Evaluation of superconducting characteristics on the multilayer thin-film structure using the third harmonic voltage method

Ryo. Katayama, Y. Iwashita, H. Tongu (ICR, Kyoto University),
H. Hayano, T. Kubo, T. Saeki (KEK, Ibaraki), H. Oikawa (Utsunomiya University, H.Ito (Sokendai), R.Ito, T. Nagata (ULVAC inc.)

Outline

- Introduction
- Measurement method
- Experiment Setup
- Experiment and Result
  - Experiment result shows that the effective H_{c1}, which limits the maximum accelerating gradient of superconducting cavities, is improved by about 20 %.
- Summary

Outline

- Introduction
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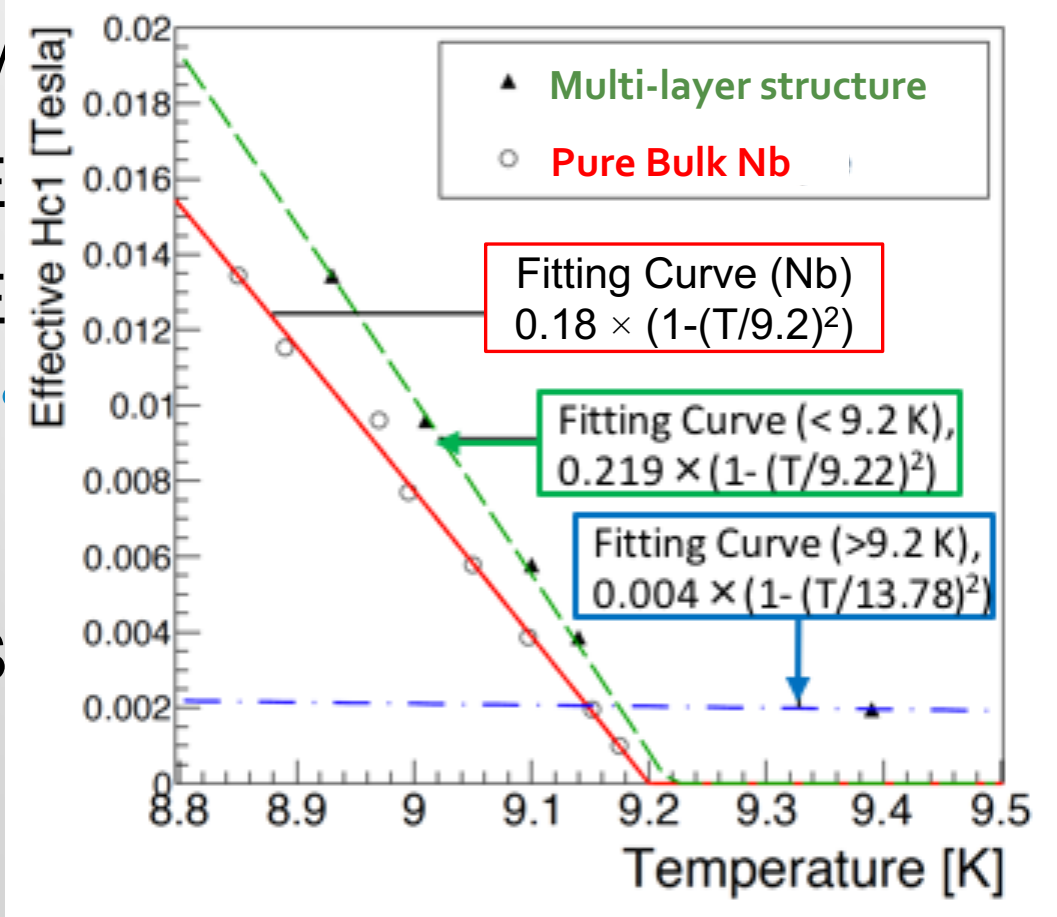

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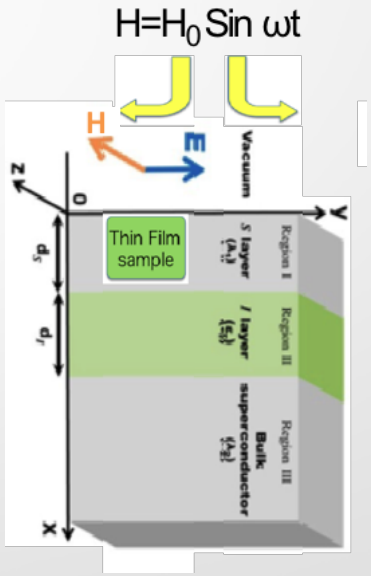
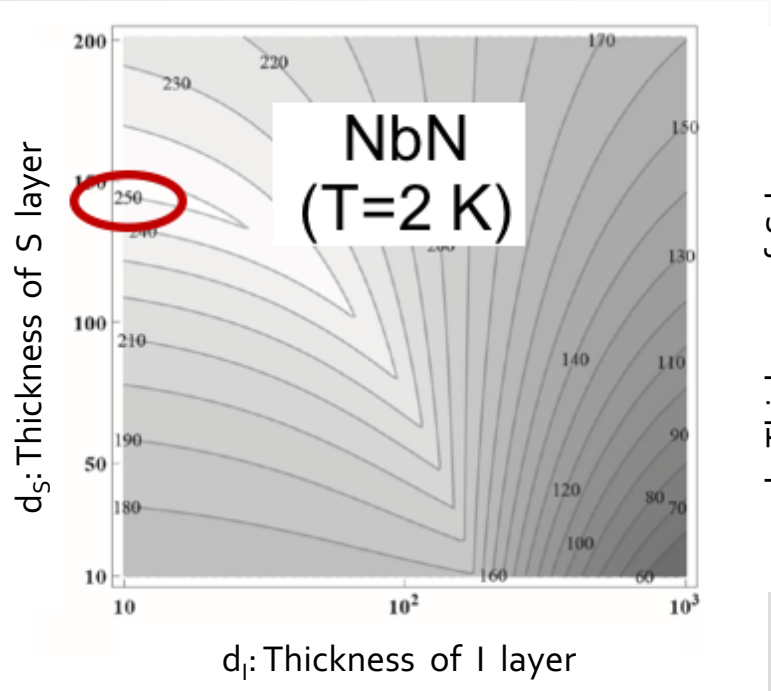
Introduction

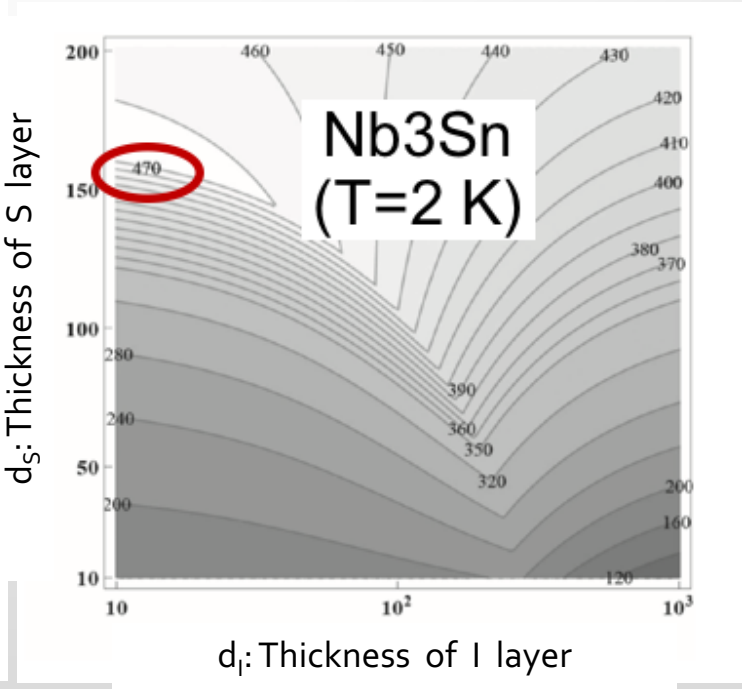
- The maximum accelerating gradient of superconducting cavity is limited by the magnetic field at which vortex avalanche occurs.
  - In this study, we calls such magnetic field as "**effective H_{c1}**", H_{c1}.
- Recently proposed theory predicts that H_{c1} is pushed up by Superconductor-Insulator-Superconductor (**S-I-S**) structure (Gurevich,2006, T.Kubo et al., 2013).
- In order to verify this scheme, we are trying to make some experiments at Kyoto University.



Motivation of this study

- The proposed theory predicts a optimum set of the parameters to exhibit a good performances.
  - The H_{c1} is shown as the following two contour plots.
    - cf.) The effective Hc1 of Nb is ~ 200 mT.





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

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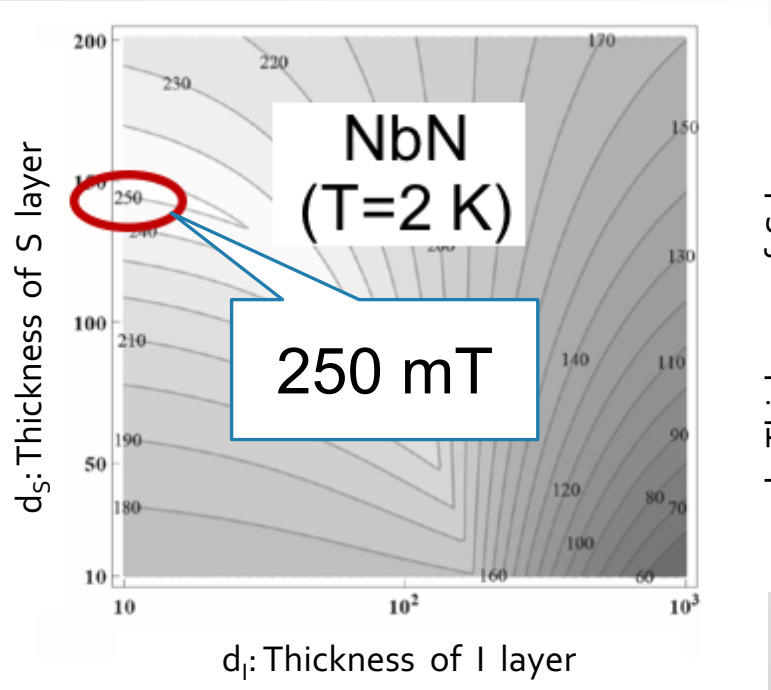

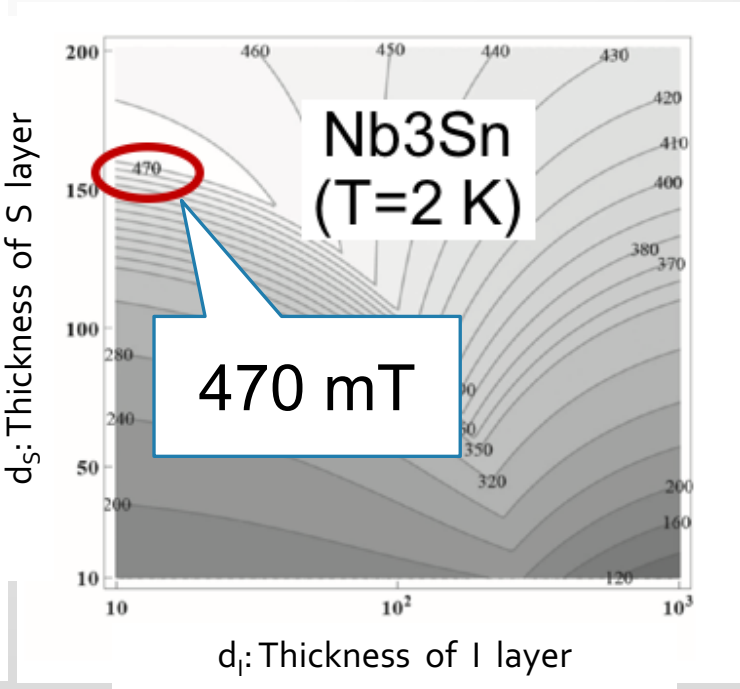

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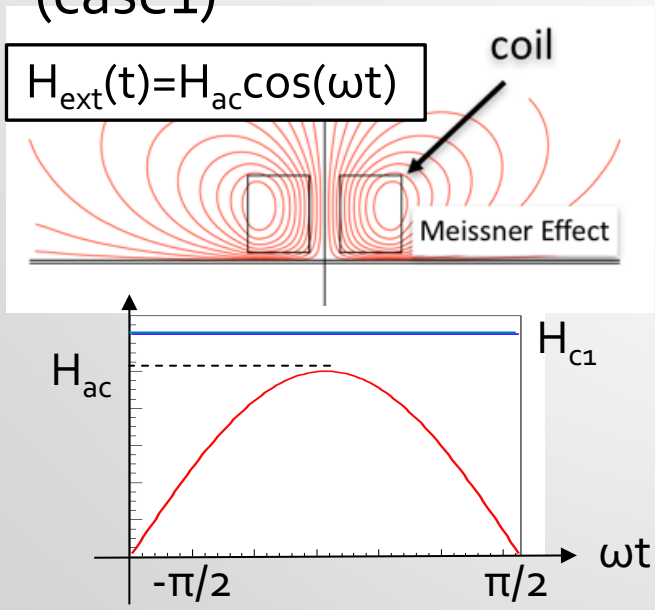
Measurement method

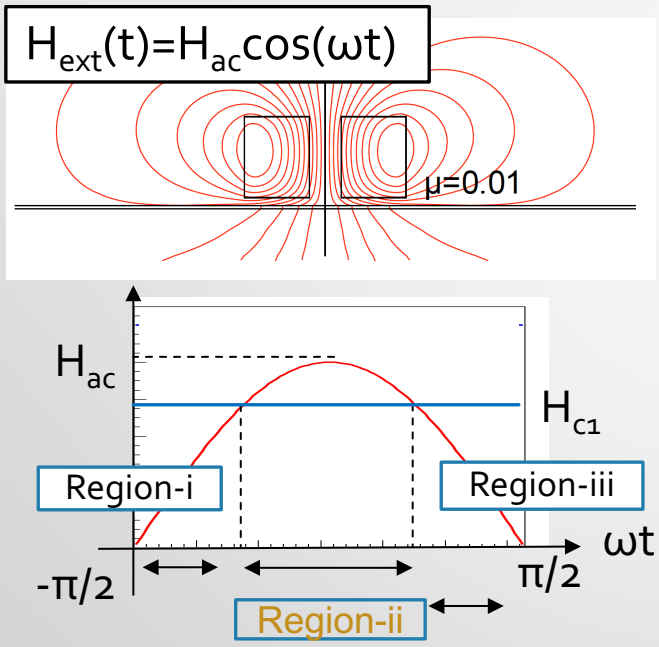
(case1)



- Let us consider the situation in the left figure (case1).
- AC field cannot penetrate the super conducting material (Meissner Effect).
  - Screening currents generate a magnetic field H_{sc} that can perfectly shield AC field.
  - H_{sc} induces the voltage in the coil as a sinusoidal function, $\sin(\omega t)$.

Measurement method

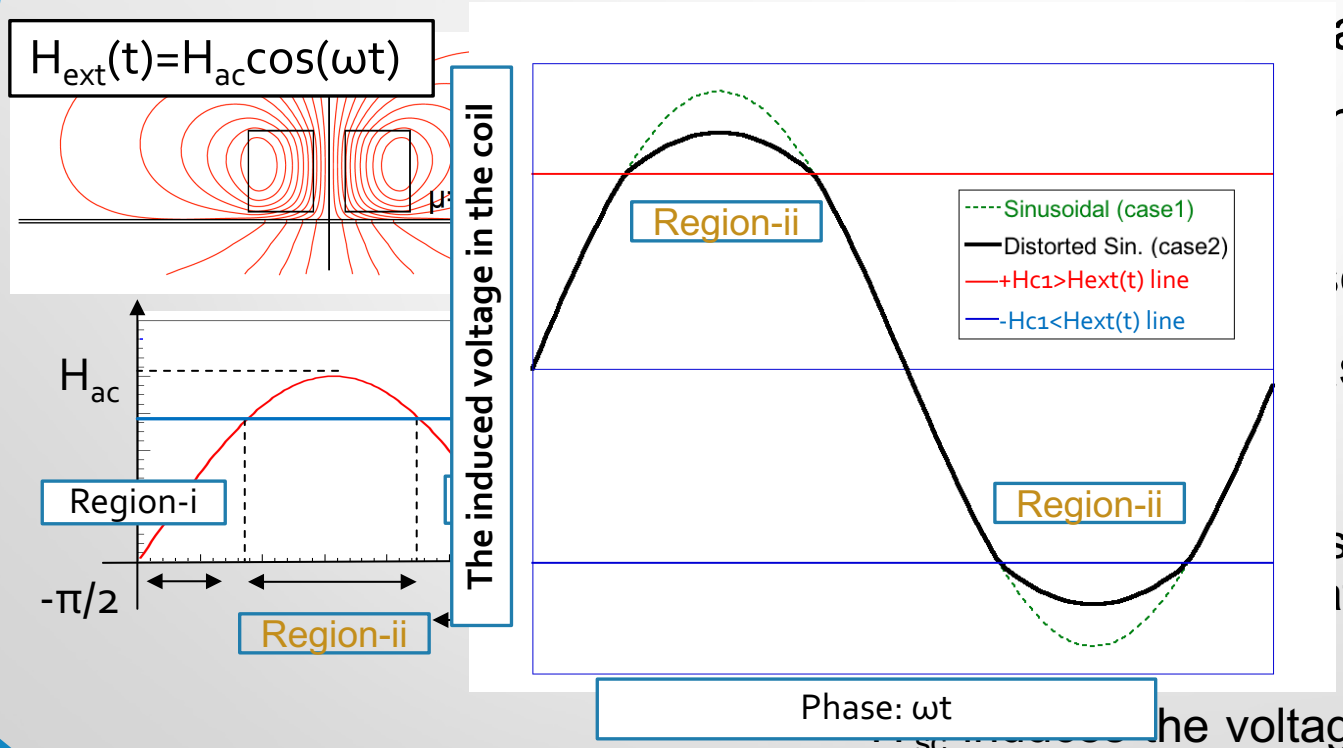
(case2)



- Let us consider the another situation in the left below figure (case2).
- Whether AC field penetrate or not depends on the ωt.
  - (Region-i) → same (case1).
  - (Region-iii) → same (case1).
  - (Region-ii)
    - Screening currents generate a magnetic field H'_{sc} that cannot perfectly shield AC field.
    - H'_{sc} induces the voltage in the coil as a distorted Sin that contains the third harmonics such as $\propto \sin(3\omega t+\delta')$.

Measurement method

(case2)



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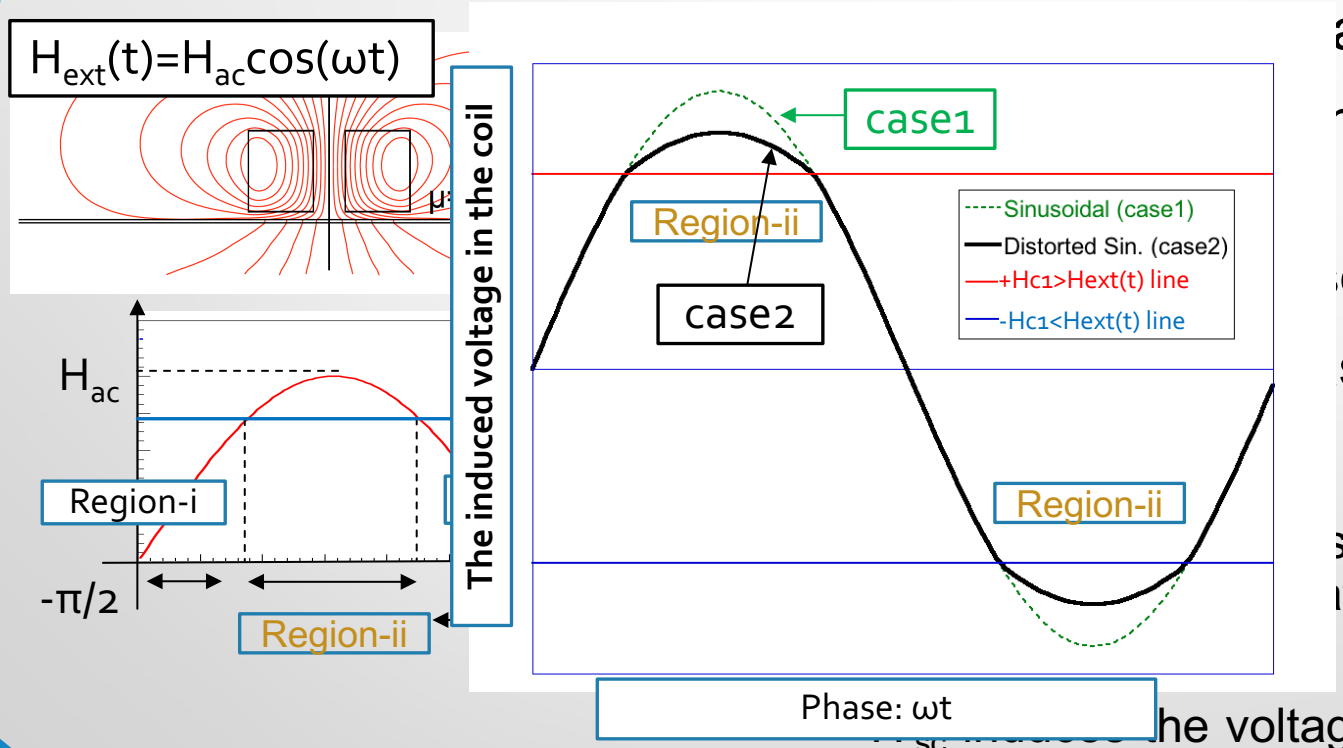

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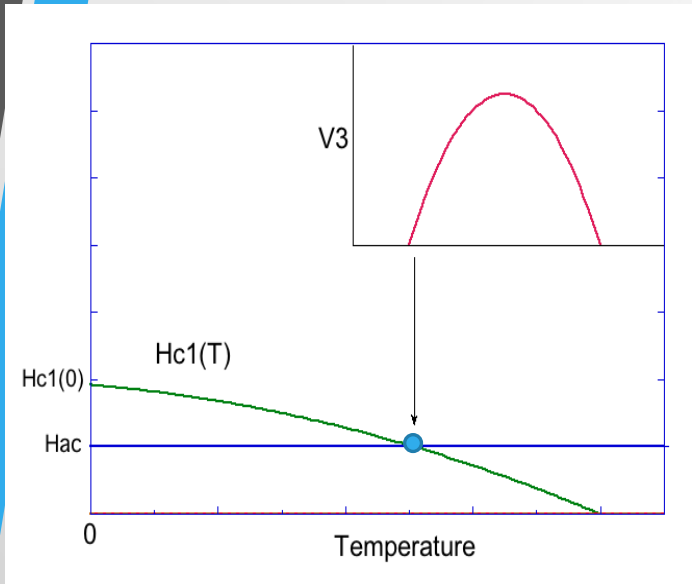
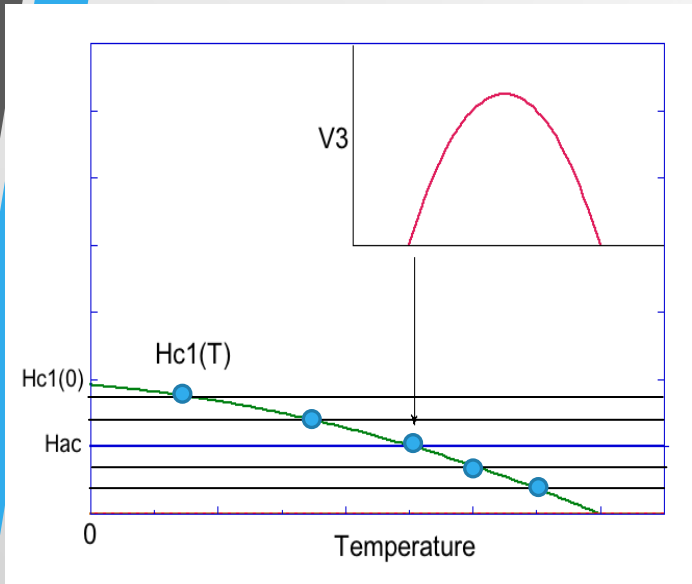


- The H_{c1} at a certain temperature can be determined as left figure.
  - Empirical curve:
    - $H_{c1}(T) = H_{c1}(0)\times(1-(T/T_c)^2)$
  - H_{ac} is the amplitude of the AC field.
  - H_{c1} is determined from the cross point.
- By repeating measurements for different combination of H_{ac}, we can clarify the temperature dependence of H_{c1}.

Measurement method



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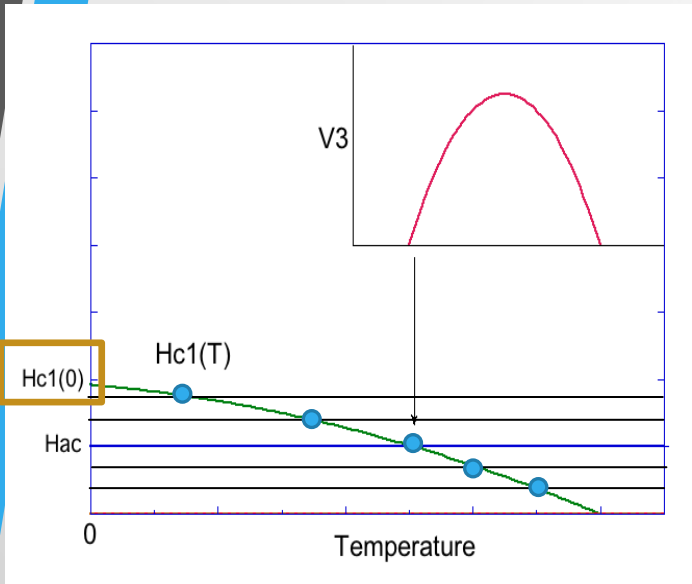

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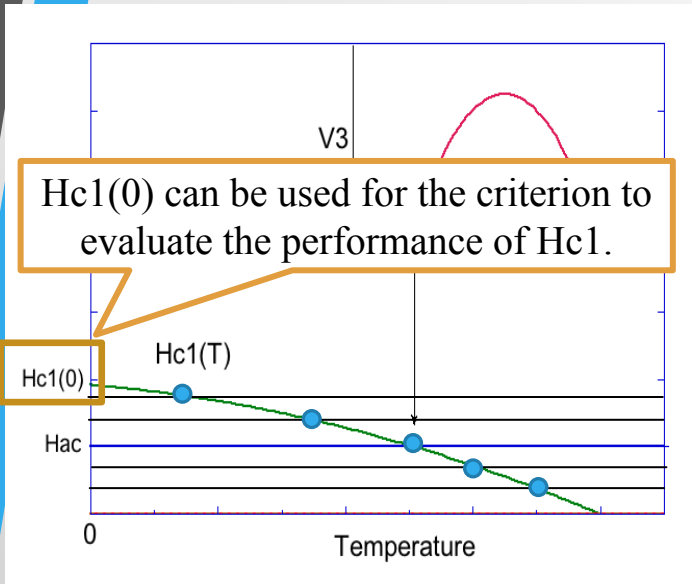

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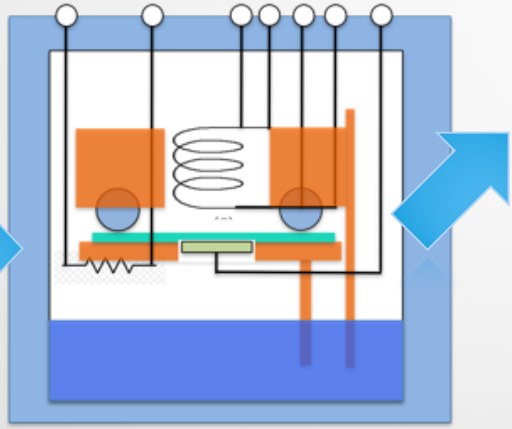
Experiment setup

- We have an experiment setup at Kyoto University, Institute of Chemical Research.
  - This system is designed based on that at Saclay Lab.
- This setup consists of the following parts:
  - Cryogenic System
    - This system consists of some apparatuses installed in a cryostat.
    - This system is used for controlling the temperature.
  - Electric Circuit
    - This system consists of several electric devices.
    - This system is used for controlling electric signals.

Details of these systems are described in the following.

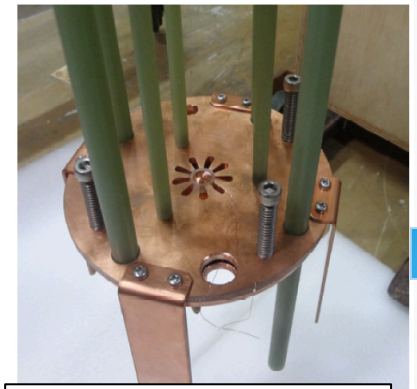
Cryogenic System

Cryostat

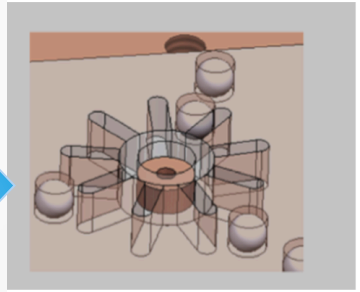


Inside of Cryostat

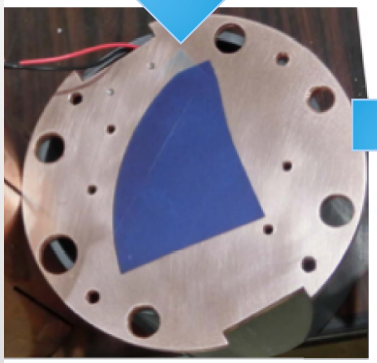
- Temperature of a sample is cooled to the cryogenic temperature.
- By using heater, it can be increased gradually.



Measurement Stage



Coil and balls are embedded in the upper plate

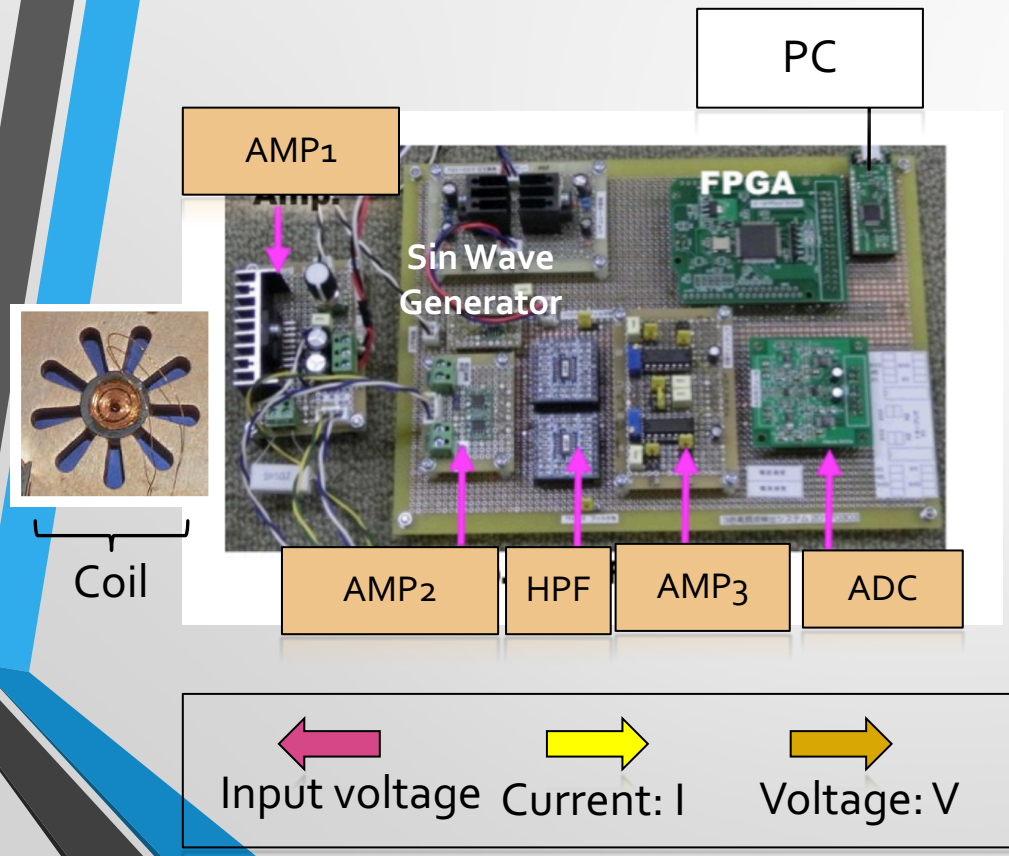


Sample sets on the lower plate

Two copper plates are fixed

- Coil set just above the sample
- Balls guarantee the distance between the coil and the sample.

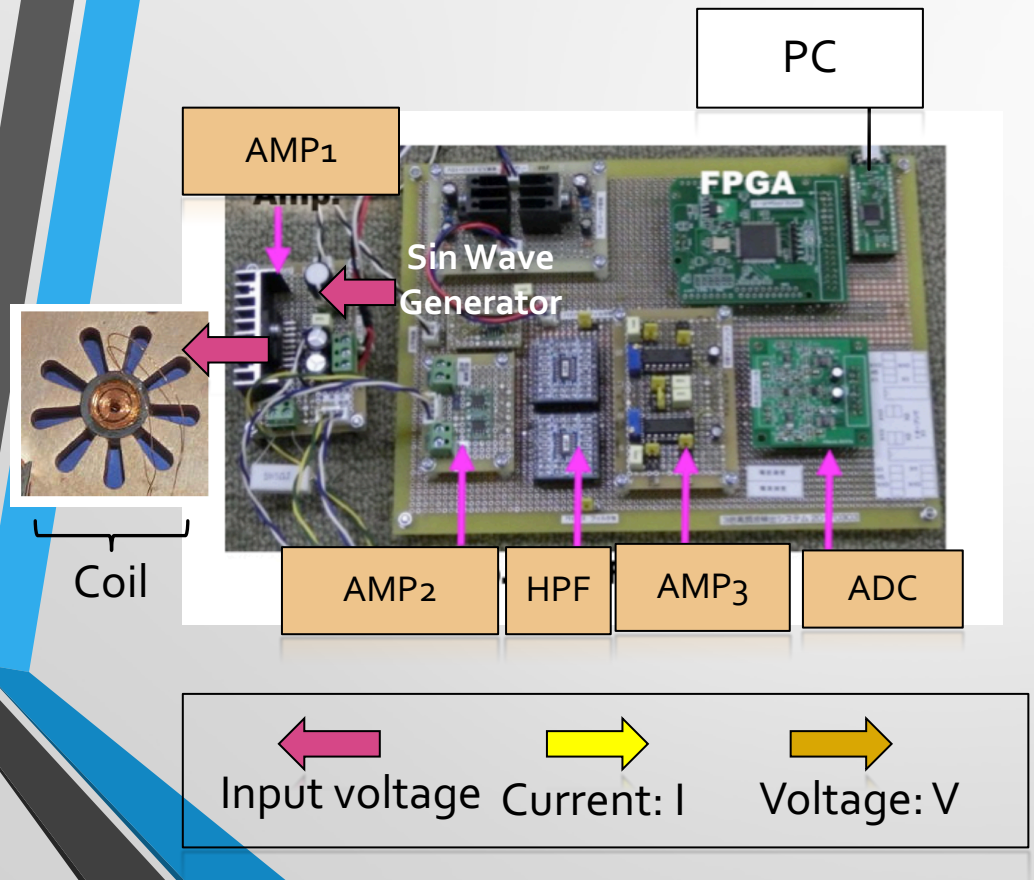
Electric Circuit



The electric circuit operates as shown in the left figure.

- Current is used for the calibration of the coil magnetic field.
- Only voltage signal passes through High-Pass-Filter (HPF).

Electric Circuit



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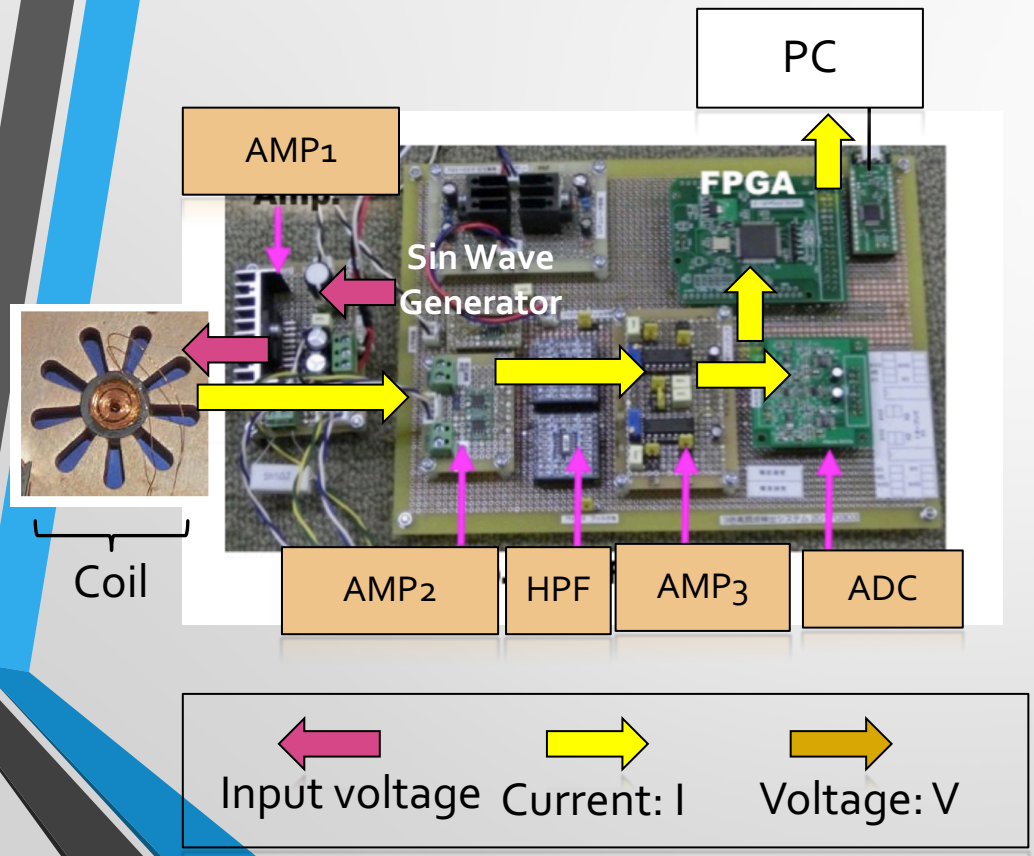

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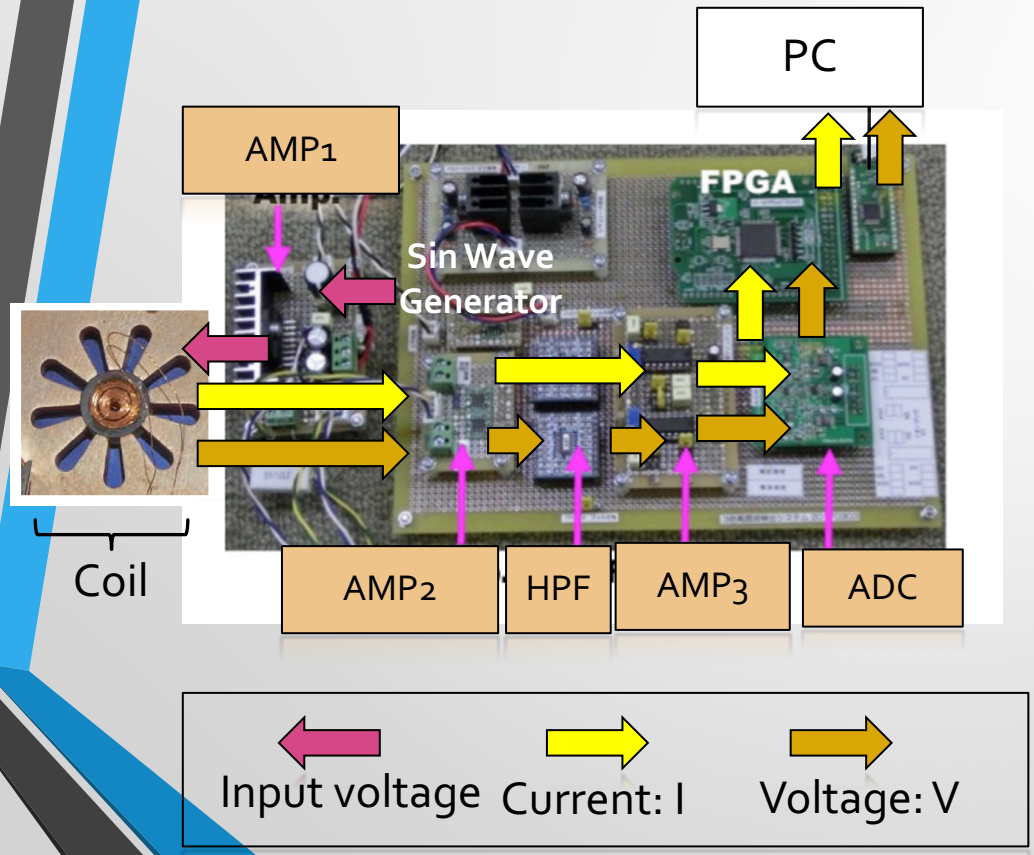

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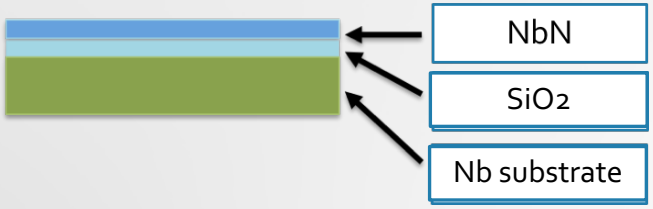
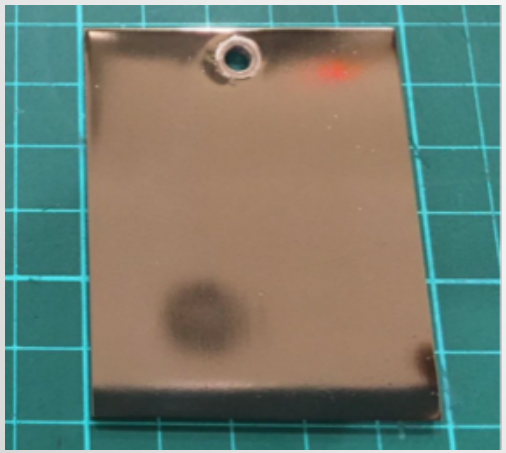
S-I-S sample used in this study





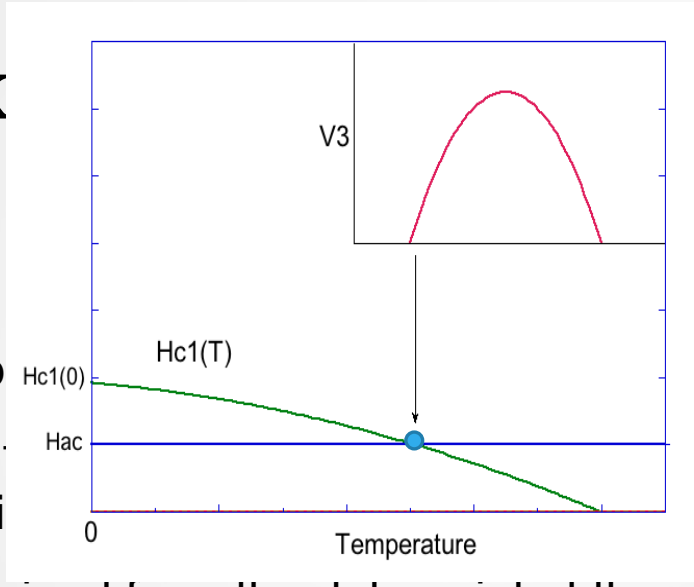
- We measured the effective Hc1 of S-I-S sample[1]
  - NbN/SiO2 thin-film is formed on pure bulk Nb (Left Figure).
  - This sample is fabricated by ULVAC inc. with DC magnetron sputtering [2].
  - Critical Temperature, T_c, is 13.8 +- 0.1 K, evaluated at KEK by RRR measurement [3].

[1] R. Katayama, et al., IPAC2018 Proceedings, THPAL015
[2] R. Ito, T. Nagata, et al., IPAC2018 Proceedings, THPML120
[3] H. Ito, et al., IPAC2018 Proceedings, THPAL105

Experiment and Analysis

1. Input voltage (5 kHz) is applied to the coil.
2. AC magnetic field is applied to the sample from the coil, and the temperature of the sample rises up gradually.
3. By detecting the induced voltage in the coil, third harmonic voltage, V3, is extracted.
4. Hc1 is determined from the data point at the moment when V3 arises at a certain temperature.
5. Measurements from 1 to 4 repeat for different coil magnetic fields.
6. Compiling all data, the temperature dependence of Hc1 is determined by fitting with $H_{c1}(T) = H_{c1}(0) \times (1-(T/T_c)^2)$.

Ex nalysis



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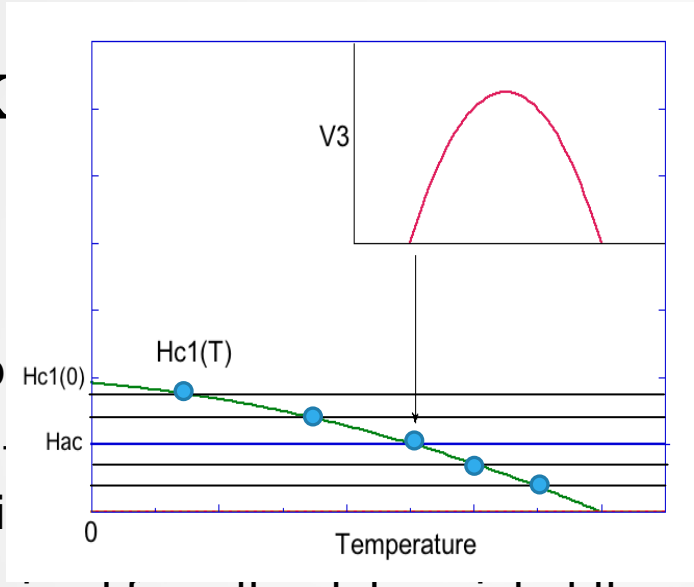

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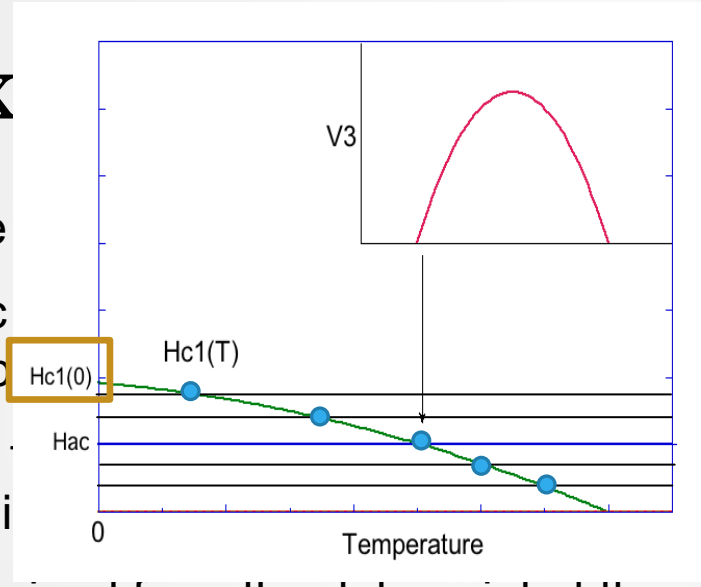

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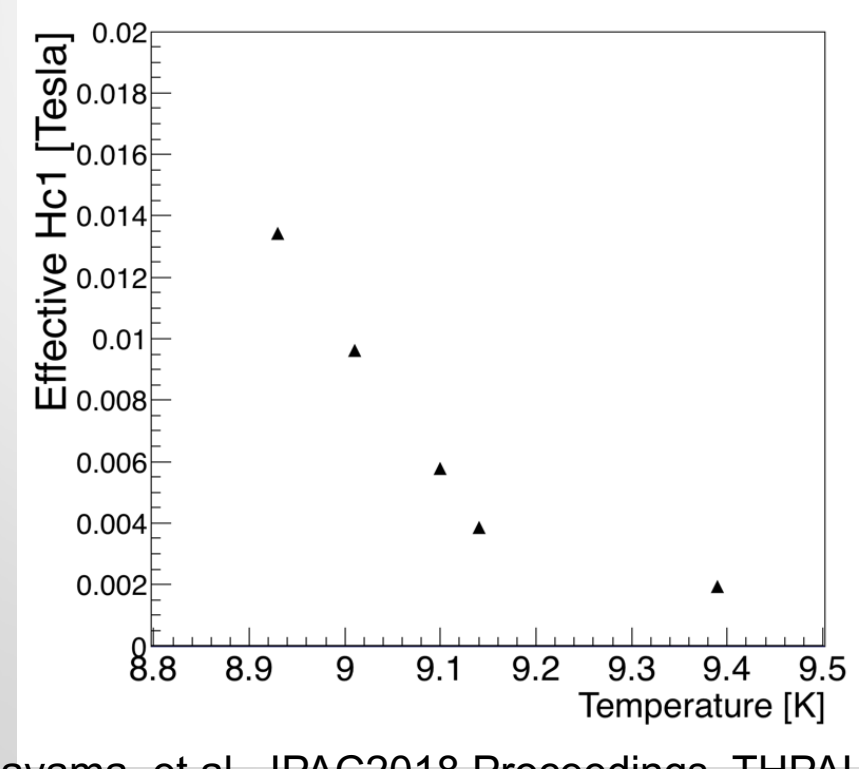
Effective Hc1 of S-I-S sample (1/4)

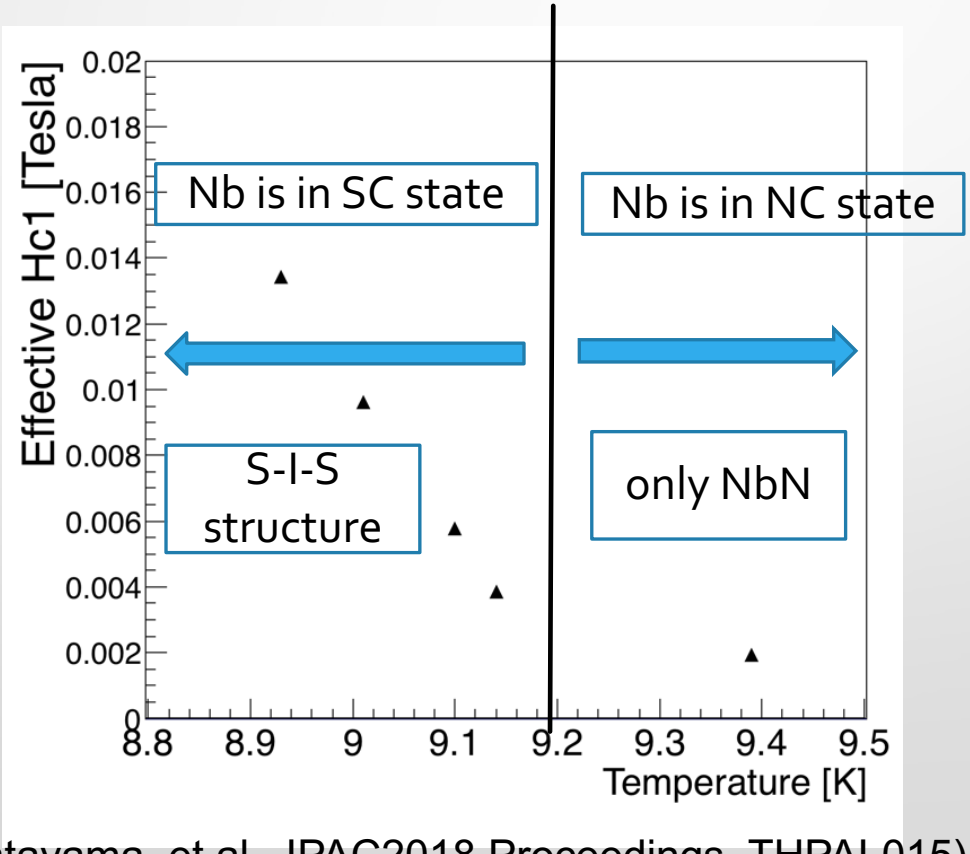
- The temperature dependence H_{c1}, obtained from the actual measurement, is given as below.
  - Vertical axis is H_{c1} [T], Horizontal axis is Temperature [K]



(R. Katayama, et al., IPAC2018 Proceedings, THPAL015)

Effective Hc1 of S-I-S sample (2/4)

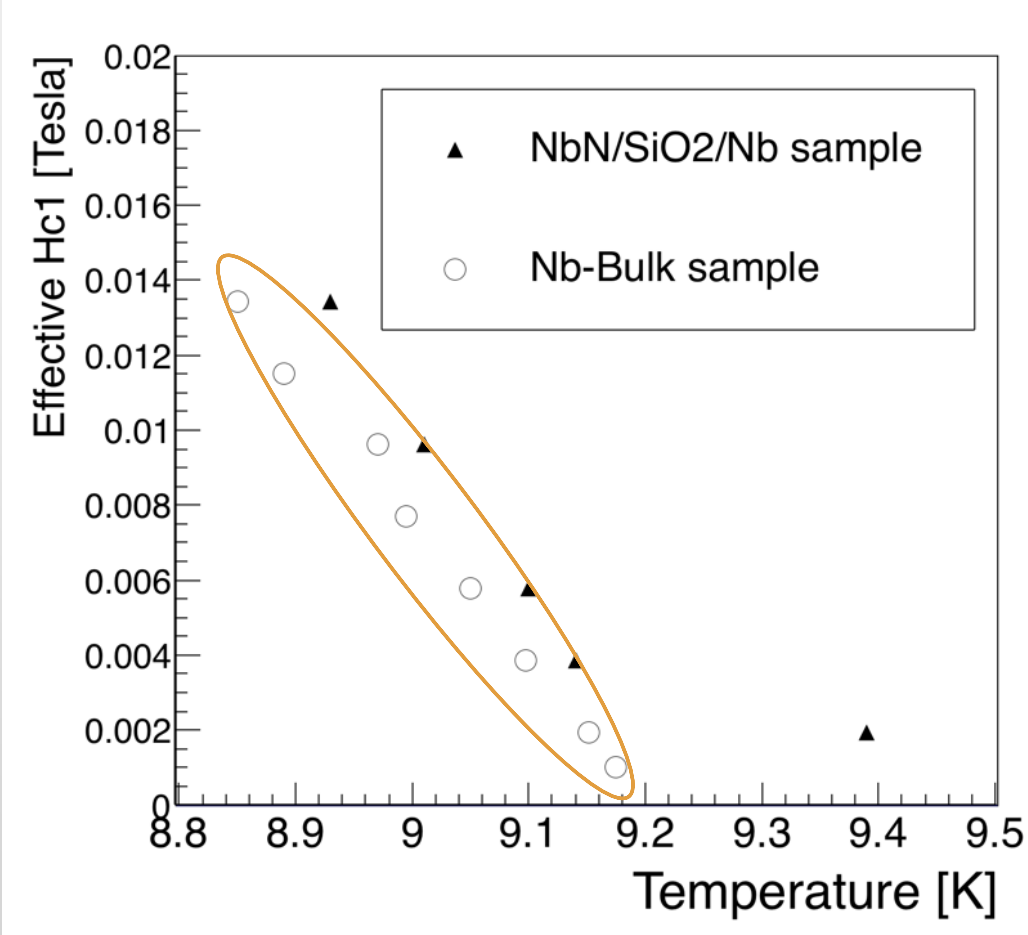
- Note that S-I-S structure satisfies in the temperature less than 9.2 K, the critical temperature of niobium.



(R. Katayama, et al., IPAC2018 Proceedings, THPAL015)

Effective Hc1 of S-I-S sample (3/4)

- For comparison, the temperature dependence of Hc1 of niobium is also plotted below.



(R. Katayama, et al., IPAC2018 Proceedings, THPAL015)

Effective Hc1 of S-I-S sample (4/4)

- Fitting is performed $H_{c1}(T) = H_{c1}(0) \times (1-(T/T_c)^2)$

It can be used for the criterion to evaluate the performance of Hc1.

Effective Hc1 of S-I-S sample (4/4)

- Fitting is performed $H_{c1}(T) = H_{c1}(0) \times (1-(T/T_c)^2)$

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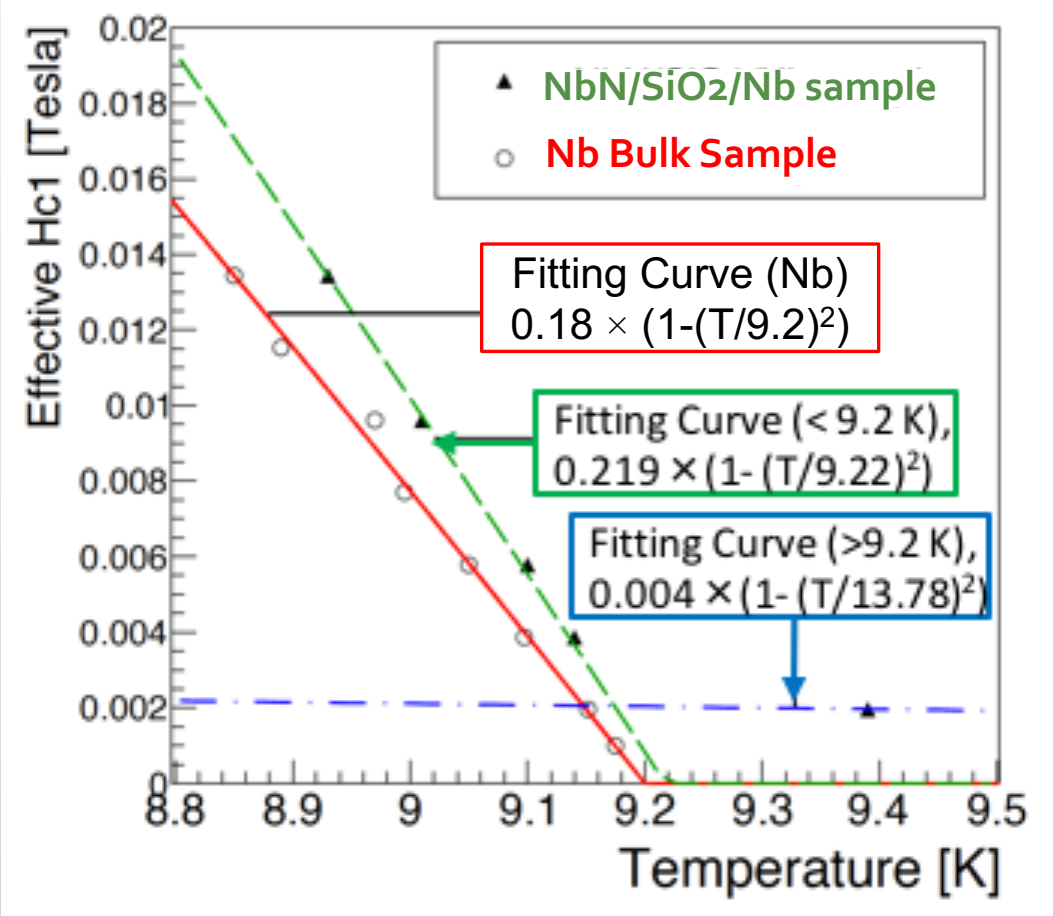

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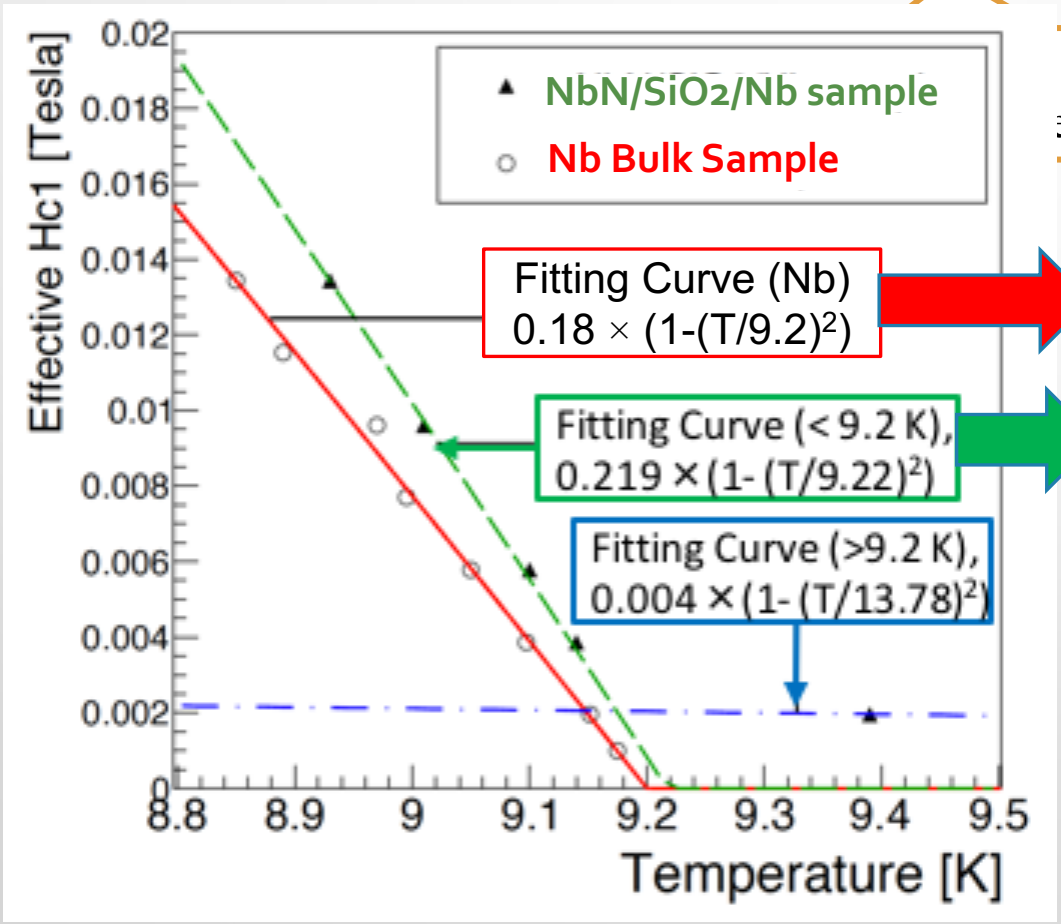

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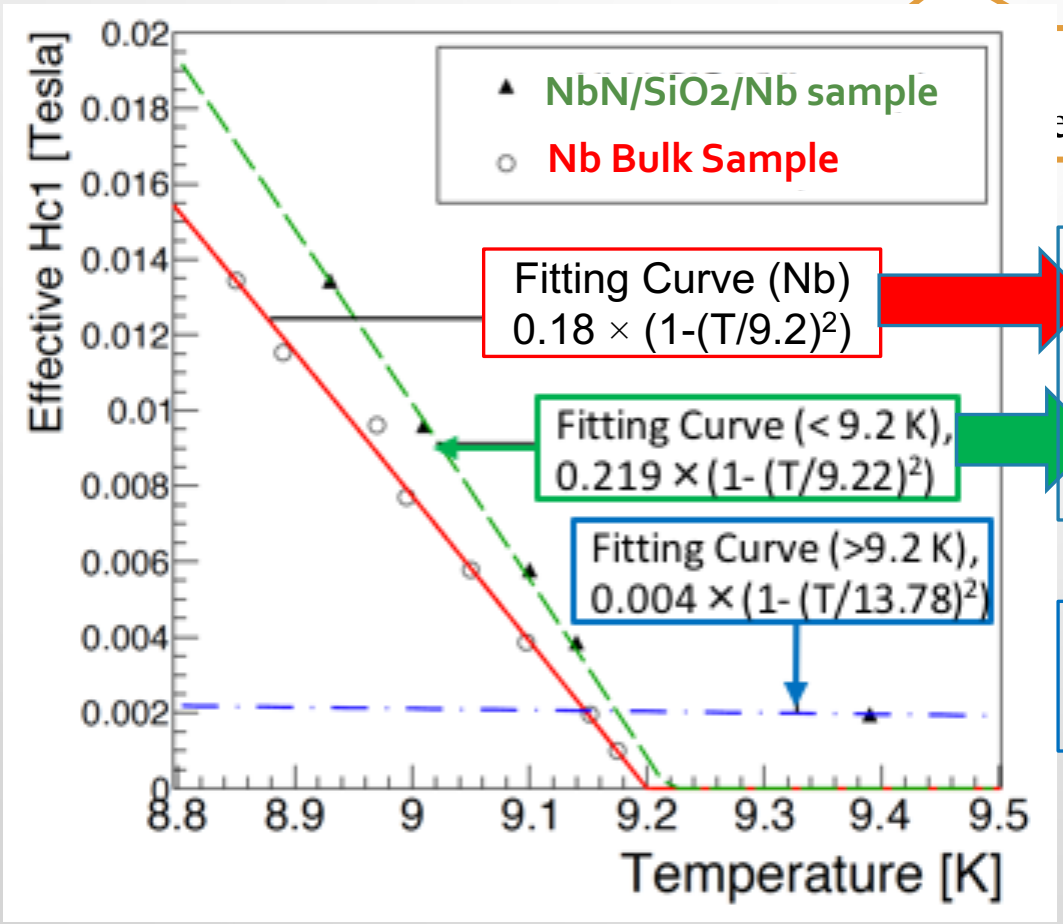

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Hc1(0)=180 mT
(pure bulk Nb)

Hc1(0)=219 mT
(S-I-S structure)

Gain Factor:
219/180 ~ 1.22

(R. Katayama, et al., IPAC2018 Proceedings, THPAL015)

Future Prospect

- In order to ensure the reliability, we plan to ask to test the sample fabricated by the same method at another experiment setup.
- We would like to evaluate effective Hc1 using a stronger magnetic field in lower temperature region.
- In addition, we would like to clarify the temperature dependences of various multilayered thin film samples with different thickness and the number of layers.

Summary

- We evaluated the temperature dependence of effective Hc1 of multi-layer thin-film sample consisting of NbN superconductive layer (200 nm) and SiO2 insulator layer (30 nm) formed on bulk pure Nb.
- This study is the first case that multi-layer thin-film formed on pure bulk Nb substrate which has RRR> 250 is evaluated with the third harmonic measurement.
- **We could successfully demonstrate that the S-I-S structure can improve the effective Hc1 by 20 %.**