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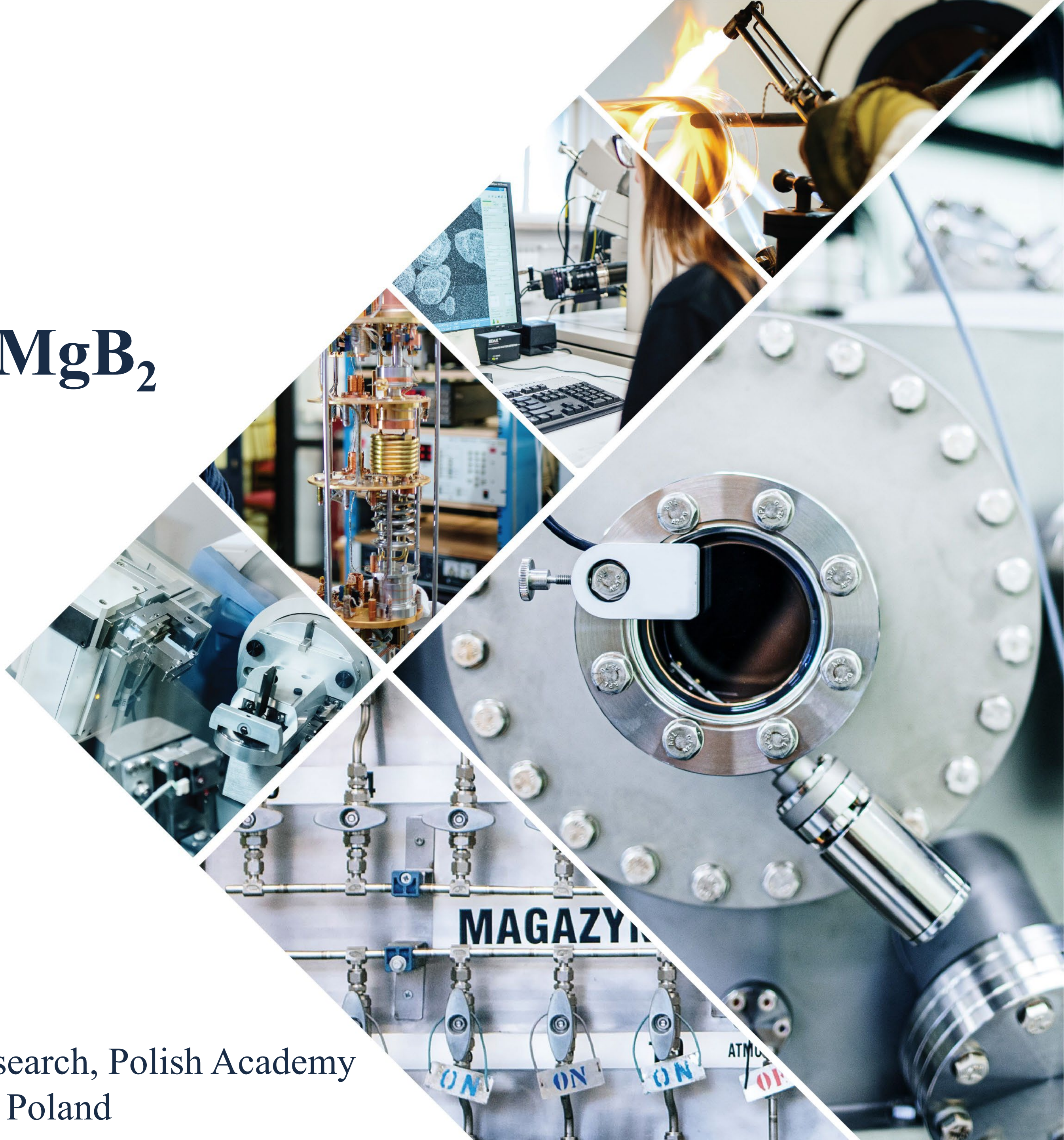
Properties and applications of MgB$_2$ wires for coils



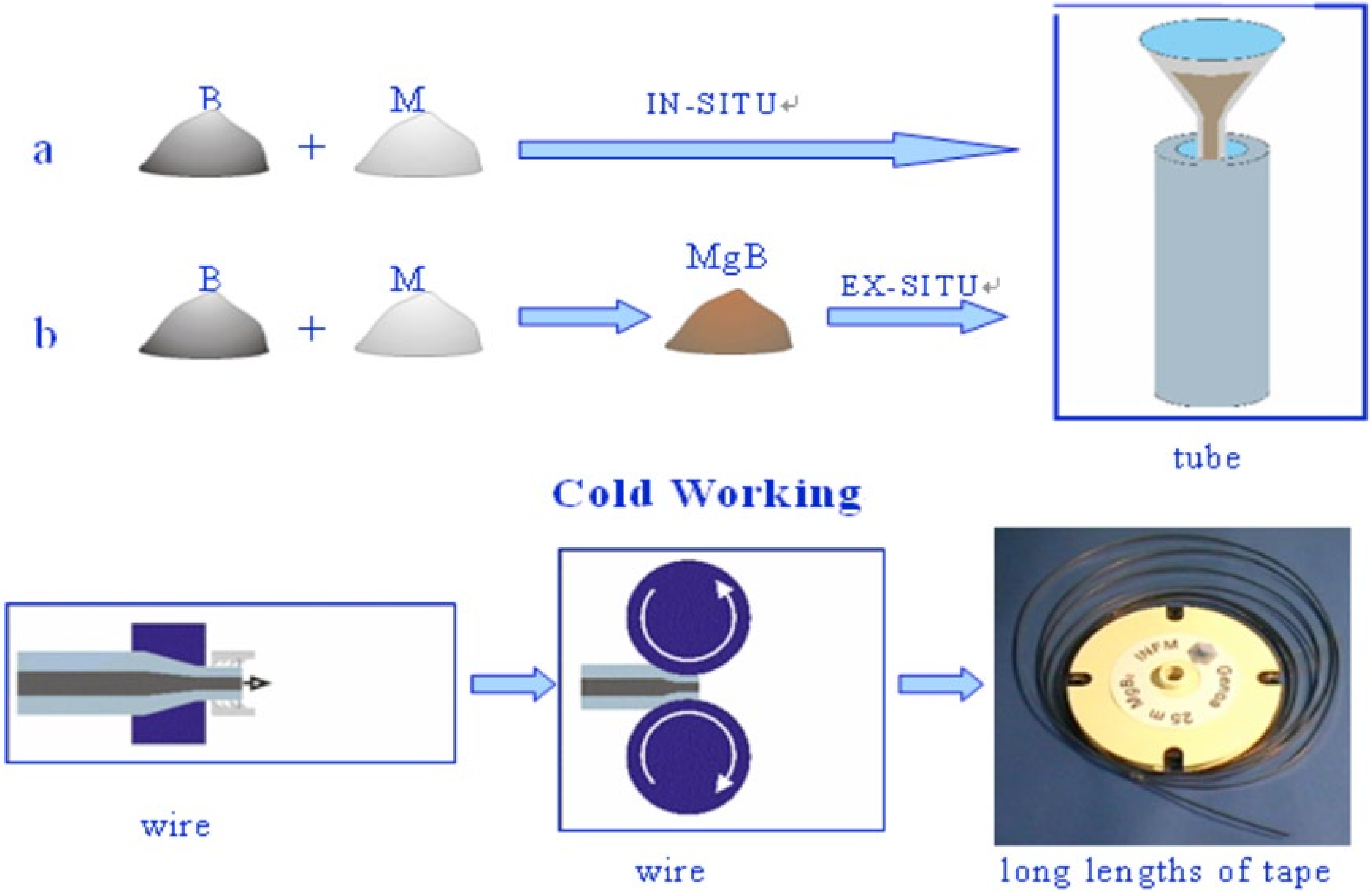
Daniel Gajda, Michał Babij, Andrzej Zaleski

Institute of Low Temperature and Structure Research, Polish Academy of Sciences (PAS), Okólna 2, 50-422 Wroclaw, Poland

Presentation plan

1. Powder in the tube (PIT) technique
2. Measurement systems for transport critical current
3. Diffusion barriers in MgB_2 wires
4. The detection of damaged Nb barrier in MgB_2 wires
5. Effect of dopants on pinning centers and J_c
6. The *n value*
7. PIT MgB_2 wires with ^{11}B
8. Conclusions

1. Powder in the tube (PIT) method - *in situ* and *ex situ* MgB_2 *powders*



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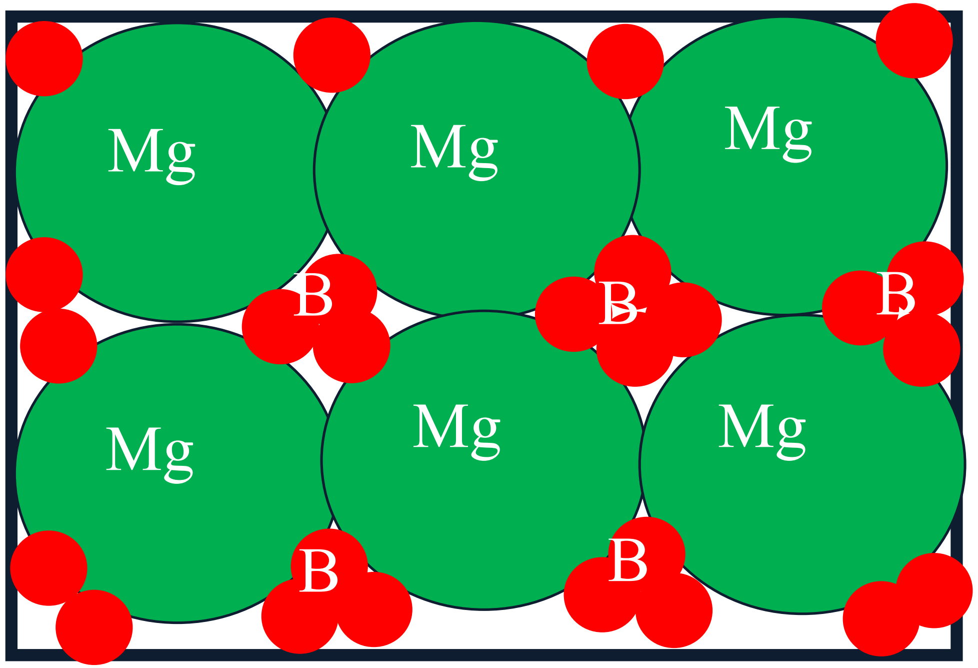
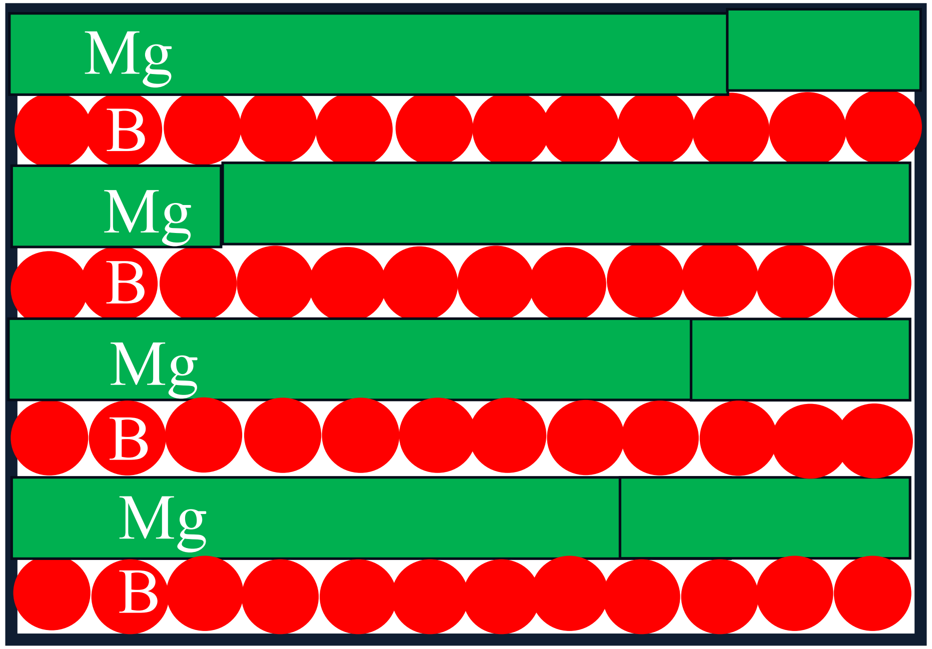
Cold drawing

Unreated MgB_2 bulks → **Unreated MgB_2 wires**





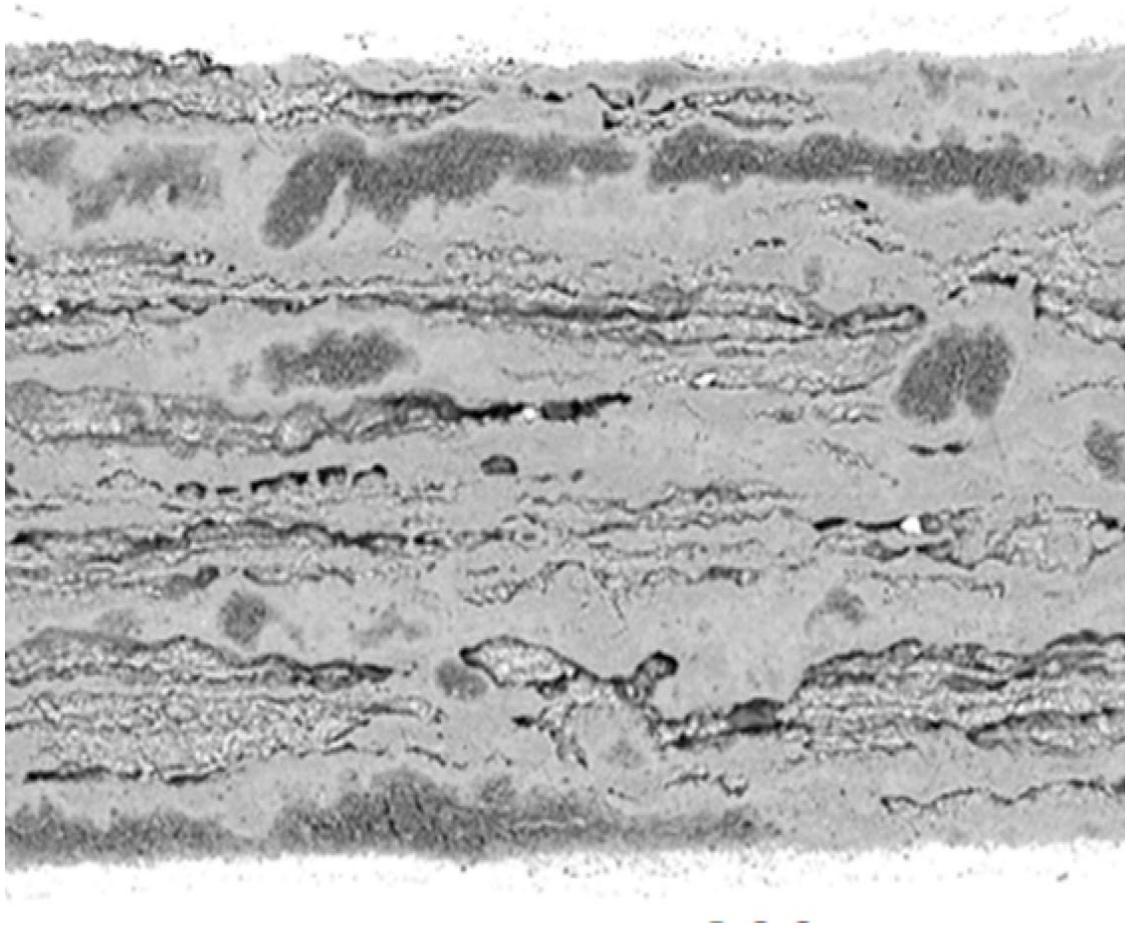
Mg particle size – 40 µm
B particles size – 250 nm

D. Gajda et al. Journal of Alloys and Compounds, 889 (2021) 161665.
G.Z. Li, M.D. Sumption, E.W. Collings, Acta Materialia 96 (2015) 66-71.

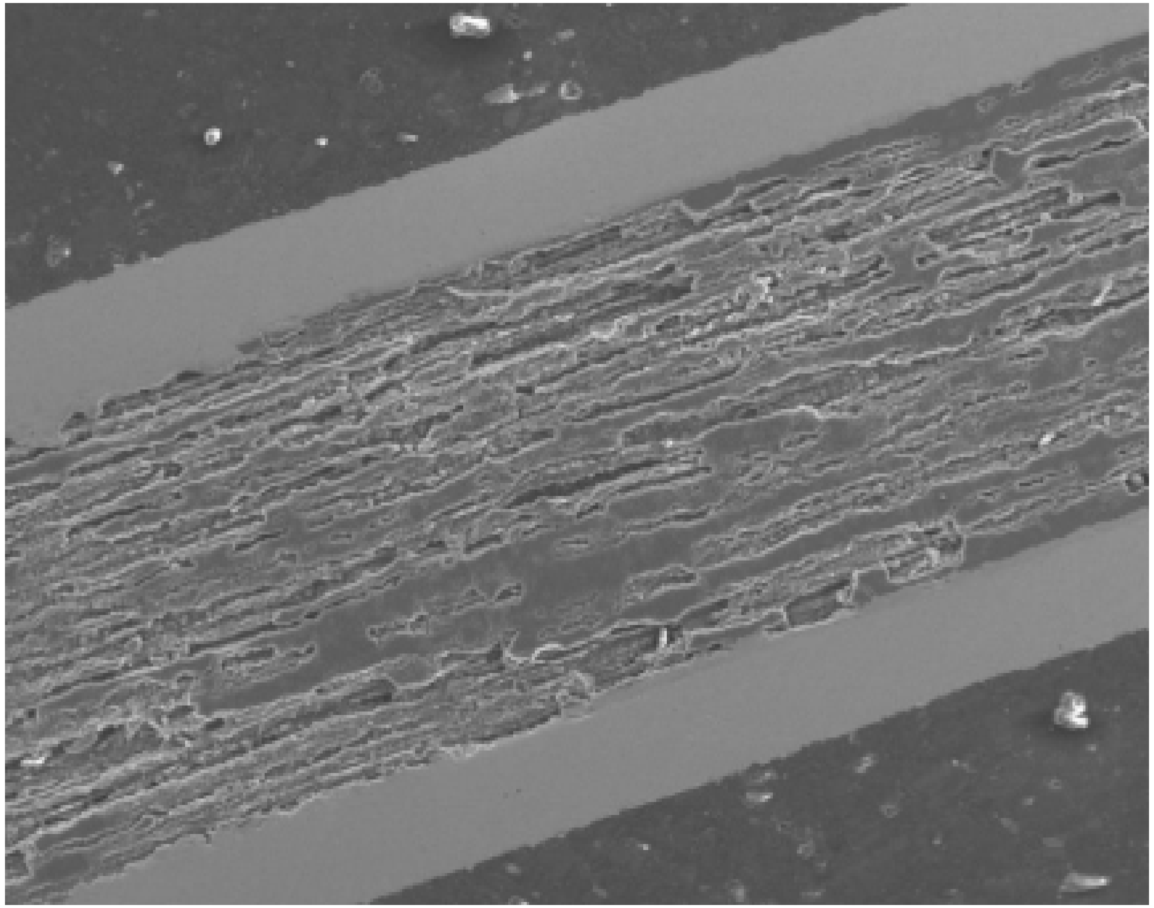
Heat treatment

Unreated MgB_2 wires

MgB_2 wires



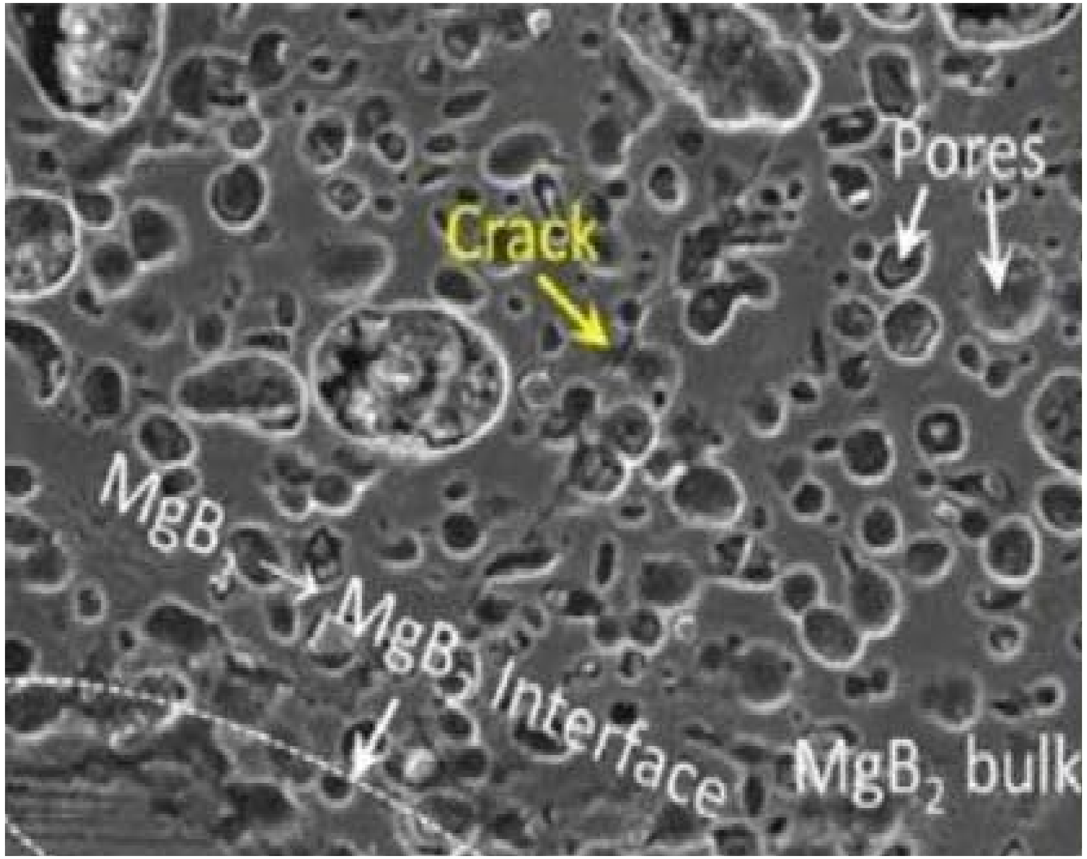
D. Gajda et al. Materials 17 1362 (2024)



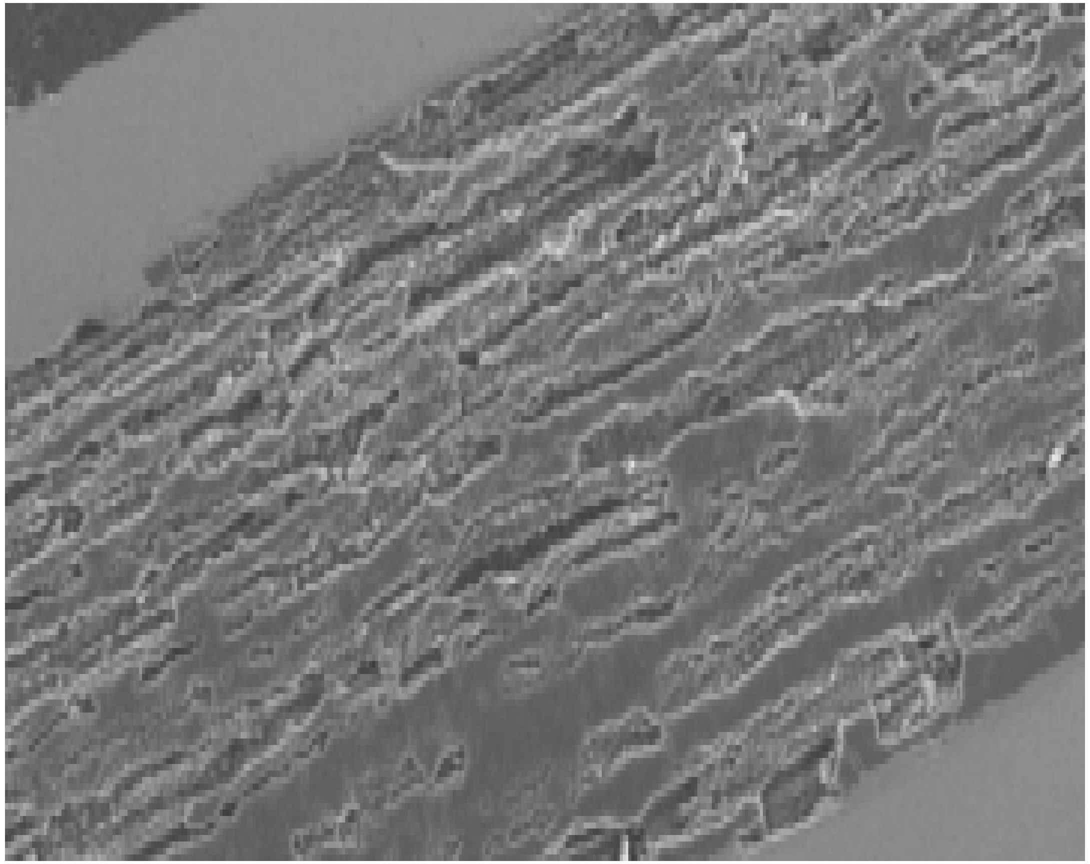
Z. Mroczek, D. Gajda et al. J. Alloy Compd. 776, 636-645 (2019)

MgB_2 bulk

MgB_2 wires



H. Lianga , D. Gajda, M.S.A. Hossain, J. Magn. Alloys, 11 (2023), 2217-2229



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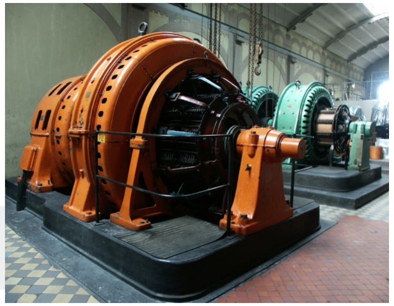
2. Measurement systems for transport critical current

Bitters magnets

measurement conditions

- Temperature – 4.2 K and 77 K
- Magnetic field – 10 T, 14 T and 17 T
- DC source – 150 A
- sample length – 30 mm



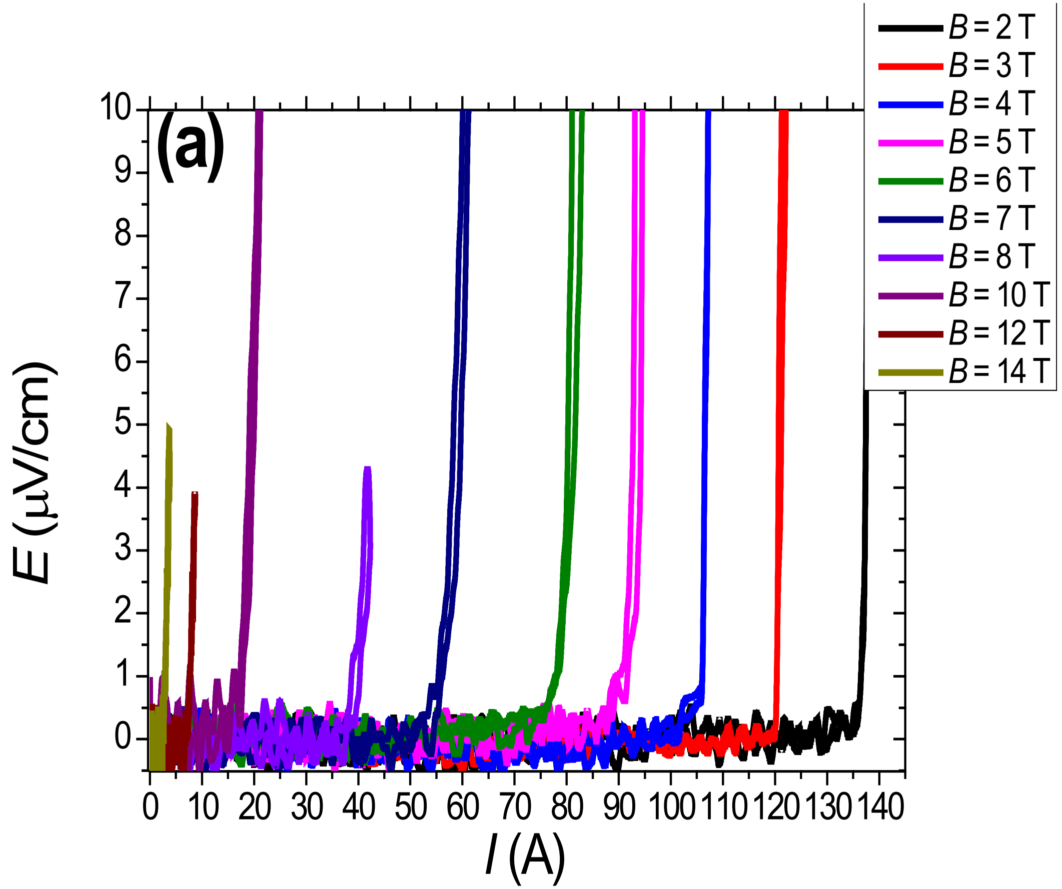
Superconducting magnets

measurement conditions

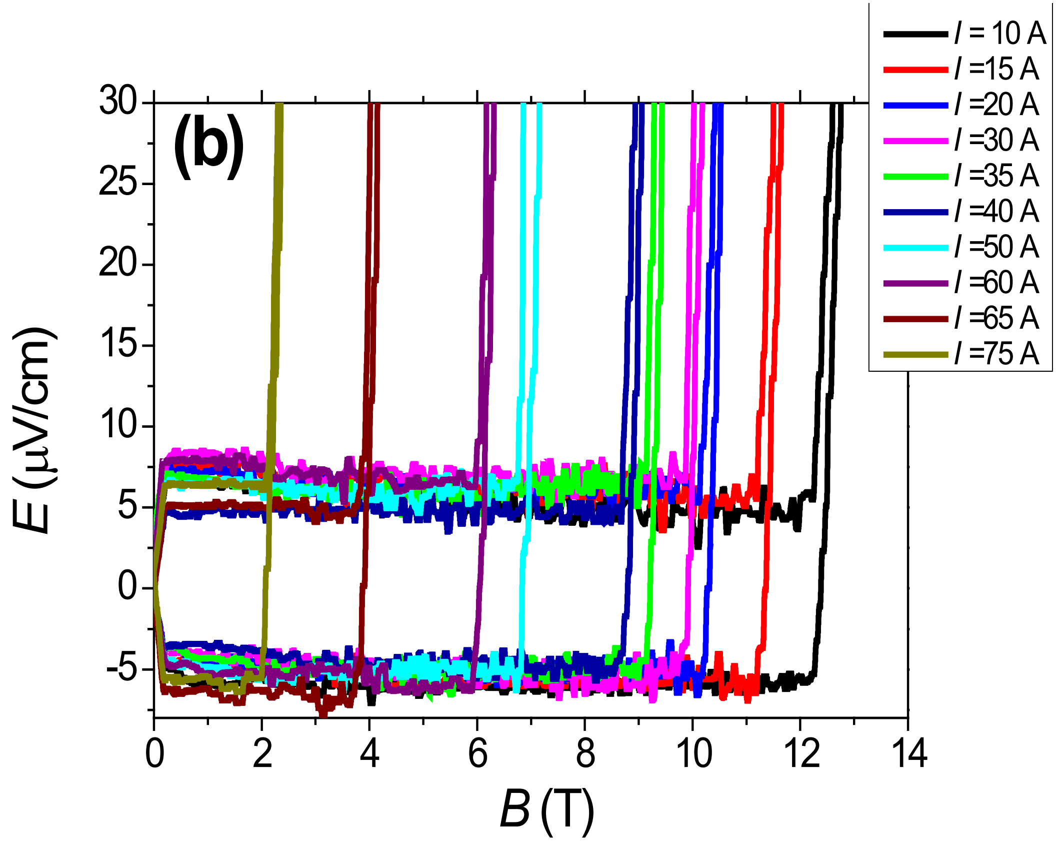
- Temperature – rang from 1.4 K to 100 K
- Magnetic field – 9 T
- DC source – 150 A
- temperature control - three lakeshore cernox sensors
- vapor helium
- sample length – 30 mm

Critical current measurements - four-point probe method

The current sweep method - constant magnetic field and increasing current



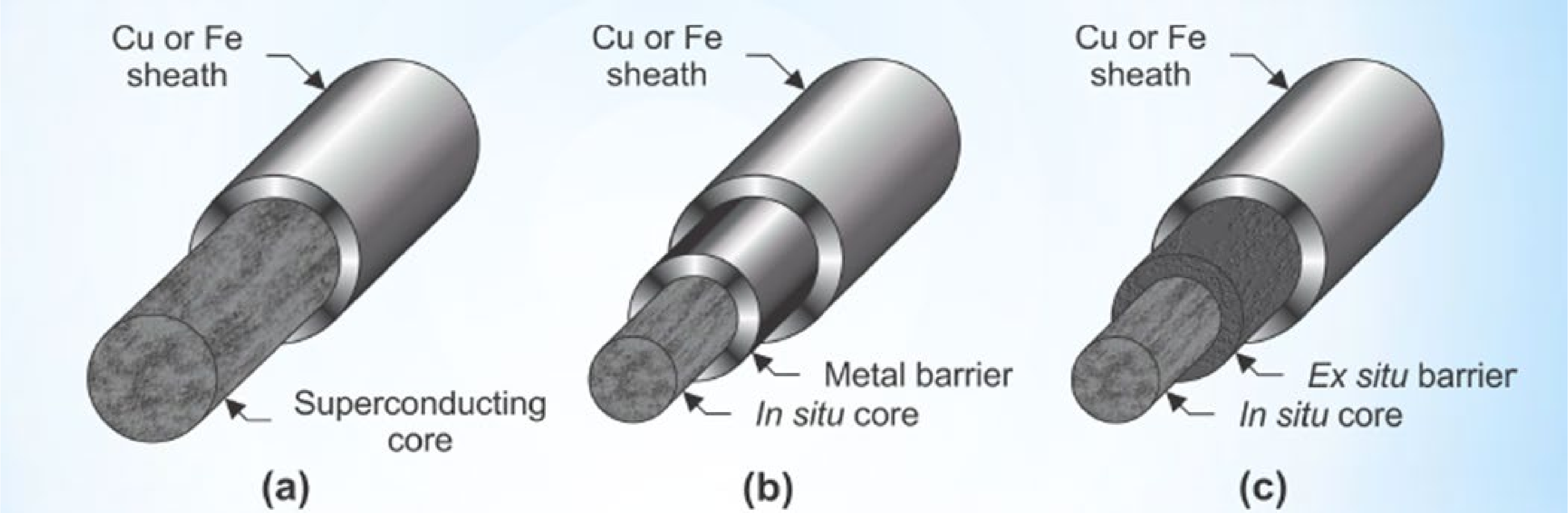
The field sweep method - constant current and rapidly increasing magnetic field



Criterion for determining I_c – 1 µV/cm

D. Gajda et al. Supercond. Sci. Technol. 28, 115003 (2015)
D. Gajda et al. Supercond. Sci. Technol. 29, 85010 (2016)

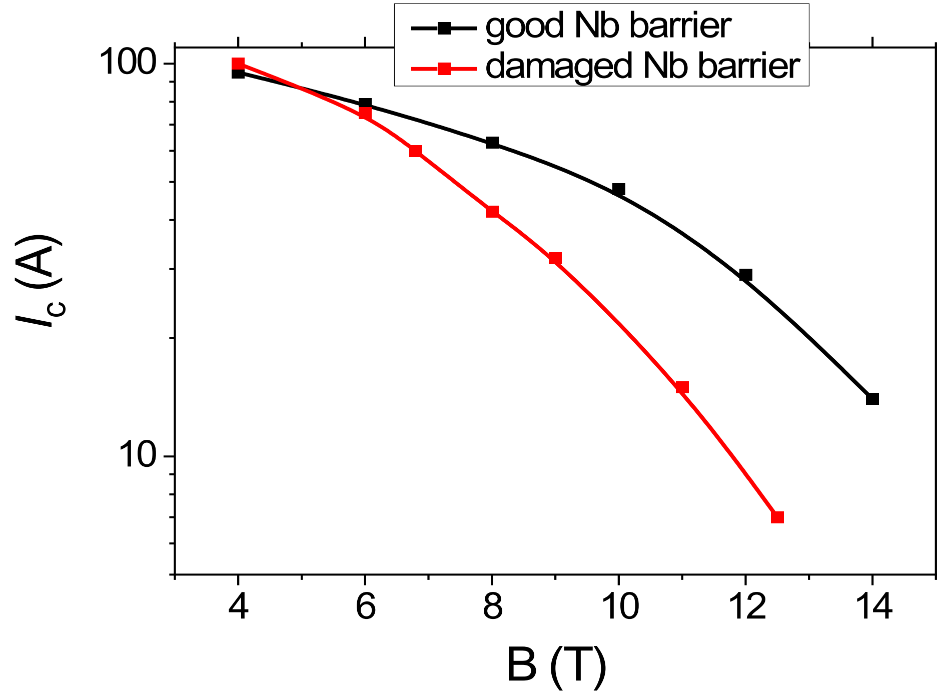
3. Diffusion barriers in PIT MgB_2 wires

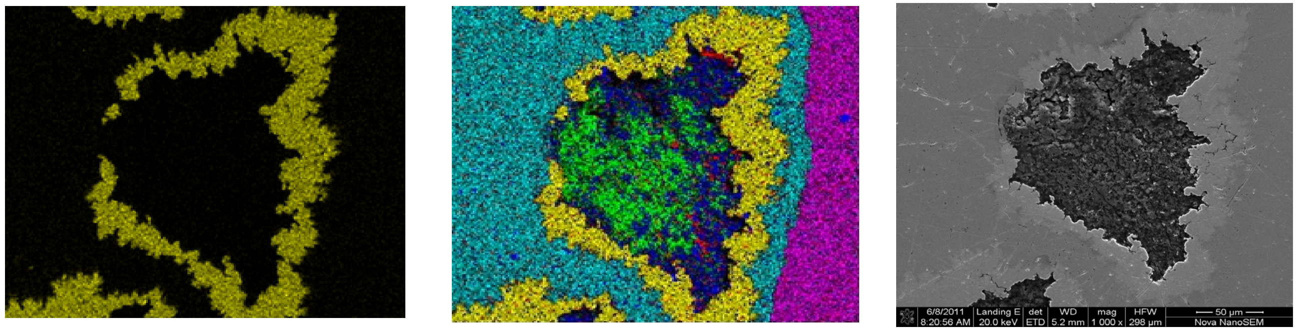


The price of MgB_2 wire with a length of 1 m from \$5 to \$10

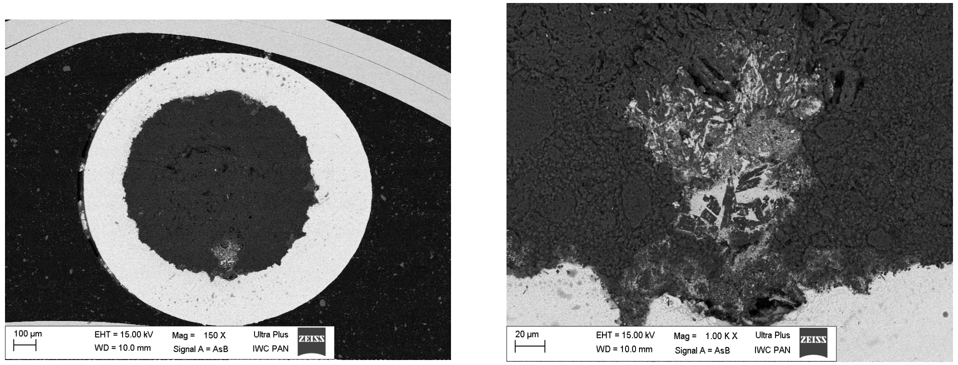
4. The detection of damaged Nb barrier in MgB_2 wires

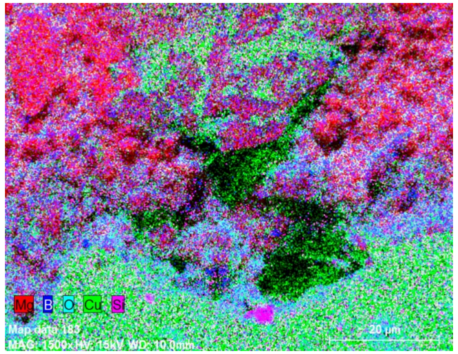
Nb barrier





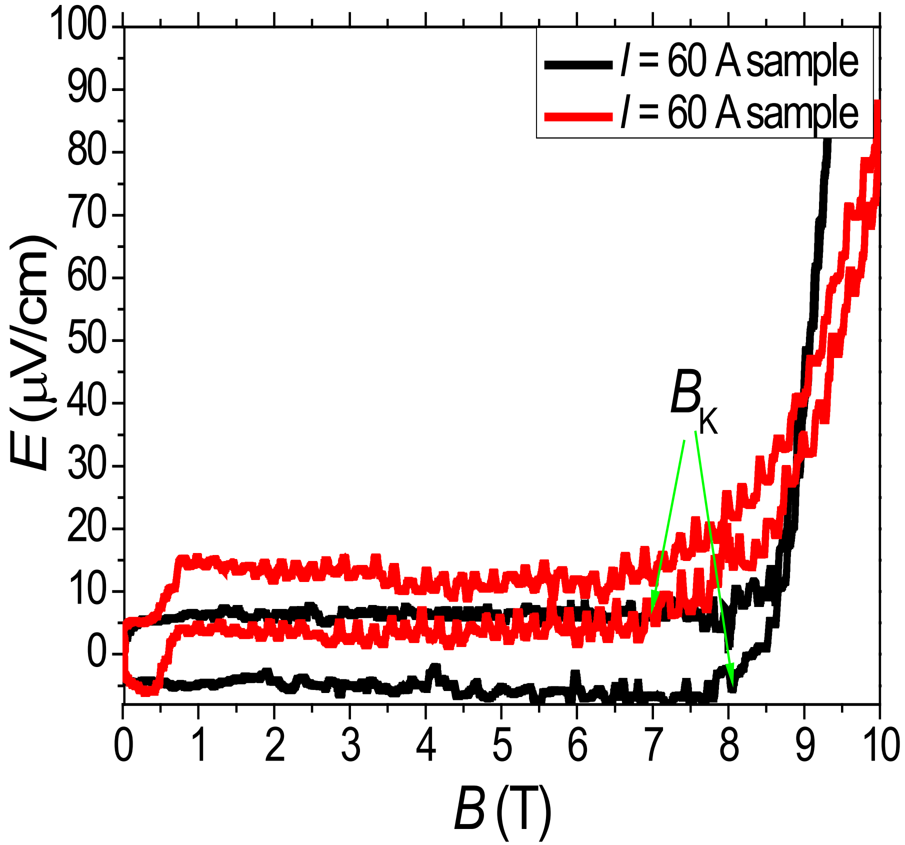
ex situ MgB_2 barrier



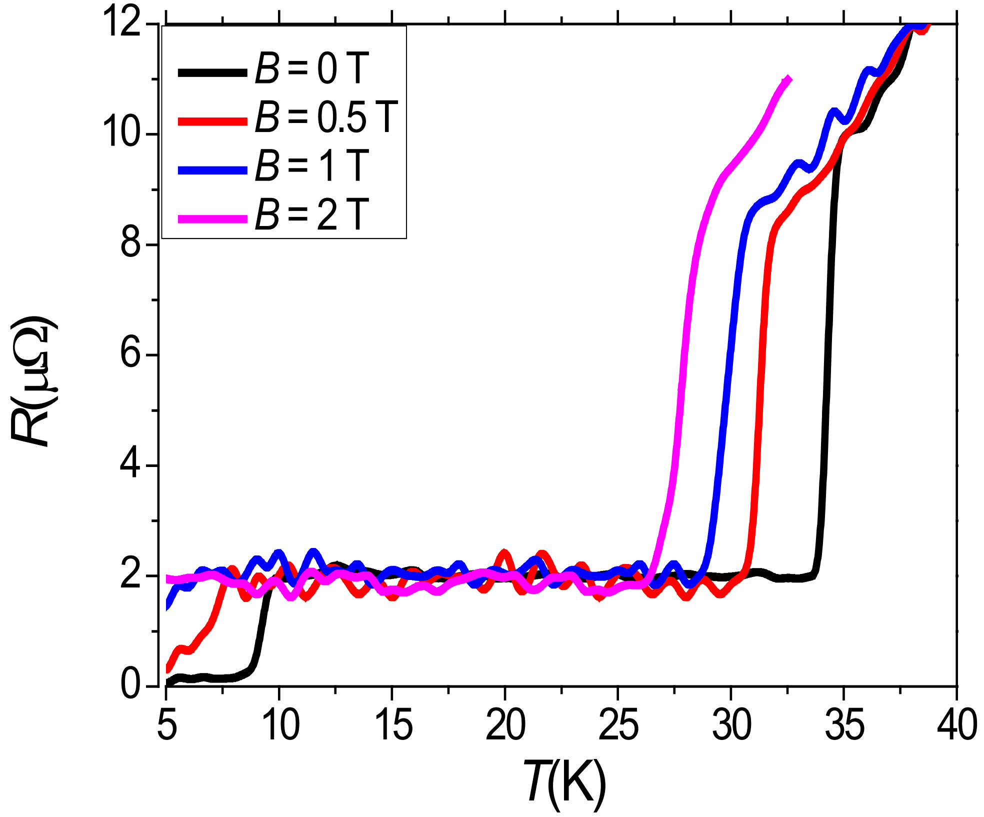


D. Gajda et al. Supercond. Sci. Technol. 28, 115003 (2015)
D. Gajda et al. J. Alloy Compd. 647, 303-309 (2015)

Bitter Magnets



PPMS system



D. Gajda et al. Supercond. Sci. Technol. 28, 115003 (2015)
D. Gajda et al. Mater. Lett. 160, 81-84 (2015)
D. Gajda et al. J. Alloys Compd. 647, 303-309 (2015)
D. Gajda et al. Appl. Phys. Lett 108, 152601 (2016)

5. Effect of dopants on pinning centers and J_c in MgB_2 wires

C admixture

line pinning center
substitution of C for B

point pinning centers
precipitates with a
coherence length of 5 nm

Surface pinning centers

Sm_2O_3, Dy_2O_3 admixture

Surface pinning centers

point pinning centers

SiC admixture

Surface pinning centers

point pinning centers

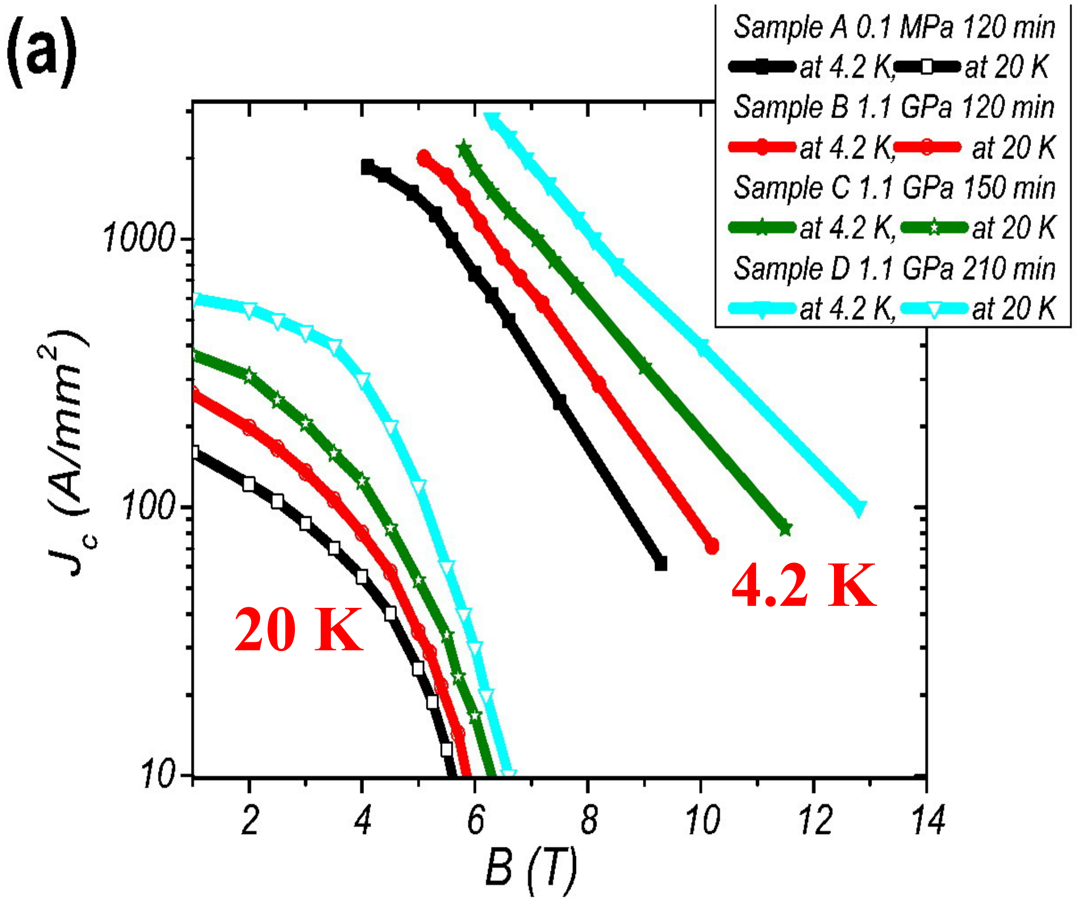
HIP process

line pinning center

D. Gajda et al. Supercond. Sci. Technol 28, 015002 (2014)
D. Gajda et al. J. Alloy Compd. 687, 616-622 (2016)
D. Gajda et al. Supercond. Sci. Technol 29, 085010 (2016)
D. Gajda et al. J. Appl. Phys. 117, 173908 (2015)
D. Gajda et al. J. Appl. Phys. 120, 113901 (2016)
D. Gajda. Low Temp. Phys. 194, 166–182 (2019)
D Gajda et al. Physica C 570, 1353606 (2020)
D. Gajda et al. J. Alloy Compd. 889, 161665 (2021)
G. Gajda, D. Gajda et al. Ceram. Int.49, 36031-36043 (2023)

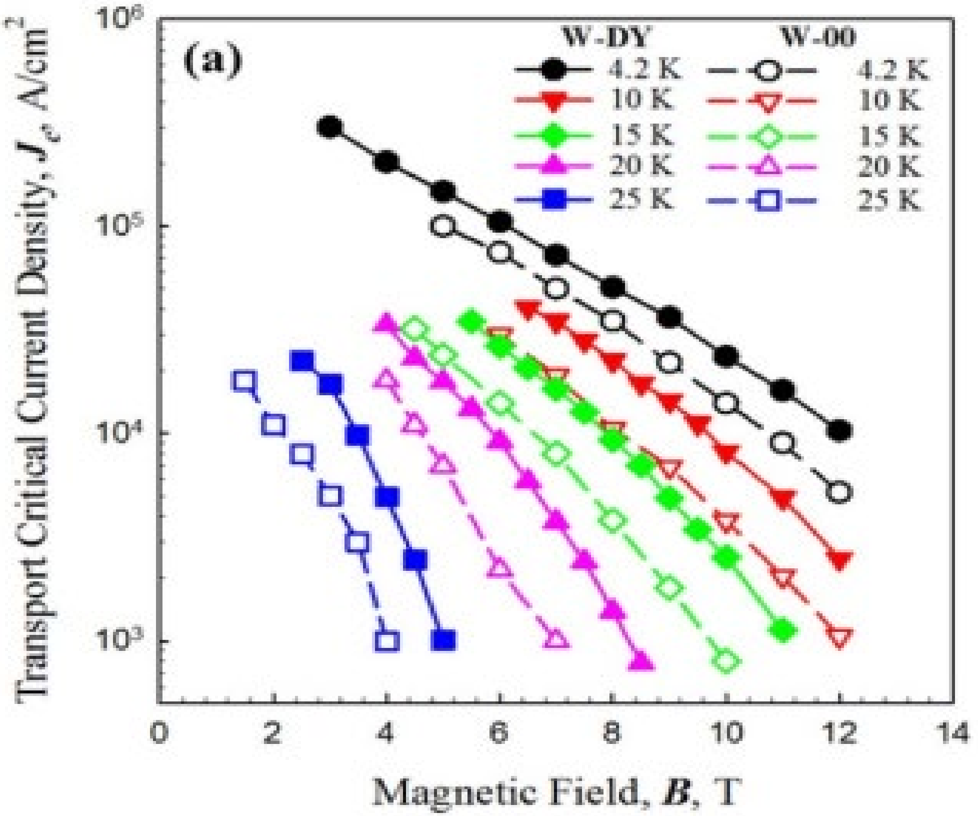
Transport critical current density in MgB_2 wires

Undoped MgB_2 wires



D Gajda et al. Scr. Mater. 143, 77-80 (2018)

0.5wt% Dy_2O_3 and 2wt% C doped MgB_2 wires



Y Yang et al. Supercorde. Sci. Technol. 34, 025010 (2021)

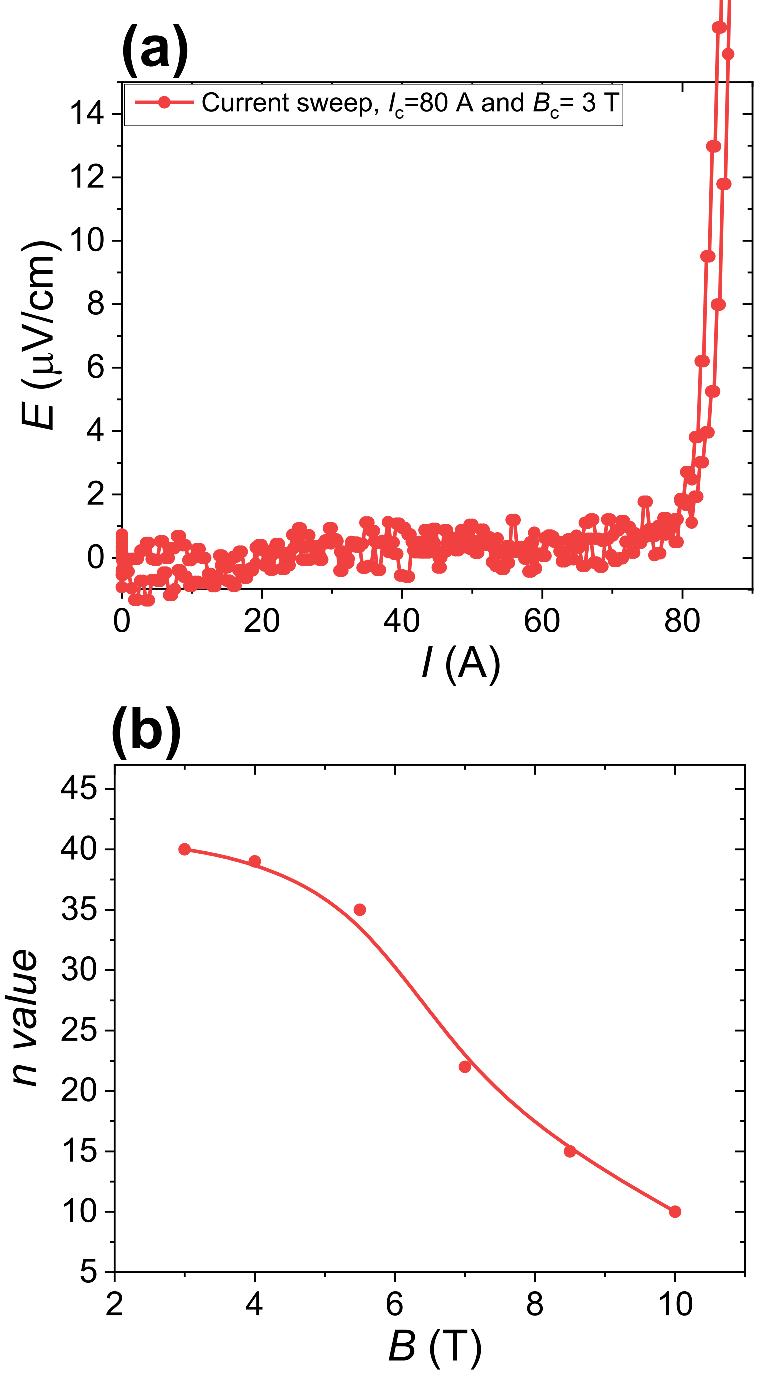
6. The *n value*

The *n value* describes the slope of the $U = f(I)$ curve during transition from the superconducting state to the resistive state.

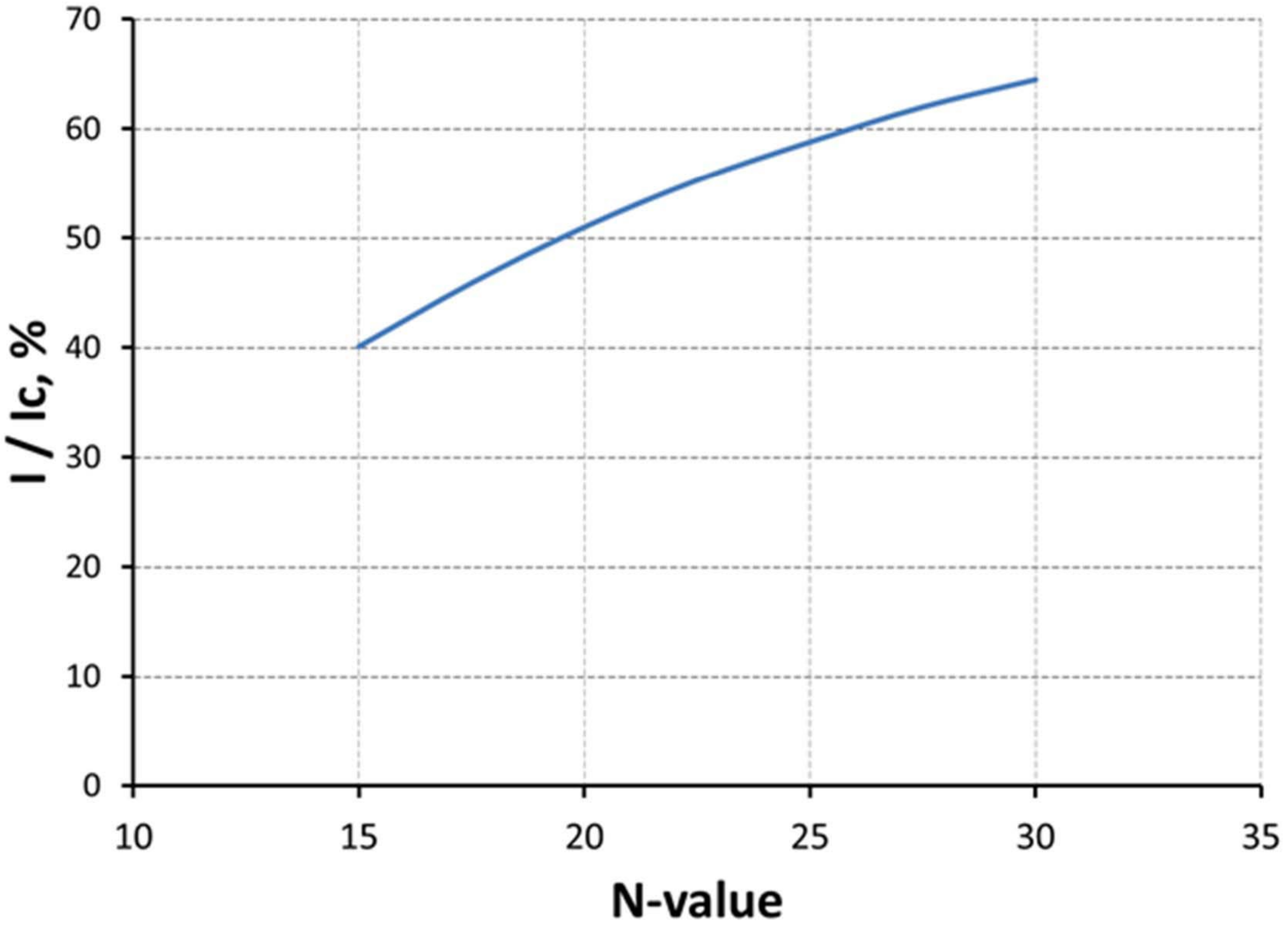
Intrinsic effects and extrinsic effects

Intrinsic effects are created by connections between grains, grain microstructure, pinning centers and flux creep.

Extrinsic effects are created mainly by the filament (distribution and quantity), metal shield of the wires, diffusion barrier and bending of the wire on the carcass.

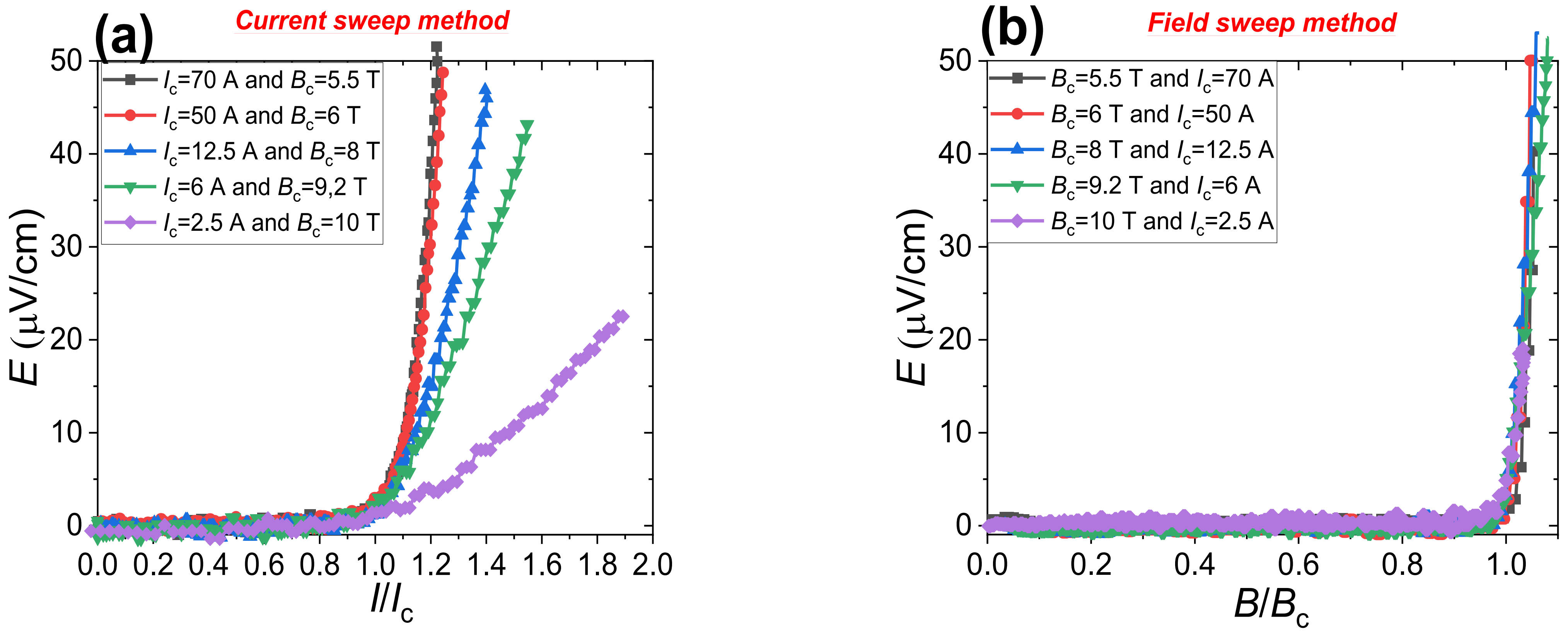


D. Gajda et al. J. Appl. Phys. 136 053901 (2024)



n value – 20 – we can use olny 50 % J_c for colis

M. Parizh et al Supercond. Sci. Technol. 30, 014007 (2017)



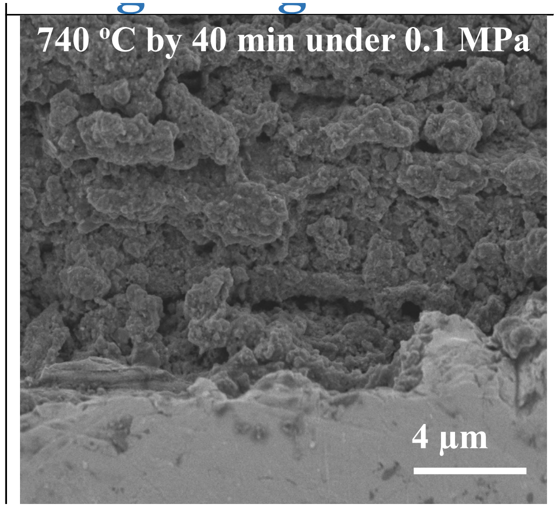
The field sweep method is similar to the operation of a superconducting coil

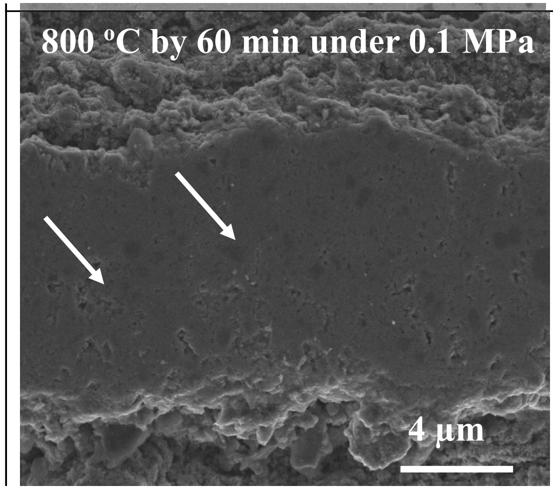
sweep current - 1 A generates a field of 0.5 mT
sweep field - 1 A generates a magnetic field - 93 mT (for a 14 T coil)

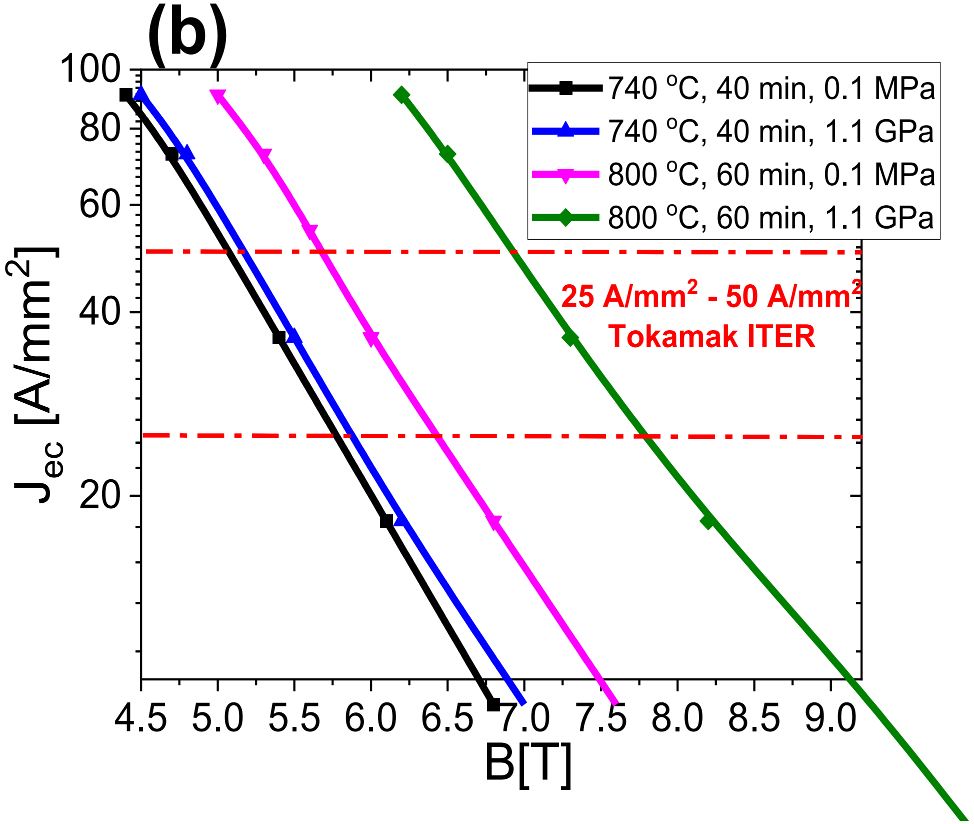
D. Gajda et al. J. Appl. Phys. 136 053901 (2024)

7. PIT MgB_2 wires with ^{11}B

The boron possesses two stable isotopes ^{10}B (18.98%) and ^{11}B(81.02%). The two stable isotopes have different atomic mass, magnetic moment, neutron absorption cross section. These properties affect the physical and chemical parameters of the compound, such as chemical (reaction rate), mechanical (hardness, stiffness etc.) and thermal (temperatures of the phase transitions). Additionally, $Mg^{11}B_2$ material has low activation energy, shorter decay time compared with Nb-based superconductors and has higher T_c of 39.2 K; and the ^{11}B isotope is stable for neutron irradiation. This indicates that $Mg^{11}B_2$ wires may be better than NbTi and Nb_3Sn wires **for fusion reactors**.







The results showed that the rate of the synthesis reaction for PIT $Mg^{11}B_2$ wires made with nano-amorphous ^{11}B is much slower than for PIT MgB_2 wires made with nano-amorphous natural B

D. Gajda, A.J. Zaleski, M. Babij et al. J. Alloy Compd. 871, 159579 (2021)
D. Gajda, A.J. Zaleski, M. Babij et al. Fusion Eng. Des.168, 112383 (2021)

Conclusions

- 1. The MgB_2 wires have the layered morphology which is hard and brittle. This is the important factor for the winding process of MgB_2 coils and influences the bending radius of the MgB_2 wires.
- 2. Diffusion barriers in MgB_2 wires are very important because allow to obtain homogeneous and clean superconducting material over long wire lengths e.g. above 1 km.
- 3. Diffusion barrier damage leads to a significant reduction in J_c.
- 4. The admixtures allows to significantly increase J_c in PIT MgB_2 wires in high magnetic fields.
- 5. The high *n value* allows the use of high transport current to power superconducting coils.
- 6. In the future, MgB_2 wires with nano-^{11}B may be very good for fusion reactors because radiation does not degrade their J_c and have the very short radiation decay time - 1 year.

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Thank you very much for your attention