Magnetic shielding up to 1 T: achievements of machinable MgB_2

M. Burdusel [1], M. A. Grigoroscuta [1,2], D. Batalu [2], G. Aldica [1], L. Gozzelino [3,4], R. Gerbaldo [3,4], G. Ghigo [3,4], F. Laviano [3,4], D. Torsello [3,4], A. Agostino [4,5], V. Bonino [4,6], M. Truccato [4,6], P. Badica [1]

[1] National Institute of Materials Physics, Măgurele, Romania
[2] University Politehnica of Bucharest, Romania
[3] Department of Applied Science and Technology, Politecnico di Torino, Italy
[4] I.N.F.N., Sezione di Torino, Italy
[5] Department of Chemistry, Interdepartmental Centre NIS and INSTM Centro di Riferimento University of Torino, Italy
[6] Department of Physics and Interdepartmental Centre NIS, University of Torino, Italy

National Institute of Materials Physics, Bucharest-Magurele, Romania

University POLITEHNICA of Bucharest Romania

EUCAS 2017

Among the superconducting bulk applications, in the past few years the fabrication of magnetic shields and permanent magnets has generated remarkable interest [1, 2]. In this framework, MgB_2 bulks are a promising solution due to their more homogeneous J_c distribution compared to (RE)BCO bulks. This is provided by the fabrication technique which allows manufacturing products as large and shaped as required by the specific applications. MgB_2 is a light weight material and this can provide key advantages for portable and space applications.

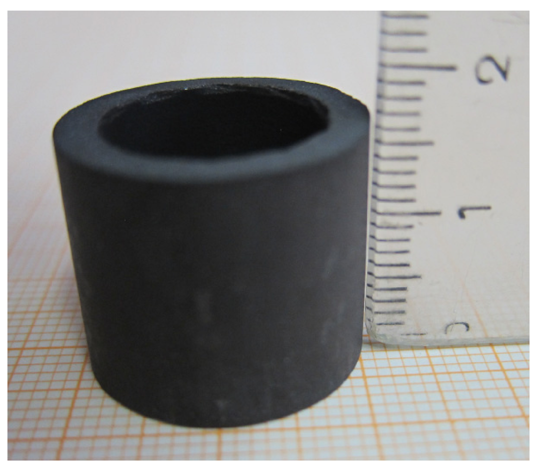
Here we report the results obtained for an MgB_2 tube produced via an innovative technique: a machinable MgB_2-hBN cylinder is produced by Spark Plasma Sintering and it is axially drilled [3]. The length of the tube is 17.5 mm, the outer and inner radius are 10 and 7 mm, respectively. The transition temperature is higher than 38.3 K. Critical current densities over 2×10^8 A/m² were measured at T = 30 K and $\mu_0 H_{appl}$ = 0.5 T.

The shielding properties of the tube were determined as a function of temperature and applied magnetic field both in axial and in transverse field configuration, using a cryogenic Hall probe array [4]. Although the aspect ratio of length/outer radius is only 1.75, which makes the magnetic flux penetration from the tube edge not negligible, shielding factor values higher than 175 and 55 were achieved in the center of the tube at T = 20 K, in the presence of external fields $\mu_0 H_{appl}$ = 0.1 and 1 T, respectively.

The fabrication technique

Commercial powders of MgB_2 and hexagonal BN were mixed. Spark plasma sintering (SPS) was applied on the powder mixture to produce a bulk cylinder with the average relative density of 91%, height of 18.7 mm and radius of 20 mm. SPS temperature was 1150° C for a dwell time of 8 min. The maximum pressure applied on the sample during sintering was 95 MPa.

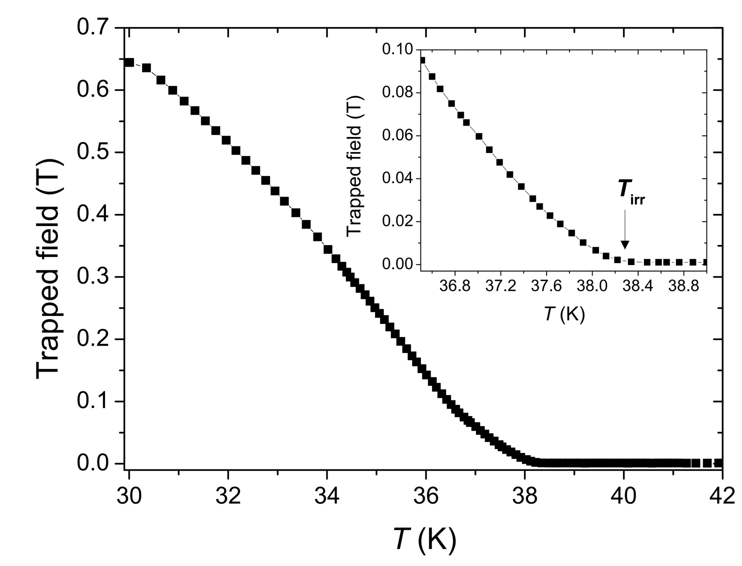
The as-prepared specimen is machinable [3]. An axial hole was drilled using drills with different radii. The inner radius of the final product of 7 mm was obtained with a lathe machine. The final height of the tube was 17.5 mm.



Outer radius: r_{out} = 10.0 mm
Inner radius: r_{in} = 7.0 mm
Length: h = 17.5 mm

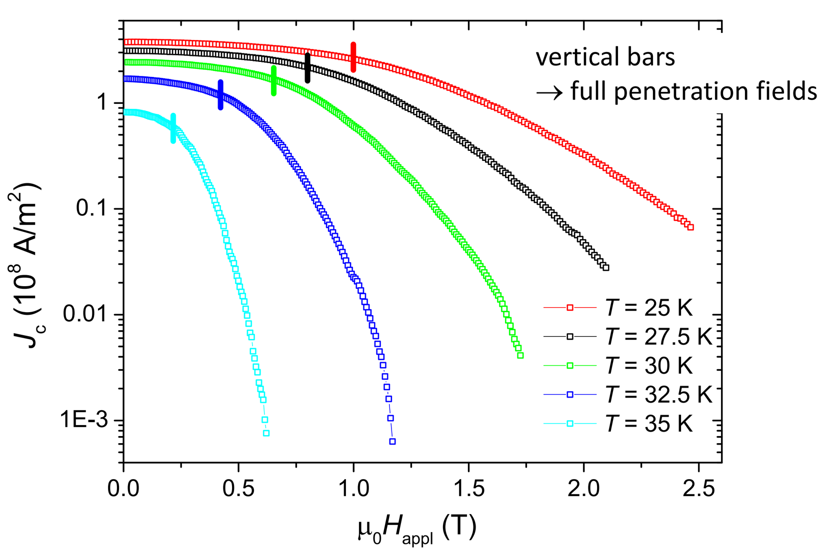
Aspect ratio = $\frac{h}{r_{out}}$ = 1.75

Irreversibility temperature and critical current density



Temperature behavior of the field trapped in the center of the tube after the application of the external field $\mu_0 H_{appl}$ = 1.2 T (|| to the tube's axis) at T = 30 K.

➢ **Irreversibility temperature, T_{irr} = 38.3 K**



Critical current densities evaluated from the magnetic induction values, measured by the Hall probes along the tube axis in the axial field configuration , as [5]:

$$J_c = \Delta B / [\mu_0 \, f(r_{out}, r_{in}, h, z)]$$

where ΔB is the difference between the induction field measured while increasing and decreasing the external field

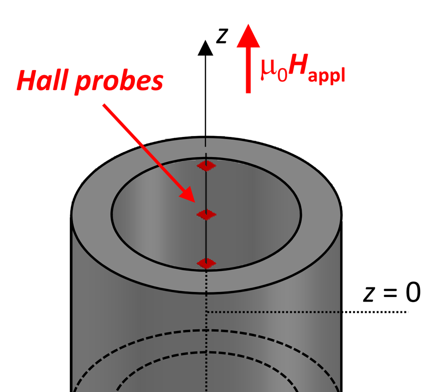
$$f = \left(\frac{h}{2} - z\right) \ln\left(\frac{r_{out} + \sqrt{r_{out}^2 + (z - h/2)^2}}{r_{in} + \sqrt{r_{in}^2 + (z - h/2)^2}}\right) + \left(\frac{h}{2} + z\right) \ln\left(\frac{r_{out} + \sqrt{r_{out}^2 + (z + h/2)^2}}{r_{in} + \sqrt{r_{in}^2 + (z + h/2)^2}}\right)$$

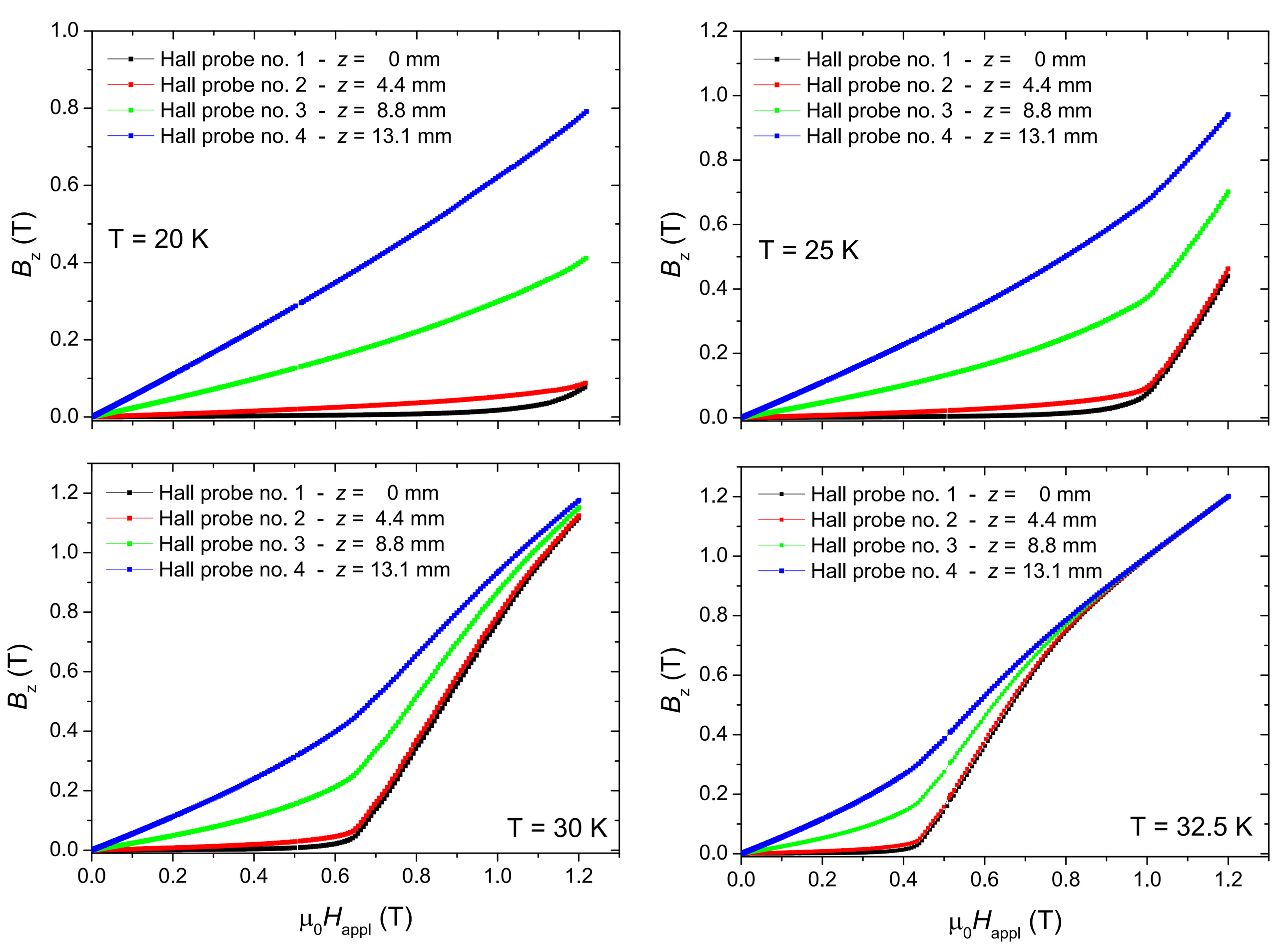
being z the axial coordinate (z = 0 ⇔ tube center)

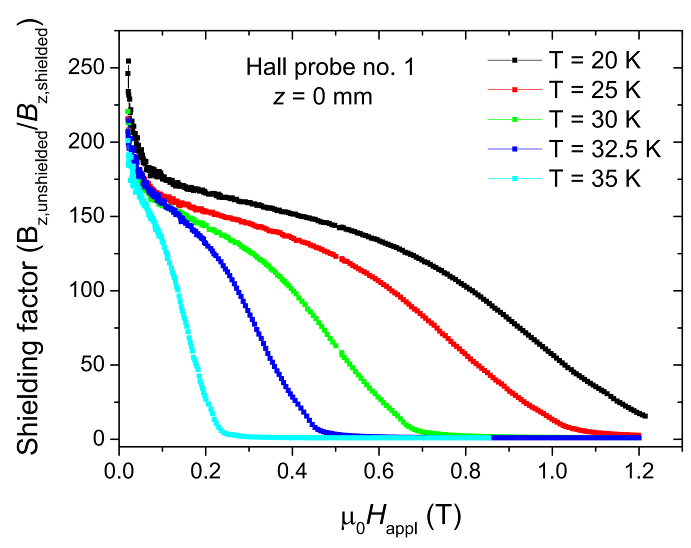
Since we did not take into account the J_c dependence on magnetic field, the real J_c values could be higher.

Shielding properties

Axial field configuration



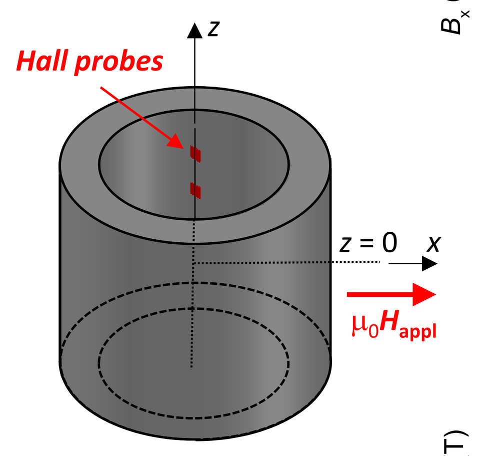


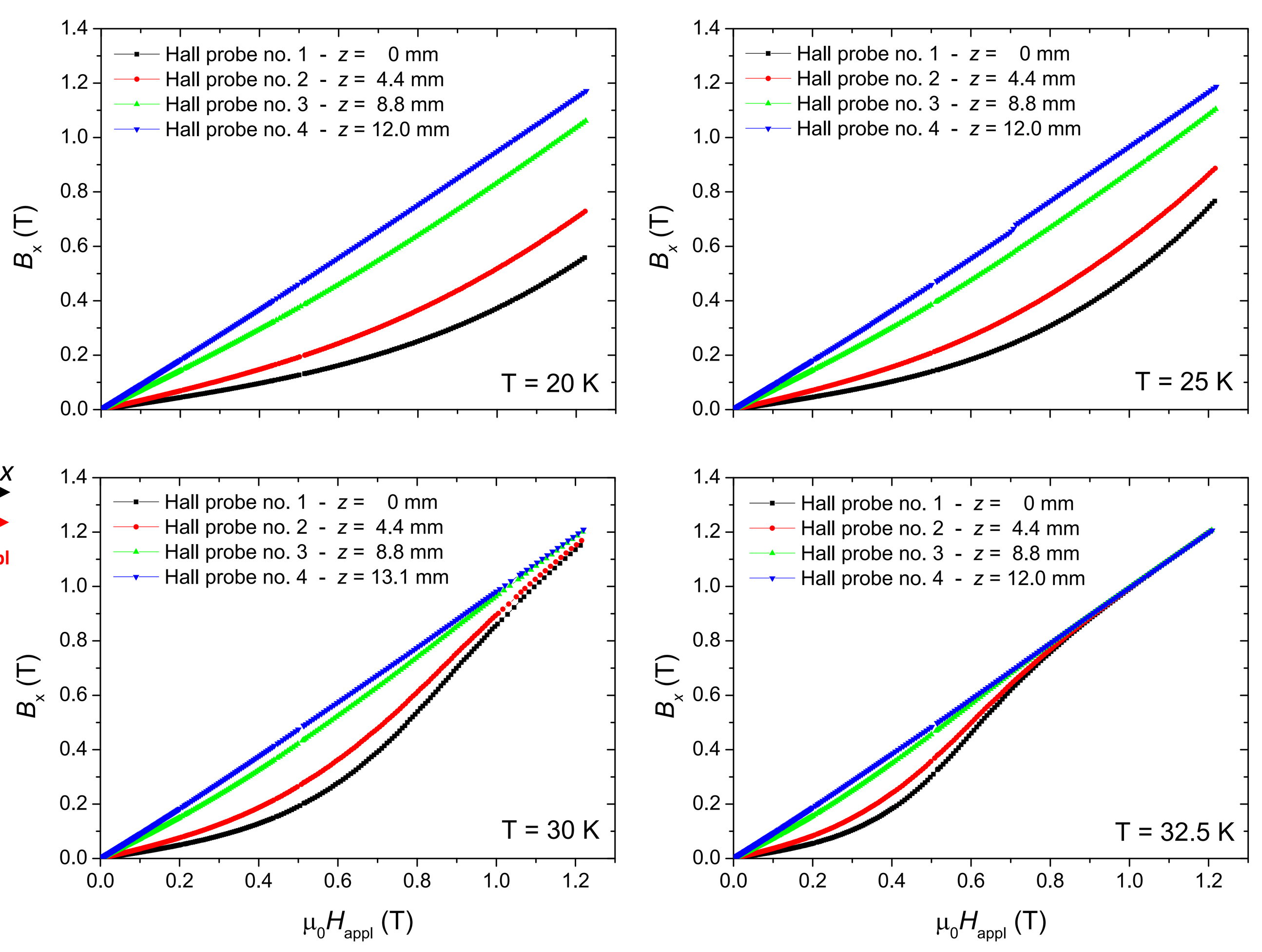


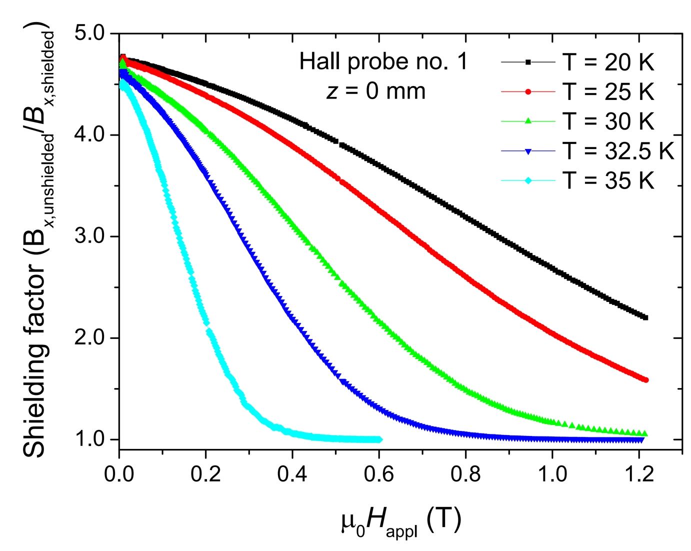
Shielding factor higher than (tube center):

- 175 (T = 20 K, $\mu_0 H_{appl}$ = 0.1 T)
- 55 (T = 20 K, $\mu_0 H_{appl}$ = 1.0 T)
- 155 (T = 30 K, $\mu_0 H_{appl}$ = 0.1 T)
- 60 (T = 30 K, $\mu_0 H_{appl}$ = 0.5 T)

Transverse field configuration







Shielding factor higher than (tube center):

- 4.6 (T = 20 K, $\mu_0 H_{appl}$ = 0.1 T)
- 2.6 (T = 20 K, $\mu_0 H_{appl}$ = 1.0 T)
- 4.3 (T = 30 K, $\mu_0 H_{appl}$ = 0.1 T)
- 2.6 (T = 30 K, $\mu_0 H_{appl}$ = 0.5 T)

Conclusion

❖ **An innovative technique for the fabrication of MgB_2 samples has been developed**
➔ **As-sintered machinable MgB_2 with shapes required by the specific applications**
➔ **T_{irr} = 38.3 K, J_c > 2 × 10^8 A/m² (T = 30 K, $\mu_0 H_{appl}$ = 0.5 T), both uniform on centimeter scale**

❖ **Tubular magnetic shields with an aspect ratio of length/outer radius lower than 2 has been characterized**
➔ **Shielding factor > 175 (axial field configuration, $\mu_0 H_{appl}$ = 0.1 T, T = 20 K, tube center)**

❖ **In future:**
➔ **Cylinders with a higher aspect ratio and improved pinning are in progress.**
➔ **Shielding test on superimposed ferromagnetic/superconductor tube [6, 7] are scheduled.**

References

[1] H. Kogan et al., *Supercond. Sci. Technol.* 28 (2015) 035011.
[2] D. Zhou et al., *Appl. Phys. Lett.* 110 (2017) 062601.
[3] G. Aldica et al., patent No RO130252-A2/13-11-2013.
[4] L. Gozzelino et al., *Supercond. Sci. Technol.* 25 (2012) 115013.
[5] E. Bartolomé et al., *Phys. Rev. B* 72 (2005) 024523.
[6] G. P. Lousberg et al., *IEEE Trans. Appl. Supercond.* 20 (2010) 33.
[7] L. Gozzelino et al., *Supercond. Sci. Technol.* 29 (2016) 034004.

Acknowledgements

Work was supported by:

➢ MEC-UEFISCDI, Romania through projects: POC 37_697 no. 28/01.09.2016 REBMAT, 214/2014 BENZISUPRA, Core Program PN 16-480 P2, P3; UPB-Excelenta 2016 51/2016 (code 300) NEWADD, Romania
➢ INFN –CSN5, experiment SR2S-RD, Italy