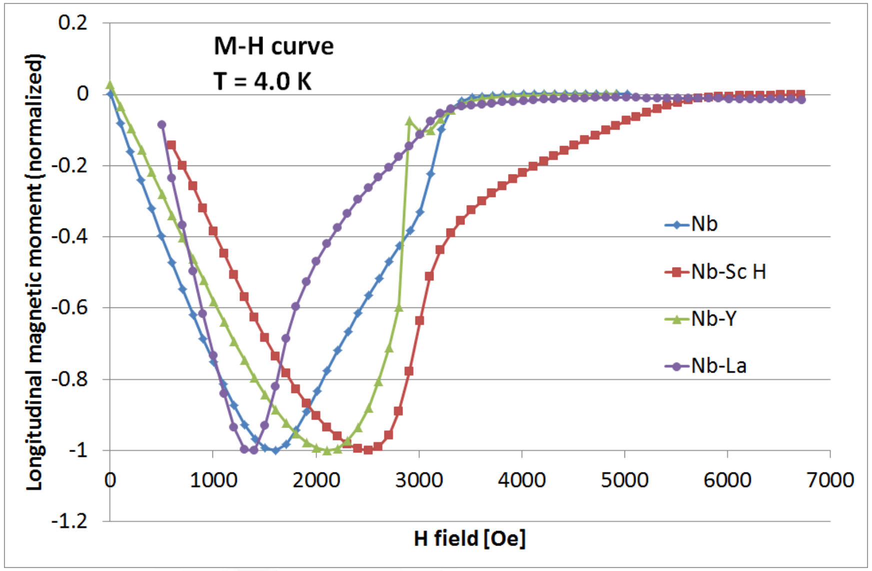
Impurities of rare earth element in bulk Nb as a potential way to improve the cavity SRF performance



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Background and motivation

- The performance of niobium has been pushed to the limit
- Techniques such as large grain Nb or thin film are being developed to increase gradient and quality factor further.

- PKU group has been working on a new idea since 2010: introducing impurity to the ingot niobium

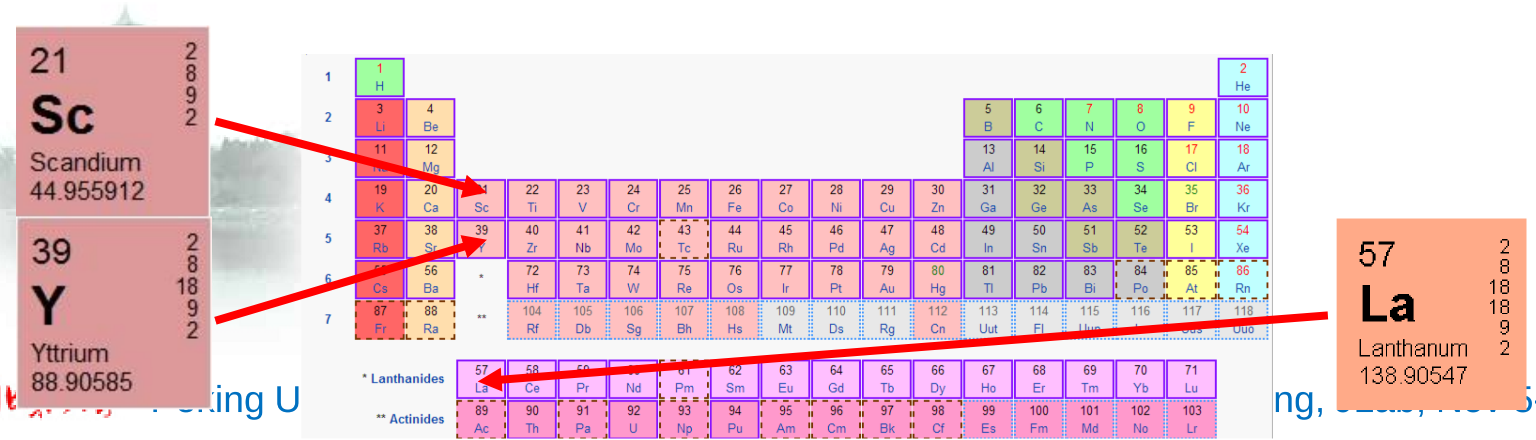
Why impurity?

- Small amount of non-magnetic impurity does not reduce Tc [1].
- It increases H_{c2}
  - Longer penetration depth λ
  - Shorter mean free path, thus shorter coherent length ξ
  - $\kappa = \lambda/\xi$ is increased
- Nb of RRR~10 has minimum R_{bcs} at low field[2]
- It may keep Rs low at high field [3]

[1] P. W. Anderson, J. Phys. Chem. Solids, vol. 11, no. 1–2, pp. 26–30, Sep. 1959.
[2] H. Padamsee, RF Superconductivity. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim, 2009, p42 -44
[3] F. P.-J. Lin and A. Gurevich, Phys. Rev. B, vol. 85, no. 5, p. 054513, Feb. 2012.

Choice on impurity

- Requirement:
  1. Strong electronegativity to enhance scattering
  2. Non-magnetic
  3. Chemically stable in the air to simply melting
- With comprehensive consideration, rare earth element Sc and Y are chosen. La is also used for comparison



Sample preparation

- Process:
  - Arc melting pure Nb to clean furnance
  - Arc melting Nb with Sc, Y or La
  - Annealing at 900~1000 ^{o}C
  - Cold machining
  - Post purification at 1200 ^{o}C
  - BCP
- The melting is not easy

Sample preparation (2)

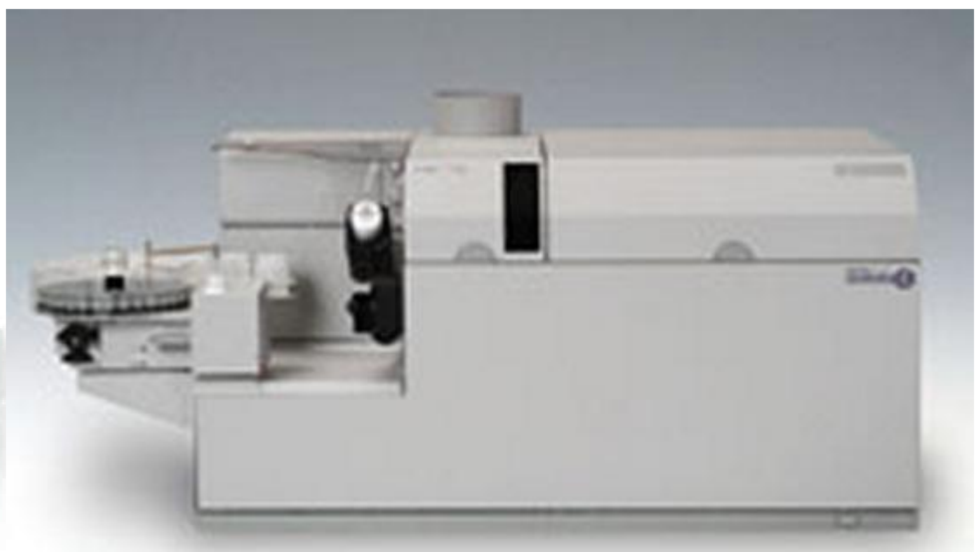
- PKU prepared 2 samples with different Sc proportions, 3 with Y and 3 with La.
- Ningxia OSTEC provided 7 samples with different Sc proportions.
- It is around 30~50 g of one sample (before cold machining)

Sample test

- The compositions are analyzed in school of earth and space sciences, PKU. The results agree well with our expectation.
- The superconductivity was tested in school of physics, PKU as well as in the institute of physics, Chinese Academy of Science. M-T, M-H and R-T curve were measured.
- The samples were too small to test mechanical, thermal and properties.

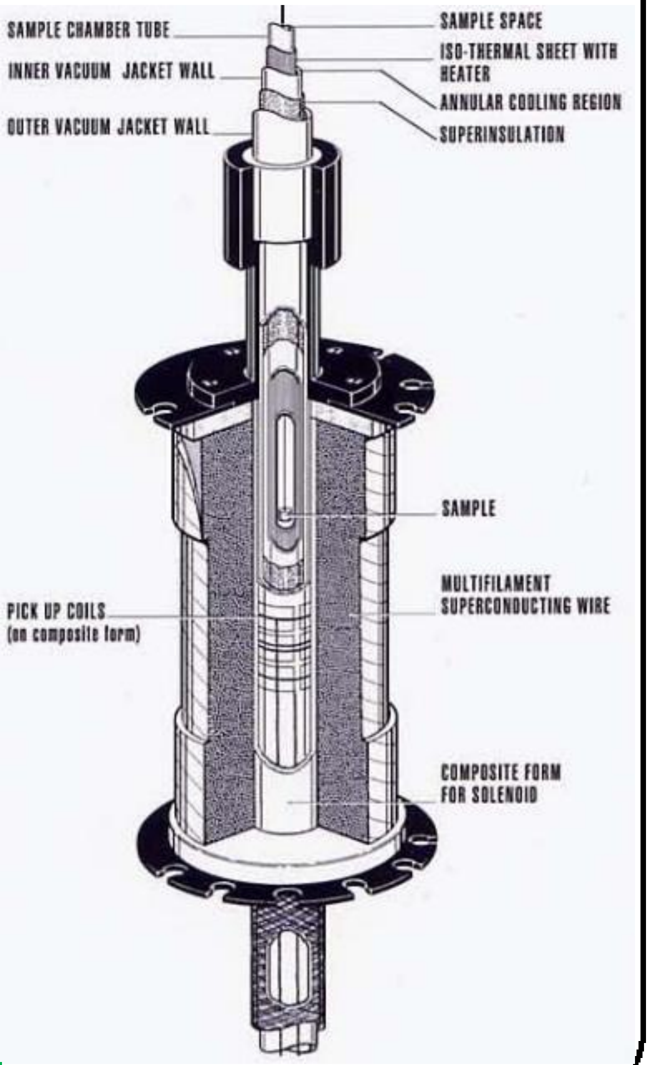
Composition analysis

- Equipment: mass spectrometer (Agilent ICP-MS 7500cs)
- Sample: around 2 mm^3
- The results agree well with our expectation.



M-H and M-T measurement

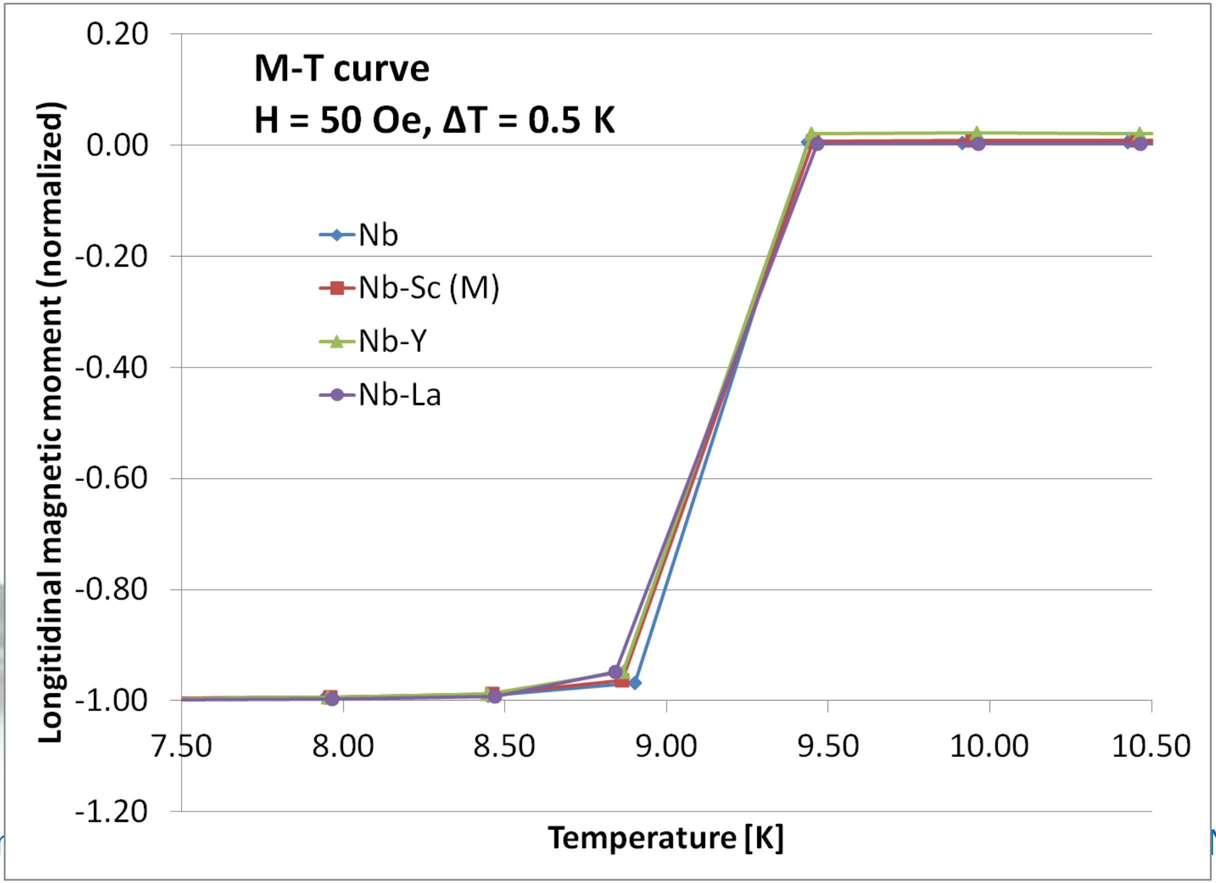
- Equipment: MPMS-XL (Quantum Design)[4]
- Sample: around 1 mm^3



[4] Mike Mcelfresh, “Fundamentals of magnetism and magnetic measurement”, 1994.

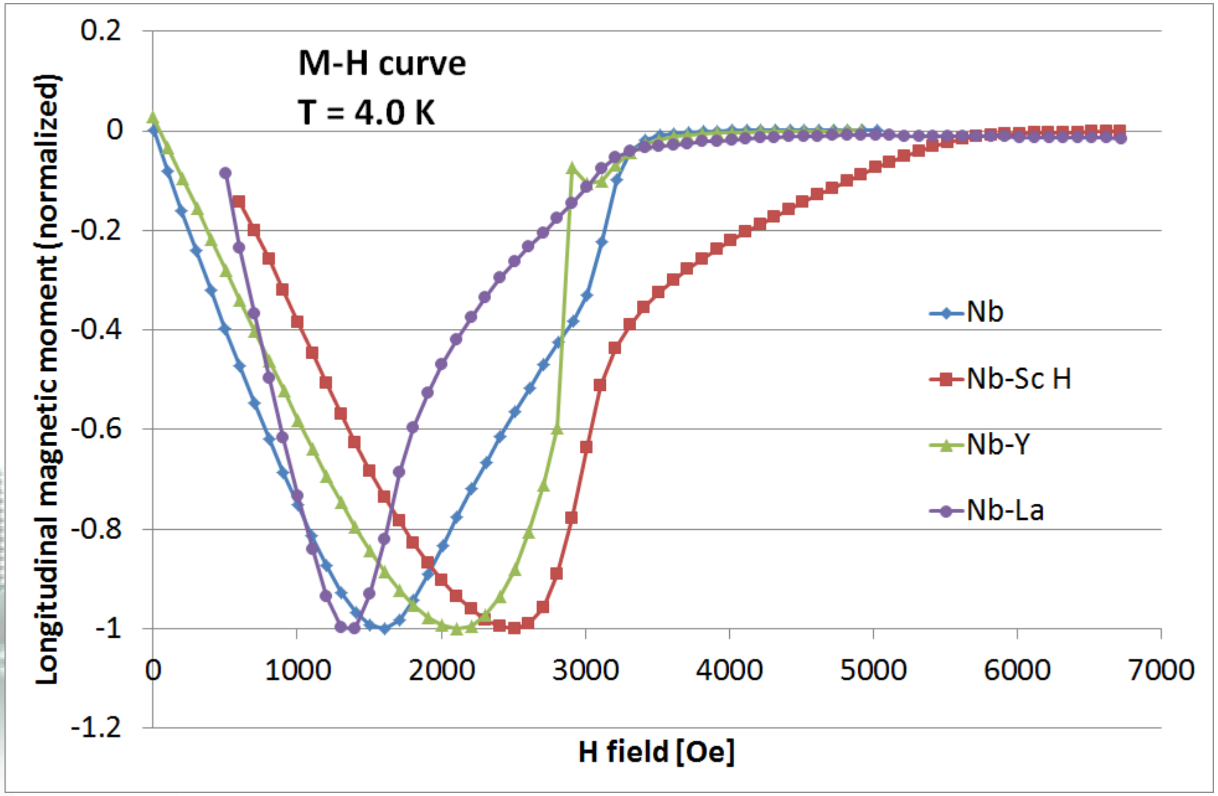
M-T measurement

- The impurity does not change the transition temperature Tc



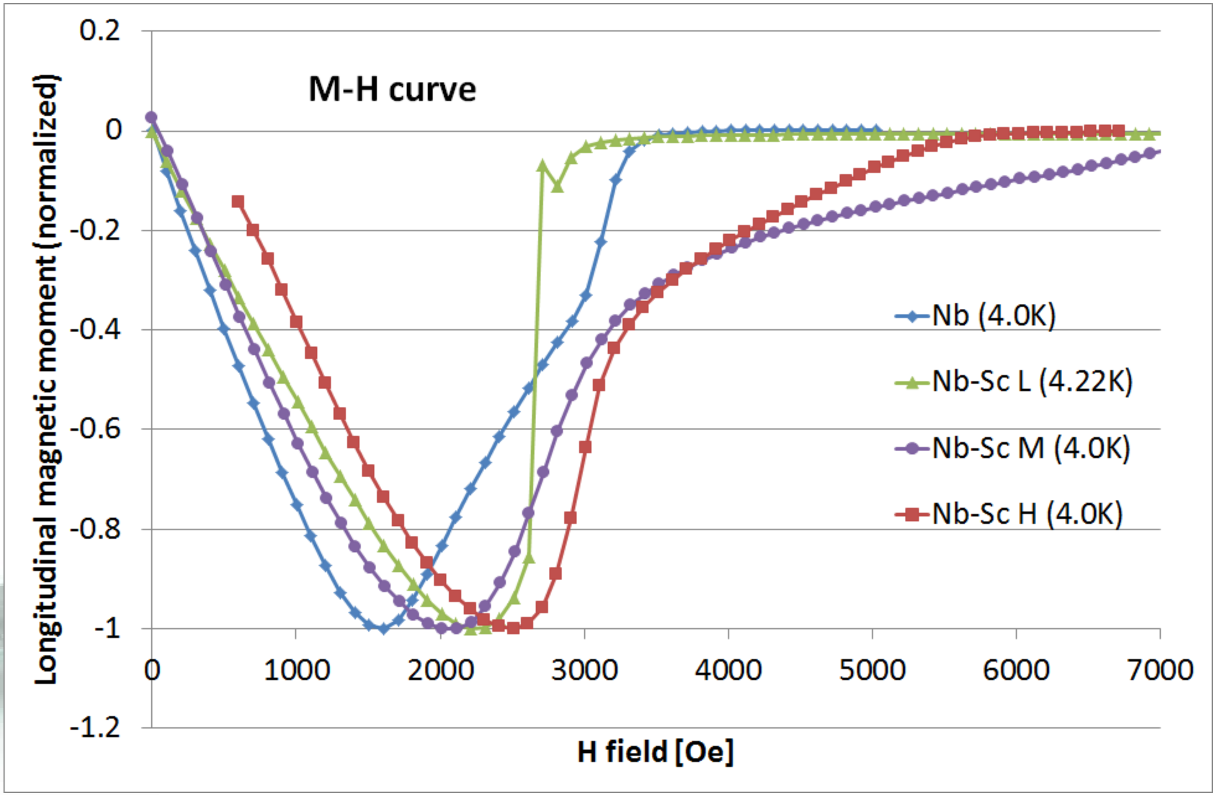
M-H measurement

- Non-magnetic impurities Sc and Y increase Hc1, while La reduces Hc1



M-H measurement (2)

- Hc1 is increased by up to 90 mT with different Sc proportions

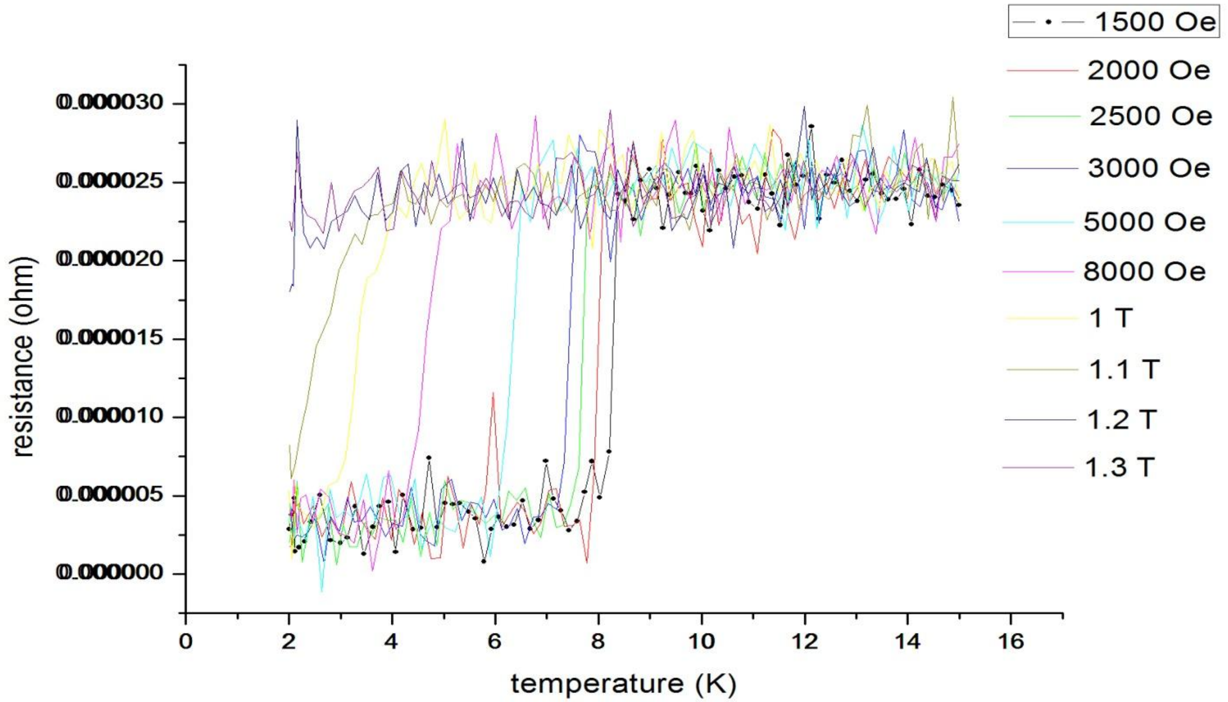


R-T measurement

- Equipment: PPMS EverCool (Quantum Design)
- Rh-Fe thermometers
- Sample: ~7x2x2 mm^3
- 4-probe method

R-T measurement

- Hc2 is around 1.1 T for Nb-Sc(L) sample
- The sample is too small to measure RRR accurately



Conclusions

- Nb was doped with rare earth element Sc, Y and La
- The transition temperature doesn't change.
- Hc1 and Hc2 are increased by non-magnetic impurities Sc and Y, while they are decreased by La. Hc1 is increased by up to 90 mT with different Sc proportions.
- The samples are too small to measure mechanical and RF properties.
- A single-cell Nb cavity doped with Sc is being fabricated in China. Vertical test, RRR measurement and mechanical properties tests are in plan

Acknowledgement

- We would like to express our gratitude to the general manager Zhao Hongyun, and engineer You Yusong at OSTEC for their skilled melting technology and professionalism. They provided two batches of samples doped with Sc, laying the foundation for our work.

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Thanks for your attention

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