MgB_2 Thin Film Studies

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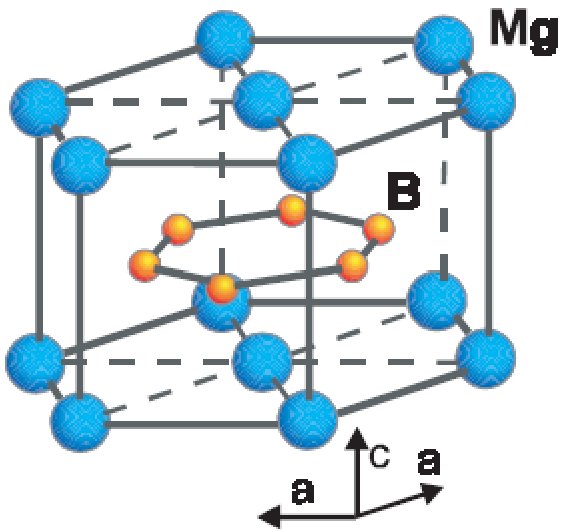


- Relatively easy to deposit compared to other higher-TC SC.
- Absence of weak links $\Rightarrow$ Less Q_0 drop as H (equiv. of E) goes up.
- Similar behavior to other low-temperature superconductors except for 2-gap nature

[**Cristina Buzea and Tsutomu Yamashita**, Supercond. Sci. Technol. **14** (2001) R115–R146]

Magnesium Diboride (MgB_2)

Discovered by Jun Akimitsu et al. of Aoyama Gakuin Univ., Japan, in 2001 (Announced in January) [J. Nagamatsu et al., *Nature* 410 (2001) 63.]

Outline

- Background / motivation
- Results of $B_{penetration}$ measurements using SQUID magnetometry at LANL (Nestor Haberkorn's poster THPO012). Samples from Superconductor Technologies, Inc. (STI)
- Results of RF surface resistance and quench field measurements at SLAC (Jiquan Guo's talk about the measurement system and Nb results in the next session). Samples from STI.
- Some updates from Xiaoxing Xi's group at Temple Univ.
- Conclusion

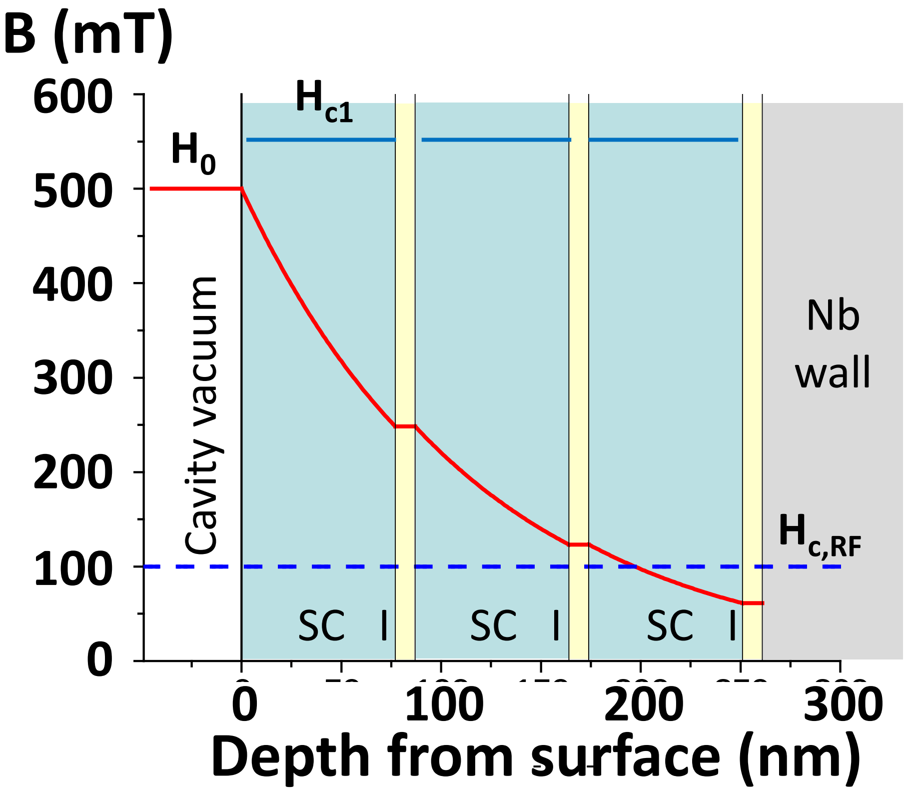
See my tutorial for other studies done in the past, and D. Agassi's talk on MgB_2 films from the same source (STI)

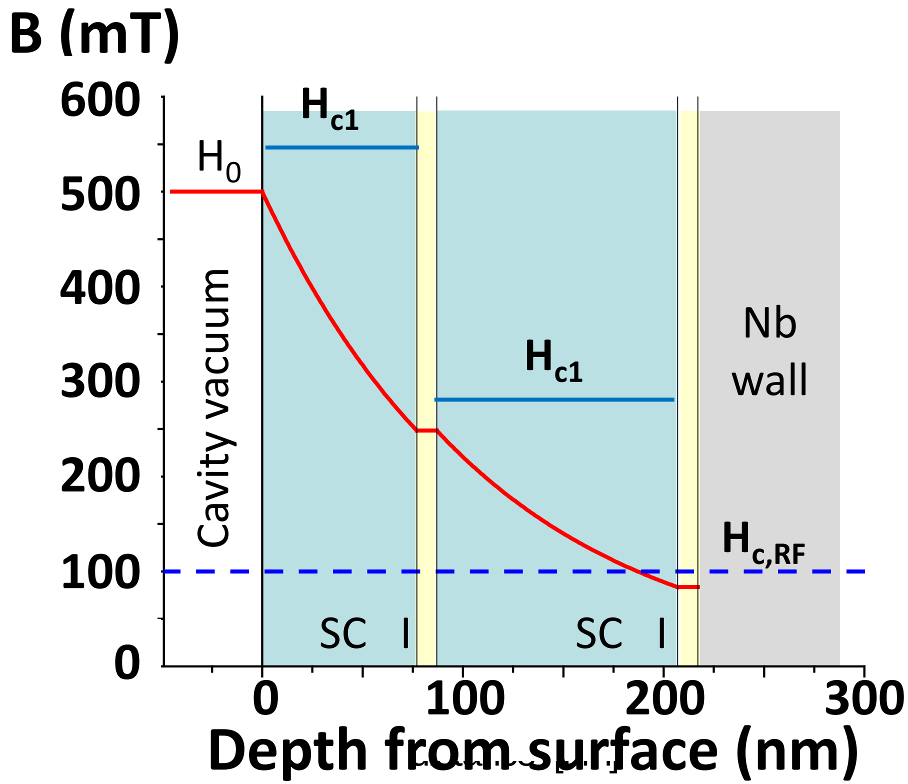
Background/Motivation

- **The highest operational accelerating gradient (E_{acc}) of existing accelerators is ~20 MV/m, but there have been more and more cavities with >35 MV/m (ILC goal), and even 45 MV/m!**
- **Fundamental limit of Nb cavity is 50-60 MV/m due to its superheating magnetic field of ~200 mT.**
- **Overcoming this limit and producing >100 MV/m cavities will allow us to;**
  - **Greatly benefit all the future projects that use SRF cavities**
  - **Open up a variety of other applications such as compact and less expensive accelerators for homeland security, medical and other applications**
- **Demonstrating Gurevich's idea (multilayer superconducting thin films) and realizing >100 MV/m is our primary goal**

Variable thickness films could reduce the number of layers

An example of achieving ~125 MV/m using MgB_2 layers (λ = 110 nm) with 10 nm insulation layers

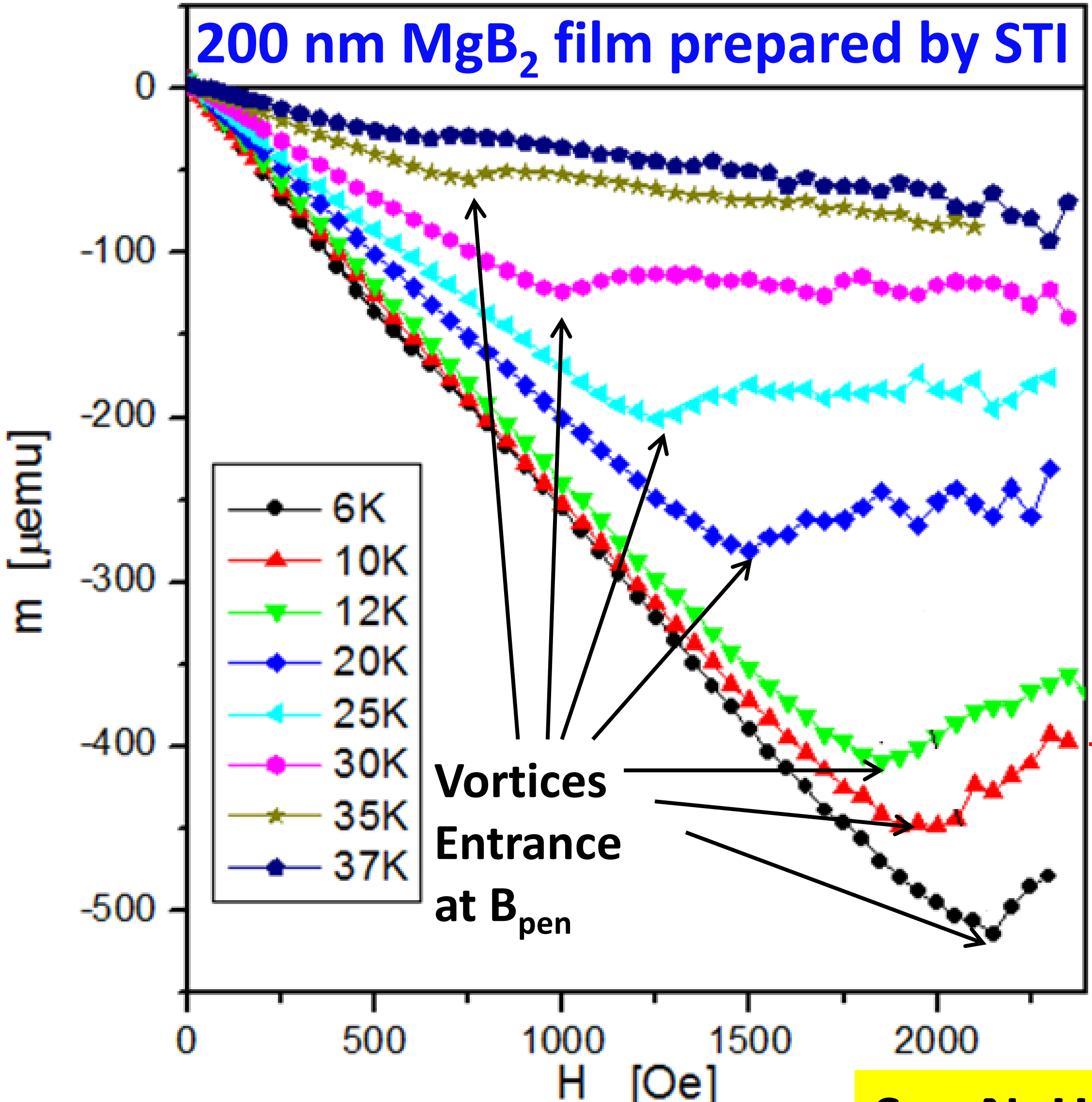




<u>Fixed thickness multilayers</u>:
- $d \leq$ 77nm for $H_{c1} \geq$ 5500 Oe
- 3 layers needed
- coating curved walls with very thin uniform of layers is challenging

<u>Variable thickness multilayers</u>:
- $d_1 \leq$ 77nm for $H_{c1} \geq$ 5500 Oe
- only 2 layers needed
- 2nd layer is thicker: 100nm $\leq d_2 \leq$ 120nm

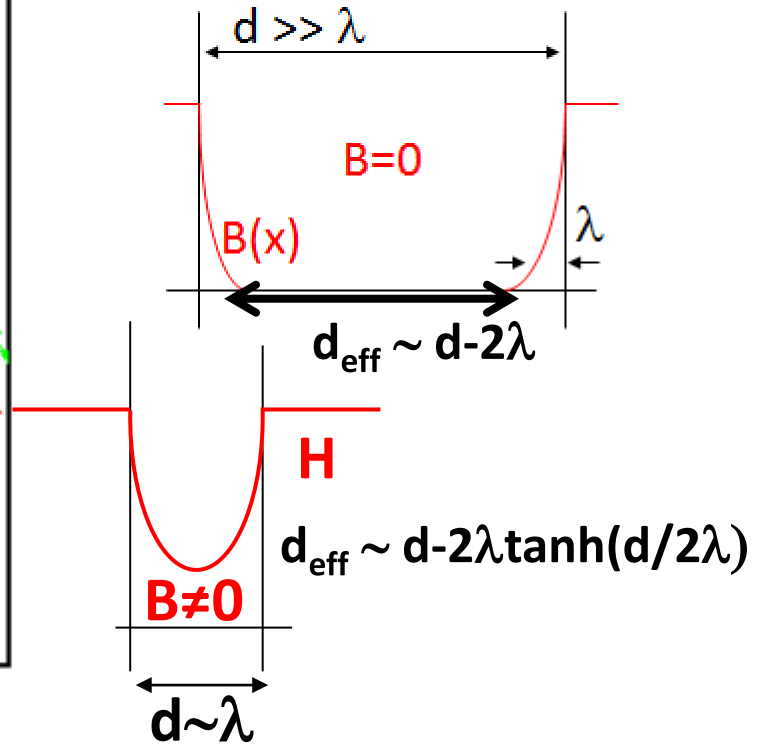
Magnetization measurements with a SQUID magnetometer



Meissner state:

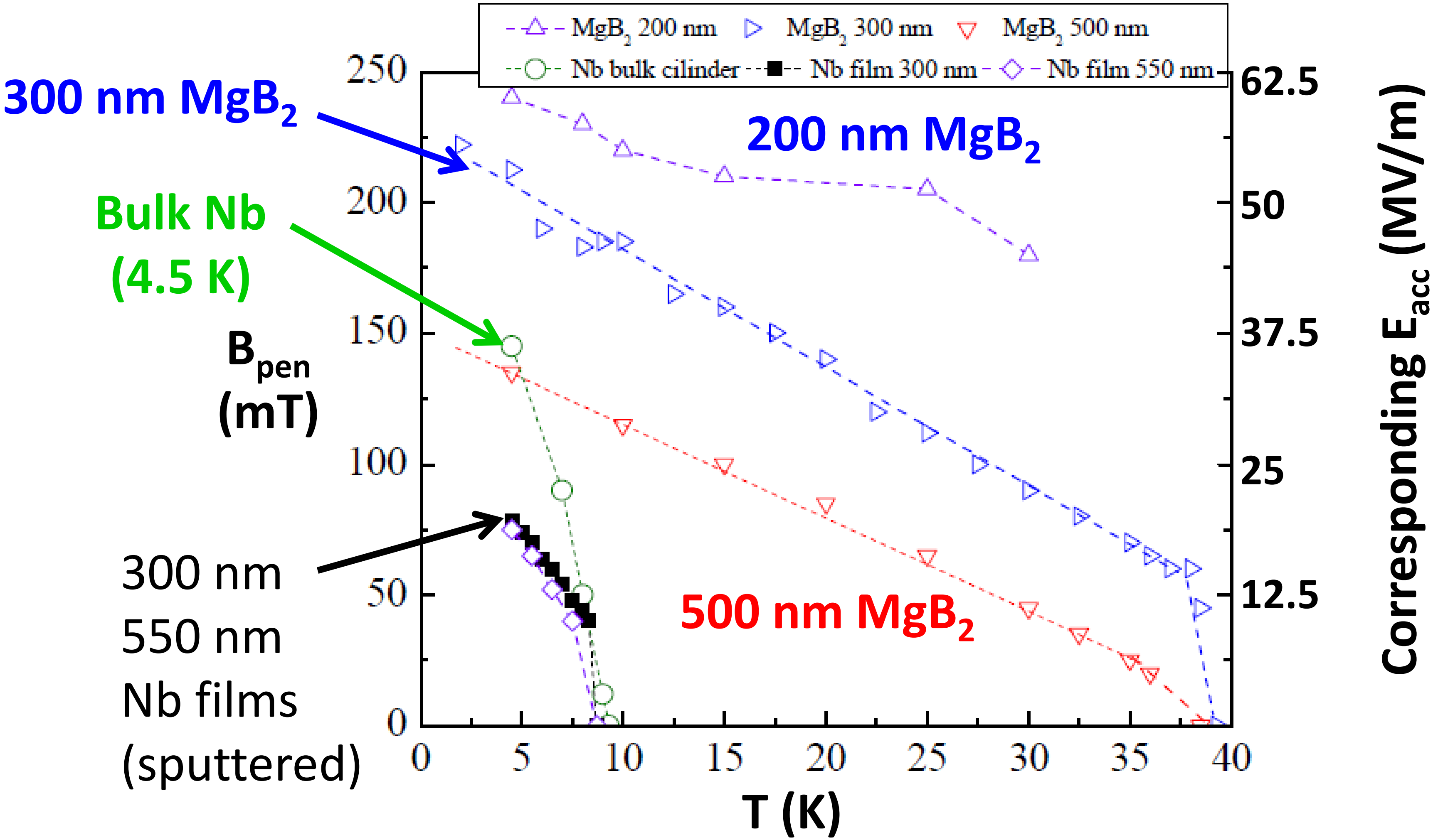
$dm/dH = -V_{eff}/4\pi \propto d_{eff}$

Slope changes with T due to the change in λ



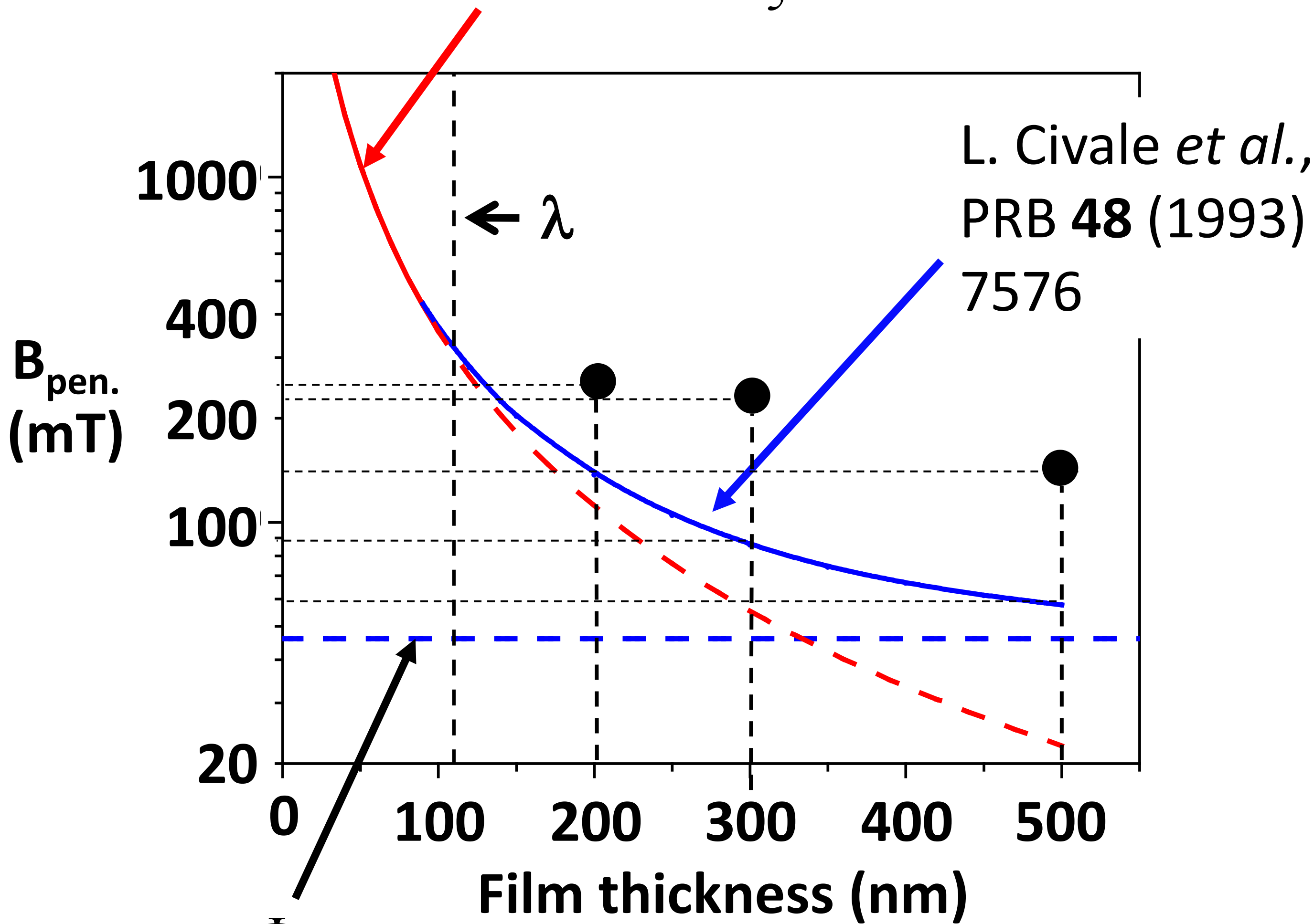
See N. Haberkorn's poster THPO021

DC magnetization measurement results: MgB_2 thin films (<500 nm) prepared by STI show higher B_p than that of Nb



B_{pen} data are higher than expected B_{c1} (λ=110 nm, ξ=6 nm)

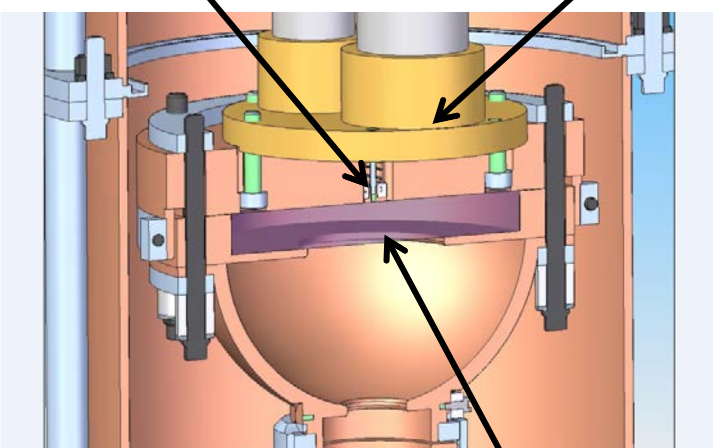
$$H_{c1}(d << \lambda) \approx \frac{2\Phi_0}{\pi d^2} \ln \frac{d}{\tilde{\xi}}$$ Gurevich, APL **88** (2006) 012511



$$H_{c1}(d >> \lambda) = \frac{\Phi_0}{4\pi\lambda^2} \ln \kappa \sim$$ **46 mT**

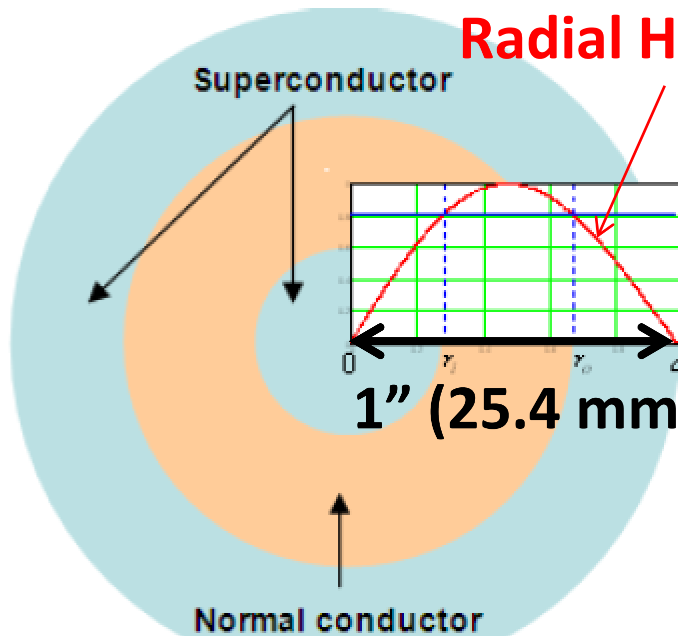
RF measurements of 2-inch (50.8 mm) diameter wafers (~1 mm thick) have been carried out at SLAC using 11.4 GHz system [S. Tantawi, J. Guo et al.]

Hemi-spherical TE_{013}–mode cavity with magnetic fields in parallel with the sample surface



Pulse length: 1.6 μs
Repetition rate: 1 Hz

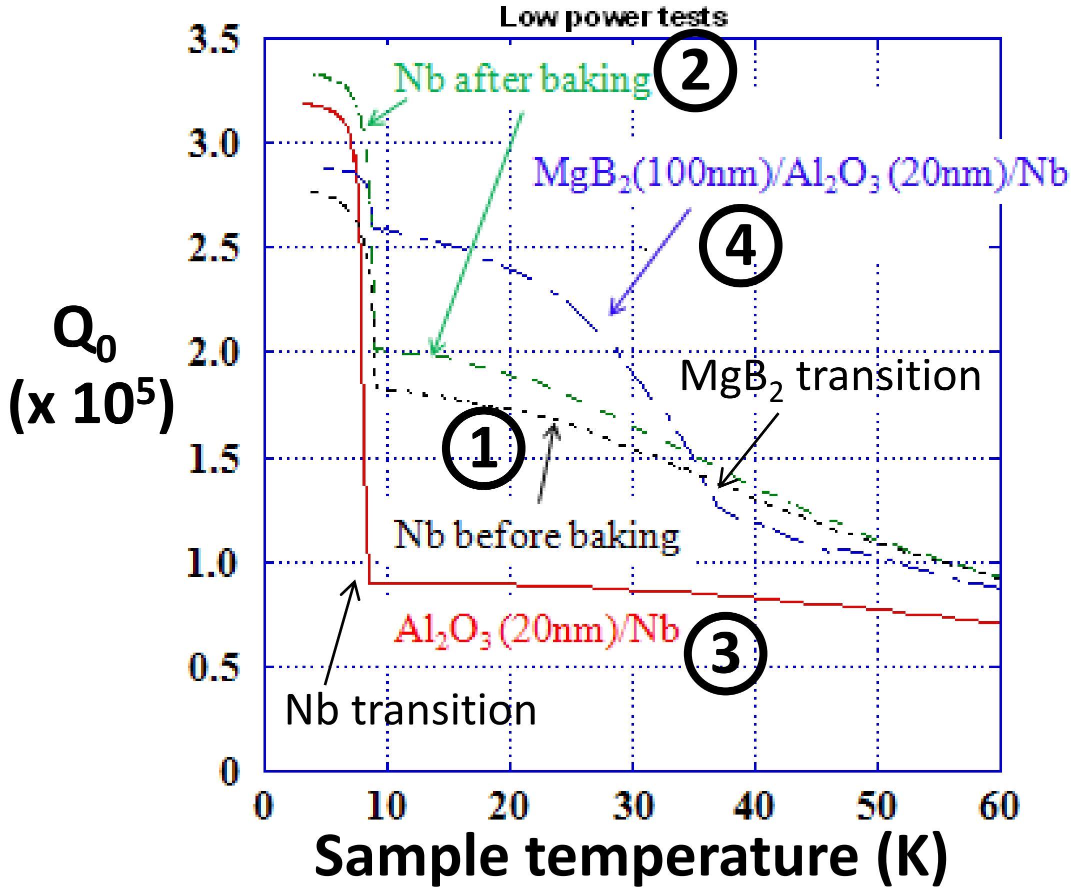
Typical distribution of superconducting and normal-conducting regions after quench



Talk by J. Guo in the next session

Low-power test results on Nb, Al_2O_3(20nm)/Nb and MgB_2(100nm)/Alumina(20nm)/Nb

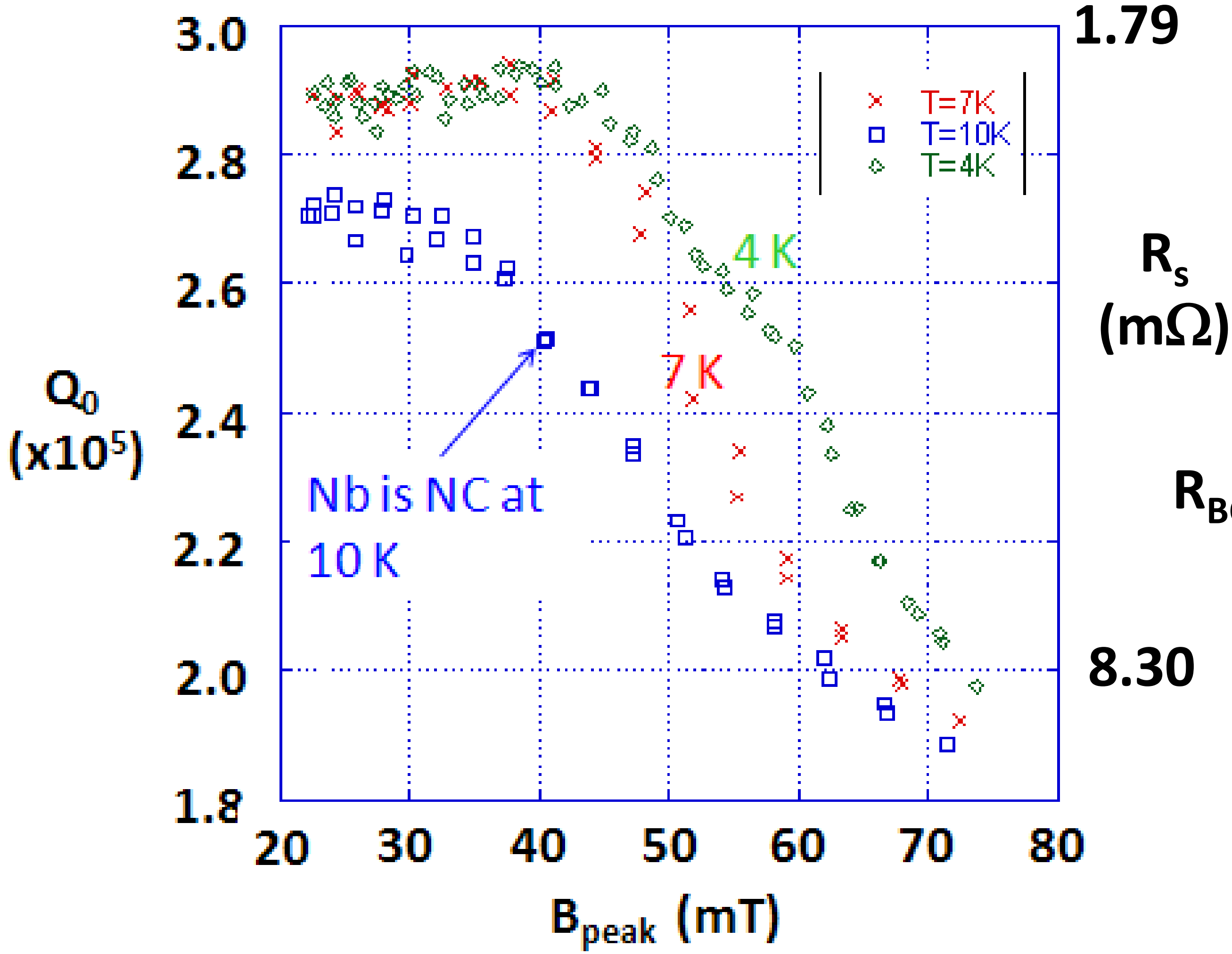
Max. Q_0 ~ 3.5 x 10^5 due to Cu host cavity



11.4 GHz

- UHV baking at 800 °C for 4 hours cleaned the Nb surface
- Alumina coating with ALD at 300 °C increased RF resistance in both NC and SC states
- Subsequent MgB_2 coating with reactive co-evaporation at 550 °C reduced NC resistance down to Nb transition, but increased SC resistance at <9 K.

High-power test results of MgB_2(100nm)/Al_2O_3(20nm)/Nb: Quenched at ~43 mT at 4 K and at ~33 mT at 10 K



Very high R_s

R_{BCS}^{Nb} (4K) ~ 40 μΩ

The power density that causes thermal quench has been determined using experimental data

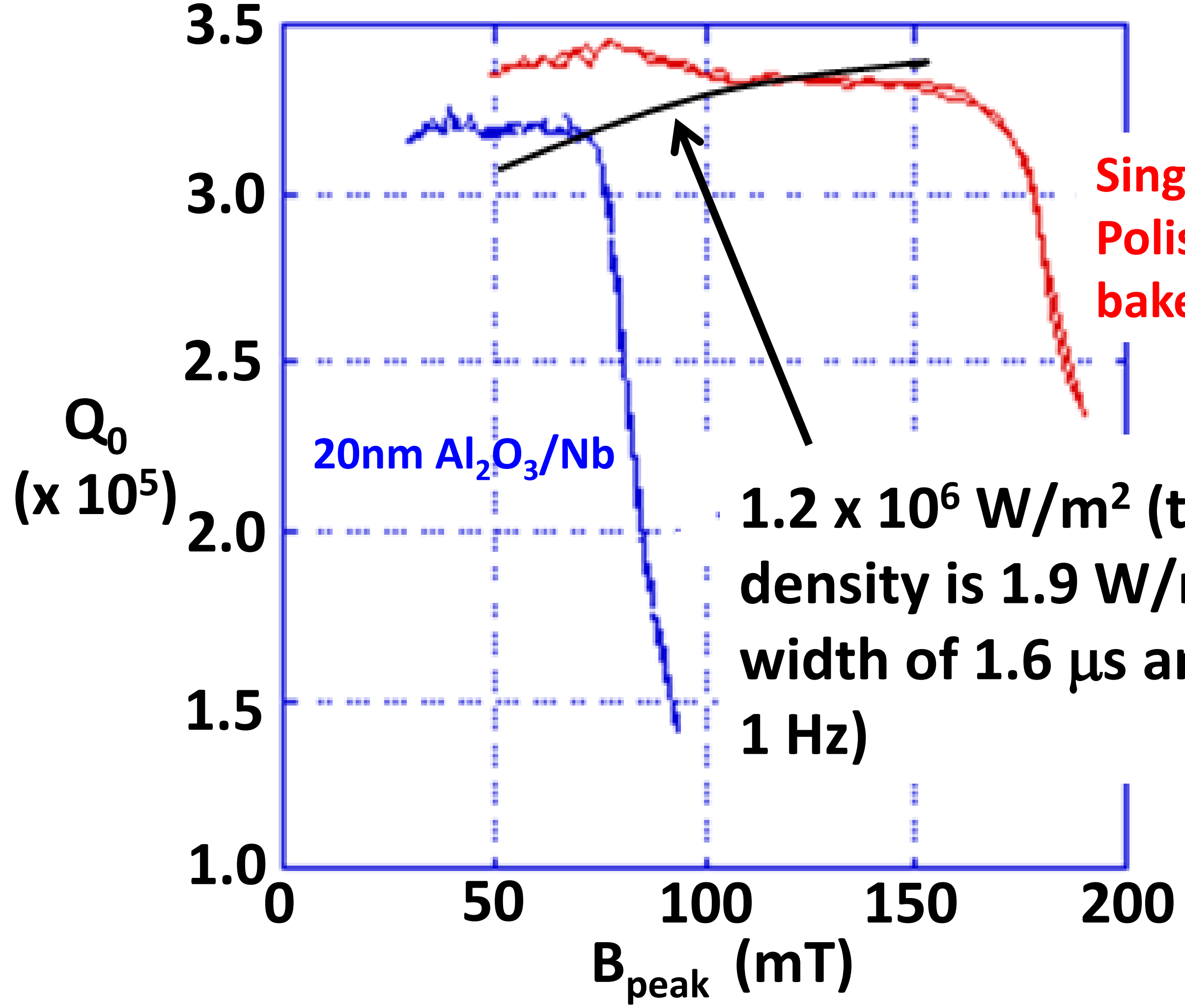
With the SLAC system, the following relationship between Q_0 and B_{peak} holds

$$Q_0 = \left[8.08 \times 10^{-10} \times \frac{P_{diss}[\mathrm{W/m^2}]}{\left\{ B_{peak}[\mathrm{mT}] \right\}^2} + 2.87 \times 10^{-6} \right]^{-1}$$

P_{diss} : peak power density

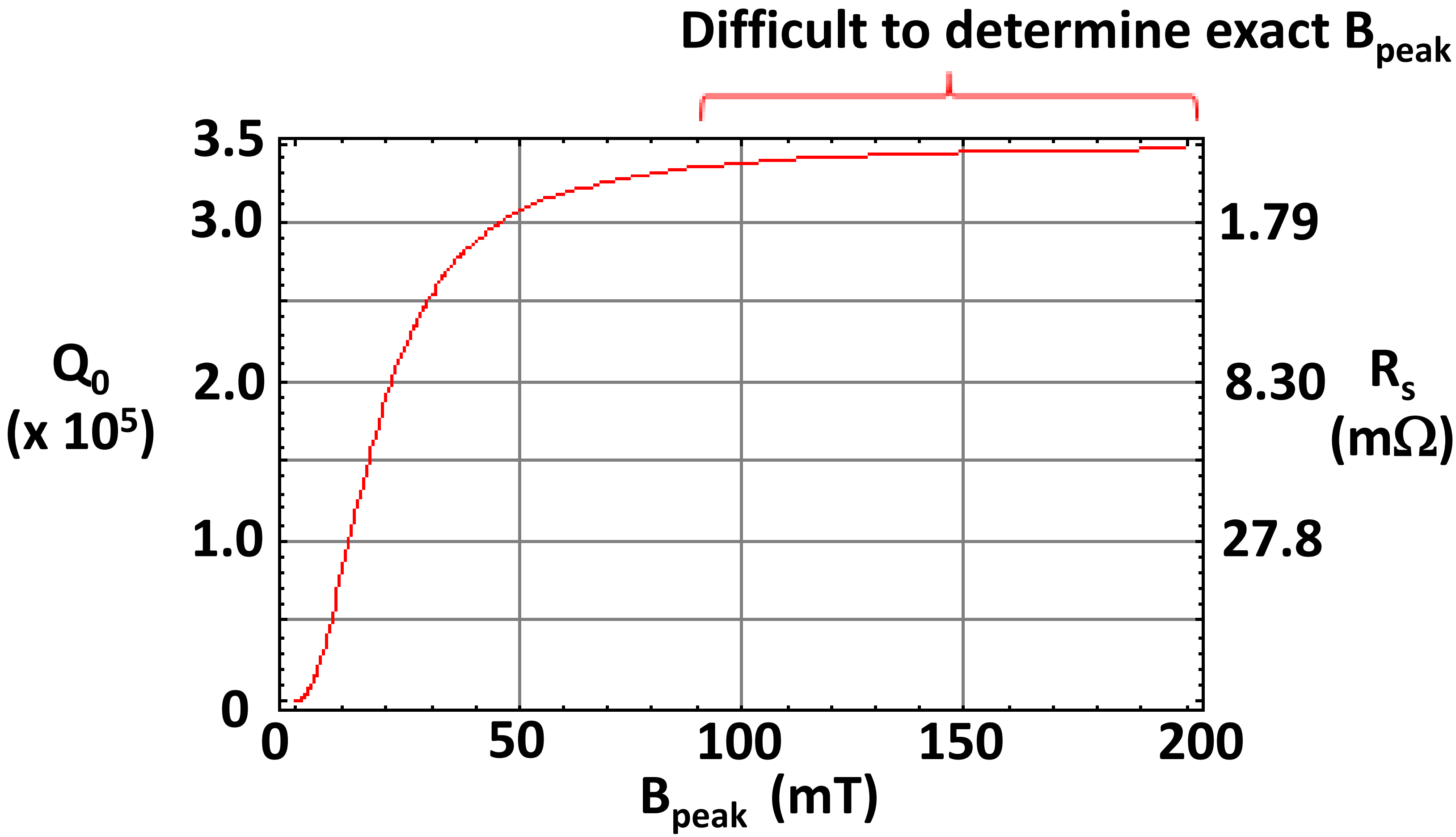
A peak power density needed to thermally quench the sample was determined from other data

Max. $Q_0 \sim 3.5 \times 10^5$ due to Cu host cavity

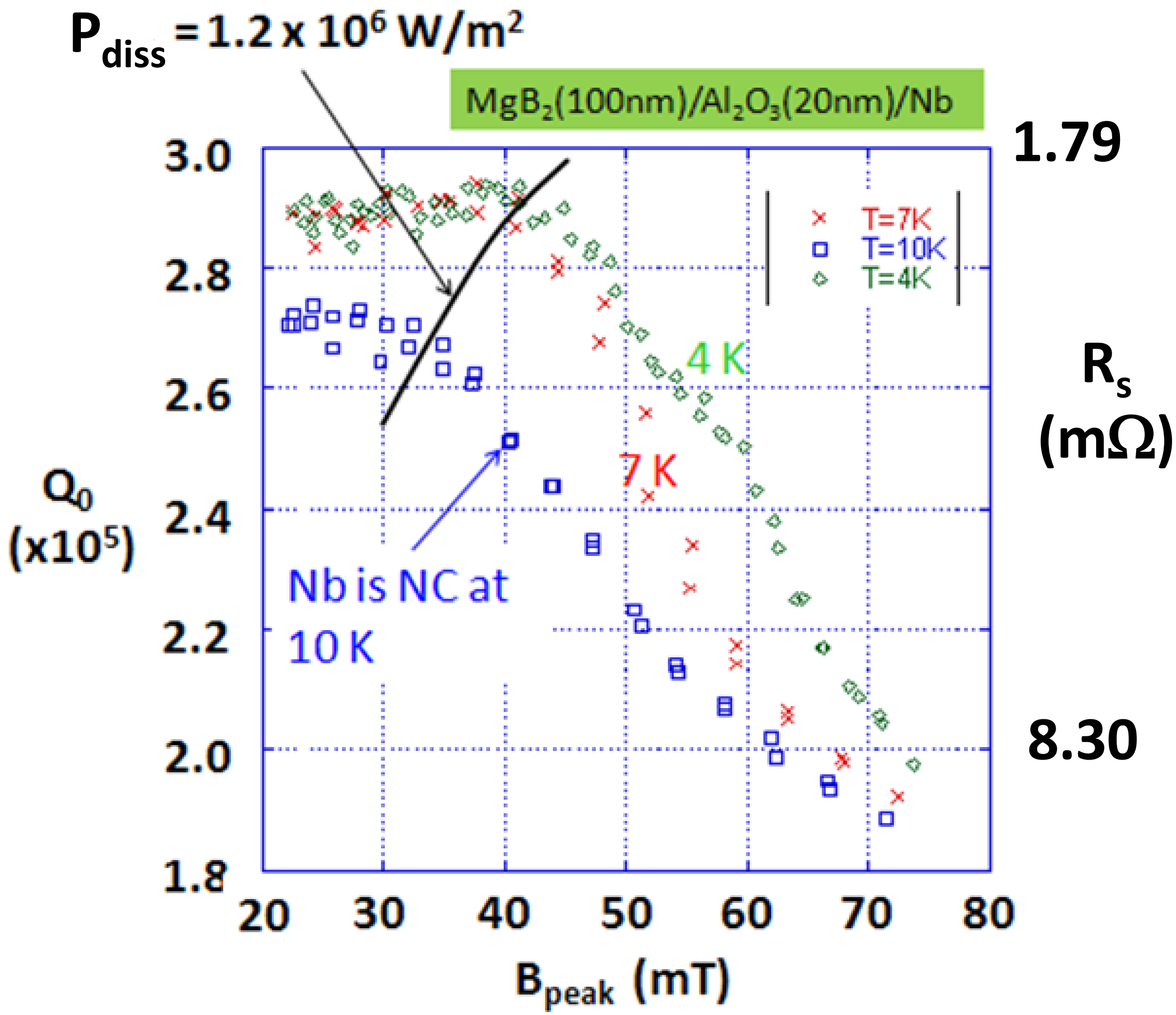


1.2×10^6 W/m^2 (time averaged density is 1.9 W/m^2 from pulse width of 1.6 μs and rep rate of 1 Hz)

Q_0 vs. B_{peak} at $P_{diss} = 1.2 \times 10^6\ W/m^2$ in the case of 2-inch single-grain Nb (thickness approx. 1.06 ± 0.06 mm) RRR > 300.

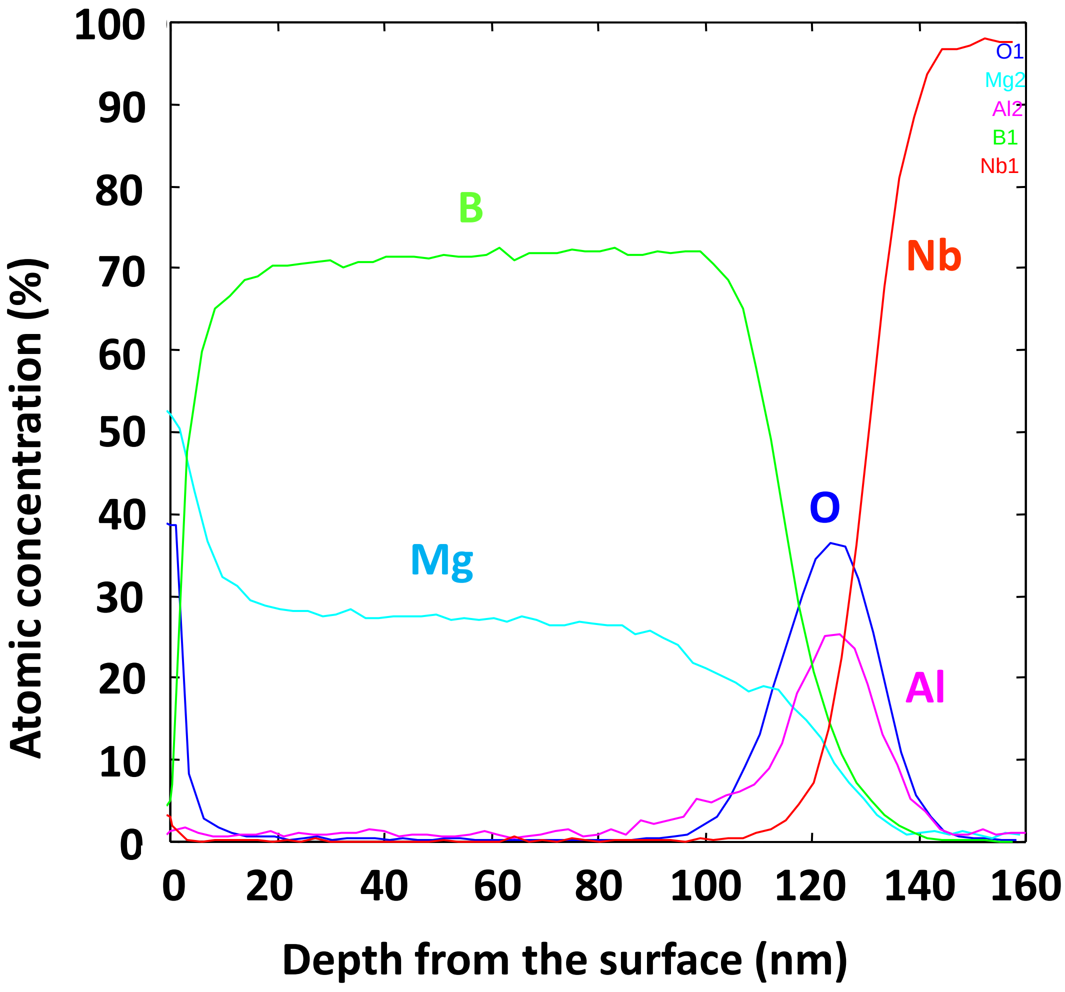


The $Q_0 - B_{peak}$ curve at $P_{diss} = 1.2 \times 10^6$ W/m^2 fit the quench field of MgB_2(100nm)/Al_2O_3(20nm)/Nb sample, indicating these quenches are thermal, not magnetic



An issue that needs to be addressed:

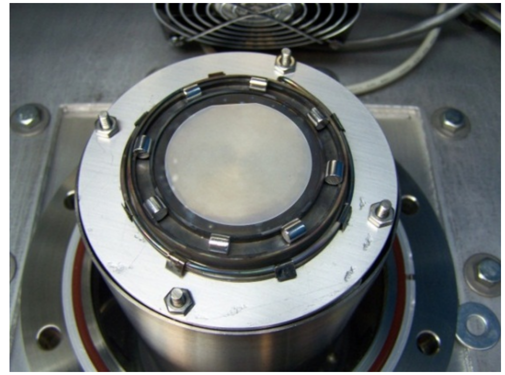
Auger depth profile shows inter-diffusion of all the elements at the interfaces of MgB_2(100nm)/Al_2O_3(20nm)/Nb system

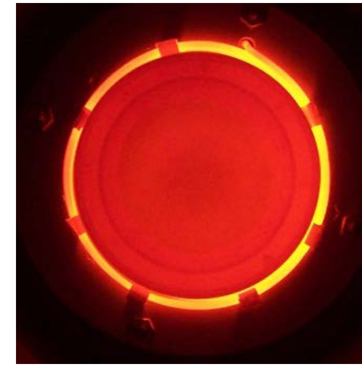


- Both ALD Alumina coating at 300 °C and MgB_2 coating at 550 °C have contributed to this inter-diffusion
- This interface layer is probably responsible for high RF resistance
- Developing a technique to prevent this inter-diffusion will be the key to success

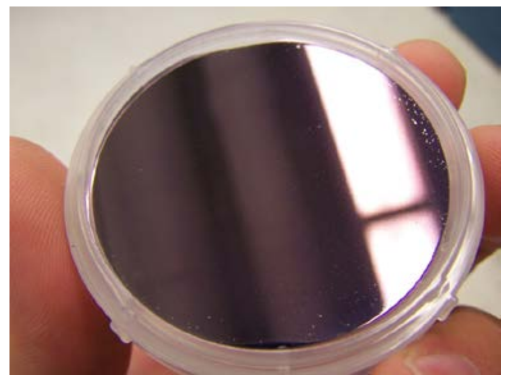
MgB_2 work at Temple University – HPCVD for high quality films (up to 2" wafers and 6 GHz cavities) [C. Zhuang, X. Xi]

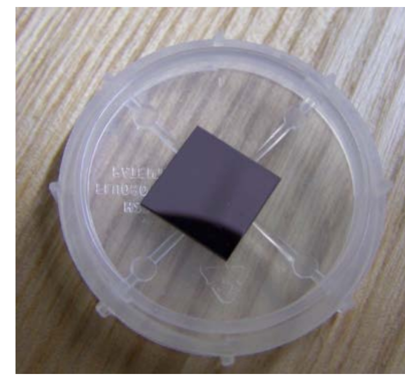
HPCVD system


Susceptor with 2'' wafer and Mg source loaded


heater run @ 740° C

Reactor chamber for regular film and 2'' film

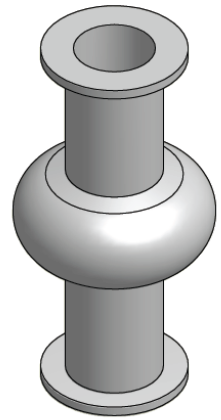

2'' MgB_2 on Sapphire


1cm^2 MgB_2 on sapphire

- ❑ Hybrid physical chemical vapor deposition
- ❑ Be able to make high quality MgB_2 films on different size (from 5x5mm^2 to 2'' wafer) and type substrates
- ❑ **Posters TUPO063 and TUPO064**

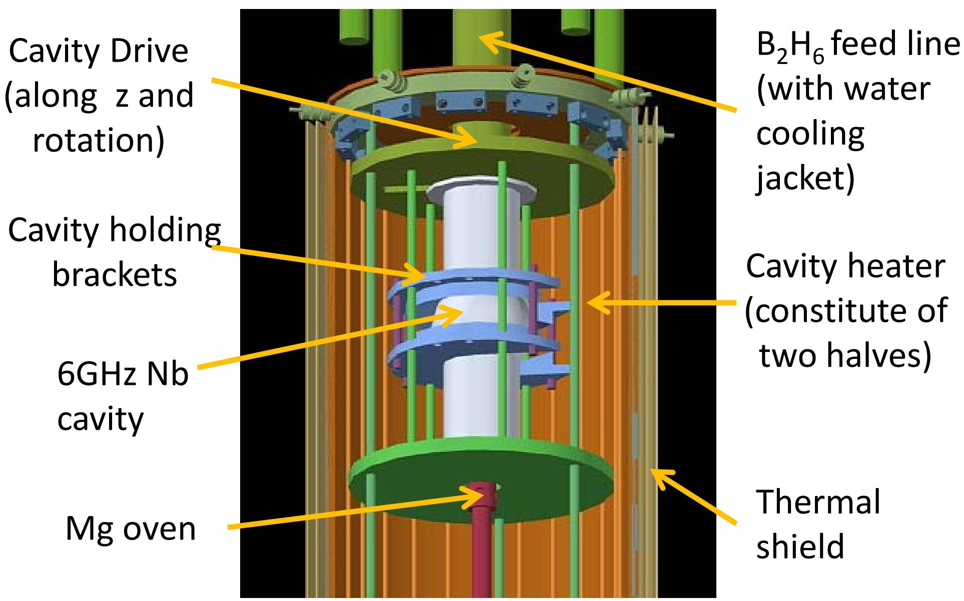
MgB_2 work at Temple – 6 GHz Nb cavity coating system

Integrated HPCVD system for cavity coating

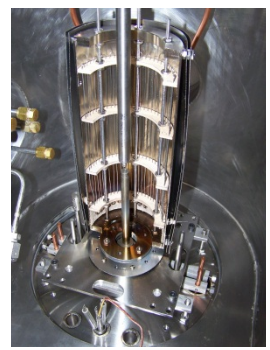


6 GHz Nb cavity
(4’’ high, 1.5’’dia.)

S.S. Dummy
(4’’ high, 1.5’’dia.)



Cartoon of cavity coating system



Front view

under test

Top view

- System for in-situ coating a real 6GHz Nb cavity
- B_2H_6 and Mg feeding line fixed, the cavity will move vertically in z direction and rotate
- System is close to completion, heater testing finished, same-size stainless steel dummy will be first coated for uniformity test

Conclusions

- **High B_{pen}'s (>200 mT) with STI 200-300 nm MgB_2 films were demonstrated. Measurements on thinner films are underway.**
- **High-power RF tests of MgB_2(100nm)/Al_2O_3(20nm)/Nb at 11.4 GHz have shown quench fields significantly lower than the values predicted with DC magnetization measurement. However, it was found that these quenches are mostly thermal, not magnetic, due to high R_s.**
- **We are working on a coating technique to reduce the inter-diffusion responsible for the increase in R_s**
- **Temple University started to provide high-quality MgB_2 samples up to 2-inch wafers and the facility for coating 6 GHz cavities is near completion. Their samples will be measured and compared with STI samples.**
- **Not shown here, but surface impedance measurements at 7.5 GHz are underway at JLab. See Binping Xiao's poster THPO048**