Overview of thin-film studies at KEK and Kyoto University.

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Author list of this presentation

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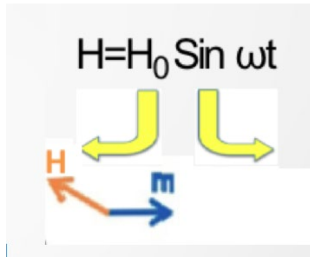
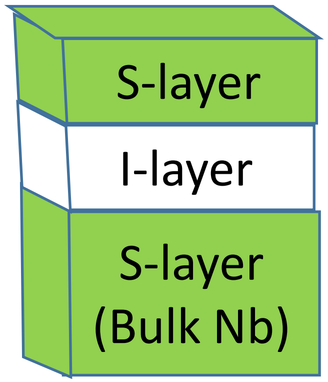
Introduction

- The maximum accelerating gradient of superconducting cavity is limited by the magnetic field at which vortex avalanche occurs.
    - In this study, we calls such magnetic field as "**effective H_{c1}**", $H_{c1,eff}$.
- Recently proposed theory predicts that $H_{c1,eff}$ is pushed up by Superconductor-Insulator-Superconductor structure (**S-I-S structure**) [1][2][3][4].
- In order to verify this scheme, we performed experiments.



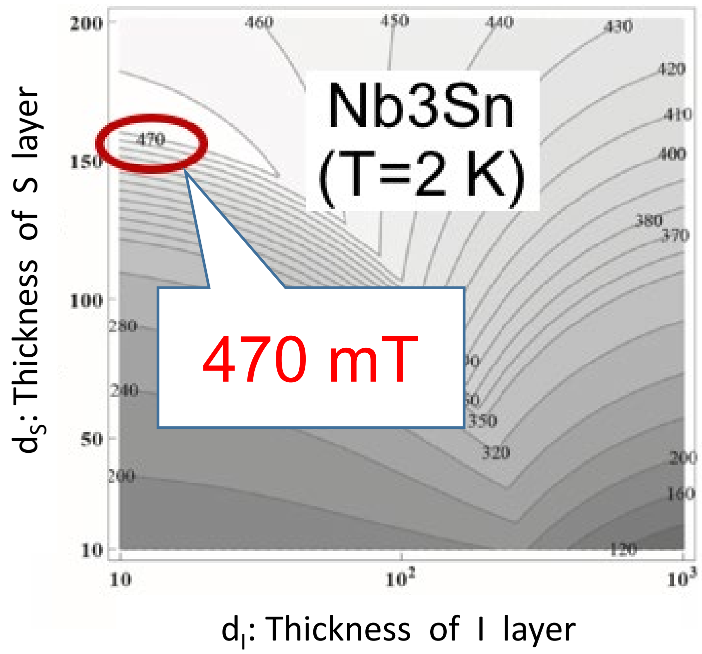


[1] A. Gurevich, Appl. Phys. Lett. 88, 012511 (2006).
[2] T. Kubo, Y. Iwashita, and T. Saeki, Appl. Phys. Lett. 104, 032603 (2014).
[3] A. Gurevich, AIP Adv. 5, 017112 (2015).
[4] T. Kubo, Supercond. Sci. Technol. 30, 023001 (2017).

Slide by R. Katayama (KEK)

Motivation of multilayer study

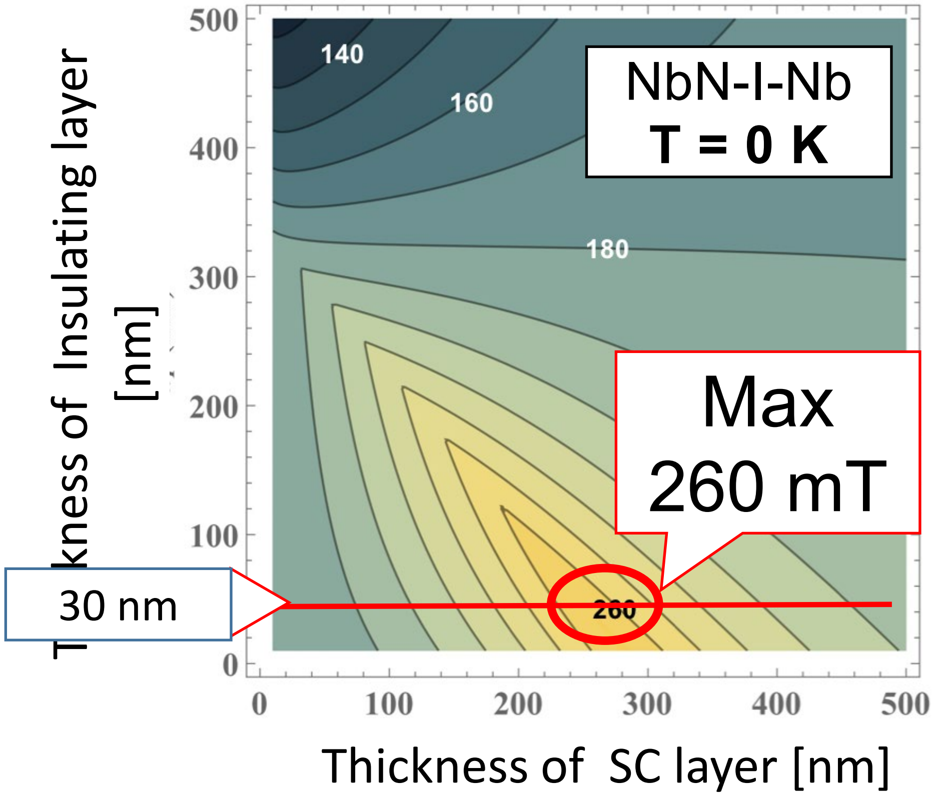
- The proposed theory predicts an optimum set of the parameters to exhibit a good performances
  - Theoretical calculation of effective H_{c1} at 0 K for Nb3Sn/Insulator/Bulk-Nb-substrate is plotted below.
  - The expected maximum effective H_{c1} is 470 mT.
    - Note that Hc1 of pure bulk Nb is assumed to be 200 mT at 0 K in this calculation.



(T. Kubo, Supercond. Sci. Tech-nol. 30, 023001 (2017).)

Motivation of multilayer study

- The proposed theory predicts an optimum set of the parameters to exhibit a good performances
  - We focused on NbN-Insulator-Nb structure.
  - Theoretical calculation of effective H_{c1} at 0 K is plotted below.
    - Note that Hc1 of pure bulk Nb is assumed to be 180 mT at 0 K in this calculation.

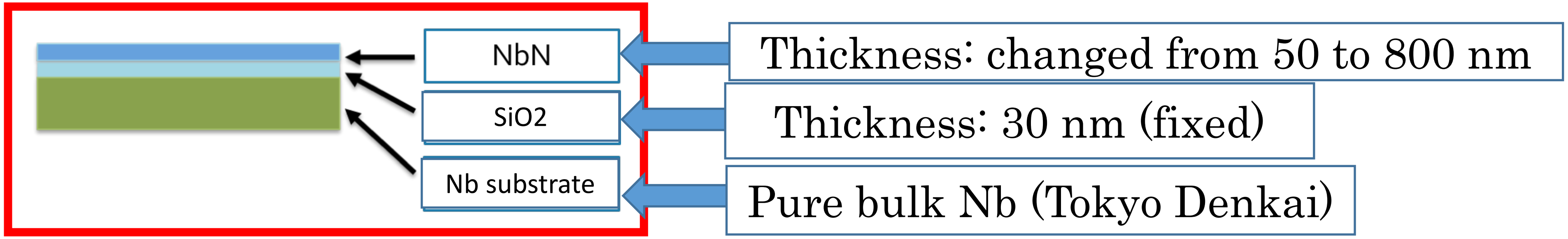


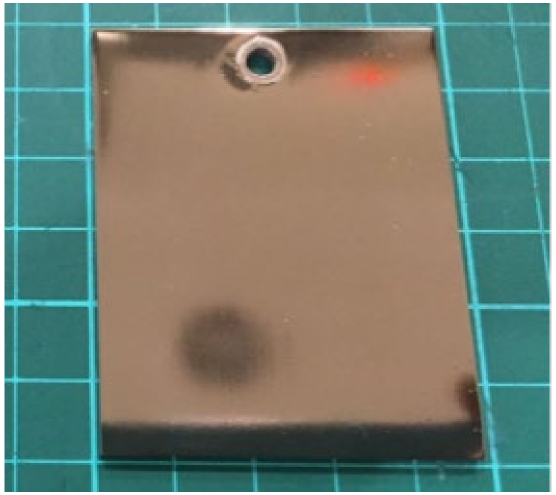
- In order to evaluate this scheme, we scanned parameter regions (red line).
  - NbN thickness: 50 - 800 nm
  - SiO_2 thickness is fixed to 30 nm.
- In this study, in order to determine effective Hc1, the third harmonic voltage method is used (explained in the following).

Slide by R. Katayama (KEK)

(T. Kubo, Y. Iwashita, and T. Saeki, Appl. Phys. Lett. 104, 032603 (2014).).

NbN/SiO2/Nb-Substrate samples

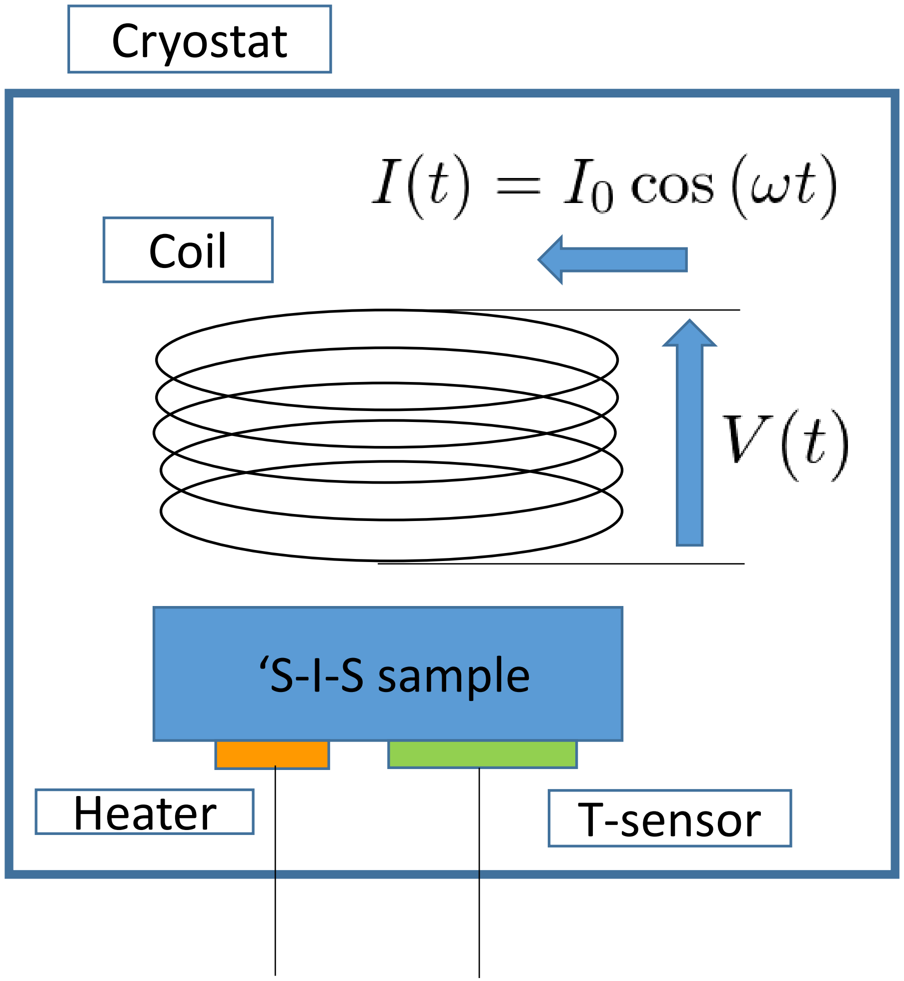




- NbN/SiO_2 thin-films with various thicknesses are formed on pure bulk Nb [5].
- These samples were fabricated by ULVAC, Inc. with **DC magnetron sputtering**.

[5] R. Ito (ULVAC), T. Nagata (ULVAC) , et al., LINAC 2018 Proceedings, TUPO050

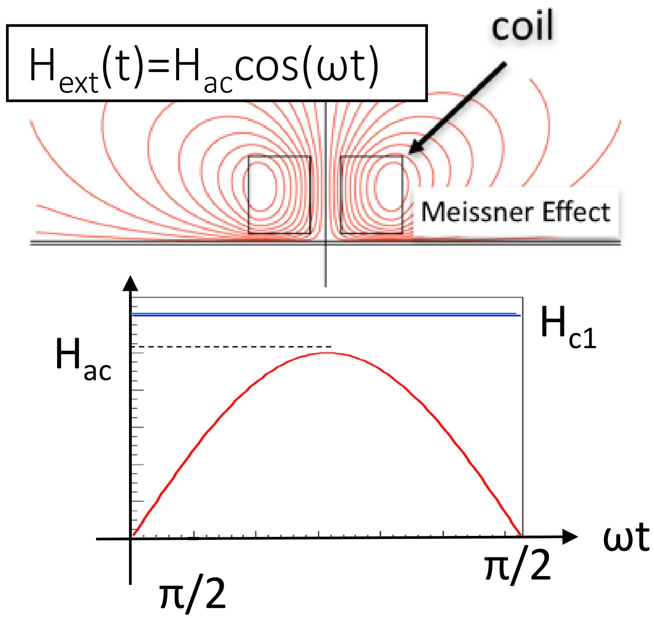
Setup of the third harmonic measurement



- **'S-I-S sample** is installed in **Cryostat**.
- **Liquid Helium** keeps the temperature of 'S-I-S sample at the cryogenic temperature.
- **Coil** is set just above 'S-I-S sample, which can apply an AC magnetic field $H_{ac}\cos(\omega t)$ (f ~ 5 kHz).
- Temperature of 'S-I-S sample is monitored by **Temperature sensor**, and gradually increased by **Heater**.
- Coil voltage and current are detected and digitized by **V-A meters** installed outside of cryostat.
- Measure the third-harmonic component of coil-voltage.

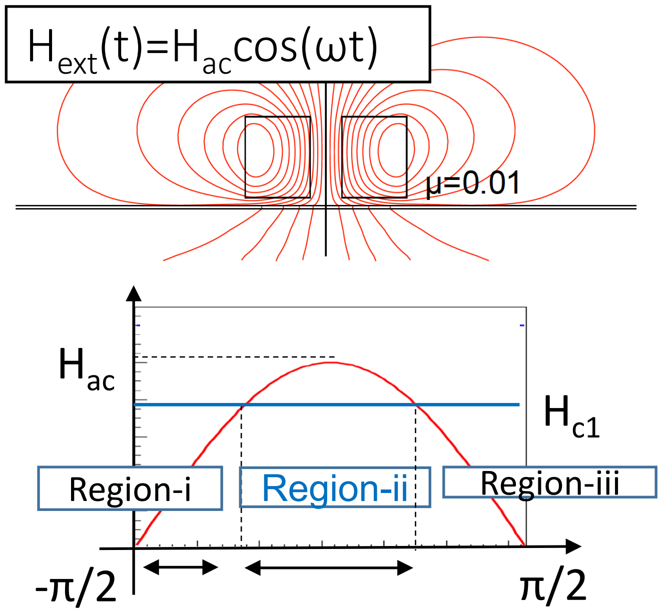
We can control the temperature and the magnetic field

Principle of third-harmonic measurement



(case1)

- H_{c1} (critical field) > H_{ac} (applied H)
- Perfect Meisner effect of 'S-I-S sample.
  - Coil voltage is simply sin(ωt) function.

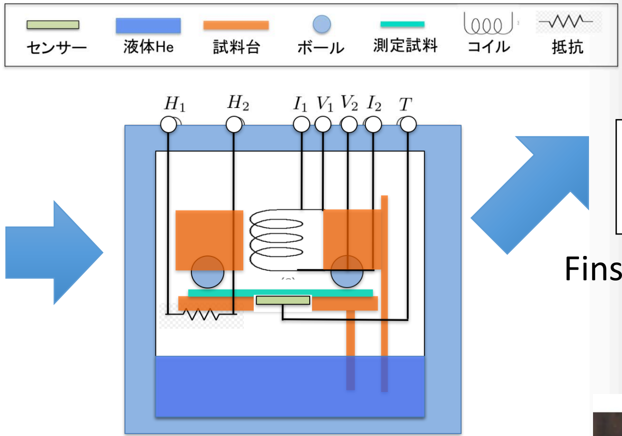


(case2)

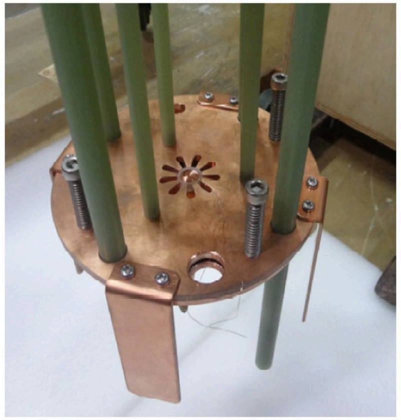
- H_{c1} (critical field) < H_{ac} (applied H)
- Voltex goes into the 'S-I-S sample in region-II.
  - (region-I or III) → Perfect Meisner effect which is the same as case1.
  - (region-II) The third harmonic component appears in the coil voltage: sin(3ωt+δ').

Setup of third-harmonic measurement at Kyoto University

Cryostat

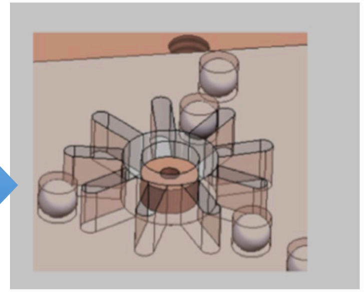


Setup inside the cryostat

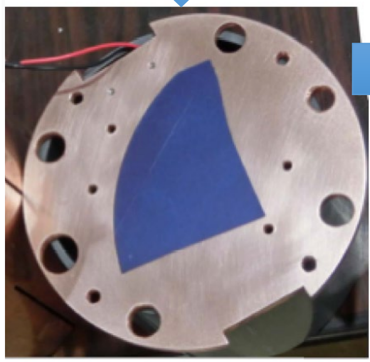


Cu plate measurement stage

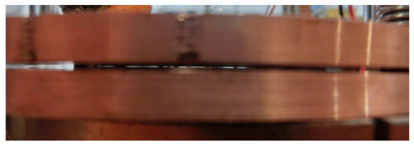
Fins are dipped in the liquid helium.



Coil set in the upper Cu plate



Sample on the Cu plate measurement stage



Sample is set in between two Cu plates.

Coil is just on the upper side of the sample.

We have a similar and independent setup at KEK.

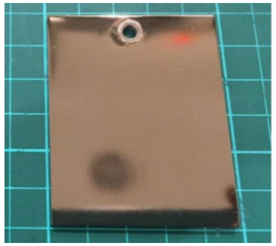
Independent measurement systems and analysis processes at Kyoto University and KEK

NbN/SiO2/Nb multilayer samples are prepared by ULVAC (industry) in collaboration with KEK.

Kyoto Univ.

Measurement and analysis
by Ryo Katayama (Kyoto Univ. / KEK)

SRF2019 THFUA2



NbN-I-Nb samples
by ULVAC, Inc.

KEK

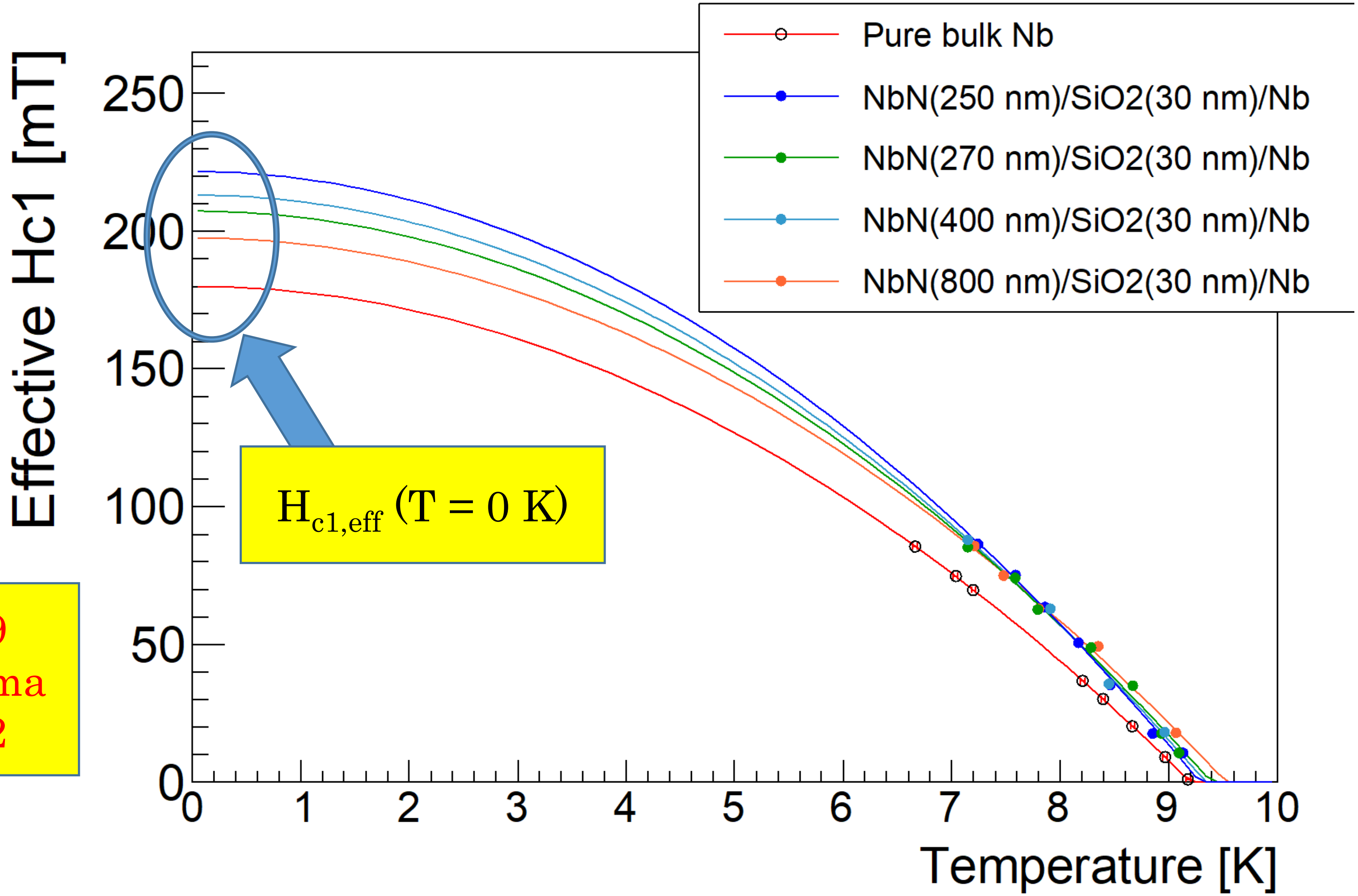
Measurements and analysis
by Hayato Ito (Sokendai Univ. / KEK)

SRF2019 TUPO78

We obtained consistent results at two independent setups!

Both measurements and analysis processes were presented at SRF2019 (THFU2 and TUPO78)

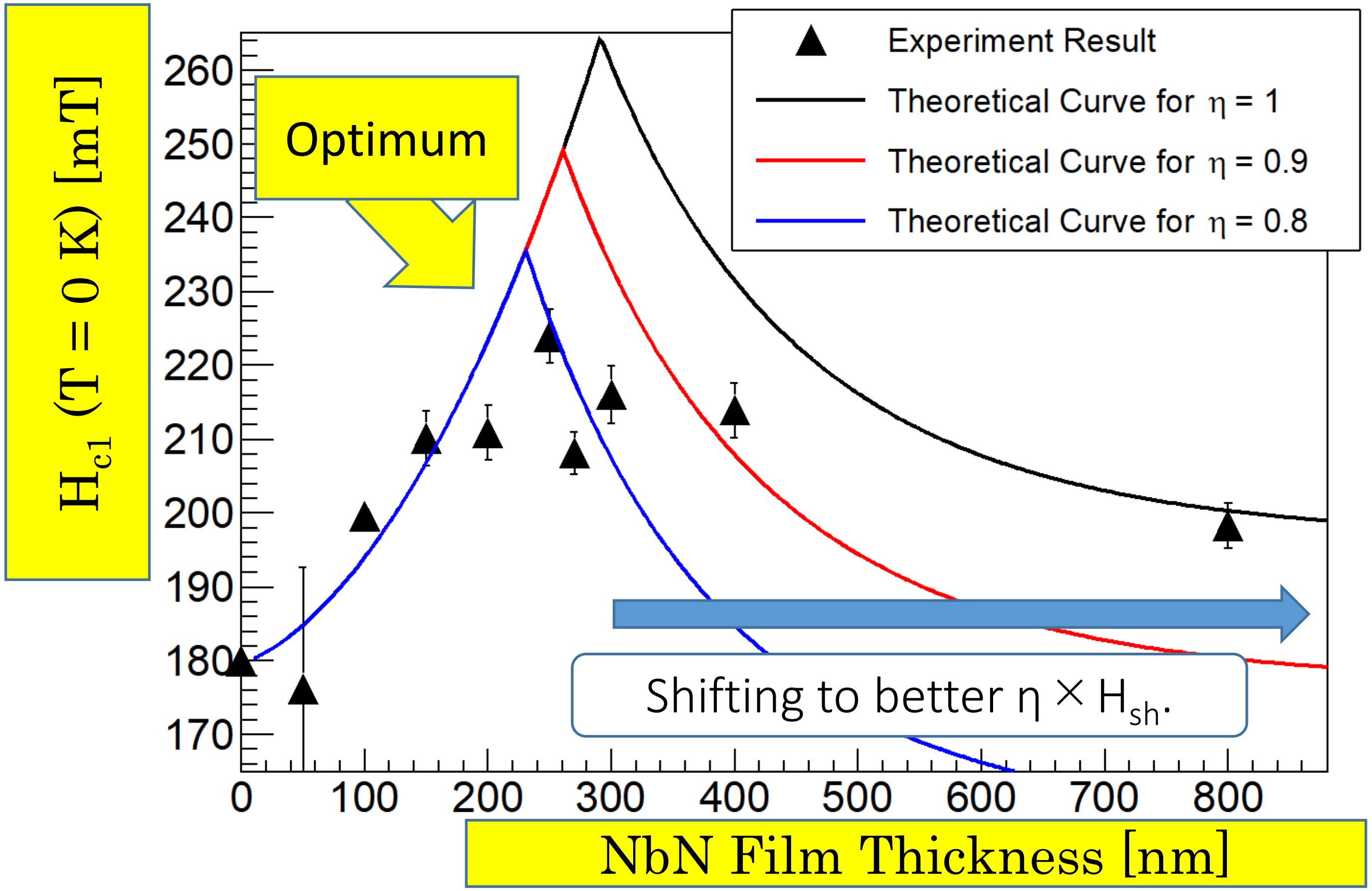
The measurement result of the effective Hc1 of NbN/Insulator/bulk-Nb by the setup at Kyoto Univ.



SRF2019
R. Katayama
THFUA2

Hc1 (T=0K) vs. thickness of NbN layers.

- Experimental results and theoretical curves are superimposed below.



Data from the setup at Kyoto University.

SRF2019
R. Katayama
THFUA2

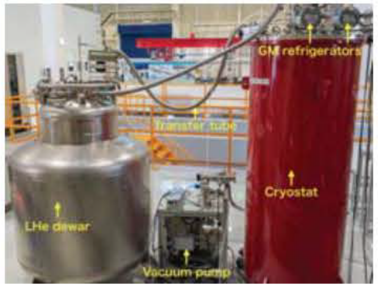
SUSP013
TUP078

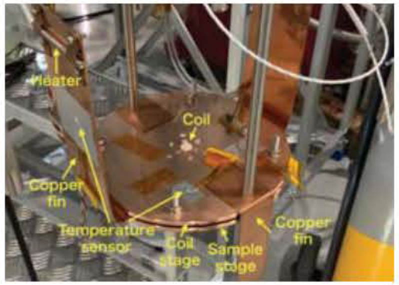
LOWER CRITICAL FIELD MEASUREMENT OF NbN MULTILAYER THIN FILM SUPERCONDUCTOR AT KEK

H. Ito [#, A)], H. Hayano [B)], T. Kubo [B)], T. Saeki [B)], R. Katayama [B)], Y. Iwashita [C)], H. Tongu [C)], R. Ito [D)], T. Nagata [D)], C. Z. Antoine [E)]
[A)] SOKENDAI (The Graduate University for Advanced Studies), [B)] KEK, [C)] Kyoto University, ICR, [D)] ULVAC, Inc., [E)] CEA, Irfu
[#)] hayatoi@post.kek.jp

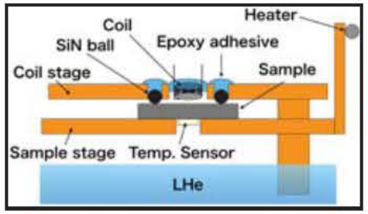
from the applied magnetic field.

Measurement system



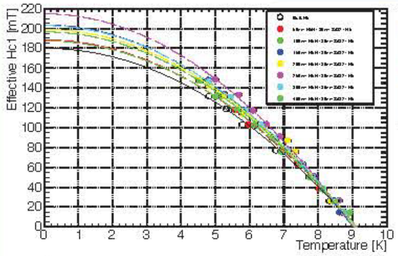


The sample stage has two copper fins which are equipped with heater for increase sample temperature. The coil stage has also two copper fins whose bottom ends are immersed in LHe to cool down the solenoid coil. The gap distance of 0.05 mm between sample surface and coil stage is kept by nine SiN balls embedded in the coil stage.

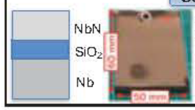


Please find **arXiv:1906.08468** which describe our measurement system in detail.

NbN-SiO_2-Nb sample



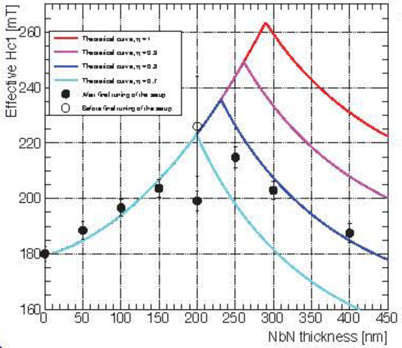
sample



Seven NbN-SiO_2-Nb sample were produced by ULVAC, Inc.. (50, 100, 150, 200, 250, 300, and 400 nm thickness NbN and 30 nm thickness SiO_2)

R. Ito, T. Nagata, et al., "Construction of Thin-film Coating System Toward the Realization of Superconducting Multilayered Structure", LINAC2018 Proceedings, Beijing, China.

The above samples were measured and compared with H_{c1} of bulk Nb sample.



- The comparison between the measurement values and the theoretical curve show that optimum thickness exists for the NbN-SiO_2-Nb multilayer structure.
- Our measurement results are in good agreement with the theoretical curve with η = 0.7 to 0.8 except for the result of the 200 nm sample. (the open circle for 200 nm sample, which is measurement result during the development stage of the measurement setup, is in good agreement with the theoretical curve.)

CONCLUSION

- The third harmonic measurement system was constructed in KEK, and the bulk Nb sample and the NbN-SiO_2-Nb samples were measured and compared each other.
- We found that the optimum thickness existed for the NbN-SiO_2-Nb multilayer structure.
- In the case of η = 0.7 to 0.8, the maximum improvement of 24 to 31 % for the NbN-SiO_2-Nb multilayer structure is expected compared with bulk Nb.
- These results support that SRF cavity with the NbN- SiO2-Nb multilayer structure has the potential to achieve the higher accelerating gradient respect to conventional SRF cavity.

Data from the setup at KEK.

SRF2019
H. Ito
TUPO78

Third-harmonic measurement results of NbTiN thin-film samples

New results!

NbTiN/Insulator/bulk-Nb thin-film samples were prepared at Jlab and sent to KEK/Kyoto-Univ. for the third-harmonic measurements.

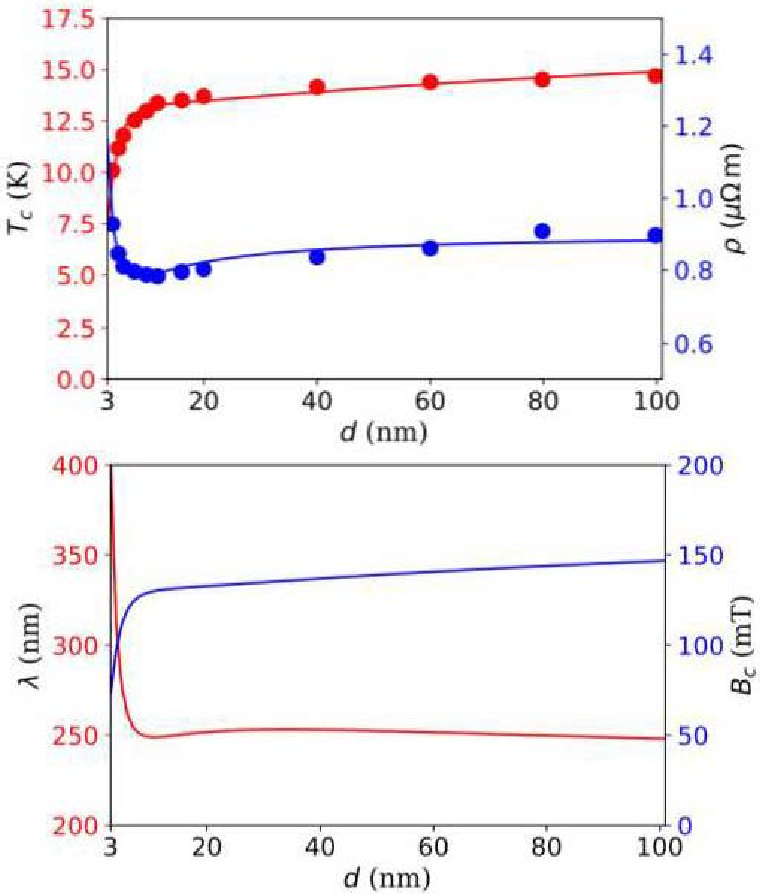
The NbTiN/AlN bi-layers were deposited on bulk Nb substrates using reactive DC magnetron sputtering (R-DCMS) in an ultra-high vacuum deposition system with a base pressure in the 10-10 Torr range. The NbTiN films were deposited using an 80/20 (%wt) NbTi target at a fixed distance to substrate of 8 cm. The AlN films were deposited with an Al target and with a fixed target to substrate distance of 11 cm. The N2 partial pressure was respectively ~23 and 33 % for NbTiN and AlN, for a total pressure of ~2 mTorr, and a substrate temperature of 450 ° C. Prior to film growth, the substrates were etched with BCP 1:1:2, rinsed with DI water with a final rinse in an ultrasonic bath of methanol and annealed at 600 ° C for 24 hours under vacuum.

Theoretical calculation of Hc1-effective for NbTiN/Insulator/Nb sample

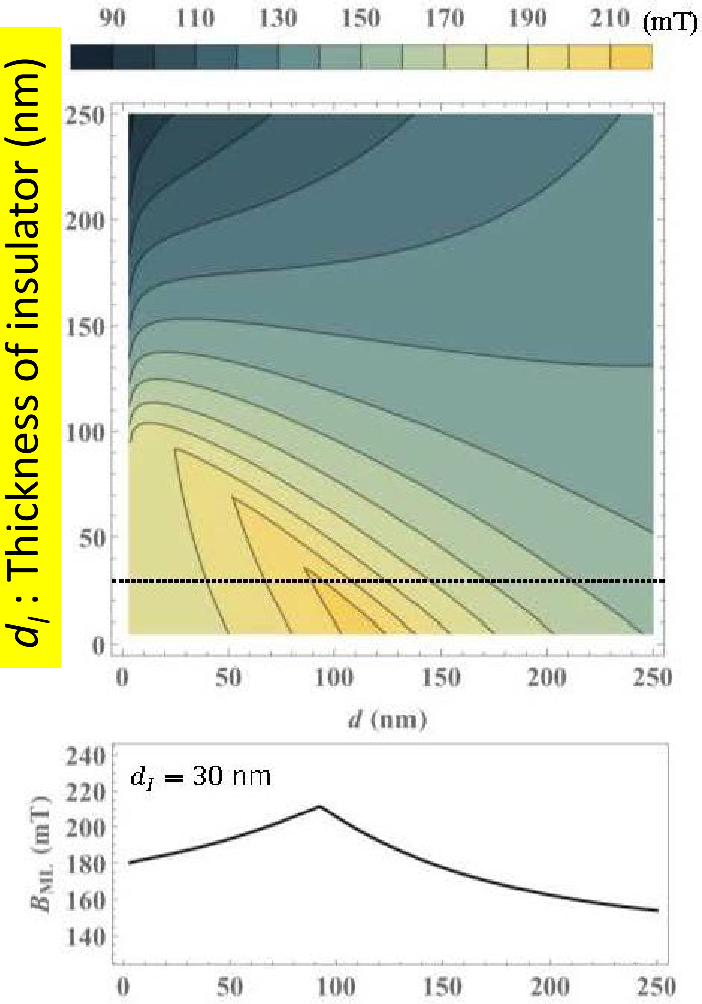
- T. Kubo (KEK) calculated the expected Hc1-effective as the function of d_I (Insulator thickness) and d (NbTiN thin-film thickness).

NbTiN

Data from L. Zhang et al., Appl. Phys. Lett. 107, 122603 (2015)



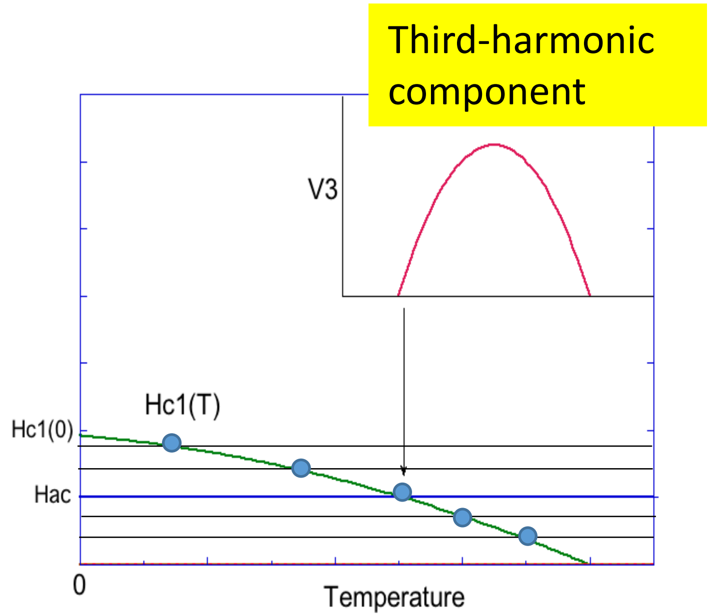
d_I : Thickness of insulator (nm)



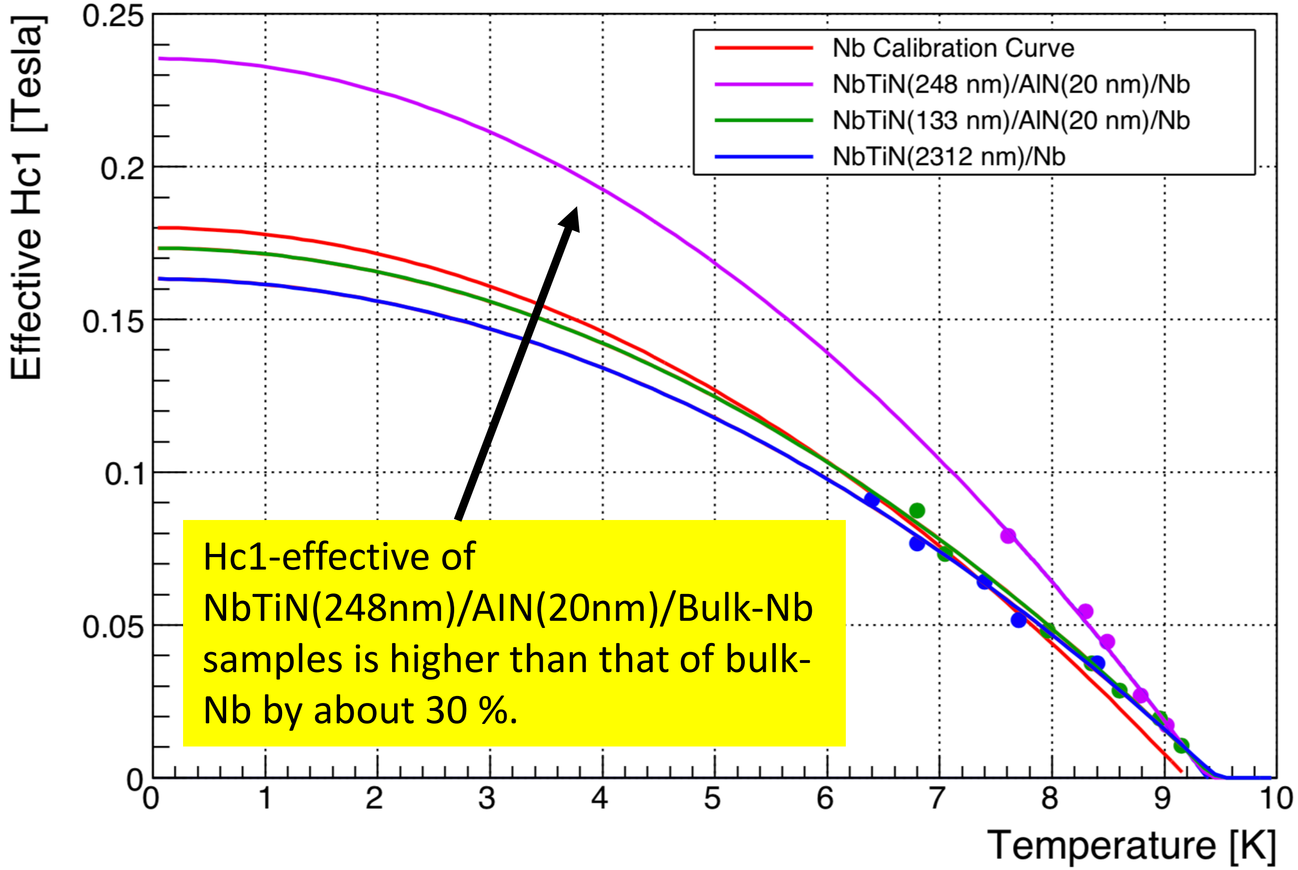
d : Thickness of NbTiN film (nm)

Third-harmonic measurement result of NbTiN/Insulator/bulk-Nb sample

Preliminary



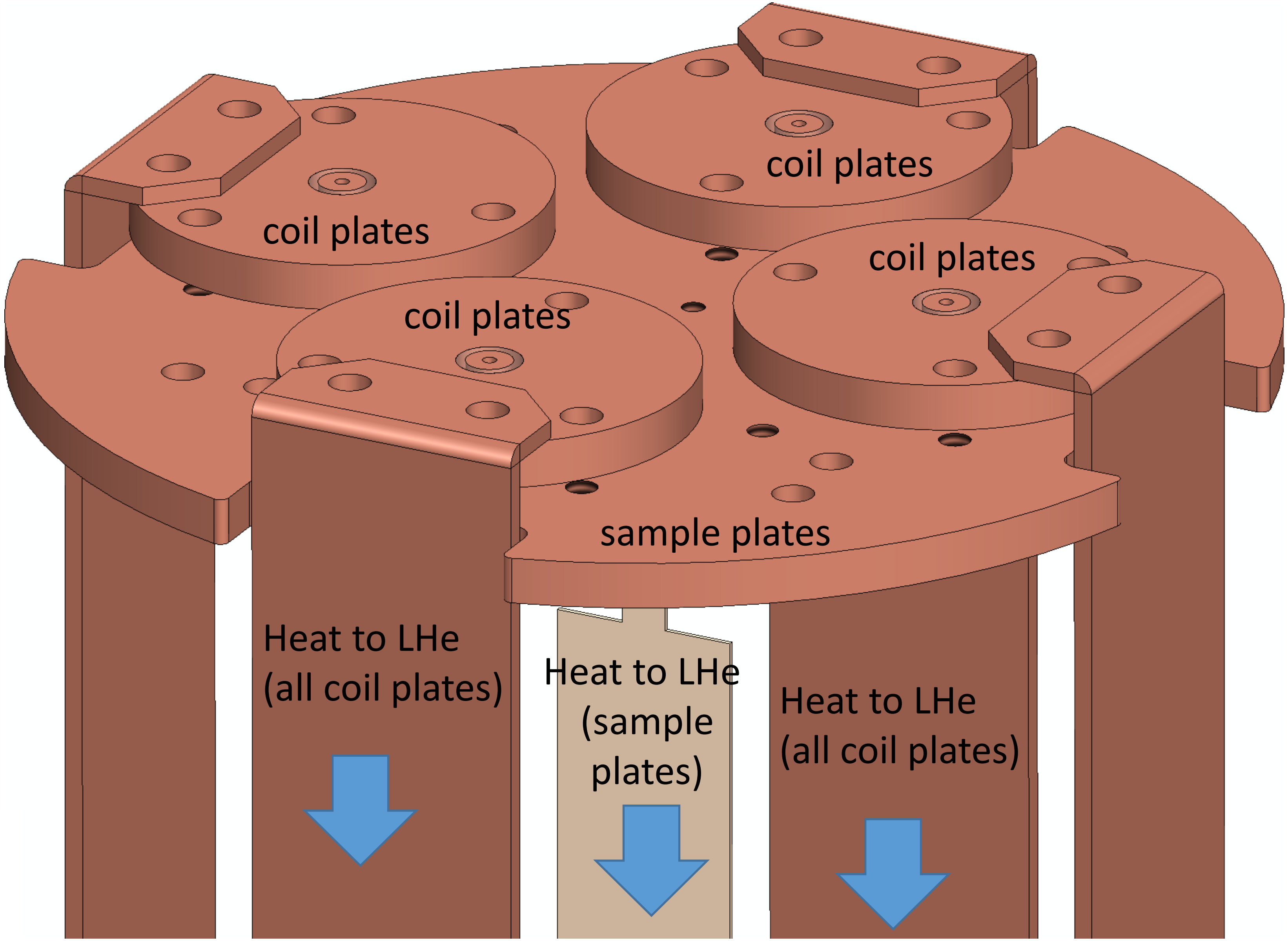
- Fitting function of H_{c1} :
  $H_{c1}(T) = H_{c1}(0) \times (1-(T/T_c)^2)$



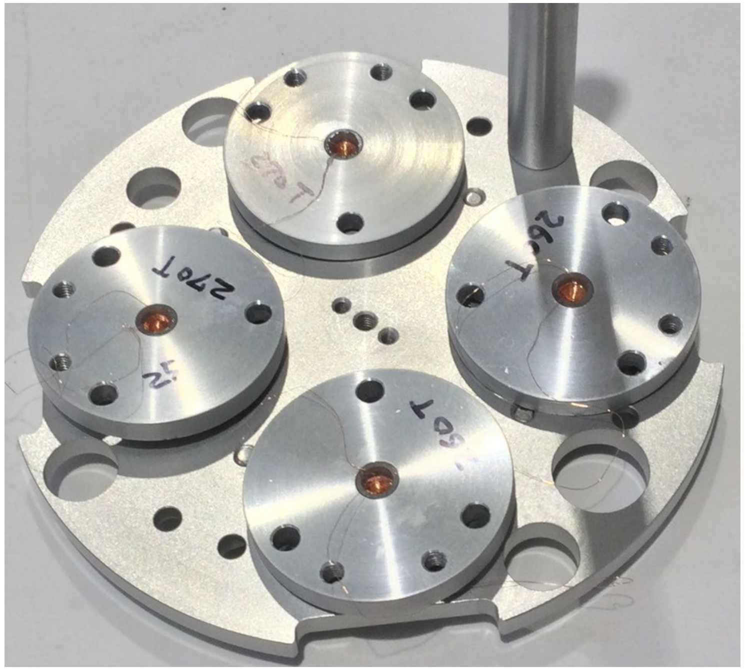
Development of Quad THD system @ Kyoto U.

Test setup under preparation:

- **Four samples can be measured at one LHe charge (~one day).**
- **Programmable heater and measurement sequence.**

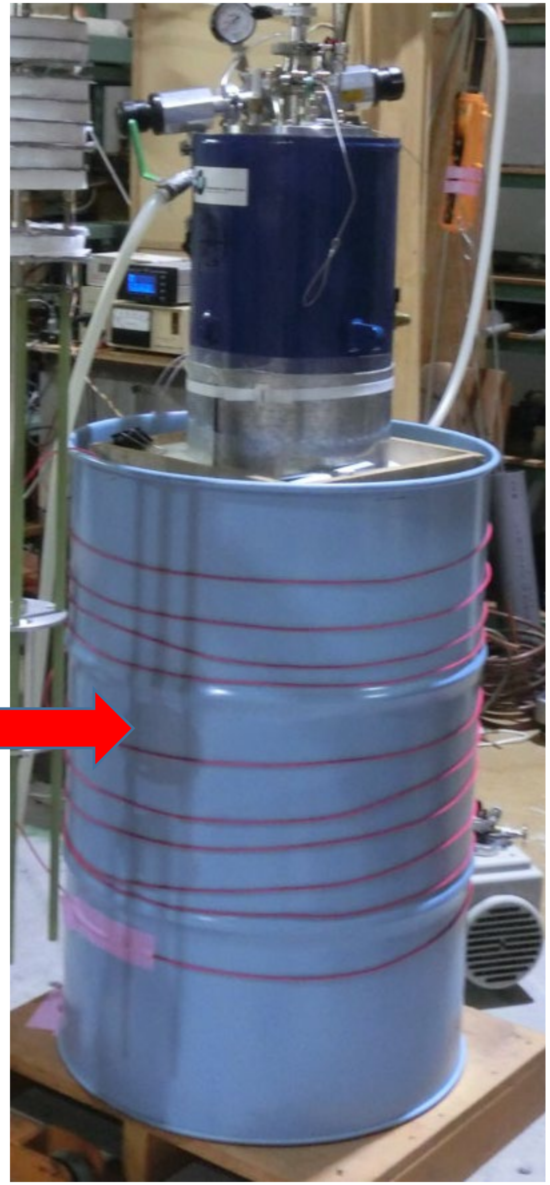


Development of Quad THD system @ Kyoto U.



Speed up
the measurement cycle.

Fast search of wide parameter space! Both thin-film creation parameter space and film-thickness / material parameter space.



Summary

- Theoretical predictions of Nb3Sn and NbN thin-film structures are discussed.
- Creation of NbN/Si/Nb-substrate thin-film sample by ULVAC is explained.
- Setup and principle of third harmonic measurement system are shown.
- We have the third-harmonic measurement systems at Kyoto university and KEK, one for each.
- The third-harmonic measurement results of NbN/Si/Nb-substrate samples at Kyoto university and at KEK are shown.
- NbTiN/Si/Nb-substrate thin-film sample was coated at Jlab. The third-harmonic measurement results of the NbTiN/Si/Nb-substrate samples at Kyoto university are shown. New results!
- Development of quad third-harmonic measurement system at Kyoto university is reported.