EUCAS 2017
Geneva 17th - 21st September 2017

13th European Conference on Applied Superconductivity

20 Sept. 17, 10:15-10:30, 3MO2-01

Magnetic Flux Invasion and Field-Capturing in Pulsed-Field Magnetization for Layered MgB_2 Bulk Magnets

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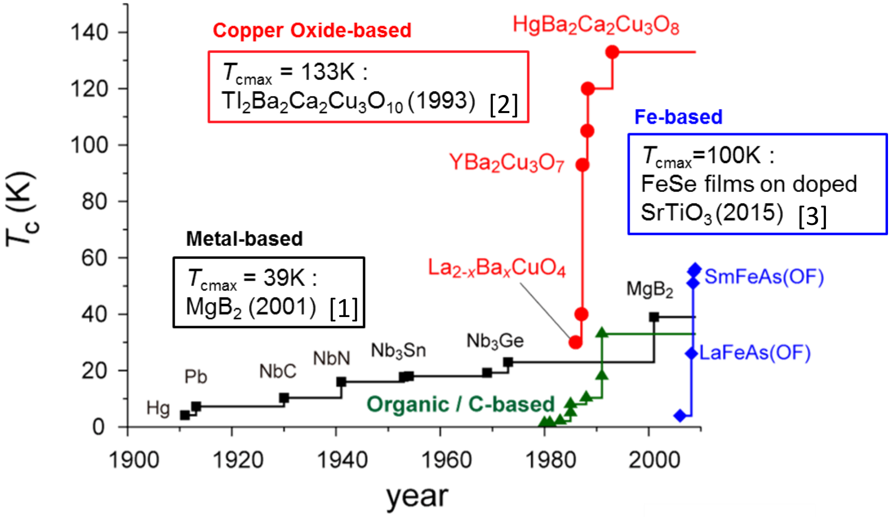
MgB_2

- **T_c = 39 K**
→ the highest among metallic compounds

- **No weak links among crystal grains**
→ no needs for crystal grain alignment

- **Pinning centers reside at grain boundaries**
→ fine particle size results in high Jc values

- **Easy to produce for near-net shapes**
→ feasible practical application to such as
NMR, DDS etc.



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[2] A. Schilling, *et al.*, *Nature*, vol. 363, pp. 56-58, 1993
[3] J-F. Ge. *et al.*, *Nature Materials*, vol. 14, pp. 285-289, 2015
[4] M. Kambara *et al.*, *Supercond. Sci. Technol.* 14 (2001) L5
[5] D.C. Larbalestier *et al.*, *Nature* 410 (2001) 186
[6] P Mikheenko *et al.*, *Supercond. Sci. Technol.* 20 (2007) S264–S270

Fabrication of samples

Sample preparation

Leibniz-Institut für Festkörper - und Werkstoffforschung Dresden (IFW Dresden)

Dr. Wolfgang Häßler,
Ms. Juliane Scheiter

Ball-milled mixture of Mg and B powders

- 250 rpm x 10 h

Hot pressing was operated

- under pressure of 480 MPa
  temperature 700 C
  time 10 min

COMPOSITION AND DIMENSIONS OF MgB_2 BULK SAMPLES

Sample No.	MH1	MH2	MH3	MH4	MH5	MH6	MH7	MH8
Composition	Un-doped	Un-doped	Un-doped	Un-doped	Un-doped	SiC 3%	SiC 3%	SiC 3%
Thickness t (mm)	1.12	1.10	1.13	1.37	1.36	3.30	3.34	6.58

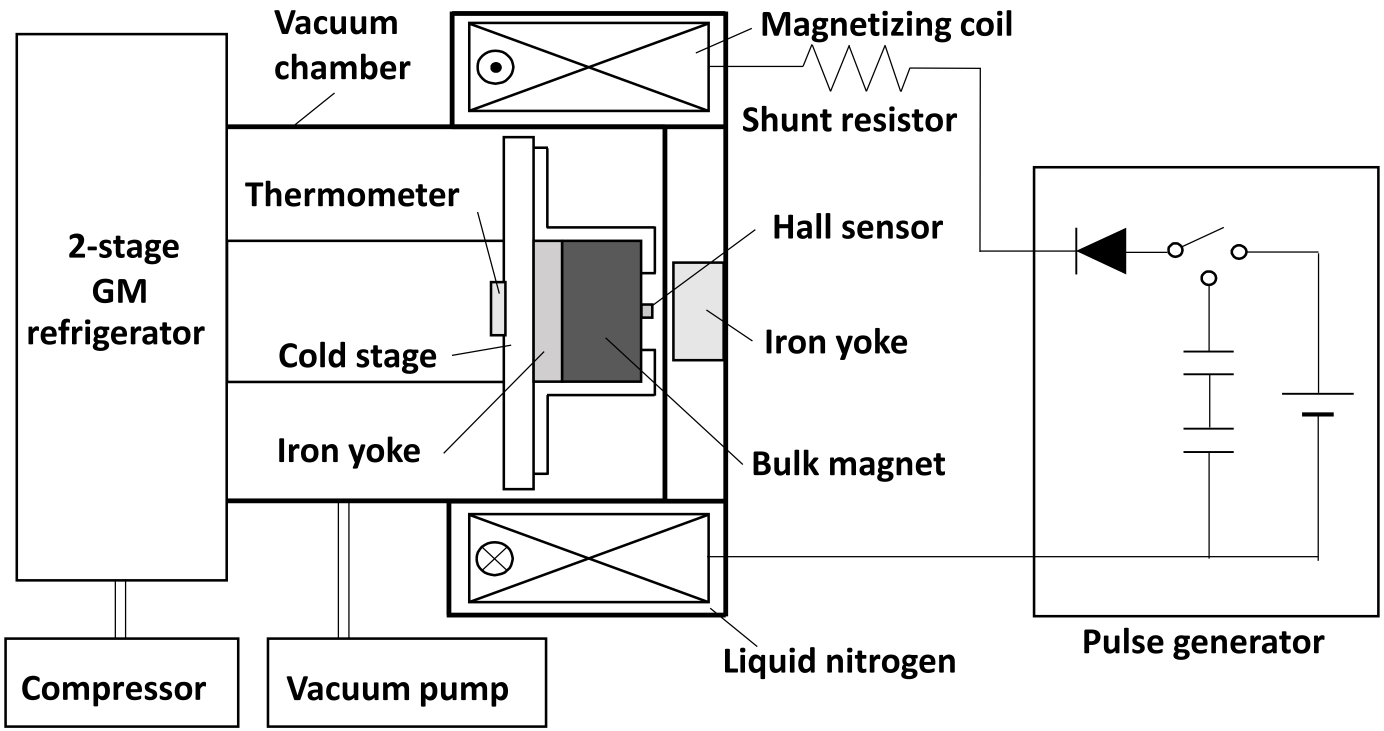
All samples are 20 mm in diameter

< Magnesium powder >
Goodfellow, purity 99.8 %,
grain size < 250 μm

< Boron powder >
PAVEZYUM, purity 98.5 %,
grain size < 250 μm

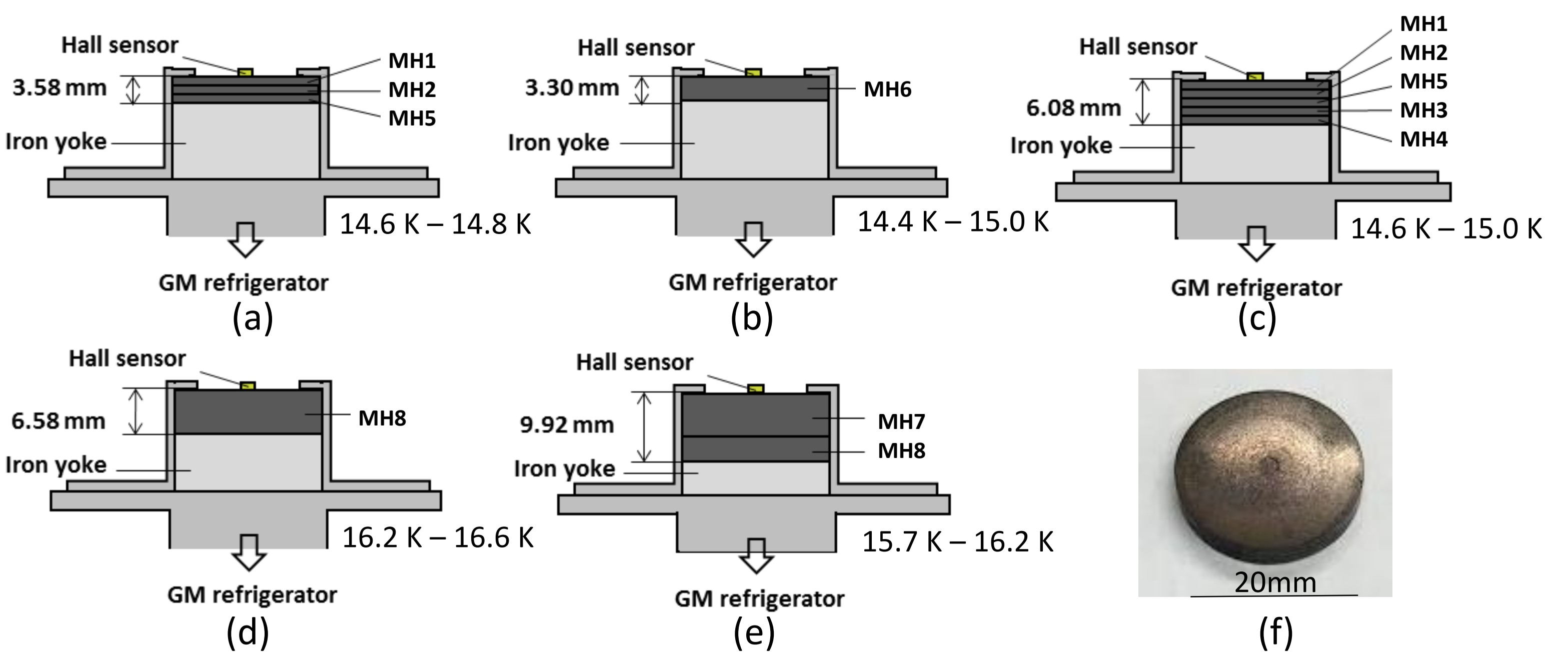
< SiC powder >
Alfa Aesar, purity 95.0 %,
grain size < 30 nm

Schematic drawing of experimental setup for PFM



- The temperature reached about 14.4-16.6 K
- Thermometer is attached at the cold stage
- A pair of iron yokes are attached close to the both side on the sample

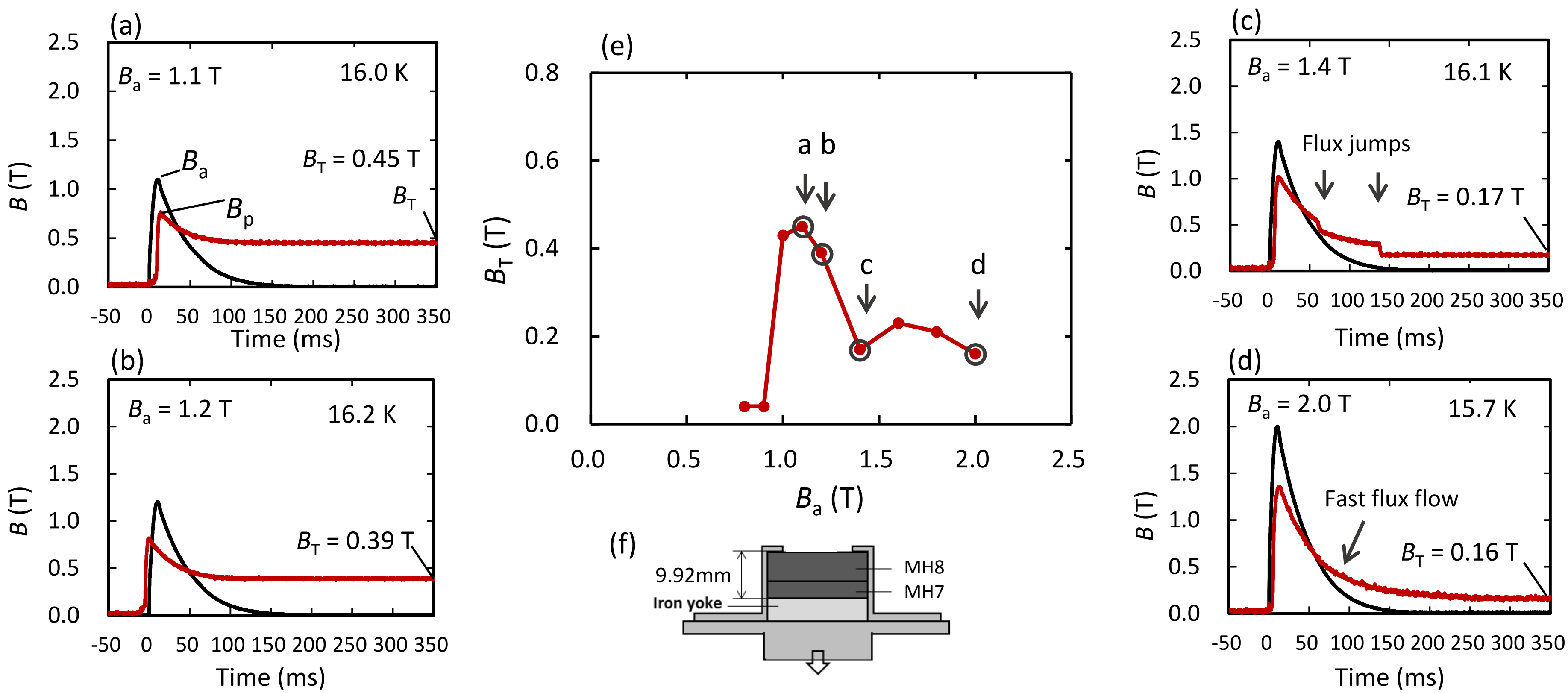
Sample arrangements on the cold stage



- **Applied field B_a**
  0.4 T – 2.0 T
- **Magnetizing coil**
  112 Turns (Copper winding)
  Outside/inside diameter : 114/83

- Operating temperature measured at the cold stage before each PFM shot

Trapped field B_T and evolutional profiles during PFM



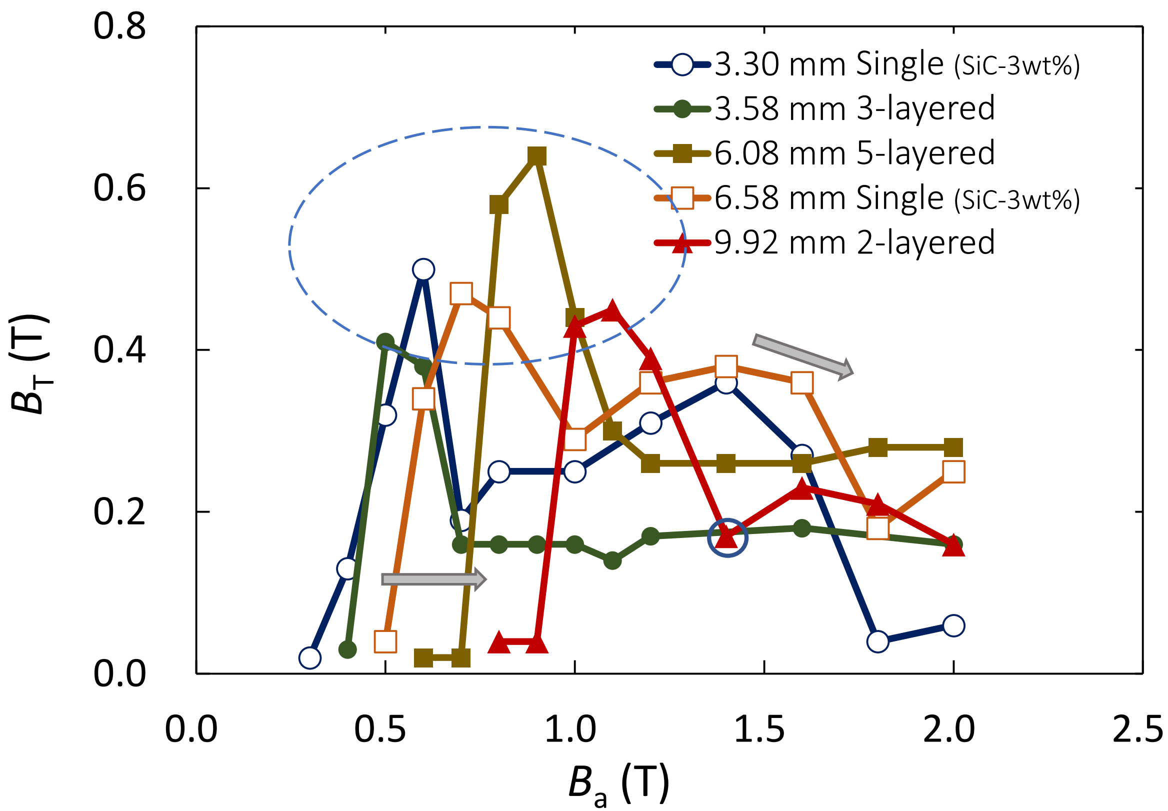
B_a: Maximum applied field calculated by the pulsed current

B_p: Penetration field at the highest peak measured at the top surface during PFM

B_T: Trapped field after PFM

- The trapped field reached 0.45 T
- The flux jumps and fast flux flows were observed in high field application over 1.4 T

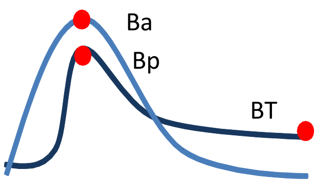
Trapped Fields measured with various sizes in thickness

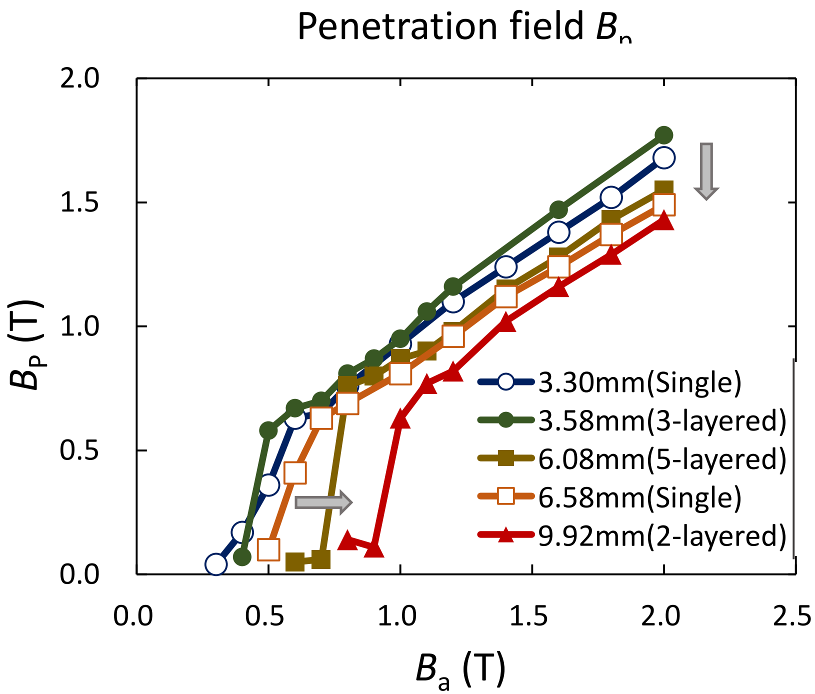


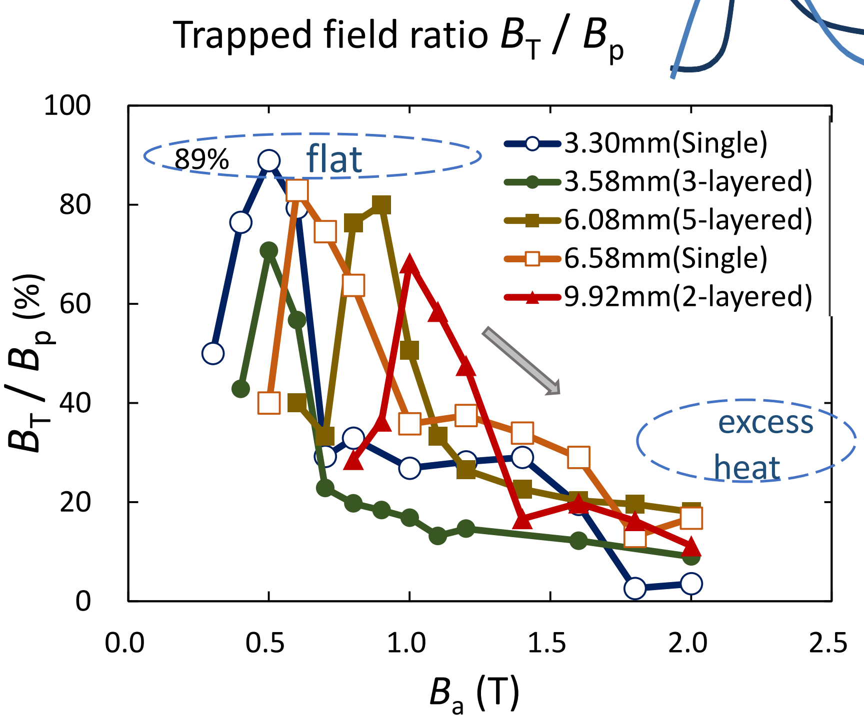
- The thicker the sample, the higher field required for flux invasion start
  → Enhanced shielding effect with size in thickness
- The samples showed the same B_a values 0.4-0.64 T
  → the sample in the critical state with the relevant Jc values
- Frequent flux jump (O) and fast flux flow → Low specific heat, weak pinning

Applied field dependence of penetration fields and ratios of trapped field B_T / penetration field B_p

with various sample thickness

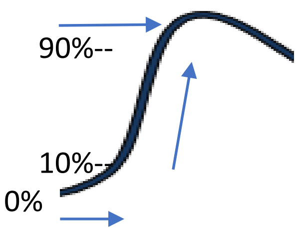


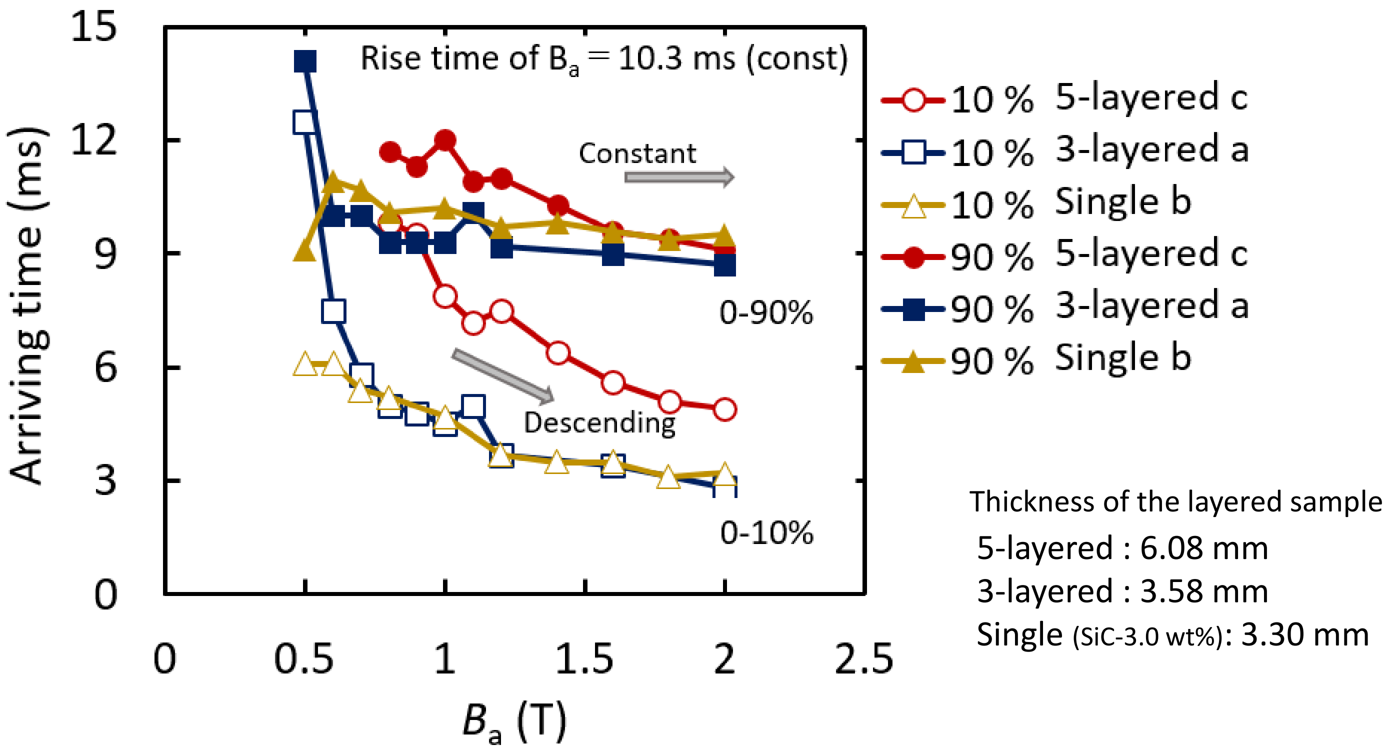




- The field invasion tends to be suppressed with increasing thickness
- B_T degrades with thickness → The shielding effect were promoted with thickness
- The ratios tend to descend → The temperature rises enhanced with thickness

Applied field dependence on the arriving time to the center from 0 to 10% and 90% of penetration field B_p as a function of sample thickness

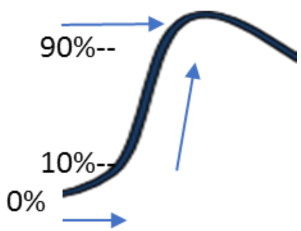


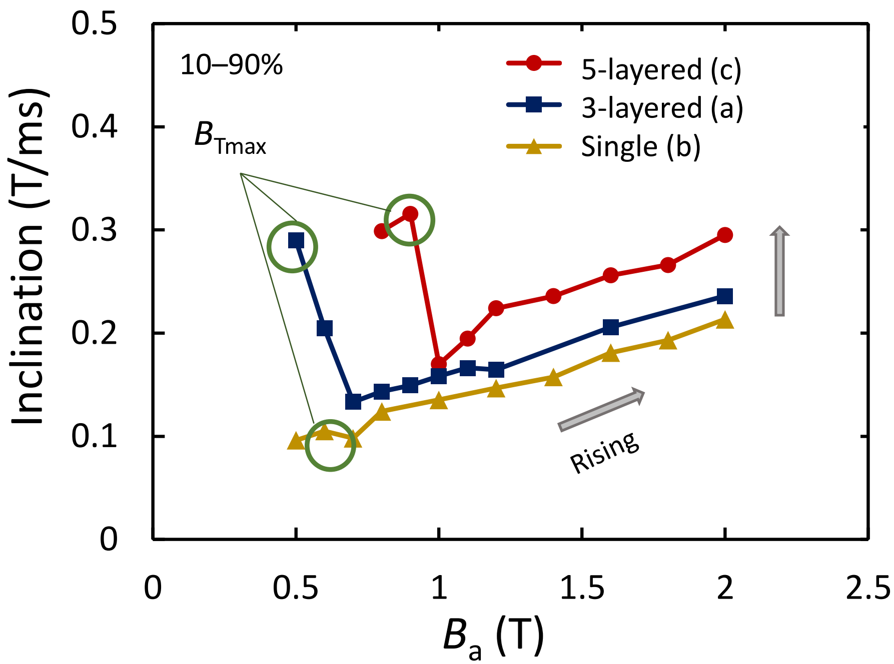


At the beginning, 0-10 % → The thicker, the longer the arriving time, due to the shielding effect, beside the flux starts to invade earlier with increasing applied field
Near the peak, 0-90 % → Almost constant arriving times as 8.7 – 9.5 ms, which means the flux-increasing speed become fast with increasing of applied field
→ The flux jumping into the sample is promoted with applied field strength

Applied field dependence of field inclination in the range from 10 to 90% of penetration fields

=Flux increasing speed at 10-90%





For three sample thickness

Total thickness of the samples

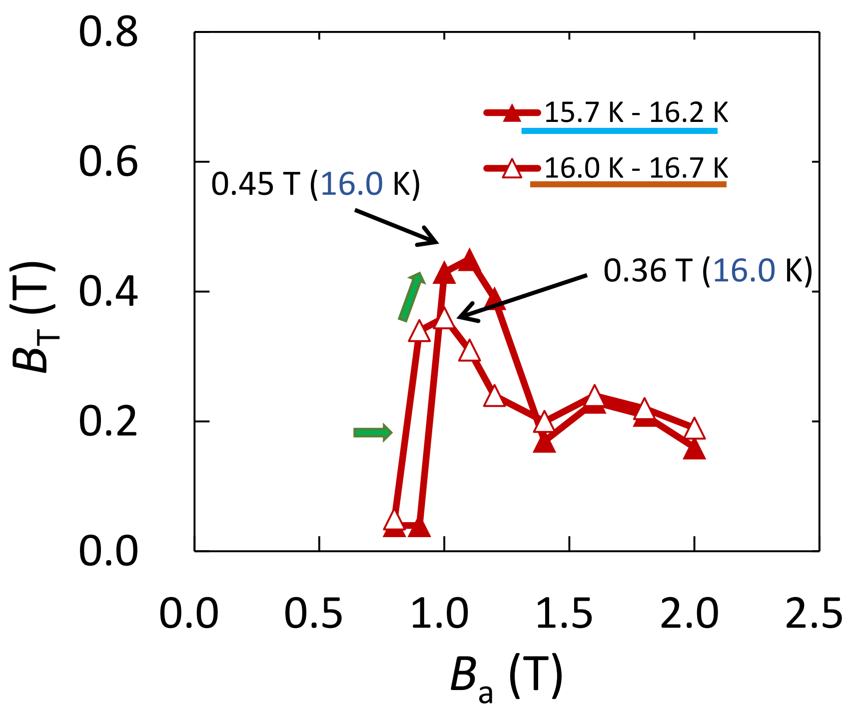
5-layered : 6.08 mm

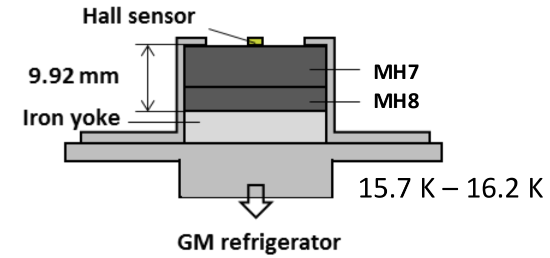
3-layered : 3.58 mm

Single (SiC-3.0 wt% 2) : 3.30 mm

- Flux increasing speed tends to rise with increasing B_a , which rise with thickness
- Rapid invasion in low fields leads to high field capture of B_{Tmax}

Temperature dependence of flux invasion and trapped fields



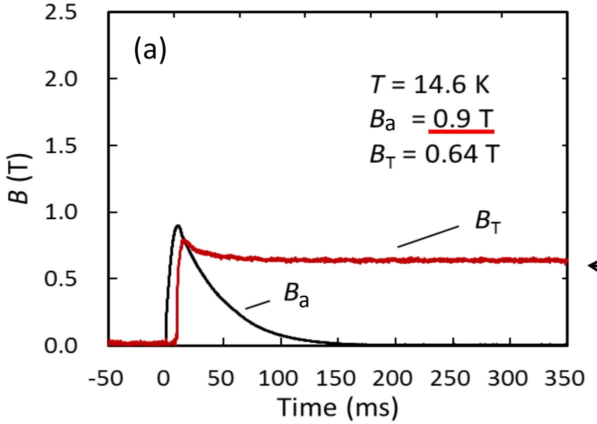


Temperature dependence
→ Enhanced shielding effect and field capturing

Conclusion

- The trapped field B_T reached 0.64 T in the narrow region of around 1 T in B_a with the least heat generation
- The ”fast flux flow“ and flux jumping occur in the region over 1.2 T, which caused significant drops in B_T
- The flux invasion behavior strongly depends on the sample thickness, which mean that the flux invasion from the side surface of the samples
- The temperature rise caused by the flux motion due to the low specific heat should be responsible for low field-capturing

Field Invasion Profiles (5-layered sample)

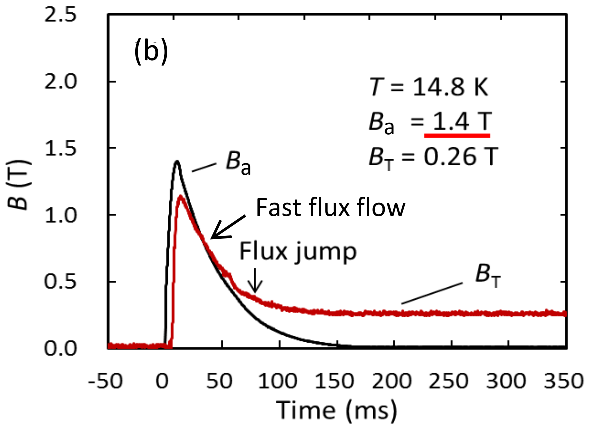


- B_a = 0.9 T

Field trapping ratio
(B_T / B_p) ×100 (%)

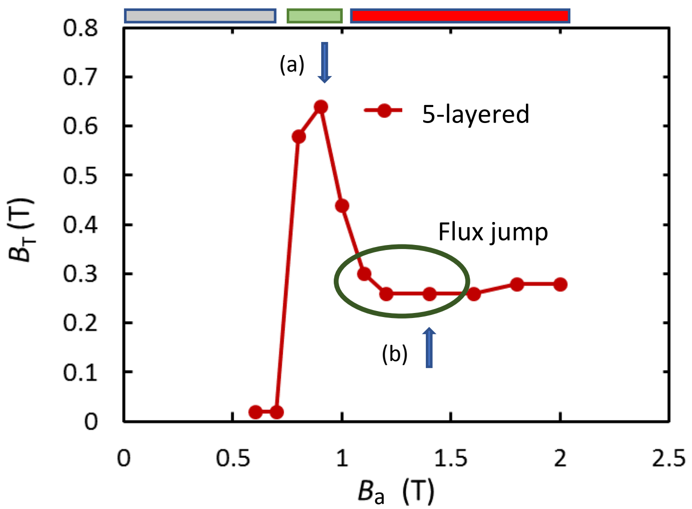
Stable flux capturing

81%



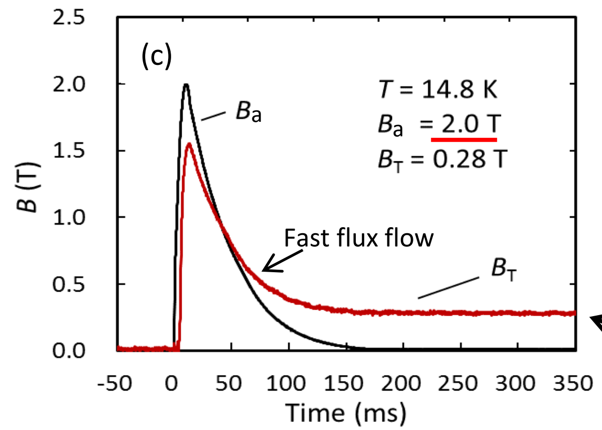
- B_a = 1.4 T

Fast flux flow and flux jump at 58 ms lowers the resultant B_T



Large temperature rise causes the flux jump and flow
→ lower the B_T values
→ narrow the optimum area of B_a

Field Invasion Profiles（5-layered sample）

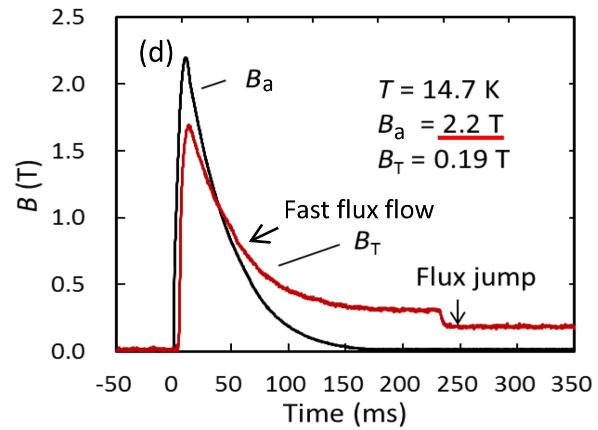


- B_a = 2.0 T

$(B_T / B_p) \times 100$ (%)

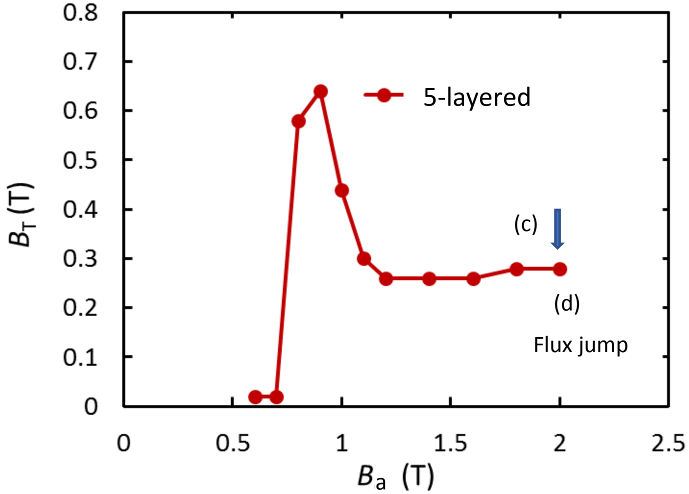
Fast flux flow lowers resultant B_T

18 %



- B_a = 2.2 T

Fast flux flow and sudden flux jump at 234 ms lowers the final B_T value



Severe heat generation causes fast flux flow and frequent/deep flux jump

3 and 5 layered samples