A Review of Studies on MgB_2 in the RF Regime

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THIN FILMS AND NEW IDEAS FOR PUSHING THE LIMITS OF RF SUPERCONDUCTIVITY
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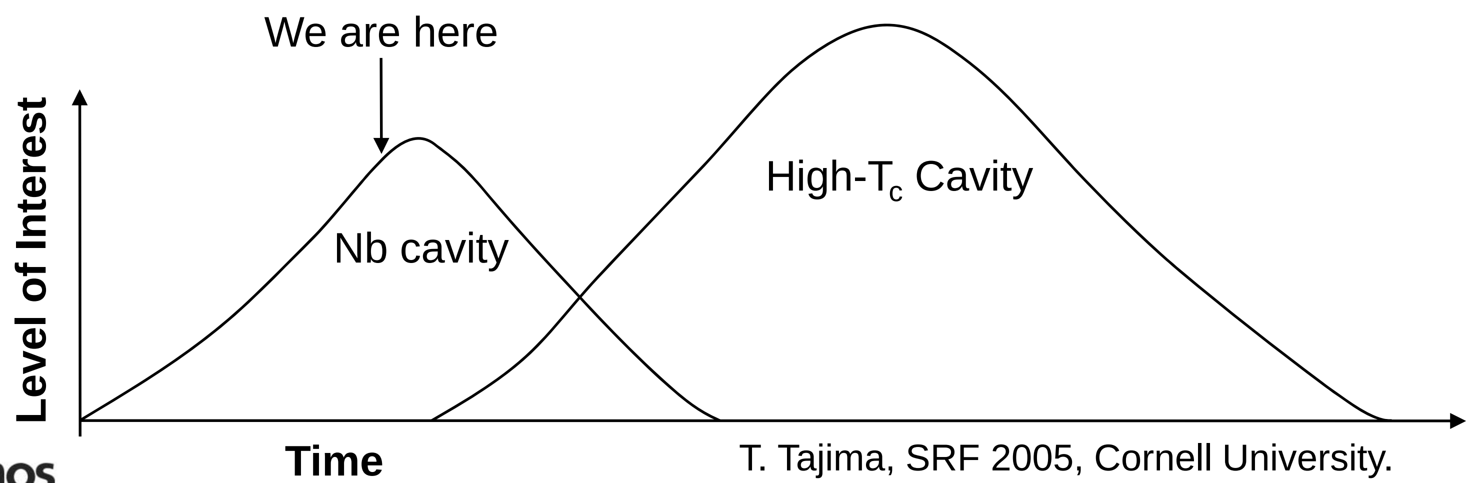
Outline

- Introduction
- Brief history of high-temperature superconductors (HTS)
- General features of MgB_2
- Measurements of MgB_2 in the RF regime
  - RF surface resistance
  - Power dependence
  - RF critical magnetic field
- Coating techniques
- Future plan
- Acknowledgment

Introduction

- High-purity Nb and cavities are still expensive.
- Refrigeration to get to 4 K or lower is costly
- Nb cavities have reached close to its theoretical limit and the recipe to get good results such as E_{acc} > 35 MV/m repeatedly will be established within ~3 years.



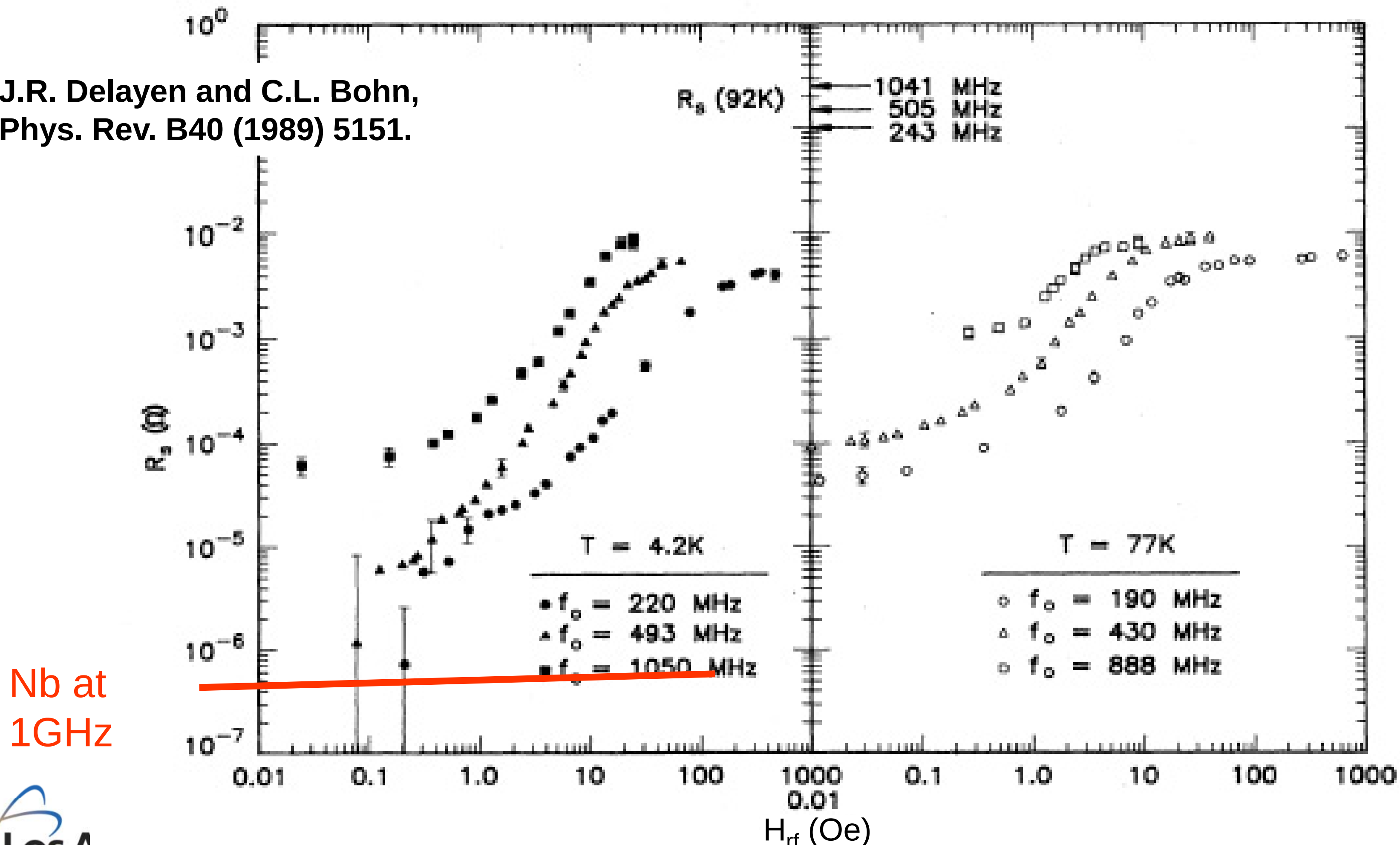
T. Tajima, SRF 2005, Cornell University.

Brief history of high-temperature superconductors (HTS)

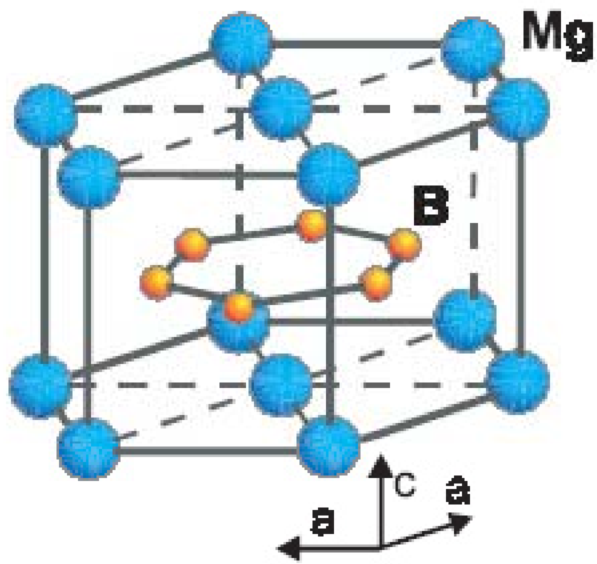
- Dutch physicist Heike Kamerlingh Onnes of Leiden University discovered in **1911** the phenomenon of superconductivity.
- In 1986, Georg Bednorz and Alex Müller discovered a superconductivity at **~38 K** in $La_{2-x}Sr_xCuO_4$ ceramics.
- In 1987, research groups in Alabama and Houston, coordinated by K. Wu and Paul Chu discovered $Y_1Ba_2Cu_3O_7$ ceramics with **T_c= 92 K**. For the first time above LN_2 temperature.
- The highest T_c so far is **138 K** with $(Hg_{0.8}Tl_{0.2})Ba_2Ca_2Cu_3O_{8.33}$
- Is room temperature superconductor possible??
- MgB_2 was discovered to be superconductive at **39 K** in early 2001. It was a surprise since it is a simple binary intermetallic compound.

R_s of YBCO: Rapid increase with magnetic field

J.R. Delayen and C.L. Bohn,
Phys. Rev. B40 (1989) 5151.



Magnesium Diboride (MgB_2) : Features



Graphite-type boron layers separated by hexagonal close-packed layers of magnesium

Superconductivity comes from the phonon-mediated Cooper pair production similar to the low-temperature superconductors except for the **two-gap nature**.

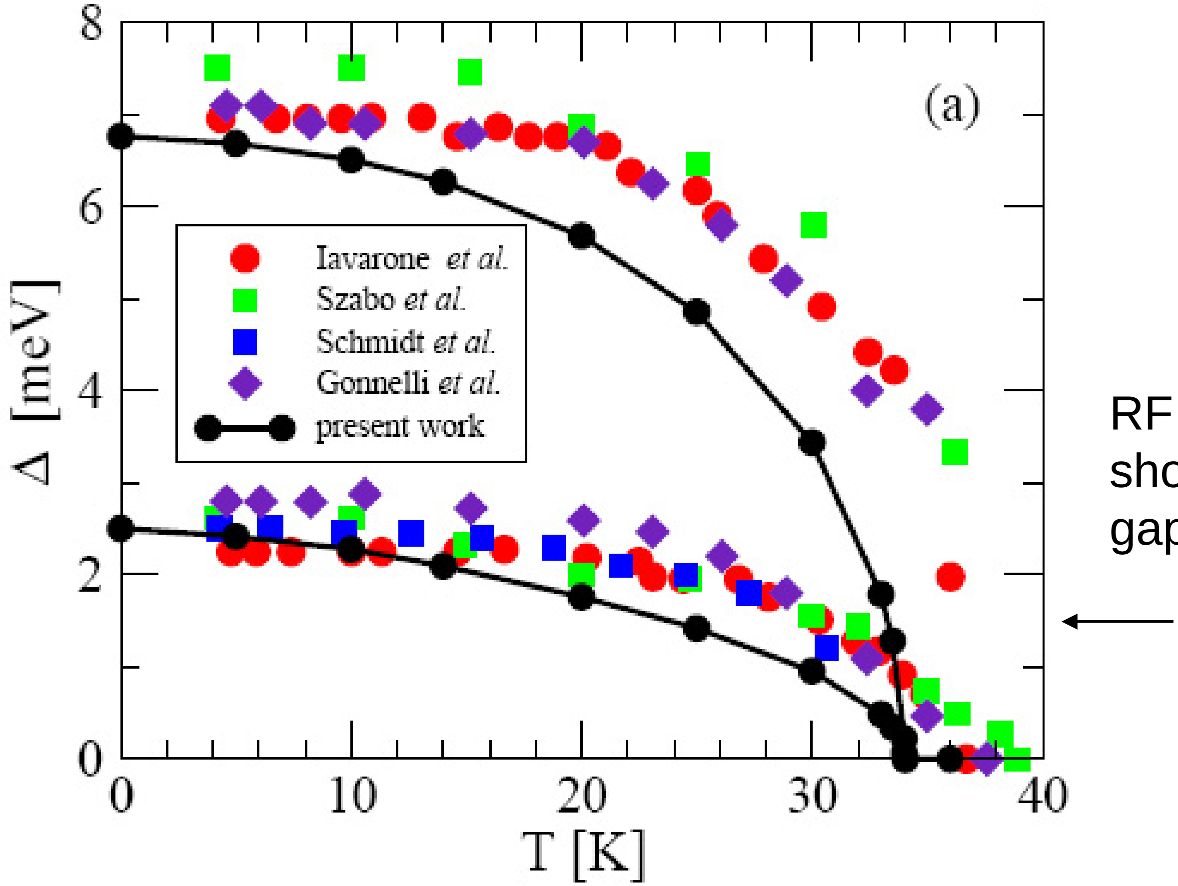
Compared to cuprates:

- Cheaper
- Lower anisotropy
- Larger coherence length
- Transparency of grain boundaries to current flows

These makes MgB_2 attractive for RF applications.

C. Buzea and T. Yamashita, Superconductor Sci. Technol. 14 (2001) R115.

MgB_2: Two Energy Gaps

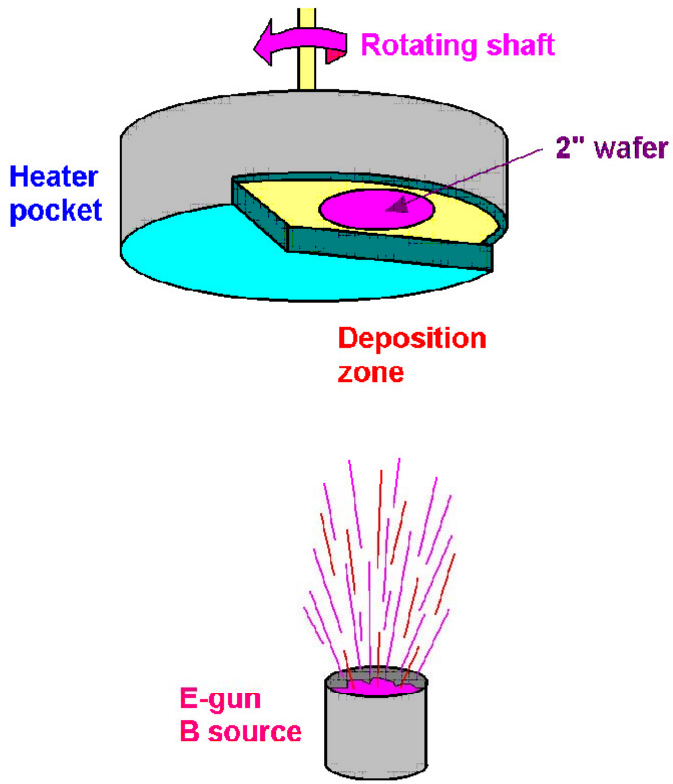


RF response has shown lower energy gap behavior.

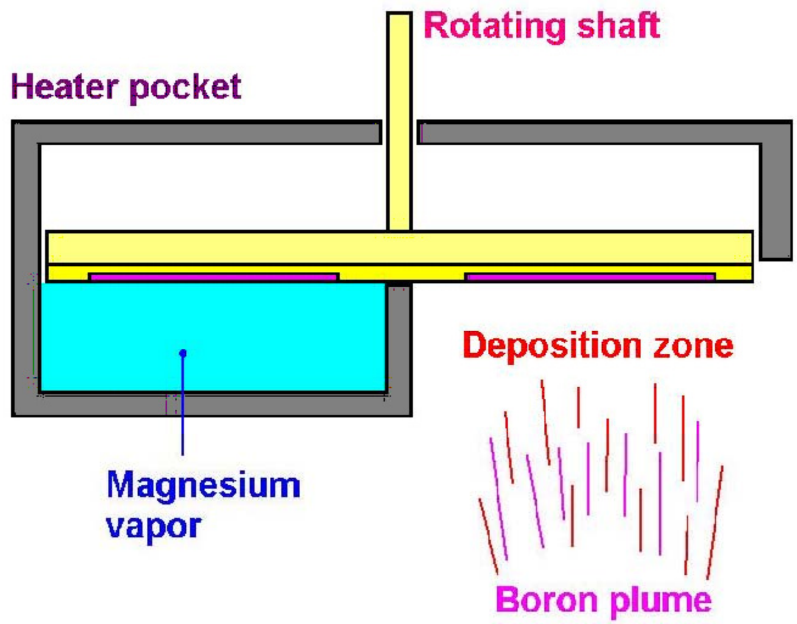
Nb

A. Floris et al., cond-mat/0408688v1 31 Aug 2004

MgB_2 Coating: Reactive Deposition System Developed at STI. One of the purest films now!!



In-situ reactive evaporation

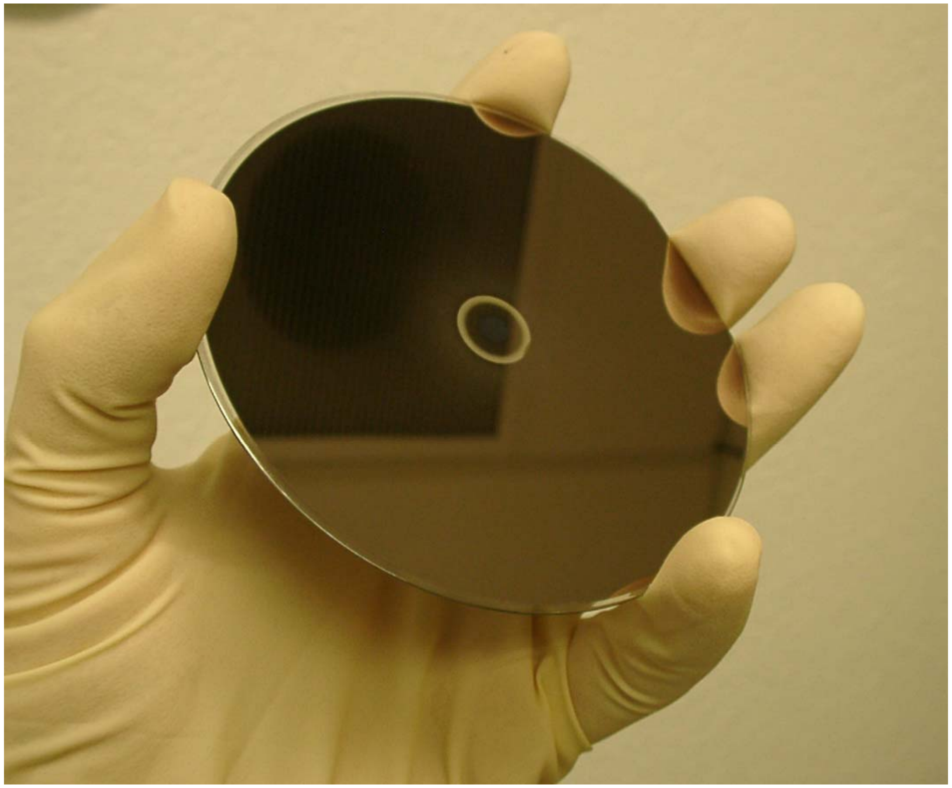


More details are found in
B.H. Moeckly et al., IEEE Trans. Appl. Supercond. 15 (2005) 3308.
T. Tajima et al, Proc. PAC05.

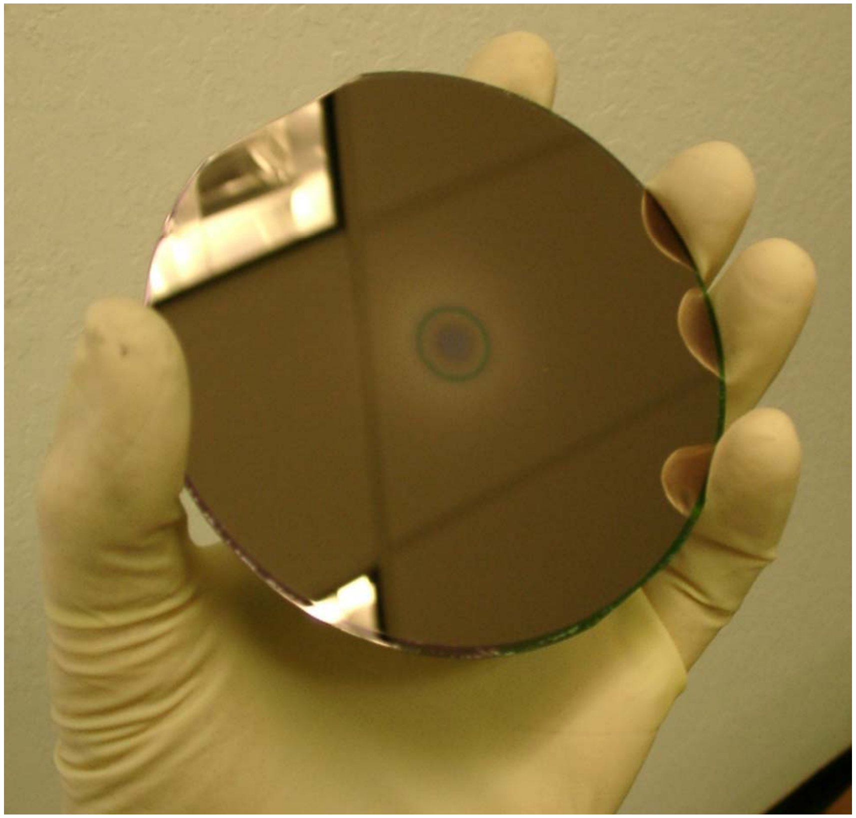
B.H. Moeckly, ONR Superconducting Electronics Program Review
Red Bank, NJ, February 8, 2005

MgB_2 on 4" substrates

R-plane sapphire



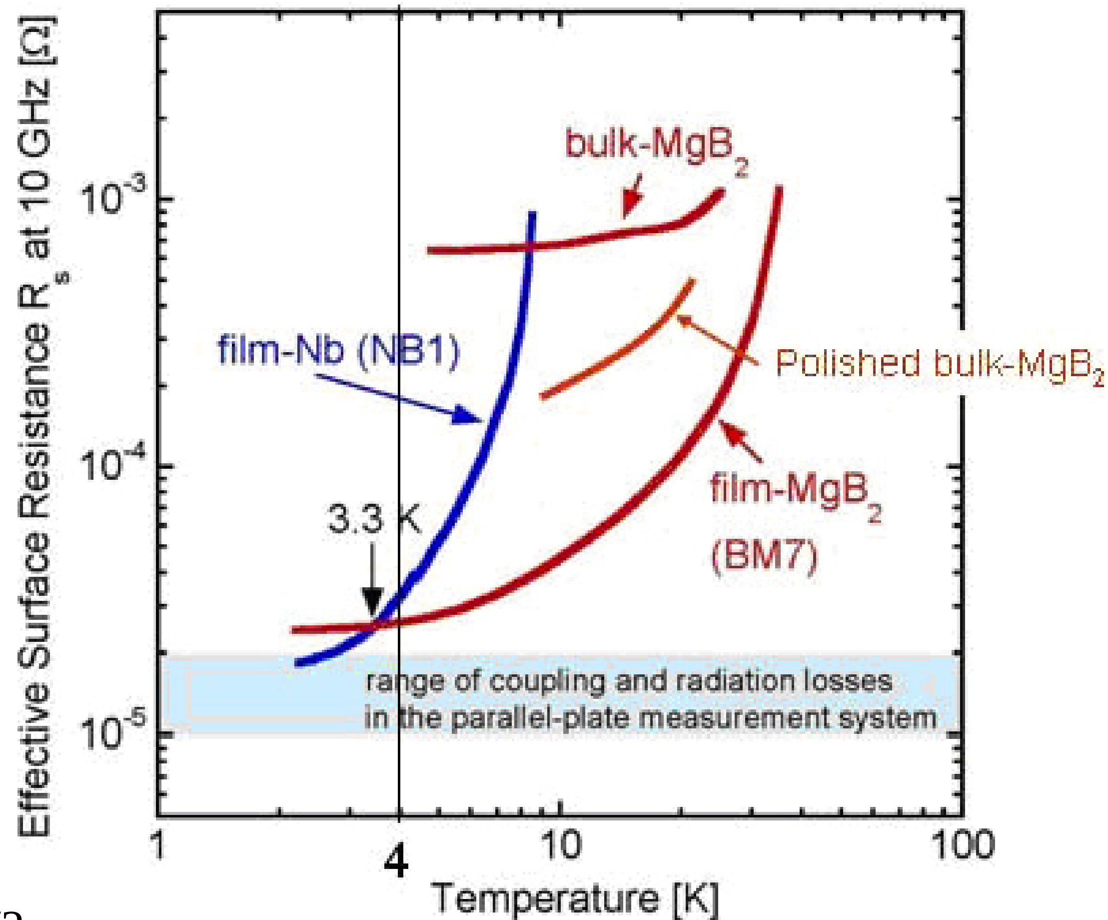
Si_3N_4 / Si



B.H. Moeckly, ONR Superconducting Electronics Program Review
Red Bank, NJ, February 8, 2005

RF Surface Resistance (R_s) at 10 GHz: LANL results with samples from STI (film) and UCSD (bulk)

- R_s lower than Nb at 4K
- Still residual resistance dominates at low temperatures

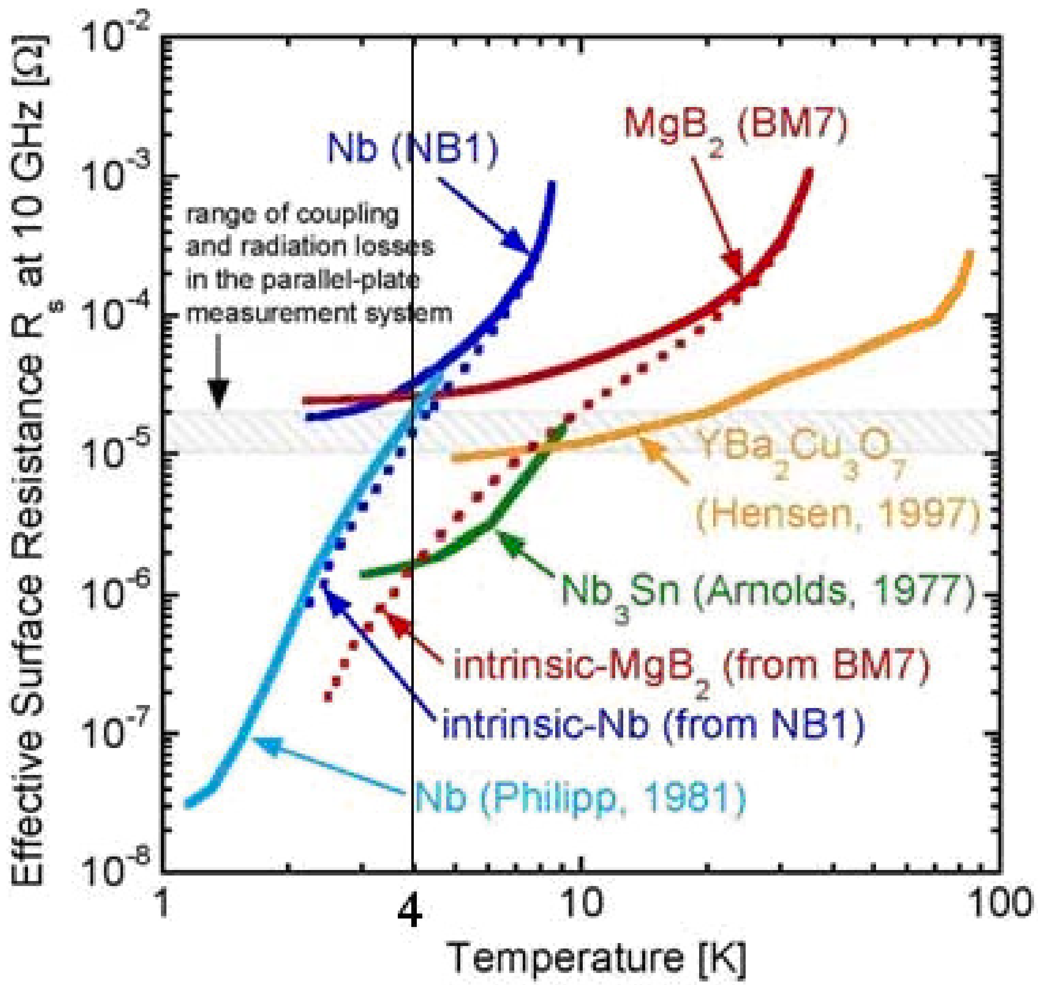


• A.T. Findikoglu et al., NSF/DOE Workshop on RF Superconductivity, Bethesda, MD, Aug. 29, 2003.
• B.H. Moeckly et al., IEEE Trans. Appl. Supercond. 15 (2005) 3308.
• T. Tajima et al., Proc. PAC05.

Generally, $R_s \propto f^2$ at $T<T_c/2$

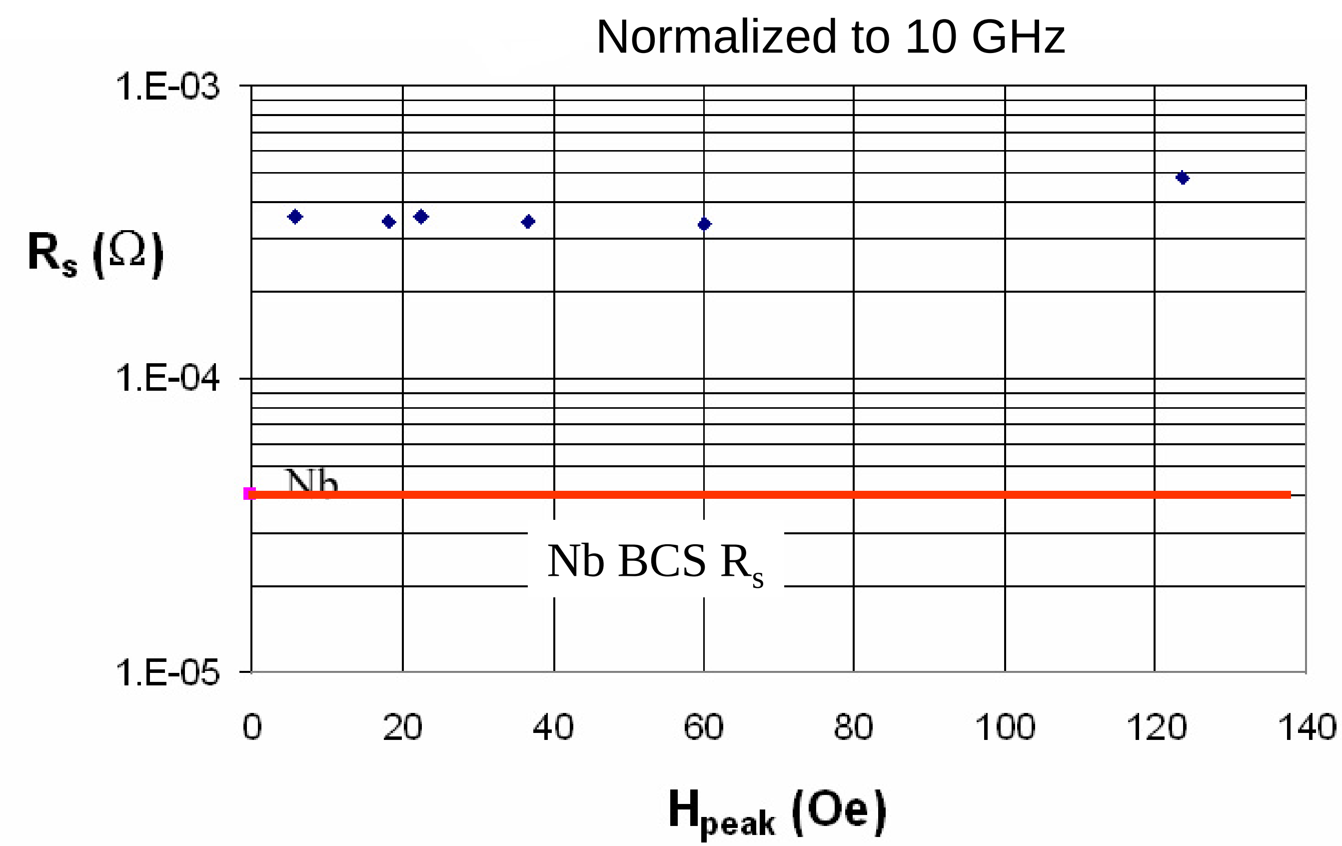
RF Surface Resistance (R_s) at 10 GHz: LANL measurements compared to the data from other references, and prediction

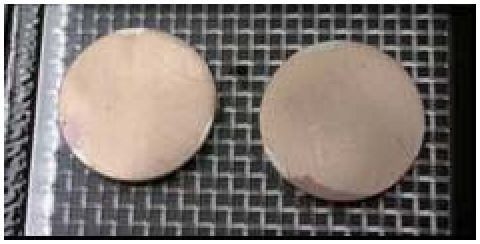
- Dotted line is the predicted BCS resistance by subtracting the residual resistance (temperature independent)



- A.T. Findikoglu et al., NSF/DOE Workshop on RF Superconductivity, Bethesda, MD, Aug. 29, 2003.
- B.H. Moeckly et al., IEEE Trans. Appl. Supercond. 15 (2005) 3308.

R_s Power Dependence Test of the sample coated on a rough Nb disk at STI with reactive evaporation method





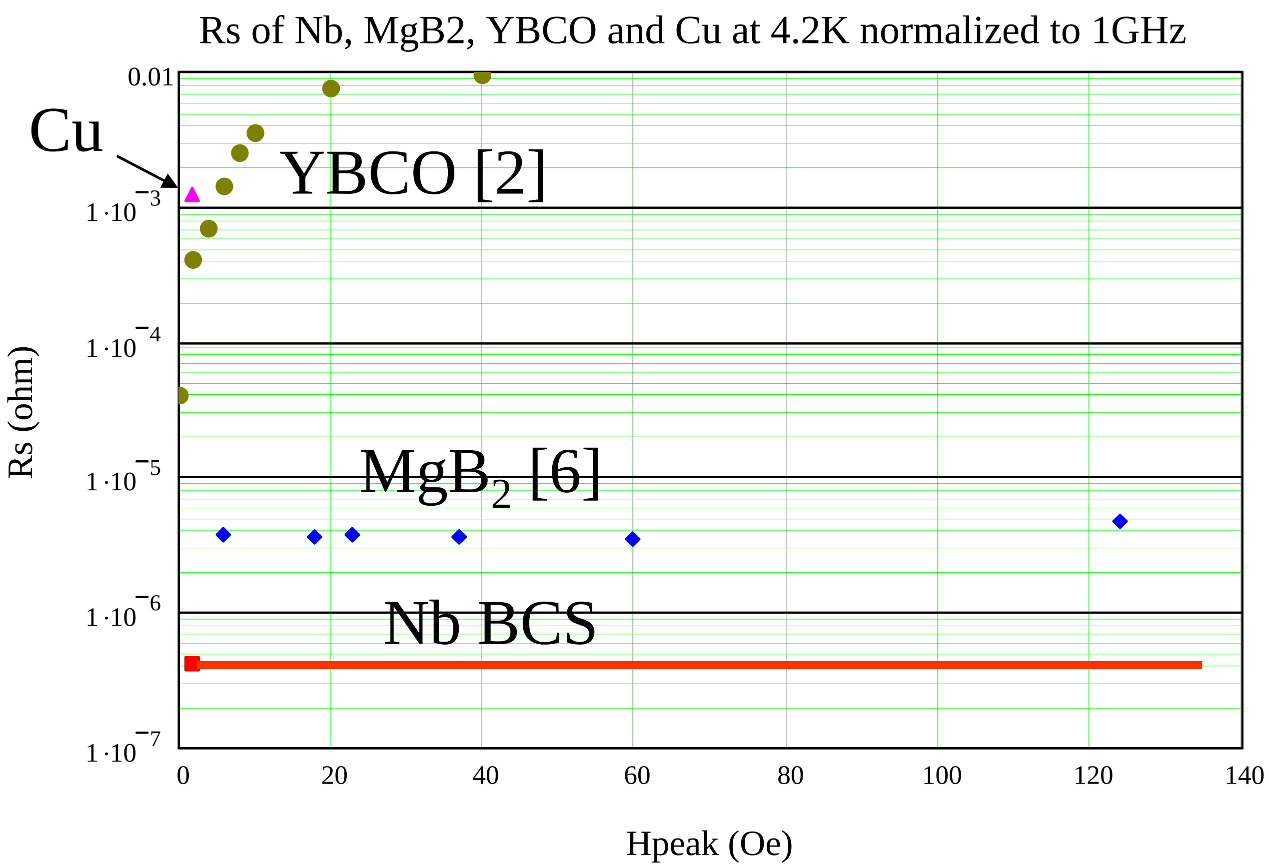
First attempt to coat on a Nb substrate (1.5 cm disk).

R_s was higher than Nb due to the rough (R_a~400nm) substrate.

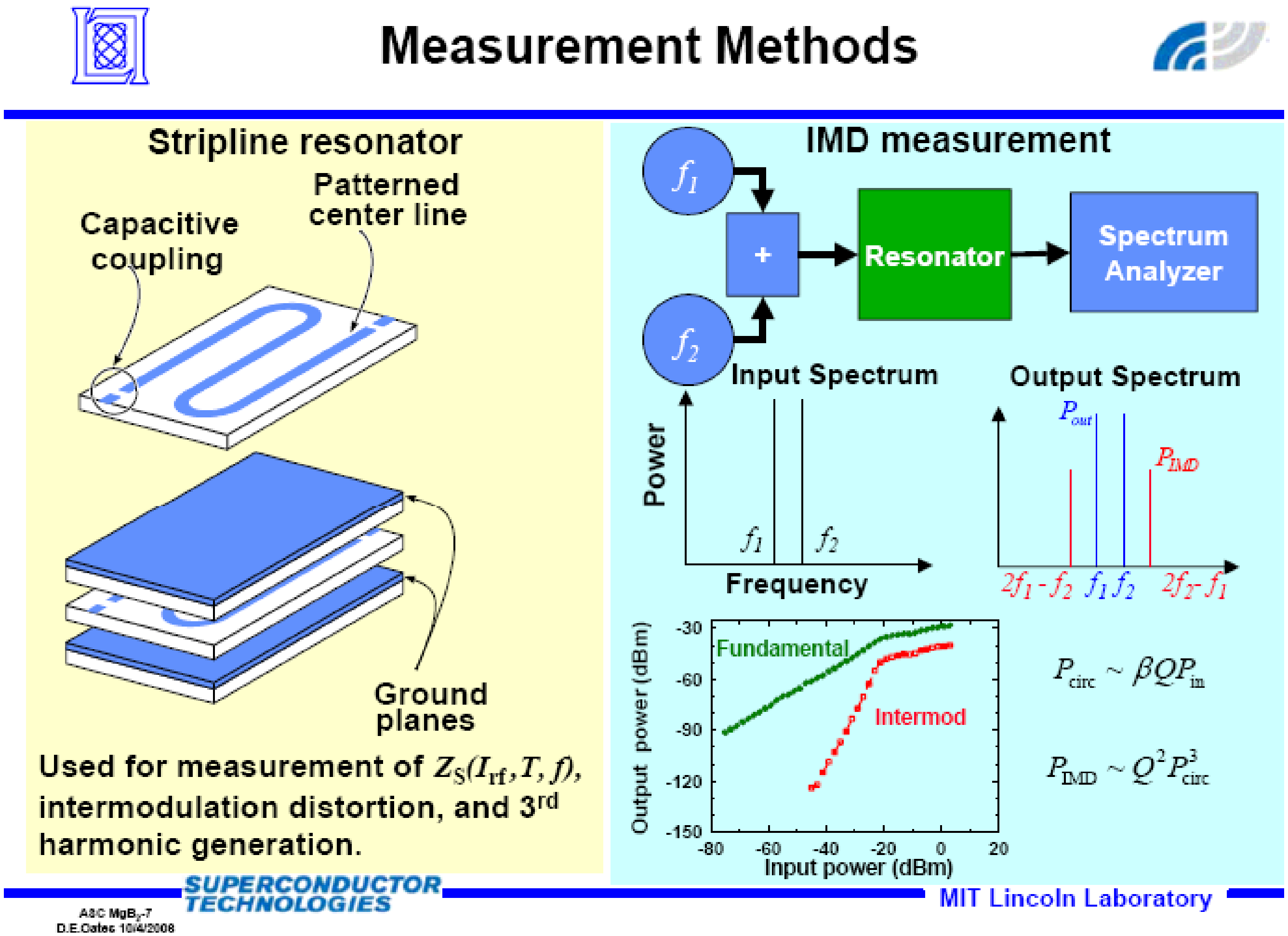
Test at Cornell with TE_{011} Nb cavity at 4.2 K.

T. Tajima et al., Proc. PAC2005, p. 4215

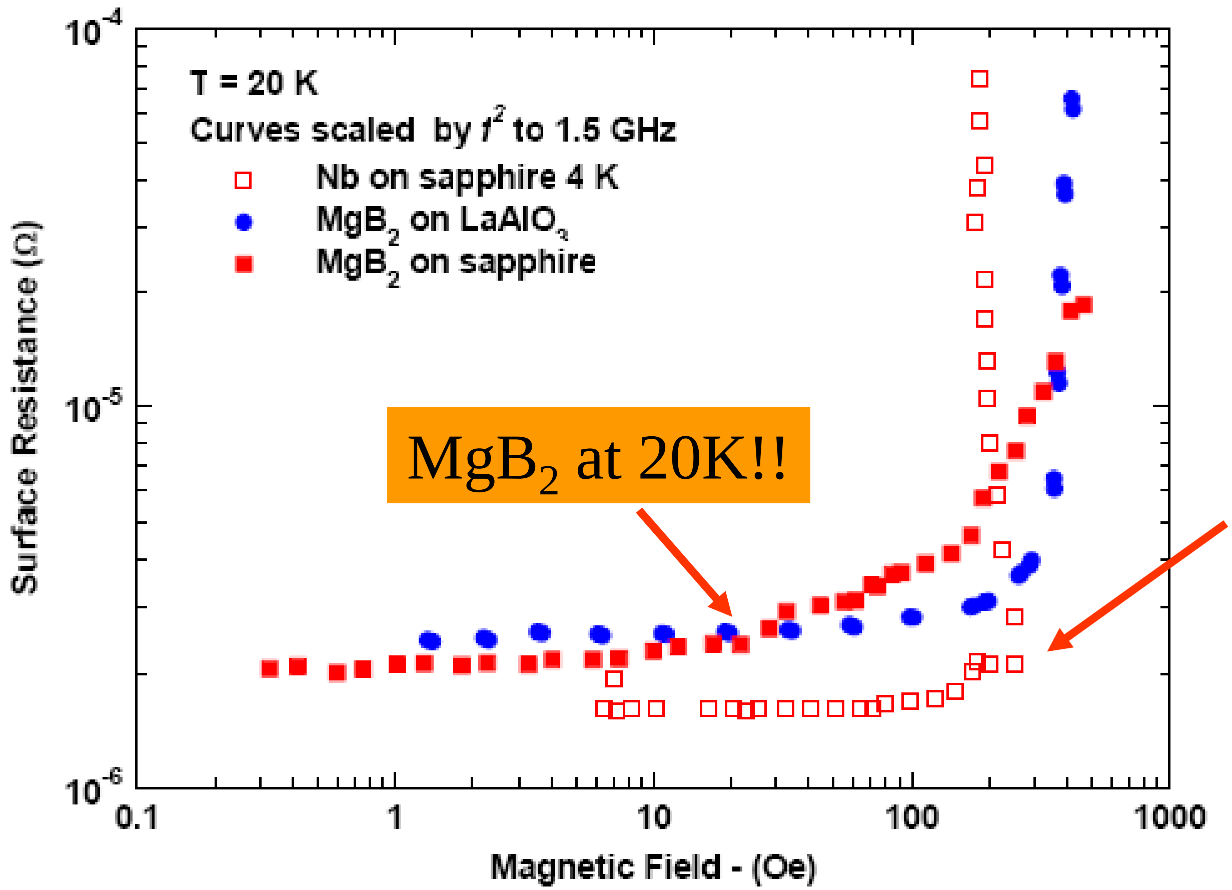
R_s Power Dependence Test at Cornell, compared to the R_s of YBCO and Cu, results normalized to 1 GHz



Recent results from MIT with STI films are very encouraging!! [D. Oates et al., ASC2006]



Recent results at MIT shows an R_s comparable to Nb even at 20 K! and does not show significant increase until ~400 Oe, equivalent of ~10 MV/m SRF cavity!!



Coated at STI with reactive evaporation

Thickness: 500 nm

Nb at 4.2 K
Why does this take off at ~200 Oe?

[D. Oates et al., ASC2006]

R_s Power dependence tests at various temperatures at MIT: The R_s at 5K is lower than that of Nb at 4.2K!, although it seems to increase faster at higher fields

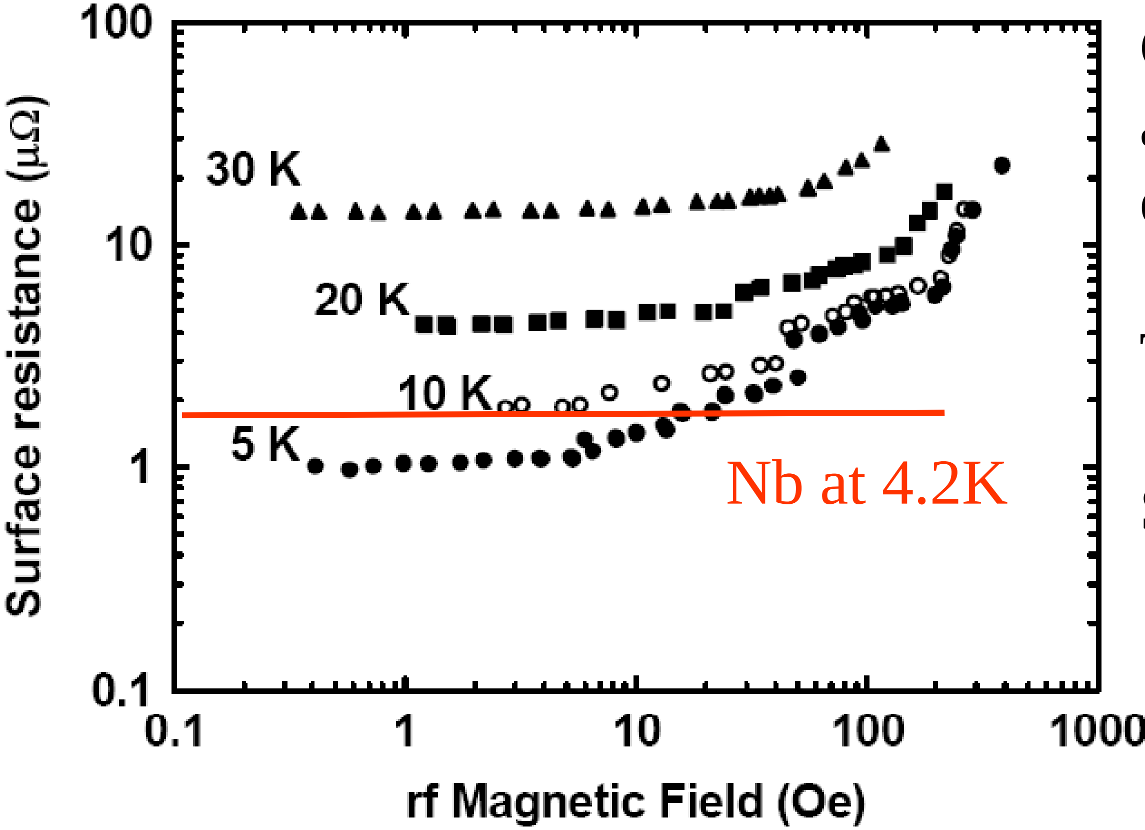


Fig. 3. R_S vs H_{rf} at several temperatures as indicated on the graph.

Coated on Sapphire at STI with reactive evaporation

Thickness: 500 nm

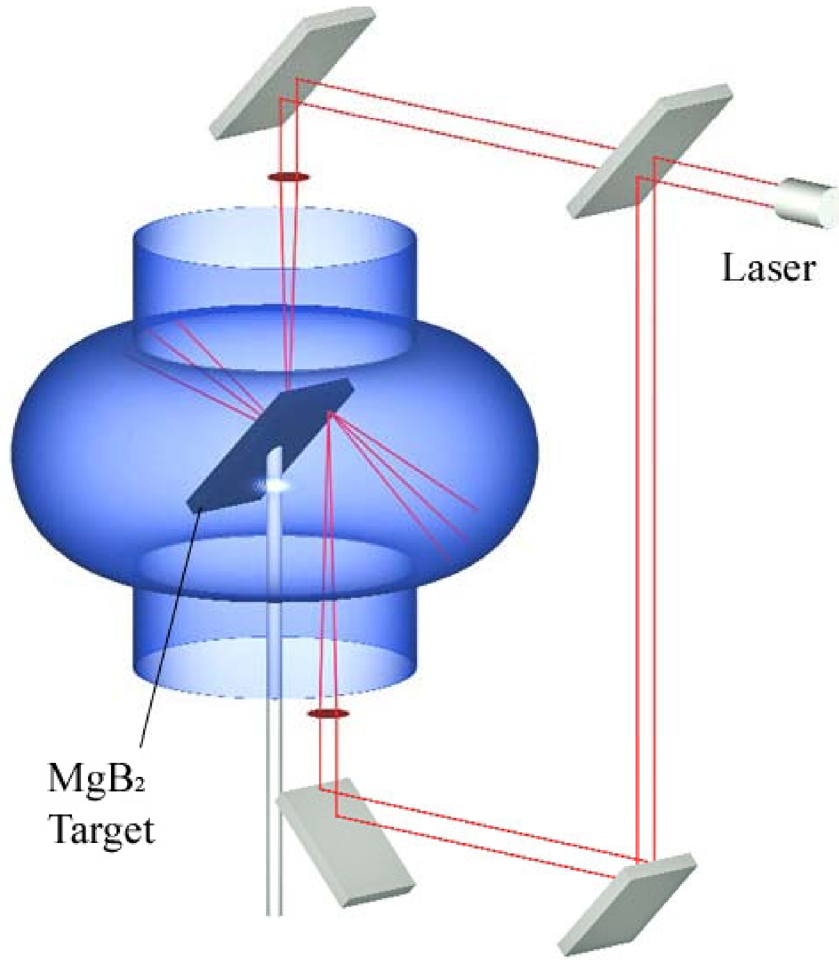
Scaled to 1.5 GHz

[D. Oates et al., ASC2006]

An Idea to coat a cavity with Pulsed Laser Deposition (PLD) was proposed [T. Tajima et al., PAC2005]

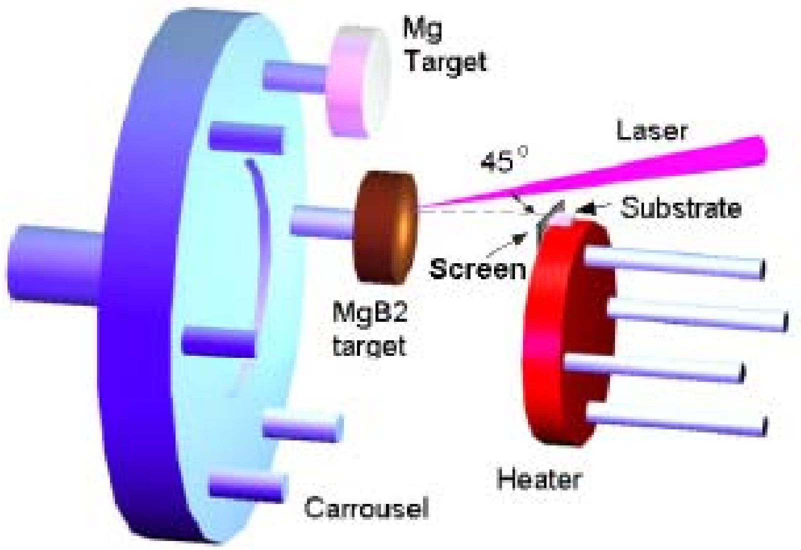
A recipe for the PLD by Y. Zhao et al.,
Supercond. Sci. Technol. 18 (2005) 395.

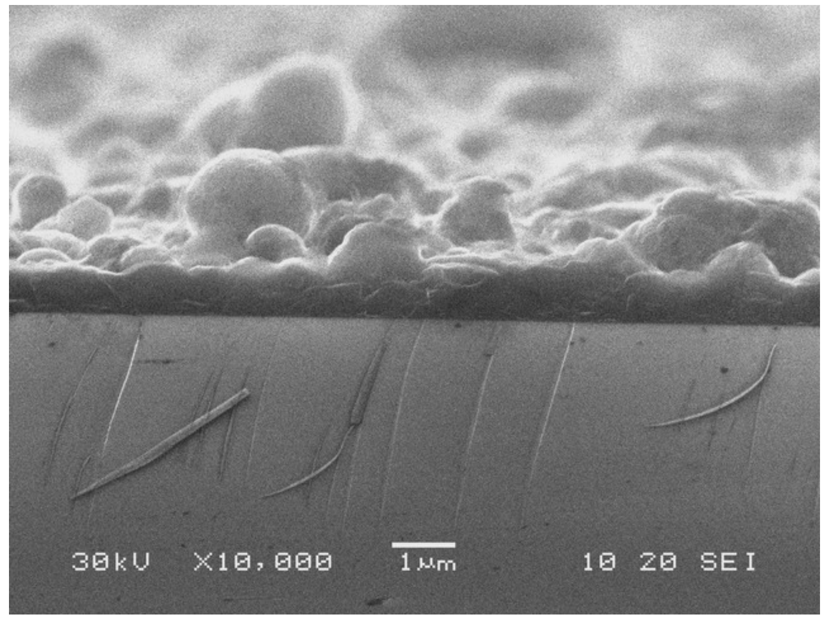
A KrF Excimer Laser of ~ 500 mJ/pulse, 5-10 Hz
Substrate heated to 250 °C during PLD in ~120 mTorr Ar
In-situ annealing at ~650 °C for ~12 min in ~760 Torr Ar



MgB_2 Coating with Pulsed Laser Deposition (PLD) at U. Wollongong in Australia [Y. Zhao et al.]

- Pulsed laser deposition



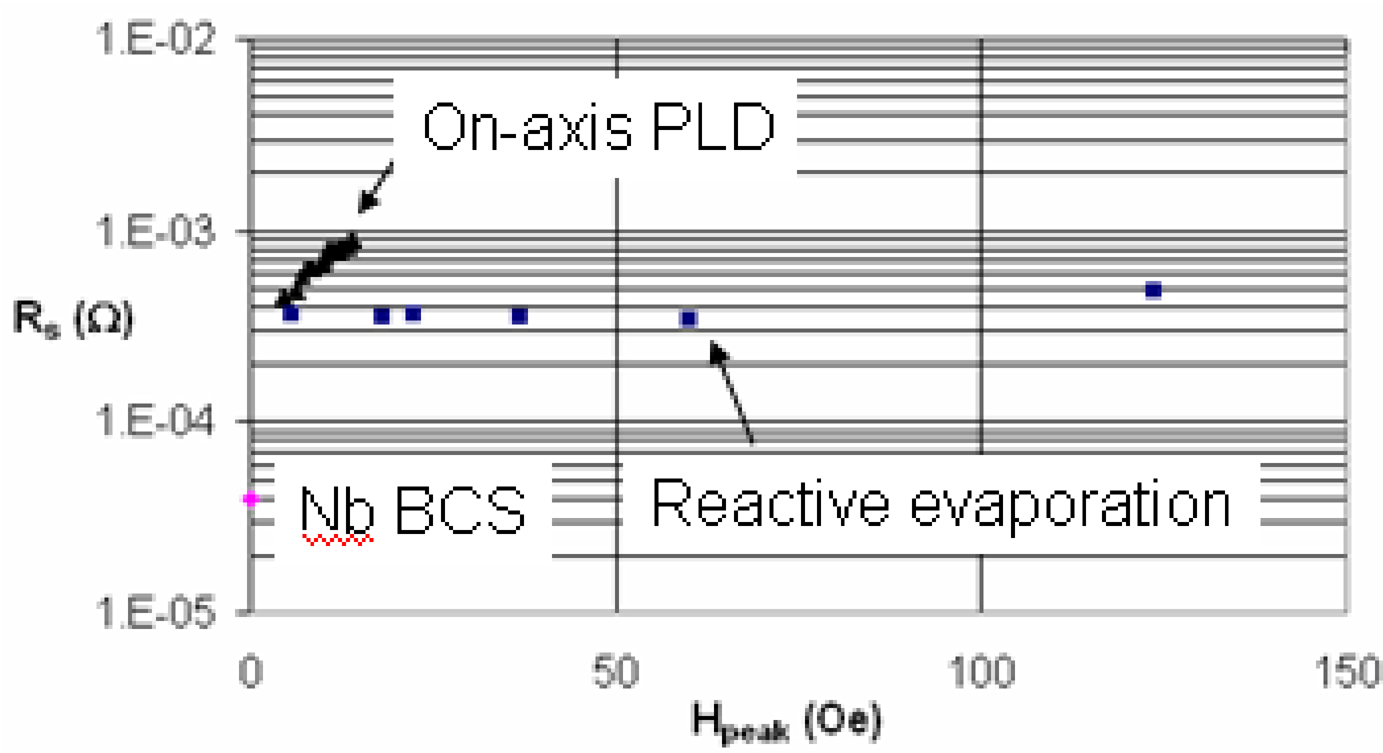


Deposition test by Y. Zhao, U. Wollongong, Australia

T. Tajima et al., EPAC06, Edinburgh, UK, June 26-30, 2006.

The film coated with on-axis PLD at U. Wollongong shows rapid increase with magnetic fields compared to the STI reactive evaporation films

[T. Tajima et al., Proc. EPAC2006, p. 481]

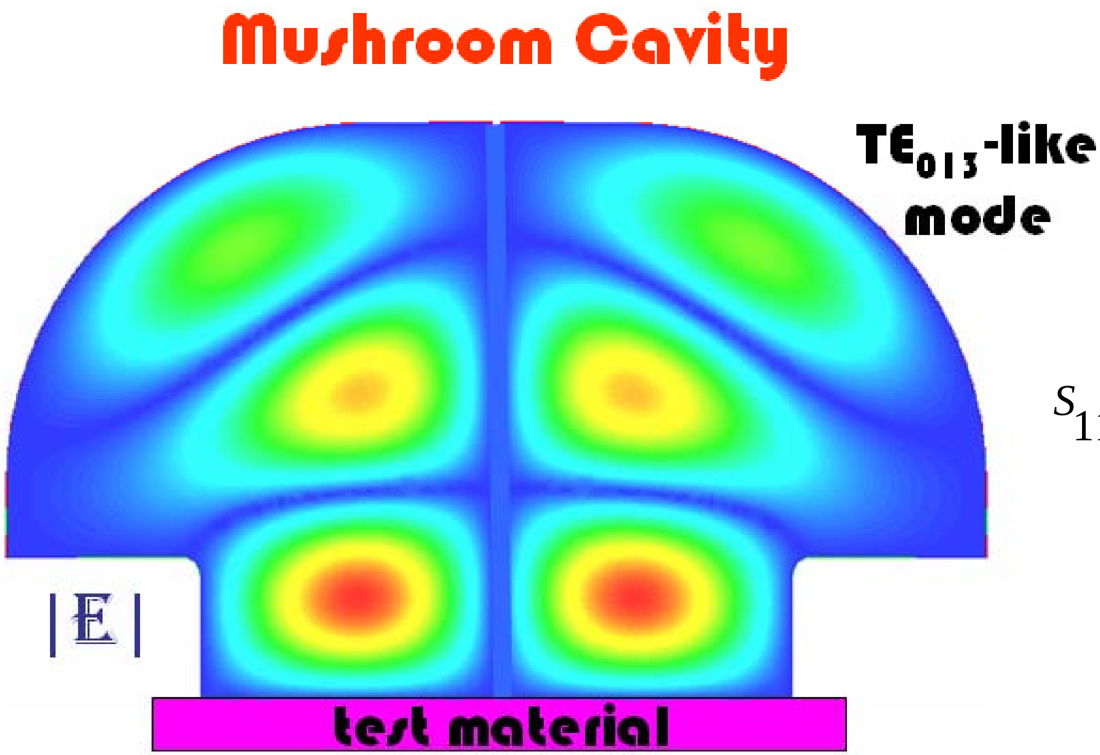


Better films with off-axis PLD will be tested in the future.

RF Critical Magnetic Field Measurement at SLAC [Sami Tantawi et al.]

- Superconducting materials test cavity
  – No surface electric fields (no multipacting)
  – Magnetic field concentrated on bottom (sample) face
- X-band (~11.424 GHz):
  – high power available
  – fits in cryogenic Dewar
  – Relatively large (2-3”) samples required

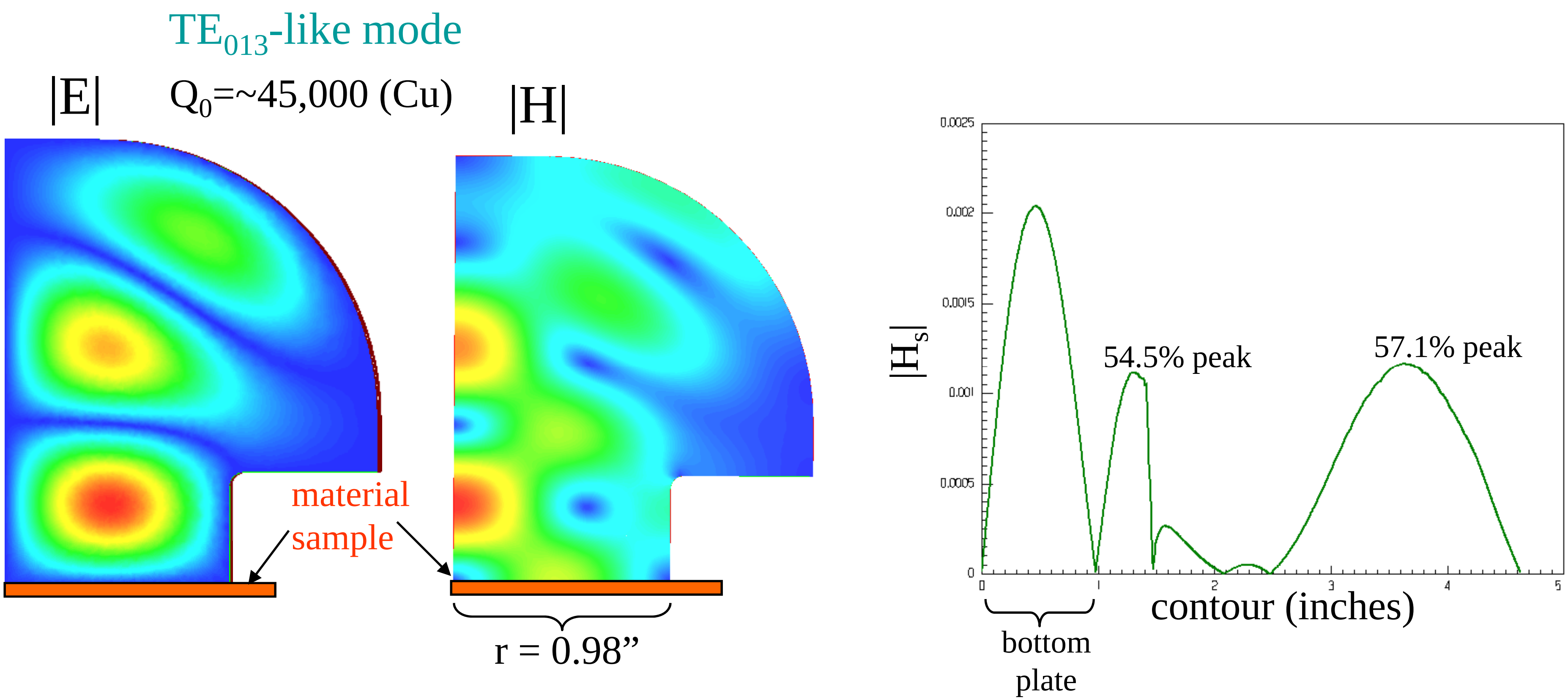
RF Critical Magnetic Field Measurement at SLAC [Sami Tantawi et al.]



Quench is detected by the change of Q_0, according to:

$$S_{11}(f) = e^{-2L(ik_g+\alpha)}\left(\frac{2i\beta}{(\beta+1)(f_S Q_L - i)}+1\right),$$

RF Critical Magnetic Field Measurement at SLAC [Sami Tantawi et al.]



RF Critical Magnetic Field Measurement at SLAC

- Issues
  - Calibration of the system for absolute measurements
  - However, it is still valid when compared to Nb as a relative measurement
  - Measurement of Nb… done!
  - Measurement of bulk MgB_2… underway!
  - Measurement of thin film MgB_2… to be tested as soon as good films are available with 2-3” in diameter

Future Plan

- Improve residual RF surface resistance: presumably better samples from PSU will be tested at MIT soon to see if their films show better performance compared to STI films.
- Develop coating techniques to coat on a curved surface and on the cavity inner surface: methods using HPCVD, reactive evaporation, PLD, etc. will be explored.
- Measure RF critical magnetic field of MgB_2: ongoing at SLAC start at JLab, films made with various techniques will be tested.
- Make MgB_2 coated cavities and test performance: collaborations and consultation with various experts are ongoing and we are hoping to do this at LANL, JLab and other places where there is RF cavity measurement capability.

Thanks to the people who have worked and are working with us on this very interesting endeavor !

- Cornell Univ.: A. Romanenko, H. Padamsee, R. Geng et al.
- LANL: A. Findikoglu, D. Peterson, F. Muller, F. Krawczyk, J. Liu (now in China), A. Shapiro et al.
- U. Wollongong: Y. Zhao, S. Dou et al.
- Superconductor Technology, Inc. (STI): B. Moeckly et al.
- MIT Lincoln Lab.: D. Oates et al.
- JLab: L. Phillips, A.-M. Valente, G. Wu (now at FNAL) et al.
- SLAC: S. Tantawi, C. Nantista, V. Dolgashev et al.
- ORNL/SNS: I. Campisi
- Alameda Applied Sciences Corporation (AASC): A. Gerhan et al.
- Kyoto U.: Y. Iwashita et al.
- USCD: V. Nesterenko et al.
- OSU: E. Collings et al.
- KEK: S. Mitsunobu, S. Inagaki

Our apologies if we missed someone, and for lacking the people in Europe due to less interactions! We hope to interact more at and after this workshop!