Pushing the Limits of RF Superconductivity Workshop at Argonne National Laboratory, September 22-24, 2004

LANL Activities on New Materials for SRF Cavities

Tsuyoshi Tajima

Los Alamos Neutron Science Center (LANSCE)

Participants in the Collaboration

- Los Alamos Neutron Science Center (LANSCE) at LANL: Tsuyoshi Tajima, Jianfei Liu, Alan Shapiro, Frank Krawczyk, Dale Schrage, Bill Clark, Rich Sheffield
- Superconductivity Technology Center (STC) at LANL: Alp Findikoglu, Fred Mueller
- Superconductor Technologies, Inc. (STI): Brian Moeckly
- University of California, San Diego (UCSD): Vitali Nesterenko and his group
- Cornell University: Alexander Romanenko, Hasan Padamsee
- Johannes Kepler University in Austria: Markus Kuehberger (now in industry)
- Ohio State University: Ted Collings

Outline

- Which materials should be studied for the application of SRF cavities? Nb_3Sn and MgB_2
- What we have done at LANL in collaboration with other institutions
- Summary and some thoughts for the future

Nb_3Sn and MgB_2 are good candidates – Refer other materials to Palmieri's review

Superconductivity parameters for Nb, Nb3Sn, and MgB2.

Material	T_c [K]	GL Parameter κ_{GL}	H_c [mT]	H_{c1} [mT]	H_{c2} [mT]	H_{sh} [mT]
Nb (0K)	9.2	0.78	200	170	240	240
Nb_3Sn (0K)	18.2	22.8	535	52	17300	401
MgB_2 (4 K)	39	36.3	429	30	22000	321
MgB_2 (20 K)	39	25.4	278	25	10000	209

T. Tajima, EPAC2002

H_{sh} was calculated using the following formula.

H_{sh}=1.2Hc for $\kappa_{GL} \approx 1$

H_{sh}=0.75Hc or $\kappa_{GL} >> 1$

However, as shown later, these formula do not seem to be consistent with experimental results.

If H_{sh} limits the field, Nb_3Sn and MgB_2 can exceed Nb theoretically

H_{peak}/E_{acc}=40 (Oe/MV/m)

Material	Operation Temp. [K]	Theoretical Limit E_{acc} [MV/m]
Nb	4	49
Nb_3Sn	4	95
MgB_2	4	80
MgB_2	20	52

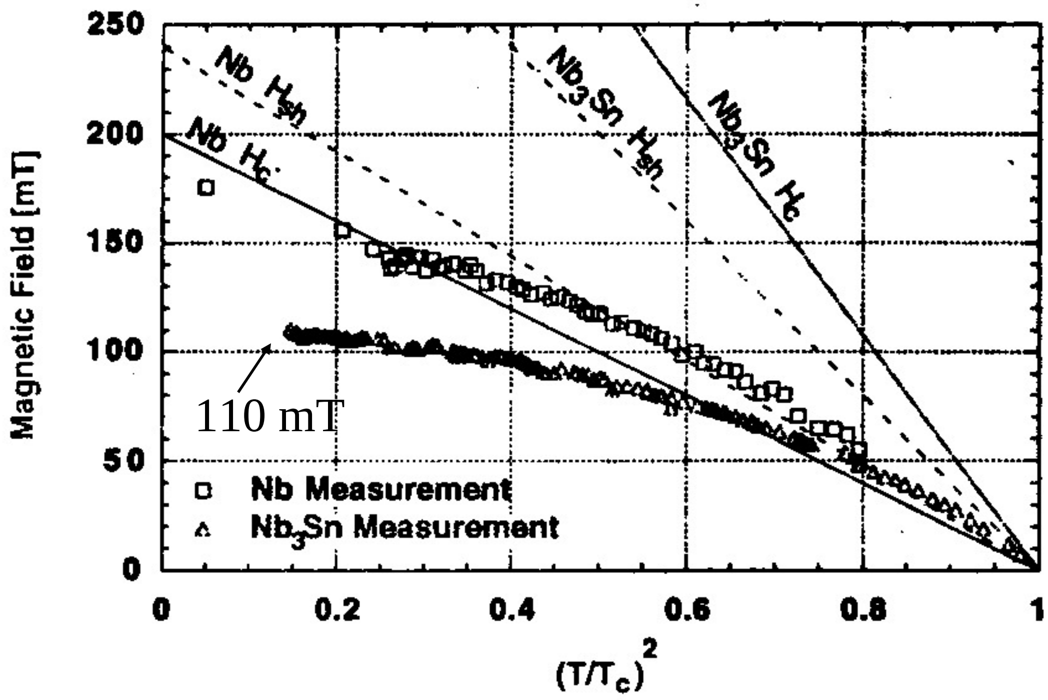
Which Material Should Be Studied First?

- In my opinion, Nb_3Sn should be the first material to be pursued because
  - If H_{sh} limits the field, the E_{acc} could exceed that of Nb
  - T_c=18.6 K, energy gap ratio $2\Delta_0/k_BT_c = 4.5$ are attractive for higher Q cavities at the same operation temperature
  - There has already been some success with real cavities, refer to EPAC96 paper by Mueller et al.
  - Nb cavities can be converted to Nb_3Sn cavities and could show better performance, which saves fundamental investment on materials

Some data on Nb_3Sn

- Unfortunately, our effort to get internal LANL funding for developing Nb_3Sn cavities has been unsuccessful. We only got some small funding for MgB_2 evaluation.
- The following data are from Cornell, SLAC and Wuppertal/Jlab.

Experimental results disagree with H_{sh} theory for Nb_3Sn

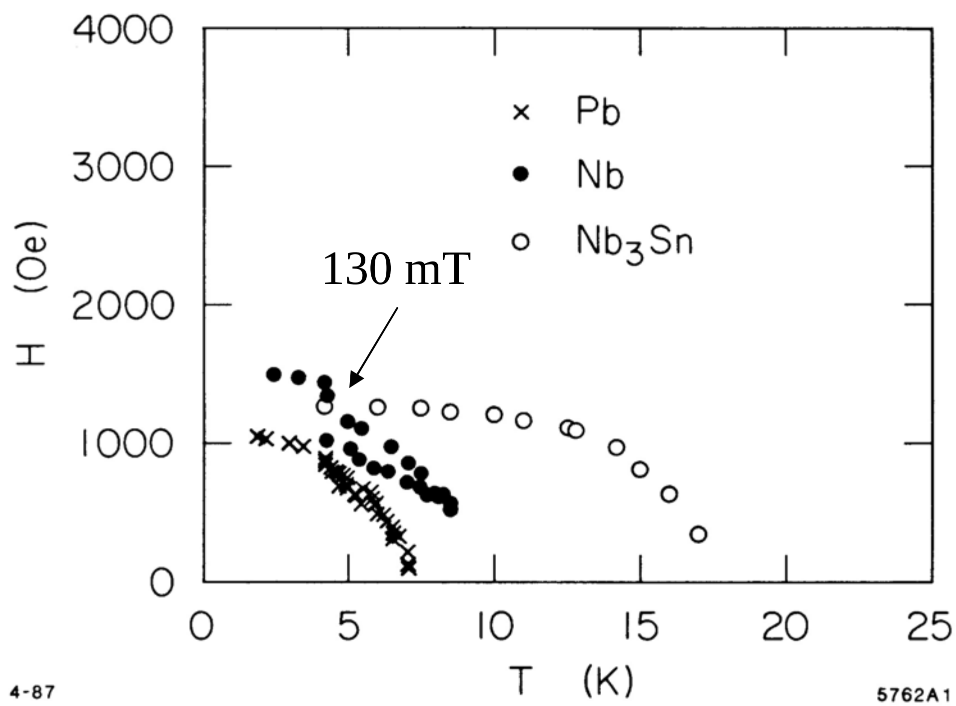


Pulse length ~ 100 μs

Nb: 1.3 GHz single-cell cavity with RRR~460
Nb_3Sn: 3 GHz single-cell cavity, coating by Wuppertal and etched at Cornell

T. Hays, et al., 7th SRF Workshop, Oct. 17-20, 1995

An older SLAC data show higher limit (130 mT) vs 110 mT (Cornell) with shorter pulse tests: This indicates that the experimental results of the field could be higher.

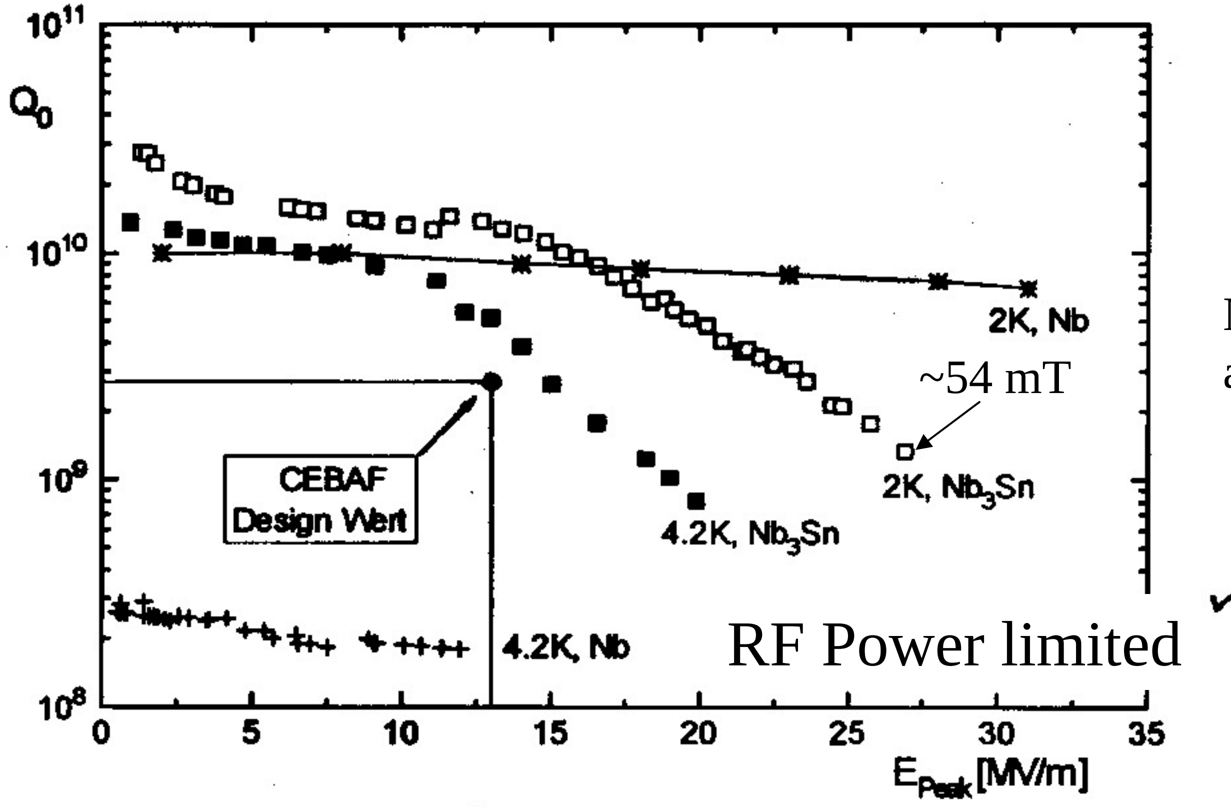


3 GHz single-cell cavity

Pulse length ~ 1 μs

I. Campisi, SLAC/AP-58, April 1987

One 1.5 GHz single-cell cavity result has shown that CEBAF accelerator could be operated at 4.2 K with Nb_3Sn cavities instead of using Nb cavities at 2 K



Cavity Q_0 was ~50x Nb at low field at 4.2 K!!

Best R_{res} = 2.2 nΩ!

Nb_3Sn coating at Wuppertal and measurement at JLAB

G. Mueller, P. Kneisel et al., EPAC96.

Magnesium diboride (MgB_2)

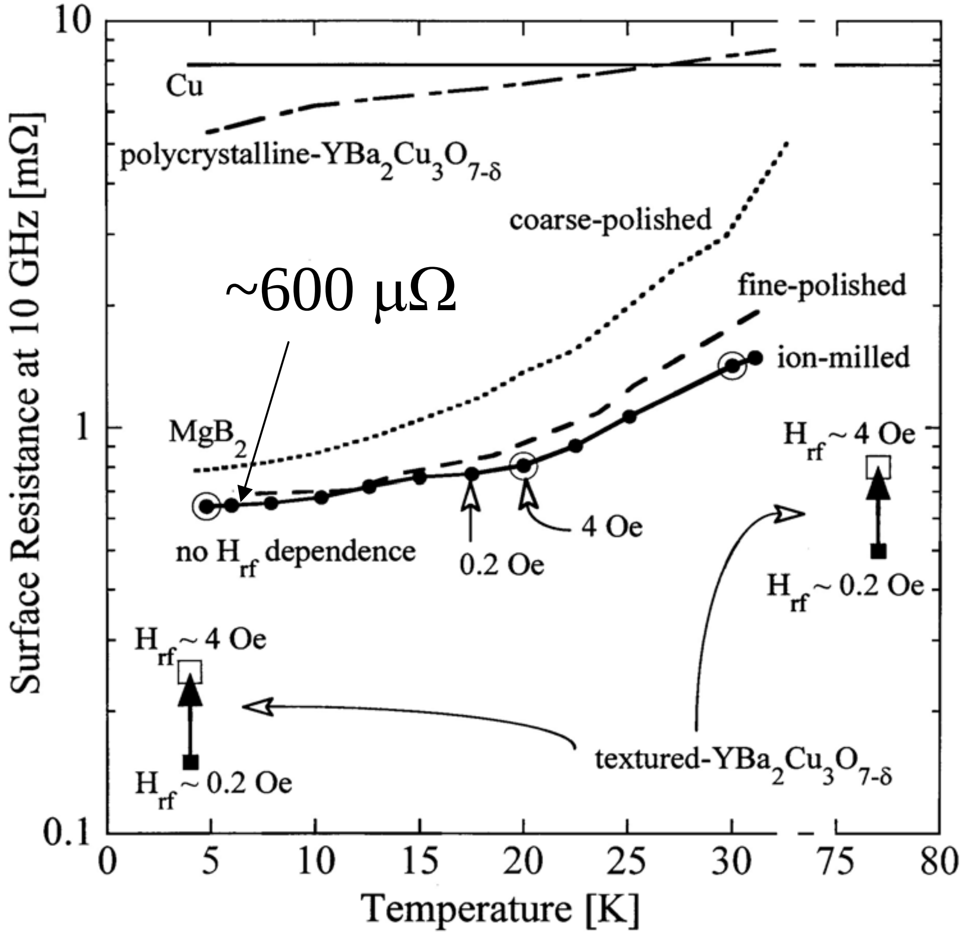
This material has been known for many years, but it was discovered to be superconducting (T_c=39K) in 2001.

MgB_2 samples made with a Hot Isostatic Press Technique developed at UCSD

Figure 7. Examples of machined samples from HIPed magnesium diboride. Notice mirror like quality of polished sample on left and third from left. Three small parallelepipeds with sharp corners were machined for high accuracy RUS measurements of elastic constants.

Vitali Nesterenko (UCSD), Invited Talk at the 11^{th} International Symposium on Processing and Fabrication of Advanced Materials Oct. 7-10, 2002, Columbus, Ohio.

First RF Surface Resistance measurement at STC of LANL

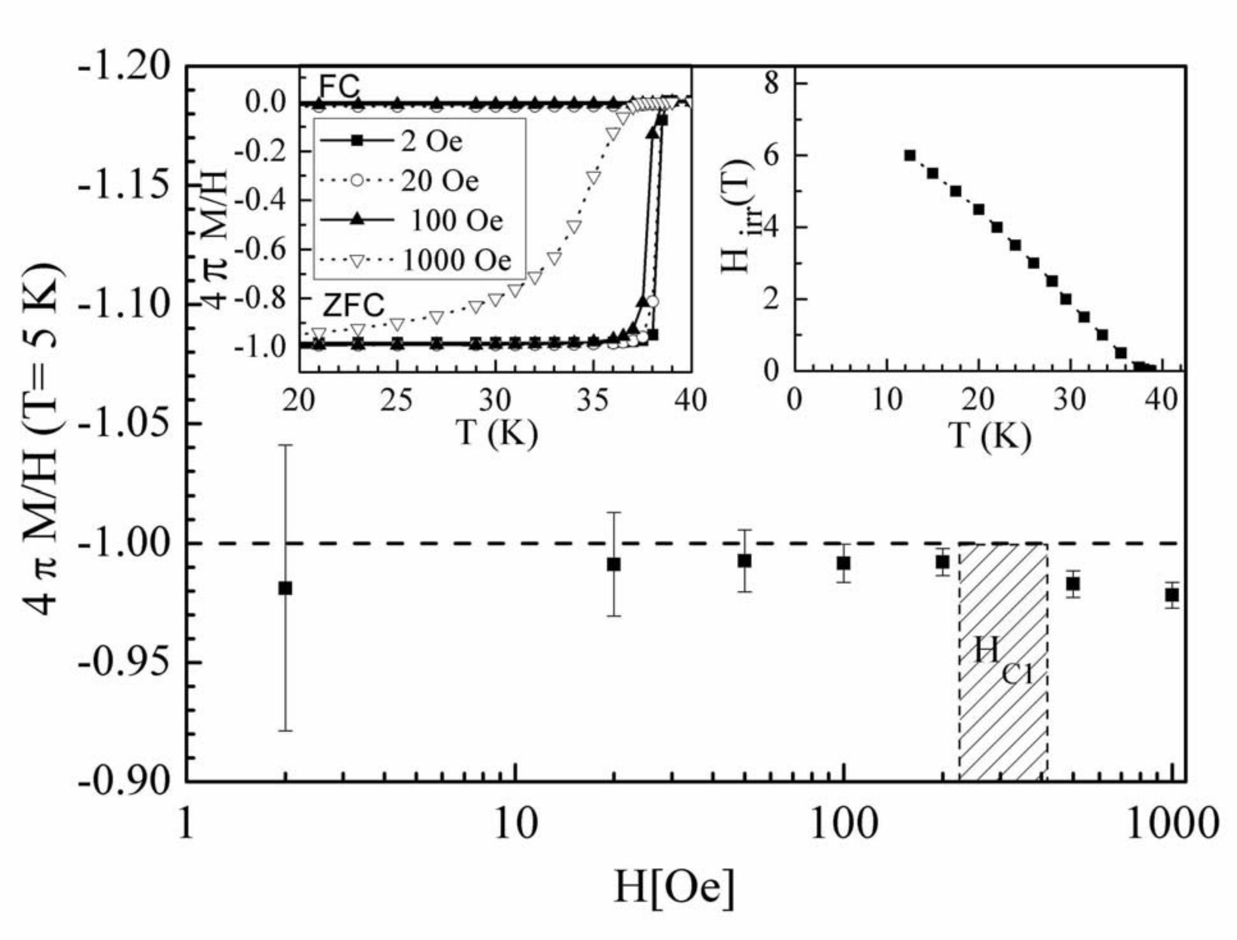


- No increase of R_s from 0.2 to 4 Oe as compared to significant increase with YBCO.
- This material is not optimized for low R_s, i.e., there is room for improvement

- R_s (BCS) of Nb (4K, 10 GHz) ~ 40 μΩ

Alp Findikoglu et al. (Superconductivity Technology Center at LANL), Applied Physics Letters 83 108 (2003).

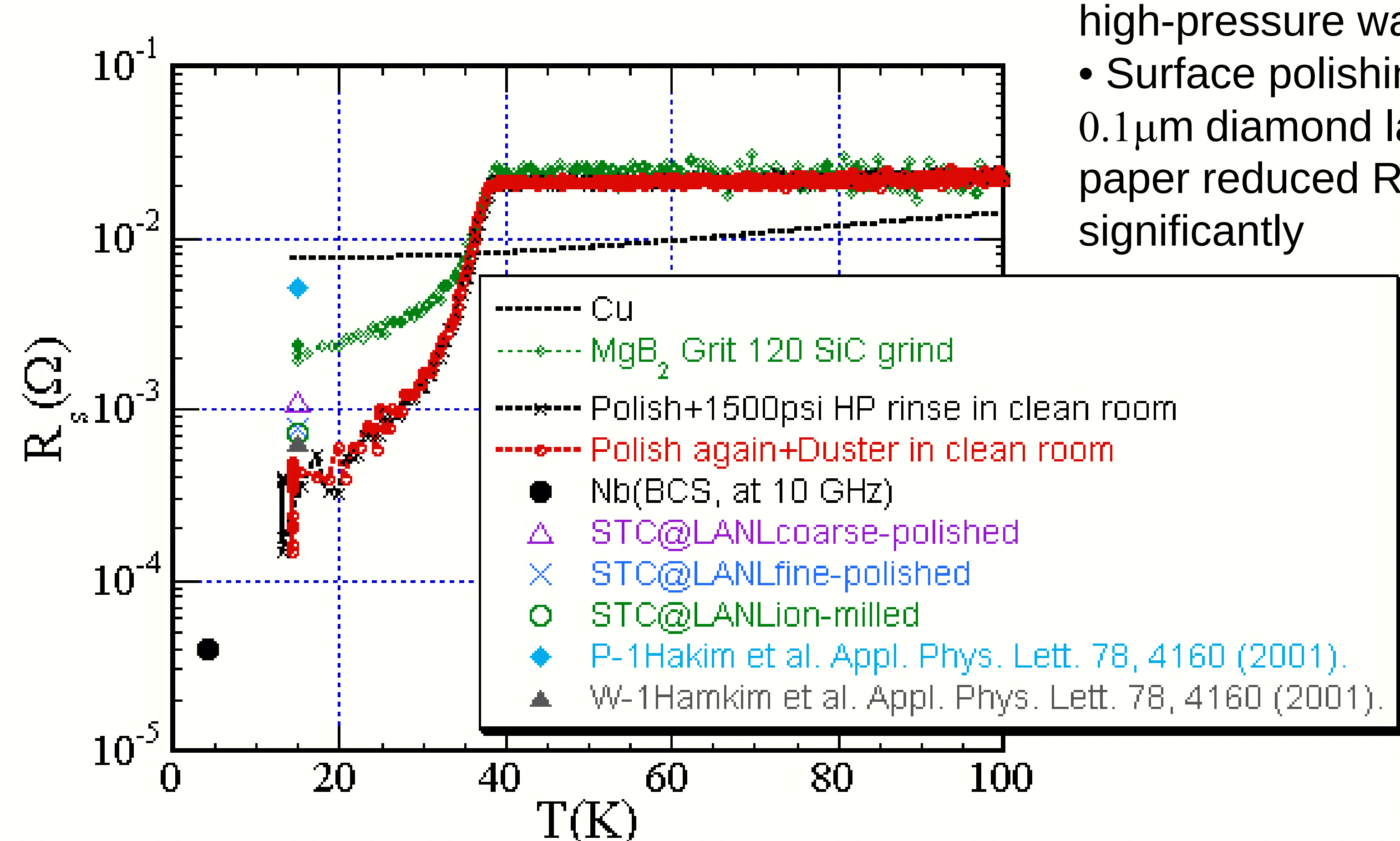
Magnetic Susceptibility Measurement for the HIPped bulk MgB_2



- Zero magnetization with field cooling (FC) compared to -1 with zero field cooling (ZFC) indicates that there is significant amount of flux pinning sites, which contributes to the increase of residual resistance.

Alp Findikoglu et al. (Superconductivity Technology Center at LANL), Applied Physics Letters 83 108 (2003).

RF Surface Resistance Measurement of HIPped bulk MgB_2 at LANSCE of LANL: Results converted to 10 GHz



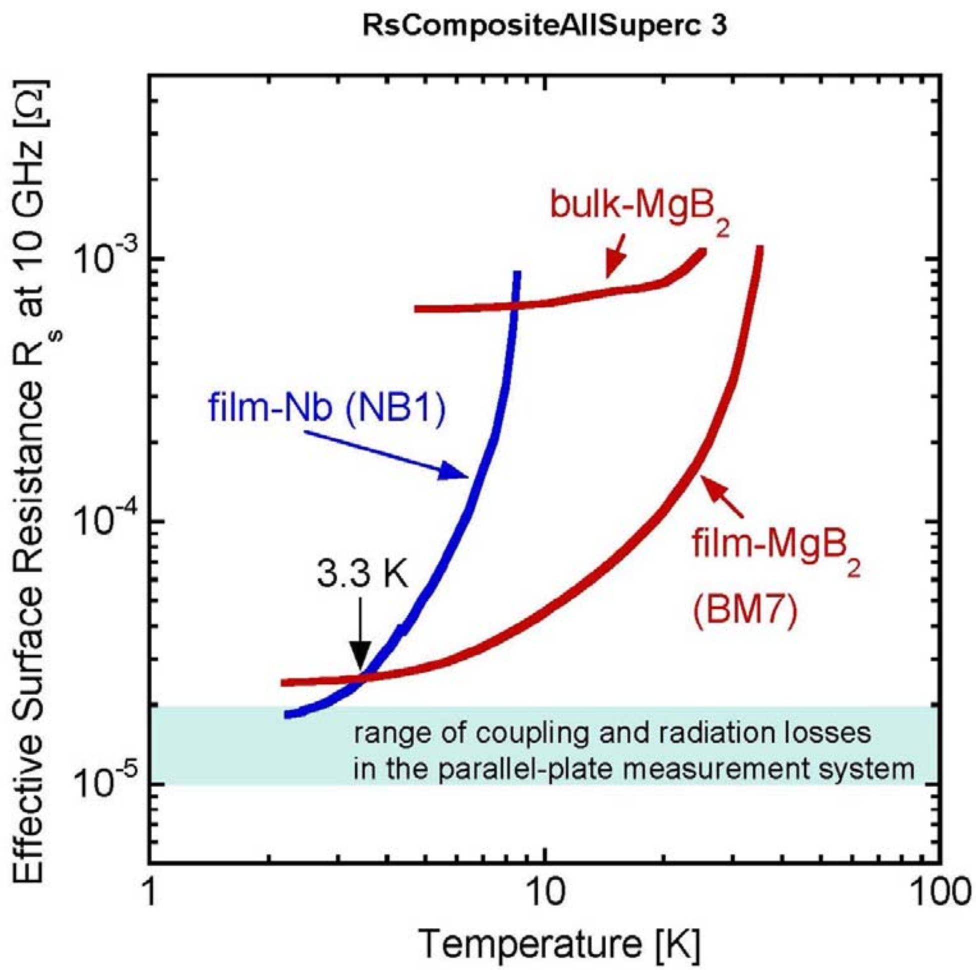
- No degradation with high-pressure water rinse
- Surface polishing with 0.1μm diamond lapping paper reduced R_s significantly

T. Tajima, J. Liu et al., 6th European Conference of Applied Superconductivity, Sorrento, September 14-18

An attempt to coat MgB_2 on metals such as Nb has started at STI

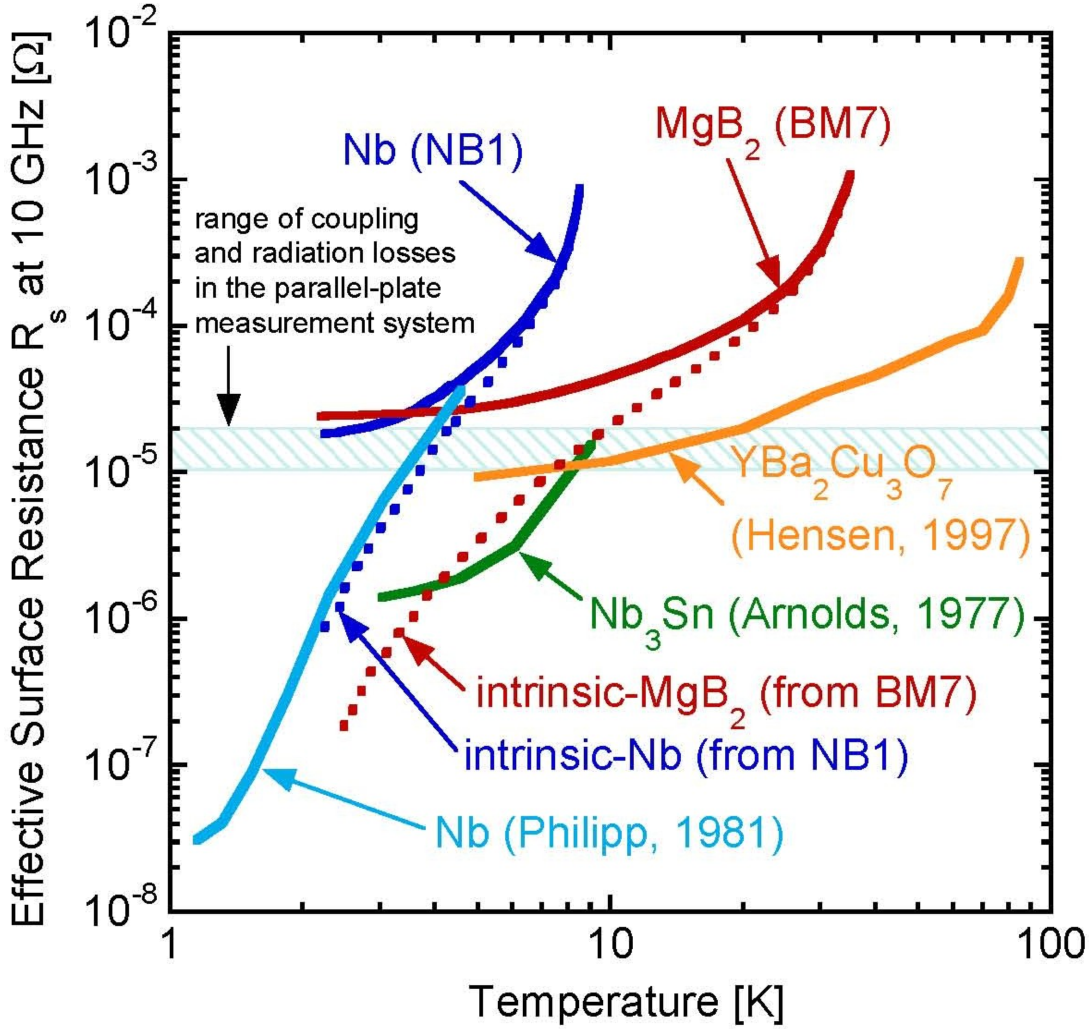
- Using the same technique on Sapphire, two 1.46 cm-diameter Nb disks (1 mm in thickness) were coated with MgB_2 by Brian Moeckly of STI.
- This is the first attempt and no optimization has been done yet.
- A parallel plate measurement was carried out by Alp Findikoglu of LANL. About one order of magnitude higher R_s , but could be improved with better substrate preparation, etc.

400nm film on sapphire substrate showed further R_s reduction, lower than Nb at 4 K!!



- Alp Findikoglu of STC at LANL, unpublished
- Film prepared by Brian Moeckly of Superconductor Technologies, Inc.
- Polycrystal, non-epitaxial film

Intrinsic (BCS) Resistance could be about one order of magnitude lower than Nb at 4 K!!

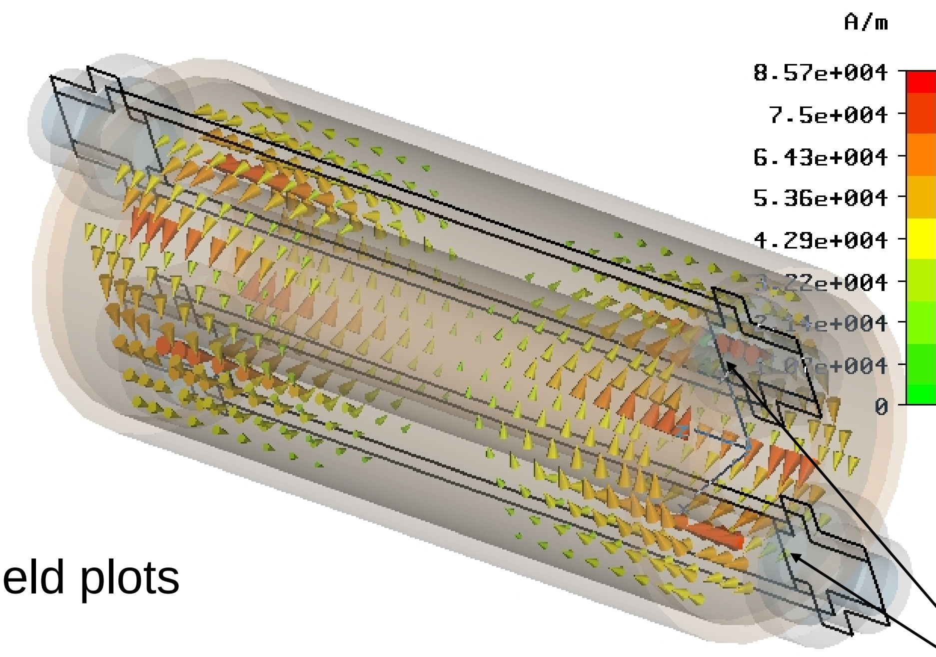


Alp Findikoglu of STC at LANL unpublished

R_s vs. Magnetic Fields Measurements are Underway

- Tests with ~760 MHz Nb coax cavity at LANSCE of LANL
- Tests with 6 GHz TE_{011}-mode cavity at Cornell

Tests at LANSCE using a 760-MHz Nb coaxial cavity



Magnetic field of up to ~140 mT can be obtained at the sample port with Epeak~0.46 MV/m if it quenches at 200 mT at maximum magnetic field region.

Necessary cavity power is less than 1 W with Q_0~1E9

Magnetic field plots

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Type         = H-Field (peak)
Monitor      = Mode 1
Maximum-3d = 85745.5 A/m at 0.0211375 / 0.004305 / 0.2087
Frequency    = 701.178
Phase        = 90 degrees
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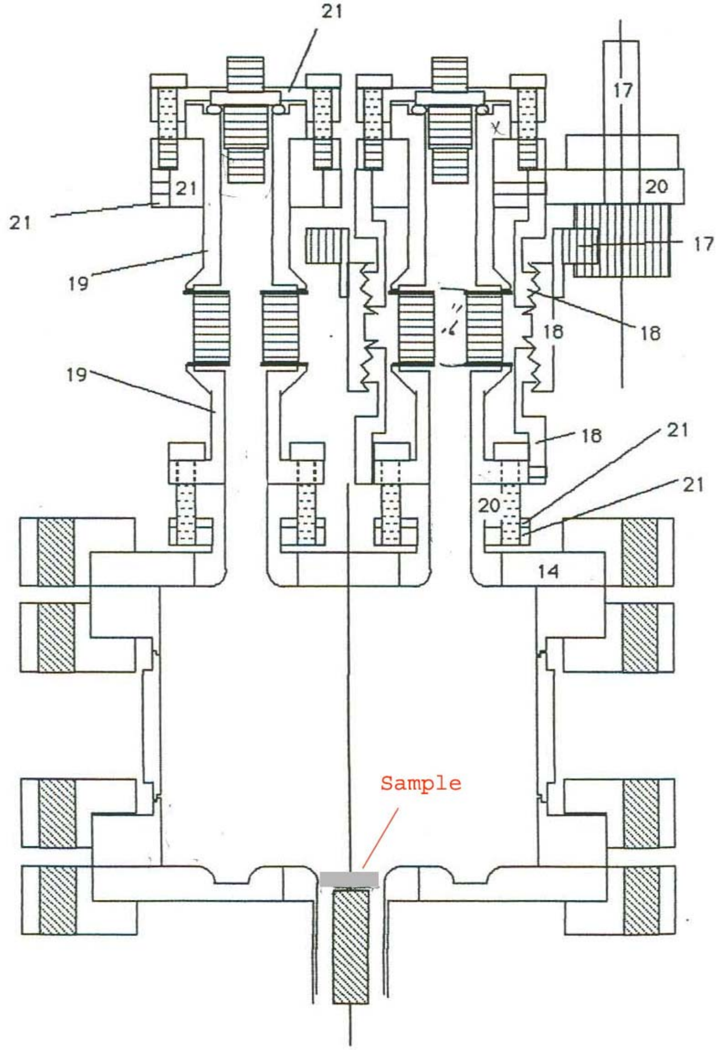
Samples will be placed at a high magnetic field region

Calculation by Frank Krawczyk of LANSCE at LANL

Tests at Cornell with 6-GHz Nb TE_{011} Cavity is underway



Measurement by Alexander Romanenko

Magnetic field calculation and test data will be shown when they are obtained.

Magnetic field can be raised up to ~20 mT

Other collaborations

- Electro-polishing of MgB_2 samples at Johannes Kepler University in Austria.
  - It was found that MgB_2 can be electro-polished to get a smooth surface, which is more suitable polishing method for SRF cavities application. Electro-polished samples have not yet been prepared for R_s measurements.
- Making solid MgB_2 by Hot Isostatic Press (HIP) technique at University of California at San Diego (UCSD). As soon as more funding is obtained, we will start optimizing the process to lower residual resistance.
- Ted Collings of Ohio State University is interested in this development. A paper on the possibility of MgB_2 written by him and Tajima will be published in SUST soon.

Summary

- Nb_3Sn work should be restarted.
- MgB_2 has already shown RF surface resistance lower than Nb at 4 K and has the potential of reaching about one order of magnitude lower than Nb at 4 K.
- Magnetic field dependence measurements are critical for SRF cavity applications and they are underway.
- Attempts to coat MgB_2 on metals such as stainless steel and Nb have started in industry.

Some thoughts for the future

- More funding is necessary for rapid developments on new materials if our target to replace Nb cavities within 5 years, especially for Nb_3Sn and MgB_2.
- For MgB_2 and other promising materials, it is better to form a strong collaboration internationally to expedite the study and cavity development.