Improving Flux Pinning at High Fields in Intermetallic Superconductors:
Clues from MgB_2 and $MgCNi_3$

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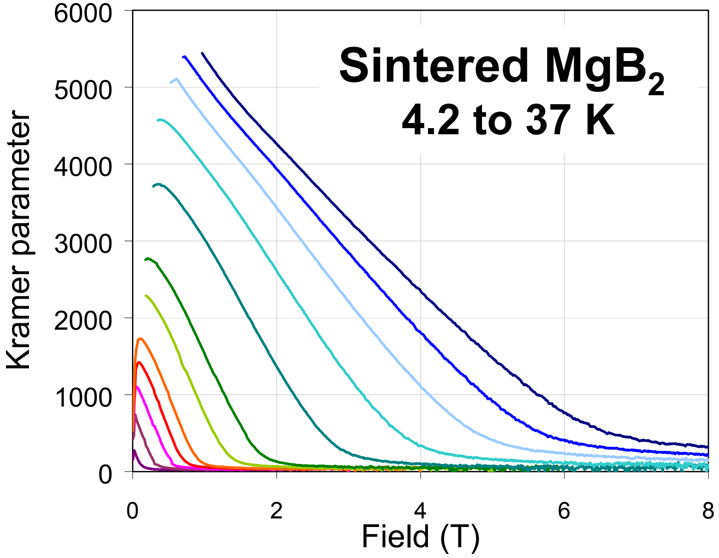
UW Collaborators:
- J Choi, S Bu, C-B Eom—MgB_2 Thin Films
- E Hellstrom, J Jiang, S Patnaik, A Polyanskii—$MgCNi_3$ and MgB_2
- P Lee, C Fischer, A Goedecke, M Naus—LTS pinning

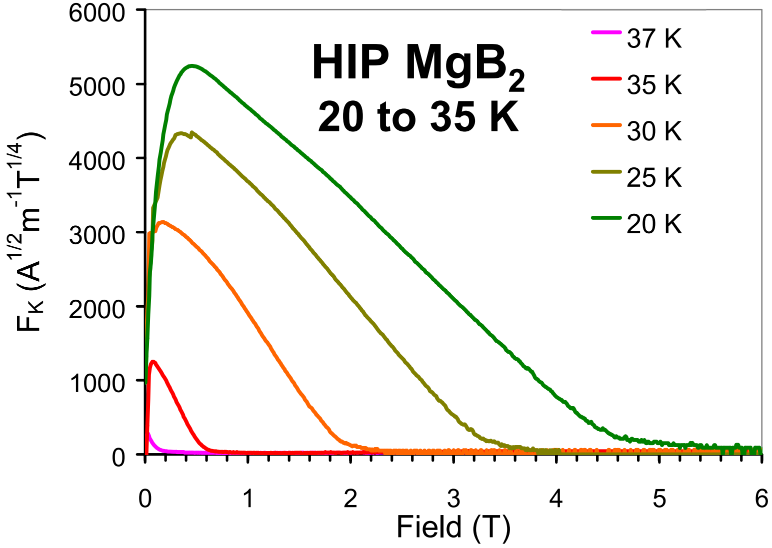
Princeton Collaborators:
- T He, K Reagan, and R Cava

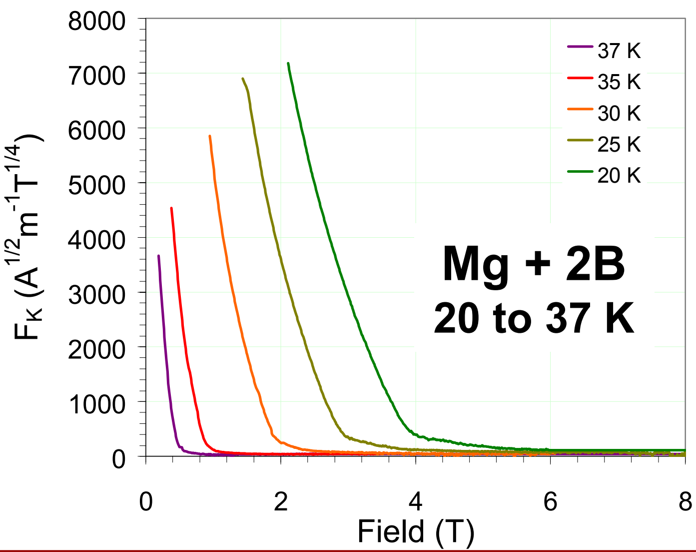
2002 ASC, 4-9 August 2002

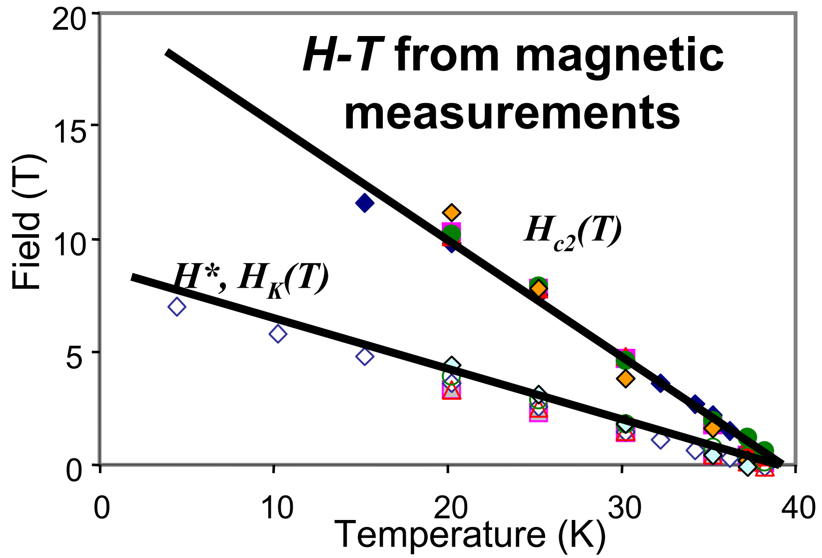
Flux shear indicated early in MgB_2

Common pinning mechanism despite sample differences?







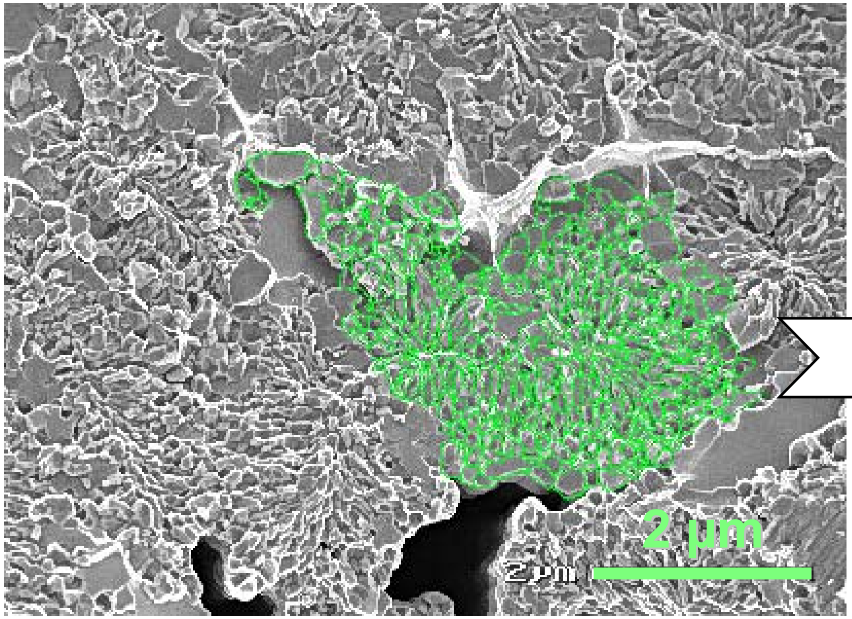


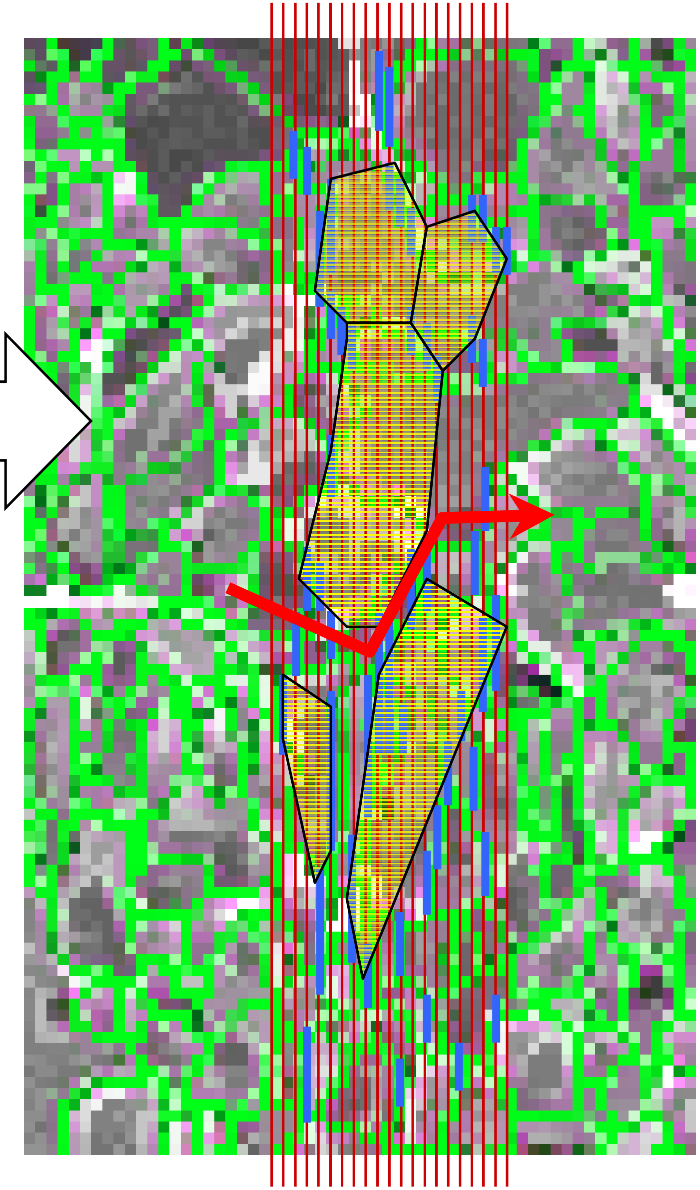
Flux Shear

Kramer phenomenology:

- $F_p = J_c \times \mu_0 H = \text{const.} \times C_{66} / a_0 = K_s h^{1/2} (1 - h)^2$
  - Shear modulus $C_{66} \propto h (1 - h)^2$ (with $h = H / H^*$)
  - Flux lattice constant $a_0 \propto h^{-1/2}$
  - $K_s \propto [B_{c2}(T)]^{5/2} \kappa^{-2}$
  - Corrections for non-local elasticity and grain size D
  - "Kramer plot" $J_c^{1/2} B^{1/4} \propto (1 - h)$
- Assumptions
  - Grain boundaries are primary (only?) pinning sites
  - Pinning interactions are far apart compared with a_0
  - Flux lattice may deform plastically due to pinning and Lorentz forces
  - At J_c:
    - Regions of correlated flux shear past each other (Khalil 1998)
    - Dislocations glide (Kahan 1991)

Grain-boundary pinning and flux shear





Tracing of fracture surface

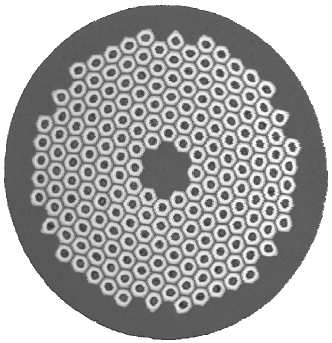
Flux lattice at ~5 T (a_0 = 22 nm)

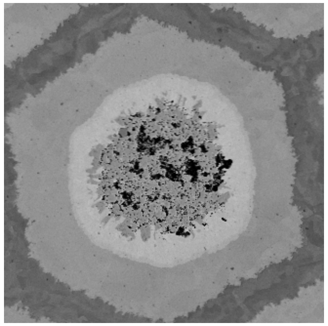
Pinning only transverse to g.b.

Domains of correlated flux separated by dislocations

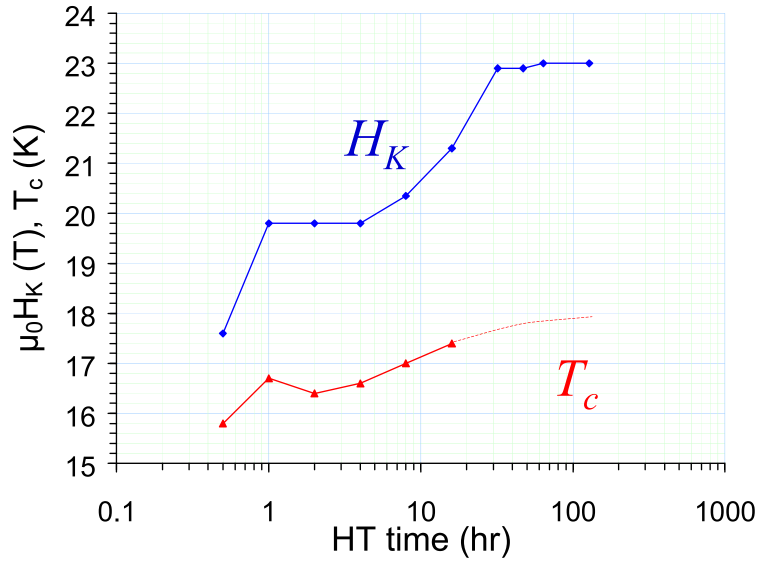
Glide of dislocations, or shear of domains

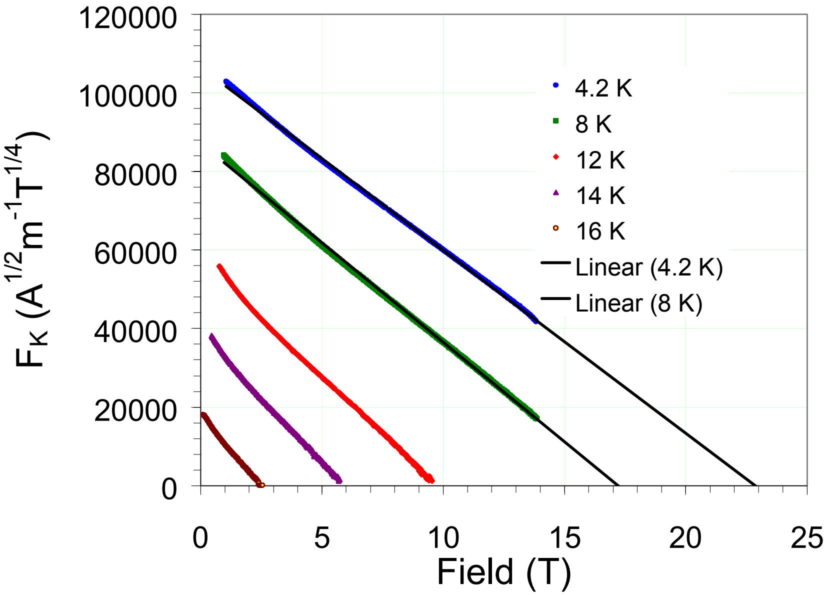
Flux shear describes Nb_3Sn well

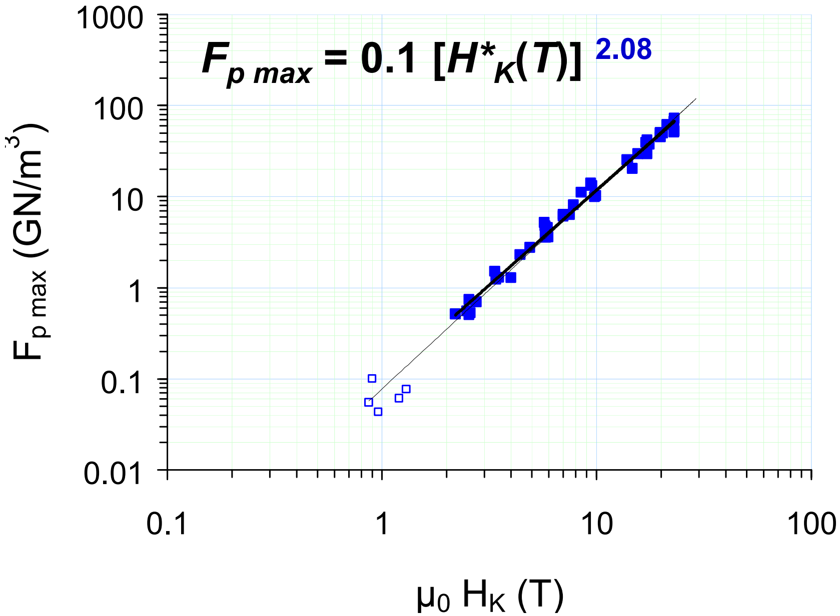




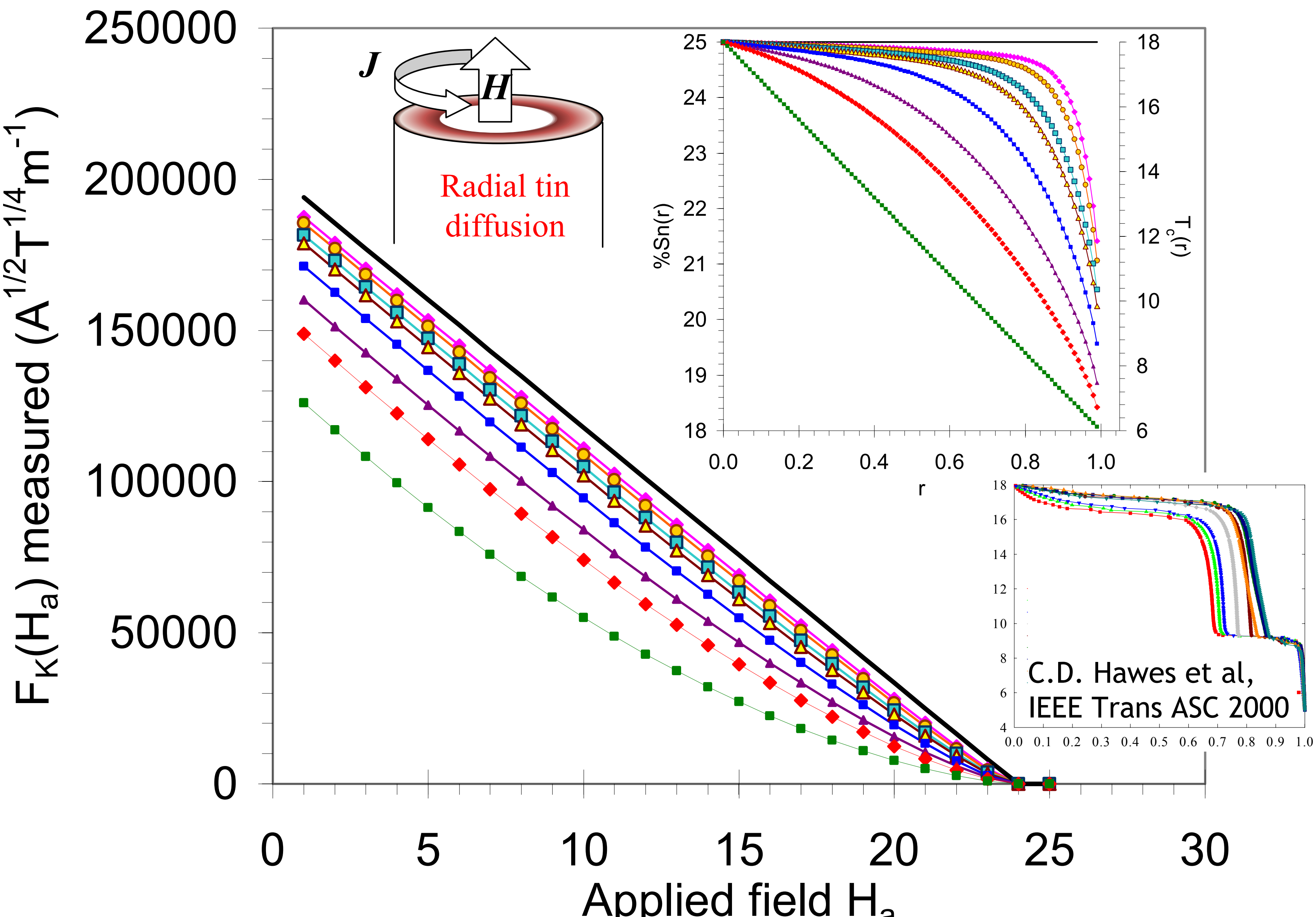
Powder-In-Tube Conductor from ShapeMetal Innovation (SMI), Holland





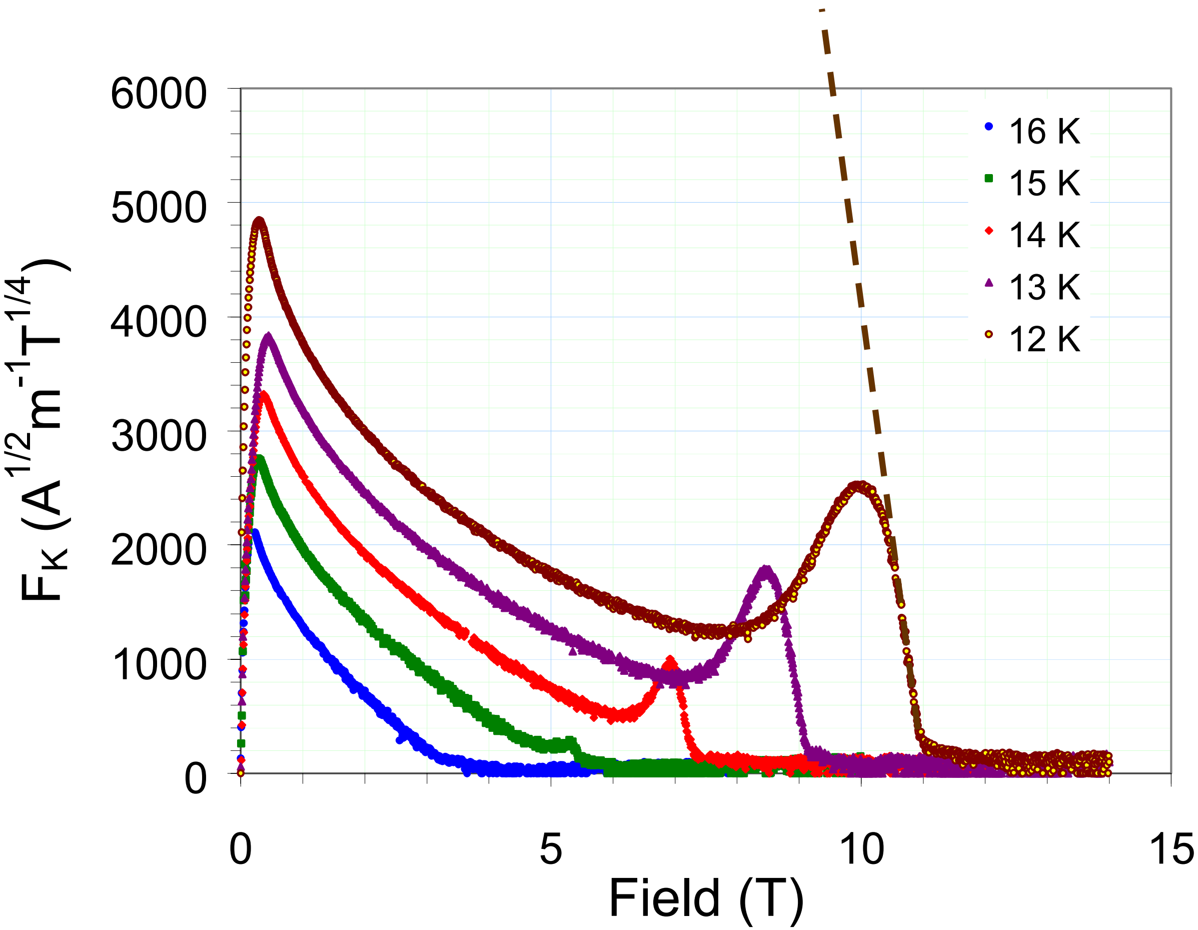


Kramer plots are robust vs. inhomogeneity



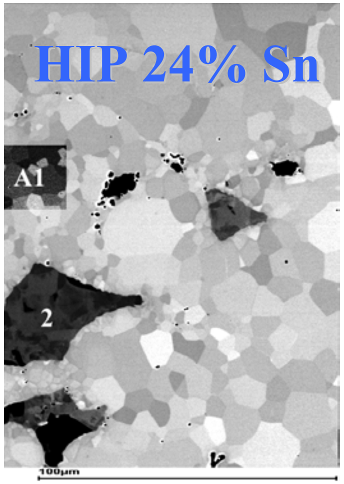
Loss of longitudinal correlation for large grains

Kramer data for 140 nm grains



~1 μm grains

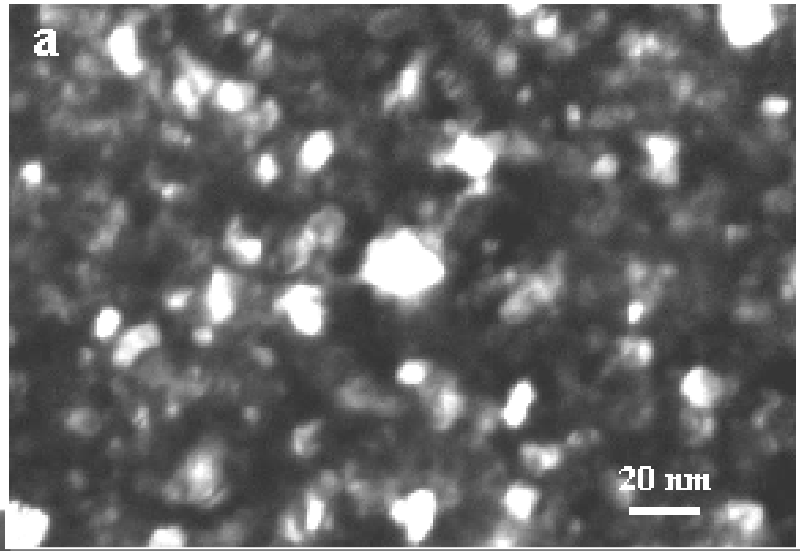
⇒ $L_{44} < D$

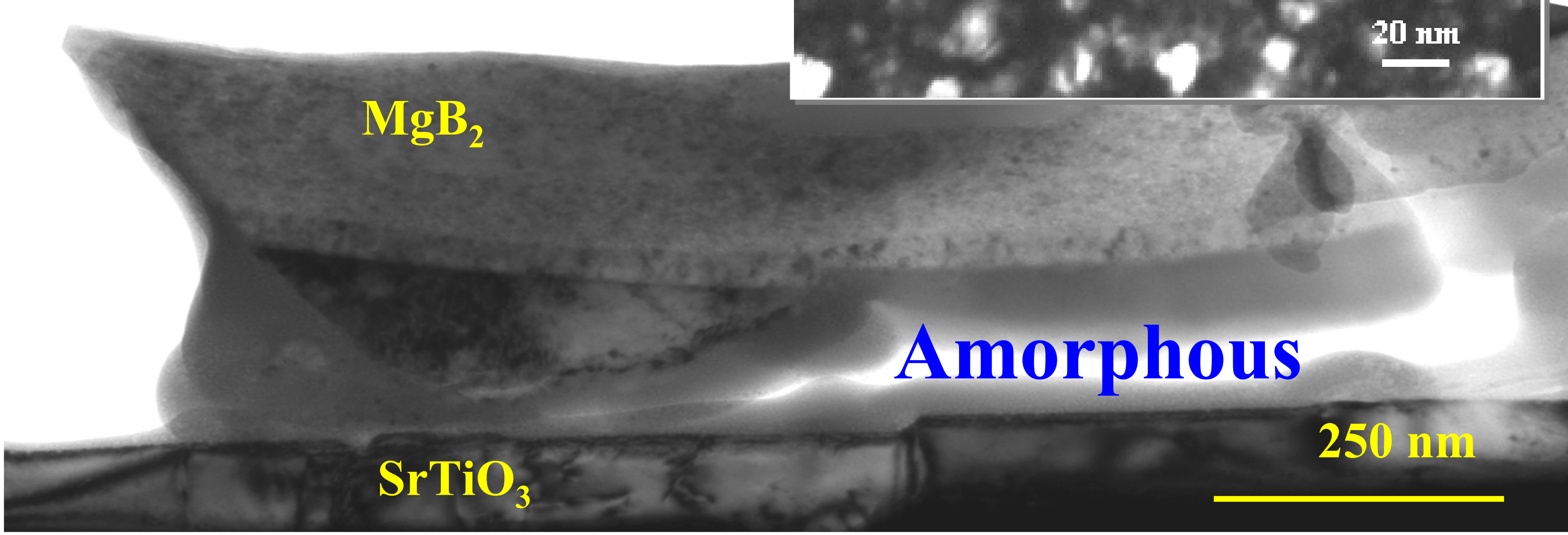


10 μm

Nanoscale grains in 1st generation MgB2 films made by PLD

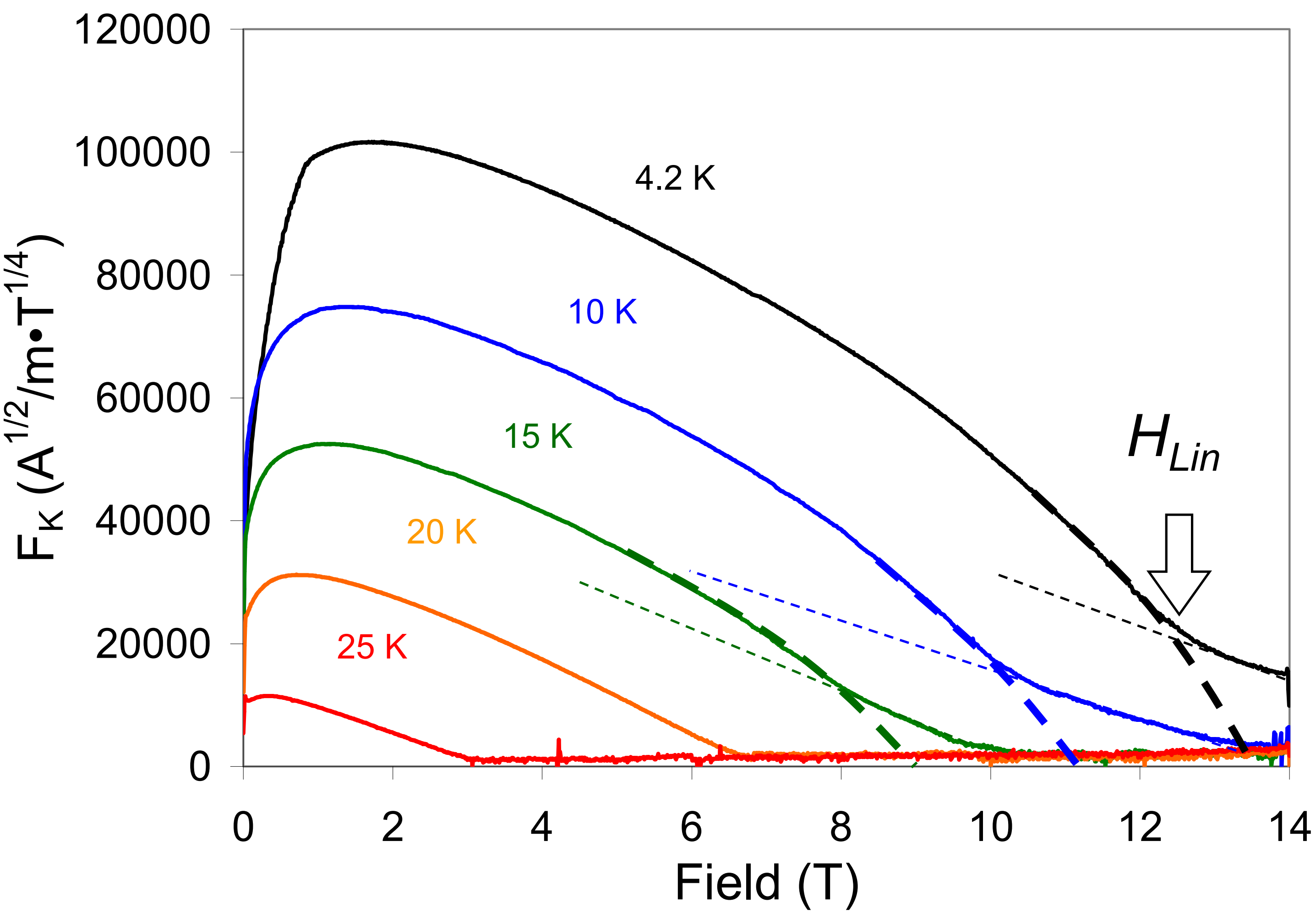
- ~10 nm MgB2 grains
- Substantial, nanoscale MgO
- C-axis fiber texture



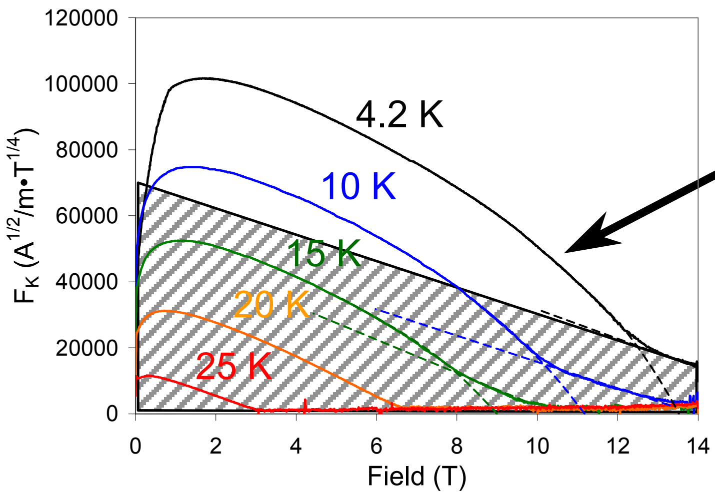


"Film 2", C. B. Eom *et al*., *Nature* **411**, 558 (2001)

Kramer plot indicates 2 regions with different pinning mechanisms?



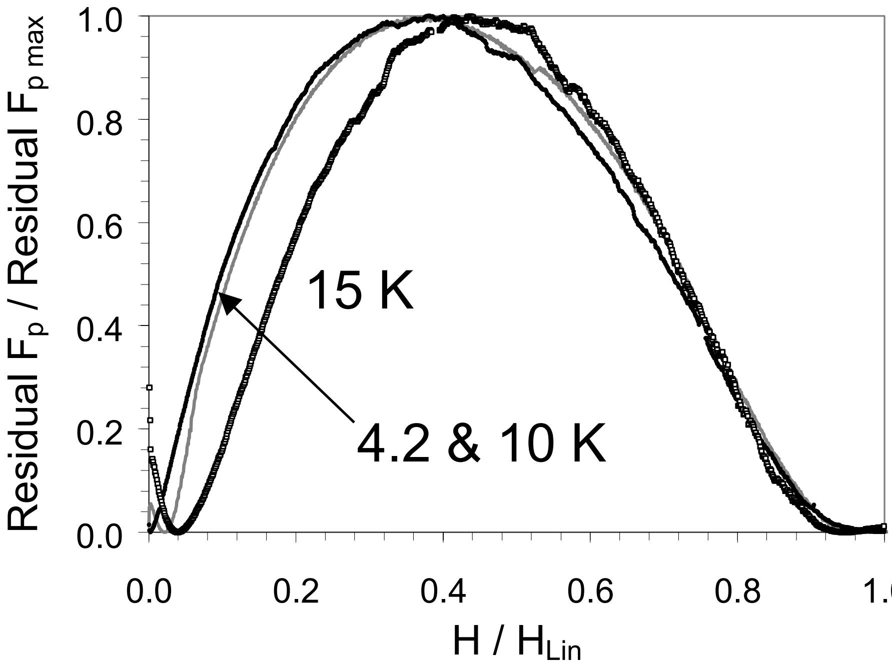
Core pinning component revealed



$$J_c \times \mu_0 H = F_p(h) \propto h\,(1 - h)$$
$$\Rightarrow J_c^{1/2} H^{1/4} \propto h^{1/4}\,(1 - h)^{1/2}$$

Linear Kramer plot subtracted

Data replotted as F_p

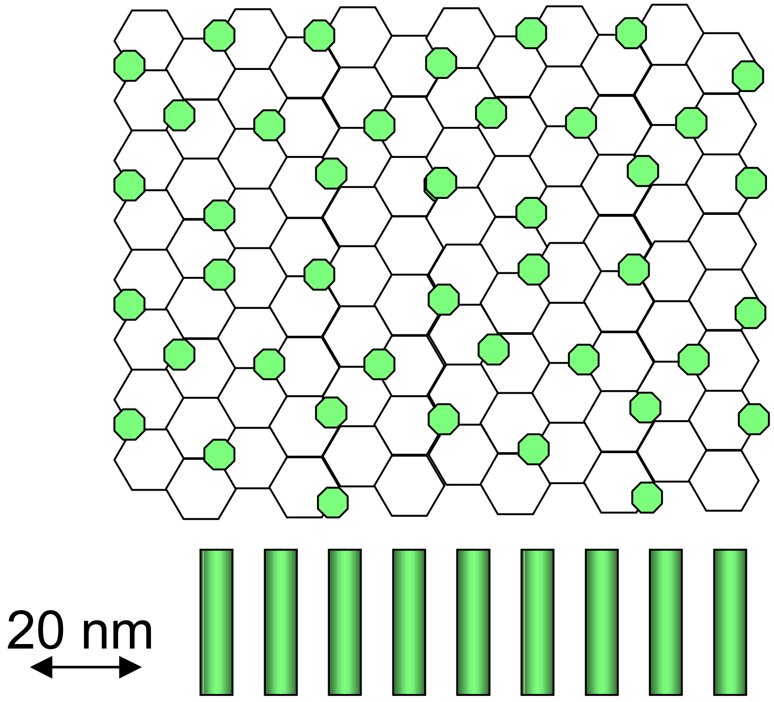


Core pinning by nanostructure of SC and N grains exceeds flux shear limit in MgB_2 film

Nanostructure of PLD film may consist of a matrix of ~10 nm MgB_2 grains surrounding ~5 nm MgO pinning centers

Can this be made artificially?

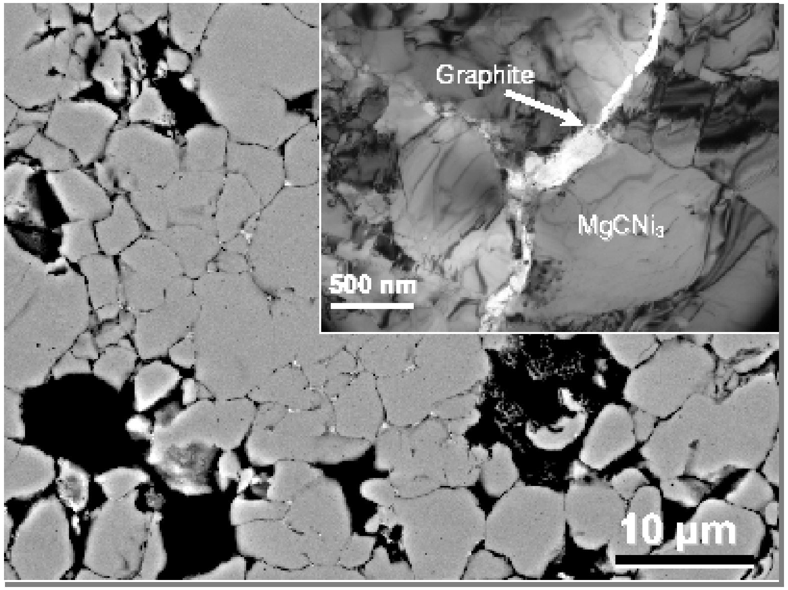
Any weakness of grain boundary amplified!

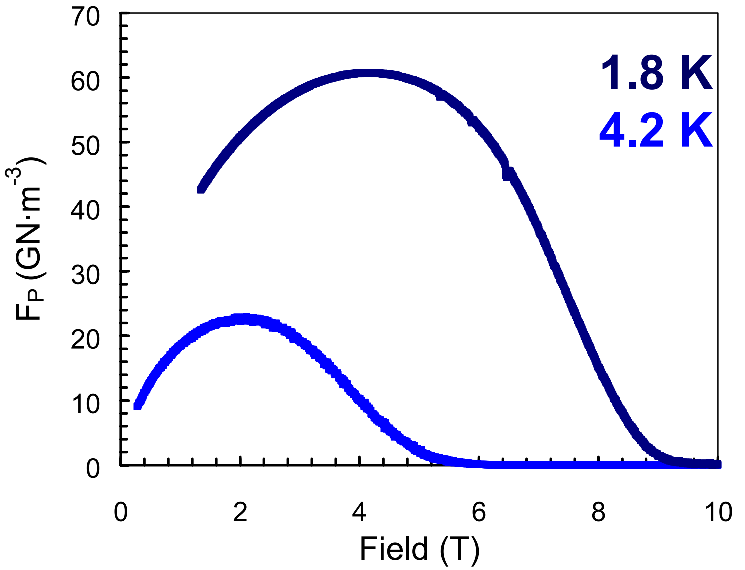


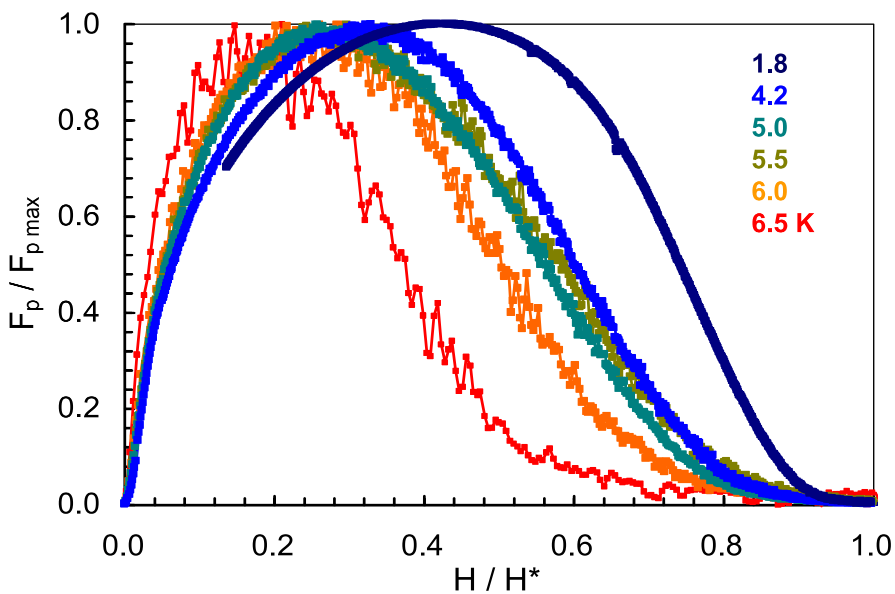
Equilibrium flux lattice @ ~5 T

$MgCNi_3$

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

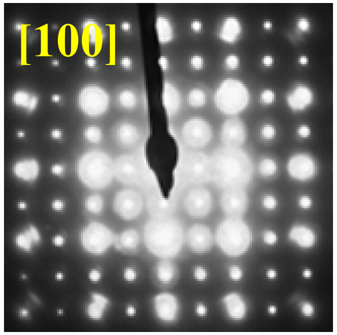


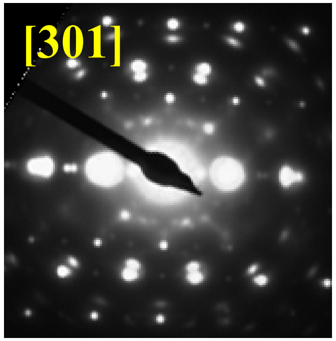




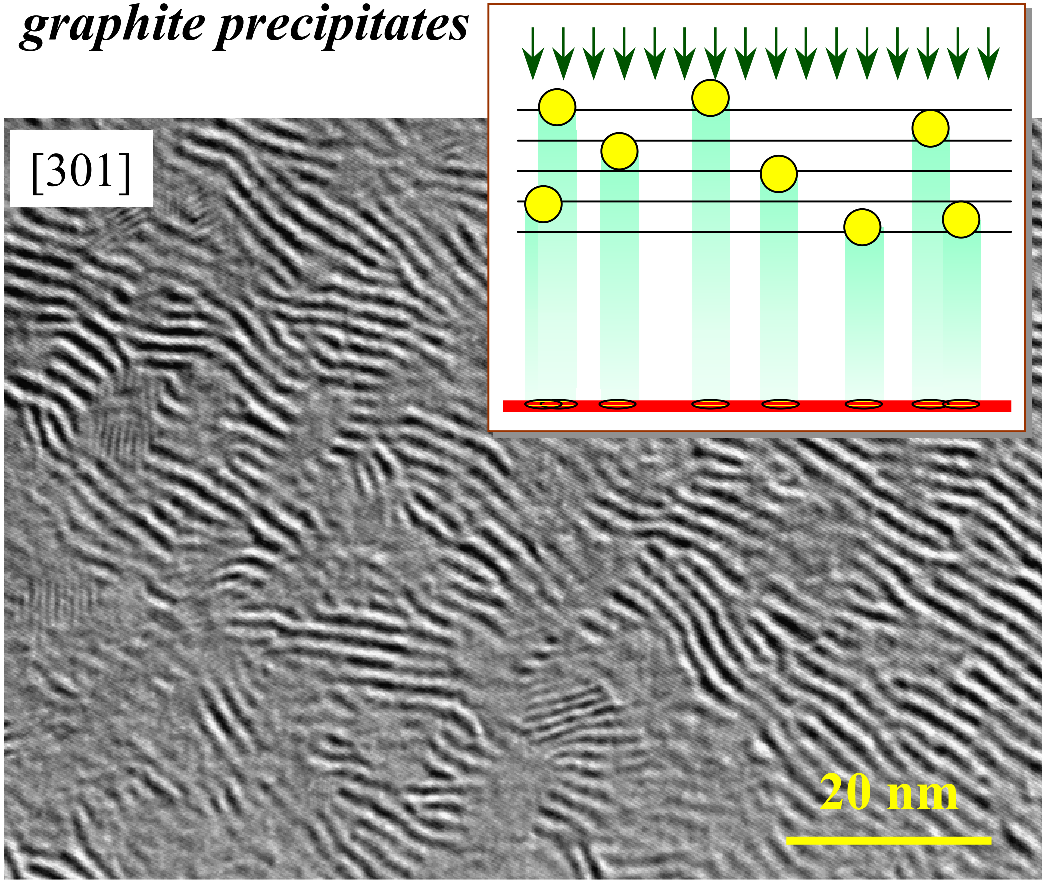
L.D. Cooley, X. Song, J. Jiang, D.C. Larbalestier, T. He, K.A. Regan, and R.J. Cava, *Phys. Rev. B* (to appear August 2002)

HRTEM reveals coherent precipitates inside grains





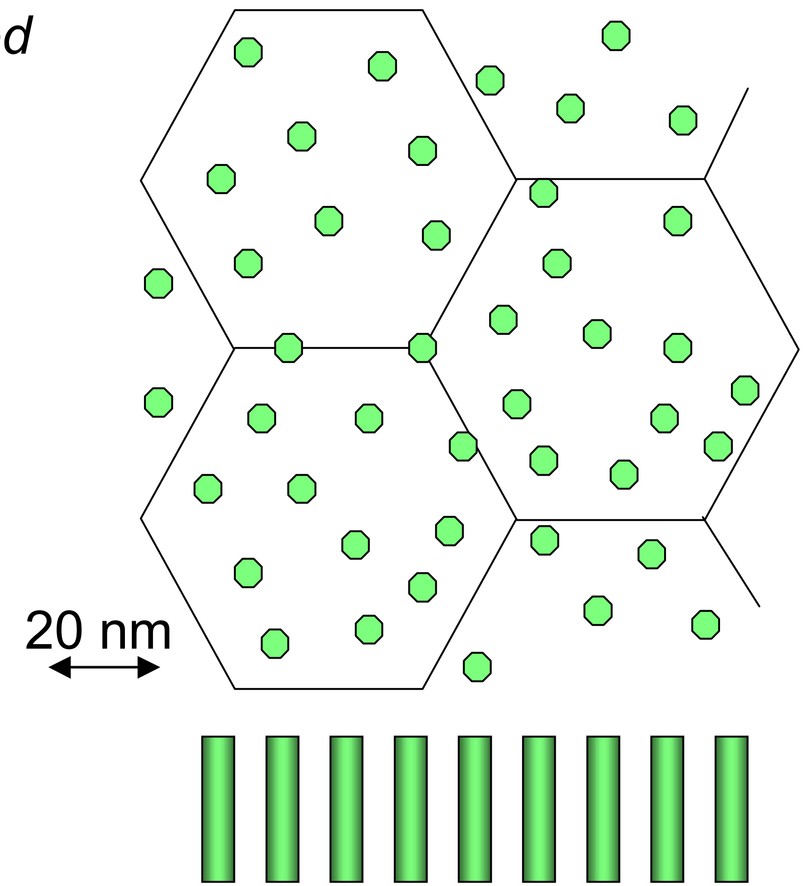
Interference from cubic, graphite precipitates



Core pinning by intragranular nano-precipitates in $MgCNi_3$ exceeds flux shear

~100 nm grains have embedded
~10 nm pinning centers

Are precipitation routes available?



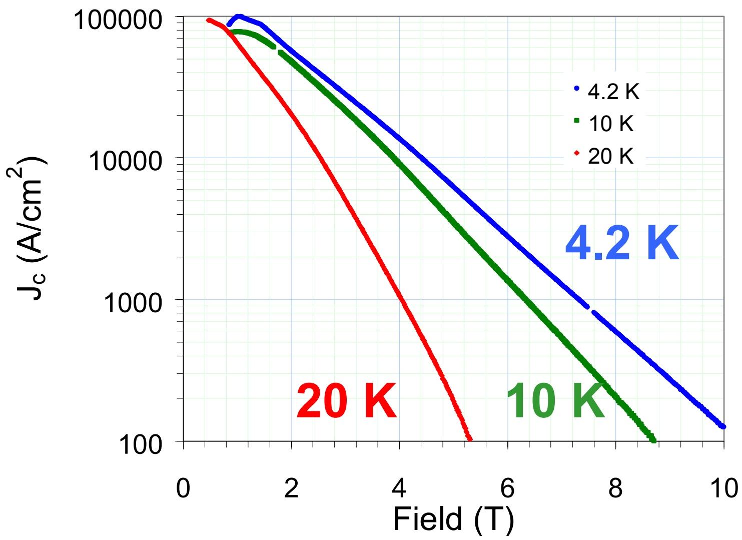
Equilibrium flux lattice @ 5 T

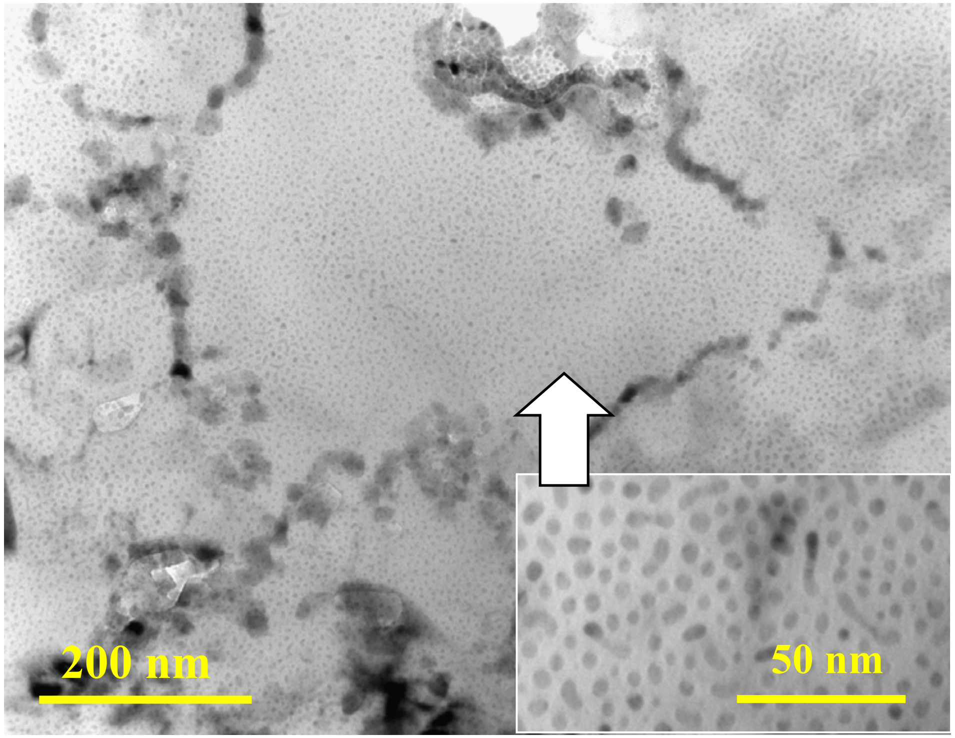
Nanoscale pinning sites MgB_2

Precipitates block grain boundaries, break up current path

- Mg + B powders + 10wt.% Y_2O_3 nanoparticles
- XRD: YB_4 nanoprecipitates ($Y_2O_3 + 4\ MgB_2 \rightarrow 2\ YB_4 + 3\ MgO + Mg$)

SNS behavior?

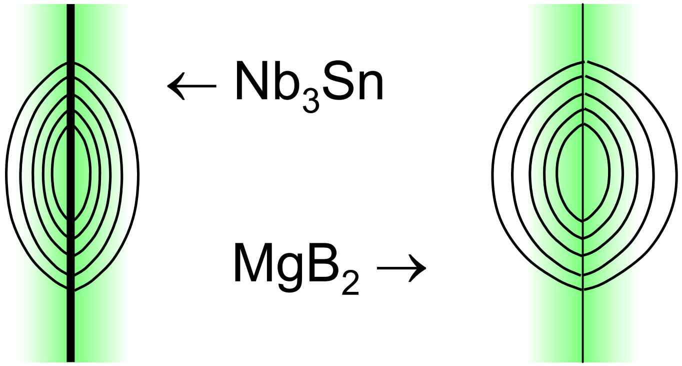




J. Wang, Y. Bugoslavsky, L. Cowey, A. Berenov, A.D. Caplin, L.F. Cohen, J.L. MacManus Driscoll (Imperial College); L. D. Cooley, X. Song, D. C. Larbalestier (UW-ASC) – submitted to *Applied Physics Lett.*

Conclusions

- New experiments show evidence for core pinning in intermetallic superconductors
  - ***Add nanoprecipitates!***
- 2 approaches conceptually similar, perhaps different implementation
  - MgB_2 thin film: nanoscale matrix of MgB_2 grains with precipitates — ***Assemble artificially?***
  - $MgCNi_3$: nanoprecipitates inside larger grains — ***Precipitation route?***
- Film: Linear Kramer plots at high temperature, even though $D \approx a_0$ — g.b. pinning weaker than usual?



Precipitates from a metastable solid solution