# $MgB_2$ coating by HPCVD for 1.3 GHz superconducting RF cavities

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Office of Science

# $MgB_2$: Higher $T_c$, Potentially Low RF loss and High Gradient

| | Nb | $MgB_2$ |
|---|---|---|
| $T_c$ (K) | 9.2 | 40 |
| $\rho_0$ ($\mu\Omega$ cm) | 5 | 0.1 |
| $\Delta$ (meV) | 1.5 | 7 (σ), 2(π) |
| $B_c(0)$ (T) | 0.20 | possibly 0.80 |
| $B_{c1}(0)$ (T) | 0.17 | <0.1 |

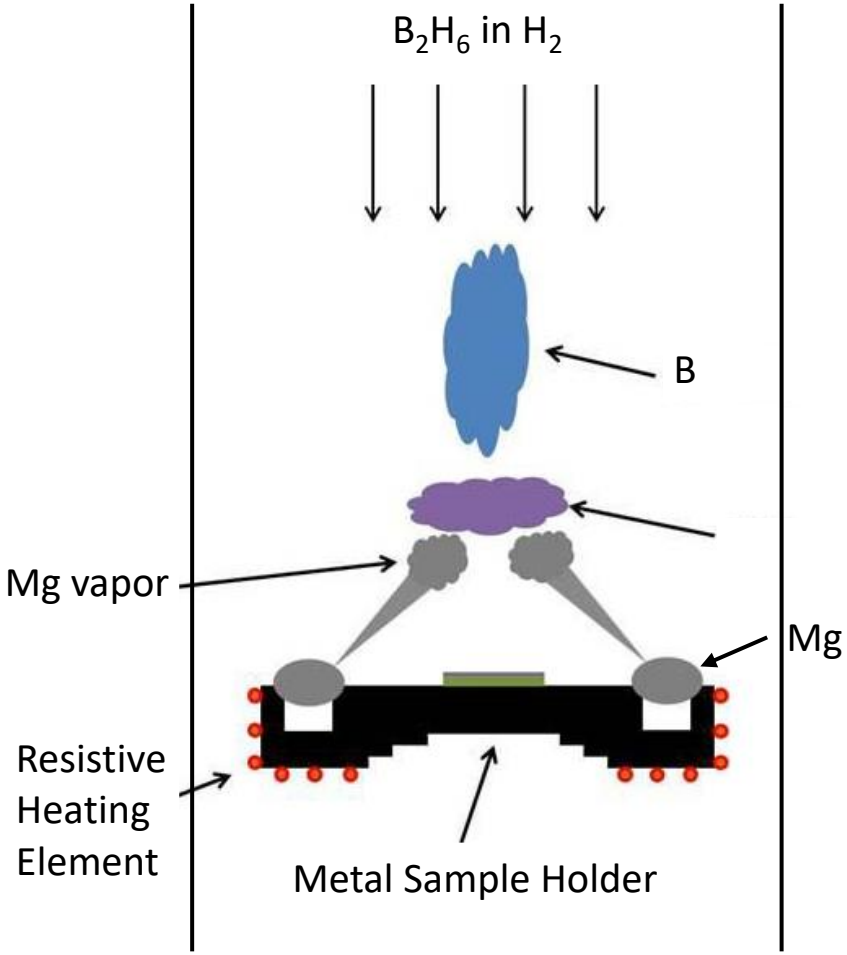
Potential to operate at 10-20 K with similar or higher energy gradient than Nb.

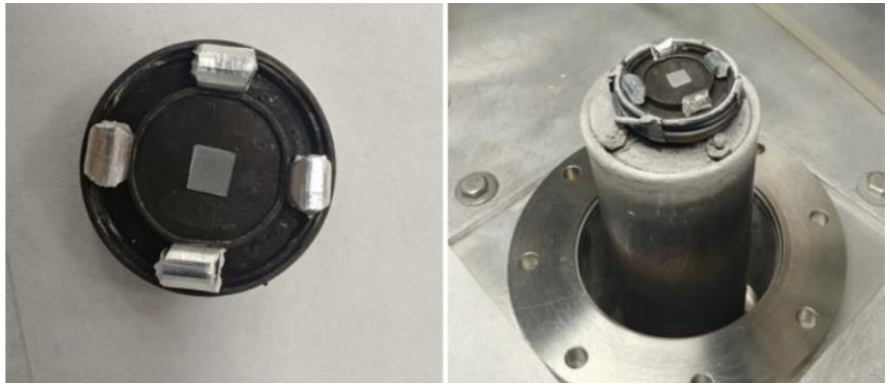
— RF surface resistance depends on energy gap and residual resistivity. Larger gap and lower resistivity indicate potential low RF loss than in Nb.

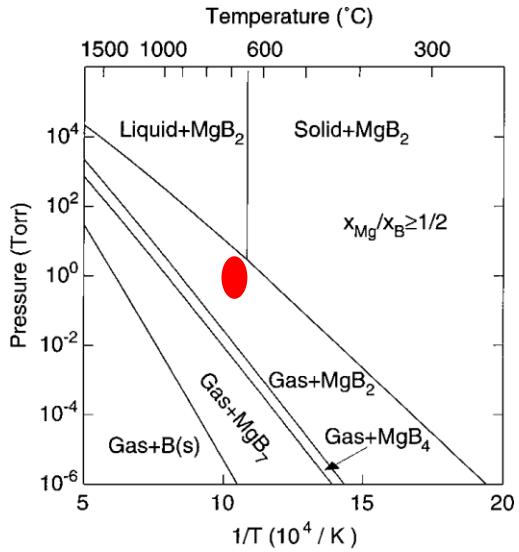
— Field gradient is ultimately limited by thermodynamic critical field. For $MgB_2$, $B_c(0)$ could be as high as 800 mT, vs. 200 mT for Nb.

— Lower critical field $B_{c1}(0)$ may be an obstacle.

# Growth of $MgB_2$ Films by HPCVD (Hybrid Physical-Chemical Vapor Deposition)

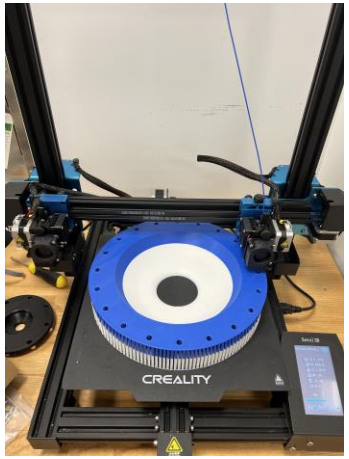


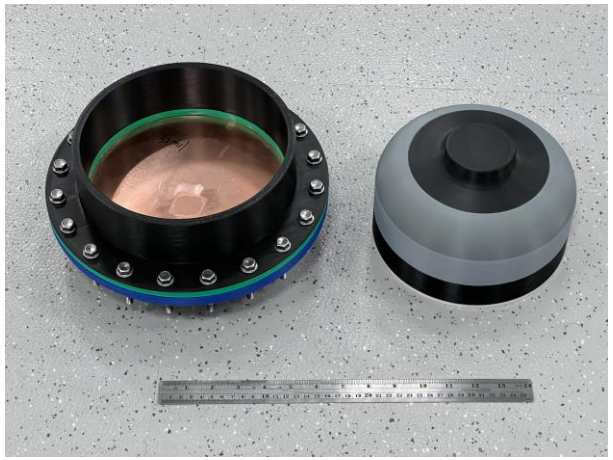





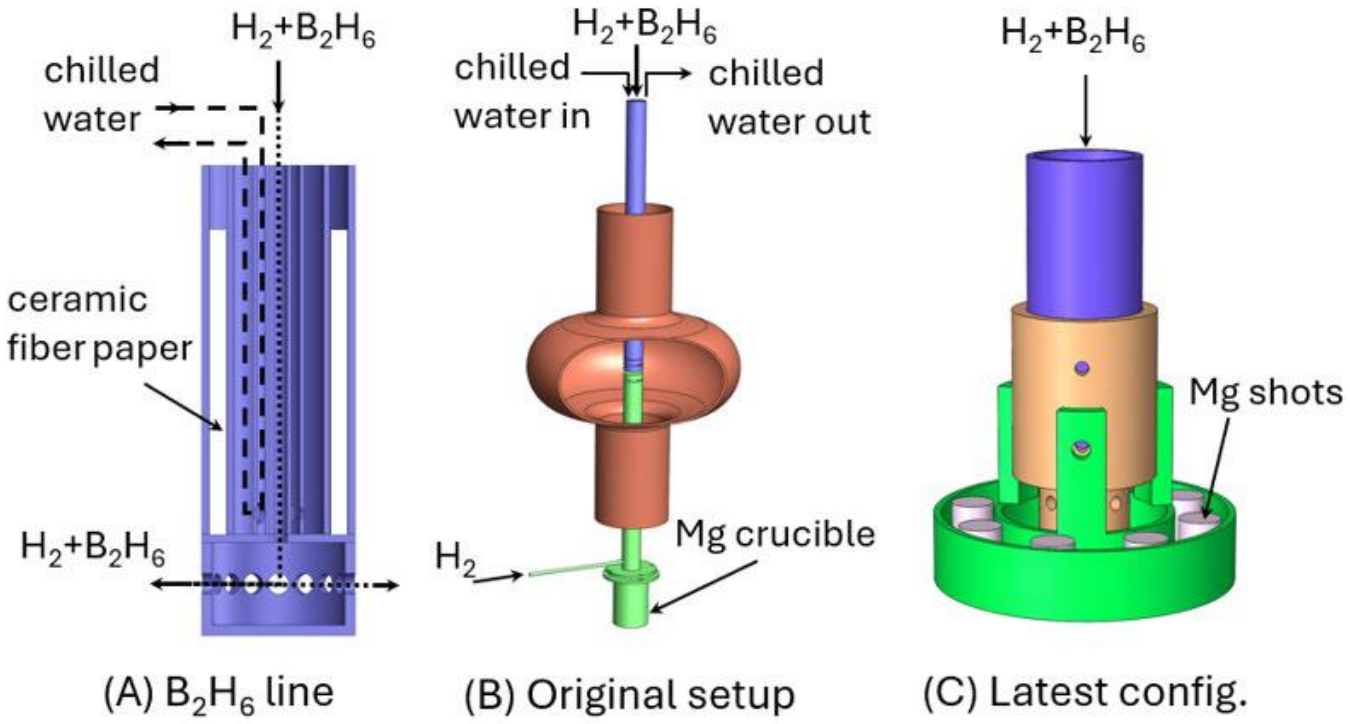

- Evaporation of Mg pellets provides high-pressure Mg vapor needed (physical vapor)
- Thermal decomposition of $B_2H_6$ provides pure B (chemical vapor)
- Presence of $H_2$ prevents oxidization of Mg
- Metal sample holder is made from stainless steel or molybdenum.
- Substrate materials: SiC (0001), $Al_2O_3$ (0001), MgO (111), etc. for epitaxial films and Ta, Mo, Cr, stainless steel, Cu, Si, etc. for polycrytalline films.

# Fabrication of mock cavities

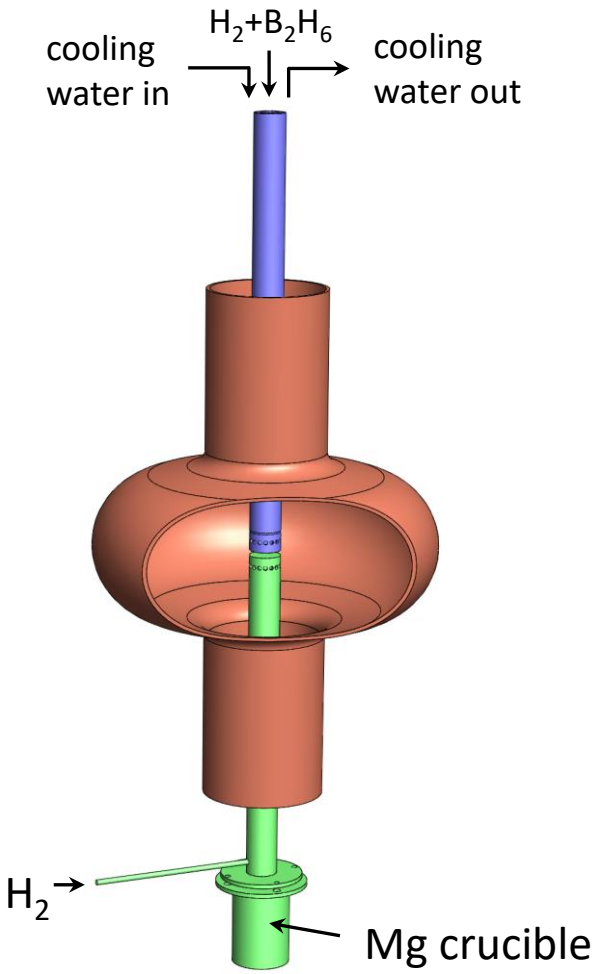


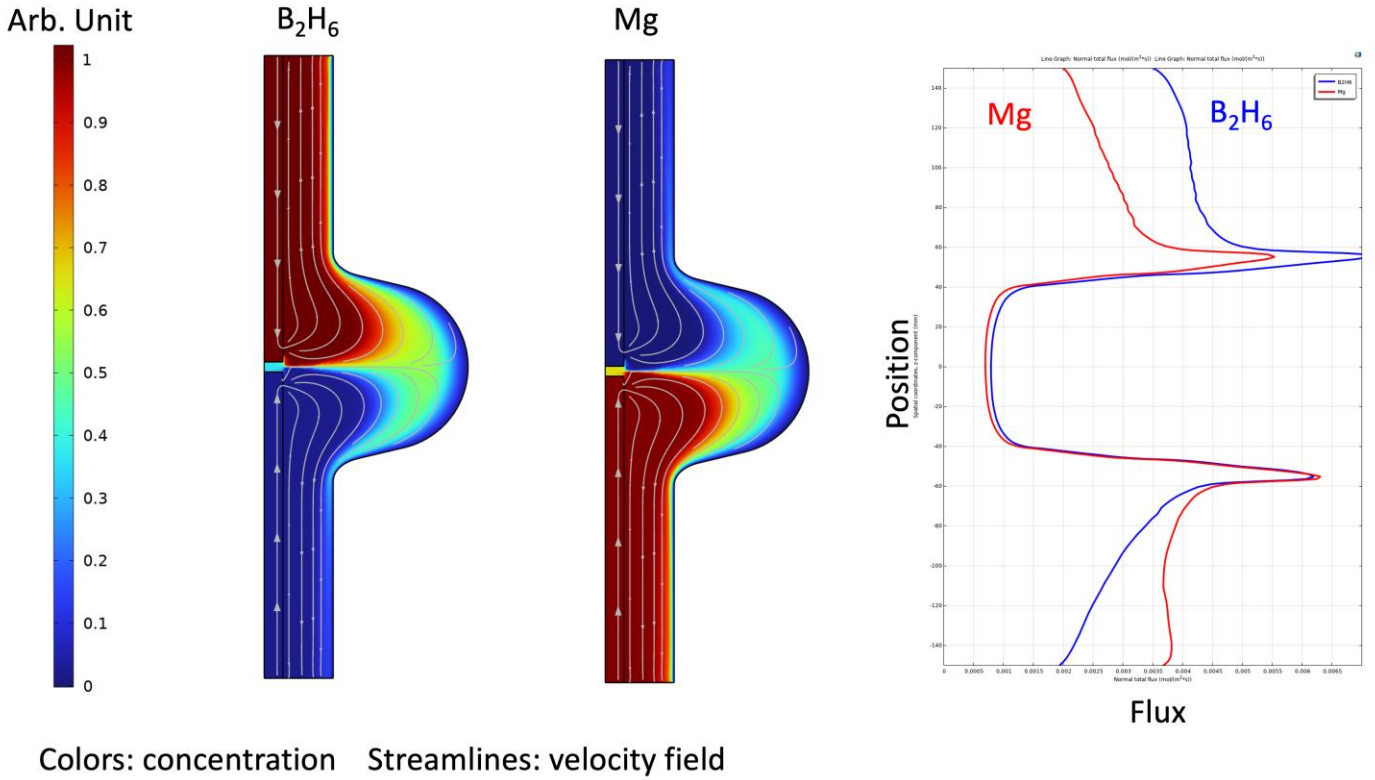
# HPCVD Coating system



# Simulation



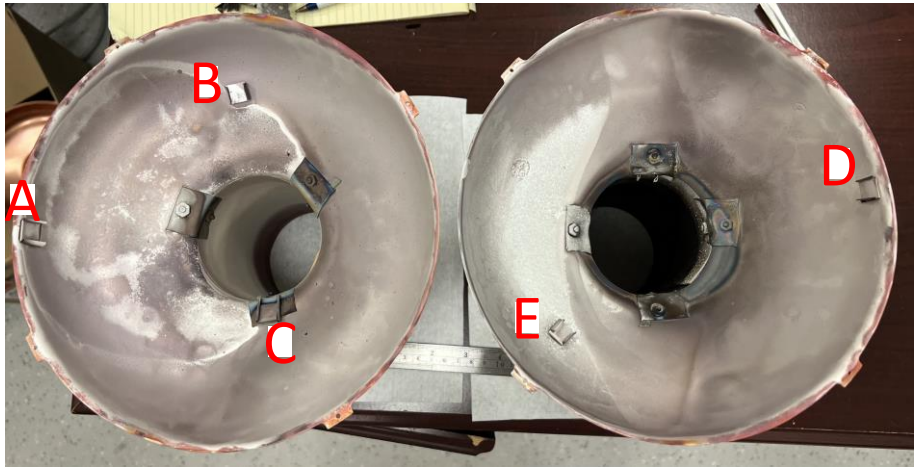

**Simulated concentration distribution and flux rates on the cavity**



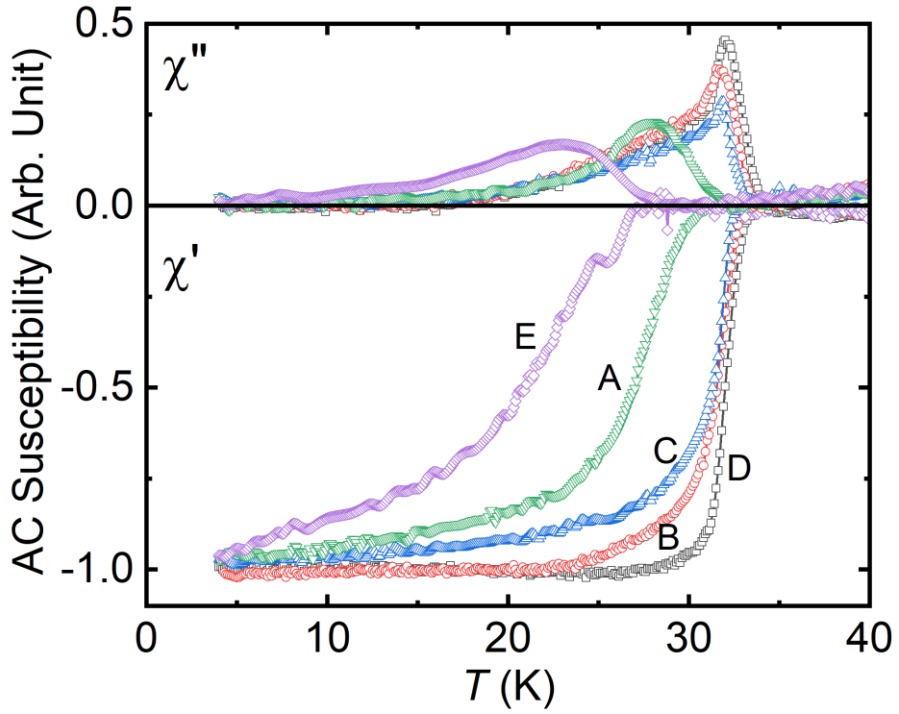

Colors: concentration  Streamlines: velocity field

- By adjusting pressure and flow rates of the $H_2$ carrier gas, $MgB_2$ film can be coated inside the cavity with higher rate at the iris region than the equator region.
- Moving B and Mg sources vertically may be necessary to achieve needed uniformity.

# AC susceptibility measurement of small samples



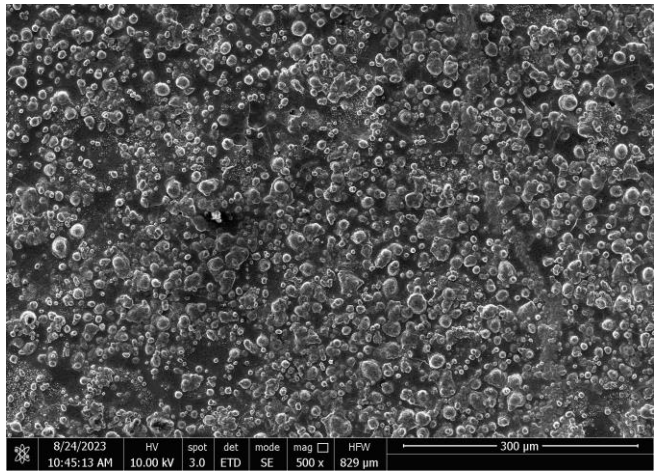

| Sample | Position | $T_c$ (K) |
|---|---|---|
| A | Top-half, equator | 32.2 |
| B | Top-half, middle | 33.2 |
| C | Top-half, iris | 33.2 |
| D | Bottom-half, equator | 34.3 |
| E | Bottom-half, middle | 28.4 |

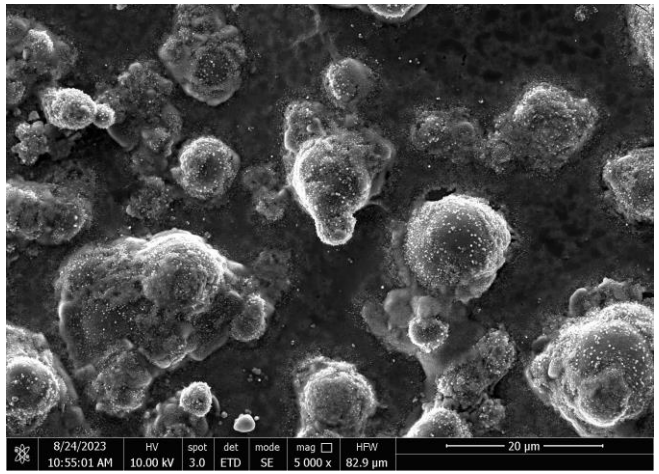


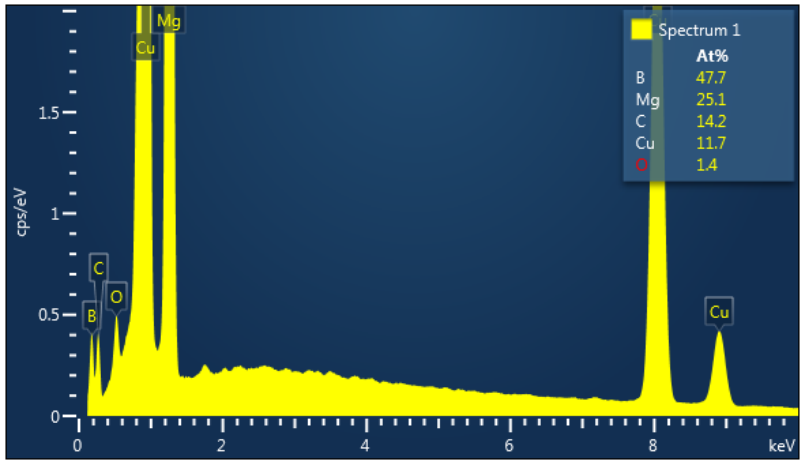

Lower $T_{c0}$ than best $MgB_2$ on Cu sample (38K) not in a cavity setting is still under investigation.

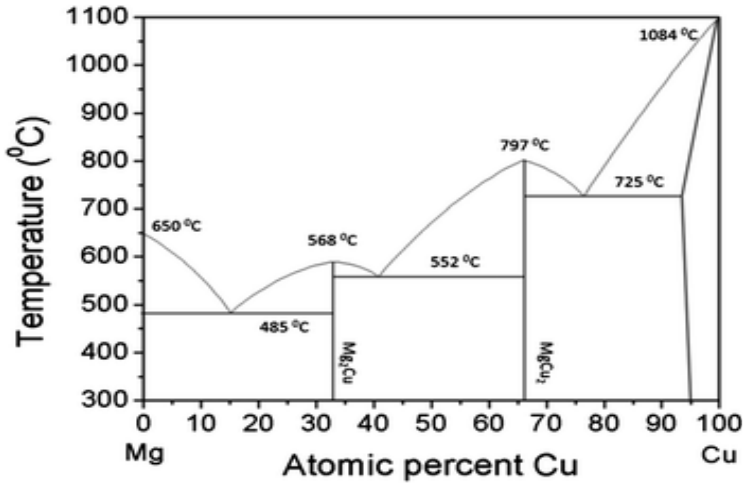
Ke Chen and Xiaoxing Xi, IEEE Trans. Appl. Supercond. 34, 3500405 (2024)
https://doi.org/10.1109/TASC.2023.3347211

# SEM Characterization of Small Samples

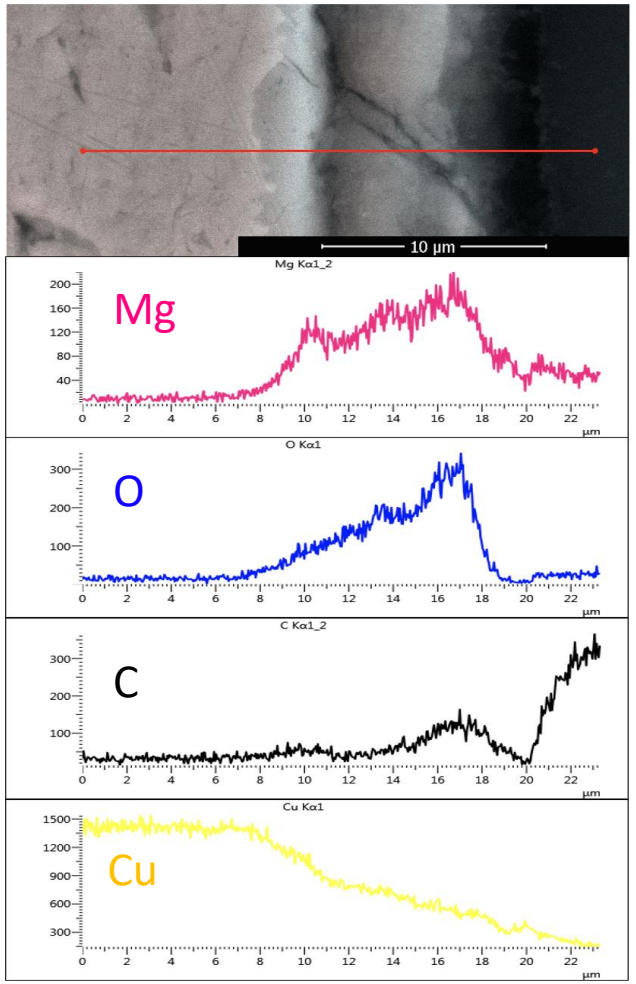


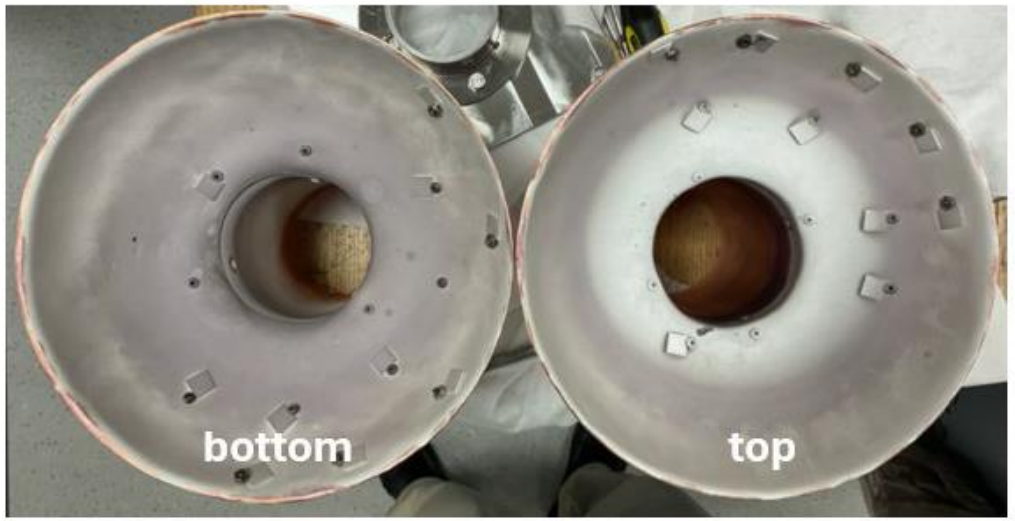

Cross section view




SEM/EDS shows a 10um thick $MgB_2$ film grains grow on top of Mg-Cu alloy layer.

# Improve film qualities by new $B_2H_6$ and Mg delivery designs

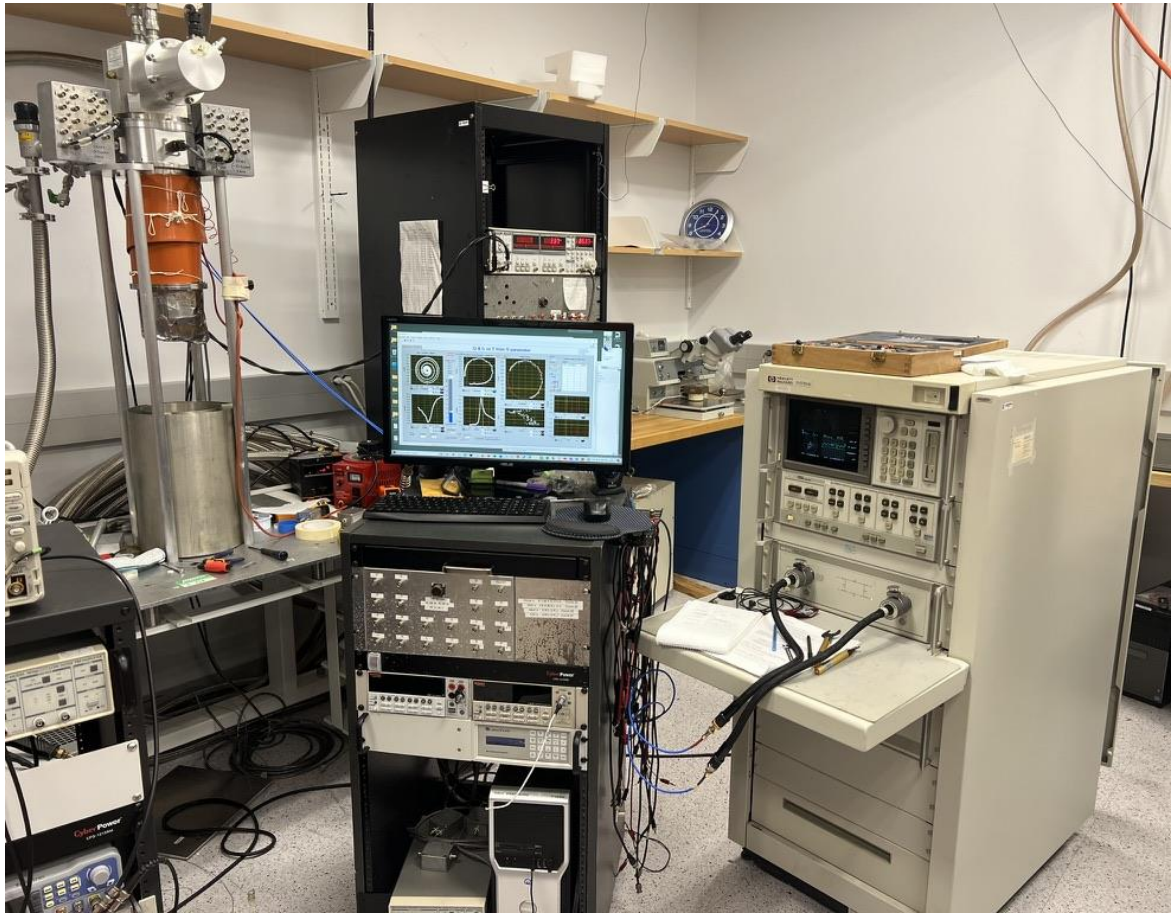
Currently being tested.
Mg heater supported from the bottom, therefore no blocking of B and Mg by three supporting arms.

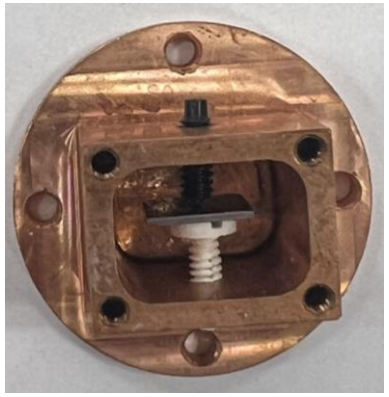


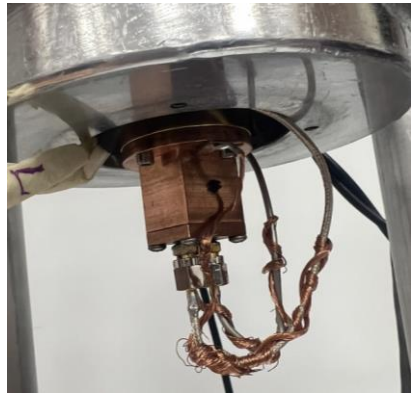

B and Mg sources vertical movement of up to 20 cm achieved, which helps to coat film inside the neck cylinders.

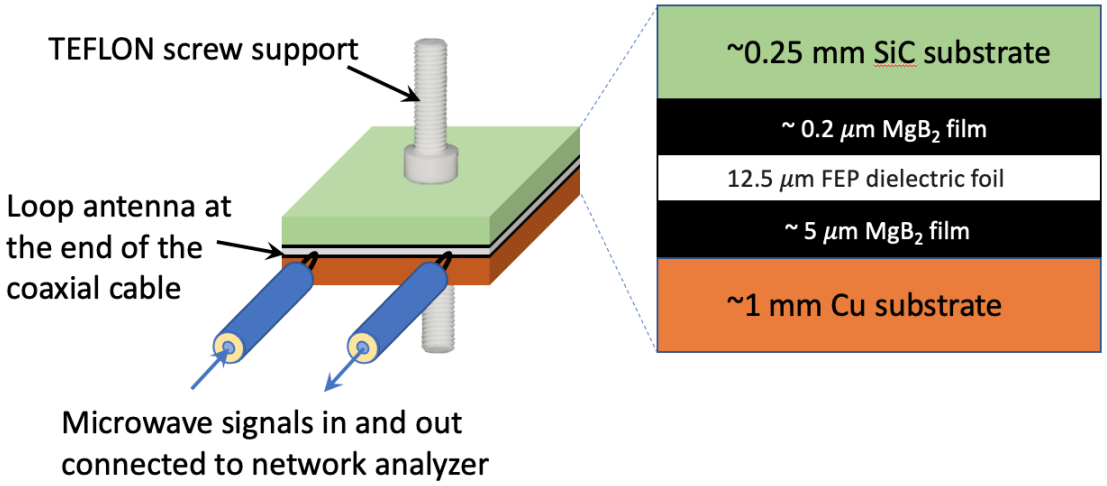
A new computer controlled moving flange up to 50 cm is expected to arrive in November 2024.

# Microwave properties measurement using parallel plate resonator

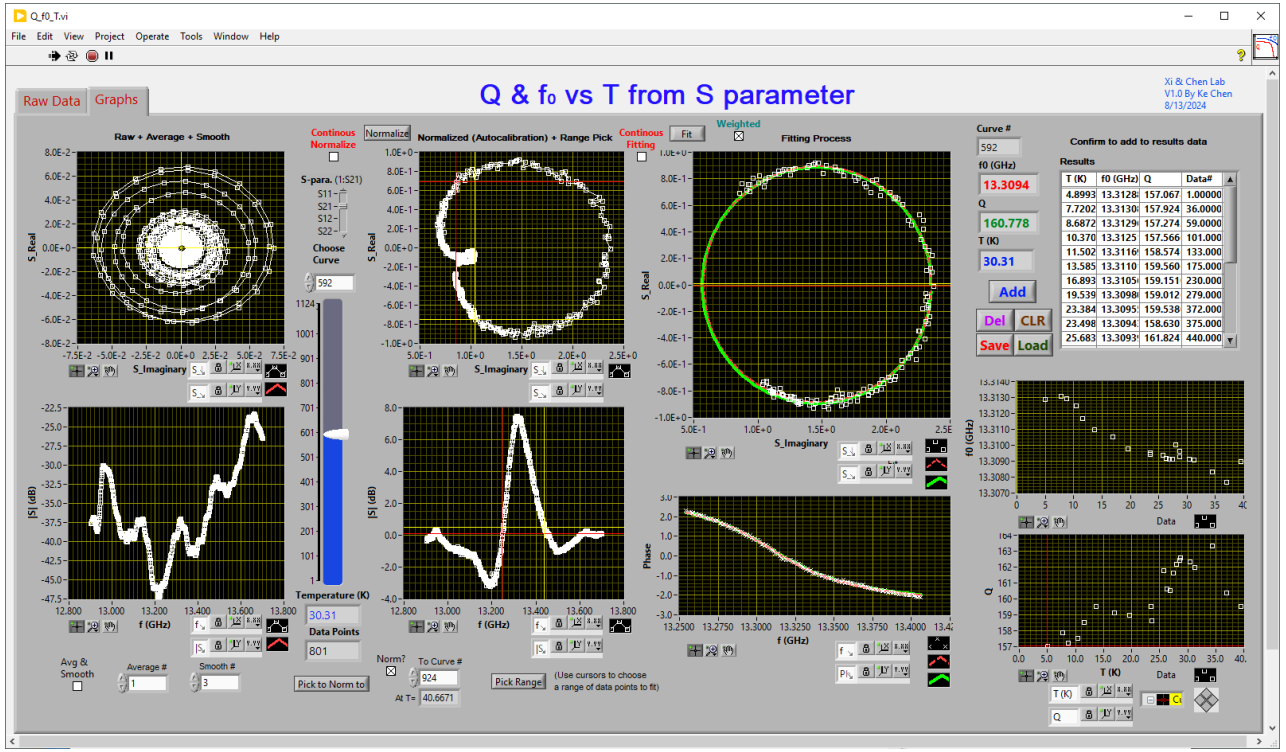




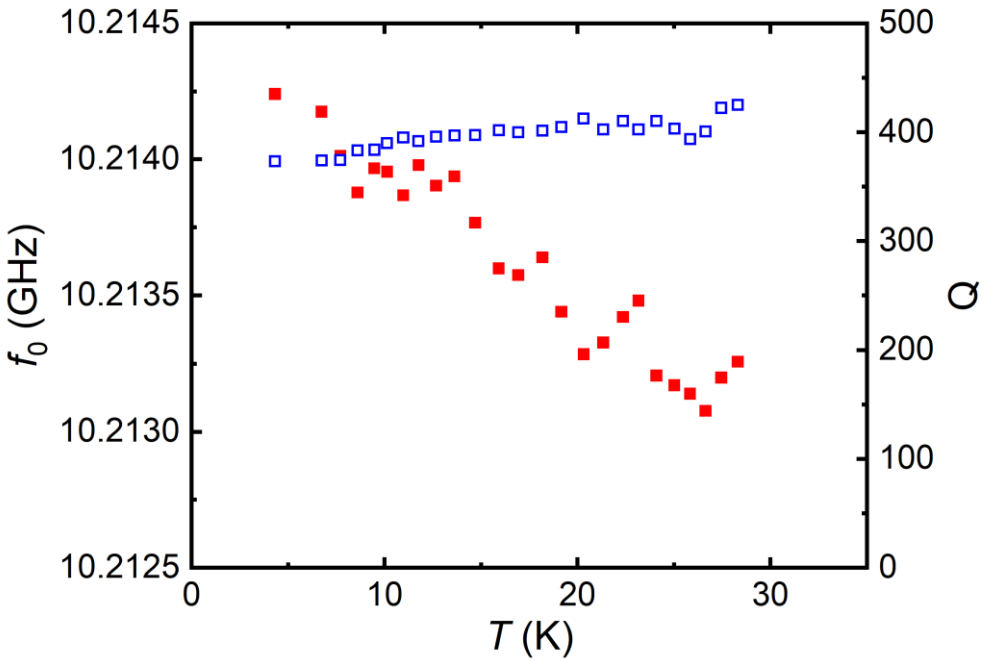




# Data analysis and preliminary data




$MgB_2$/SiC /FEP/ $MgB_2$/Cu
Parallel plate resonator




The resonance frequency is close to the TM01 mode of the 10mm x 10mm parallel plate resonator, and it increases as temperature decreases, in agreement with the fact that the penetration depth and hence the kinetic inductance is smaller at lower temperatures, confirming what measured was the mode of the superconducting parallel plate resonator.

# Summary

- $MgB_2$ films coated on mock 1.3 GHz Cu RF cavities by HPCVD with $T_{c0}$ as high as 34.2 K measured by AC susceptibility.
- Microwave measurements for surface resistance and power handling are being investigated.
- Coating uniformity across the whole cavity is being improved by revising the B and Mg delivery.

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