Status of MgB_2 Coating Studies for SRF Applications

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- KEK provided copper surrogate cavities.
- JLAB provided a Nb surrogate cavity.
- Cornell and FNAL provided their Nb disks and cavities, respectively, and FNAL offered to test MgB_2 coated cavities with diagnostics.
- Dan Oates of MIT for the email today!

Outline

- Background and motivation to use MgB_2.
- Brief summary of the characteristics of MgB_2 thin films comparing to Nb bulk and films
- Coating system at LANL
- Conclusions

Background and motivation

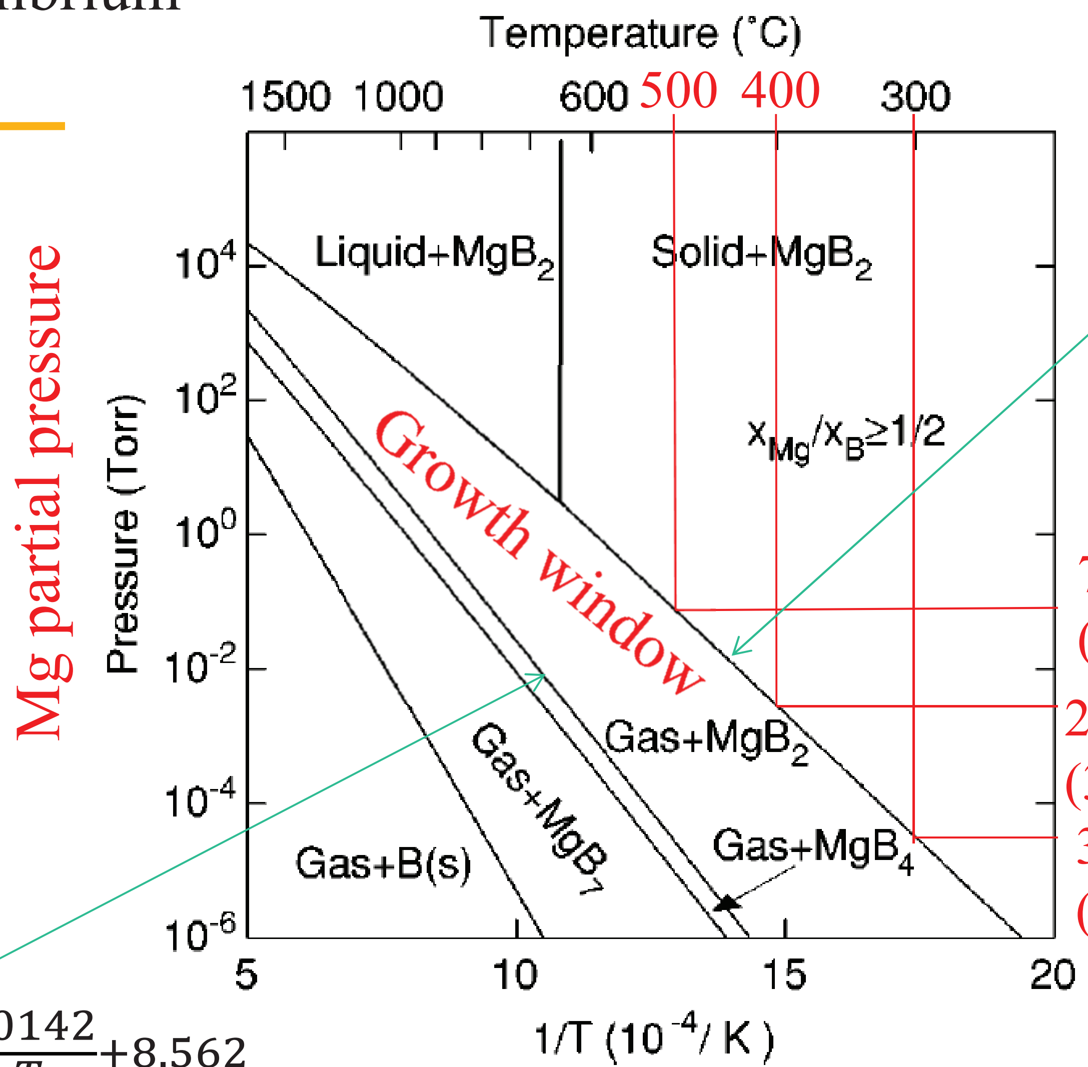
Background

- Nb technology has become close to its full capacity on gradient (E_{acc} ~ 50 MV/m for electron accelerator) due to its well known critical fields (B_{c1} ~ 170 mT and B_c ~ 200 mT)
- New materials with Gurevich's multi-layer idea could produce cavities that exceed the performance of Nb cavities and open up more opportunities to use SRF cavities.

Motivation to use MgB_2

- MgB_2 has quite high $T_c \sim 40$ K compared to other conventional s-wave superconductors (<20 K), leading to lower BCS resistance and higher thermal tolerance.
- Absence of weak links (low dependence of Q_0 on H)
- Simple chemical composition
- Can be coated at a large range or temperatures (>~250 °C)

In equilibrium



$$P = 10^{-\frac{7561}{T}+8.673}$$

(Lower boundary)

78 mTorr ↓

(2.8 x 10^{-5} Torr)

2.7 mTorr

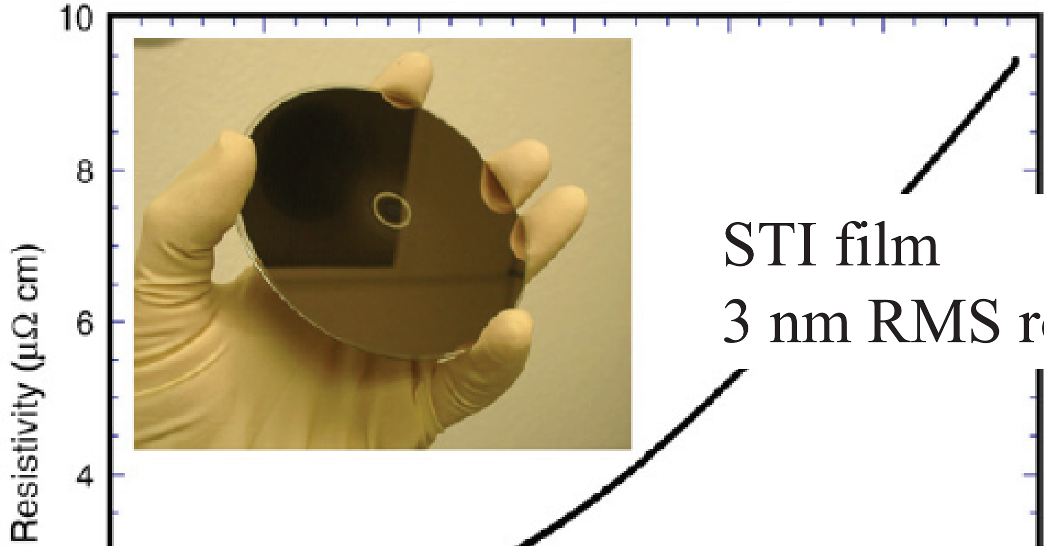
(3.1 x 10^{-7} Torr)

3.0 x 10^{-5} Torr

(7.3 x 10^{-10} Torr)

$$P = 10^{-\frac{10142}{T}+8.562}$$

[from Liu et al., APL 78 (2001) 3678.]



STI film
3 nm RMS roughness

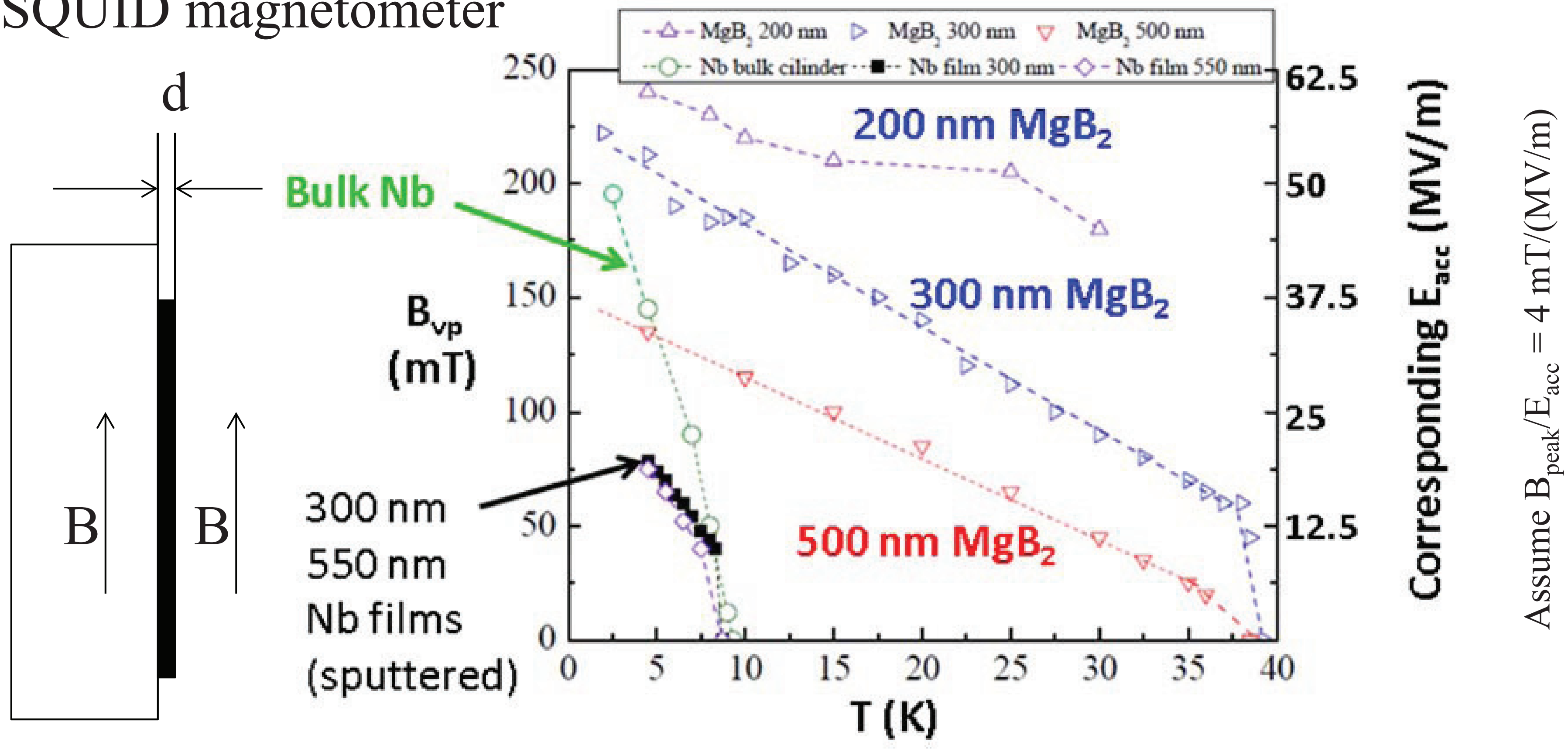
A brief summary of the characteristics of MgB_2 thin films compared to bulk and film Nb

Figure 2. Resistivity versus temperature for an MgB_2 film deposited on polycrystalline alumina. This film was grown at 550 °C to a thickness of 550 nm and has a zero-resistance T_c value of 39.1 K. The inset shows a photograph of an MgB_2 film grown on a 4 inch diameter *r*-plane sapphire substrate.

Summary of B_{vp} for STI films (200, 300 and 500 nm) compared with cavity-grade bulk Nb and sputtered Nb films

MgB_2 thin films show remarkably high B_{vp} !!

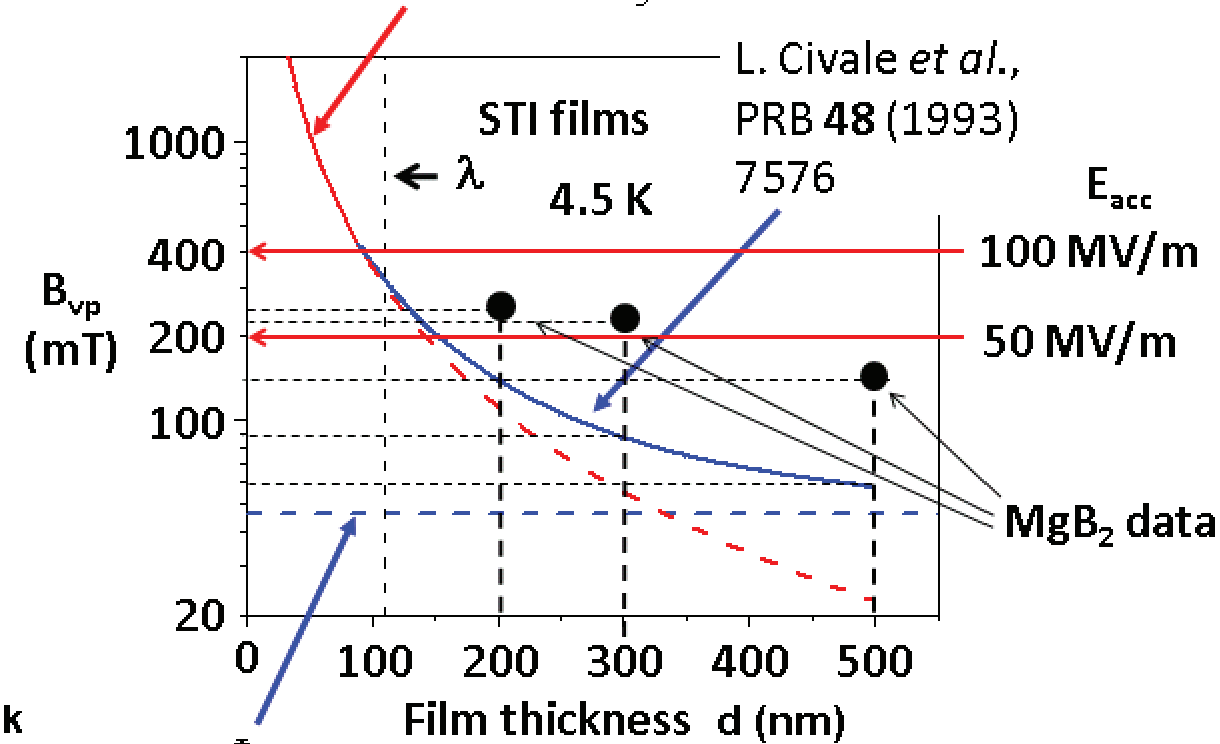
SQUID magnetometer



[Tajima et al. SRF2011] modified

Comparison with theoretical curve of B_{c1} for thin films assuming λ = 110 nm and ξ = 6 nm.

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

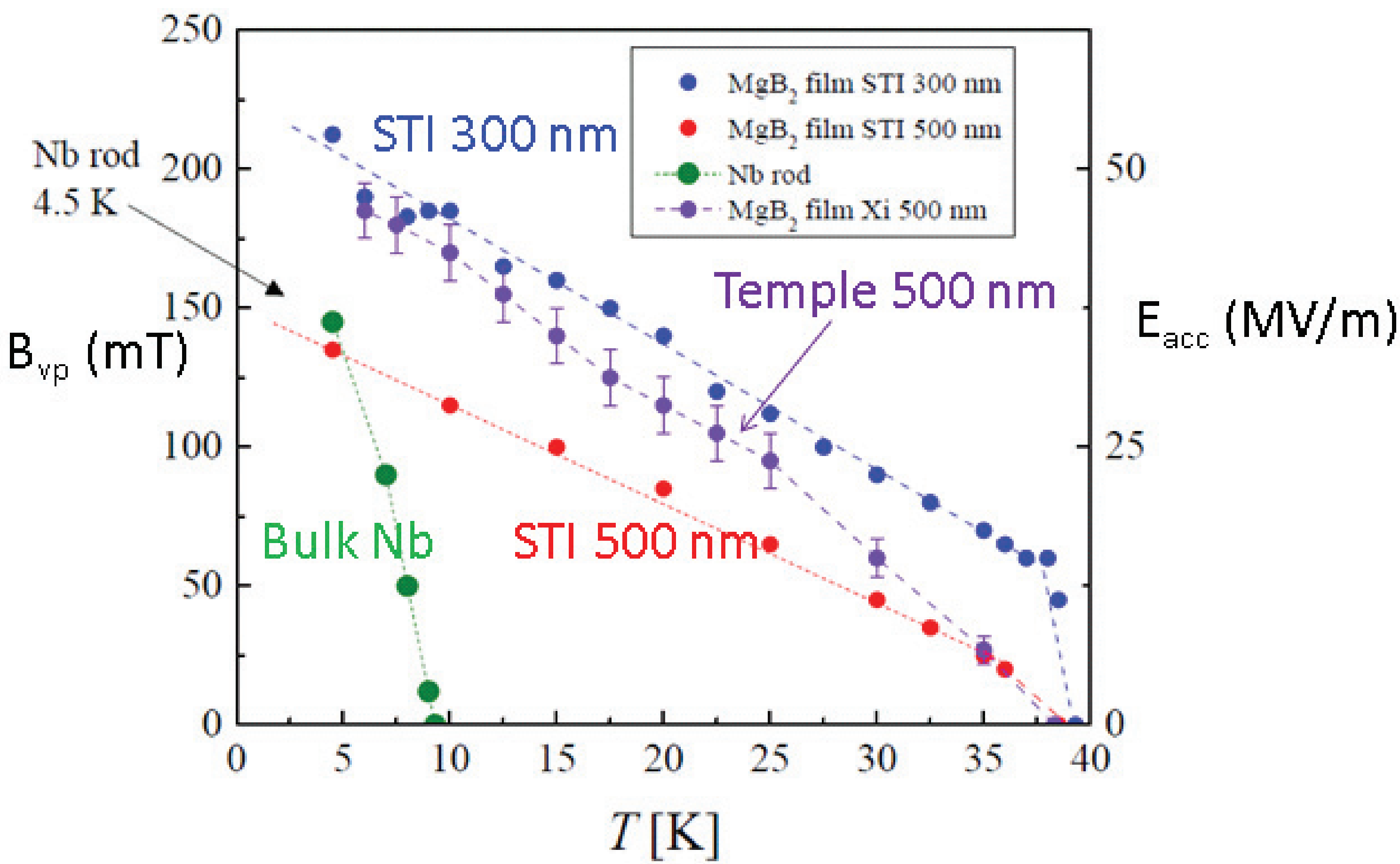


Bulk

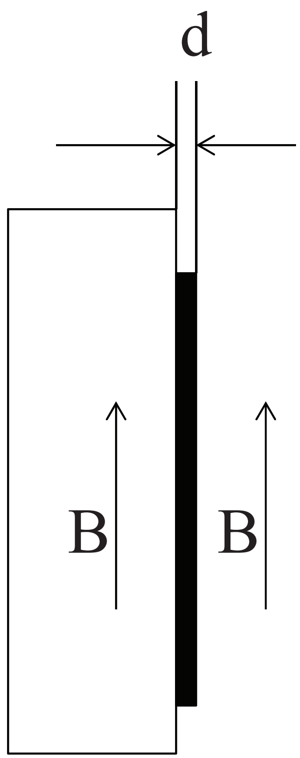
$$B_{c1}\,(d \gg \lambda) = \frac{\Phi_0}{4\pi\lambda^2} \ln \kappa \sim 46 \text{ mT}$$

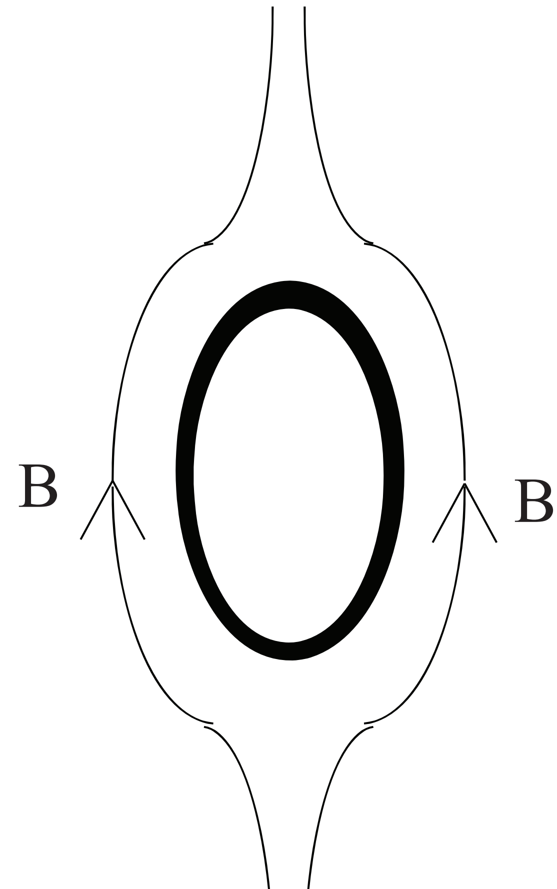
[Tajima et al. SRF2011] modified

Temple University (Xiaoxing Xi's group) samples prepared with hybrid physical chemical vapor deposition (HPCVD) showed the highest B_{vp} at the same thickness



Our plan to overcome the difficulty of measuring ultra-thin (<200 nm) films and realize cavity-like configuration

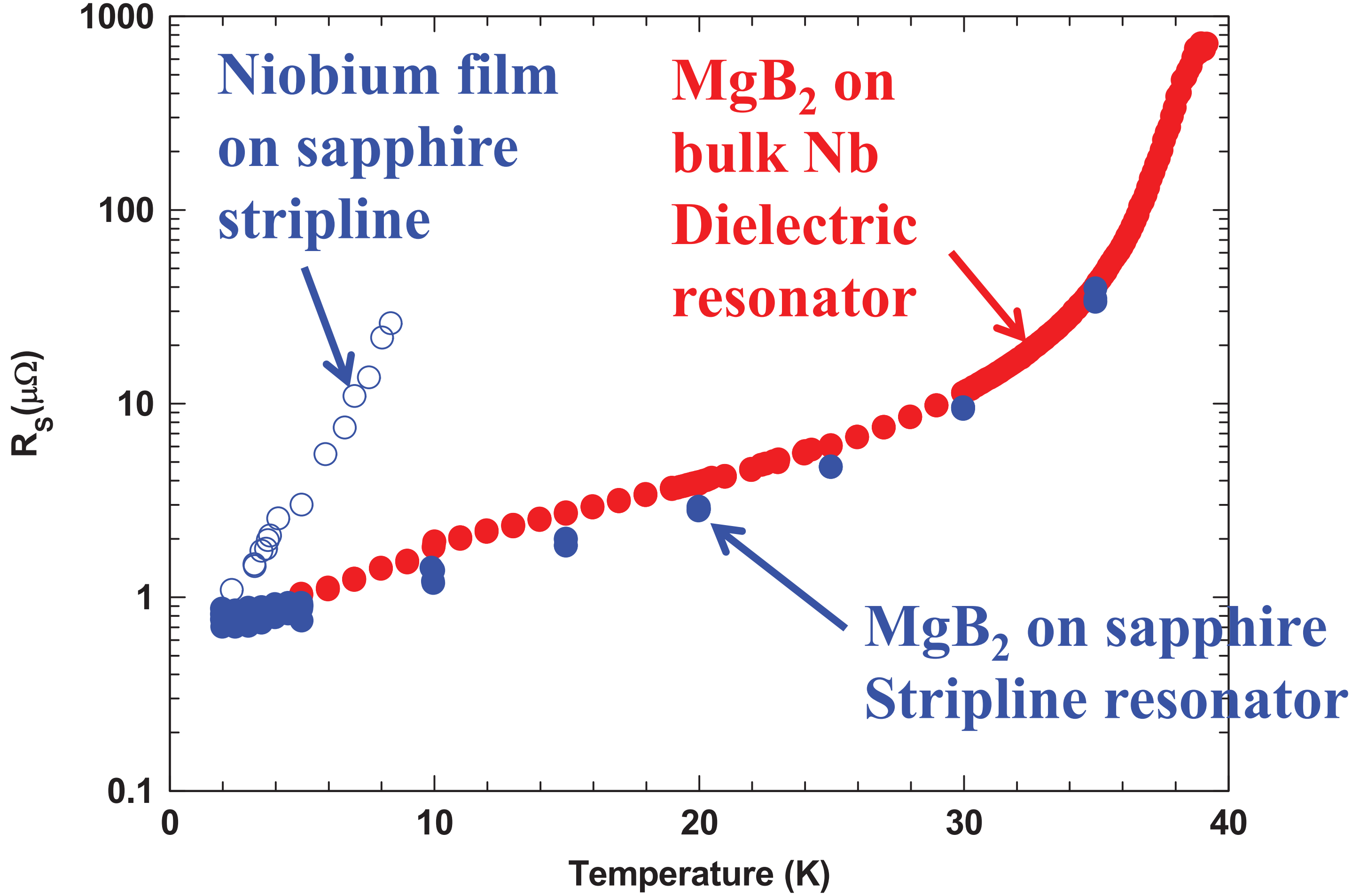




Magnetic moment m
$\propto$ volume of film (very small)

$m \propto$ volume of the football shape (very large)

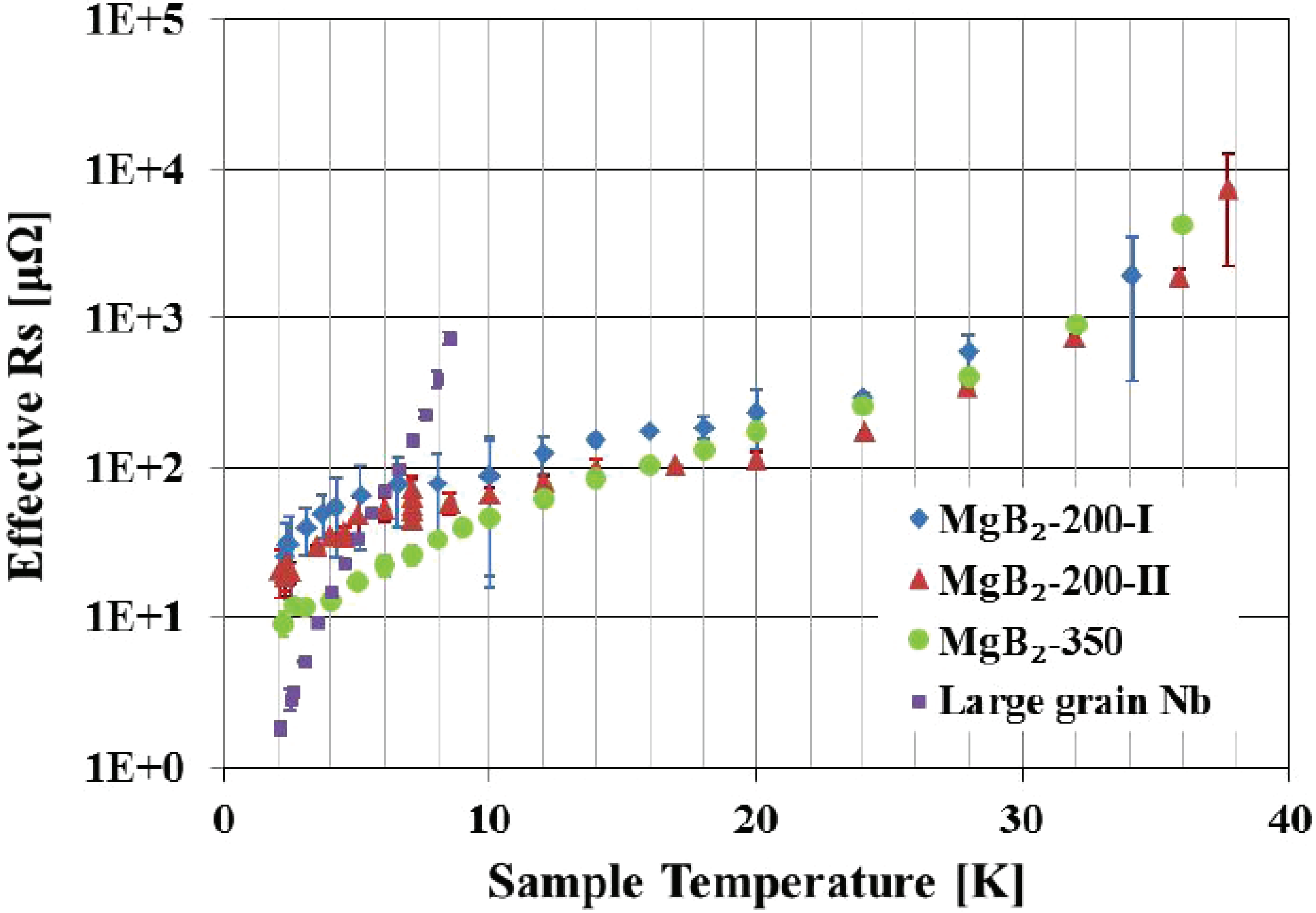
Low-power R_s (T) test results at MIT



R_S extrapolated to 2.2 GHz by f^2

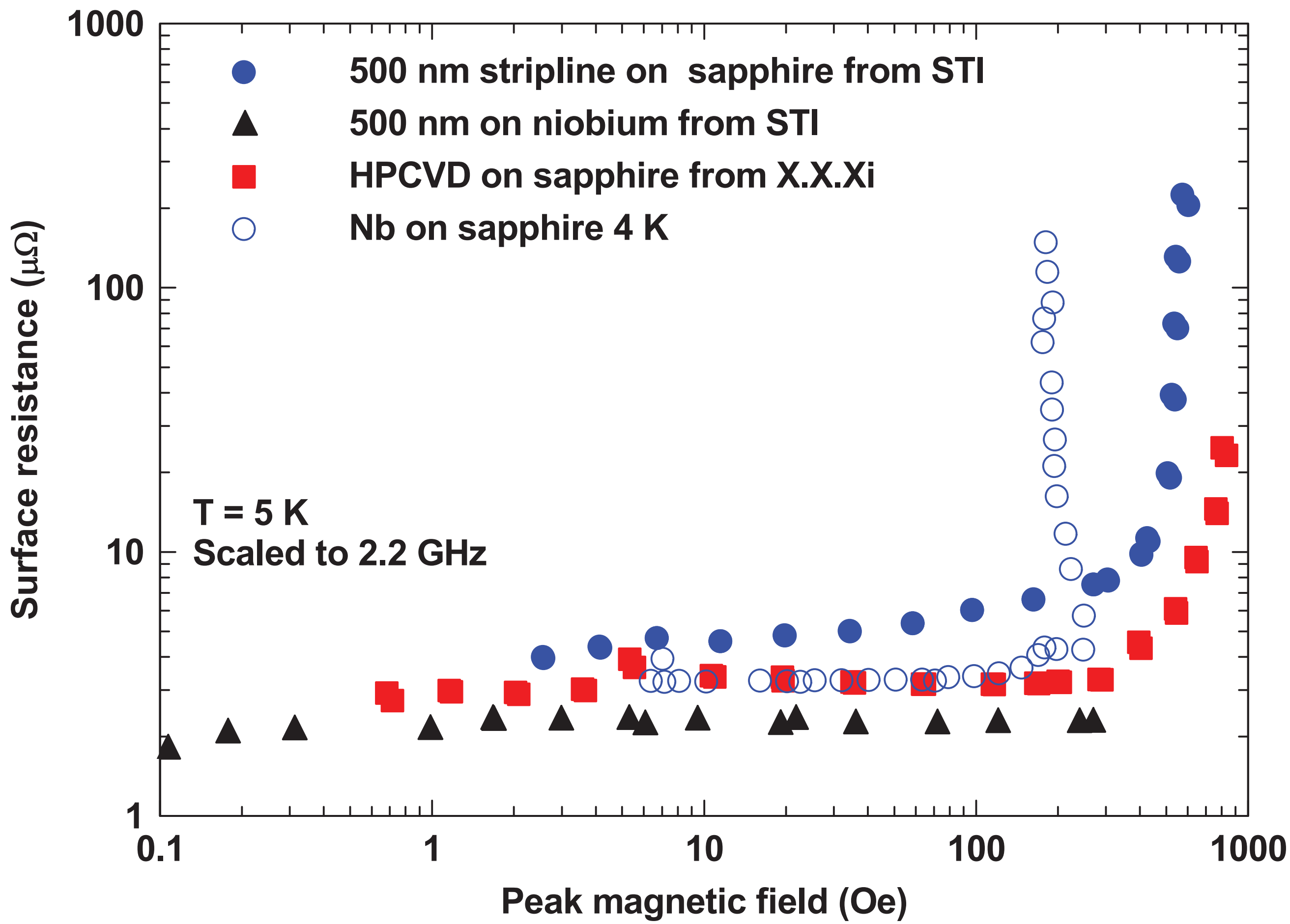
– [Oates et al., SRFTF workshop, JLAB, 2012] –

R_s (T) measured at JLAB



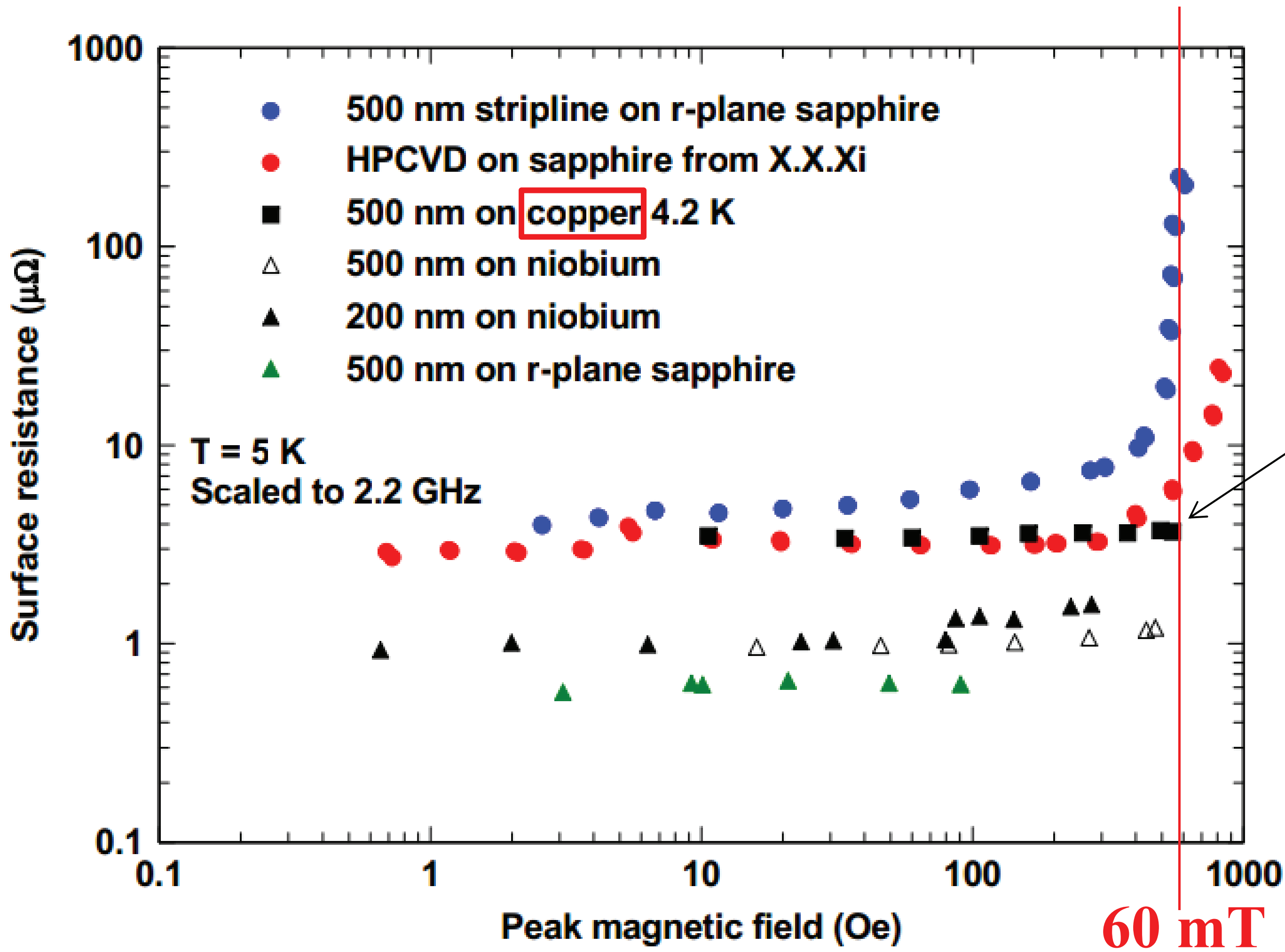
[B.P. Xiao et al., SUST 25 (2012) 095006]

R_s (H) measured at MIT



[Oates et al., SRFTF workshop, JLAB, 2012]

More recent data from MIT



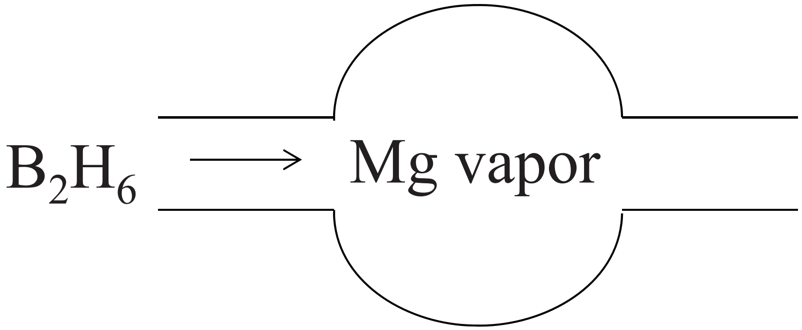
No quench
Power limited

[Dan Oates, email today]

Coating system at LANL

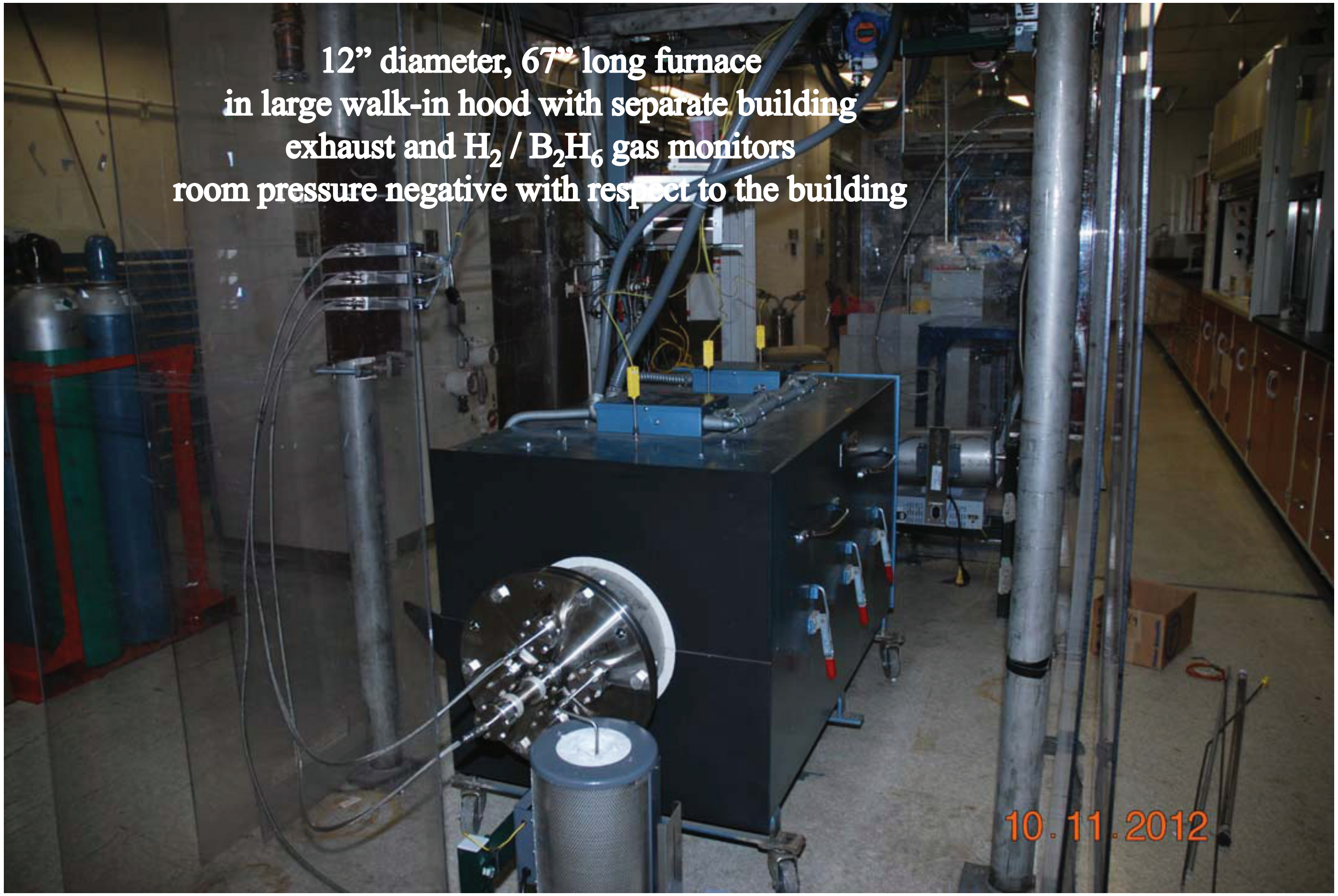
HPCVD was selected because

- Showed highest T_c
- Showed highest B_{vp}
- No UHV is required

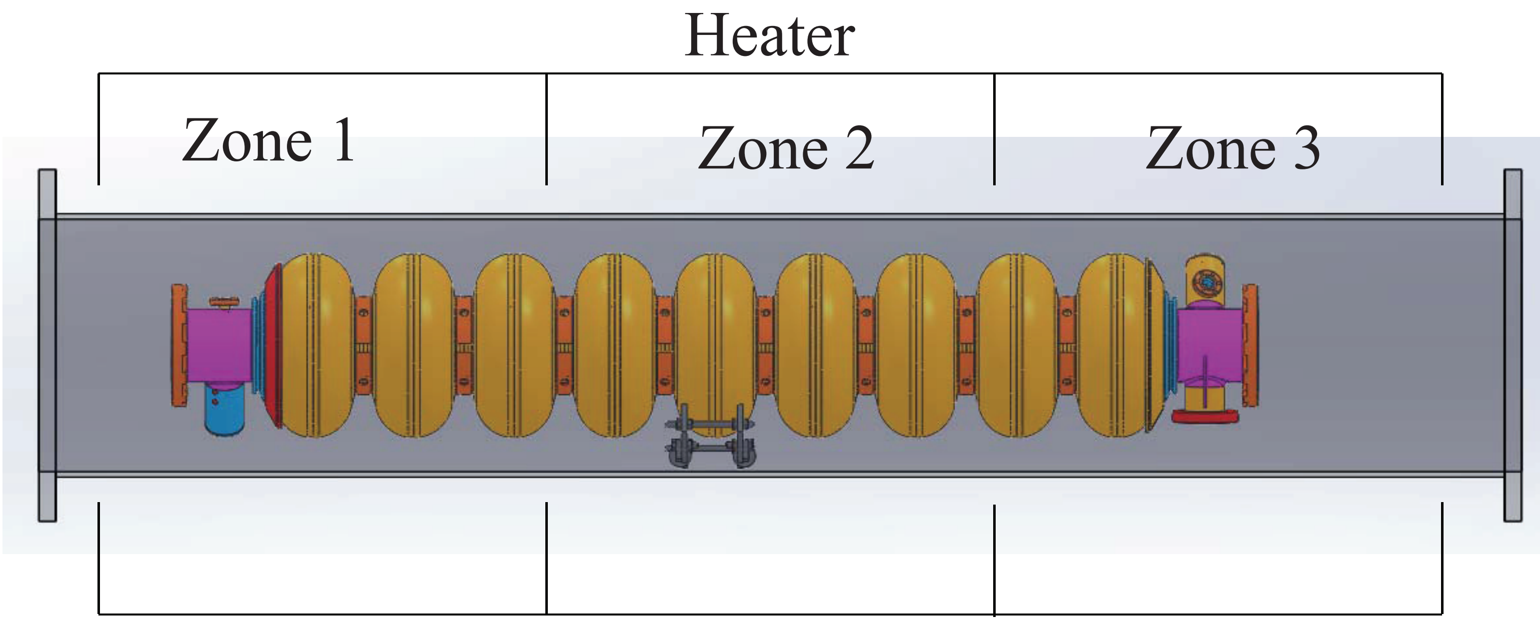


Need to be very careful about diborane (B_2H_6) gas due to its toxicity and flammability!

MgB_2 CVD reactor located at Technical Area 35 at LANL (unfortunately only US citizens allowed)

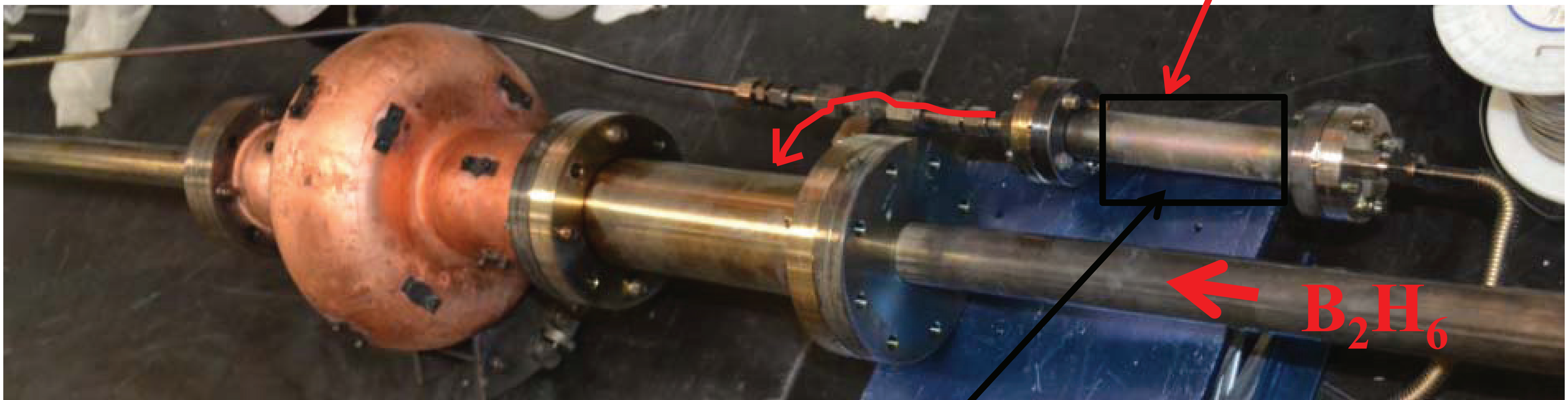


Furnace is big enough for a 1.3 GHz 9-cell cavity



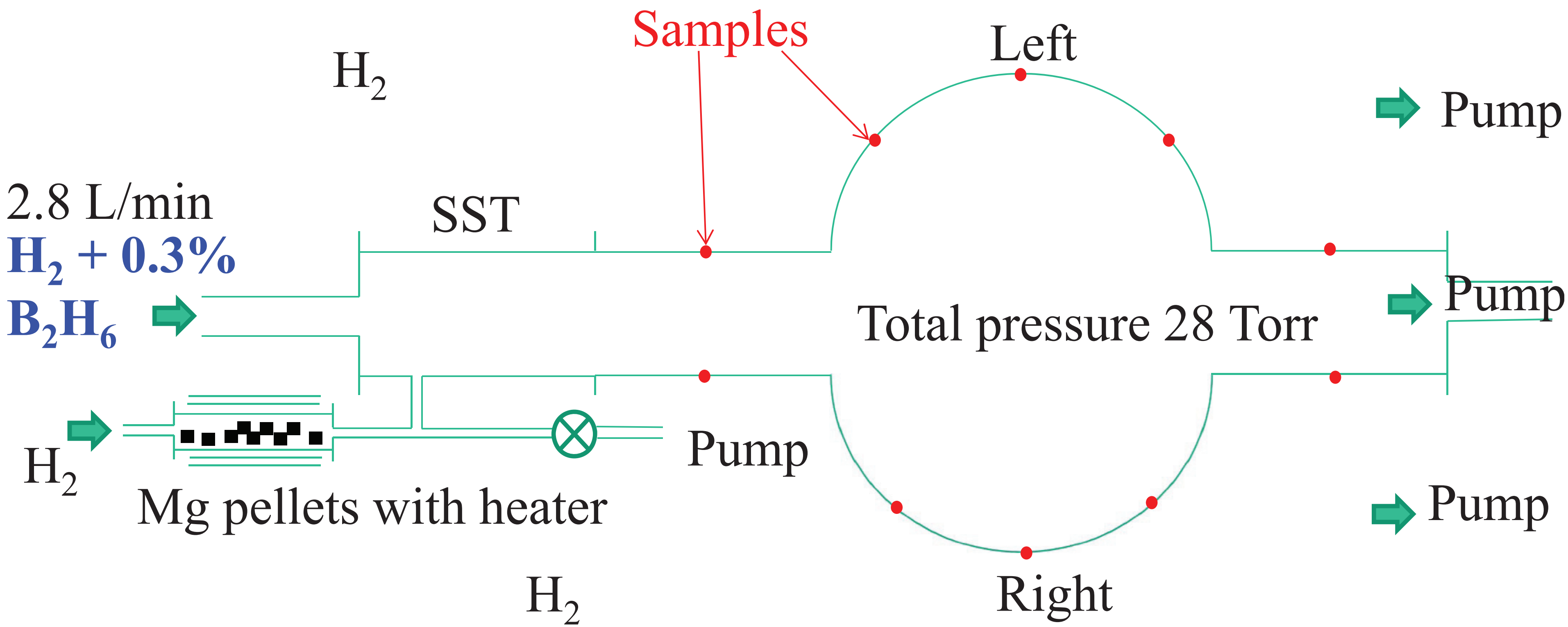
Currently a 1-cell Cu surrogate cavity is used with 6 mm × 6 mm (sapphire and Nb) samples attached in the holes on the surface

Mg pellets in this



Local heater (not shown)

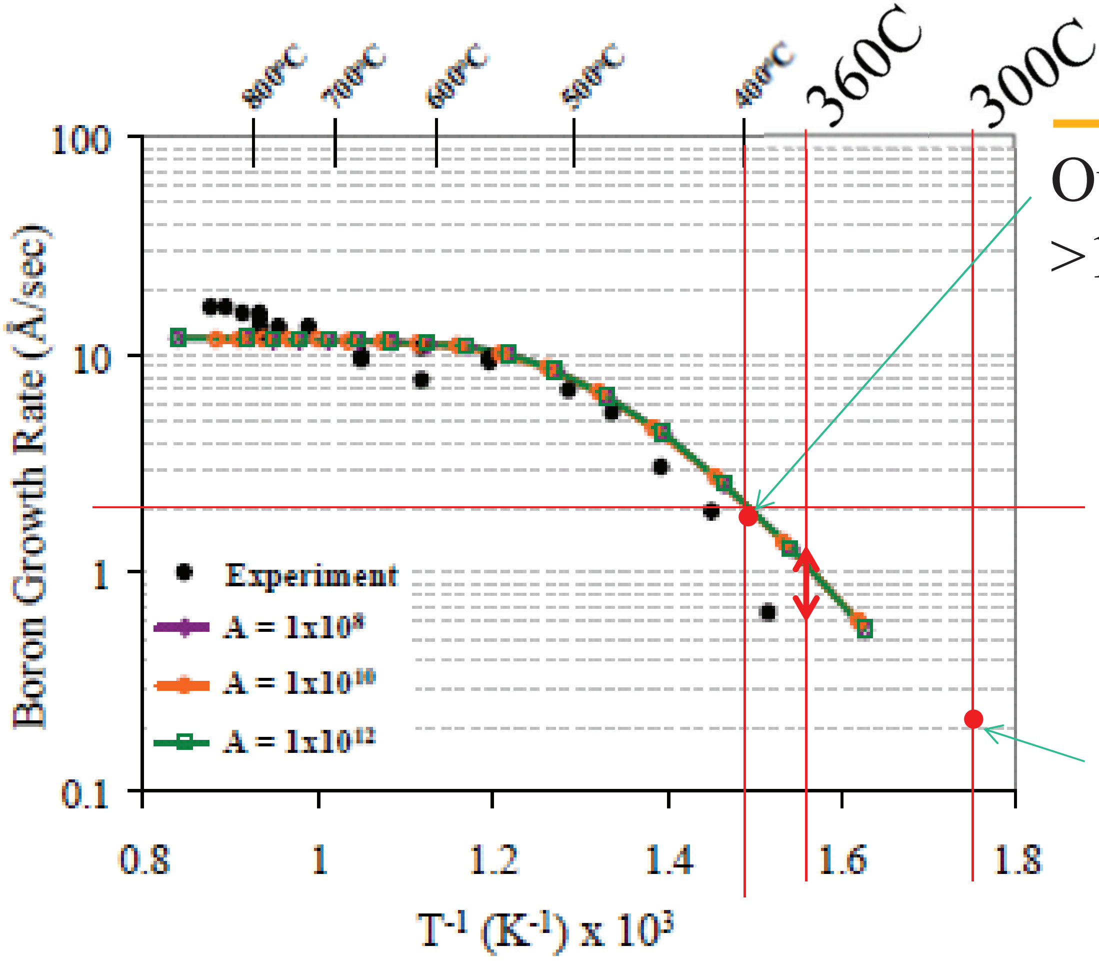
Schematic of present coating system (Looking from Top)



Learned facts after 10 runs at different furnace T (300-600 °C) and Mg source T (400-840 °C)

- Boron was not coated on the cavity surface at ≥500 °C (B_2H_6 gas was likely to be decomposed and consumed on the long inlet line before reaching the cavity)
- Insufficient Mg vapor pressure on the cavity surface. Even heating Mg pellets to ~840 °C with a local heater (Mg melting temperature is 650 °C) did not form MgB_2 on the 400 °C cavity surface, while B_2H_6 was flowing.

Boron growth rate vs. Temperature



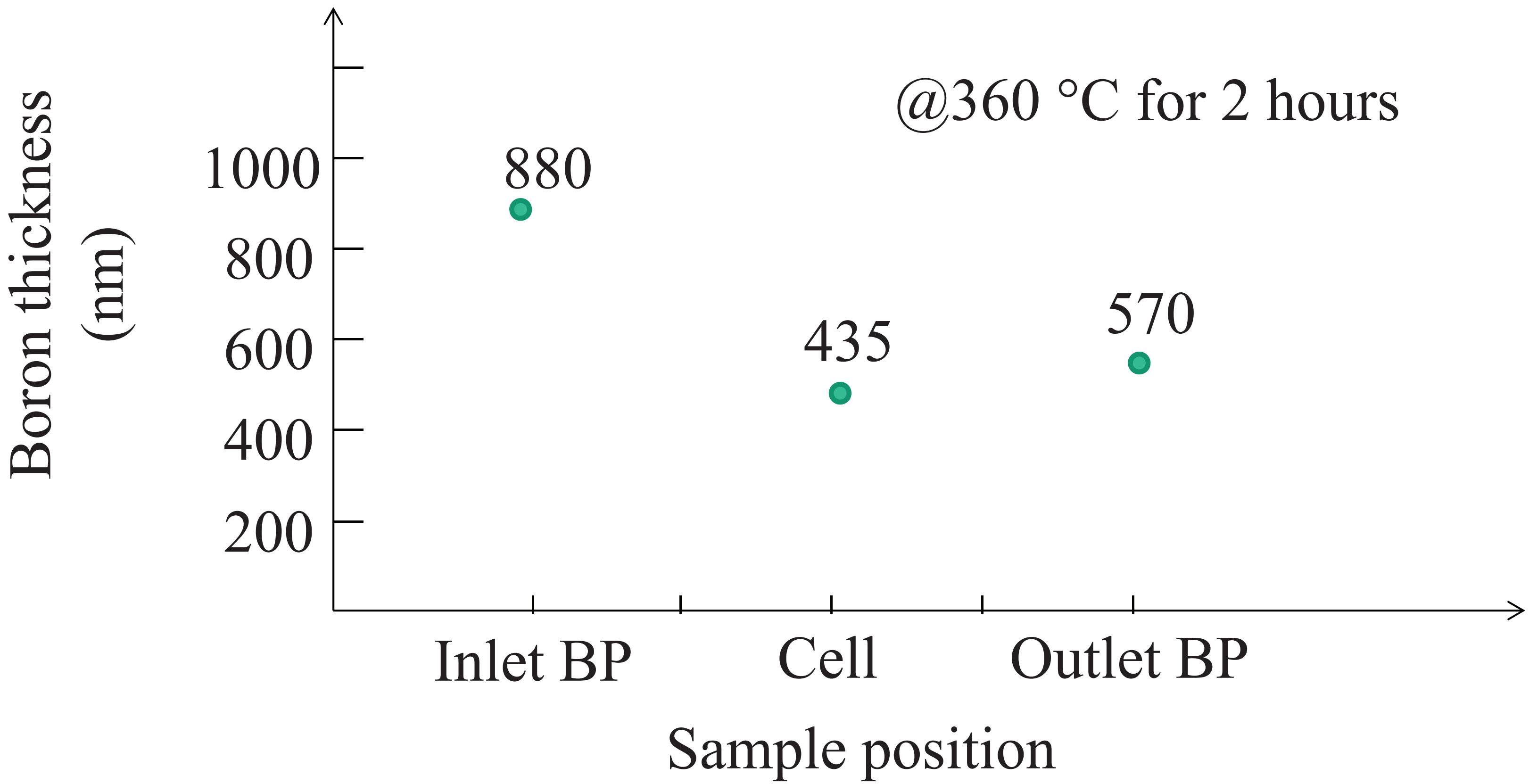
Our data on inlet BP >11.7 nm/min@400C

0.2 nm/s =12 nm/min

Our data on cell L (1.3 nm/min = 0.22 Å/s)

[from D.R. Lamborn, PhD thesis, August 2007]

B thickness profile



Future options

- Move the location of Mg source into the SST pipe attached to the cavity so that sufficient Mg vapor reaches cavity surface and maintain the coating temperature at 550 °C or lower.
- 2-stage coating (coat B then react with Mg) at a high temperature (≥700 °C, although <800 °C is preferable to avoid Nb re-crystallization when coated on Nb) (Mg diffused into B only about 20 nm at 600 °C.)

Conclusions

- MgB_2 thin film samples especially prepared by HPCVD have shown excellent properties relevant to SRF applications, which warrants the coating of practical-size cavities and study the performance as a cavity.
- LANL as well as other institutes and companies are trying to develop a suitable technique to coat cavities and hope to produce a lot of cavity results by the next SRF conference.