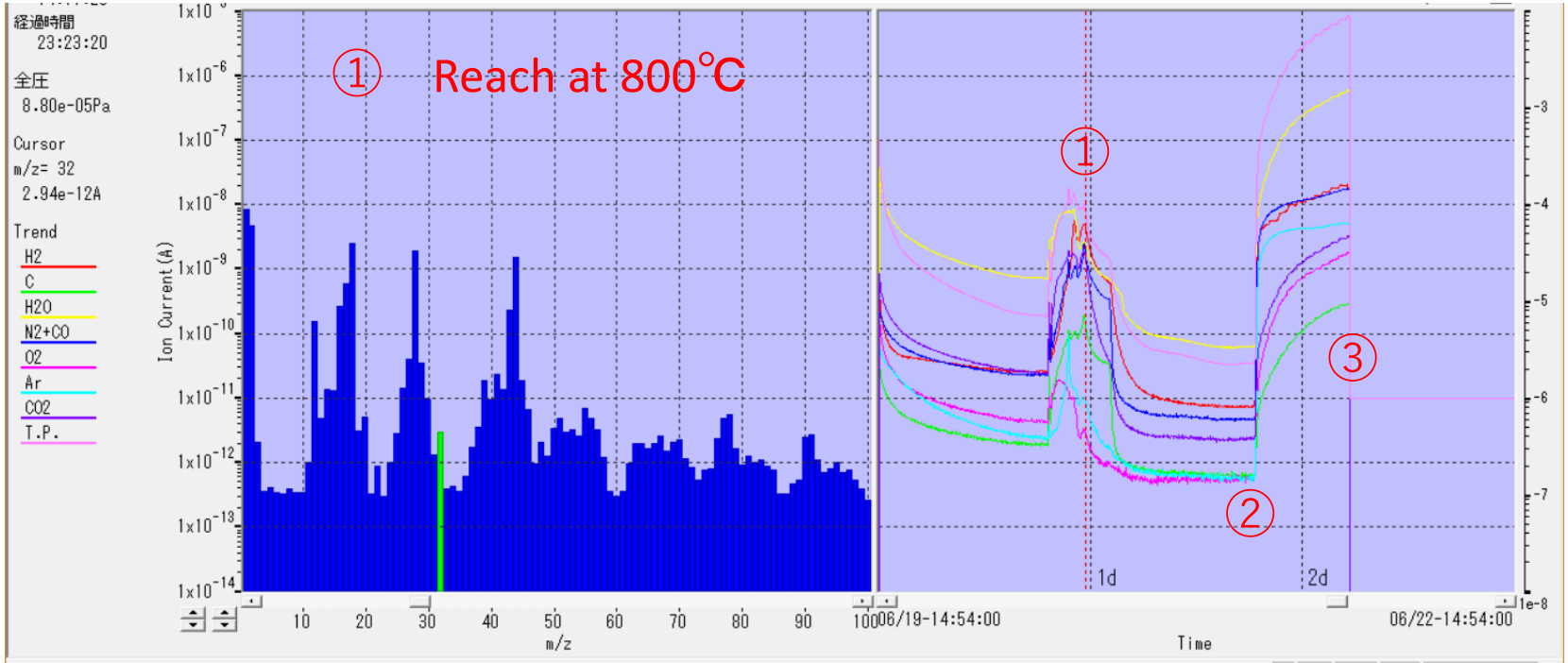
[Vacuum condition during 120 degree]

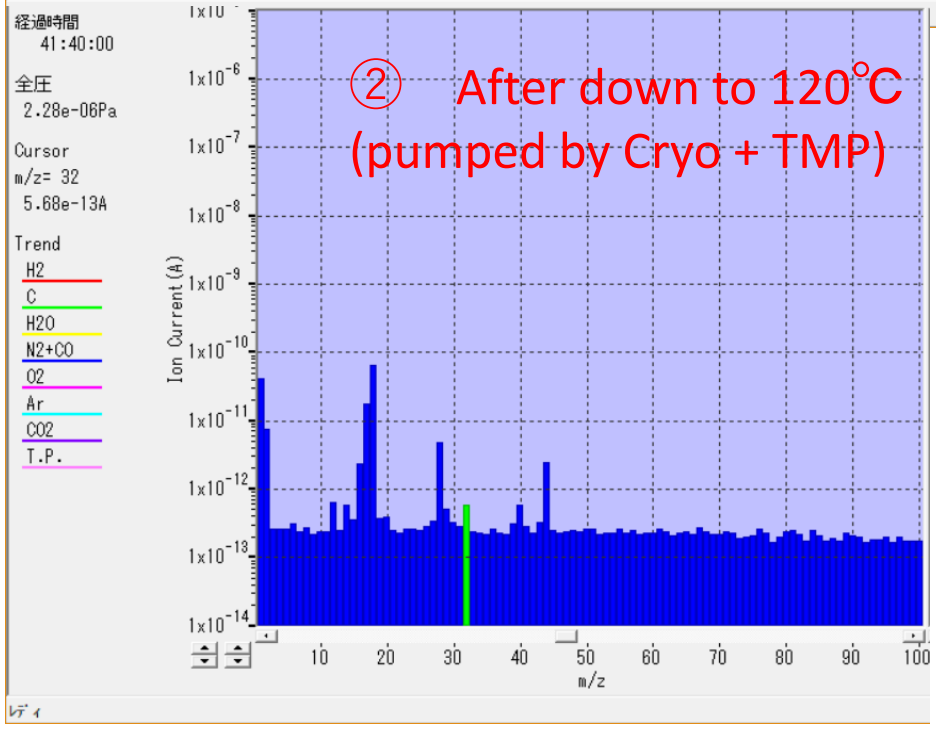
- Valve of cryopump was closed
- TMP OFF
- Vacuum pumping by small pumping system(TMP and scroll)
- Vacuum level worthened to 1.7e-2 Pa (Around 1% of Nitrogen level)

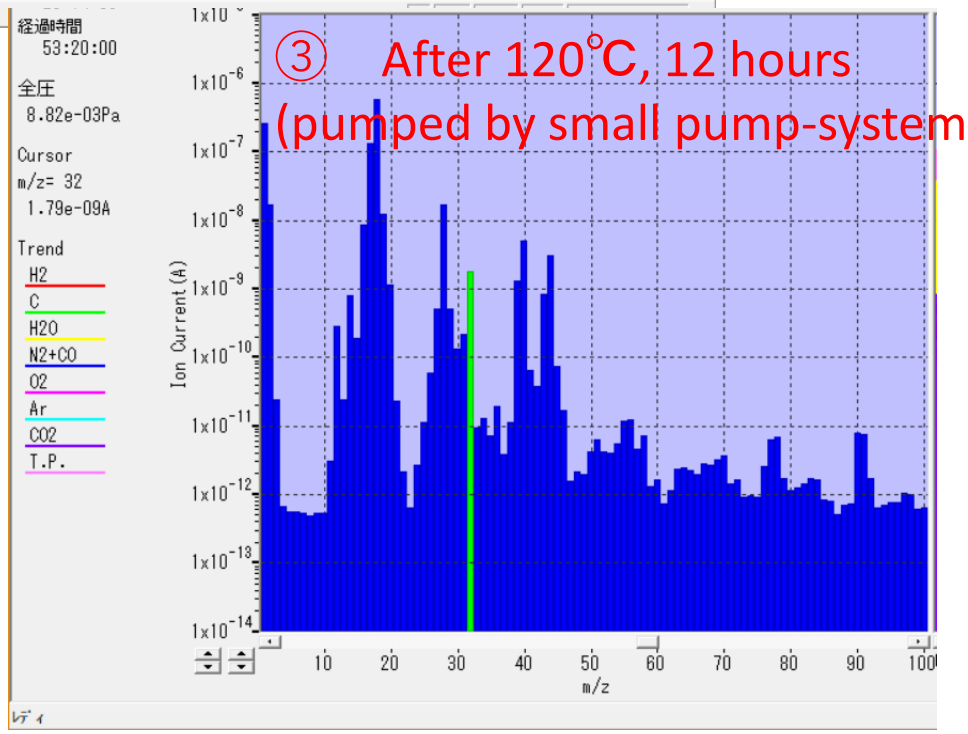


- Refresh surface by 10um EP after N-infusion
- 800C, 3h + 120C, 48h (No Nitrogen)
- HPR and assembly (No EP, No baking)
- Vertical test

- Q-slope above Eacc > 5 MV/m
- Almost same performance with N-infusion


経過時間
23:23:20
全圧
8.80e-05Pa
Cursor
m/z= 32
2.94e-12A
Trend
H2
C
H2O
N2+CO
O2
Ar
CO2
T.P.
① Reach at 800℃
Ion Current(A)
m/z
Time
1d
2d
06/19-14:54:00
06/22-14:54:00


経過時間
41:40:00
全圧
2.28e-06Pa
Cursor
m/z= 32
5.68e-13A
Trend
H2
C
H2O
N2+CO
O2
Ar
CO2
T.P.
② After down to 120℃
(pumped by Cryo + TMP)
Ion Current(A)
m/z


経過時間
53:20:00
全圧
8.82e-03Pa
Cursor
m/z= 32
1.79e-09A
Trend
H2
C
H2O
N2+CO
O2
Ar
CO2
T.P.
③ After 120℃, 12 hours
(pumped by small pump-system)
Ion Current(A)
m/z

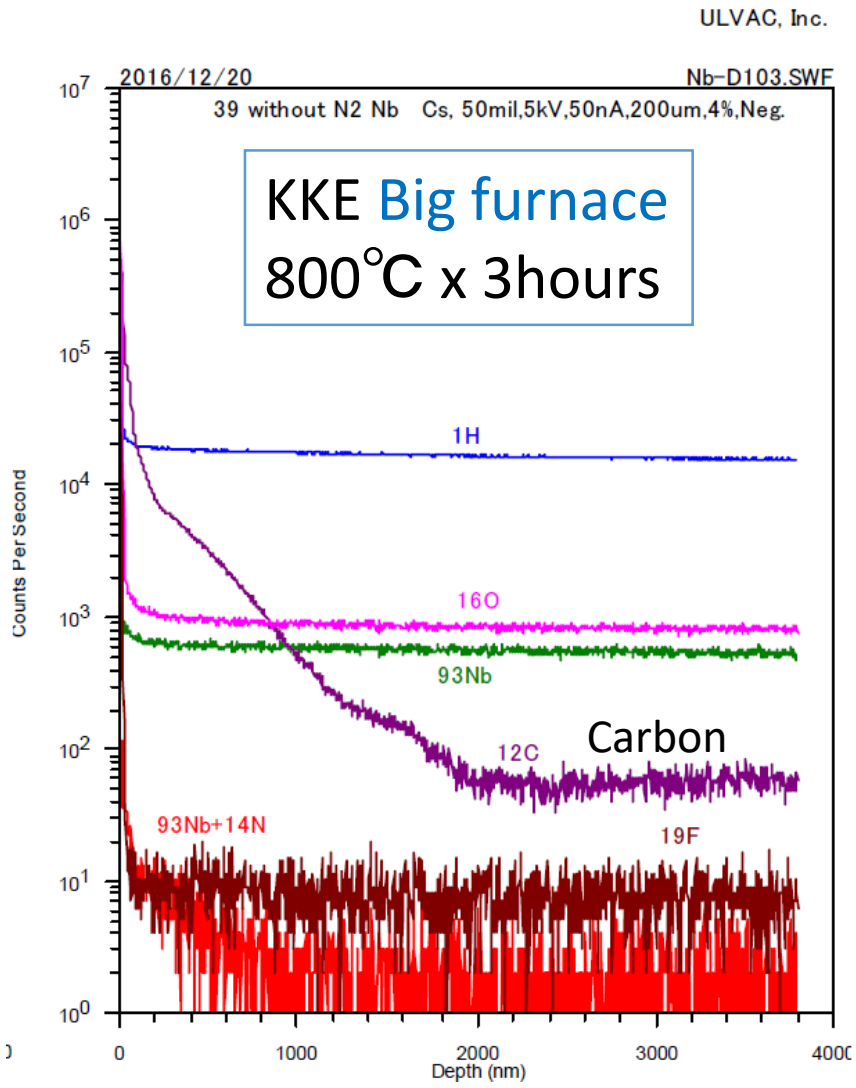
Summary

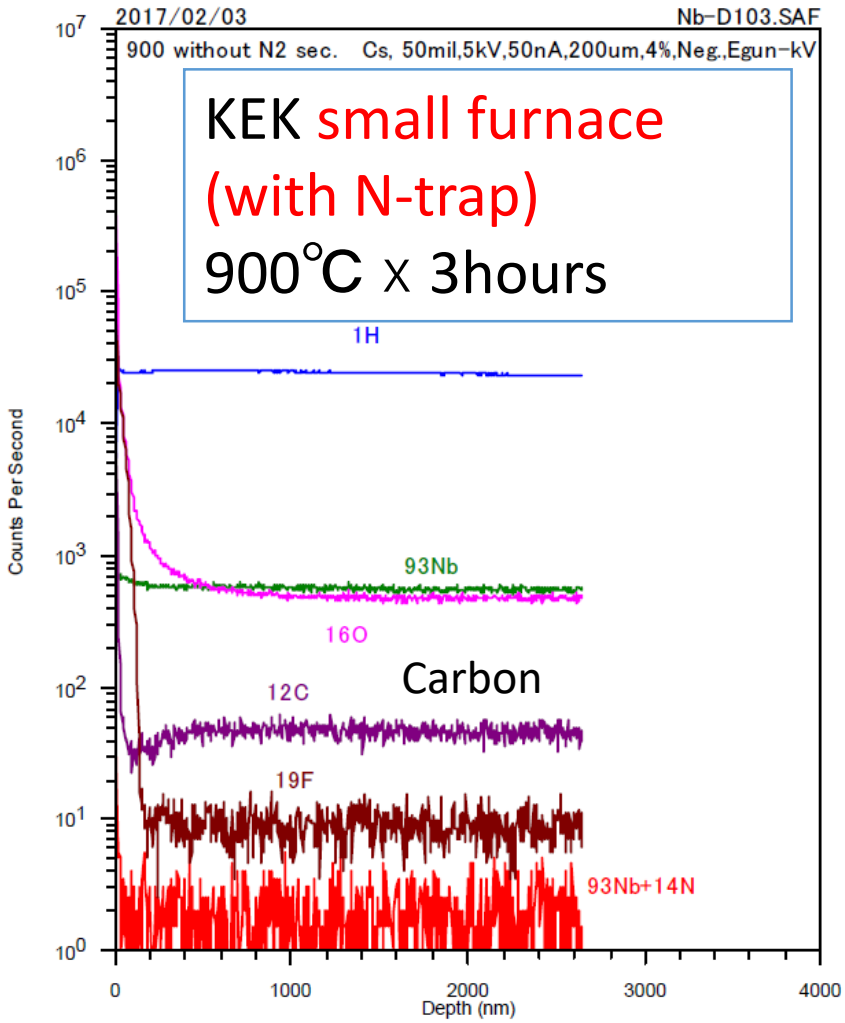
- N-dope and N-infusion study is on going at KEK to realize high performance of SRF cavities.
- Currently R&D is on-going using J-PARC furnace, which is pumped by a cryo-pump and TMPs.
- N-doping was successful. High-Q was obtained for 10-15 MV/m.
- N-infusion was carried out. Degradation occurred at more than 5 MV/m.
- We will try to push to realize N-infusion technique for high performance SRF accelerators.

Backup slide

Nb sample analysis for KEK big/small furnace (Heat treatment without N-dope)

Analyzed by ULVAC





Each figures are up to 4um.

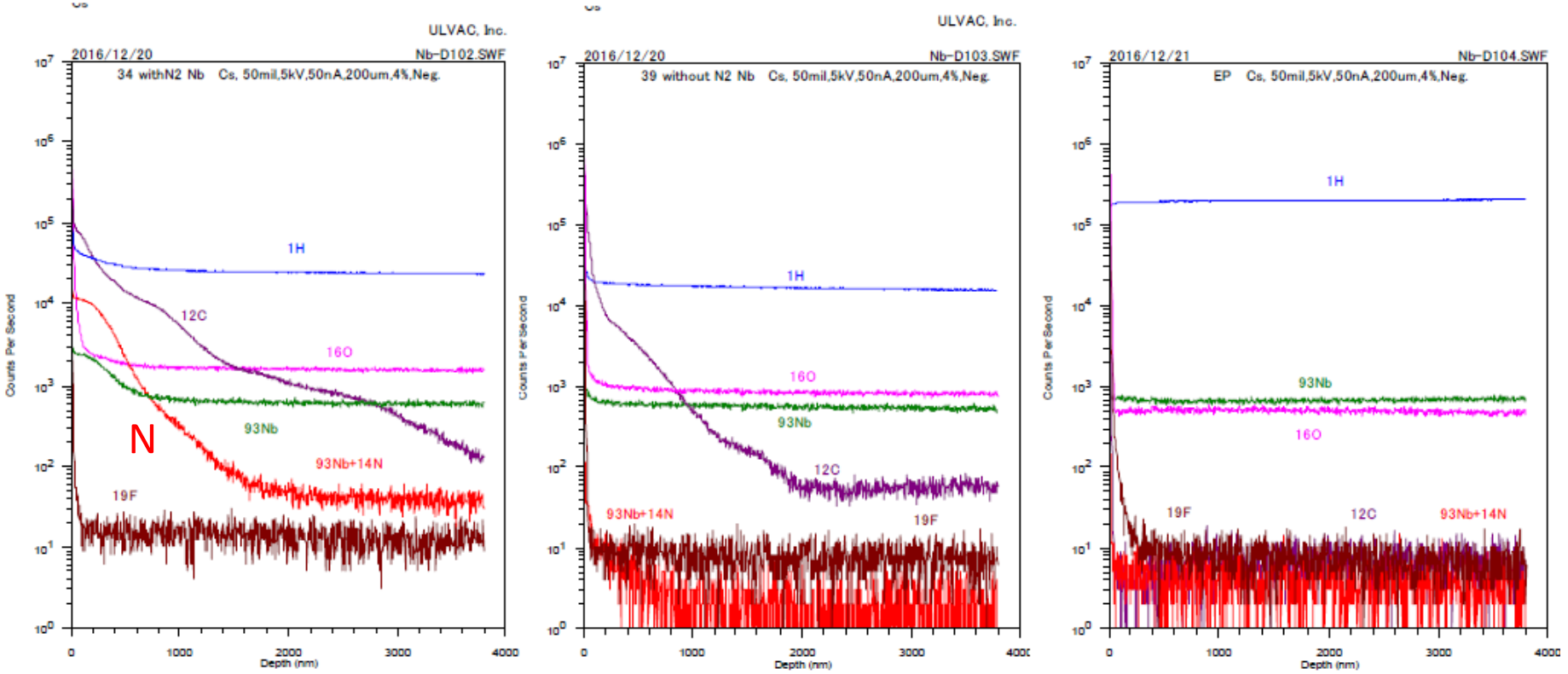
Nb sample analysis for KEK big furnace

Analyzed by ULVAC

Heat treatment with N-doping

Heat treatment No N-doping

No heat treatment (only EP)



—^{93}Nb —^{1}H —^{16}O

—^{14}N+ ^{93}Nb —^{12}C —^{19}F

Each figures are up to 4um.

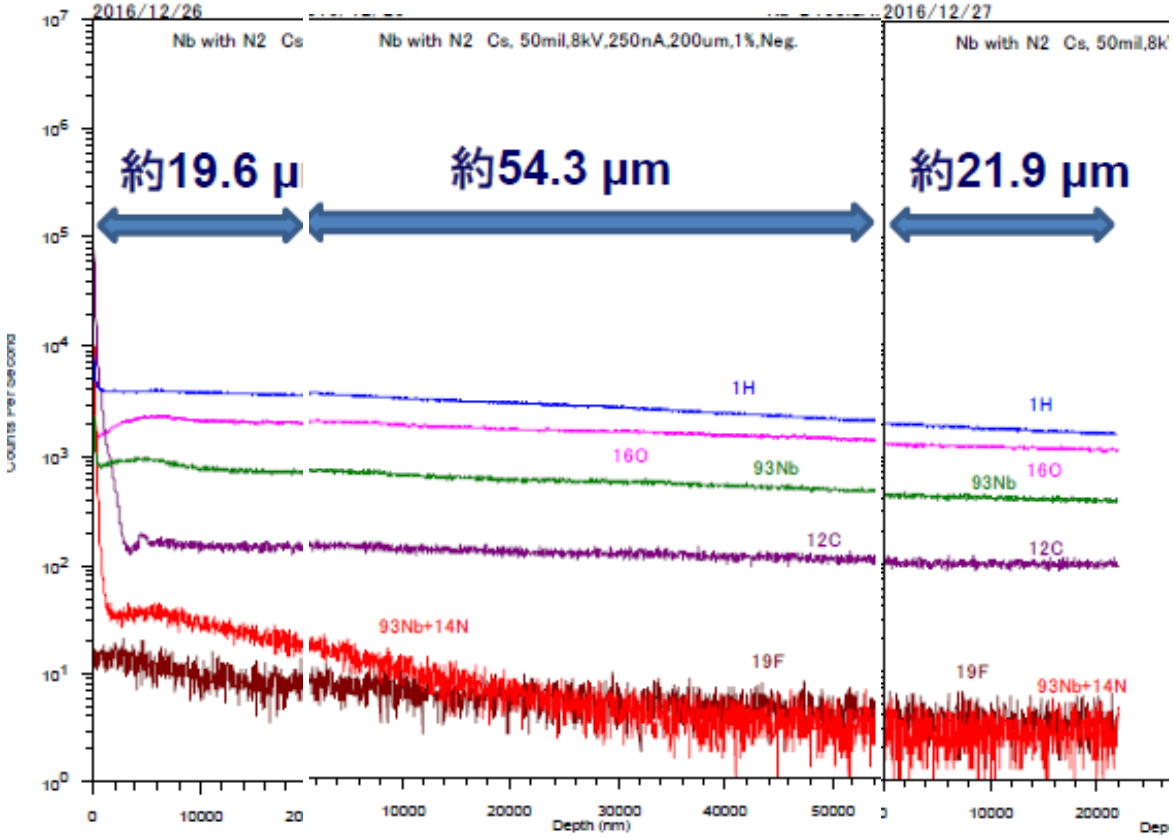
N is observed for N-doped sample

C is observed for heat treated samples.

SIMS for N-doped sample(~100um)

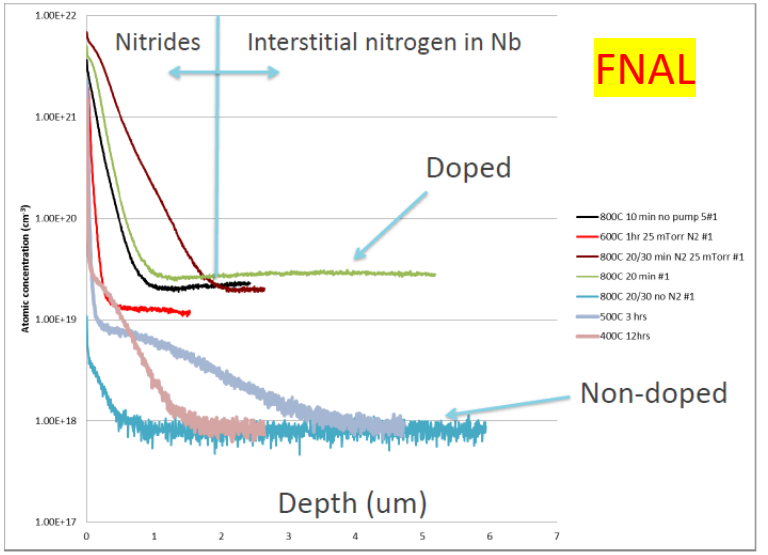
Analyzed by ULVAC

Total of three measurements



- Rapidly decrease until ~1um
- Flat up to ~10um
- Then gradually decrease (down to lower limit)
- N behavior seems to be similar

What does N treatment do? N depth profiles by SI



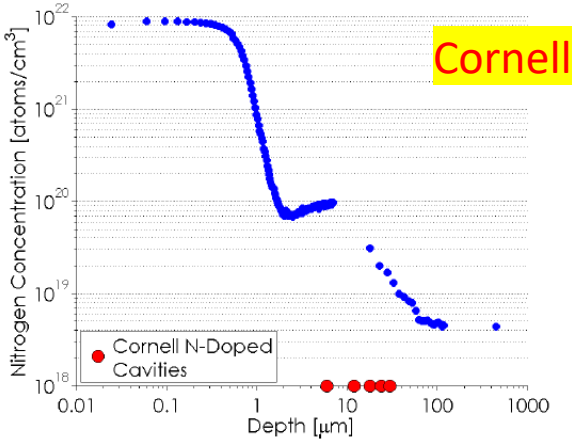


Figure 6: SIMS results from a sample treated with TE1-4 and TE1-5. Single-cell cavities are also included for reference.