Superconducting Thin Films For Levitation of NIF Targets

3rd Workshop on Microwave Cavities and Detectors for Axion Research

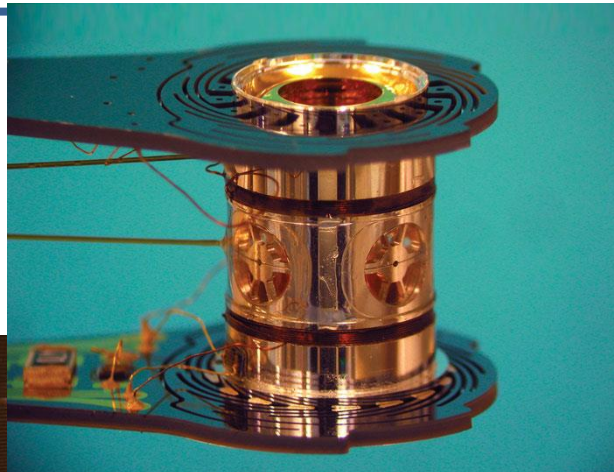
Alex Baker
Post-Doctoral Appointee

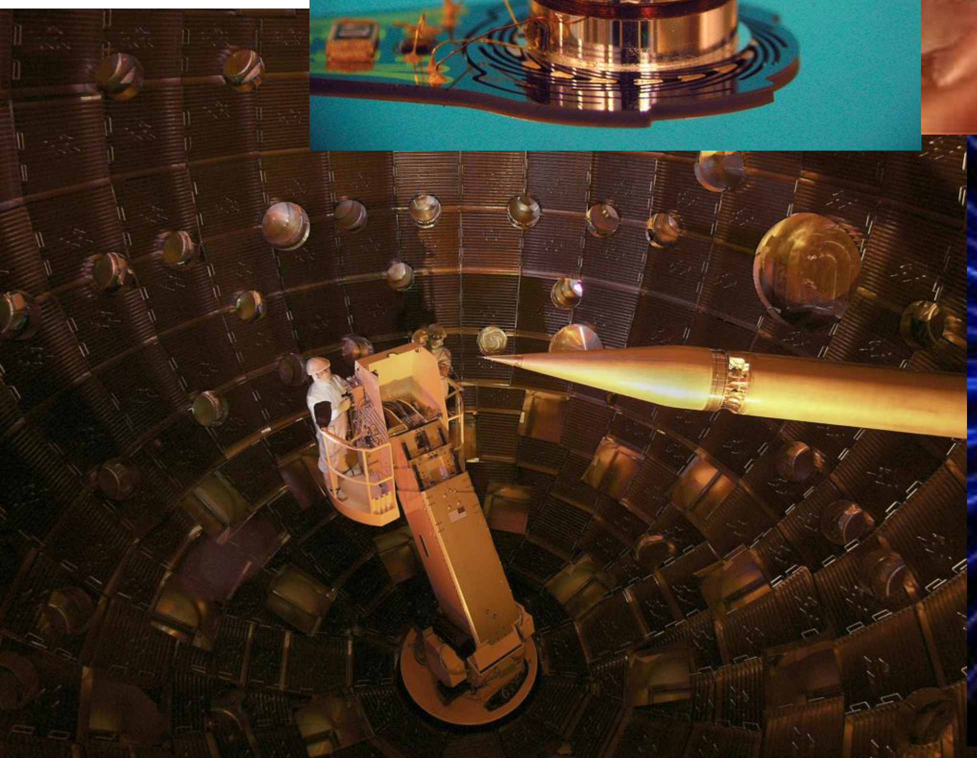
August 22, 2018

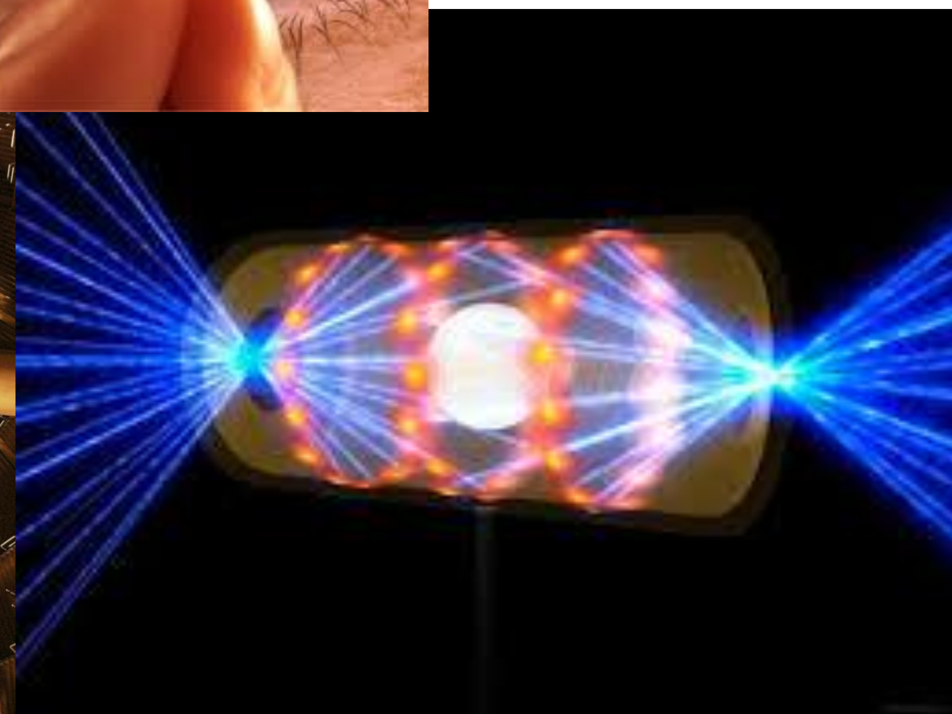
LLNL-PRES-748677
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

Lawrence Livermore National Laboratory

NIF Places Fuel Capsules Inside Hohlraums…

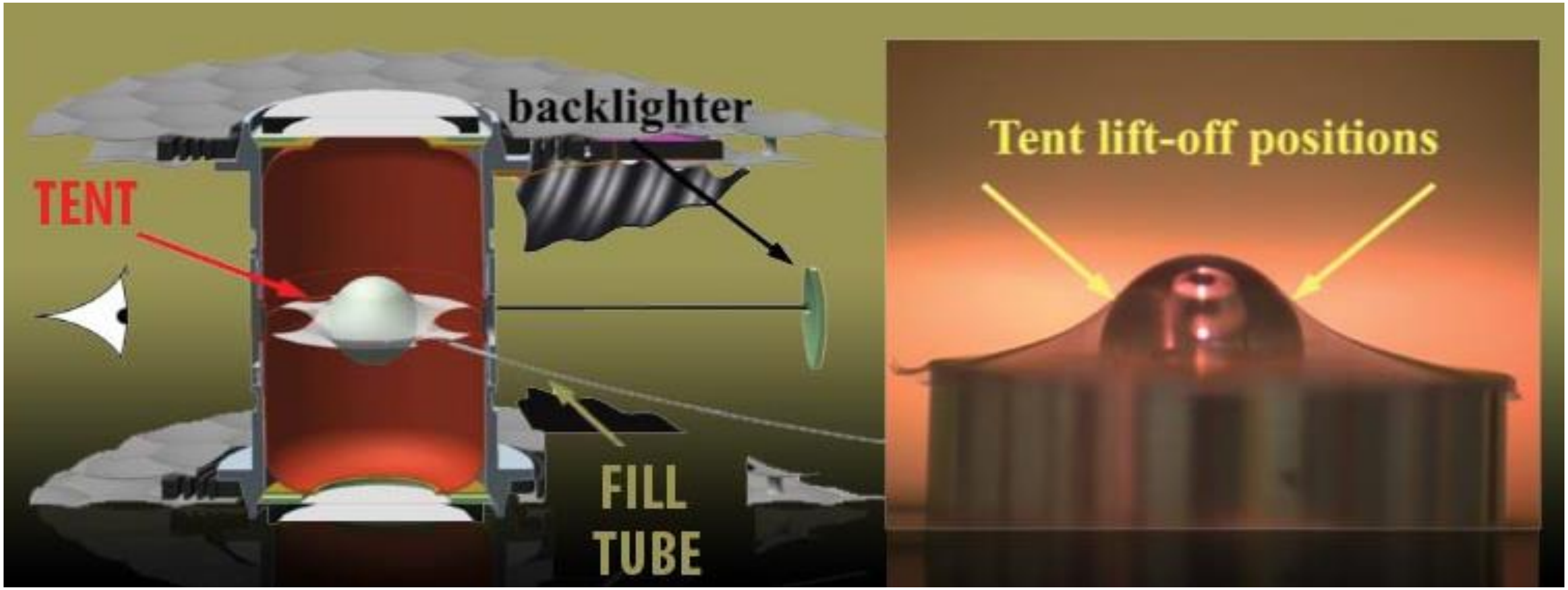






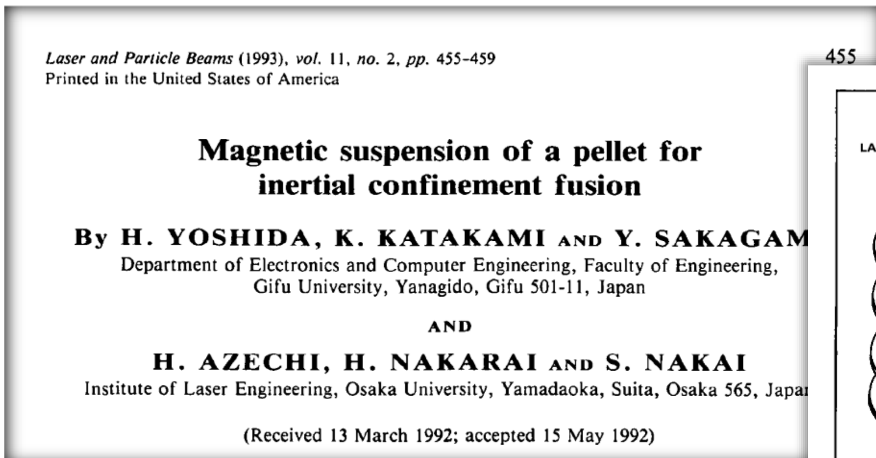
… but Capsule Supports Cause Perturbations

- Fuel capsule must be supported within center of hohlraum
- Tents can cause perturbations that affect the implosion



Levitation Offers an Alternative

Holding capsule in place without supports would allow fully symmetric implosion



Laser and Particle Beams (1993), *vol.* 11, *no.* 2, *pp.* 455–459 455
Printed in the United States of America

Magnetic suspension of a pellet for inertial confinement fusion

By H. YOSHIDA, K. KATAKAMI AND Y. SAKAGAM
Department of Electronics and Computer Engineering, Faculty of Engineering, Gifu University, Yanagido, Gifu 501-11, Japan

AND

H. AZECHI, H. NAKARAI AND S. NAKAI
Institute of Laser Engineering, Osaka University, Yamadaoka, Suita, Osaka 565, Japa

(Received 13 March 1992; accepted 15 May 1992)

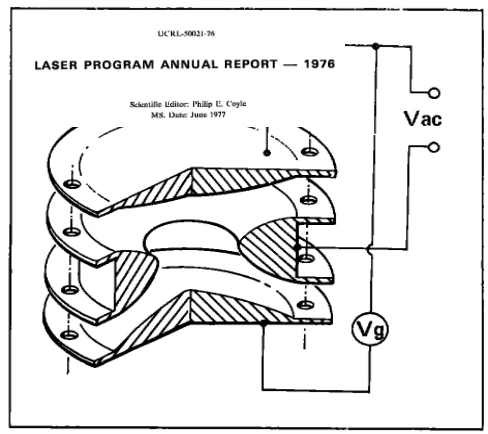
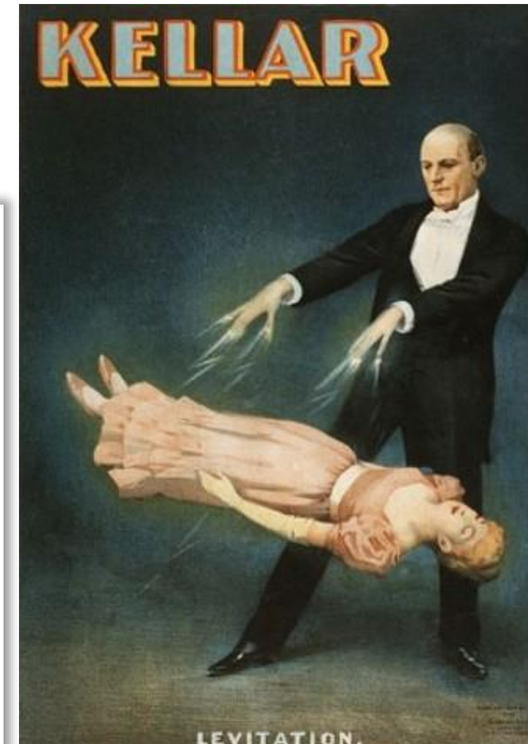


Fig. 4-163. Cylindrically-symmetric hyperbolic electrodes used to provide three-dimensionally stable levitation of charged particles.



Earnshaw's Theorem: a collection of point charges cannot be maintained in a stable stationary equilibrium configuration solely by the electrostatic interaction of the charges

Levitation Offers an Alternative

Holding capsule in place without supports w
allow fully symmetric implosion

Laser and Particle Beams (1993), *vol.* 11, *no.* 2, *pp.* 455–459 455
Printed in the United States of America

Magnetic suspension of a pellet for inertial confinement fusion

By H. YOSHIDA, K. KATAKAMI and Y. SAKAGAM
Department of Electronics and Computer Engineering, Faculty of Engineering, Gifu University, Yanagido, Gifu 501-11, Japan

AND

H. AZECHI, H. NAKARAI and S. NAKAI
Institute of Laser Engineering, Osaka University, Yamadaoka, Suita, Osaka 565, Japa

(Received 13 March 1992; accepted 15 May 1992)

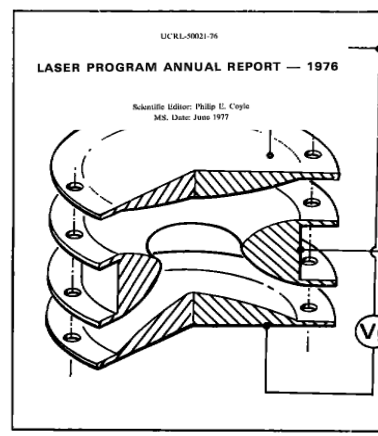
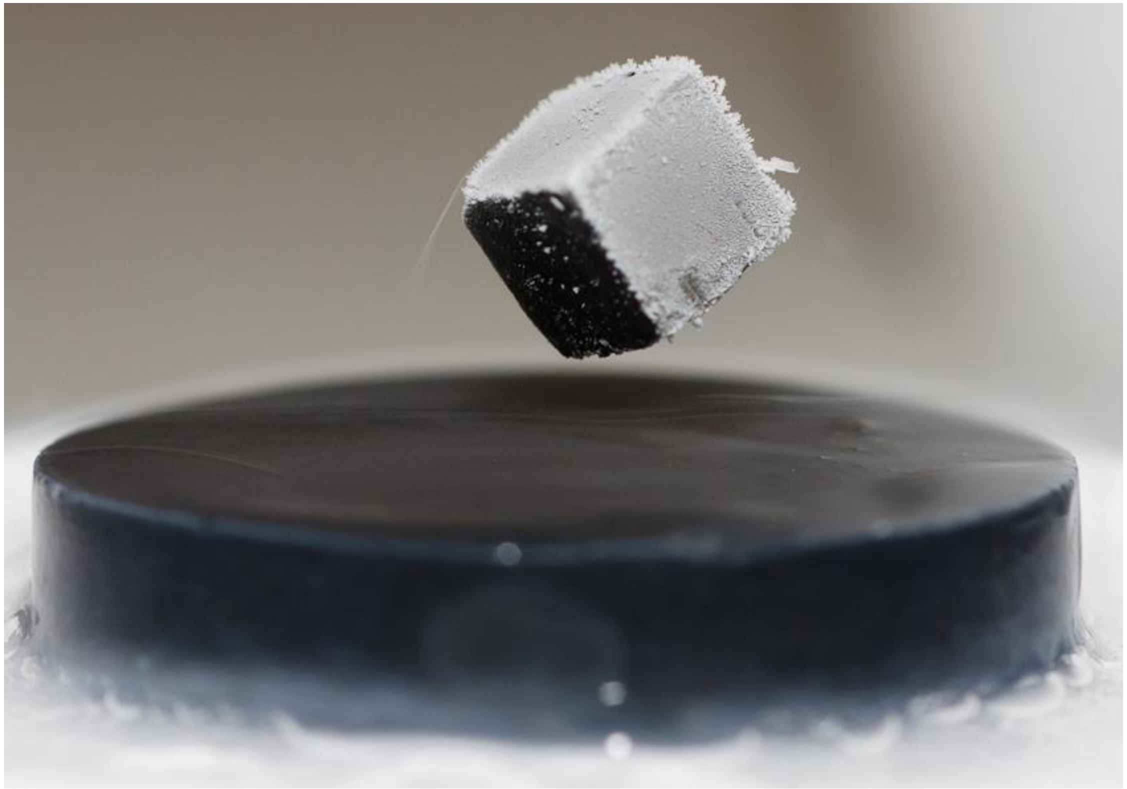


Fig. 4-163. Cylindrically-symmetric hyperbo used to provide three-dimensionally stable levitati particles.

Earnshaw's Theorem: a collection of point charges cannot maintained in a stable stationary equilibrium configuratio solely by the electrostatic interaction of the charges

Superconducting Levitation

- Expelling the magnetic field enables levitation



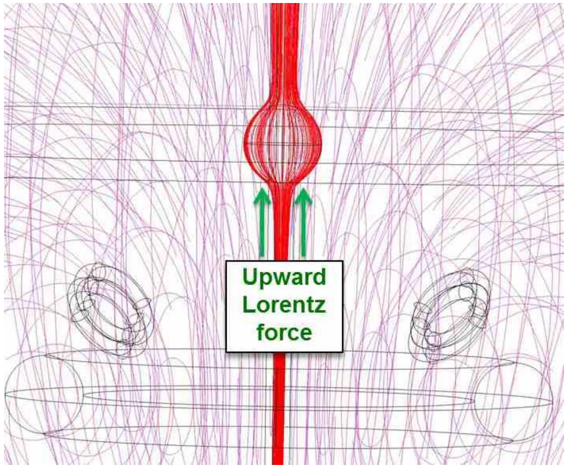
Bringing Levitation to NIF

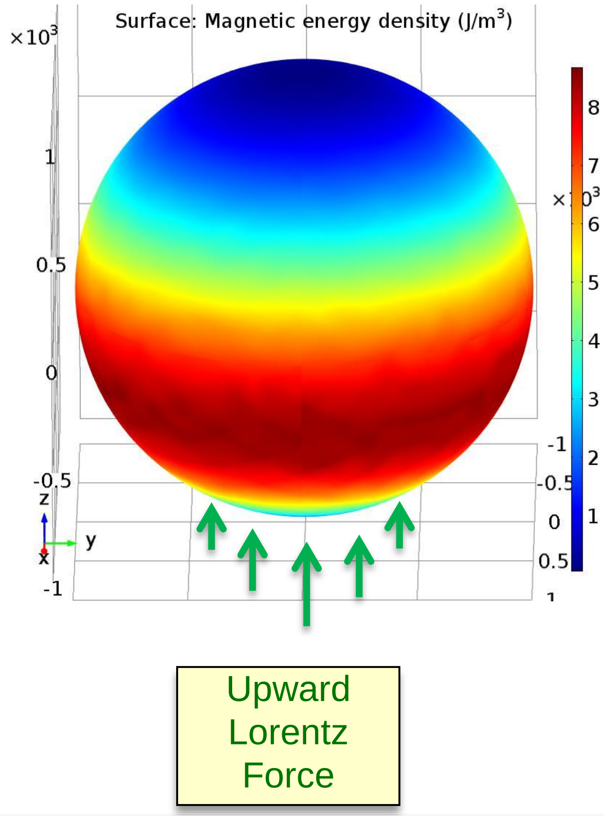
- NIF is already surprisingly compatible with superconducting levitation:

✓Targets at ~20K within chamber

✓Shape of capsule is favourable for levitation

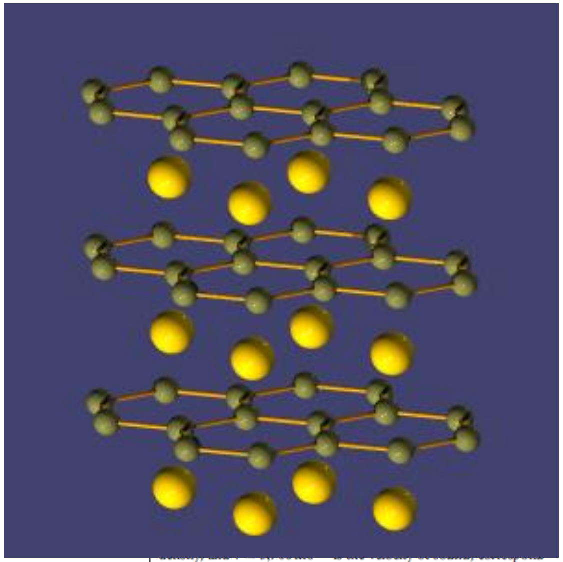
➢Coat with thin layer of low Z material





Magnesium Diboride

- Simple binary compound
- Range of fabrication routes
- Low Z
- High T_c (39 K),
- High J_c (~1e9 A/cm2 at 1 T),
- High H_{c2} (>50 T)



ing to an intrinsic decoherence rate $\gamma_2 \leq 2 \times 10^8 s^{-1}$. Such decoherence rates, more than 1,000 times slower than typical Rabi frequencies measured here, would enable more complex manipulations of the model qubits. Future experiments will attempt to measure the intrinsic decoherence time of 2*p* ($m = -1$) hydrogenic donor states, which are well below the continuum and hence robust to ionization by photons and phonons. □

Received 5 December; accepted 18 December 2000.

1. Loss, D. & DiVincenzo, D. P. Quantum computation with quantum dots. *Phys. Rev. A* **57**, 120–126 (1998).
2. Kane, B. E. A silicon-based nuclear spin quantum computer. *Nature* **393**, 133–137 (1998).
3. Sherwin, M. S., Imamoglu, A. & Montroy, T. Quantum computation with quantum dots and terahertz cavity quantum electrodynamics. *Phys. Rev. A* **60**, 3508–3514 (1999).
4. Imamoglu, A. *et al.* Quantum information processing using quantum dot spins and cavity QED. *Phys. Rev. Lett.* **83**, 4204–4207 (1999).
5. Vrijen, R. *et al.* Electron spin resonance transistors for quantum computing in silicon-germanium hetero-structures. Preprint quant-ph/9905096 at (http://xxx.lanl.gov) (1999).
6. Bennett, C. H. & DiVincenzo, D. P. Quantum information and computation. *Nature* **404**, 247–255 (2000).
7. DiVincenzo, D. P. Quantum computation. *Science* **270**, 255–261 (1995).
8. Hegmann, F. A. *et al.* Time-resolved photoresponse of a gallium-doped germanium photoconductor using a variable pulse-width terahertz source. *Appl. Phys. Lett.* **76**, 262–264 (2000).
9. Rabi, I. I. Space quantization in a gyrating magnetic field. *Phys. Rev.* **51**, 652–654 (1937).
10. Boyd, R. W. *Nonlinear Optics* (Academic, Boston, 1992).
11. Kohn, W. in *Solid State Physics* (eds Seitz, F. & Turnbull, D.) Vol. 5, 257–320 (Academic, New York, 1957).
12. Yu, P. Y. & Cardona, M. *Fundamentals of Semiconductors: Physics and Materials Properties* (Springer, Berlin, 1999).
13. Klaassen, T. O., Dunn, J. L. & Bates, C. A. in *Atoms and Molecules in Strong External Fields* (eds

Superconductivity at 39 K in magnesium diboride

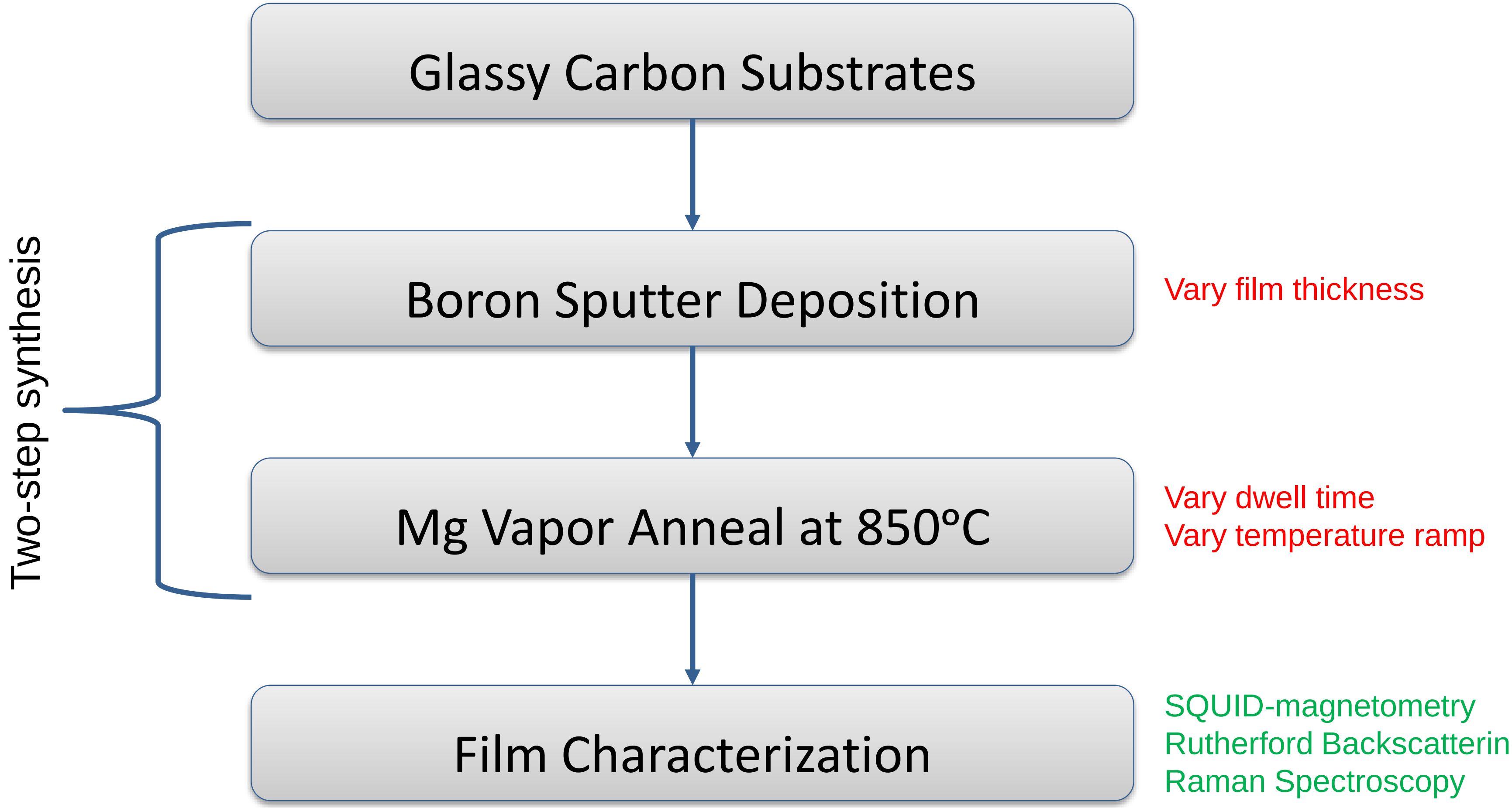
Jun Nagamatsu*, Norimasa Nakagawa*, Takahiro Muranaka*, Yuji Zenitani* & Jun Akimitsu*†

* *Department of Physics, Aoyama-Gakuin University, Chitosedai, Setagaya-ku, Tokyo 157-8572, Japan*
† *CREST, Japan Science and Technology Corporation, Kawaguchi, Saitama 332-0012, Japan*

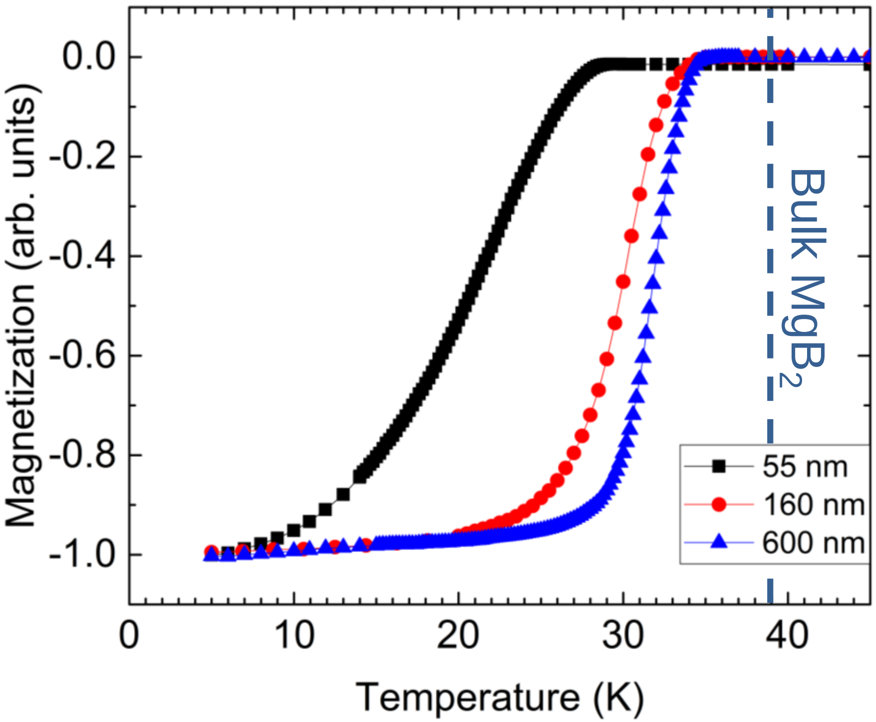
In the light of the tremendous progress that has been made in raising the transition temperature of the copper oxide superconductors (for a review, see ref. 1), it is natural to wonder how high the transition temperature, T_c, can be pushed in other classes of materials. At present, the highest reported values of T_c for non-copper-oxide bulk superconductivity are 33 K in electron-doped $Cs_xRb_yC_{60}$ (ref. 2), and 30 K in $Ba_{1-x}K_xBiO_3$ (ref. 3). (Hole-doped C_{60} was recently found[4] to be superconducting with a T_c as high as 52 K, although the nature of the experiment meant that the supercurrents were confined to the surface of the C_{60} crystal, rather than probing the bulk.) Here we report the discovery of bulk superconductivity in magnesium diboride, MgB_2. Magnetization and resistivity measurements establish a transition temperature of 39 K, which we believe to be the highest yet determined for a non-copper-oxide bulk superconductor.

The samples were prepared from powdered magnesium (Mg; 99.9%) and powdered amorphous boron (B; 99%) in a dry box. The powders were mixed in an appropriate ratio (Mg:B = 1:2), ground and pressed into pellets. The pellets were heated at 973 K

Fabrication of MgB2 Thin Films

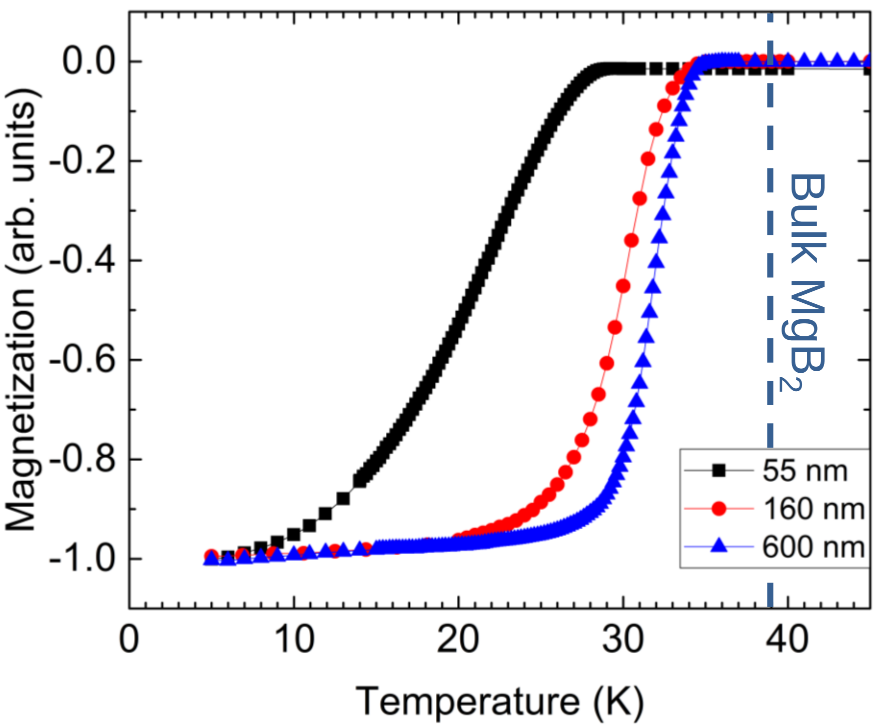


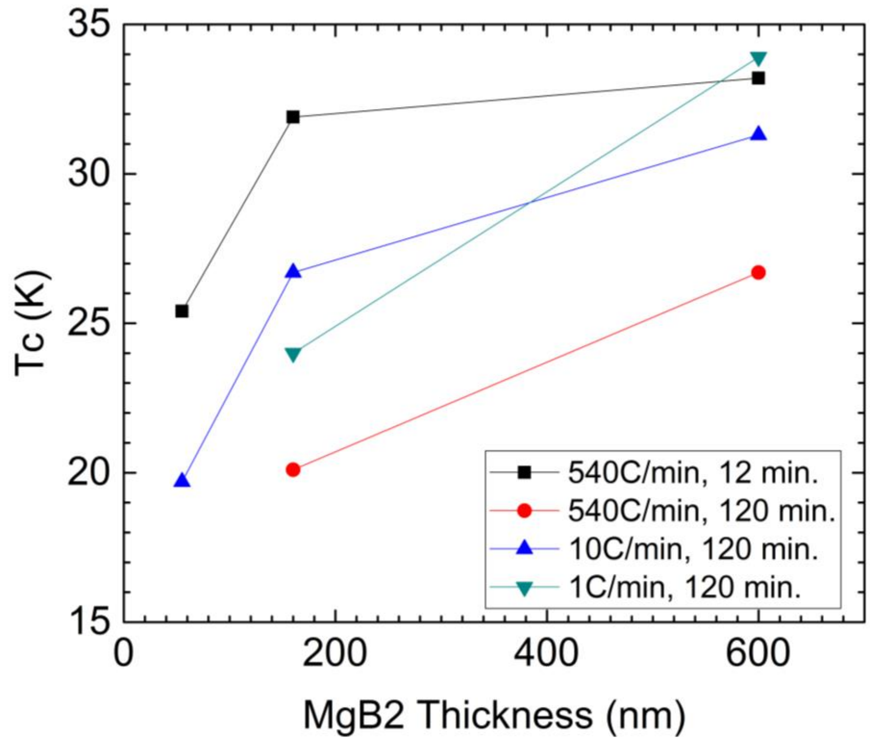
Film Thickness and Temperature Profile Matter



- Faster temperature ramps and shorter dwell times give higher T_c and sharper transition

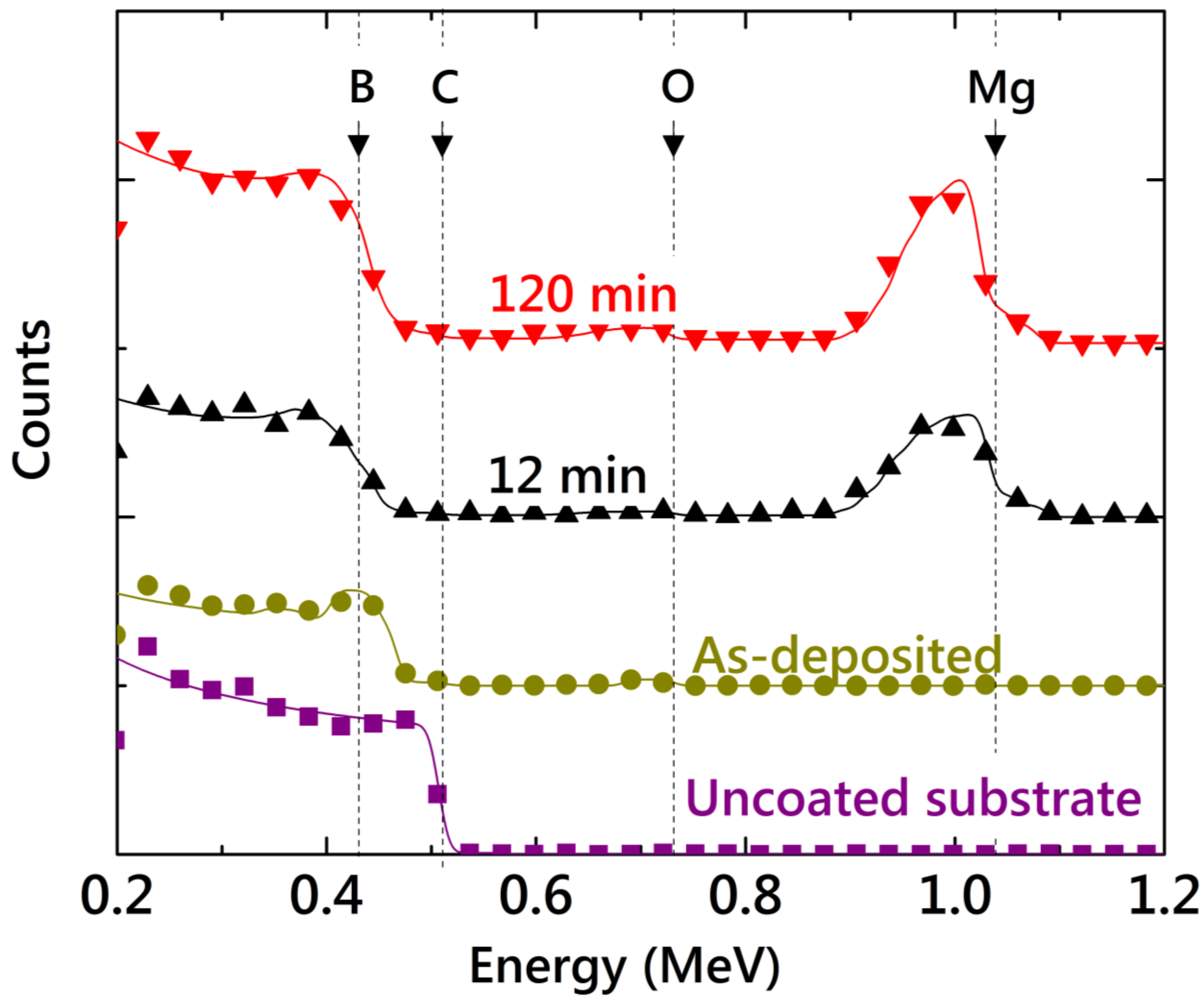
Film Thickness and Temperature Profile Matter





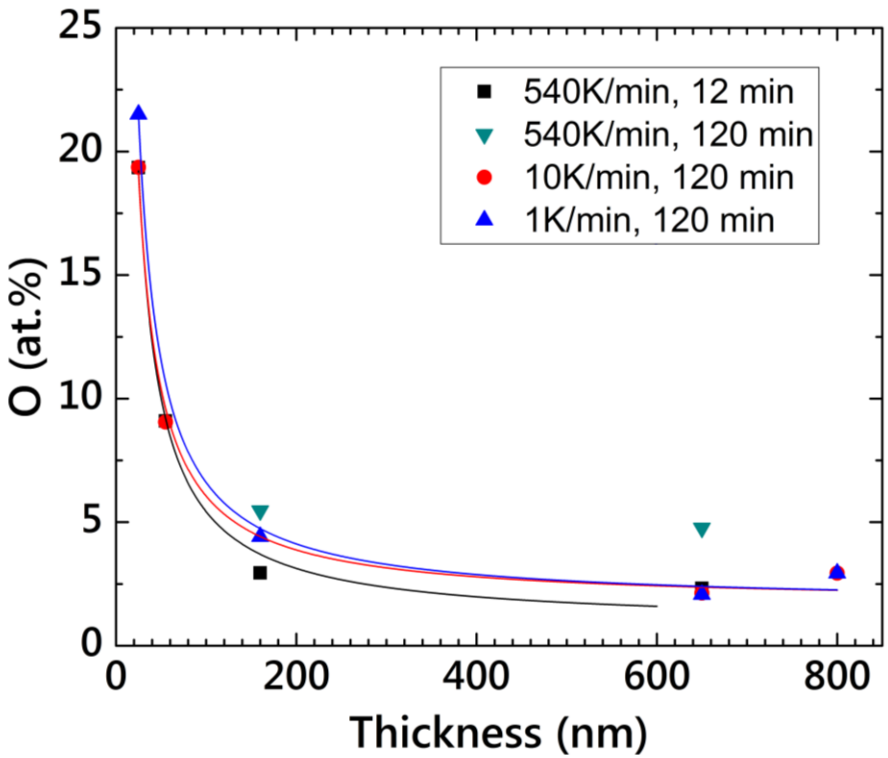
- Faster temperature ramps and shorter dwell times give higher T_c and sharper transition

Rutherford Backscattering Probes Composition



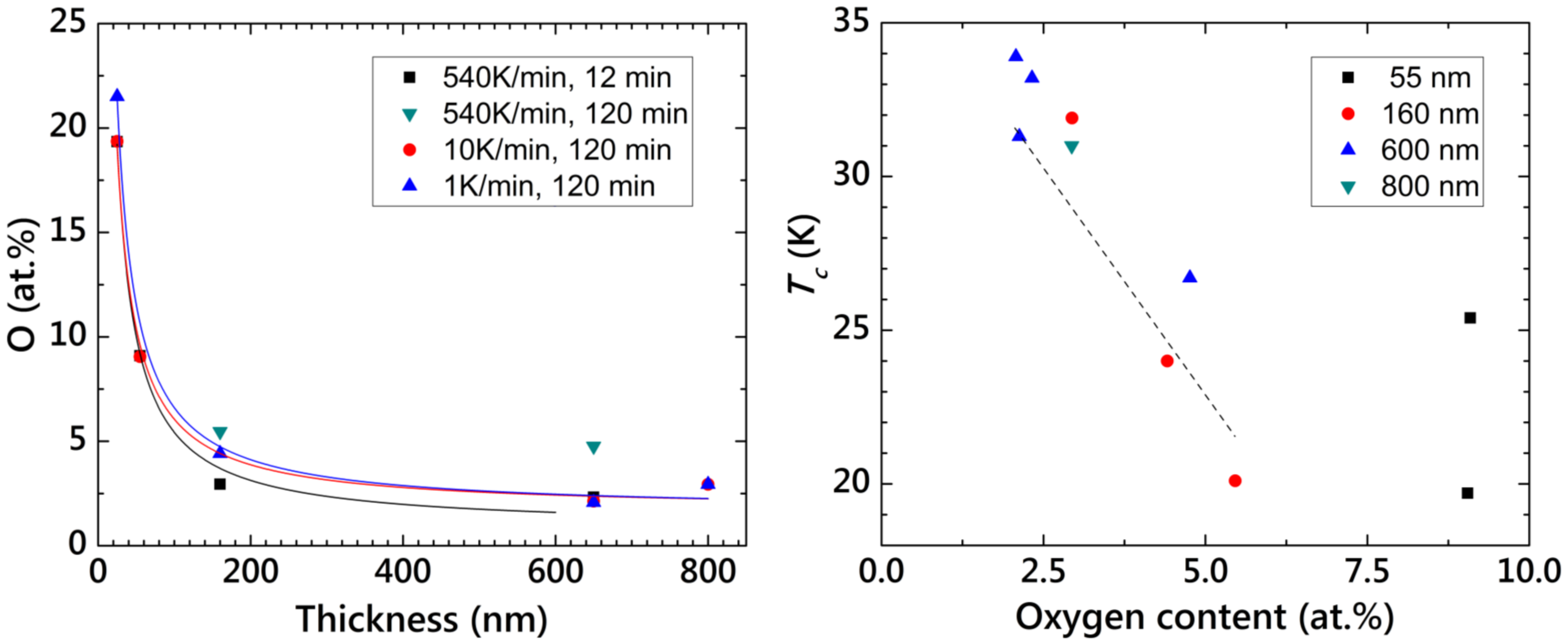
- Films are chemically homogeneous
- Oxygen distributed throughout the film
- Films tend to be slightly Mg-rich

Oxygen Depresses Tc



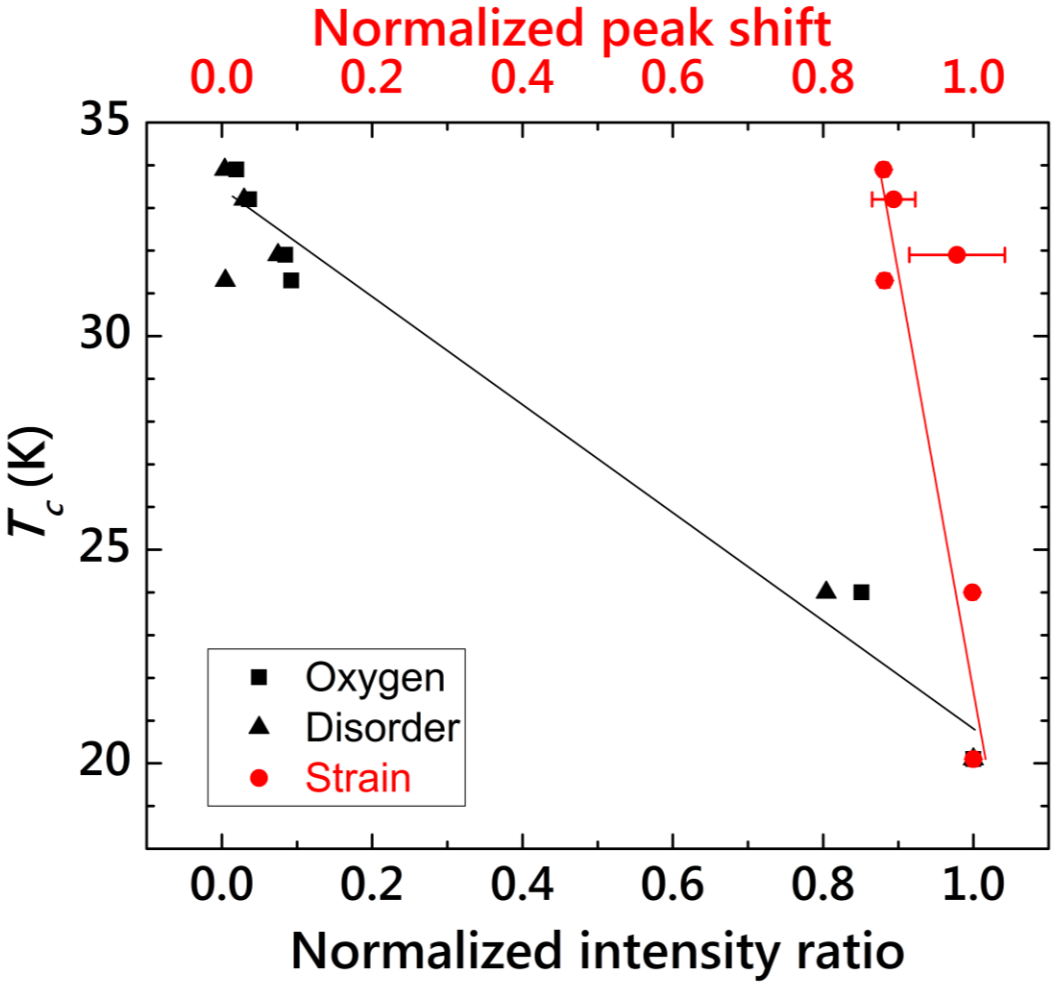
- Thinner films have significantly higher oxygen concentrations

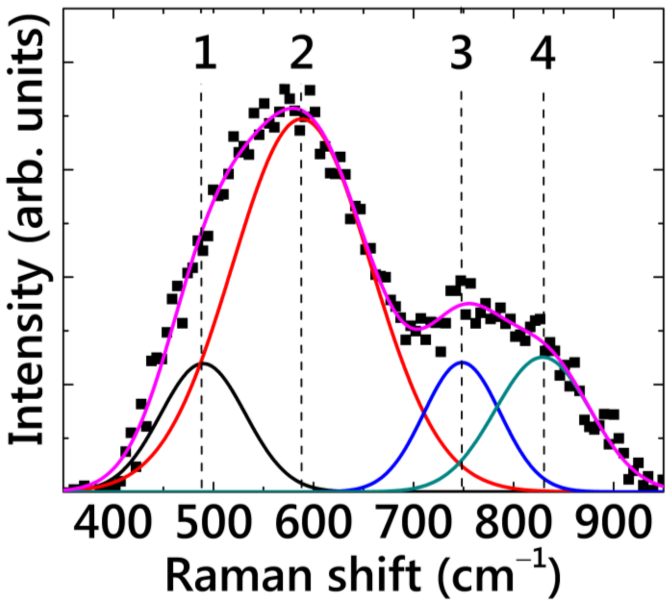
Oxygen Depresses Tc



- Thinner films have significantly higher oxygen concentrations
- But this is not the whole story

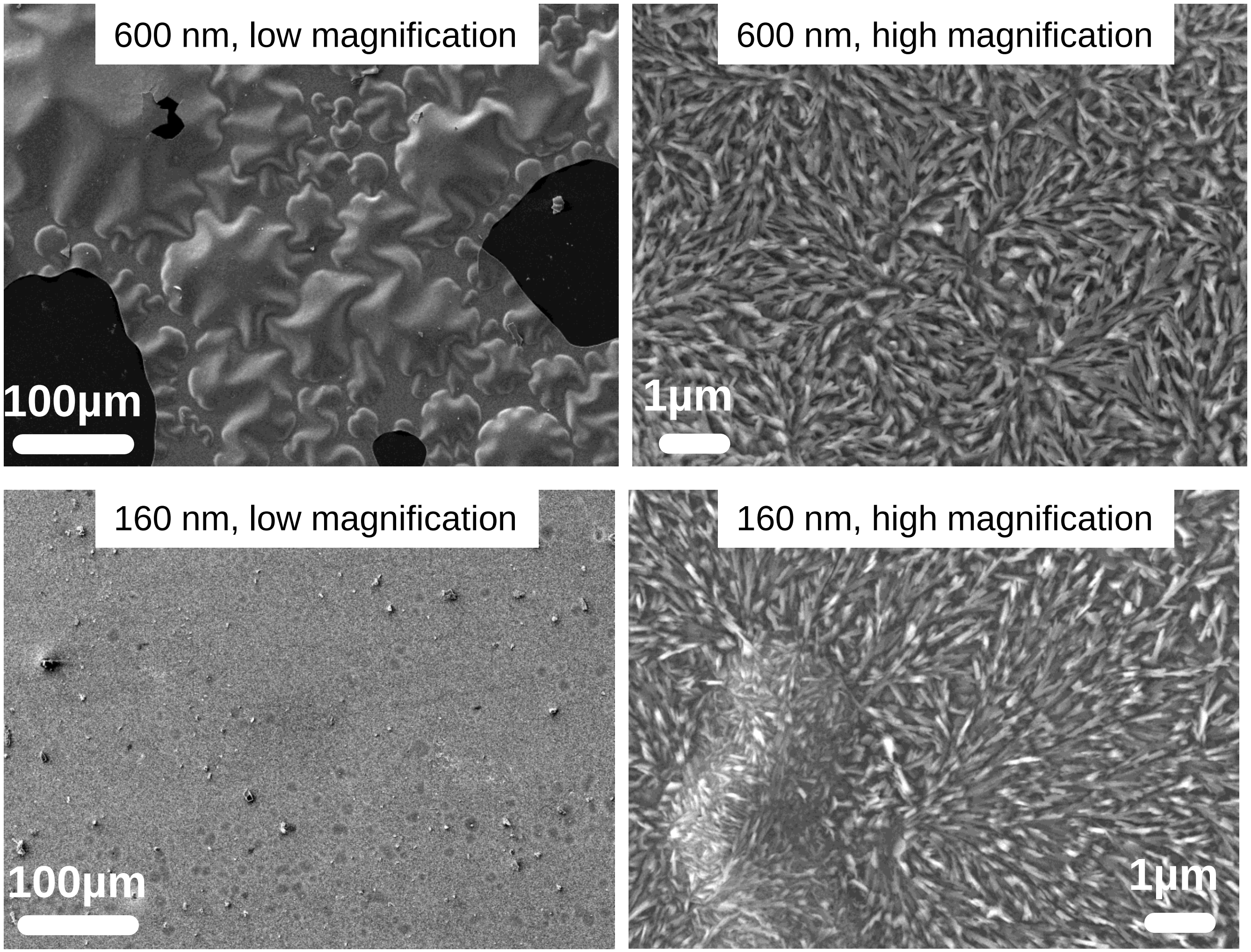
Raman Spectroscopy Reveals Disorder





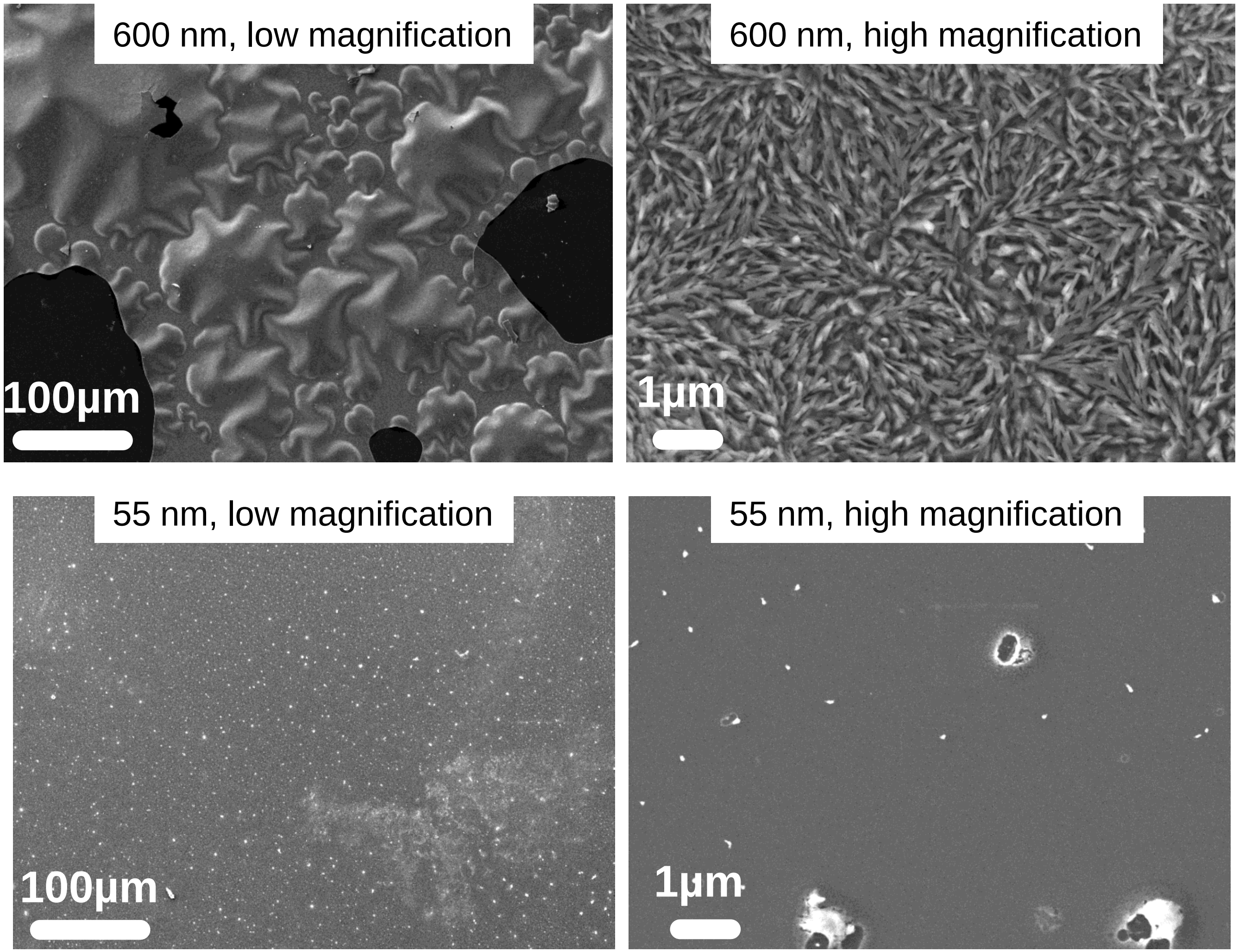
- Defects and inclusions suppress T_c
- Originates in non-epitaxial growth, mitigated by faster thermal processing

Surface Roughness Must be Controlled



- Thicker films are blister and peel
- Needle-like surface texture

Surface Roughness Must be Controlled



- Thicker films are blister and peel
- Needle-like surface texture
- Thin films are smooth, < 1nm rms.

Next Steps

- Deposition on spheres will require bounce pan and rotating tube furnace
- Early attempts to measure levitation were a mixed success, but have plans for custom modification to PPMS in coming year
- Studying ion irradiation to enhance critical current

Acknowledgments

- L. Bimo Bayu-Aji, Dante O'Hara (summer student), John Bae (GA), Elis Stavrou, David Steich, Scott McCall, Sergei Kucheyev

LDRD 17-ERD-040

Goal: Demonstrate a path to ideal ICF capsule support based on quantum levitation

Approach: Thin films of superconducting MgB_2

"Vapor annealing synthesis of non-epitaxial MgB2 films on glassy carbon", A A Baker *et al* (2018) *Supercond. Sci. Technol.* **31** 055006

Critical Current Limits Levitation

- Measured in plane of film
- Good zero field values, but drops rather precipitously.
- Hc_2 ~ 20 kOe
- Simulations predict ~$10^3 A/cm^2$ required