Karlsruhe Institute of Technology

Flux pinning behaviour of a $BaFe_2(As_{1-x}P_x)_2$ thin film on IBAD-MgO technical substrate

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INSTITUTE FOR TECHNICAL PHYSICS, SUPERCONDUCTING MATERIALS AND APPLICATIONS

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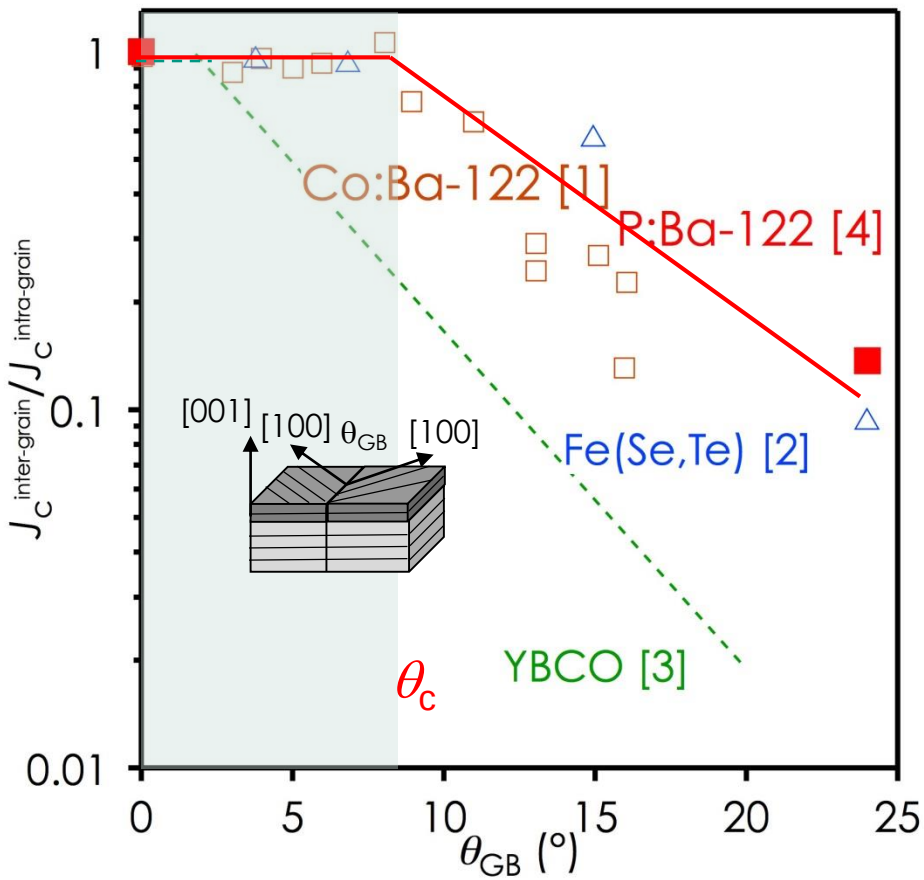
Ba-122: Grain Boundaries



Co or P-doped Ba-122

Fe(Se,Te)

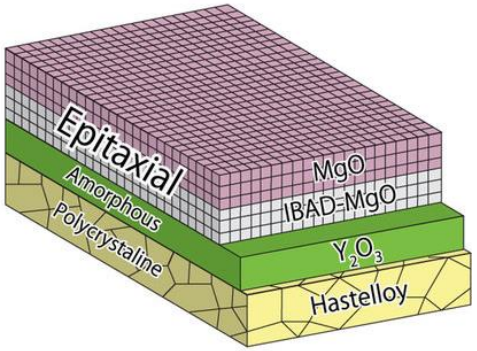
- Large θ_c (~9°)
- Gentle slope

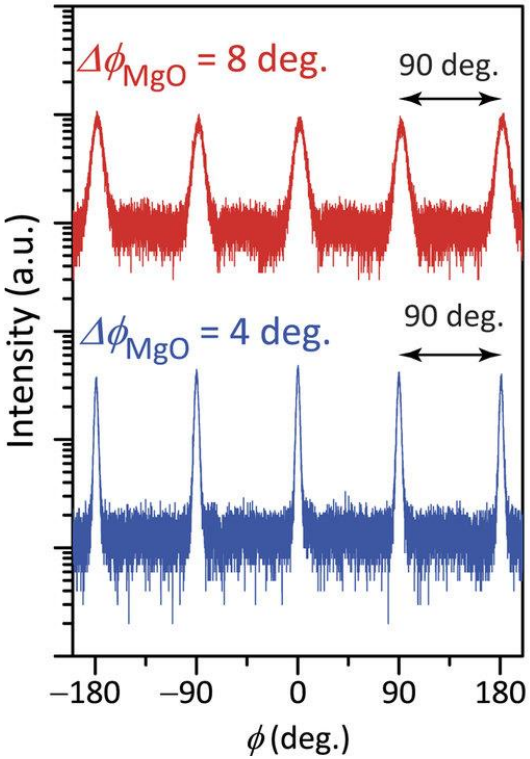
- Suitable for wire applications
- Wide experimental range for LAGB studies

[1] Katase *et al.*, *Nat. Commun.* **2**, 409 (2011)
[2] Si *et al.*, *Appl. Phys. Lett.* **106**, 032602 (2015)
[3] Hilgenkamp, Mannhart, *Rev. Mod. Phys.* **74**, 485 (2002)
[4] Sakagami *et al.*, *Physica C* **494**, 181-184 (2013)

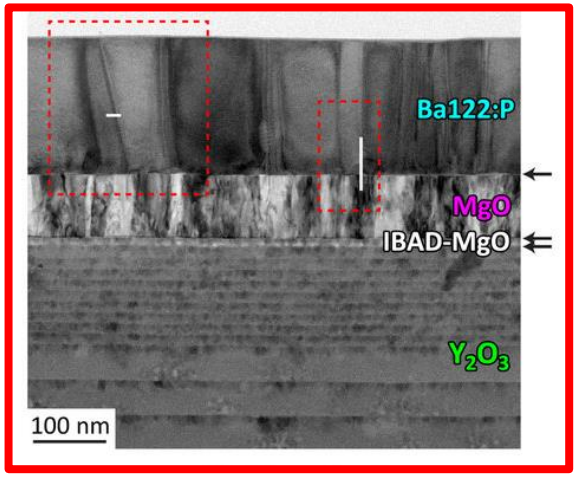
IBAD Architecture and Texture Quality

- Two IBAD-MgO templates with different texture quality
- Both with $\Delta\phi < \theta_c \sim 9^o$

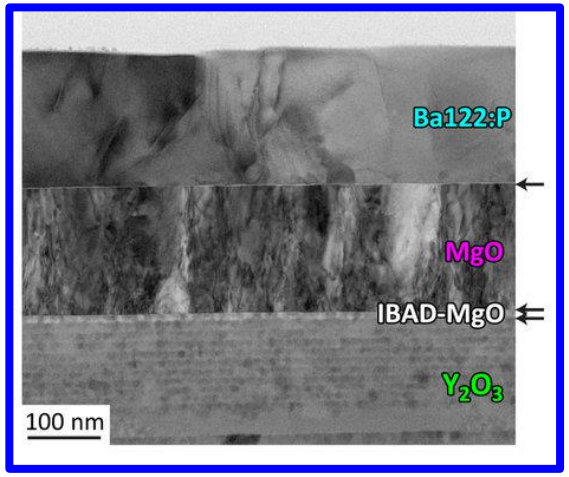




High density of defects

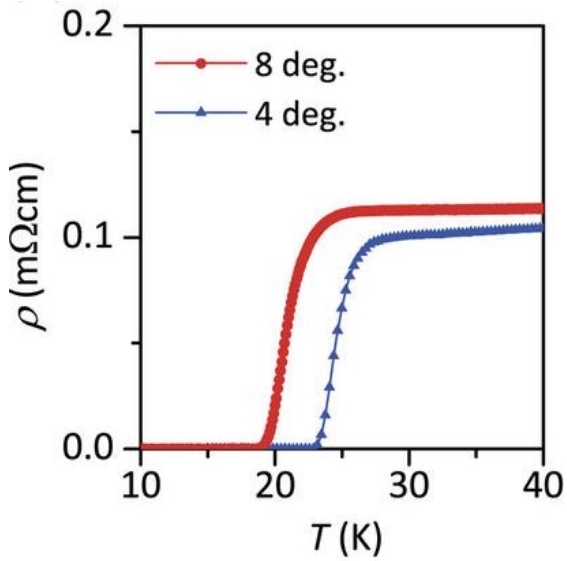


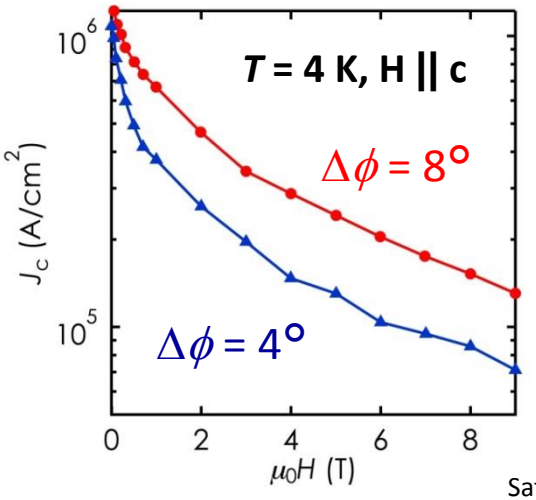
Low density of defects



Sato *et al.*, *Sci. Rep.* **6**, 36828 (2016).

Possible Grain Boundary Pinning





Sato *et al.*, *Sci. Rep.* **6**, 36828 (2016).

Film with poorer texture quality:

- Lower T_c (possible strain effect)
- Higher in-field J_c

Possible grain boundary pinning

Similar behaviour was seen for Co-Ba122/IBAD-MgO

Katase et al., APL 98, 242510 (2011)

Purpose of this Study

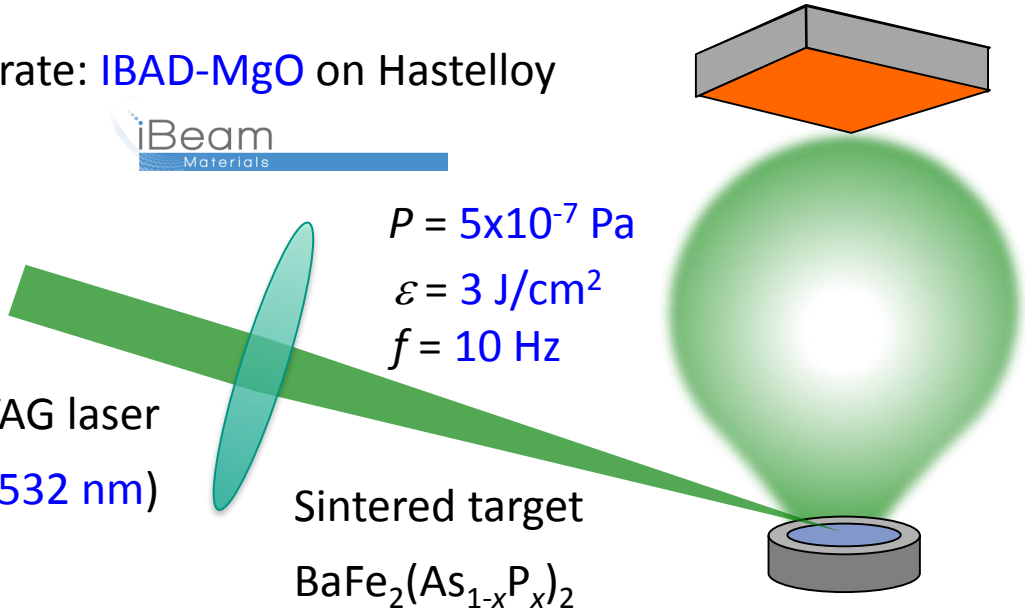
Clarifying pinning behaviour of grain boundary networks in Fe-based superconductors by investigating in-field J_c properties of a T_c-enhanced P-doped Ba-122 CC

Sample Preparation

Pulsed laser deposition

Growth temp. : 1200 °C

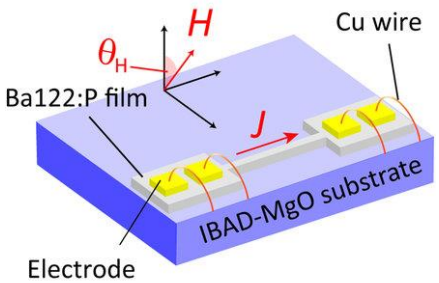
Substrate: IBAD-MgO on Hastelloy



Characterisation

Crystalline quality: XRD

Composition: EPMA



Transport: 4-probe

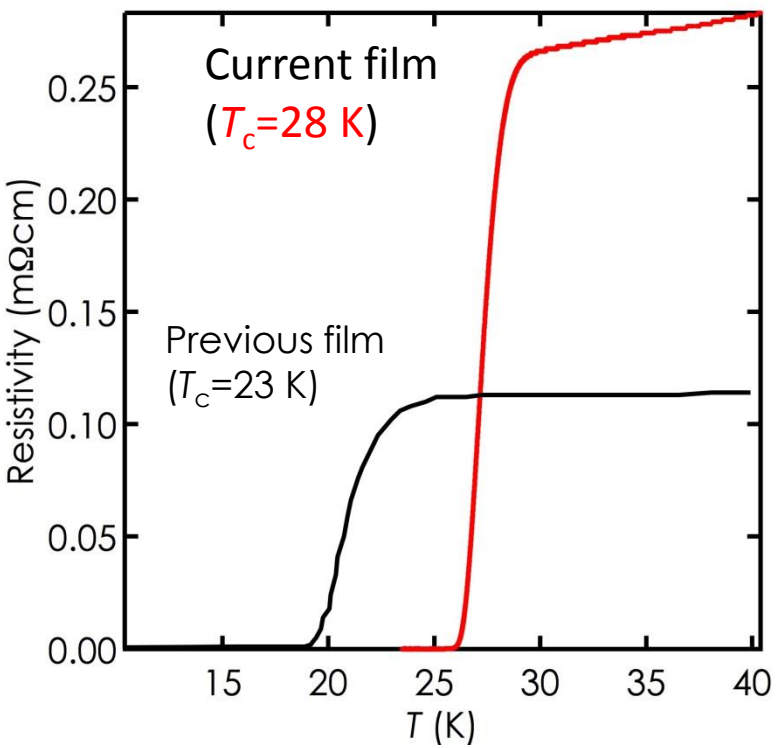
DC field facility@NHMFL

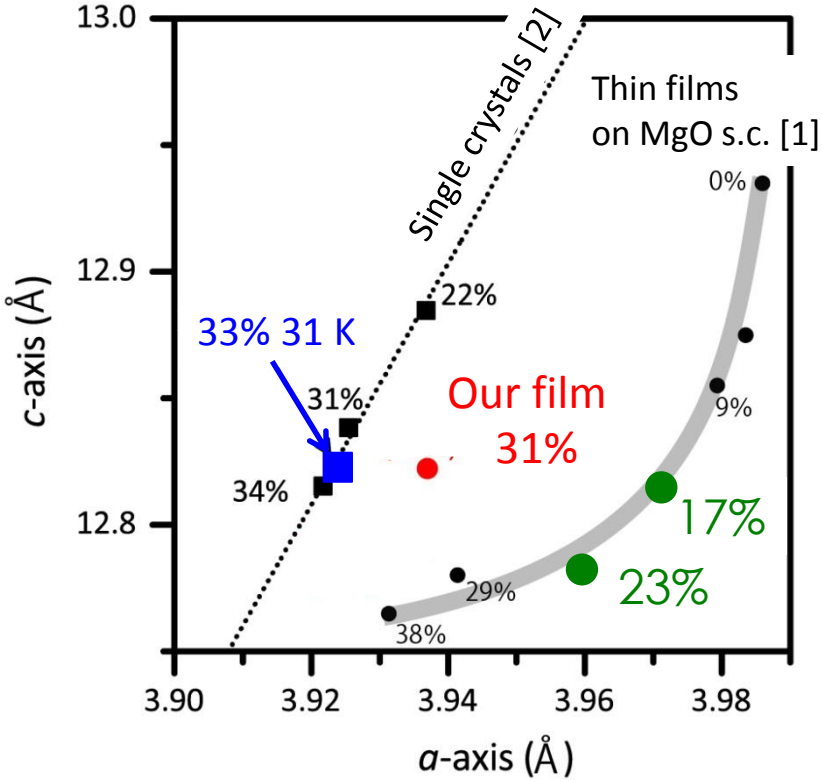
(up to 35 T)

T_c Enhancement

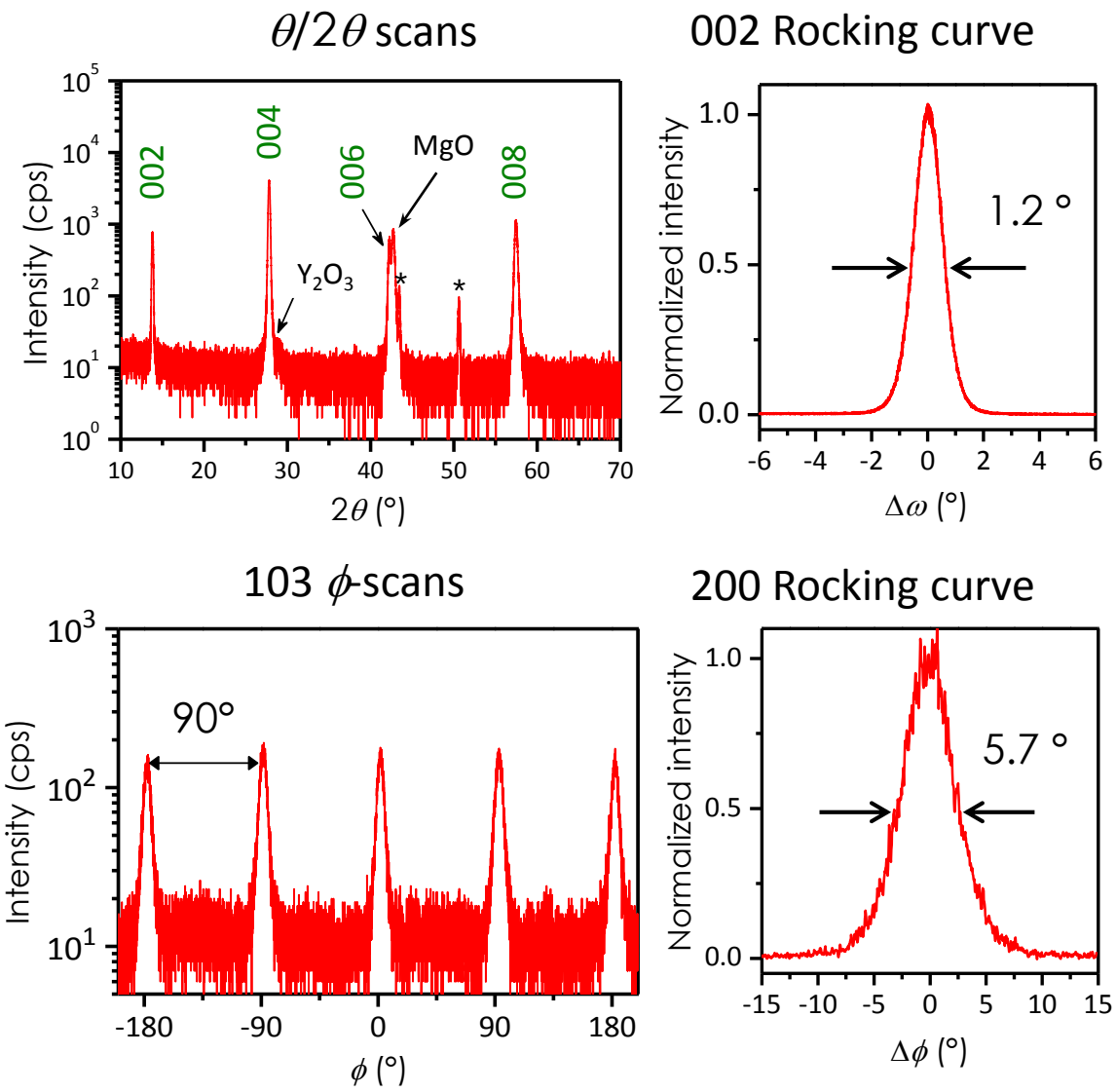
	P/(P+As)	T_s (°C)
Current film	0.31 (PLD target 0.35)	1200
Previous film	0.26 (PLD target 0.35)	1050

[1] Kawaguchi *et al.* SUST **27**, 0655005 (2014).
[2] Kasahara *et al*, Phys. Rev. B **81**, 184519 (2010).





Epitaxial Growth

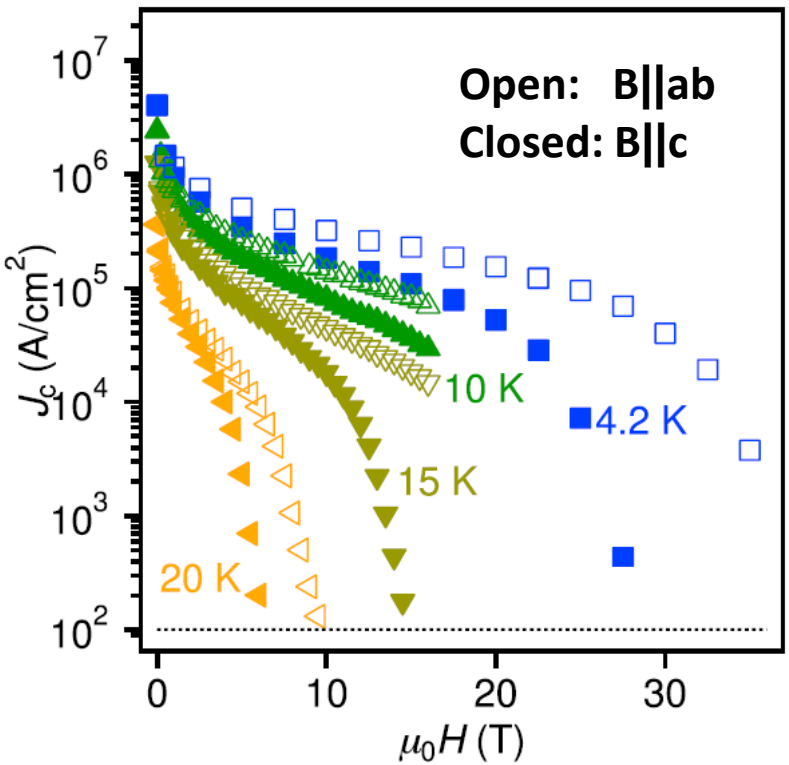


Epitaxial film

- No impurities
- 00*l* oriented
- Fourfold symmetry
- No rotated grains
- Sharply out-of-plane textured
- $\Delta\phi$ less than θ_c (~9°)

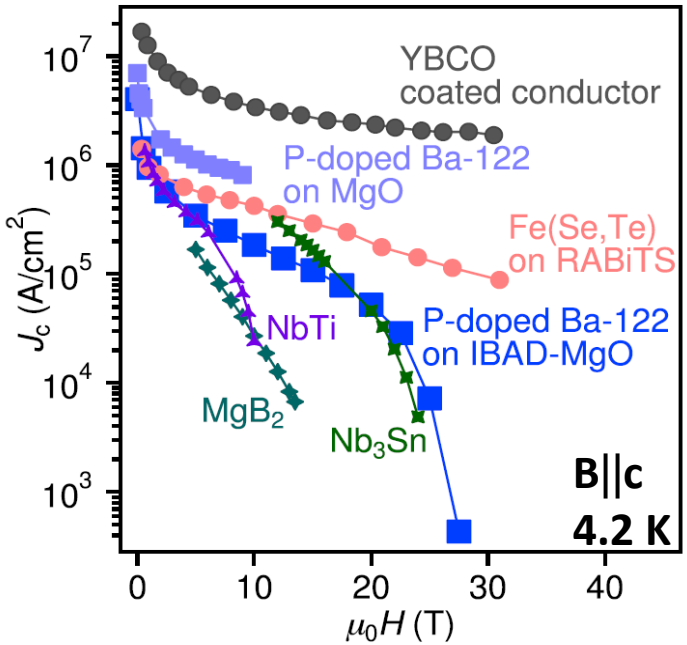
Iida *et al*, Sci. Rep. **10**, 39951 (2017).

Magnetic Field Dependence of J_c

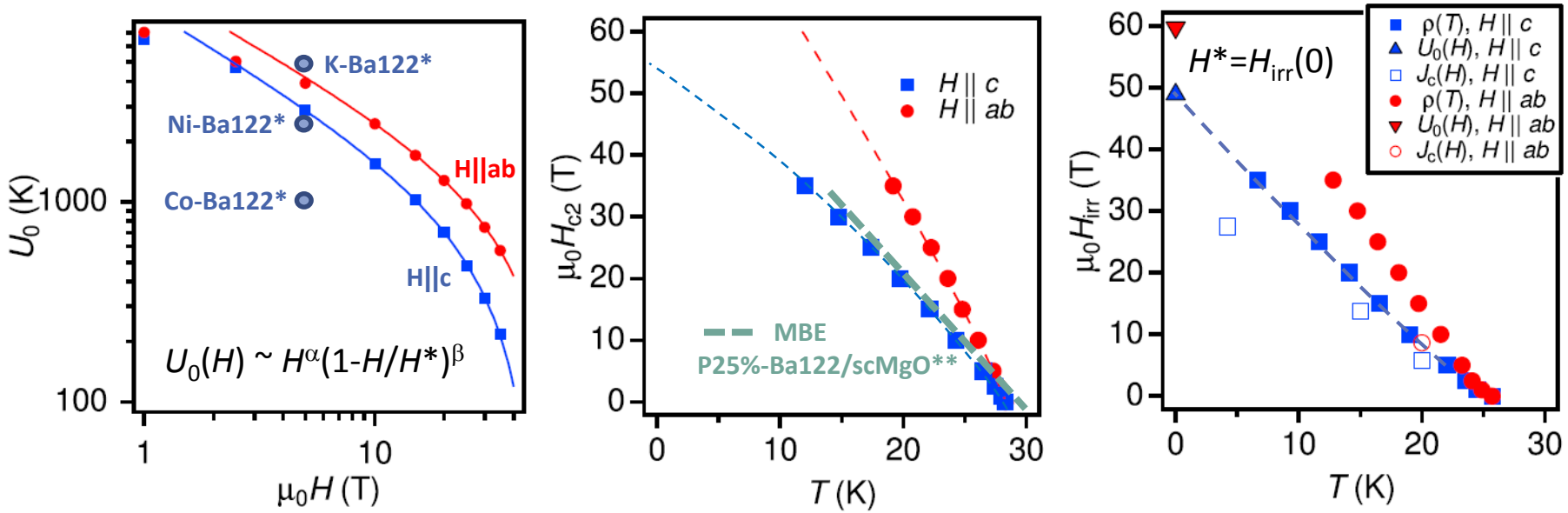


High performance P:Ba-122 CC

- Self-field J_c @4.2 K over 4 MA/cm^2
- Slightly anisotropic (γ_{Hirr} ~ 1.3 – 1.7)
- Superior to MgB_2 and NbTi
- Comparable to Nb_3Sn above 20 T



Pinning Potential and *B-T* Phase Diagram

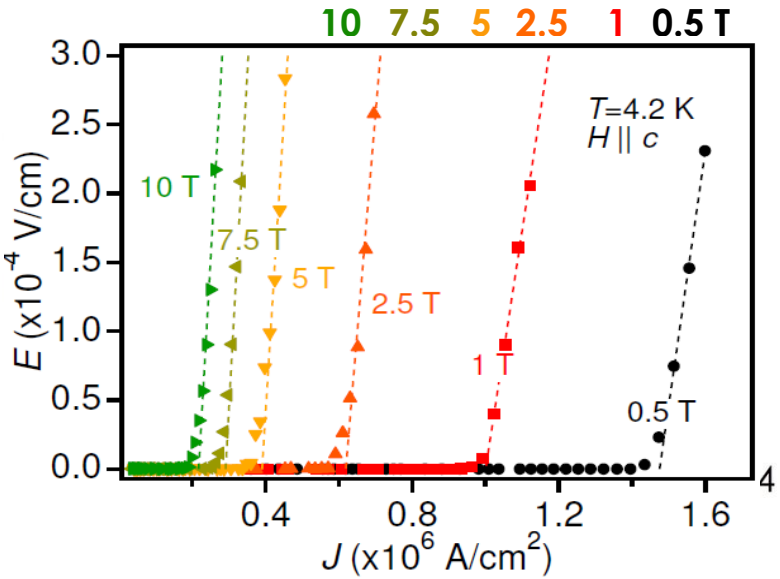


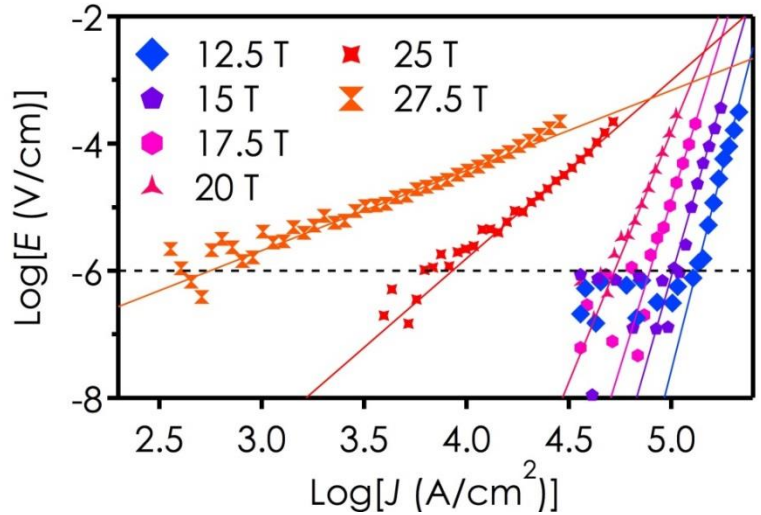
*Ghorbani et al., APL 100, 072603 (2012)

**Grinenko et al., Sci. Rep. 7, 4589 (2017)

- Pinning potential in expected range for Ba122
- Small vortex liquid region
- H_{irr} up to 50 / 60 T
- Slightly anisotropic (γ_{Hirr} ~ 1.3 – 1.7)

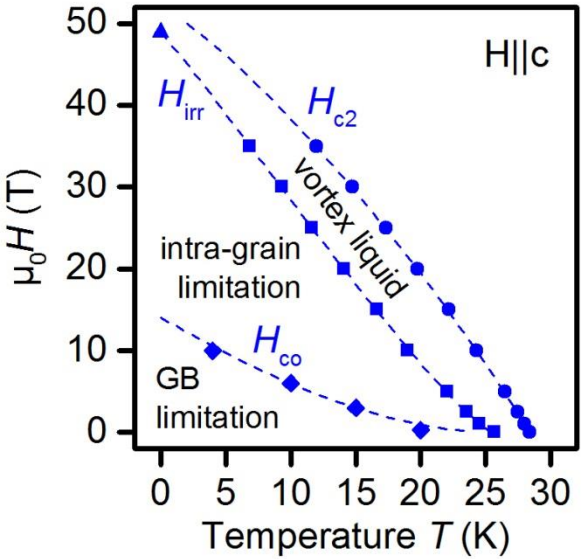
E(*J*) Characteristics



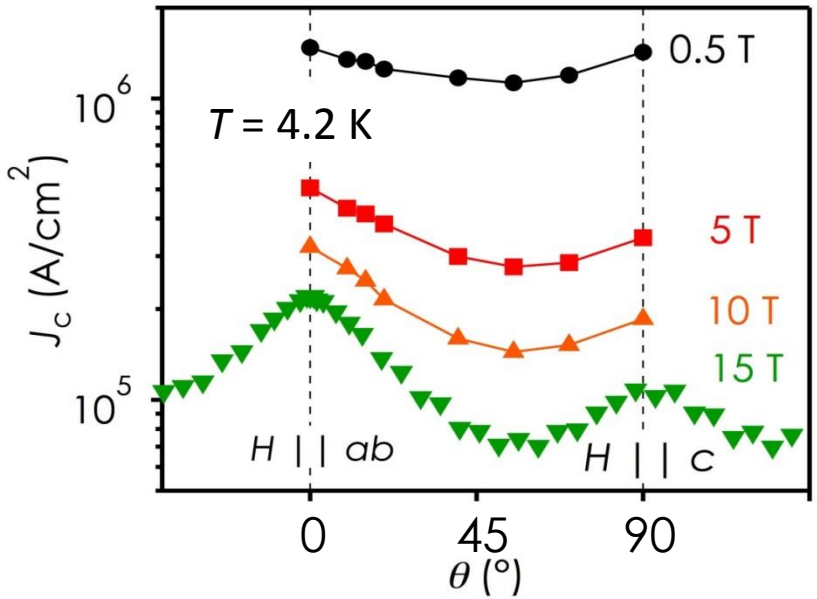


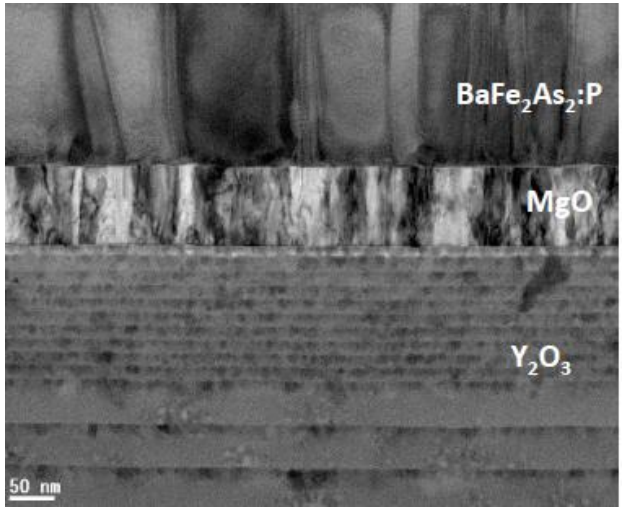
In-field transport

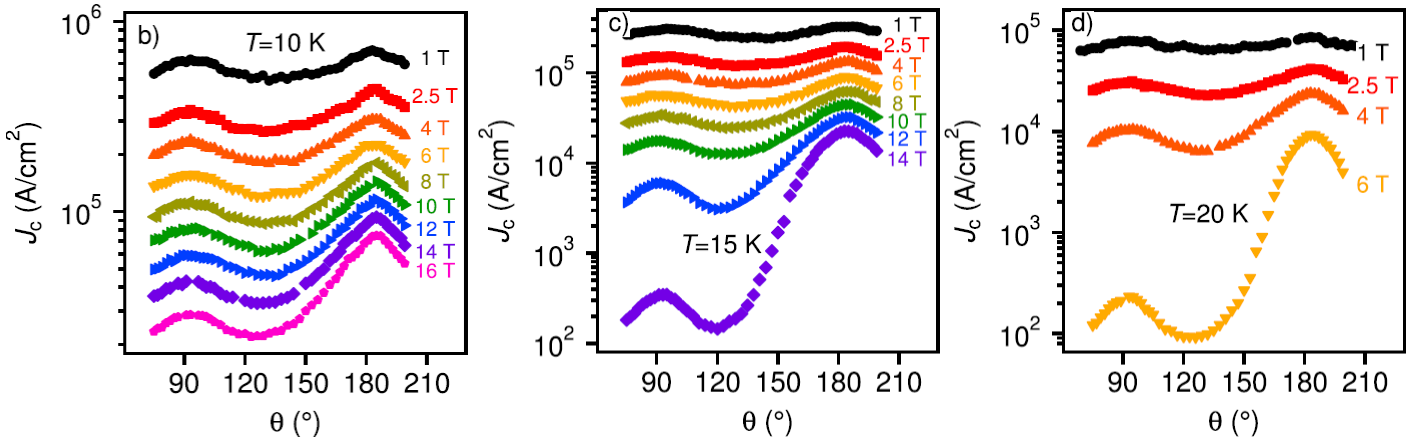
- Non-Ohmic linear differential (NOLD) signature up to 10 T
  → J_c limitation by grain boundaries
- Power-law behaviour above 12.5 T
  → J_c limitation by intra-grain depinning of flux lines



Angular Dependence of J_c

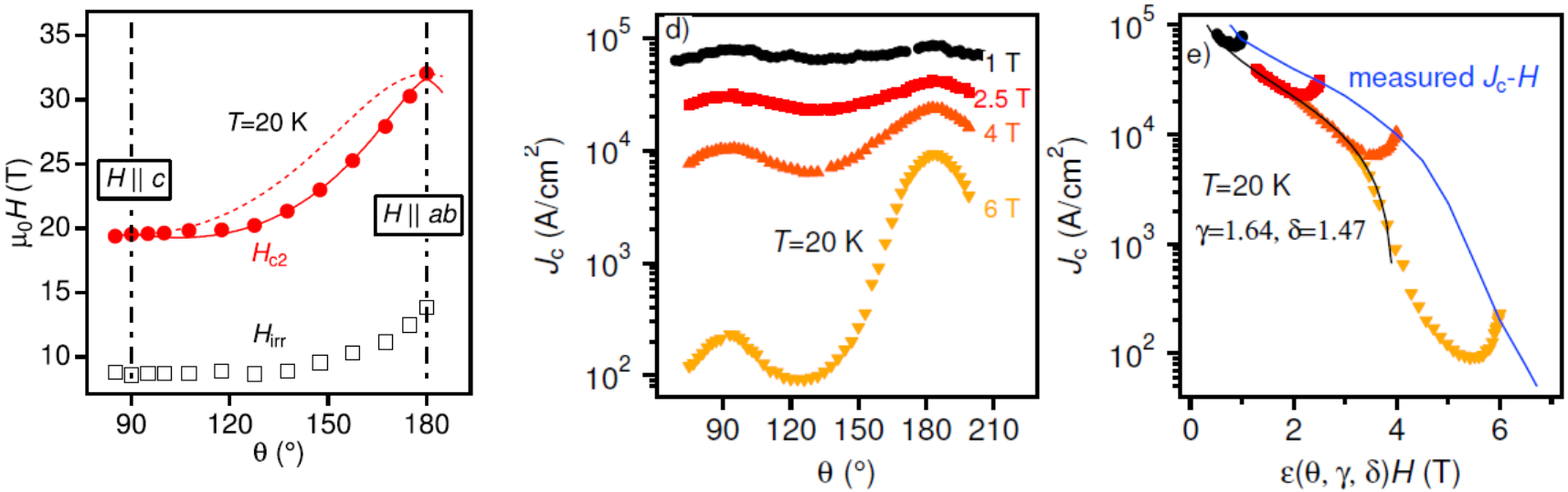






Iida *et al*, Sci. Rep. **10**, 39951 (2017)

Angular Dependence of J_c

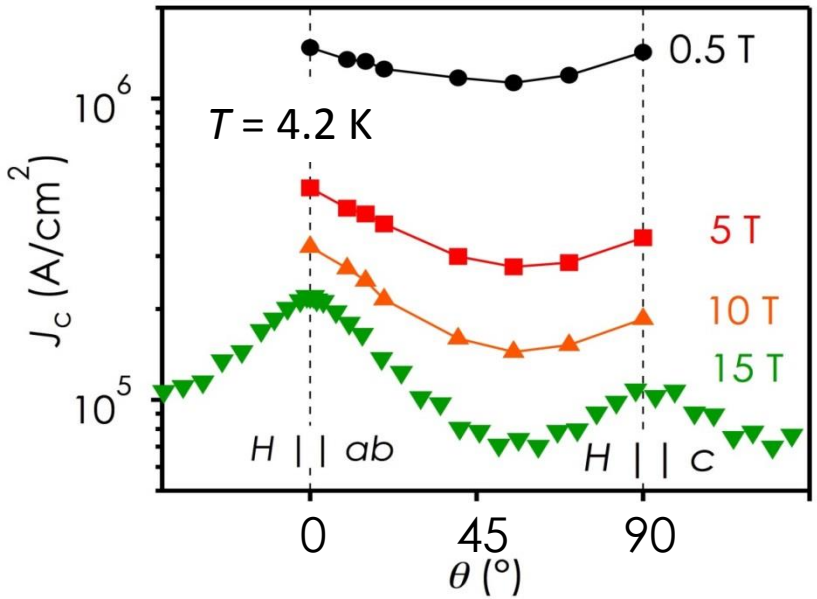


$$H_{c2}(\theta) = H_{c2}^{c}/F(\theta)$$

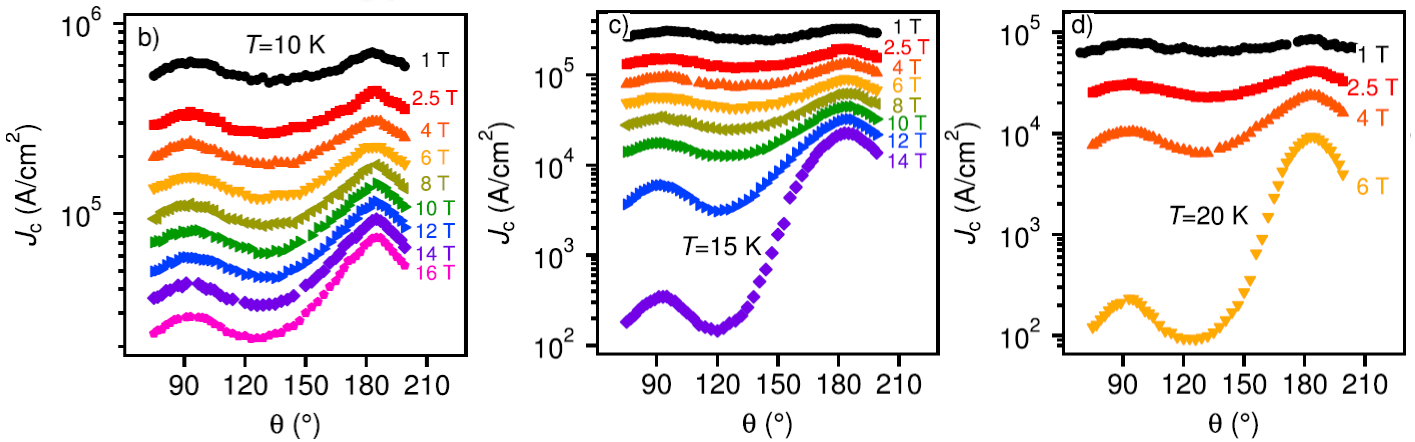
$$F(\theta, \gamma_{Hc2}, \delta) = (|\cos\theta|^{\delta} + \gamma_{Hc2}^{-\delta}|\sin\theta|^{\delta})^{1/\delta}$$

See also: J. Hänisch et al., Sci. Rep. 5, 17363(2015)

Angular Dependence of J_c

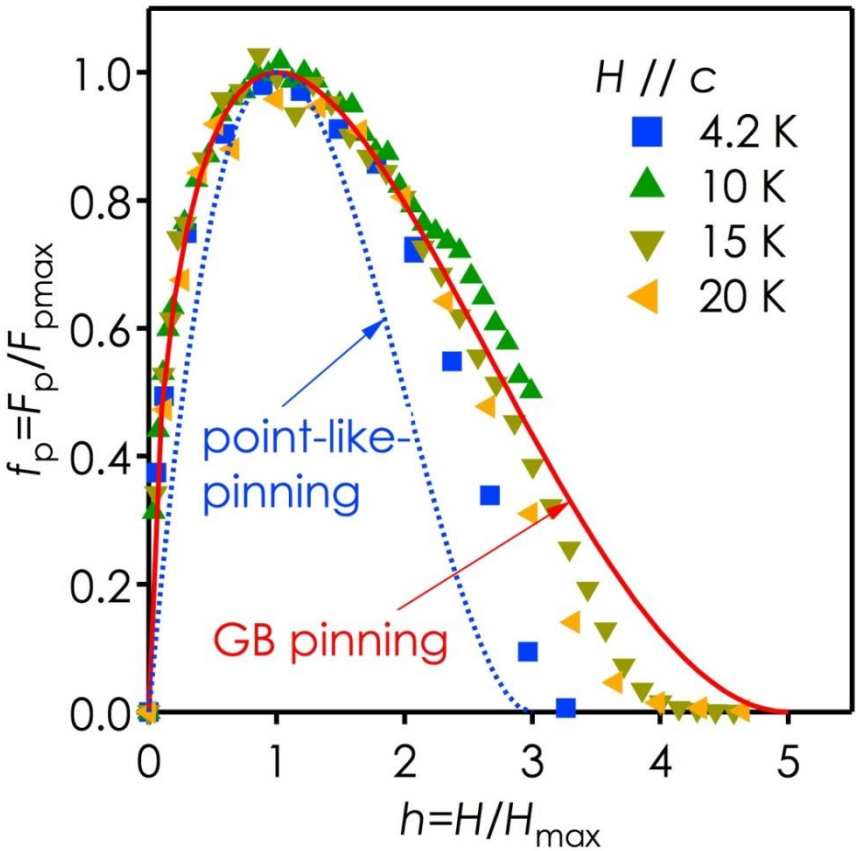


- Two distinct peaks at $H||c$ and ab
- ab-peak: fully determined by H_{c2} anisotropy
- c-axis peak: due to network of threading dislocations comprising the LAGBs



Iida *et al*, Sci. Rep. **10**, 39951 (2017)

Pinning Force Density for B || c



$$f_p = \frac{25}{16} h^{0.5} \left(1 - \frac{h}{5}\right)^2$$

Planar defects
Line defect arrays

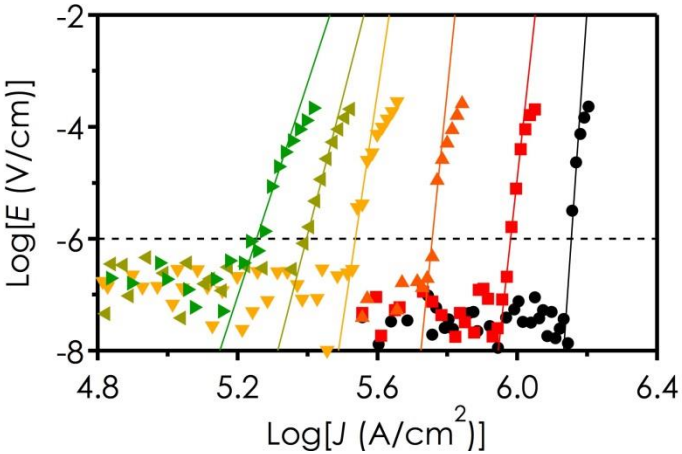
$$f_p = \frac{9}{4} h \left(1 - \frac{h}{3}\right)^2$$

Point-like pinning

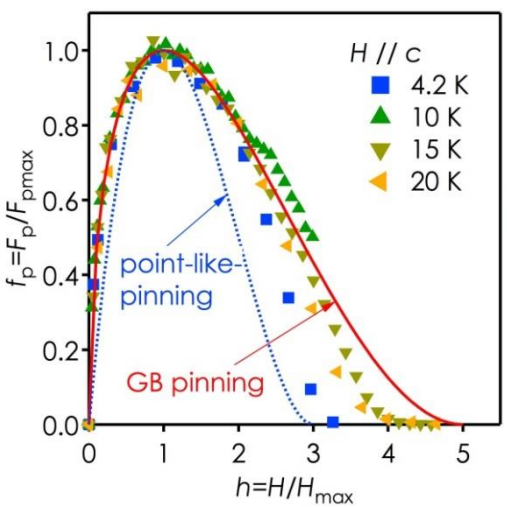
- f_p data fall onto the master curve of GB pinning for $H \parallel c$

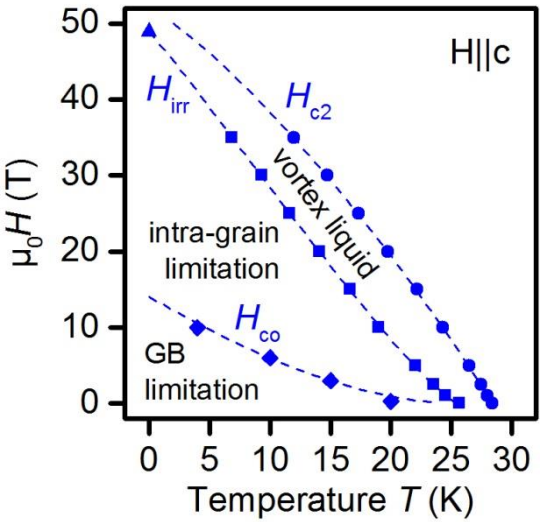
Iida *et al*, Sci. Rep. **10**, 39951 (2017).

Summary



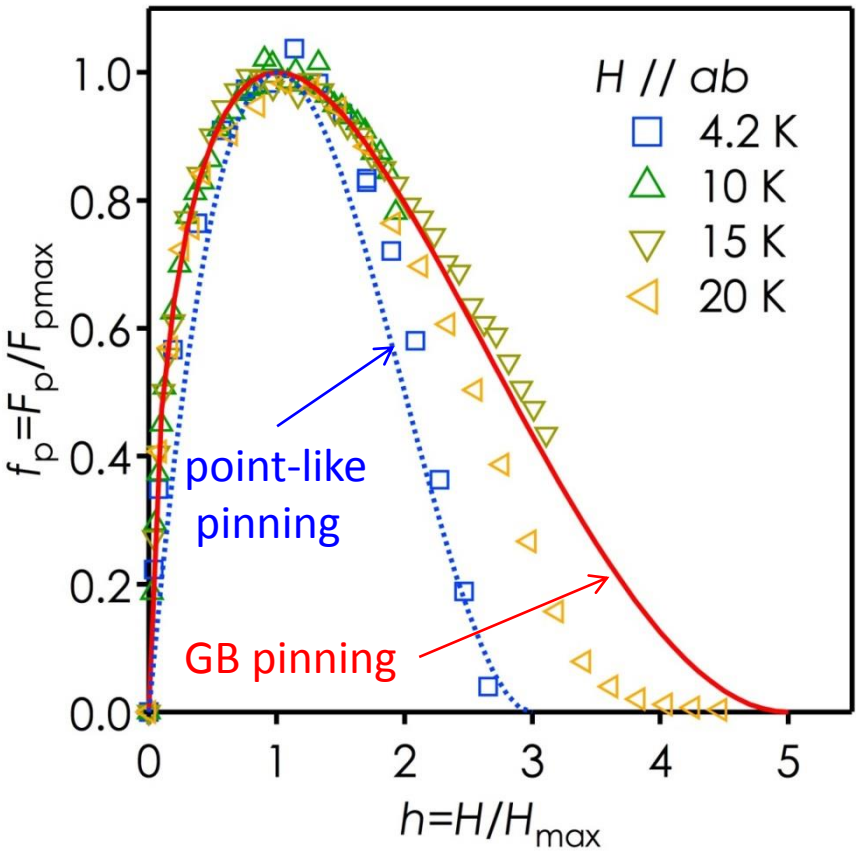
- P-doped $BaFe_2As_2$ coated conductor samples realized by PLD
- T_c increased up to 28 K by optimising growth condition
- NOLD signature at low fields due to J_c limitation by GBs → crossover field





- GBs act as flux pinning centers, justified by J_c scaling and F_p analyses
- *c*-axis peak: GB pinning, *ab* peak : H_{c2} anisotropy

Pinning Force Density for B || ab



$$f_p = \frac{25}{16} h^{0.5} \left(1 - \frac{h}{5}\right)^2$$

Planar defects
Line defects array

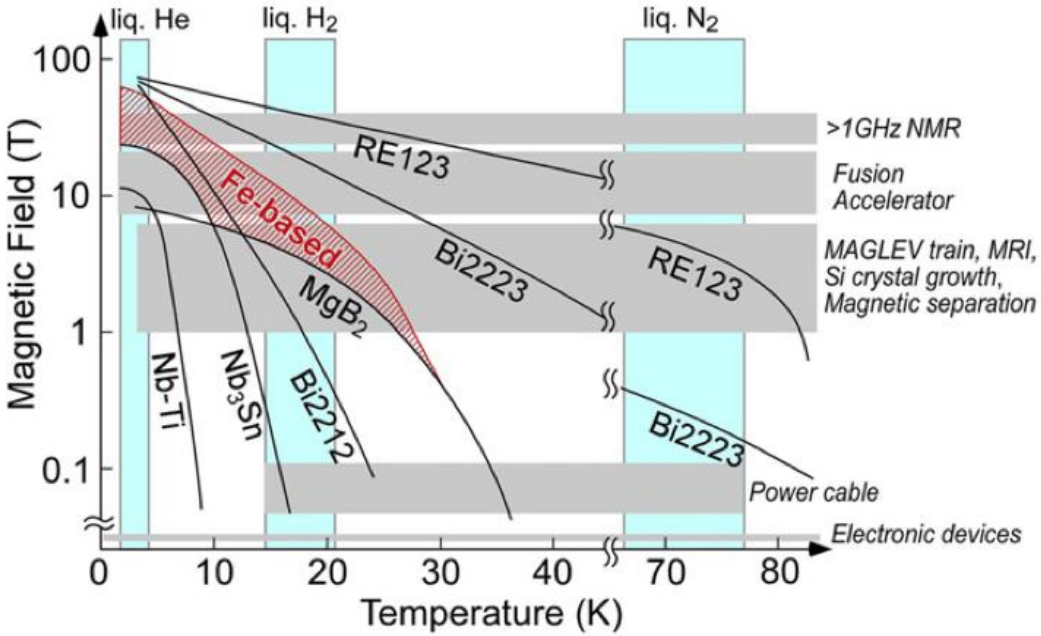
$$f_p = \frac{9}{4} h \left(1 - \frac{h}{3}\right)^2$$

Point-like pinning

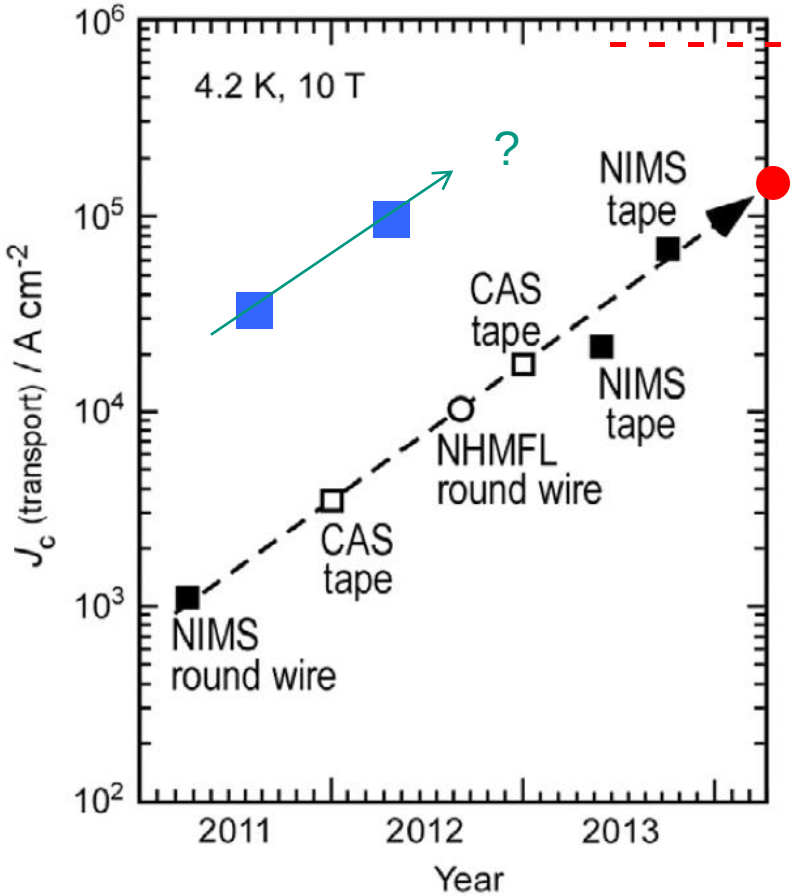
- f_p follows GB pinning @ 10 and 15 K
- f_p neither follows GB nor point-like-pinning for $h > 2$ at 20 K
- 4 K: point like pinning
- Dominant pinning mechanism changes with T for $H||ab$

Iida *et al*, Sci. Rep. **10**, 39951 (2017).

- Currently limited application fields
- (Round) Wire technology improving



J. Shimoyama, Supercond. Sci. Technol. **27** (2014) 044002



- Improved CAS tape
- Current Ba122 film limit
- Ba122 IBAD

MBE-grown P:Ba122/MgO