N-H Interaction Study of Nitrogen Doping-Treatment on Nb Samples

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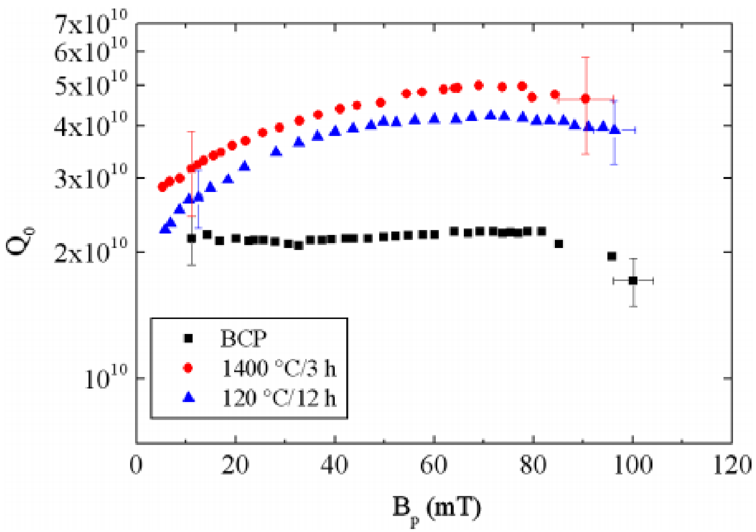
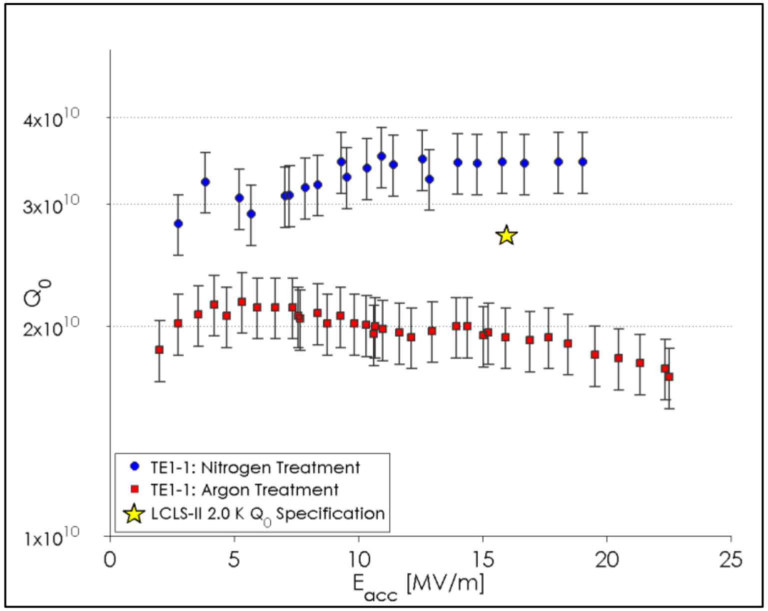
Background and tentative presumption

Selectivity of doping elements

The doped N&Ti may interact with some components/elements.



Ti doping

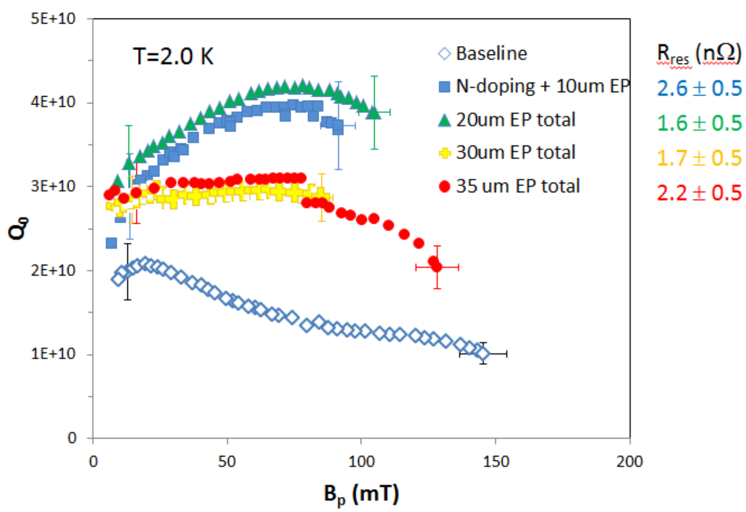


Ar doping

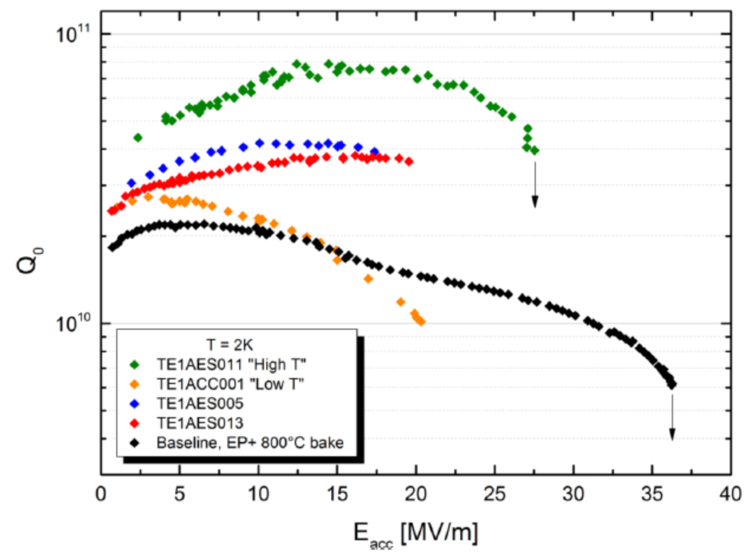
Background and tentative presumption

Change of R_{res} with subsequent EP removal

Optimum EP →highest Q_0 and lowest R_{res};
Other amounts of EP removal→ R_{res}↑ ;
Variation of R_{res} with EP may be an important aspect of the physical mechanism



Heavy doping of Cornell

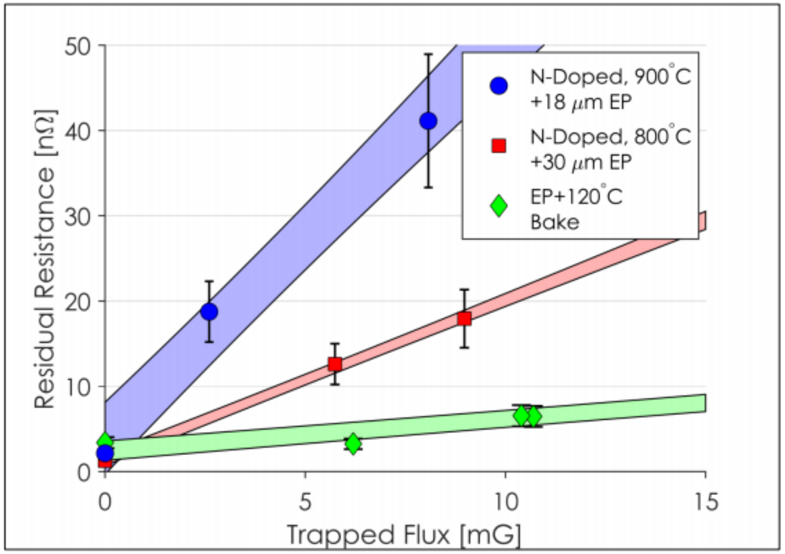


Light doping of FNAL

Background and tentative presumption

Sensitivity to trapped flux : $R_{res,flux}(n\Omega)/B_{trapped}(mG)$

ND cavities have higher sensitivity of residual resistance to trapped flux.



ND results in higher sensitivity

$$R_S = R_{BCS}(T,B) + R_{flux} + R_{nit} + R_{hyd} + \cdots$$

$R_{res,\ total}$ of ND cavities is lower ;

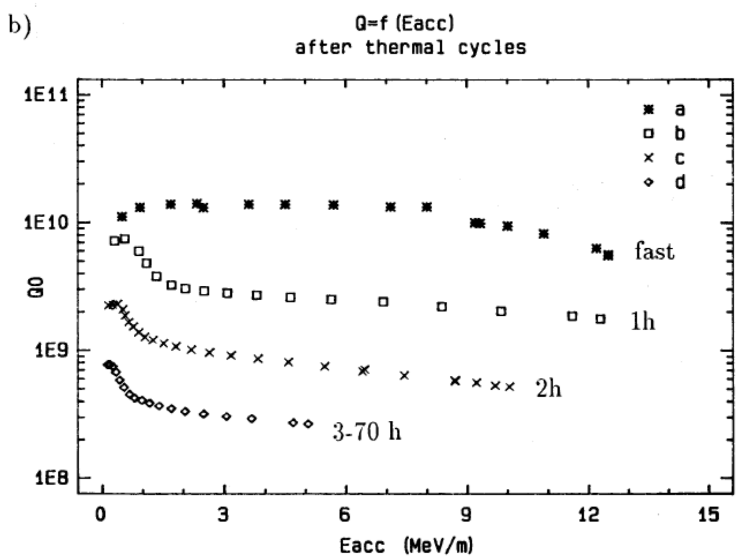
$R_{res,flux}$ of ND cavities is higher for the same $B_{trapped}$;

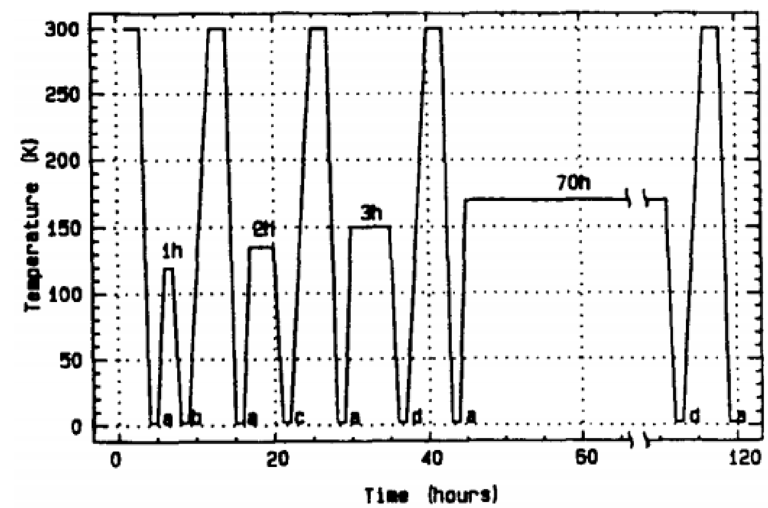
R_{res} from other contributions must be lower.

Background and tentative presumption

Influence of hydrides on Q_0

N-H interaction may be the physical mechanism for proper nitrogen doping treatment to obtain high quality factor

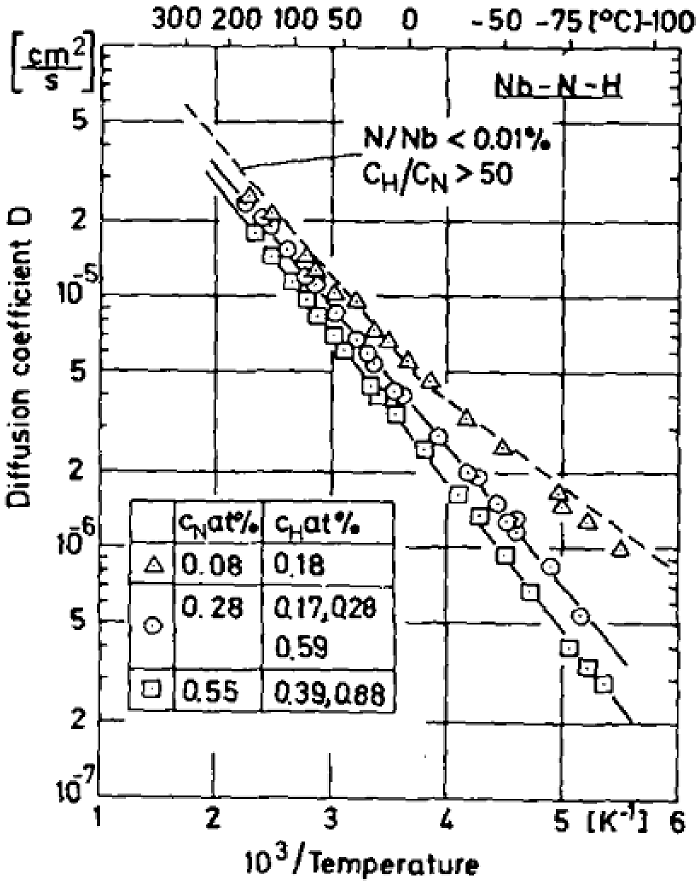


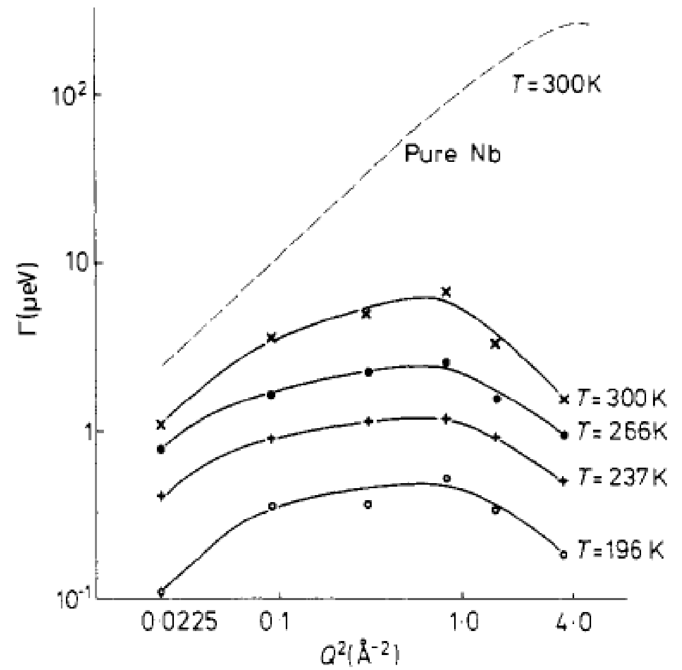


Cooling conditions and the resulting VT results of a Saclay 1.5GHz single cell cavity

Background and tentative presumption

N impurity can reduce the hydrogen diffusion coefficient in niobium at low temperatures

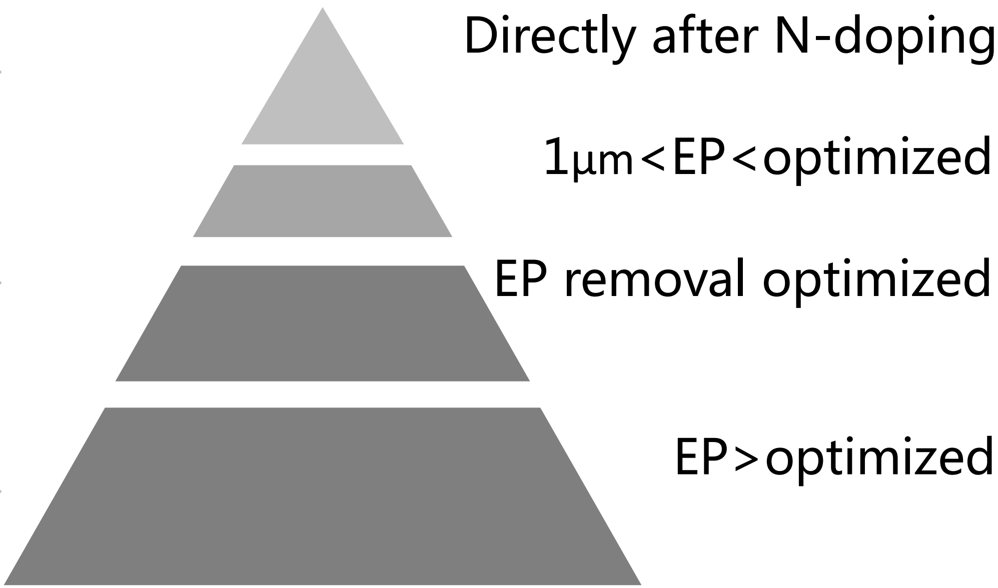




Gorsky-effect measurements (left) ; Quasielastic neutron scattering measurements (right)

Background and tentative presumption

Presumption of N-H interaction



Bad nitride results in high $R_{res\text{-}nitride}$ → Q_0~10^7

More point defects results in high $R_{res,flux}$

N-H interaction prevent H diffusion to surface → no hydride and nitride →high Q

Reduced N → more H to the surface → recovery $R_{res\text{-}hydride}$→ recovery Q-slope

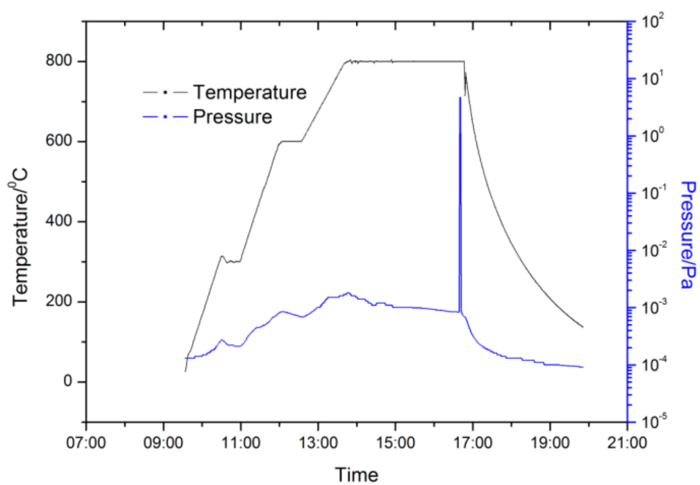
Contents

Measurement of depth profiles

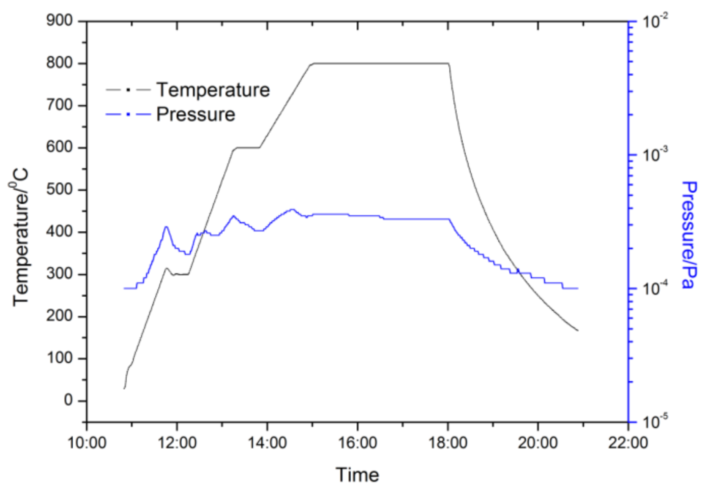
Nitrogen doping and 800^0C heat treatments

Doping@40mTorr of N_2 for 2minutes + Anealing@800^0C for 6 minutes

All samples suffered successive EP with different amounts of material removal



Nitrogen doping treatment



800^0C heat treatment

Background & Presumption

Depth Profiles

Chemical composition

Magnetic properties

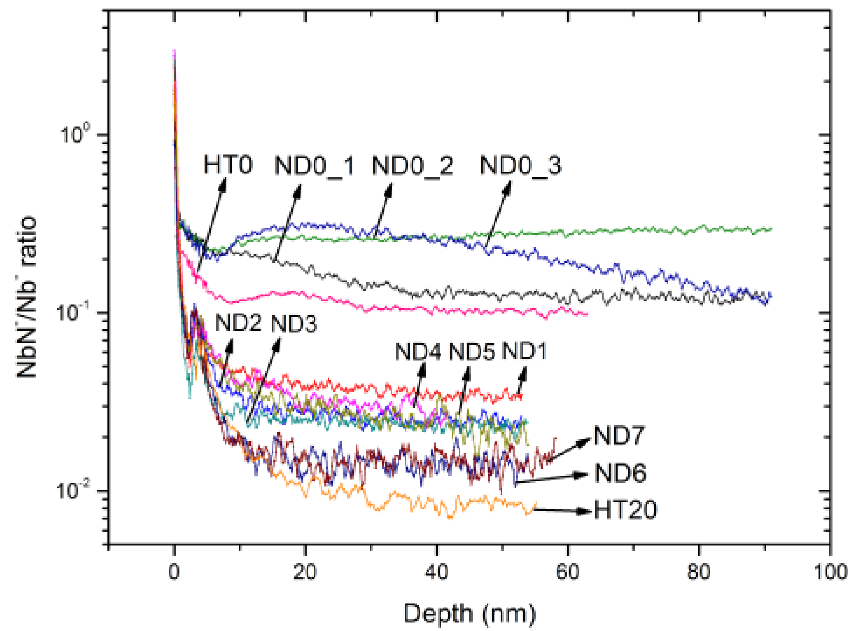
Hydrides precipitation

Summary

Measurement of depth profiles

NbN^-/Nb

higher concentration of nitrogen impurity in doped samples

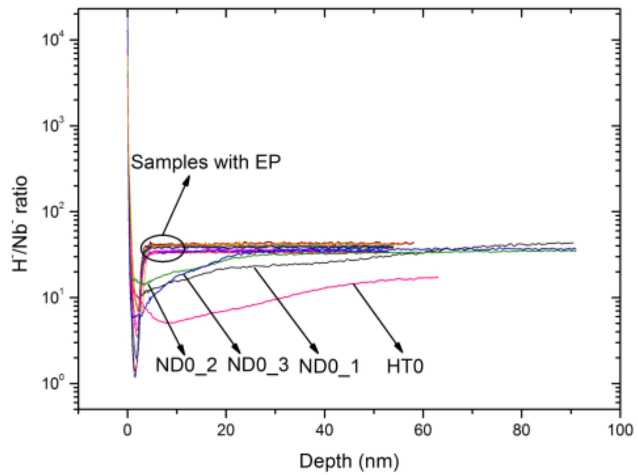


NbN^-/Nb ratio

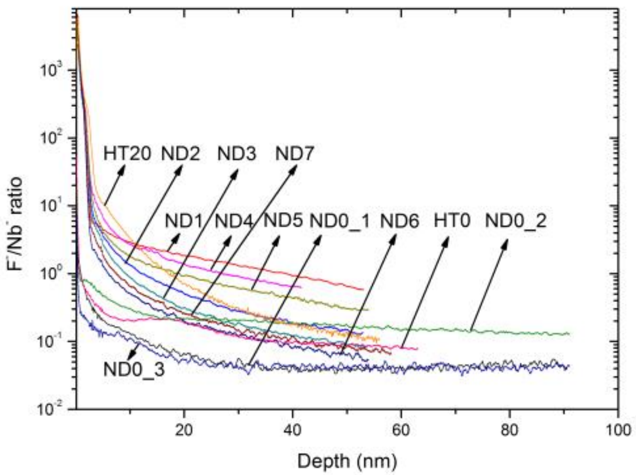
Measurement of depth profiles

H^-/Nb

EP re-introduce H to Nb



H^-/Nb ratio



F^-/Nb ratio

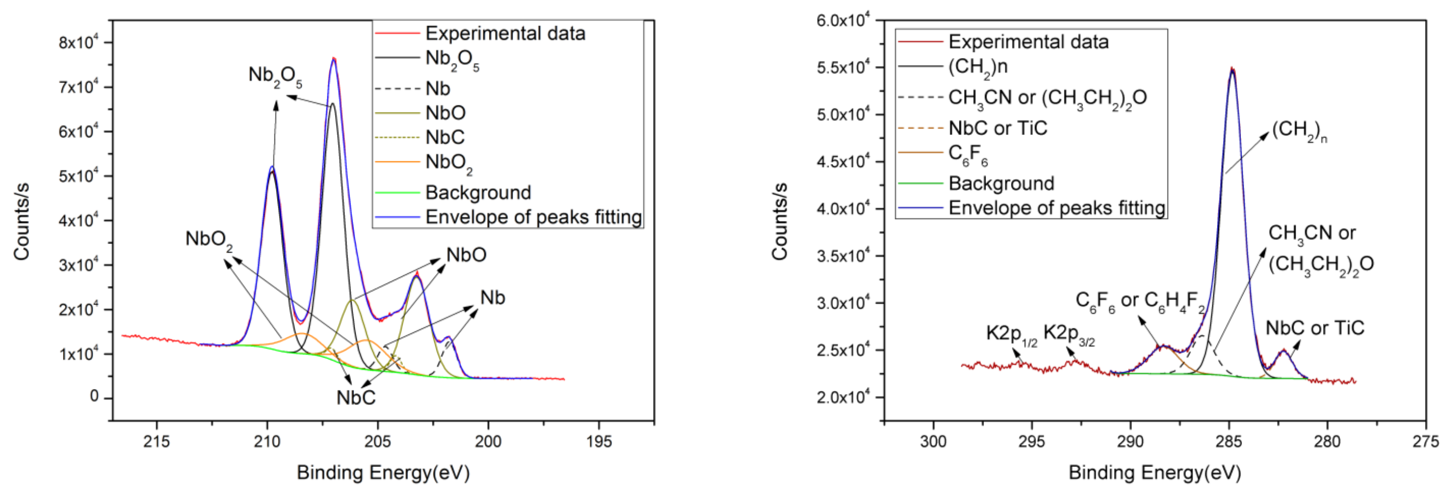
Contents

Analysis of chemical composition

Elemental compositions before etching

Nb mainly occurs as: Nb_2O_5, NbO, NbO_2 and NbC
C mainly occurs as: hydrocarbon

See poster THPB029



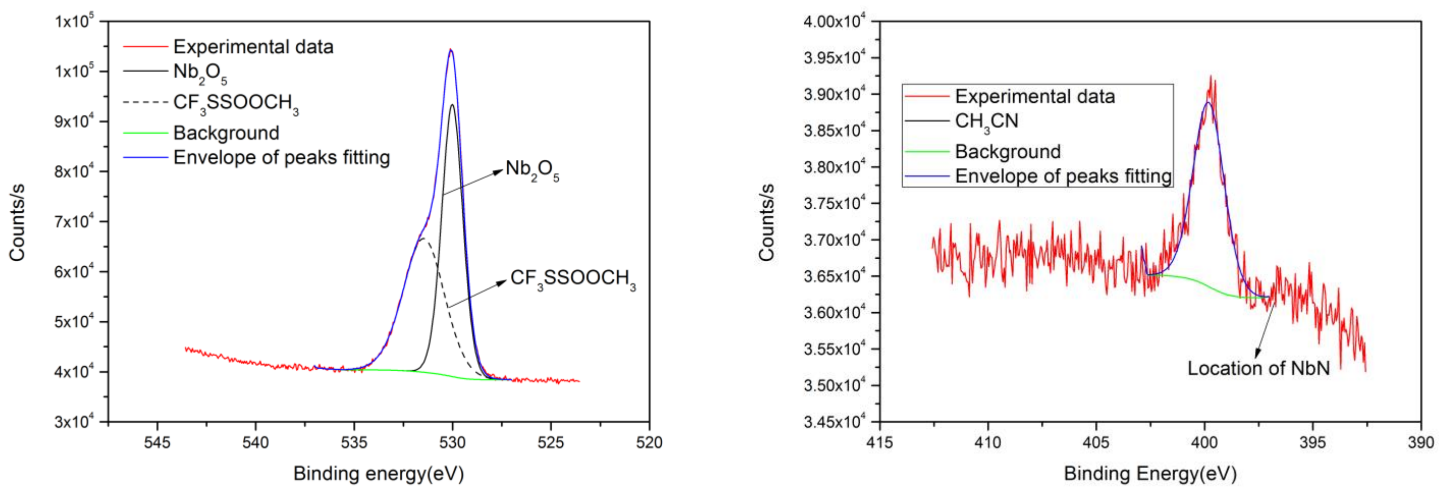
XPS spectra of Nb 3d (left), and C 1s (right) of the ND-2nd-0μm sample.

Analysis of chemical composition

Elemental compositions before etching

O mainly occurs as: Nb_2O_5
N: no nitrides was detected

The elemental compositions and chemical structures on the surface of all niobium samples with different treatments were basically the same.



XPS spectra of O 1s (left), and N 1s (right) of the ND-2nd-0μm sample.

Background & Presumption

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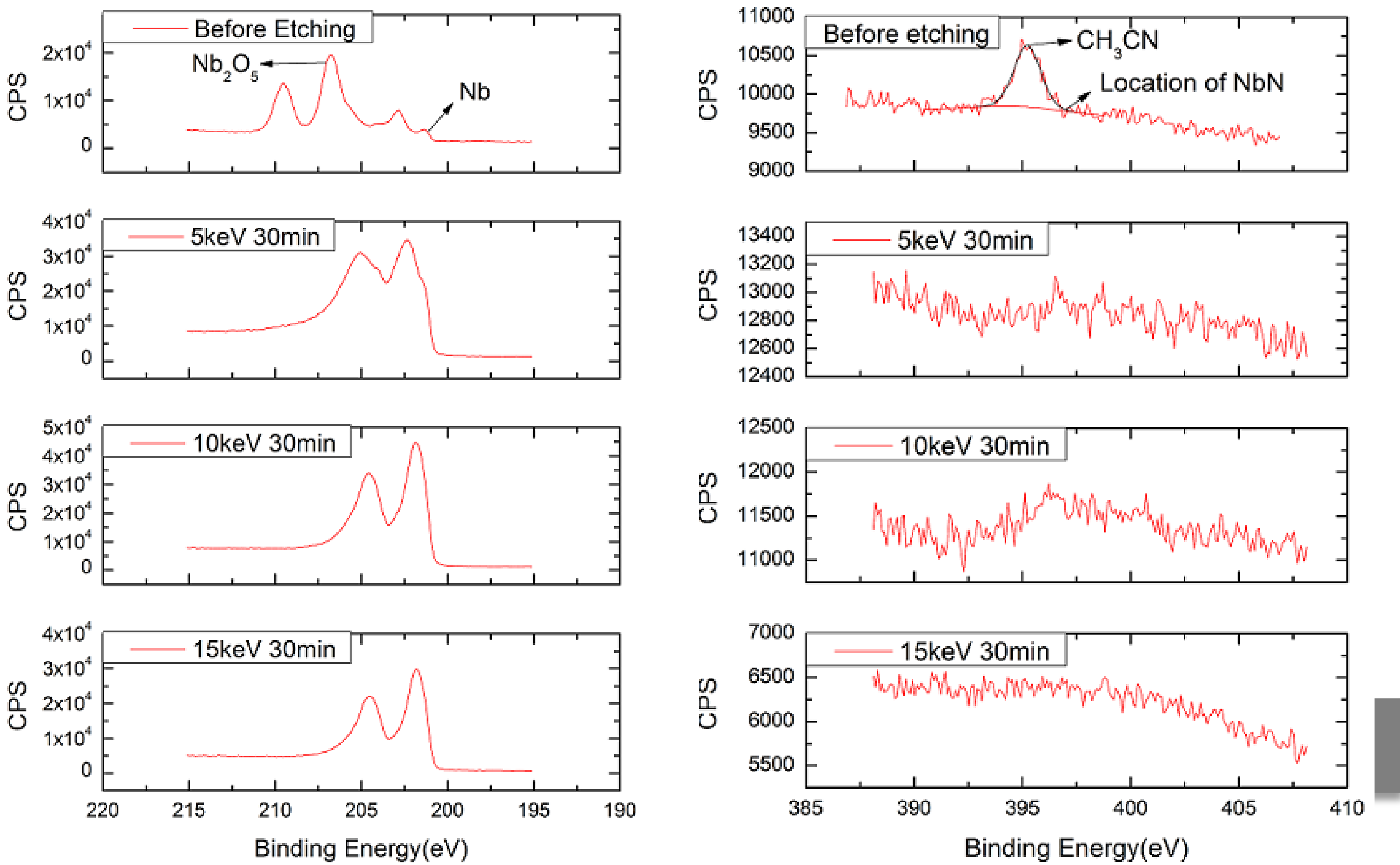
Analysis of chemical composition

Elemental compositions after GCIB etching

No effective signal peaks for N were detected during the 5 minutes collection time.

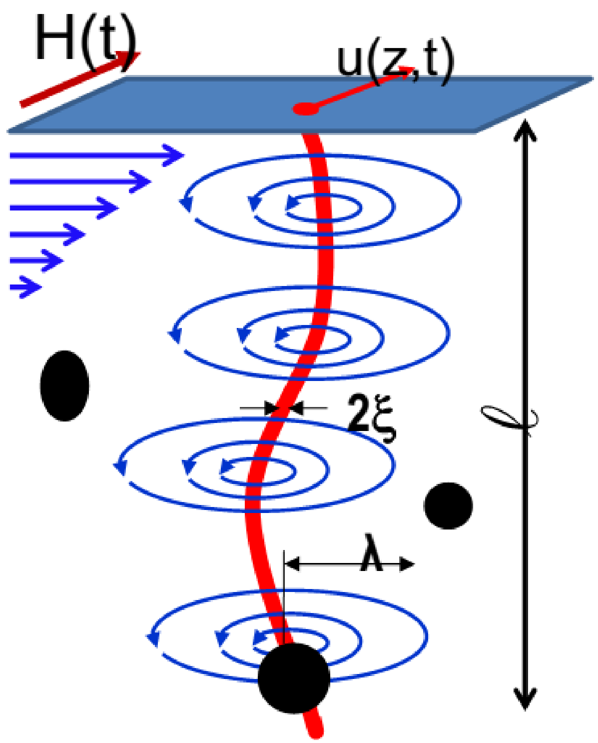


Contents

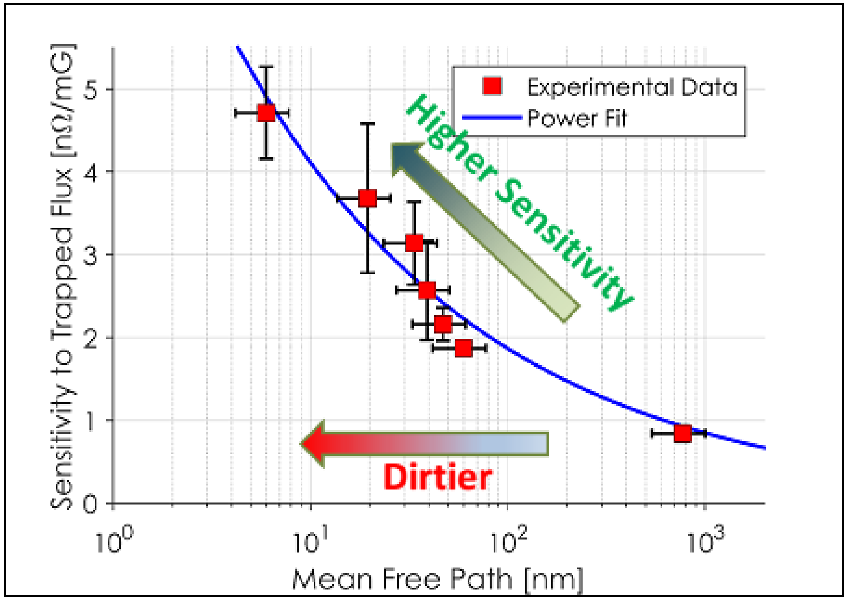
Determination of magnetic properties

Research necessity

Flux trapping is an issue cannot be ignored especially to the nitrogen doped cavity



A. Gurevich predicts $R_{res} \sim 1/l^2$ in dirty limit

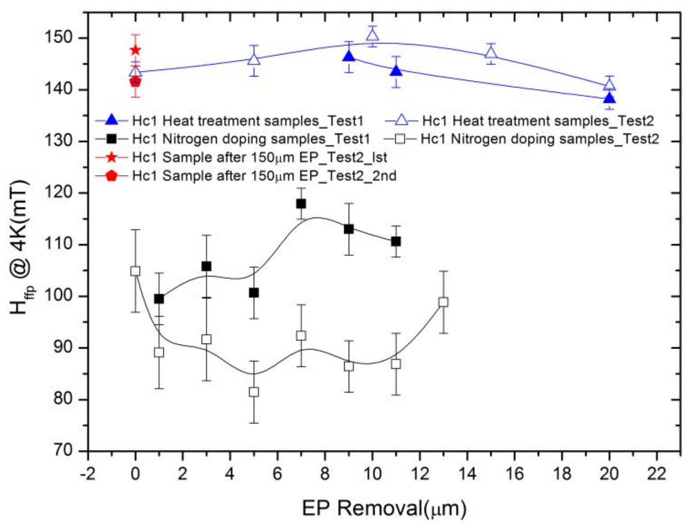


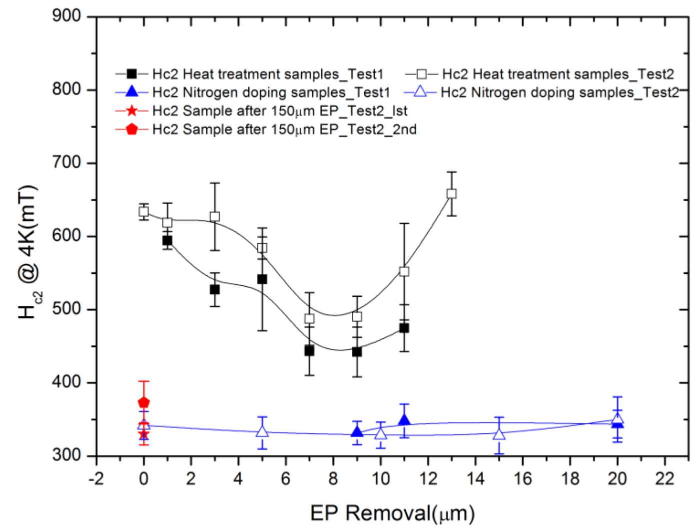
D. Gonnella ：Smaller mean free path results in higher sensitivity to trapped flux

Determination of magnetic properties

H_{ffp} & H_{c2}

H_{ffp} of doped samples is about 30% lower;
H_{c2} of doped samples is significantly higher due to the diffused nitrogen;
H_c is the key of further in-depth analysis of the experimental data.





H_{ffp} and H_{c2} of samples with different treatments

Determination of magnetic properties

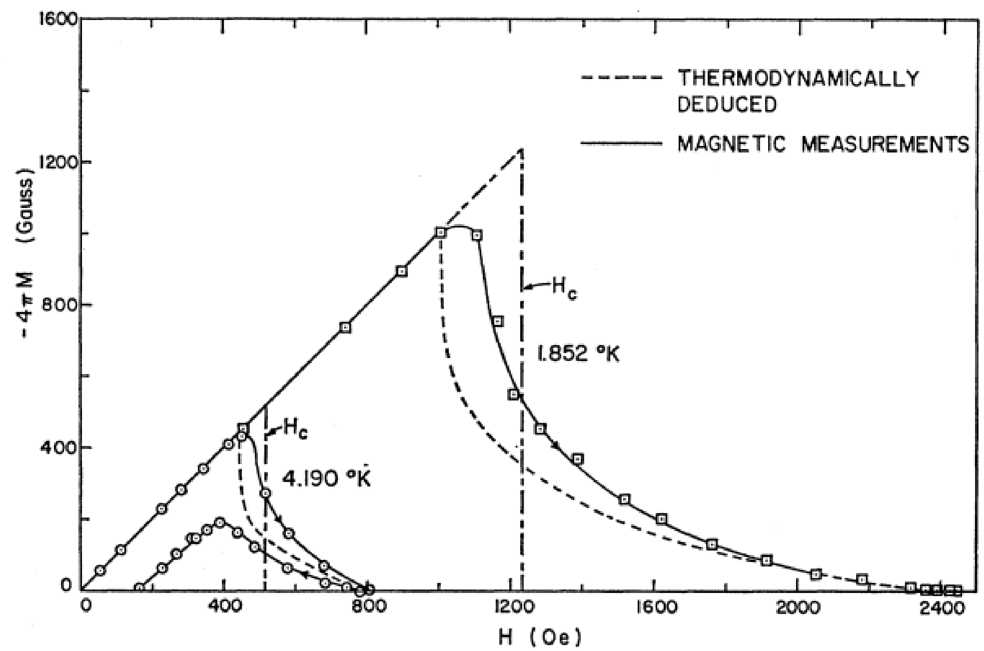
Experimental basis

R. Radebaugh found , in the field region of $H_c < H_a < H_{c2}$:

$$\mathbf{M_{rev}} = \frac{\mathbf{M_+ + M_-}}{\mathbf{2}}$$

Torque magnetometry measurements by Willemin and theoretical study of Kes have shown the validity of the above procedure

Basis of the determination of reversible magnetization curve.

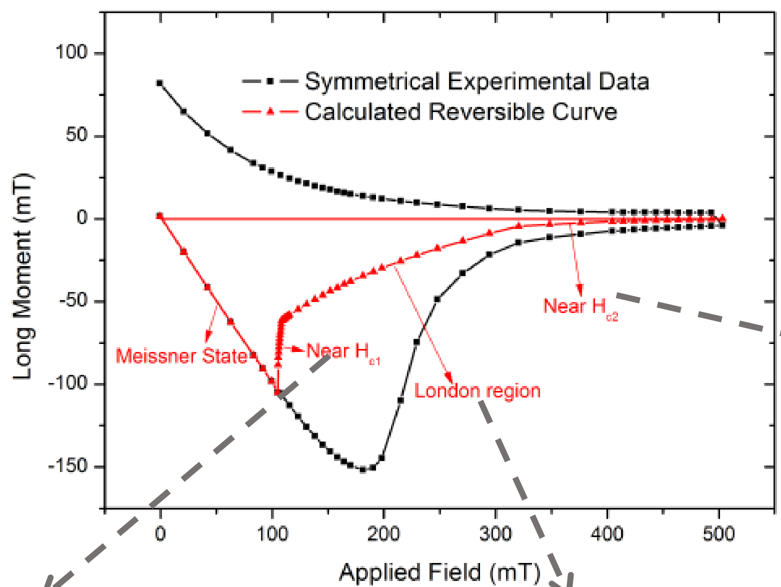


The specific heat and magnetization measurements of Vanadium by R. Radebaugh and P. H. Keesom.

Determination of magnetic properties

Determination of the reversible magnetization curve

The complete reversible magnetization curve can be divided into four parts: 0-H_{ffp} Meissner state; near H_{ffp}(London equation); intermediate field region(London theory); near H_{c2}(Abrikosov theory).



See poster THPB031

$$M = \frac{B}{\mu_0} - H_a = -\frac{H_{c2} - H_a}{1.16(2\kappa^2 - 1)}$$

$$M = \frac{2\phi_0}{\sqrt{3}\mu_0\lambda^2}\left(\ln\frac{3\phi_0}{4\pi\mu_0\lambda^2\,(H_a - H_{ffp})}\right)^{-2} - H_a$$

$$-M \propto \ln\left(\eta\frac{H_{c2}}{H_a}\right)$$

Background & Presumption

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Magnetic properties

Hydrides precipitation

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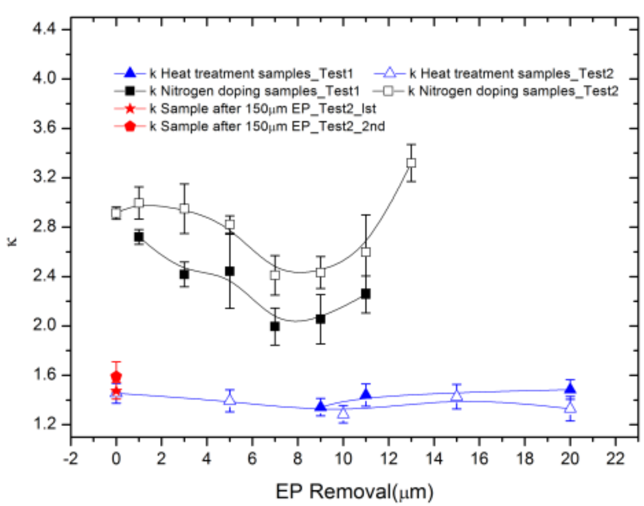
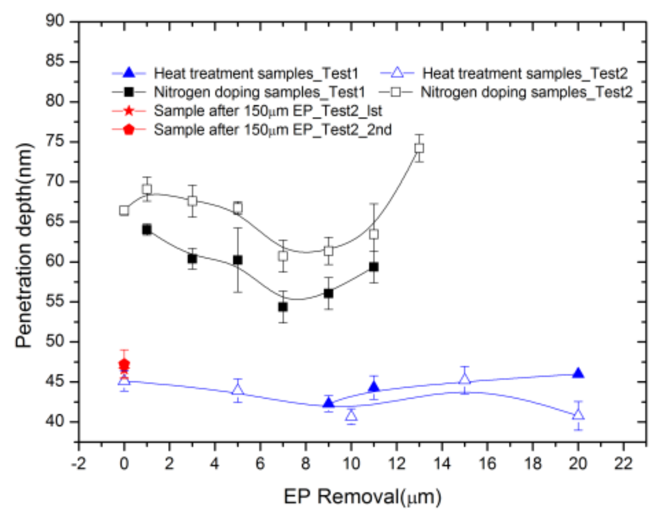
Determination of magnetic properties

Calculated superconducting paremeter





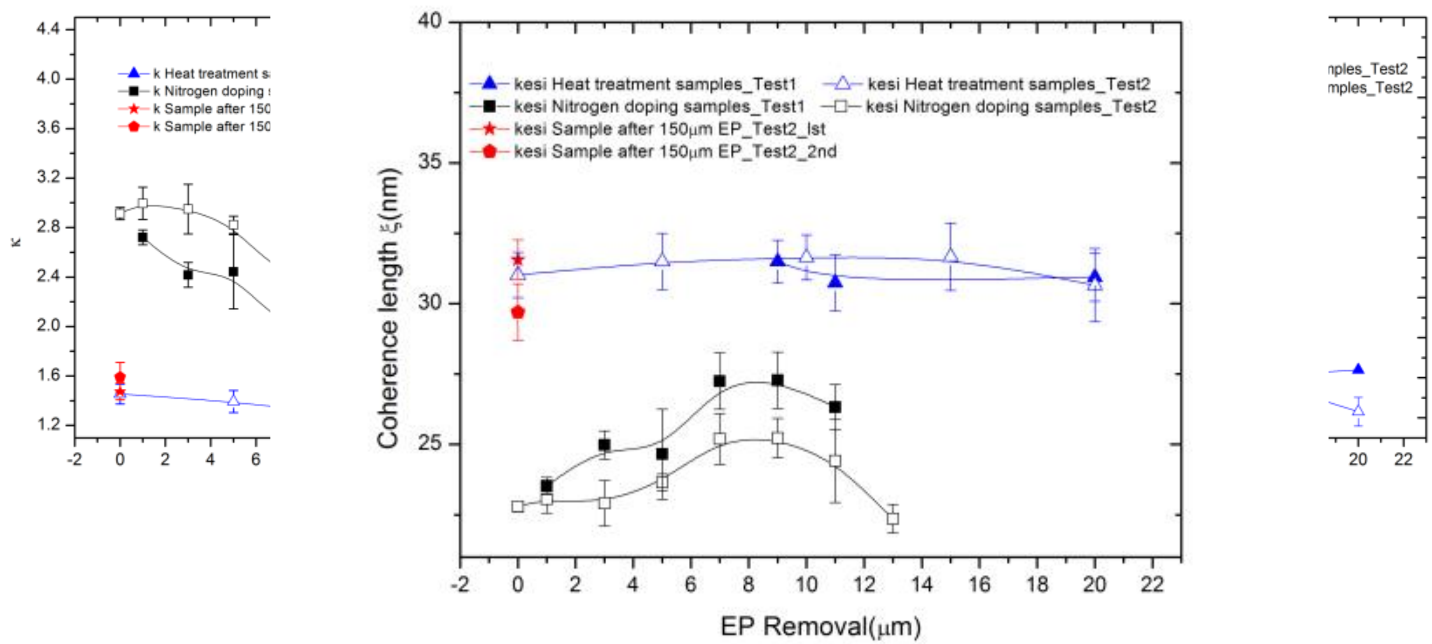
$$H_{c2} = \sqrt{2}\kappa H_c$$

$$\lambda(T) = \frac{1}{2 \cdot H_c(T)} \cdot \sqrt{\frac{\cdot H_{c2}(T)}{e \cdot \mu_0}}$$

Determination of magnetic properties

Calculated superconducting paremeter

More flux is trapped in the doped samples;
There may exist another kind of pinning mechanism that changes with the subsequent EP removal;



$$\xi(T) = \frac{\lambda(T)}{\kappa}$$

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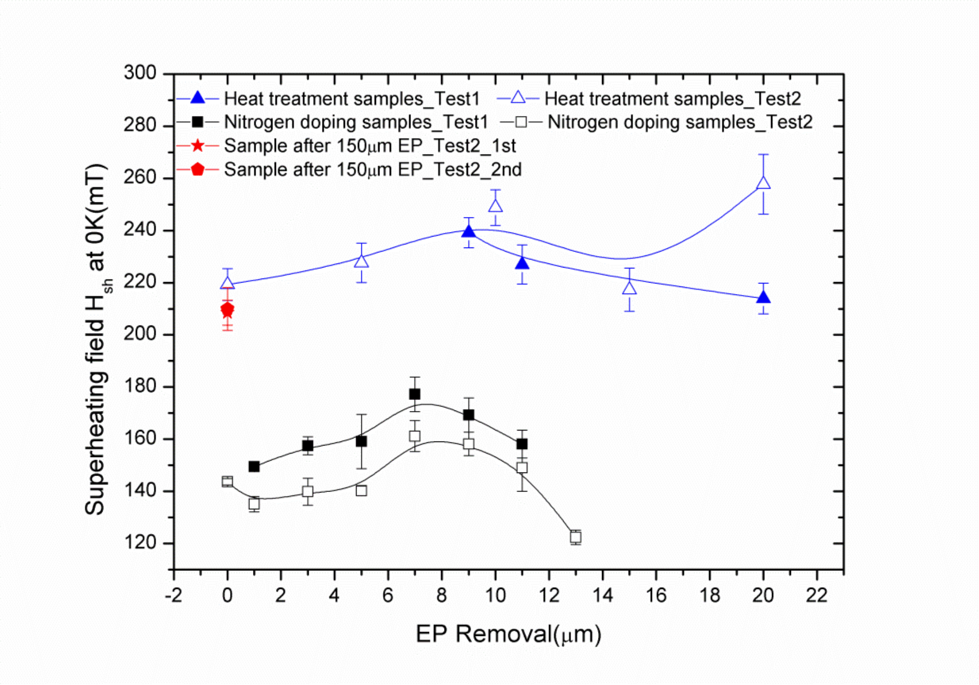
Superheating field H_{sh}

H_{sh} of doped samples is obviously smaller than that of un-doped samples.



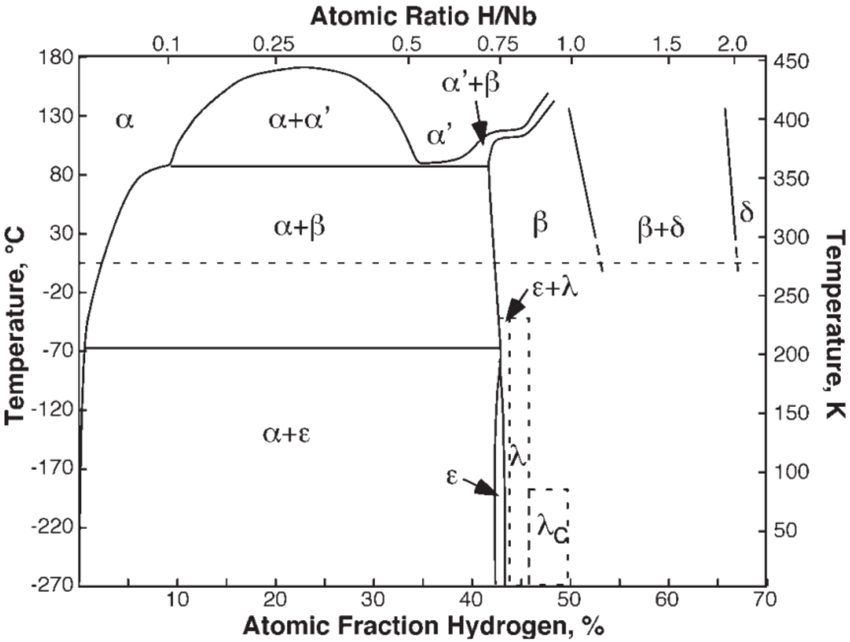
H_{sh} of samples with different treatments

Contents

Observation of hydrides precipitation

Research necessity

Solubility limit of the hydrides formation is dramatically reduced with temperature;
H interacts and keeps concentrated near the defect;
Hydrides observed by using the scanning electron microscope (SEM) with a cold stand at 80K



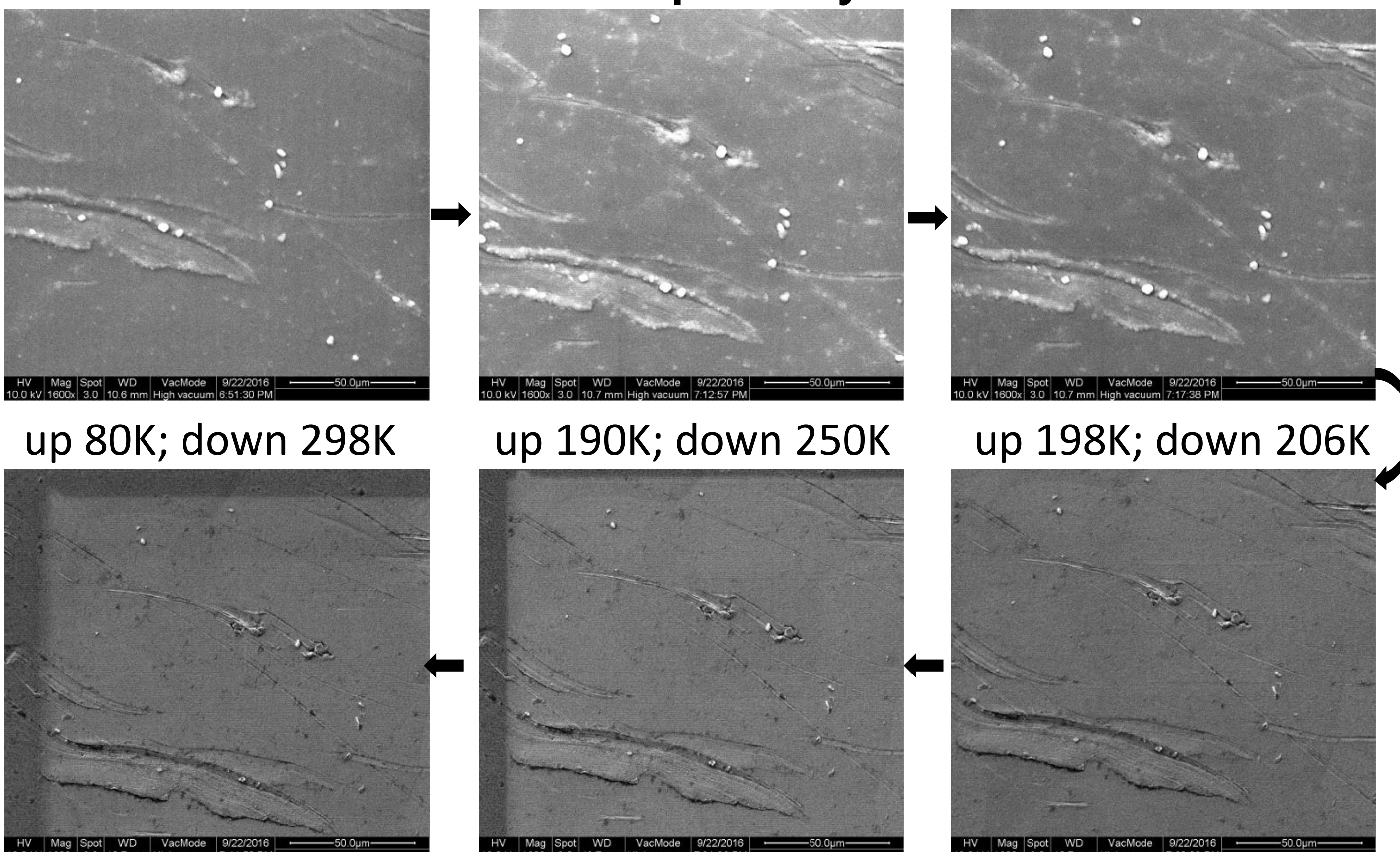
Phase diagram of Nb-H system

Observation of hydrides precipitation

See poster THPB030

Verification of hydrides

The observed white island bumps are hydrides.

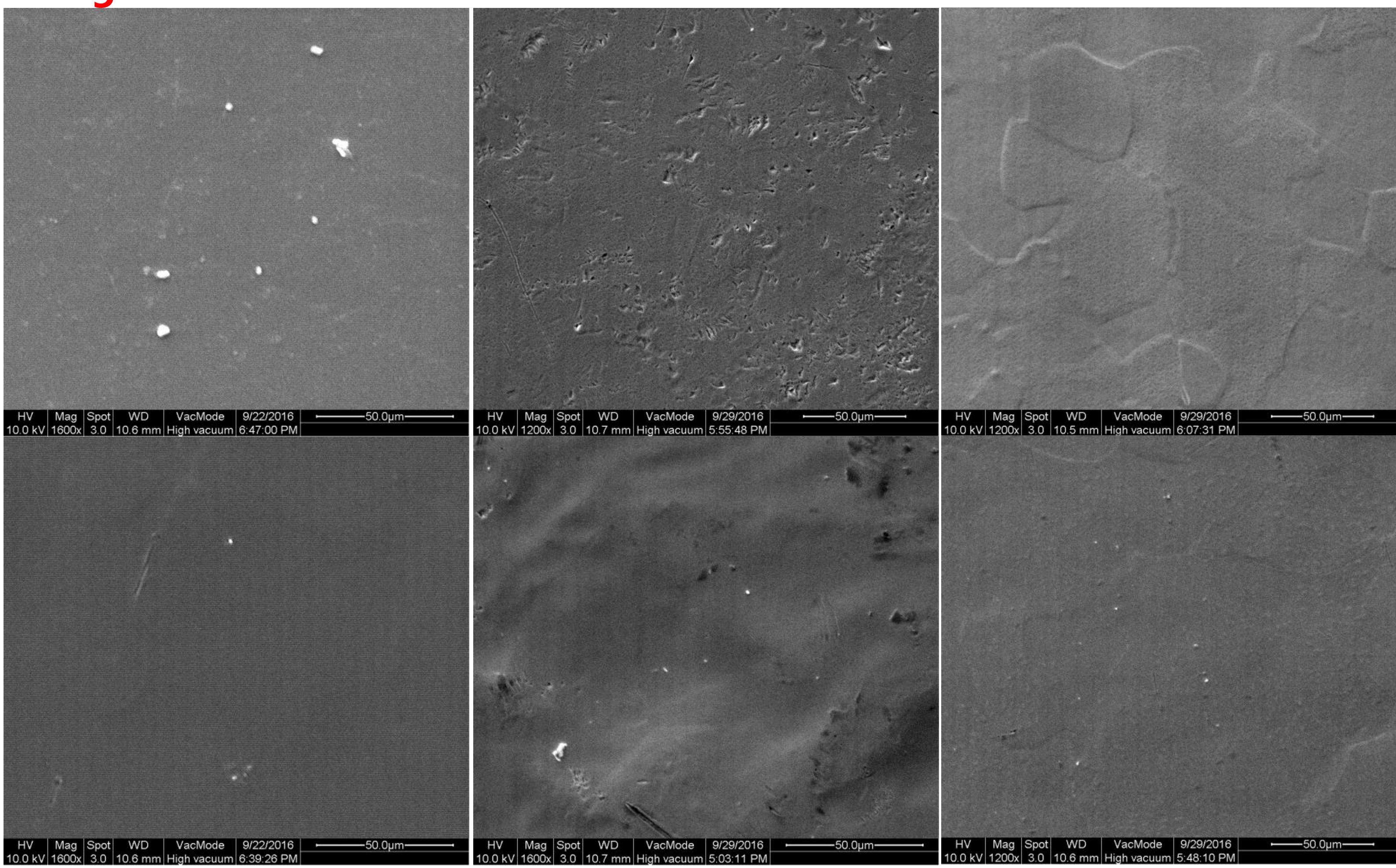


The surface morphology of the noNDnoHT sample changes with the temperature

Observation of hydrides precipitation

Hydrides precipitation comparison

Hydrides precipitation can be prevented or retarded to varying degrees with different amounts of EP removal.



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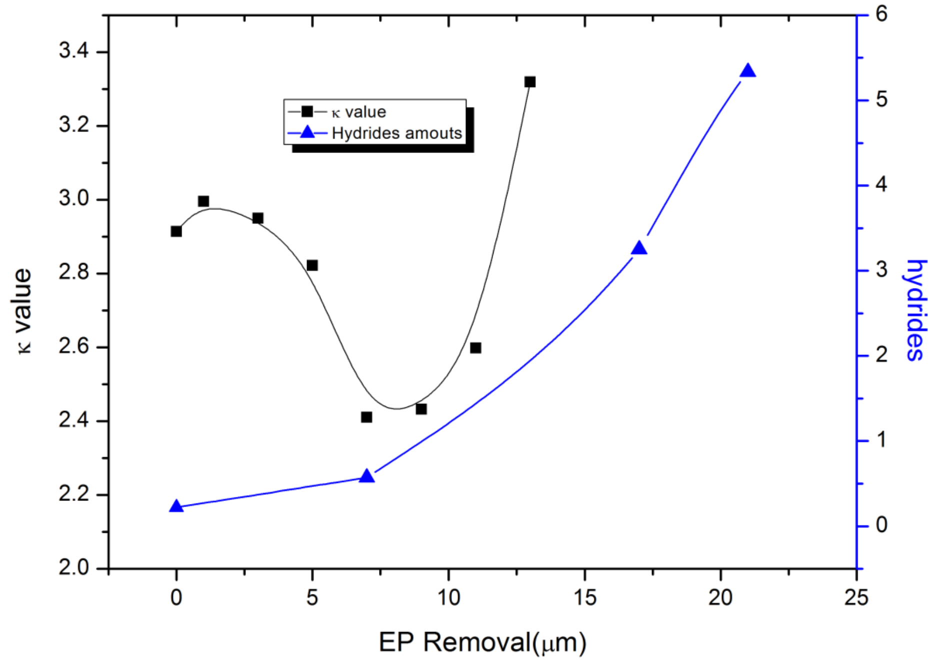
Statistics amounts of hydrides on ND sample surface

7-9μm corresponds to the minimum nitrogen concentration that can effectively reduce the amounts of hydrides formation and a relatively small amounts of flux trapping.



The average number of hydrides in all observation positions on each nitrogen doping sample surface

Summary

A possible mechanism based on N-H interaction

directly after ND treatment

High concentration of N → large amounts of flux pinning centres

EP<7μm

No hydrides + relatively high concentration of point defects from N

EP=7-9 μm

No hydrides+ significant reduction in the flux trapping

EP>9 μm

More hydrides precipitates will emerge with the increase of EP removal.

Thanks for your attention!