Flux Pinning in MgB_2:
What do we want?
How might we get it?

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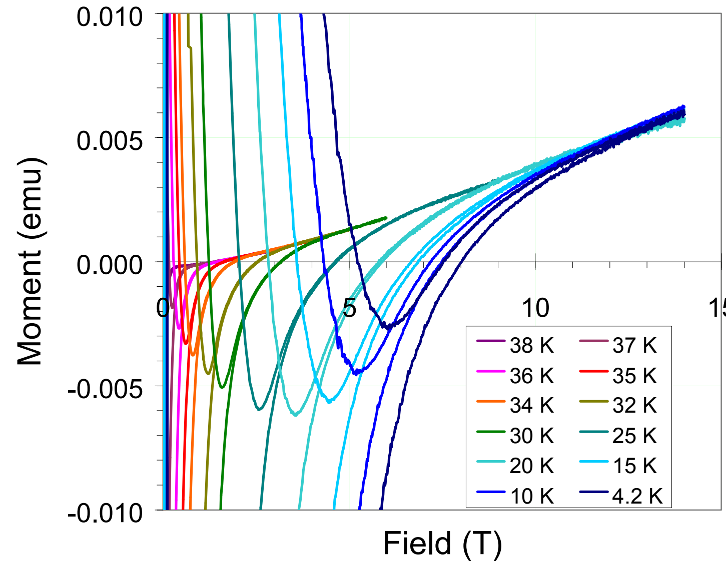
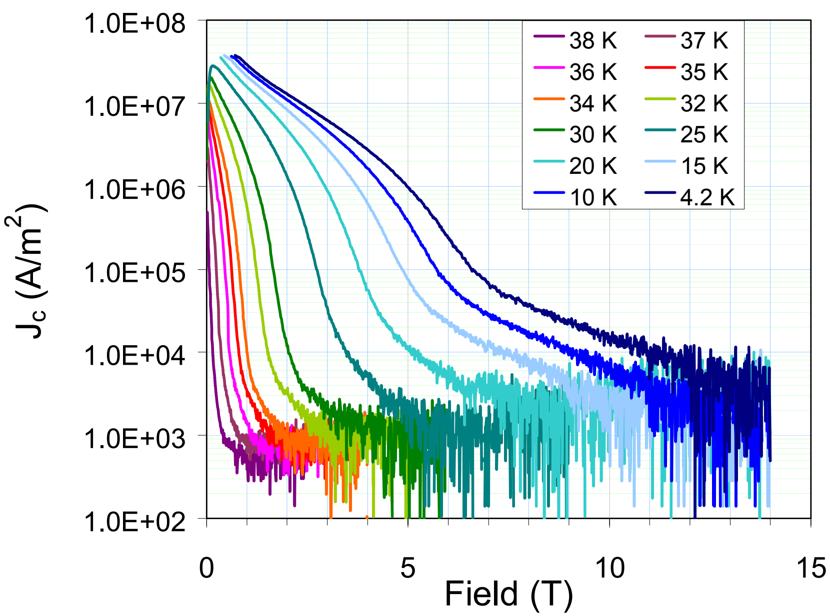
BOROMAG, 17-19 June 2002

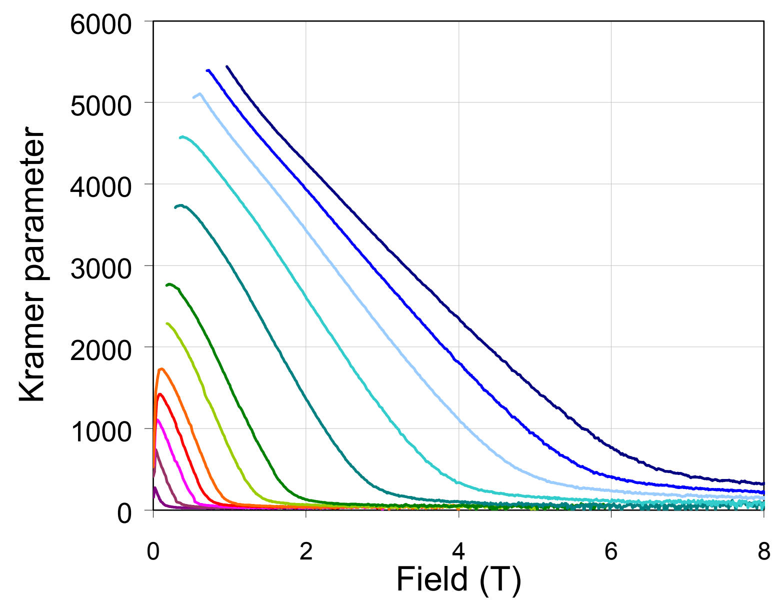
Grain-boundary pinning indicated early on

- Linear Kramer plots over wide temperature range
  - Tails due to anisotropy and percolative connection of grains oriented with H||ab



Early 2001 Princeton bulk

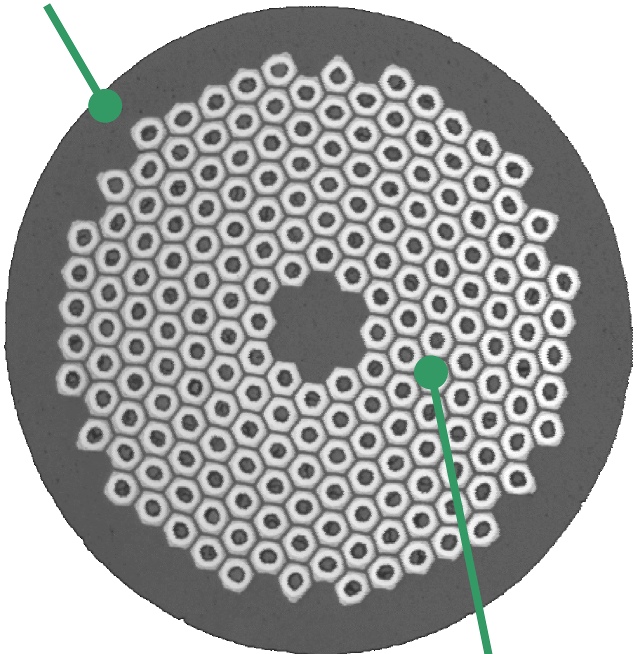




What do we want? — Clues from Nb_3Sn

Powder-In-Tube Conductor from ShapeMetal Innovation (SMI), Holland

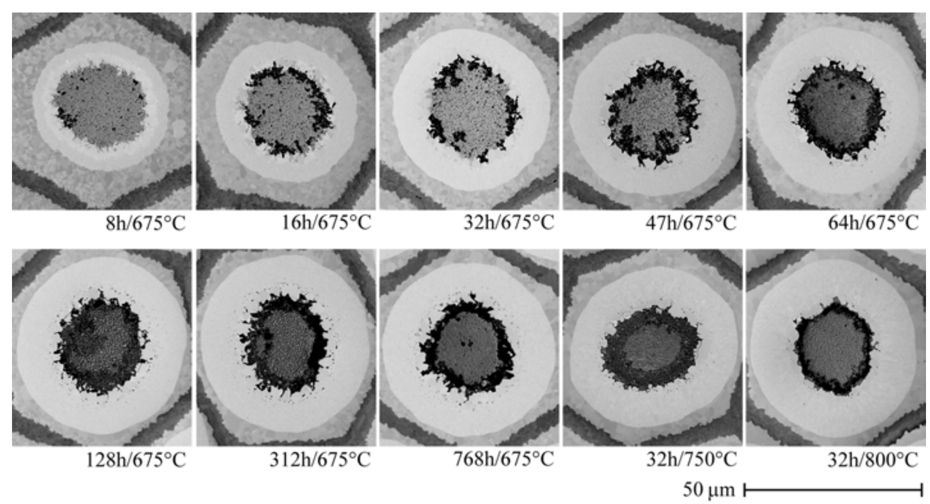
0.90 mm Diameter Wire



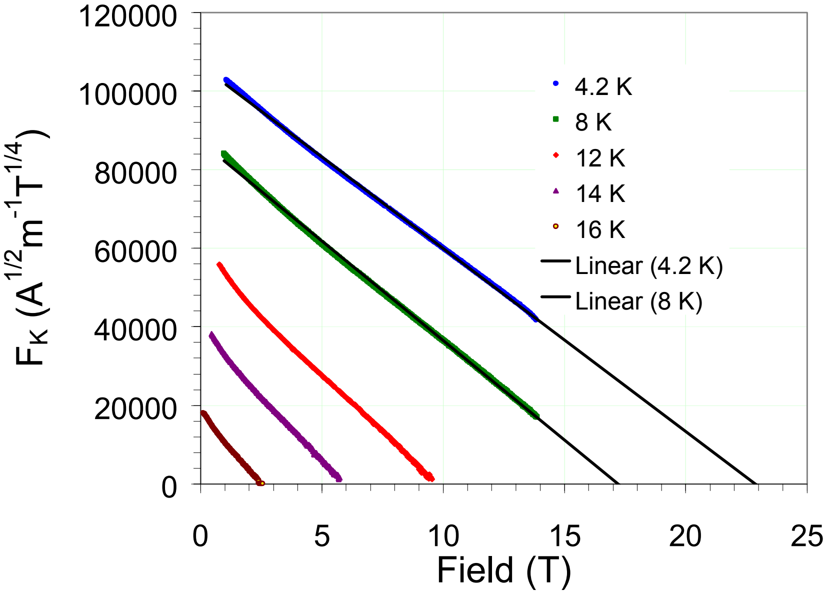
192 Nb or Nb7.5Ta filaments with $NbSn_2$ powder core

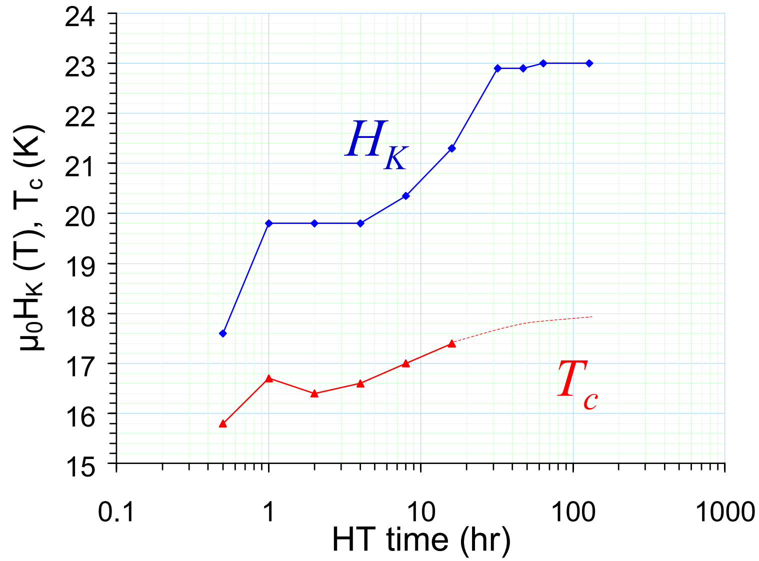
- Very uniform multifilamentary strand cross-section
- Longitudinally homogeneous
- Radial gradients of Sn
  - But gradient falls steeply only near Nb/Nb_3Sn interface
- Small grains, ~140 nm diameter

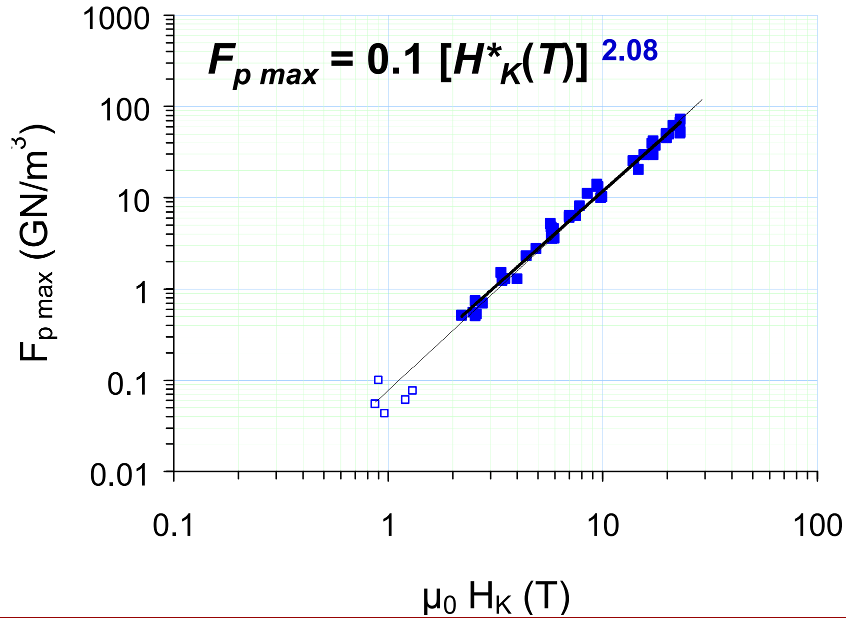
Nb_3Sn Layer grows radially



Homogeneous properties are essential





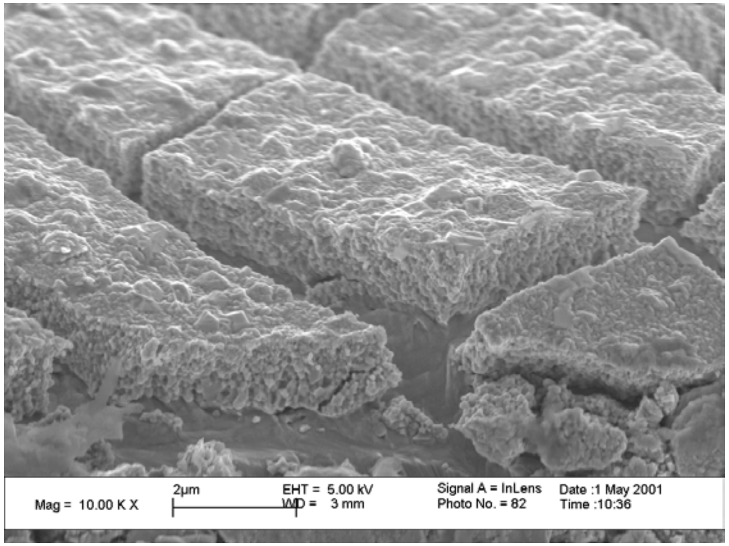


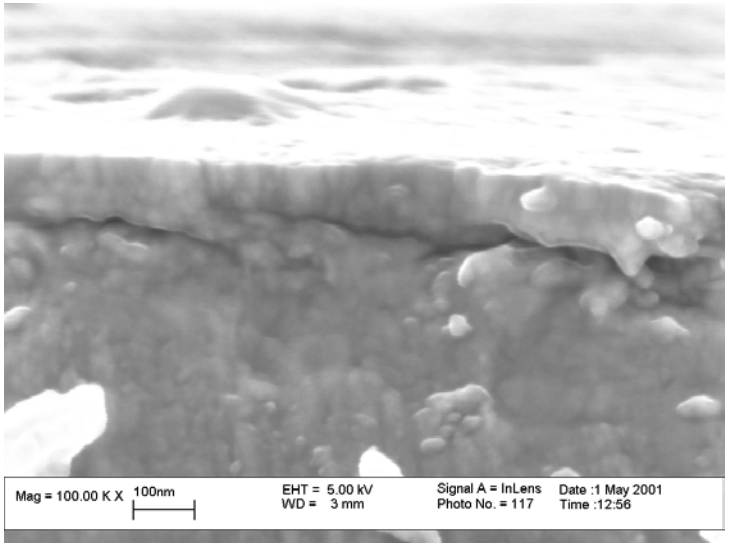
- If tin content varies by as little as 0.3%, resultant variations of T_c, H_{c2}(4.2K), H^*(4.2K) cause F_{pmax}(4.2K) to decrease by 10% and F_p(4.2K,12T) to drop 18%

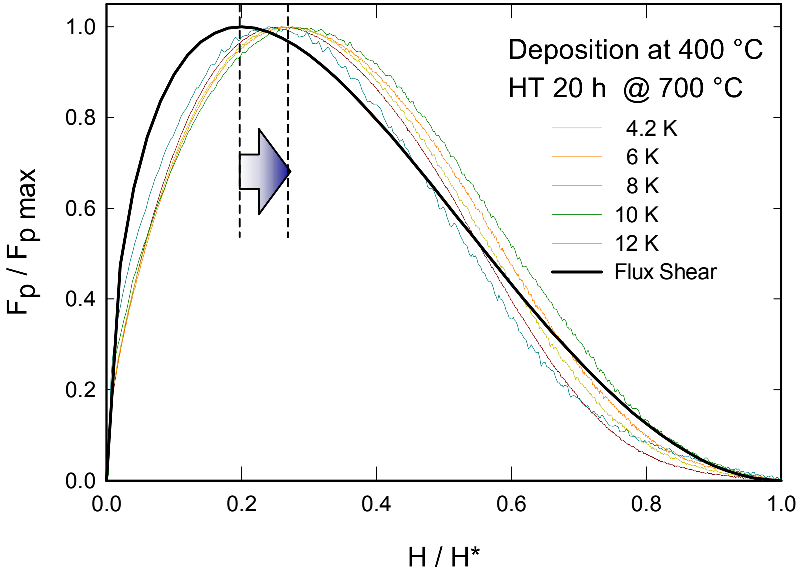
  Assumed: T_c = 17.6K; H_{c2} (4.2K) = 30T; H^*(4.2K) = 24T; linear variations of T_c(%Sn) and H_{c2}(T)

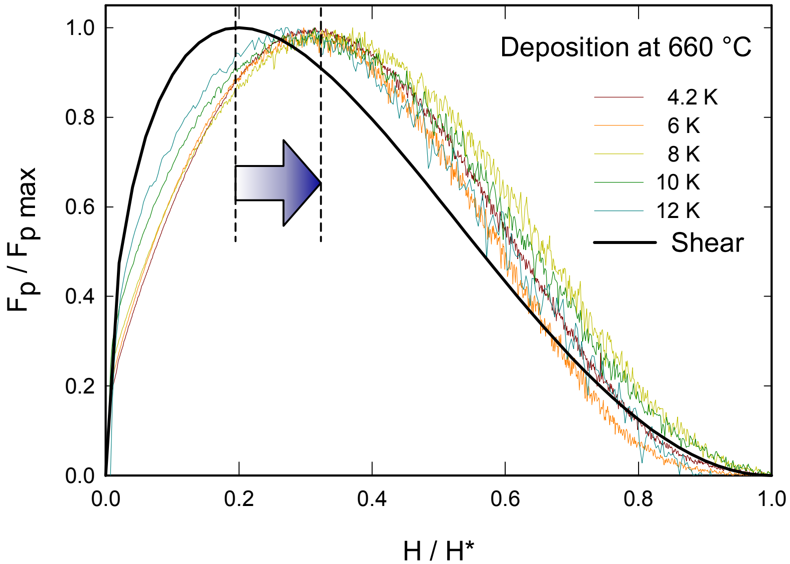
Improved high-field pinning for $D \sim a_0$

L D Cooley and P J Lee – *IEEE Trans ASC* **11,** 3820 (2001)



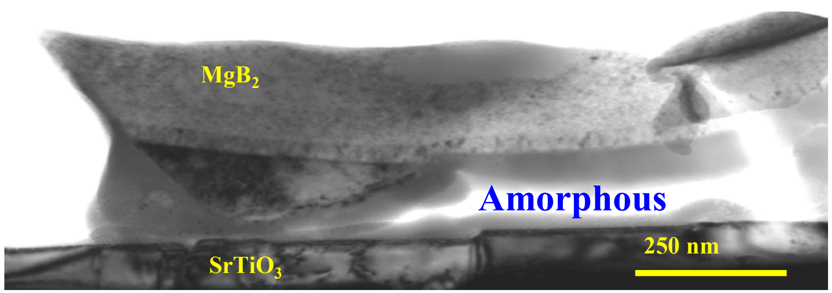




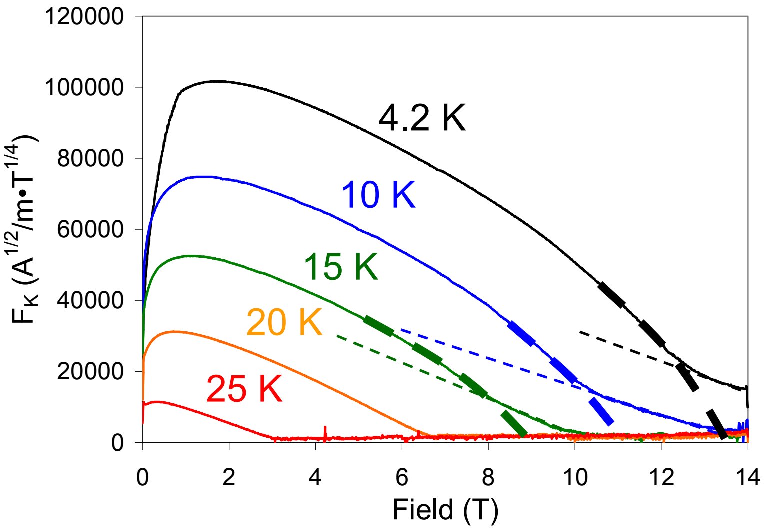


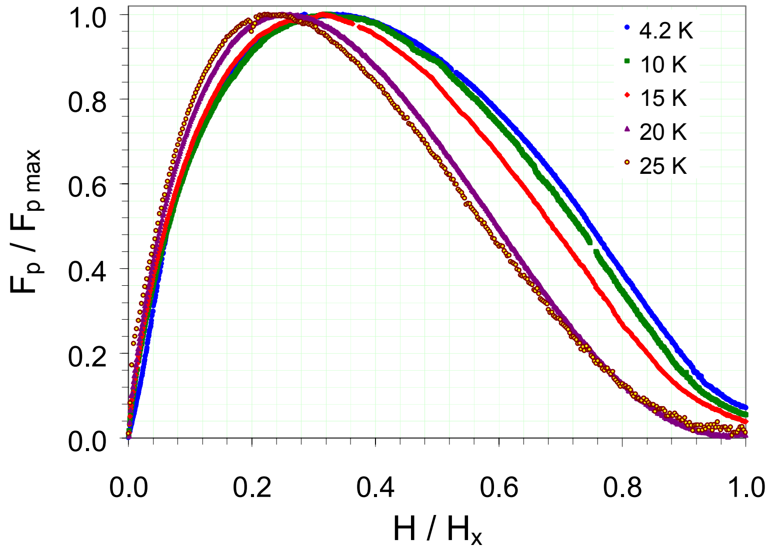
Pinning added at high fields in 1st generation MgB_2 films made by PLD

- Nanoscale grains, substantial MgO
- High field pinning:
  - Matrix of 5 nm MgB2 grains with occasional 5 nm MgO grains
  - OR
  - Embedded MgO nanoprecipitates within MgB2 grains



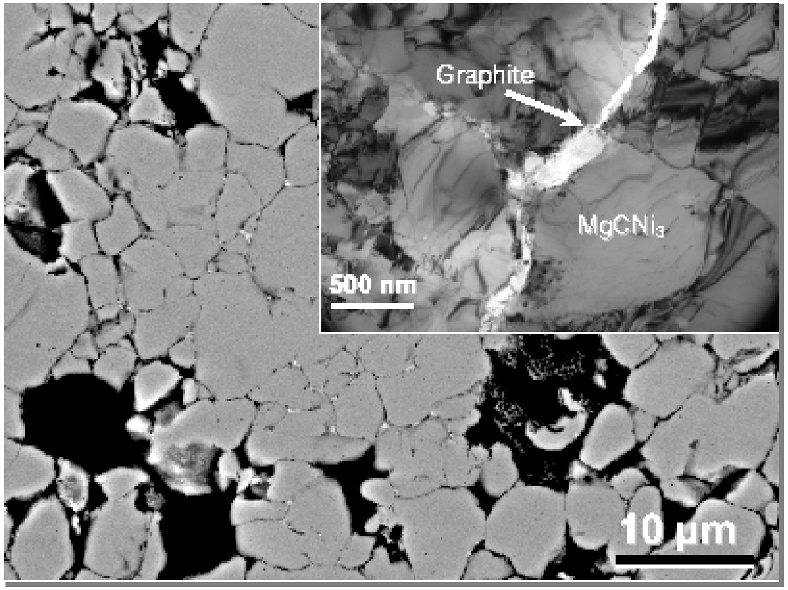
“Film 2”, C. B. Eom *et al.*, *Nature* **411**, 558 (2001)

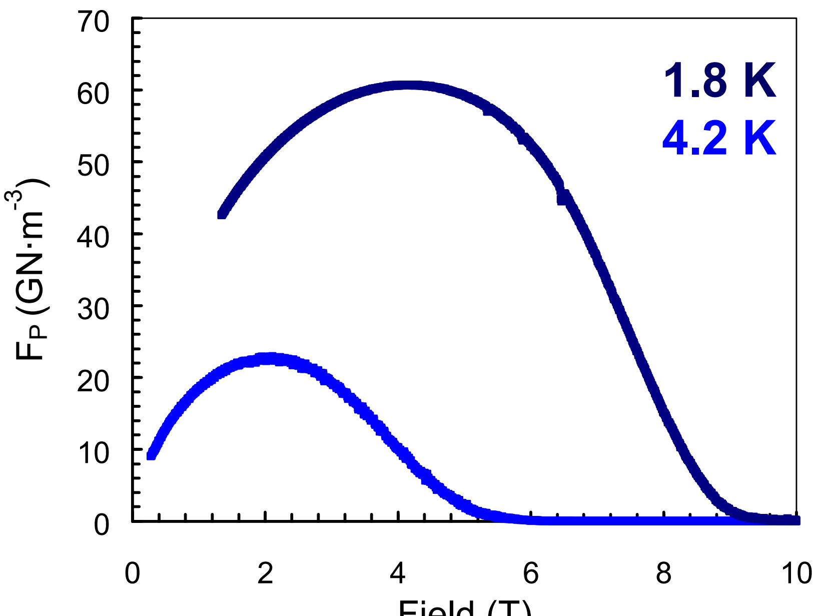


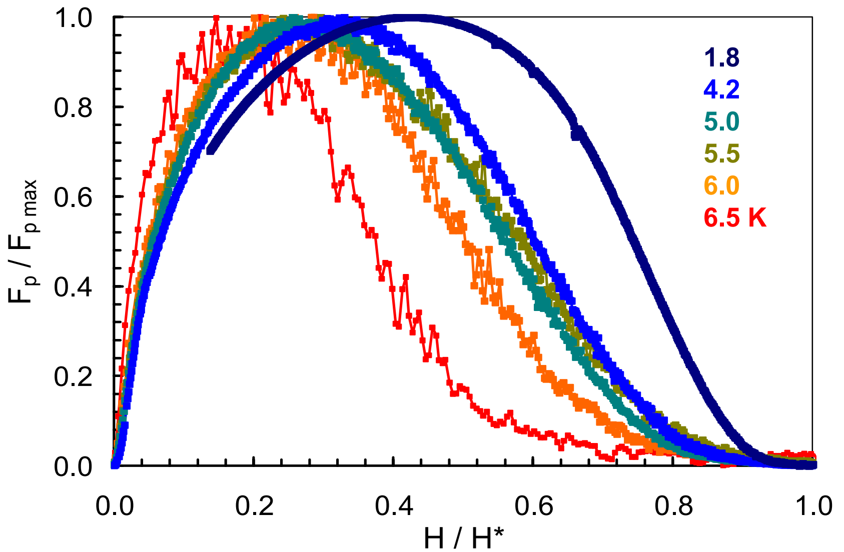


$MgCNi_3$

- Very potent pinning sites indicated by $F_p(H)$ but not obvious in microstructure
- $F_p(H,T)$ like that of Nb-Ti — nanoprecipitates?



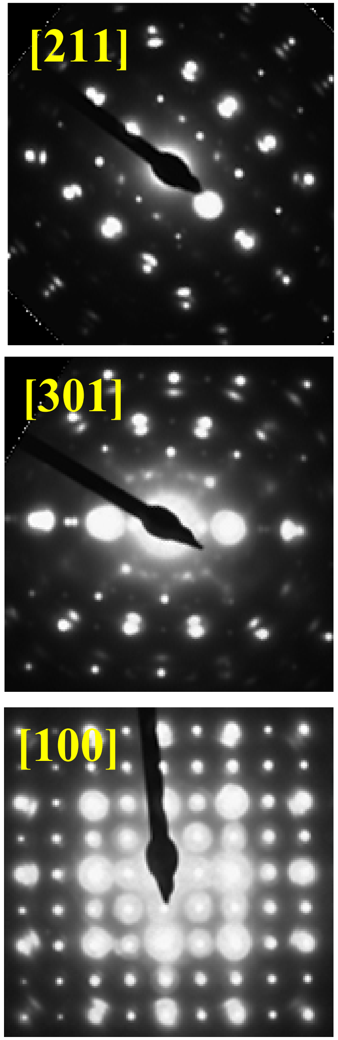




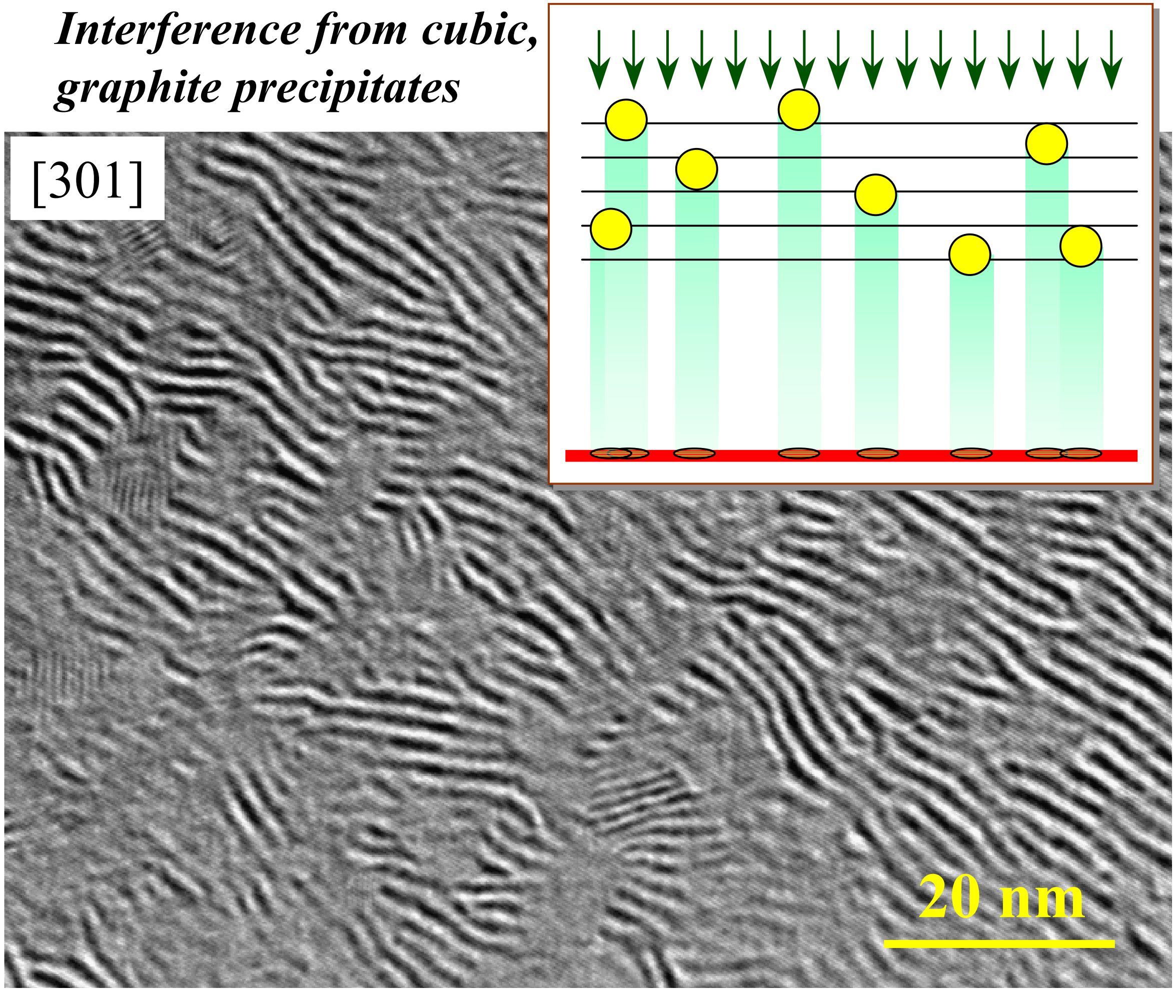
L.D. Cooley, X. Song, J. Jiang, D.C. Larbalestier, T. He, K.A. Regan, and R.J. Cava, *Phys. Rev. B* (to appear June 2002)

Intragranular nanoprecipitates in $MgCNi_3$

Diffraction from cubic precipitates



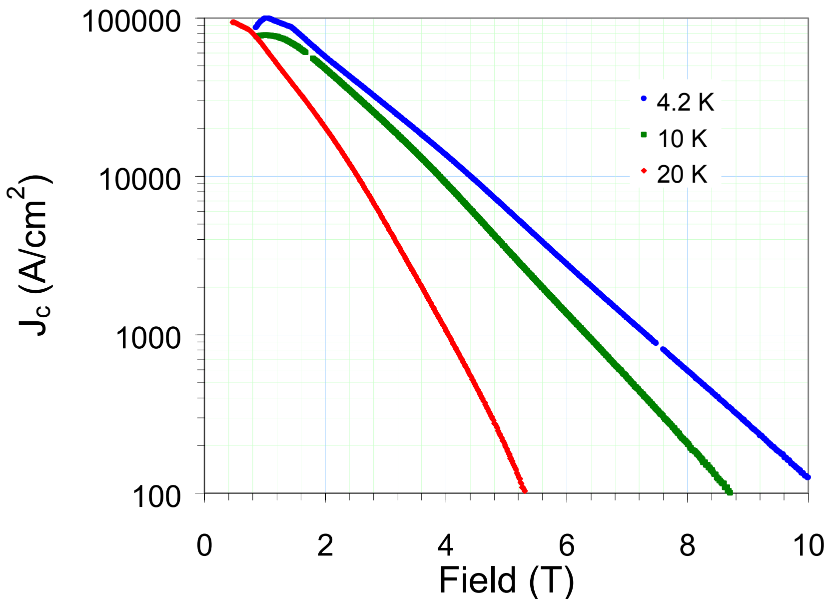
Interference from cubic, graphite precipitates



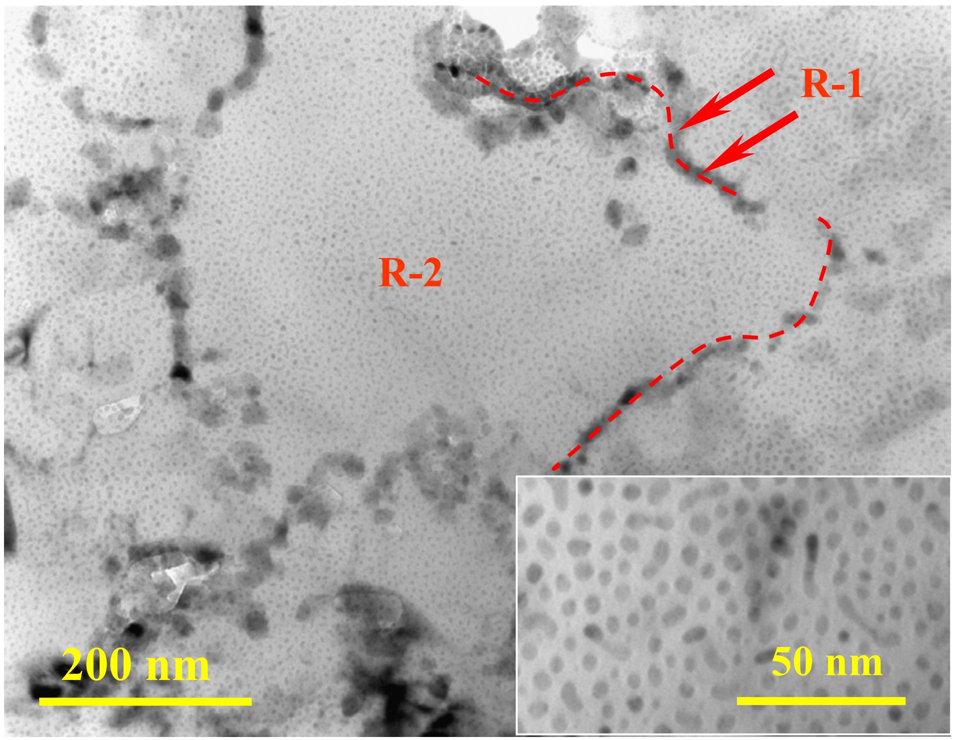
X. Song TEM analyses

Nanoprecipitation by oxide ↔ boride exchange in MgB_2

- Mg + B powders + 10wt.% Y_2O_3 nanoparticles
- XRD: YB_4 nanoprecipitates ($Y_2O_3 + 4\ MgB_2 \rightarrow 2\ YB_4 + 3\ MgO + Mg$)
- But YB_4 precipitates in GBs break up current pathways in magnetization!



J. Wang, Y. Bugoslavsky, L. Cowey, A. Berenov, A.D. Caplin, L.F. Cohen, J.L. MacManus Driscoll (Imperial College); L. D. Cooley, X. Song, D. C. Larbalestier (UW-ASC) – submitted to *Applied Physics Lett.*

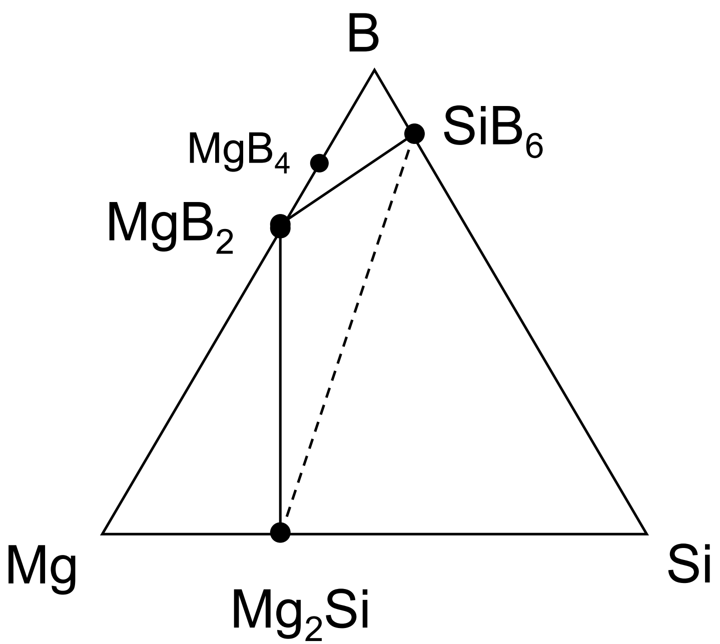


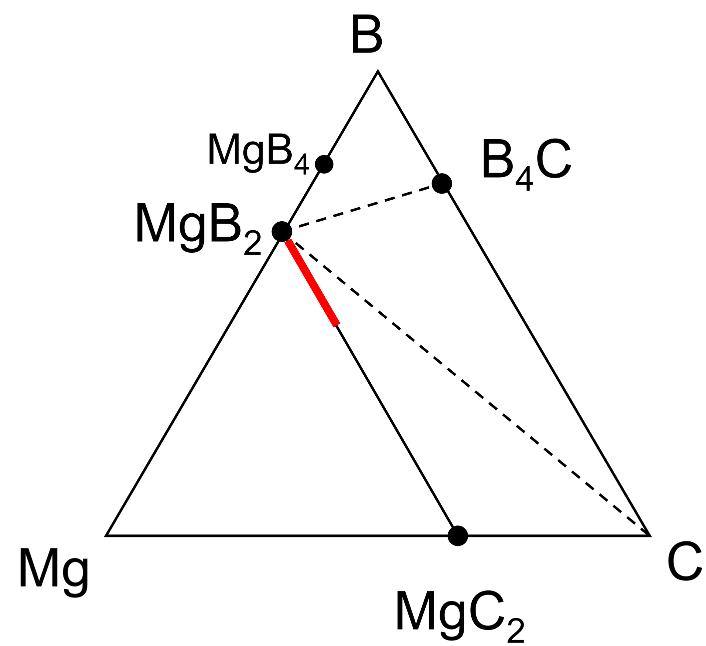
Precipitation routes from low-stability borides (work in progress…)

Free energy (per B) kJ/mol at 273 K	
B_4C	-13.82
SiB_6	-22.65
MgB_2	-25.43

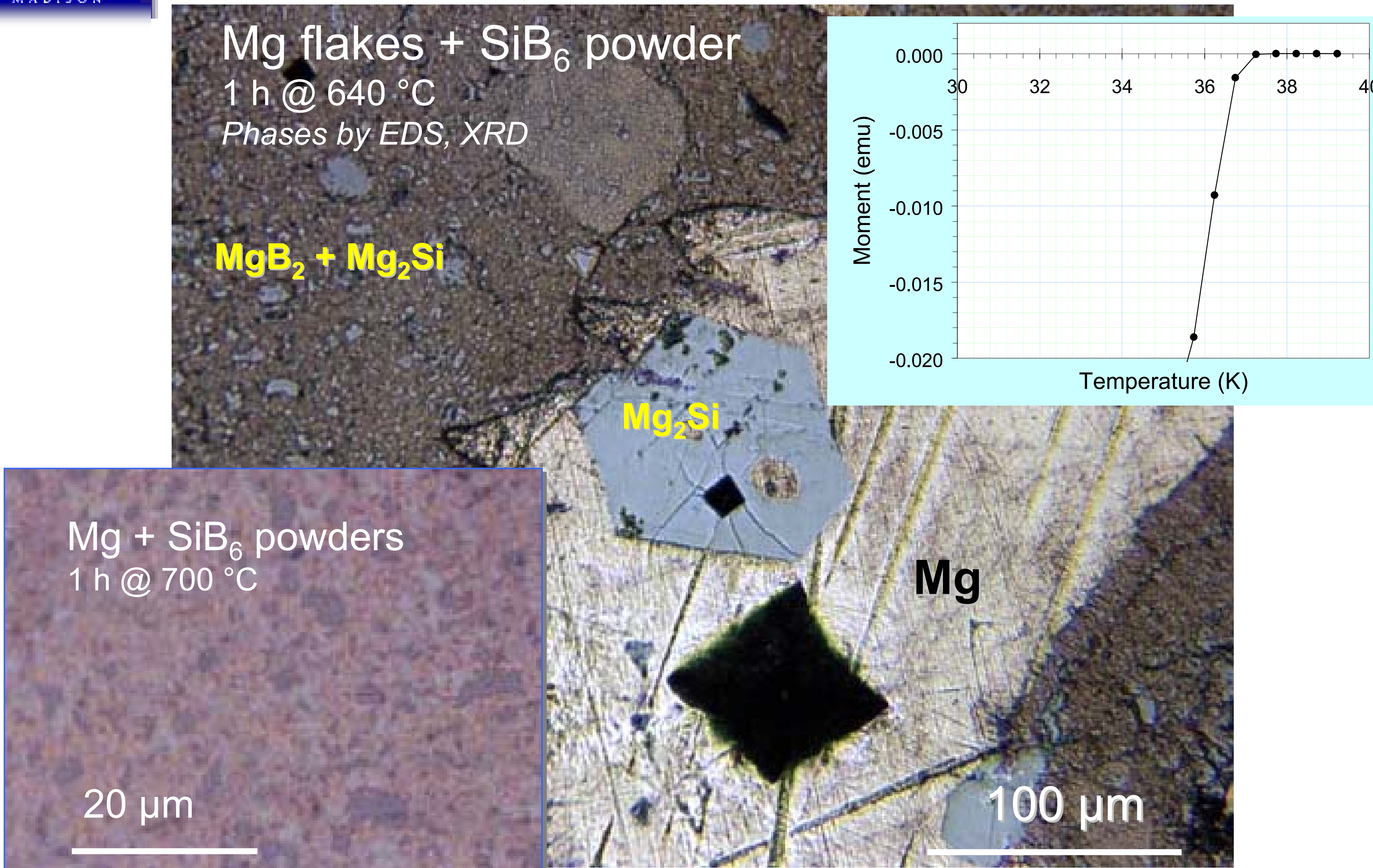
- $5\ Mg + SiB_6 \rightarrow 3\ MgB_2 + Mg_2Si$
- $2.5\ Mg + B_4C \rightarrow 2\ MgB_2 + 0.5\ MgC_2$

  $\rightarrow 2.5\ Mg(B_{0.8}C_{0.2})_2$





Rapid synthesis of 37 K MgB_2 at 640-700 °C

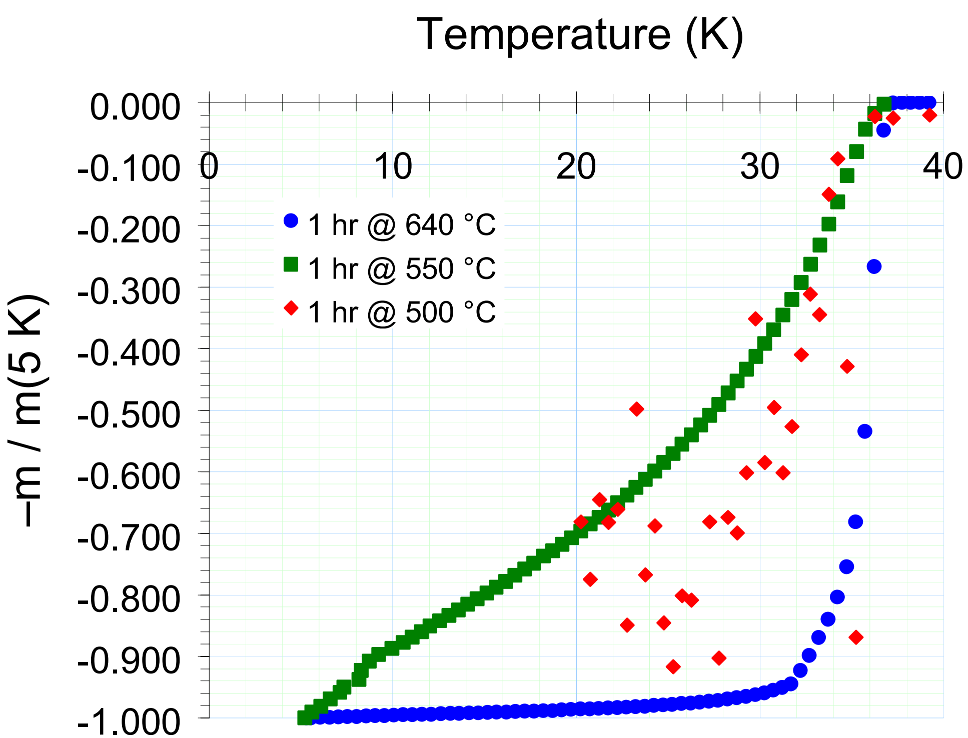


Possible low-temperature synthesis of MgB_2 from SiB_6?

- 37 K transition even for 1 h @ 500 °C
- Ternary system fixes MgB_2 composition, T_c?

Rogado et al, JAP 91:274 (2002)

Mg flakes + SiB_6 Powder



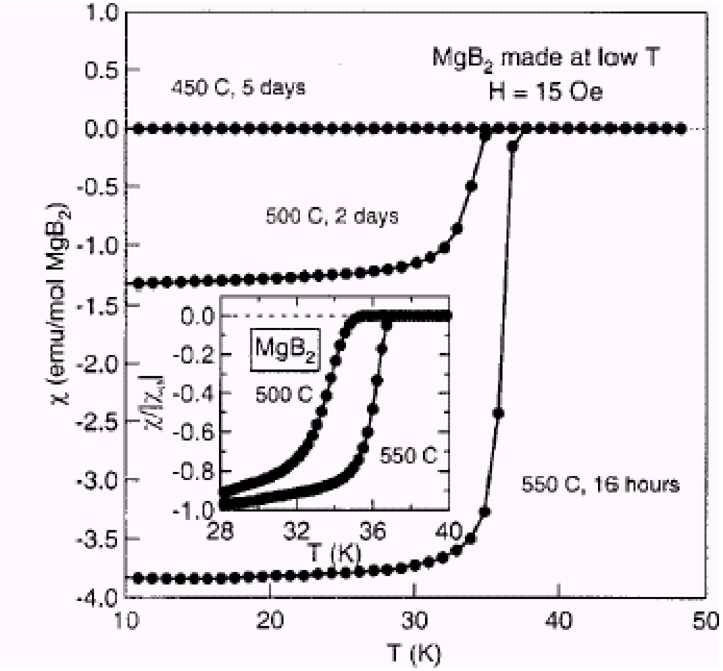
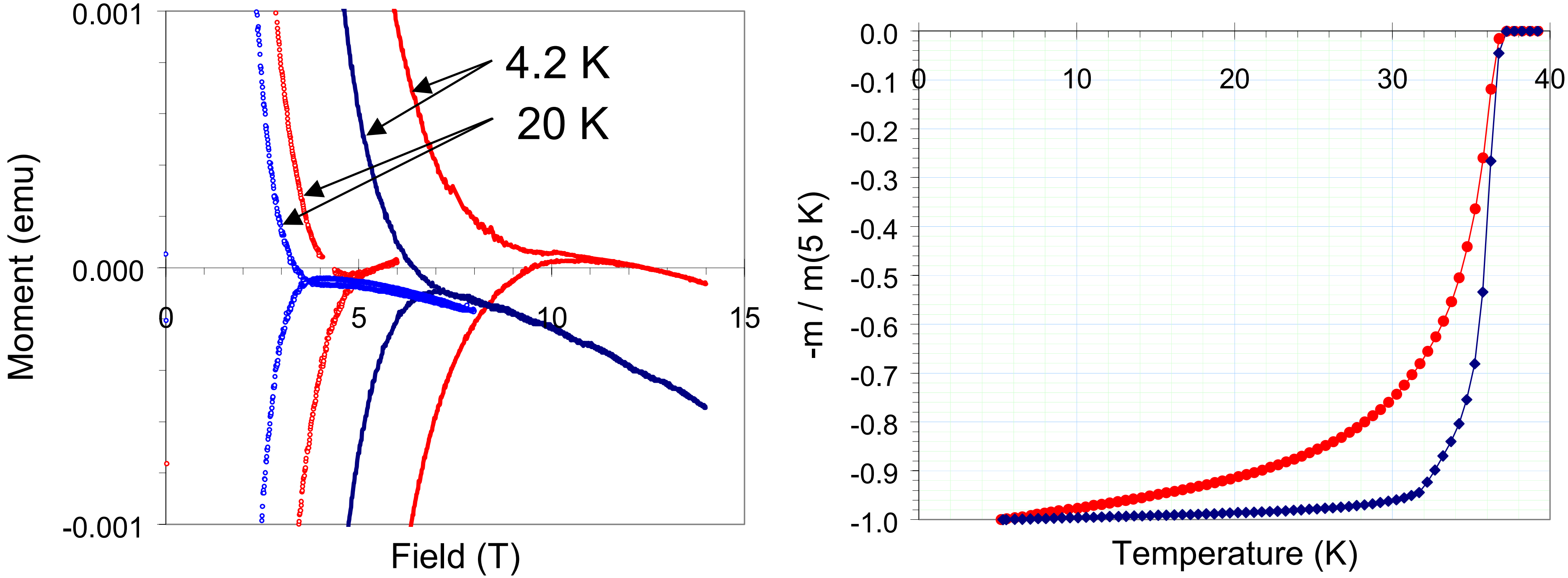


FIG. 2. Temperature dependent magnetization of polycrystalline powder samples of MgB_2 fabricated at different heating conditions. A 15 Oe dc field was applied after cooling in zero field. Inset shows detail of the region near T_c for the samples prepared at 550 and 500 °C.

Oxygen alloying from Mg powder?

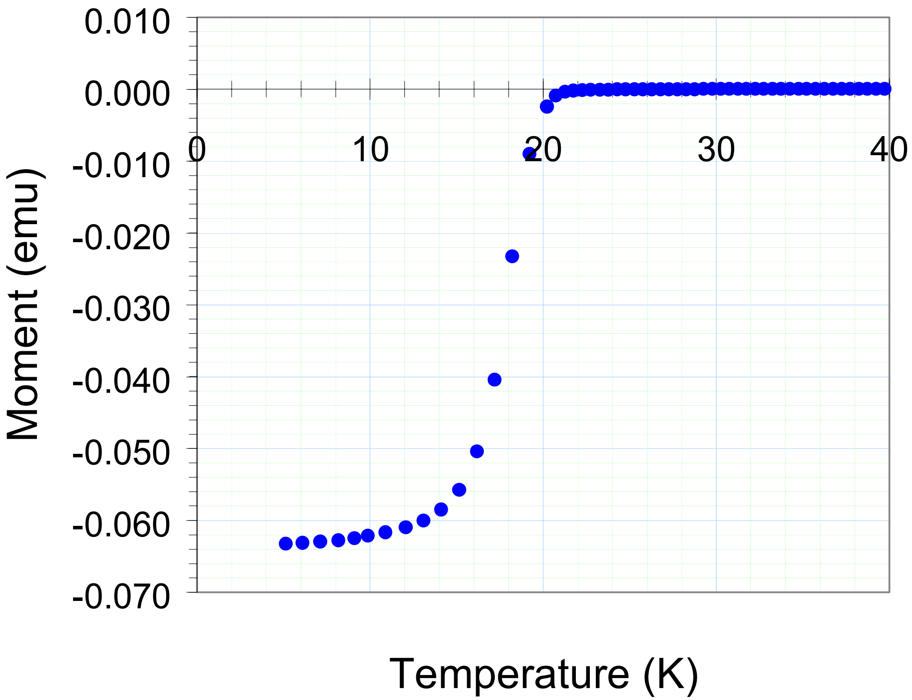
- No evidence for Si alloying from XRD
- *H** higher for Mg powder, but same T_c

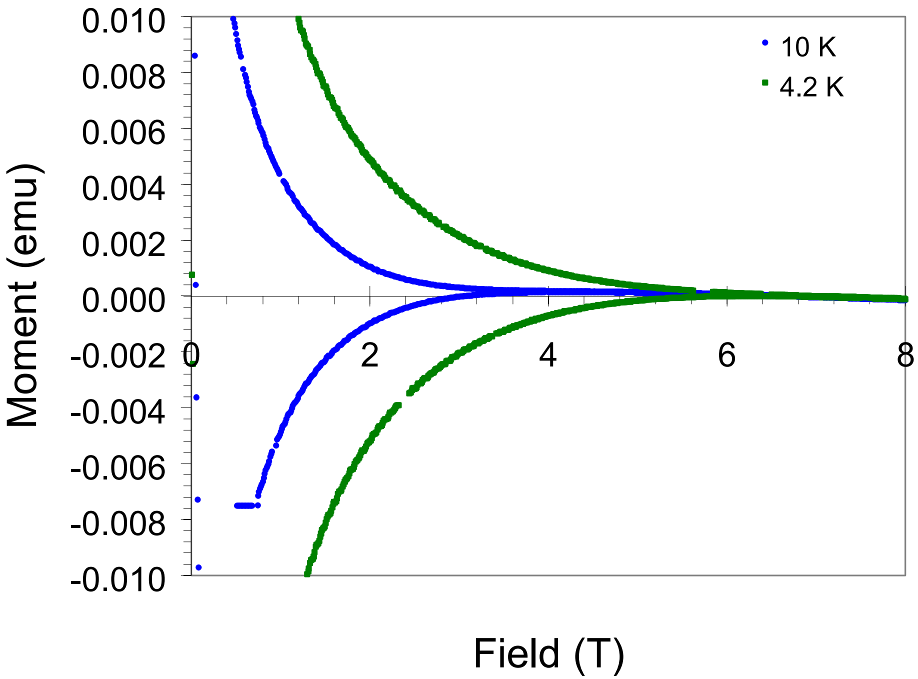
Mg powder + SiB_6 powder, 1h @ 700°C
Mg flakes + SiB_6 powder, 1h @ 700°C



$Mg + B_4C$

- Solid solution $Mg(B_{0.8}C_{0.2})_2$ after 1 hr @ 950°C indicated by T_c (Also Mickelson et al., PRB 65:052505)
- $dH^*/\underline{dT}$ slightly higher than that of MgB_2, about -0.35 T/K





Conclusions

- Must get control at multiple levels
  - Microstructure (density, homogeneity)
  - Nanostructure (grain size, precipitation)
- There are opportunities for potent pinning sites
  - Nanoscale mixtures of grains
  - Intragranular nanoprecipitates
- Borides with lower free energy than MgB_2 show promise
  - $Mg + SiB_6$: low temperature reaction of nanopowder mixture possible?
  - $Mg + B_4C$: makes solid solution