Magnesium Diboride Films for SRF Cavity Applications

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Outline

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I. Introduction and Approach:

The Need to Go Beyond Bulk-Nb Cavities

The T > 4 K Approach: MgB_2/{Cu, Nb} Films; Thickness ~2λ

Properties, Potential Payoffs, Challenges

II. The Case for MgB_2:

Reactive Evaporation	High-quality Thin-film Deposition
R_s(T, H) Data	Power Dependence (Low, High)
Film Passivation	Film stability
System Simulations	Thermal Management
► Energy Gap	Data (IMD, λ(T < 5K)) and Theory of π Energy-Gap Symmetry

III. Summary, Outlook

The T > 4 K Approach:
MgB_2 Films of Thickness O(2λ)

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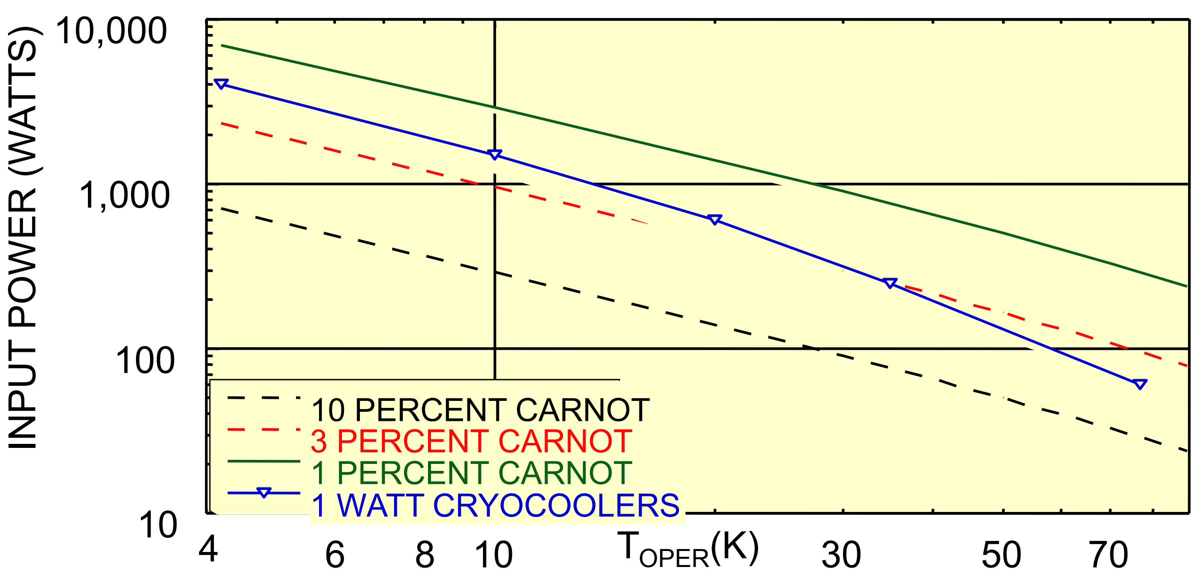
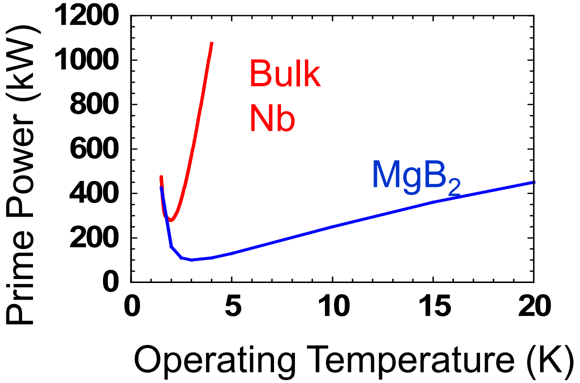
- **New** **Superconductor (2001); T_C = 39.5 K. Advantage:** **5K ≤ $T_{OPERATION}$ ≤20 K**
- **Payoffs:**
  - **Simplified Cryogenics:** **Gaseous He vs. Liquid He for Nb**
  - **Reduction** **in Size, Weight, Power (SWP)**
  - **Enhanced Reliability**

INPUT POWER vs. T_{OPER} FOR 1 WATT CRYOCOOLER



Prime Power: MgB_2 vs. Nb



REF: AES, Inc. '06

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The MgB_2 Alternative

Nb vs. MgB_2 Material Properties

Property	Nb (Type I/II)	MgB_2 (Type II)	Implications
Critical Fields (T=0K) (Tesla)	$H_C = 0.2$	$H_C > 1.55$ $(.16x15.)^{(1/2)}$	• Potential for High Gradient
Operating Temperature (K)	2	5-20	• Payoffs: Big Cost, SWP Savings • Enhanced Reliability
ξ_{ab}(T=0) (nm) (Coherence Length)	38	~ 4 - 8	• Polycrystalline Films: OK
Oxide Structure	Many Oxides Some are Magnetic	Only MgO Only B_2O_3	• Reduced Potential for Corrosion
Crystal Structure	BCC	AlB_2 (Hexagonal)	• Stable, Simple
Classification	Single Element Metal	Two Elements Ceramic	• Challenge: Quality SRF Cavity Coating

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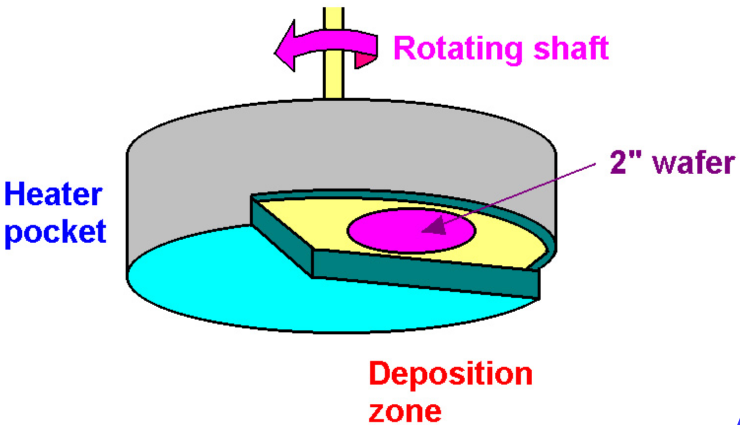
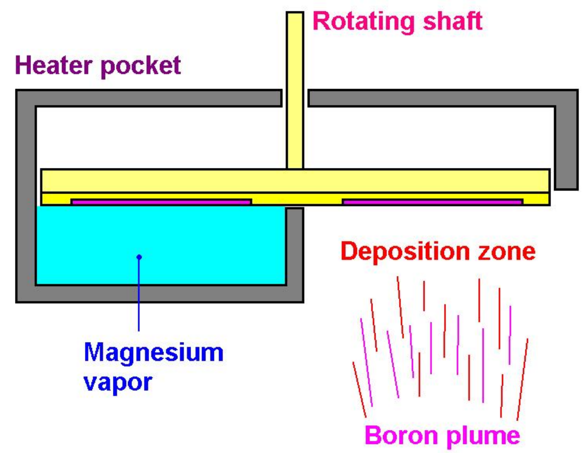
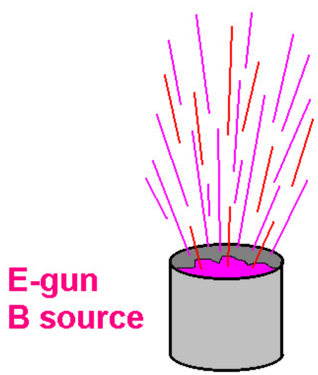
Film Deposition:
Reactive Evaporation

Solves **MgB_2 Film-growth Difficulties: Mg Volatility, Oxidation**



Rotating blackbody heater





Advantages:

- **Localized source of high-pressure Mg vapor**
- **Mg and substrate temperatures: Different**

Films:

- **$T_C \cong 39K$, $\Delta T_C \cong 1K$, Resistivity(T_c) $\cong 2\mu\Omega$**
- **2” Wafers**
- **RMS roughness = 4.4 nm**

Ref.: B. H. Moeckly et al., Supercond. Sci. Technol. 19, L21 (2006)

Low Power R_S (T)
MgB_2 vs. Nb *Films*

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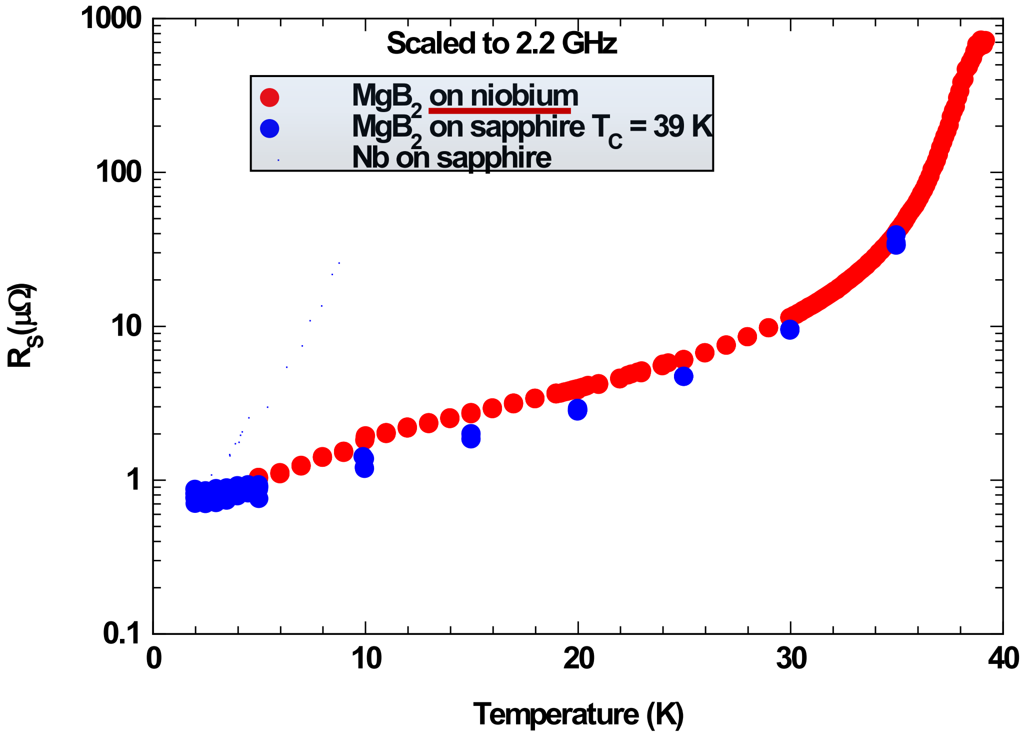
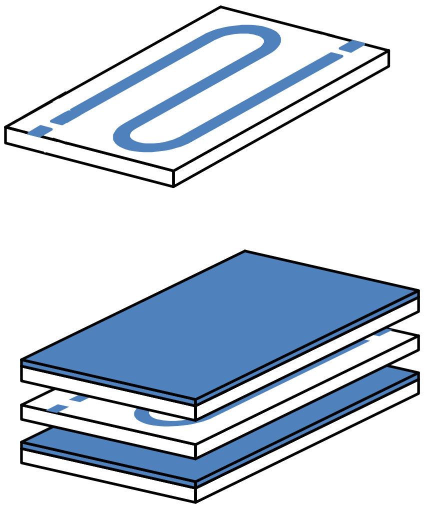
- $R_S(MgB_2; T) < R_S(Nb; T)$ for T > 2 K
- $R_S(MgB_2$ /Nb (Polished)): Comparable to MgB_2 /Sapphire



Stripline Resonator:
Films on Dielectric Substrate



- Nb-Bulk: R_S (2K, f = 2. 2GHz) ~ $R_{RESIDUAL}$ (2K) ~ 10^{-2} μΩ
- T_c (Nb) = 9.2 K, T_c (MgB_2) = 39 K

REF.: D. E. Oates, Y. D. Agassi and B. H. Moeckly, Supercond. Sci. Tech. 23, 03401 (2010)

Higher Power R_S (T)
MgB_2/(Nb, Sapphire)

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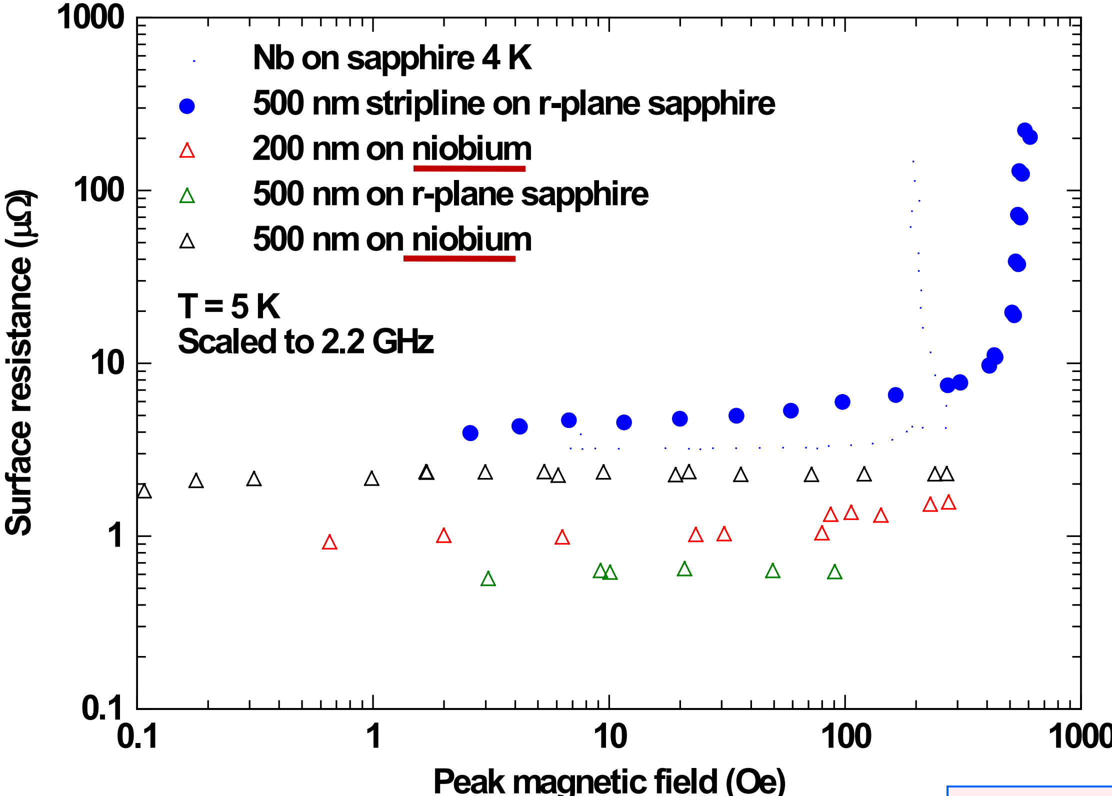
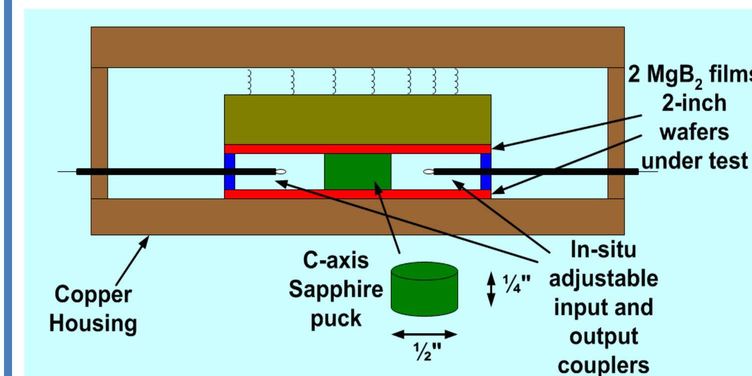


Dielectric Resonator

Films on Metallic or Dielectric Substrates



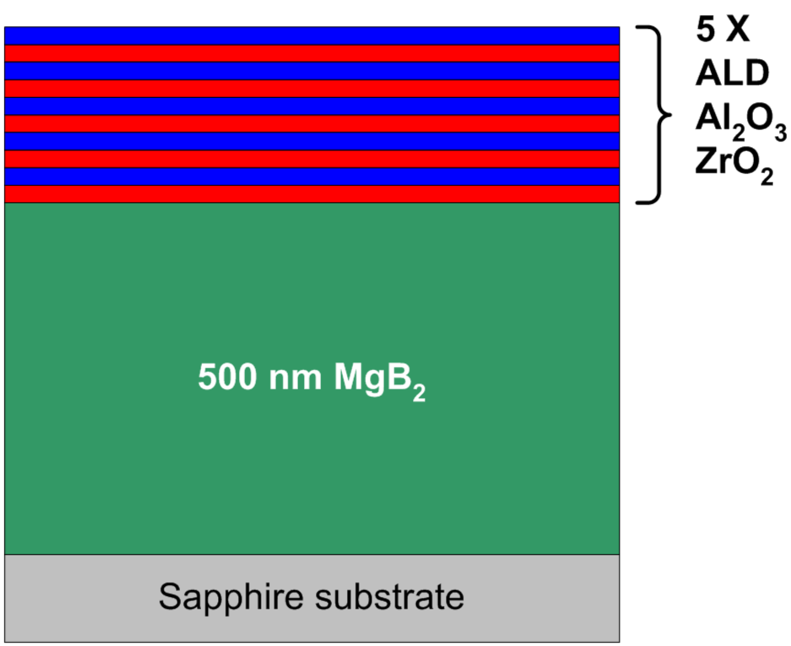
H_{C1} ~ 300 Oe

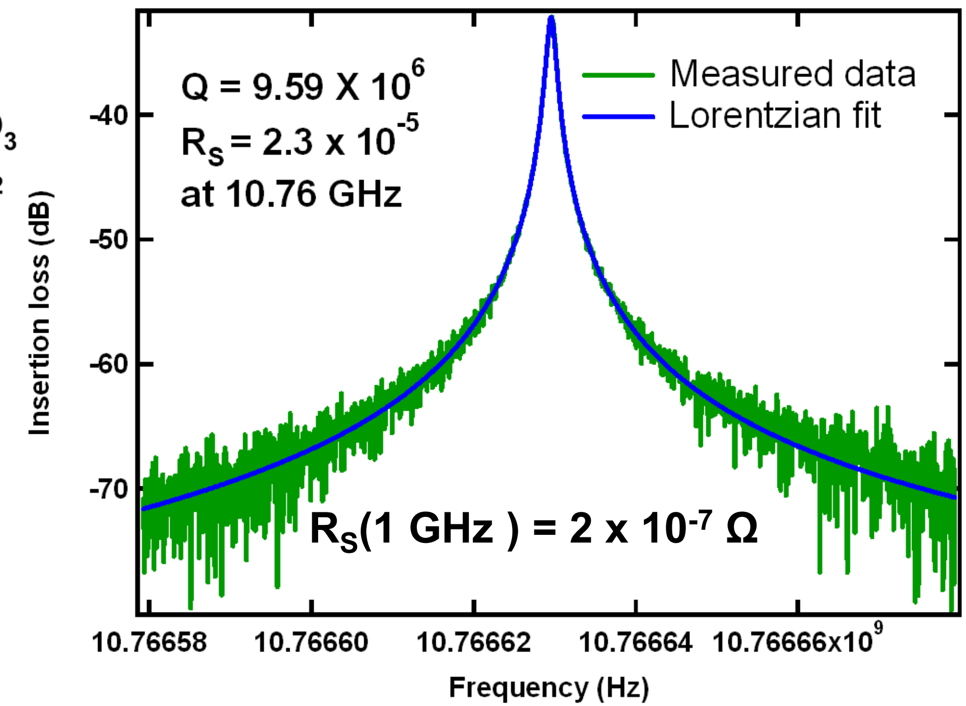
- R_S(NL Onset)/Sapp. at H ~ 800 Oe (⇔ E_{ACC} ~ 20 MV/m): **Material Limited?**
- R_S(NL Onset)/Nb at H > 200 Oe **Flat!** **Equipment Limited**
- Sample Variability

REF.: D. E. Oates, Y. D. Agassi and B. H. Moeckly, Supercond. Sci. Tech. **23**, 03401 (2010)

Passivation
Success at Film-Stabilization

- MgB_2 Degrades in Air
- Passivation with 5 X (2.5 nm Al_2O_3 and 2.5 nm ZrO_2) by ALD
- Over 6 Months & 5 Temperature Cycles R_s Unchanged. Q (f = 1. GHz) ~ 1. $\times 10^8$ (Measured in a 2" Dielectric Resonator.)





System Simulations

Thermal Management, Power (AES, Inc.)

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- **Based on Our R_S Data ⇒ Simulations Confirmed Feasibility**

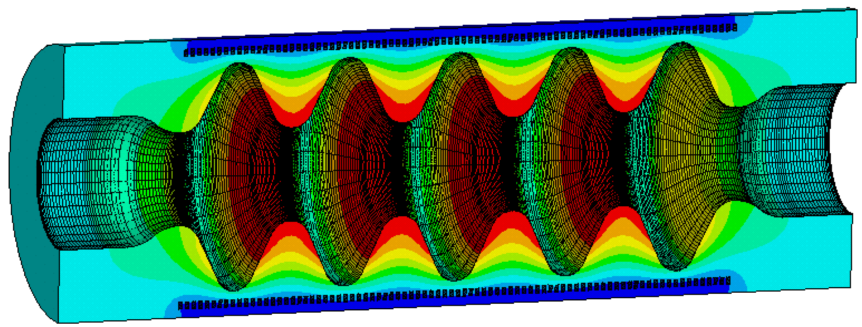
Two Thermal-management Issues:

1. **Gaseous He Cooling** : MgB_2/Cu Five-Cavity Array
2. **Resonance-Frequency Shift** : Due to Thermal Expansion

Worst Case Scenario

He(T, P) = (30K, 3 Atm)

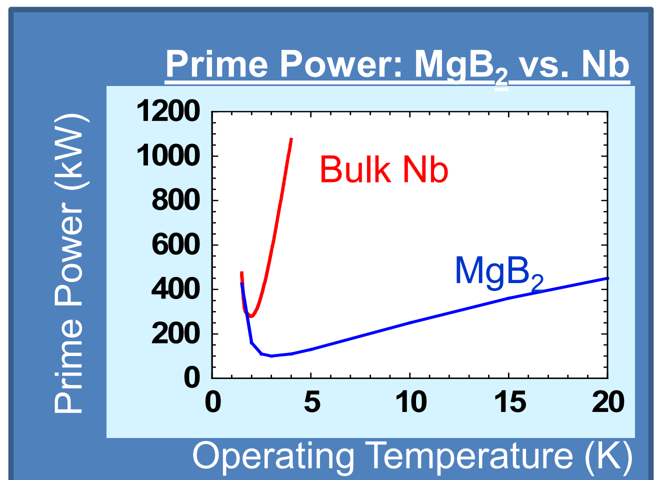
(Q = .608E 9 f = 703.75 MHz)



REF: AES, Inc.

- **Cooling Load: Not a Problem**
- **Thermal Expansion: Relatively Small**

Feasible



Energy-Gap (π-Gap) Symmetry

- **YBCO Work ⇒ IMD-Power: Nonlinear Probe of Energy-Gap Symmetry**
- **Surprise: Low-T IMD-power Upturn: Inconsistent with s-wave π-Gap**

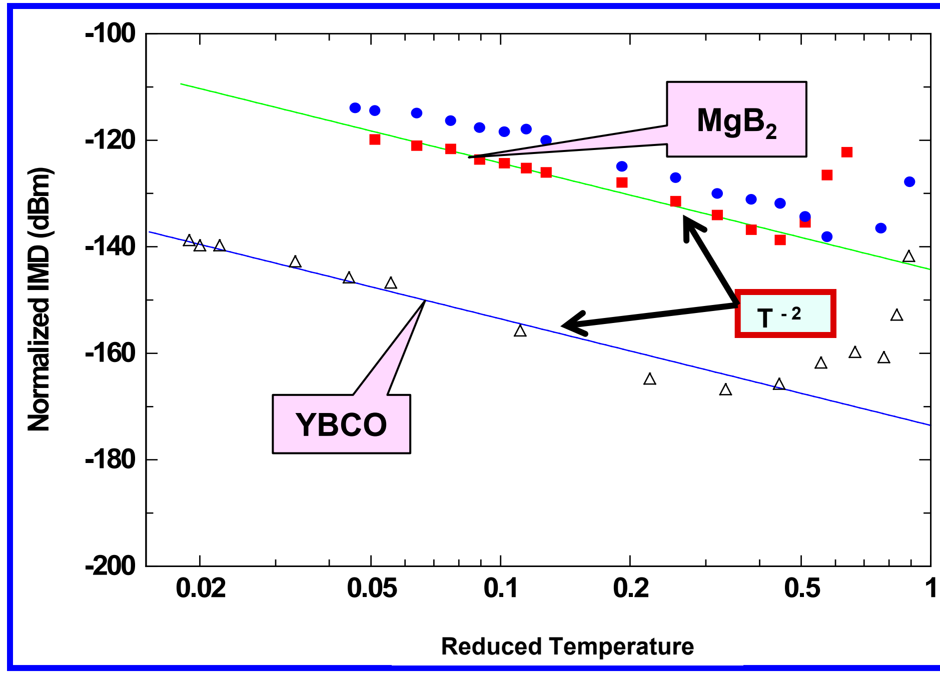
$$P_{S-WAVE}(T) \propto T^{-5} e^{-2\Delta/(k_B T)}$$

Theory

$$\Delta_\pi(T,\varphi) = \Delta_0(T)\sin(6\varphi)$$

$$\Downarrow$$

$P_{IMD}(T)$ □ T^{-2}



- **Impact of π-Gap ℓ=6 Symmetry: Surface-Resistance Variation, NL, at Low-T**

$$R_S(BCS) \propto \frac{1}{T} e^{-\Delta/(k_B T)} \Leftrightarrow R_S(\ell=6) \propto T$$

REF.: D. Agassi and D. E. Oates, Phys. Rev. B 72, 014538 (2005); Phys. Rev. B 80, 174522 (2009)

Summary

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Accomplishments

- **Materials Science (Reactive Evaporation Deposition):**
  - ▶ High-quality, Flat, Ultra Smooth MgB_2/Sapphire, MgB_2/Nb Films
  - ▶ Passivation Success with ZrO-AlO Coating

- **Data/Characterization and Analysis:**

  R_S Database: at Low, High Power of Flat MgB2/(SAPPHIRE, Nb) Films

  E_{ACC} : • CURRENT RECORD ~ 20MV/m
  • LIKELY that E_{ACC} IS HIGHER

  Thermal Management Simulation ⇒ OK

  π Energy-Gap ℓ=6 Symmetry: Data and Theory

- **Outlook:**

  The 2-λ Thick MgB -Coated Cavity Proposition: Promising

Future Challenges

High-Quality Film Deposition on Curved Metallic Surfaces

Demonstrating Low R_S in those films

Demonstrating a High Field Gradient in those Films

Theory

Make a MgB_2-based RF Cavity with High Field Gradient

End Presentation