

Additive Manufacturing of Hard Magnetic Materials $\text{Nd}_2\text{Fe}_{14}\text{B}$ and $\text{Sm}(\text{Fe},\text{Ti},\text{V})_{12}$

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OUTLINE

- ▶ Additive Manufacturing
- ▶ Motivation
- ▶ 3D-Printed Metal Magnets
- ▶ Textured 3D-Printed Metal Magnets
- ▶ Future Prospects



Benefits and Limitations

- Any shape of parts, ideal for small-series production
- Minimal waste
- Reduced production cycle time
- Local tuning of material properties
- One-step fabrication of multimaterial devices

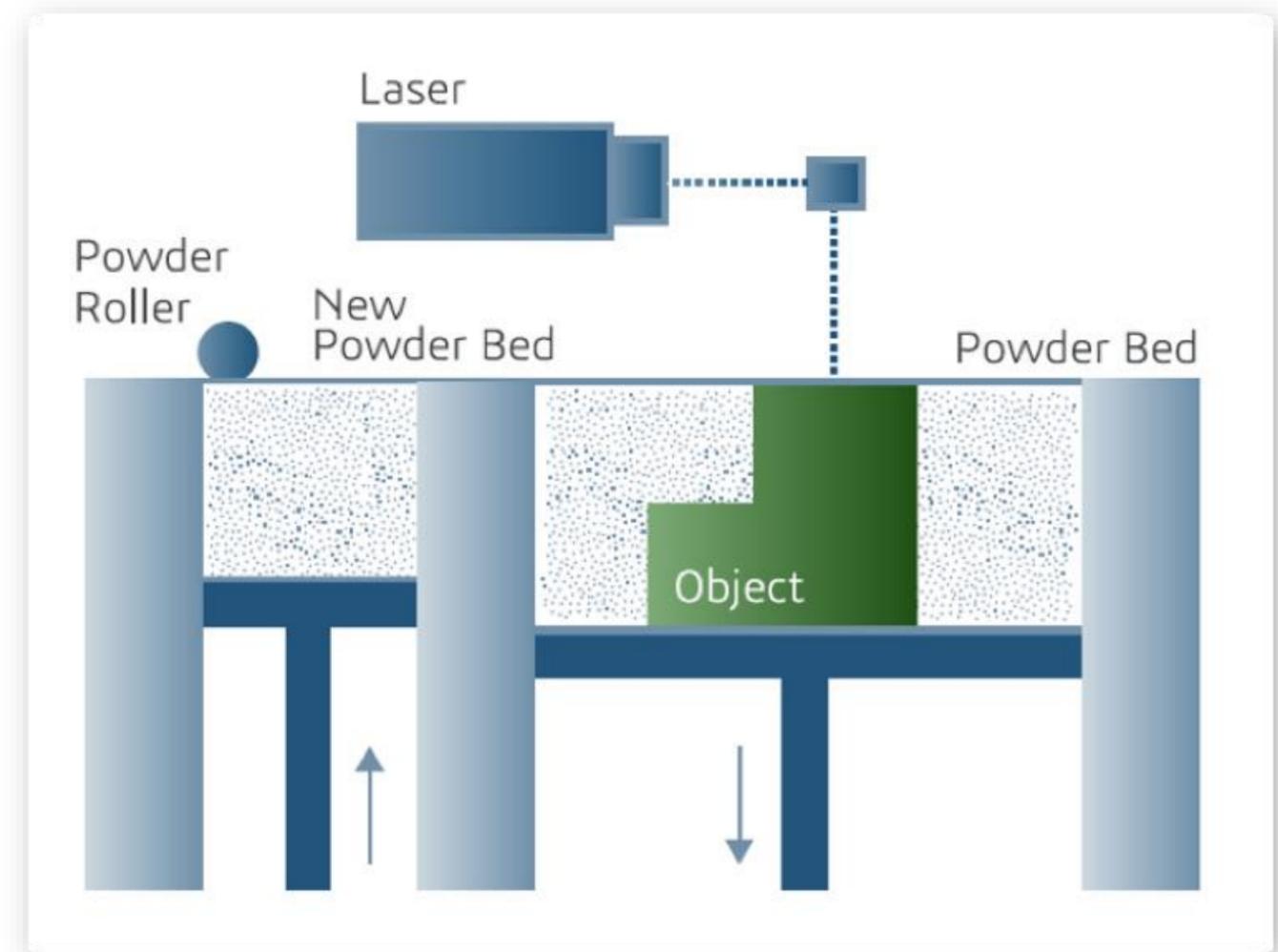
- Product performance constraints
- Limited availability of source materials
- Post-processing often required
- High production cost
- Closed software and hardware environments



ADDITIVE MANUFACTURING TYPES

- Material Extrusion
- Material Jetting
- Sheet Lamination
- Vat Photopolymerization
- Binder Jetting

- **Powder Bed Fusion**
- **Direct Energy Deposition**



Currently, **magnetic systems are assembled** from individual components, including magnets, conductors, and structural parts.



THE AIM of this work is **to realize additive manufacturing by PBF of permanent magnets and magnetic systems** with spatially tunable properties, and performance comparable with commercial magnets.

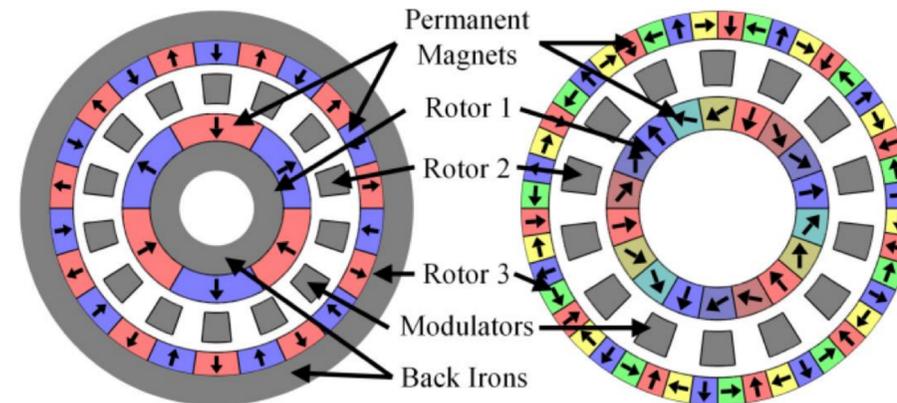
The ultimate aim is to achieve controllable texture in 3D-printing.



Simple shapes of industrial magnets



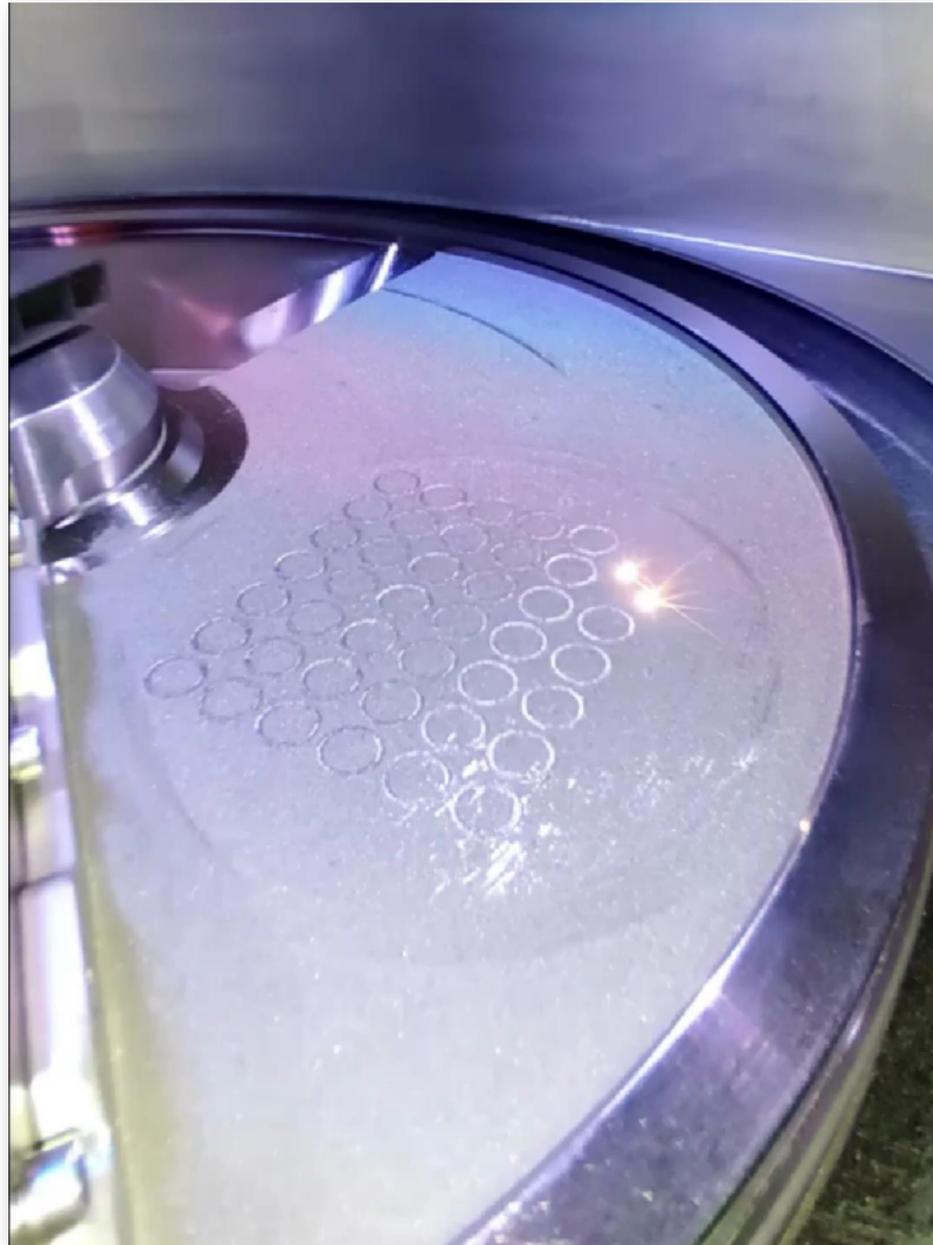
There is a need for magnetic systems with complicated magnetic flux distribution



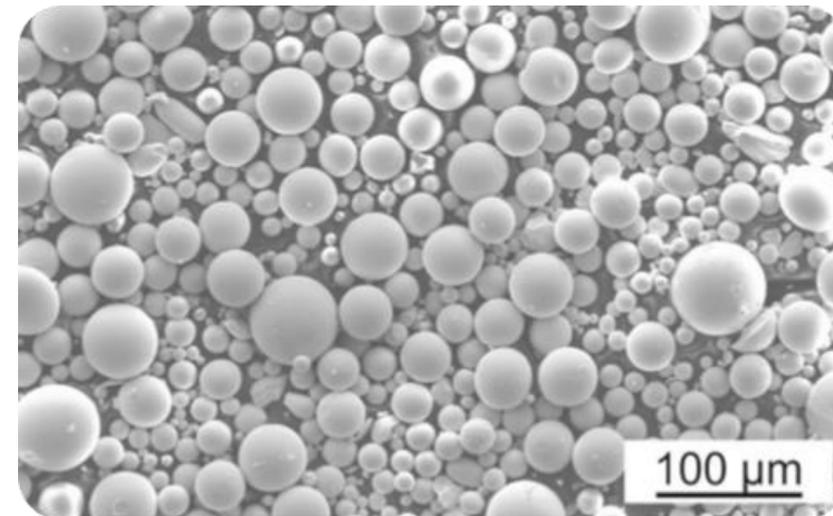
https://www.youtube.com/watchapp=desktop&v=09h3xa6nQco&utm_medium=organic&utm_source=yandexsmartcamera

Gardner M. C., Johnson M., Toliyat H. A. Performance impacts of practical fabrication tradeoffs for a radial flux coaxial magnetic gear with Halbach arrays and air cores //2019 IEEE Energy Conversion Congress and Exposition (ECCE). – IEEE, 2019. – C. 3129-3136

Starting material



MQP-S [Nd_{17.2}Pr_{1.9}Fe_{69.8}Co_{2.8}Cu_{0.1}Ti_{2.1}Zr_{4.3}Co_{0.1}B_{1.7}]



F. Bittner et. al. / Progress in Additive Manufacturing (2020) 5:3-9

Top view

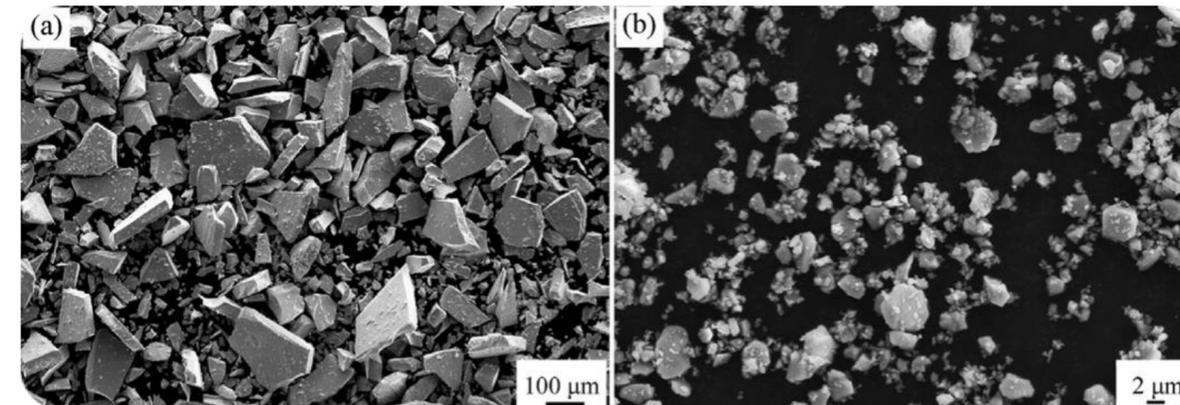


Side view

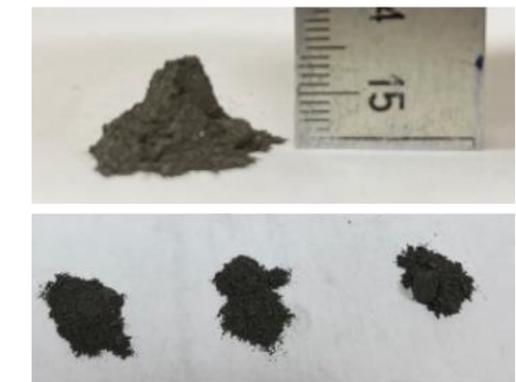


- RE lean composition
- Isotropic polycrystals

**POOR
MAGNETIC
PROPERTIES**



F. Yang et al. / Journal of Alloys and Compounds 779 (2019) 900-907

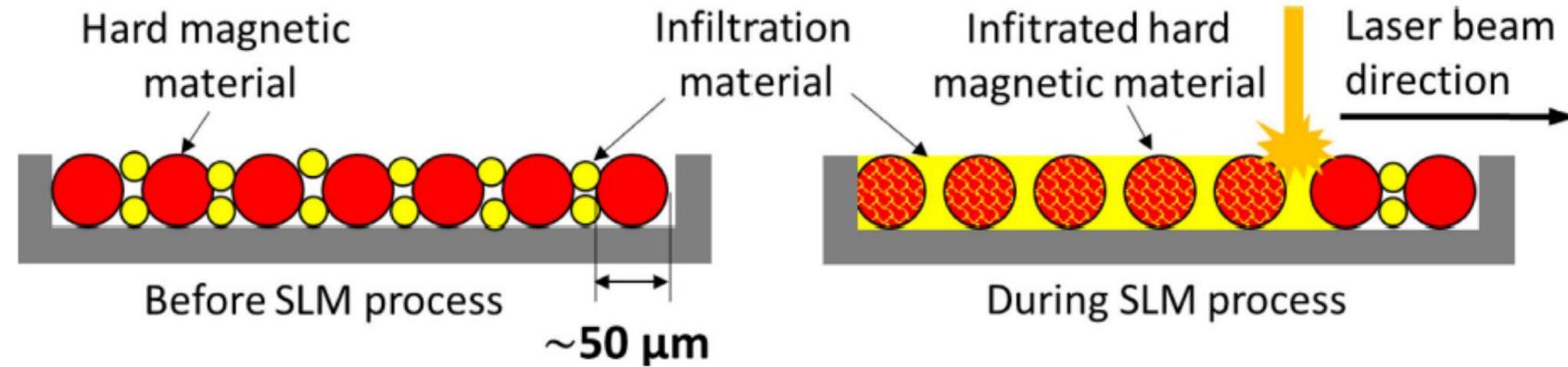


Typical powder for conventional magnets



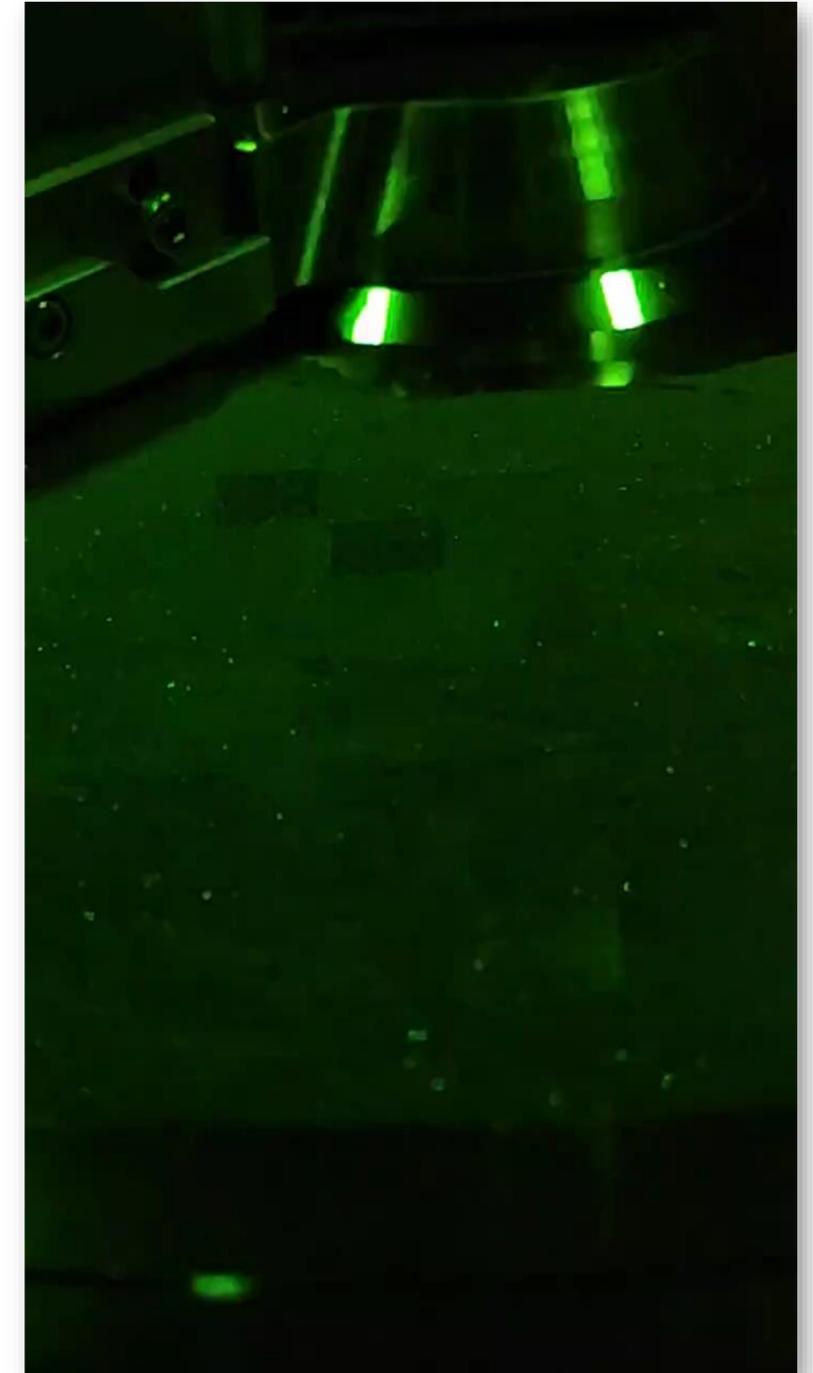
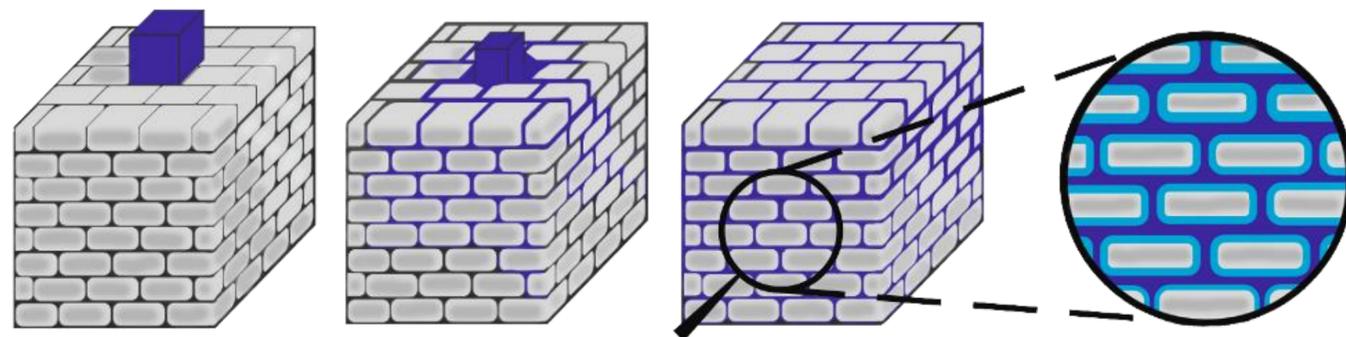
NOT suitable for PBF of permanent magnets

First try of 3D-printed magnets with *in situ* infiltration



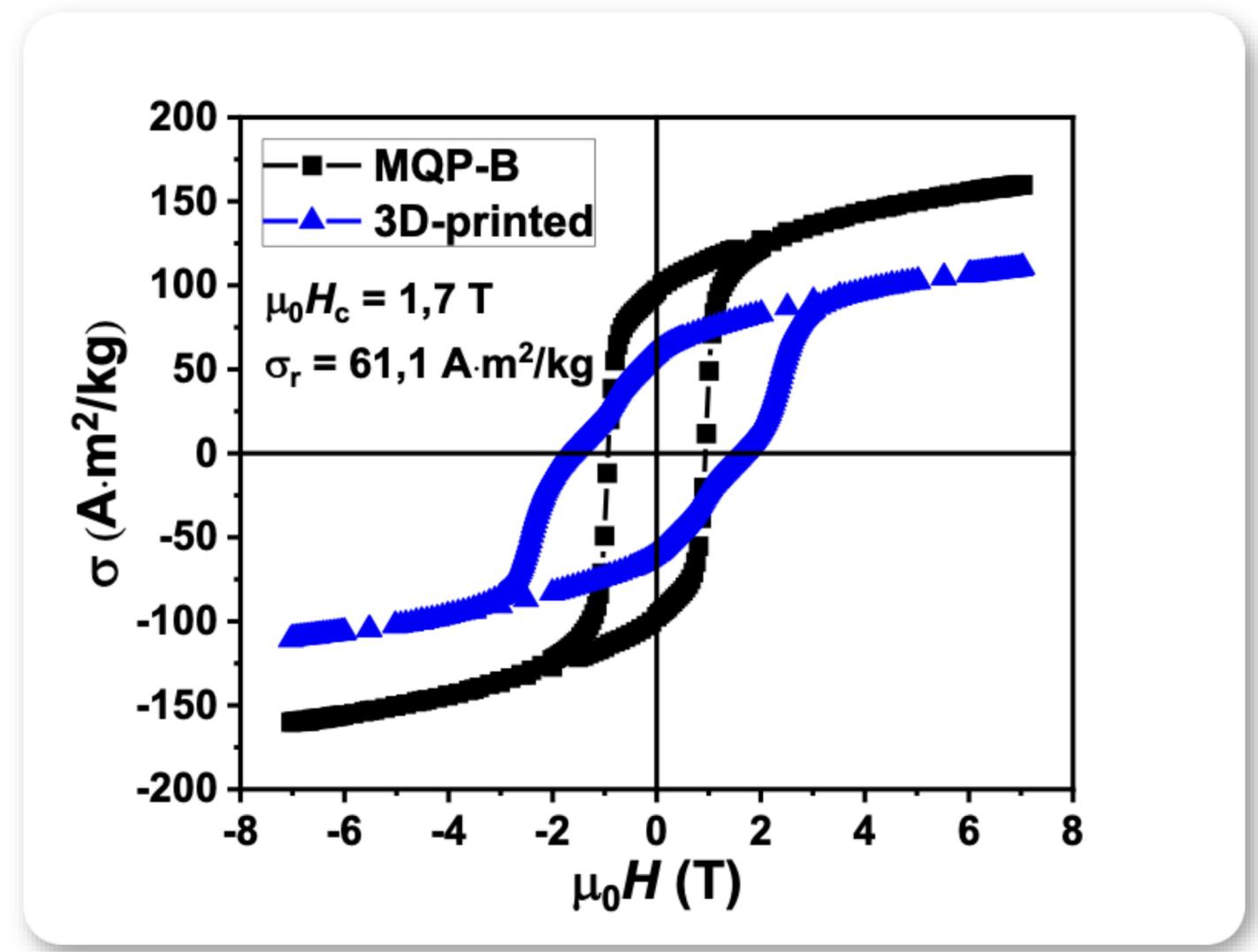
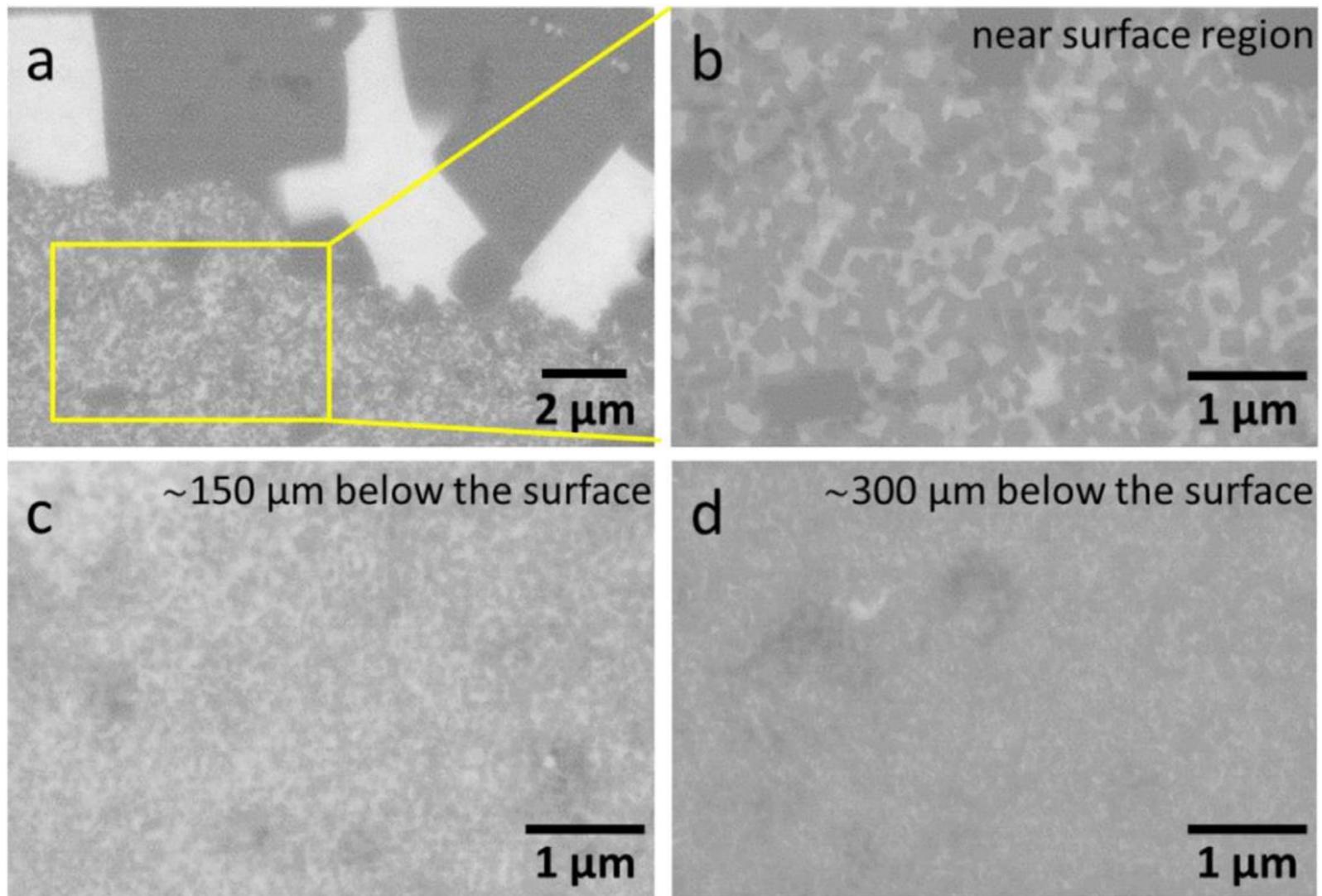
- Low melting point binder
- Overheating protection
- In situ infiltration

The feature of the method is in situ infiltration

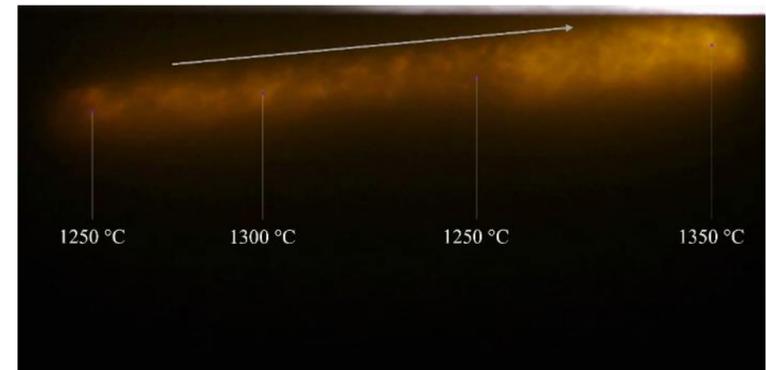
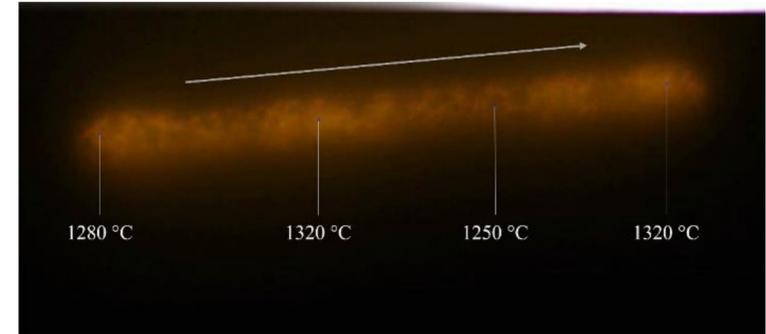
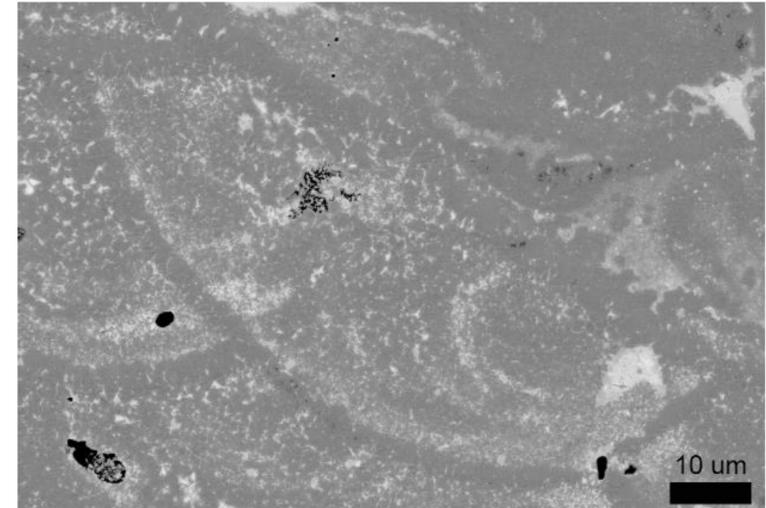
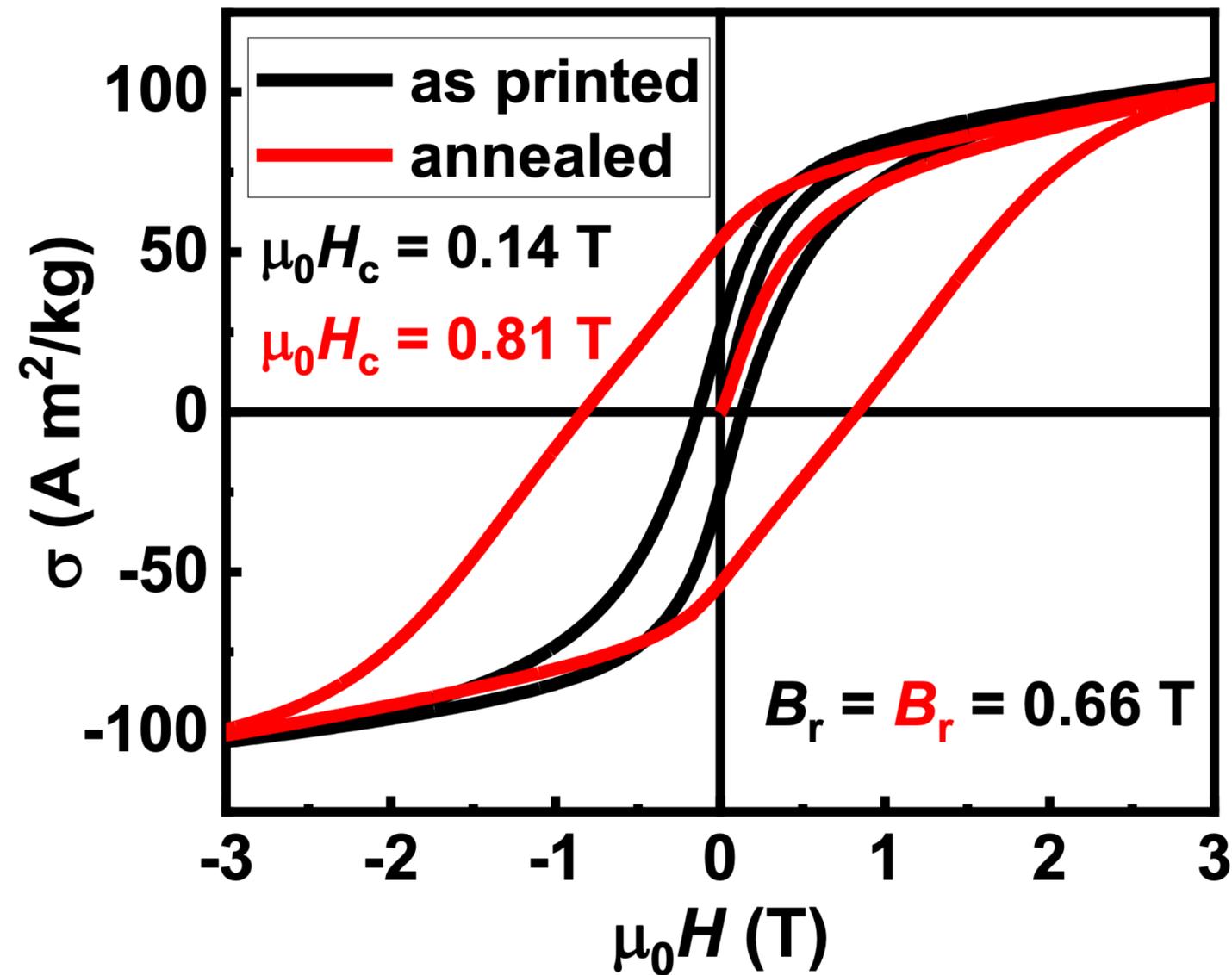


Single layer magnet

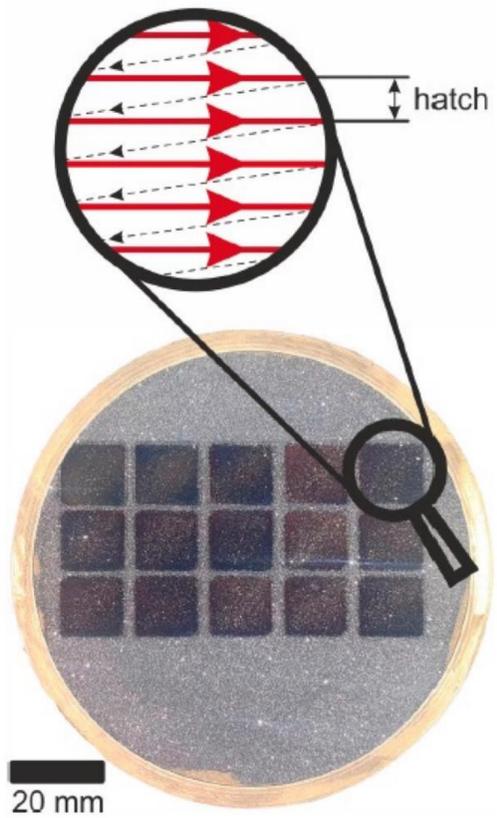
MQP-B + (Nd,Pr)-Cu-Co



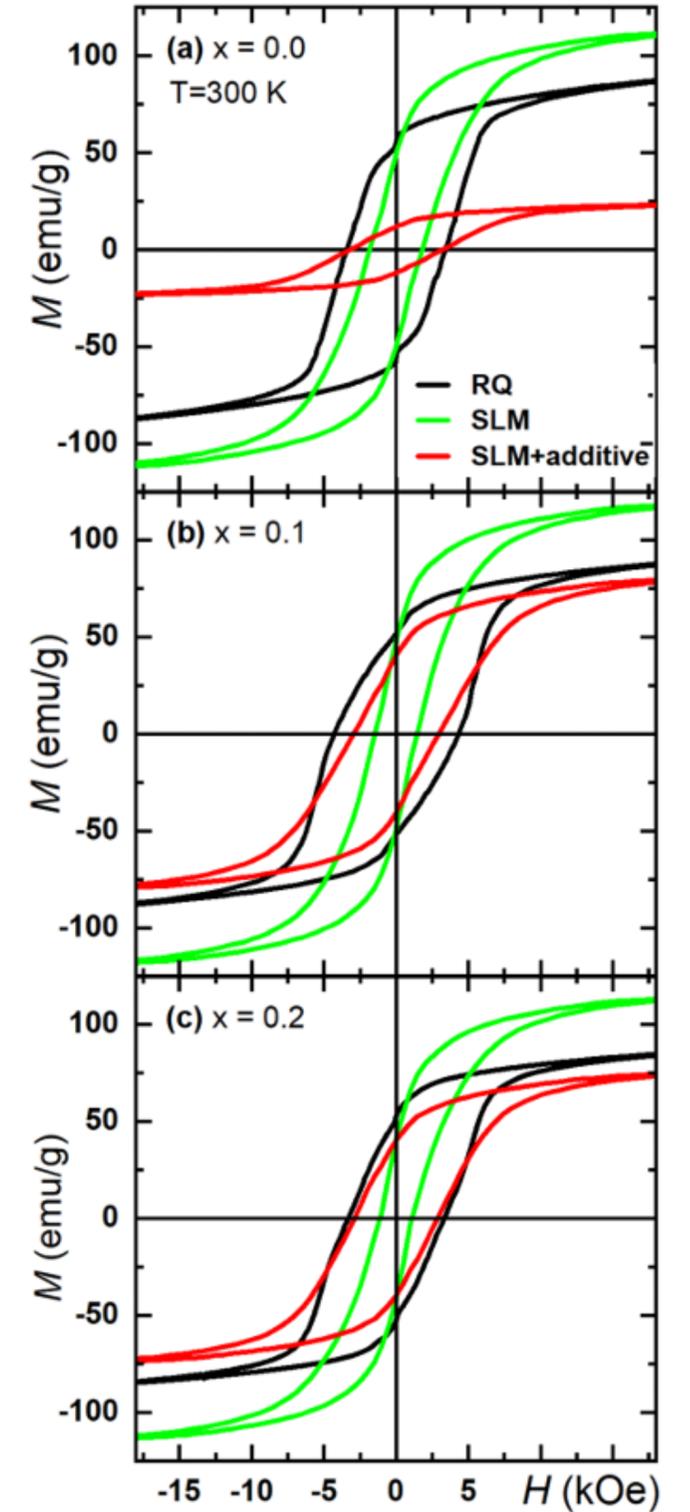
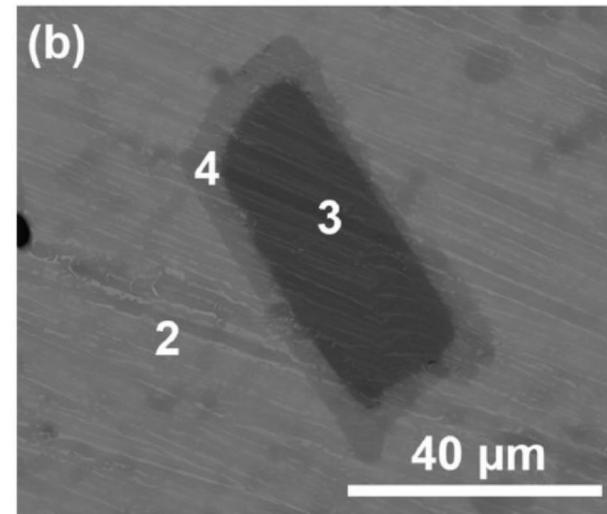
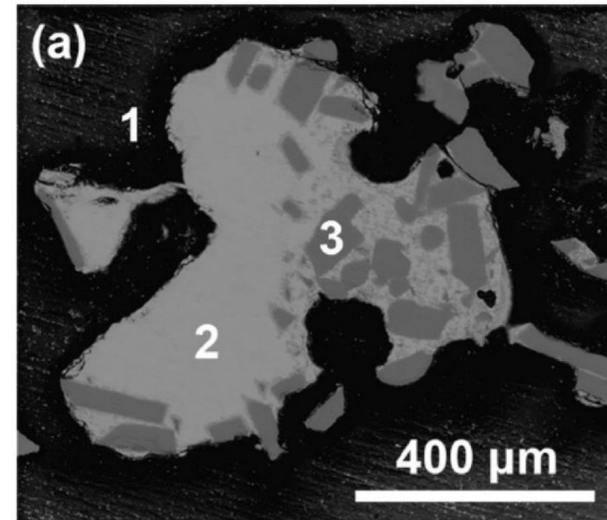
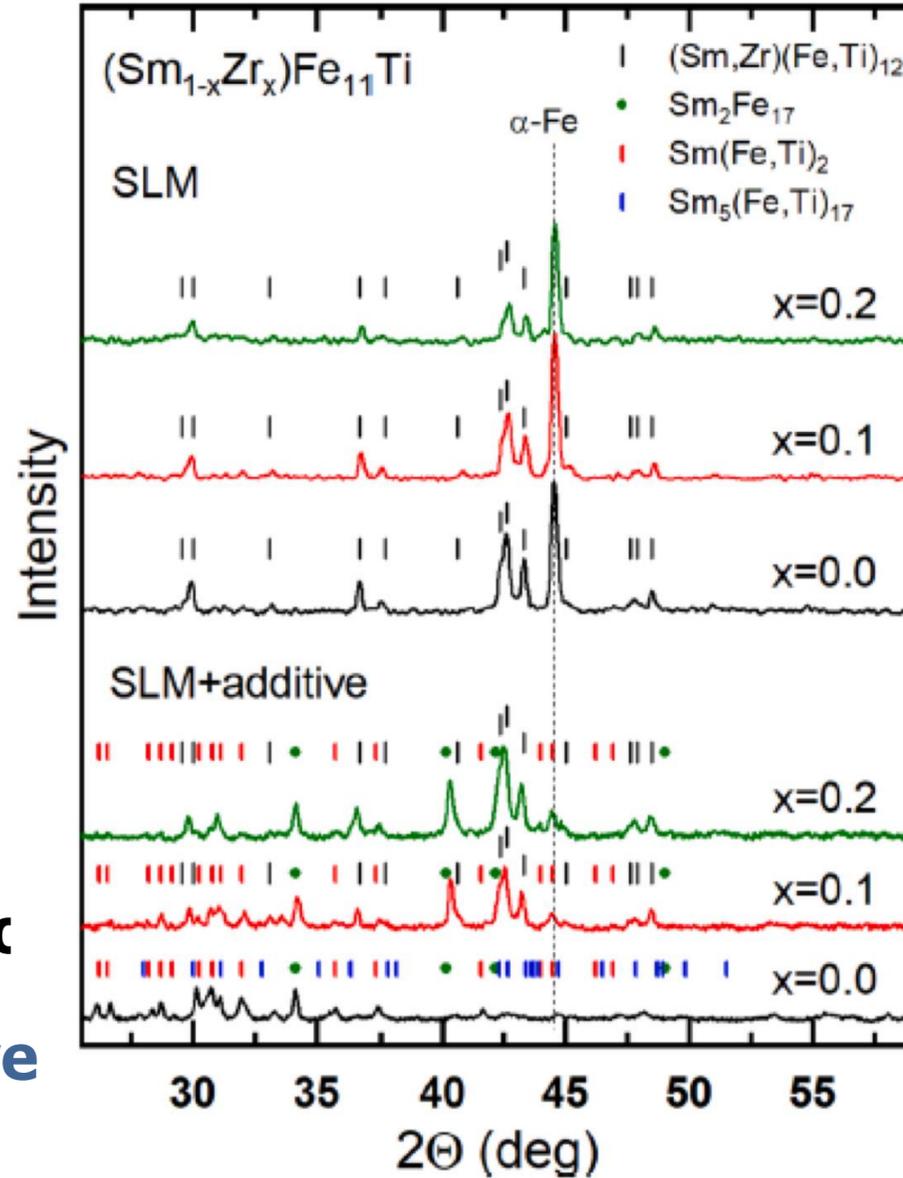
Multi layer magnets [bulk]



Additive manufacturing of (Sm,Zr)Fe₁₁Ti magnets



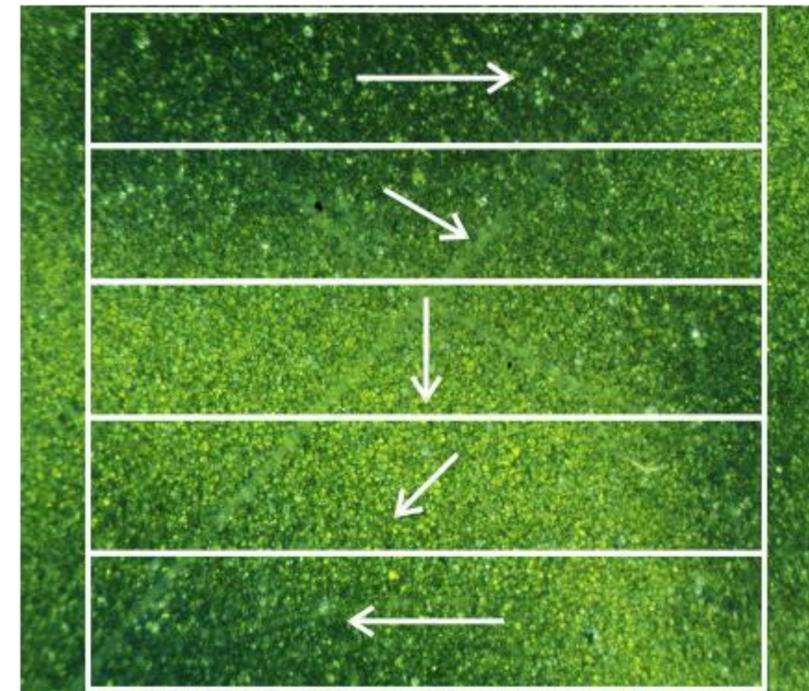
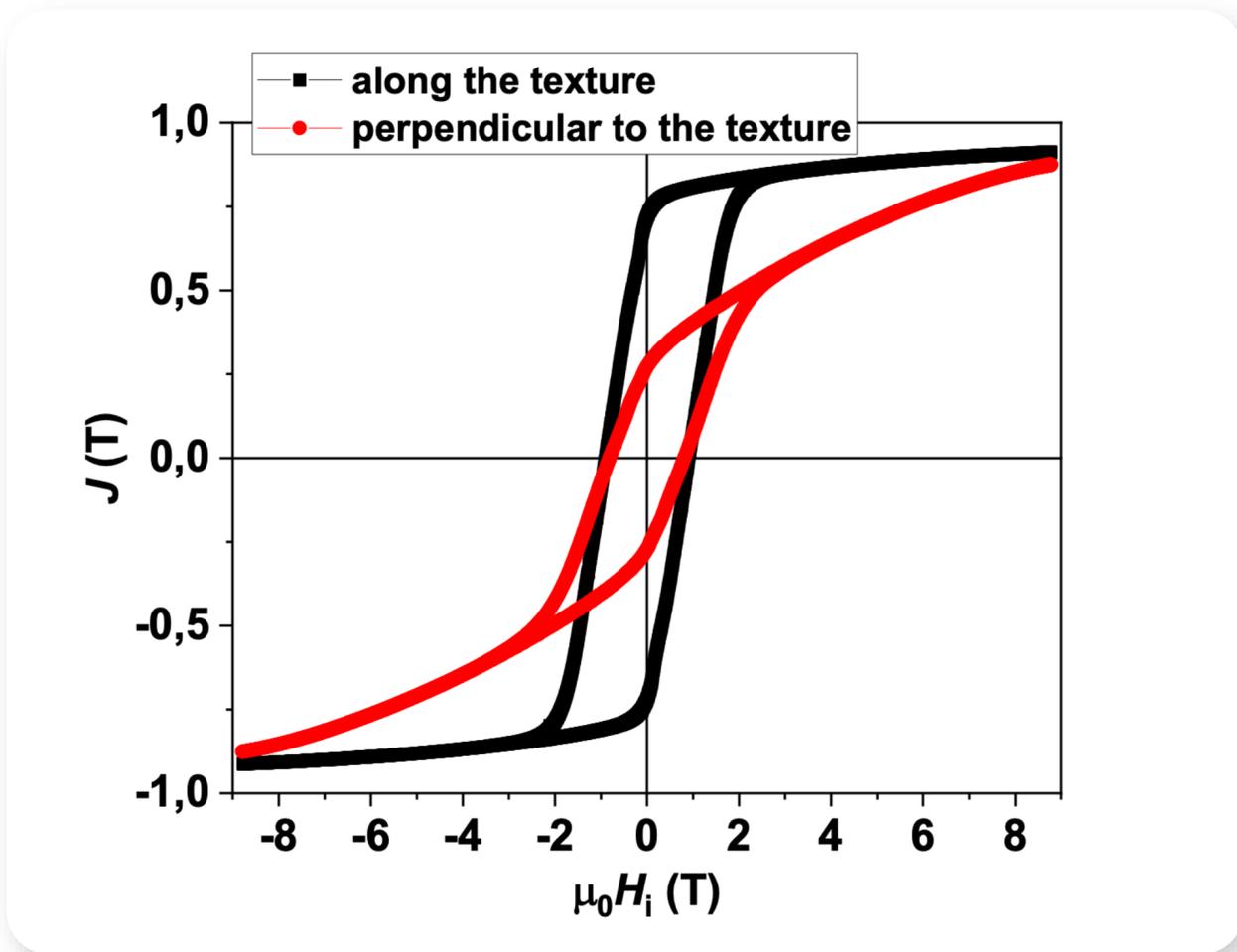
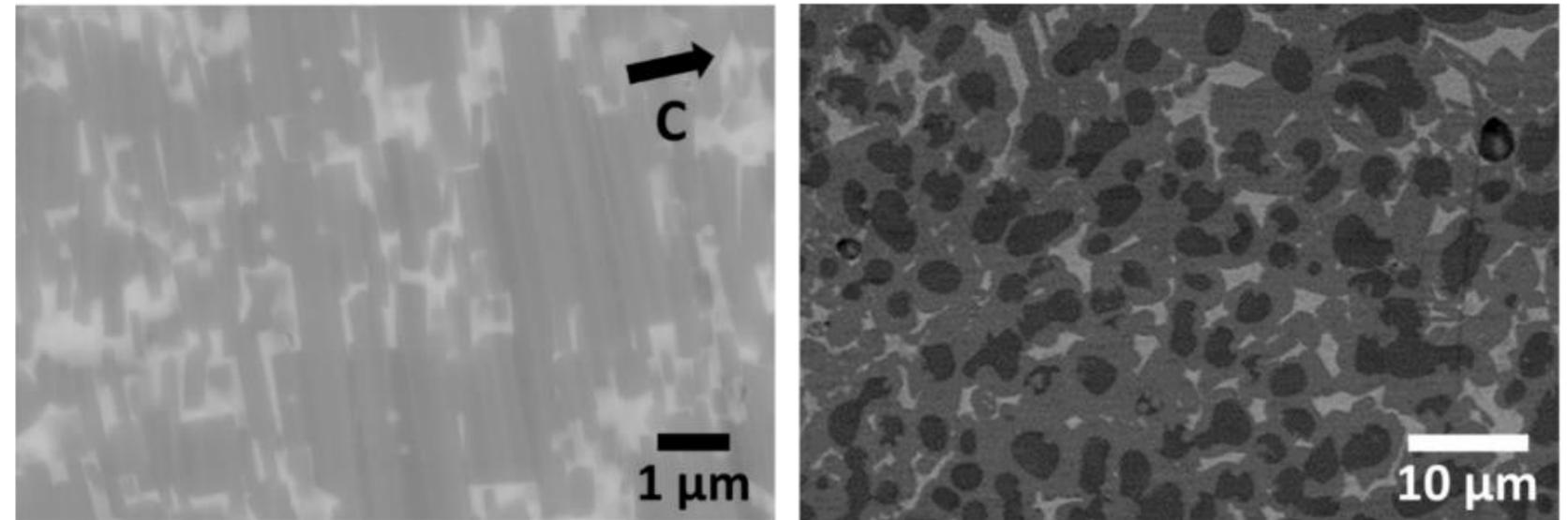
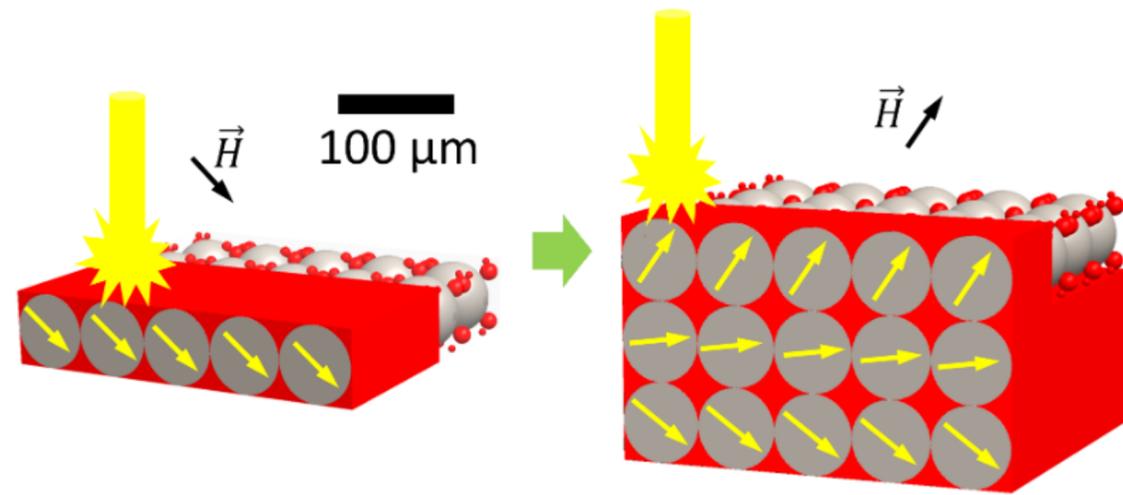
(Sm_{1-x}Zr_x)Fe₁₁Ti – main allc
Sm₇₅(Cu,Co)₂₅ – additive



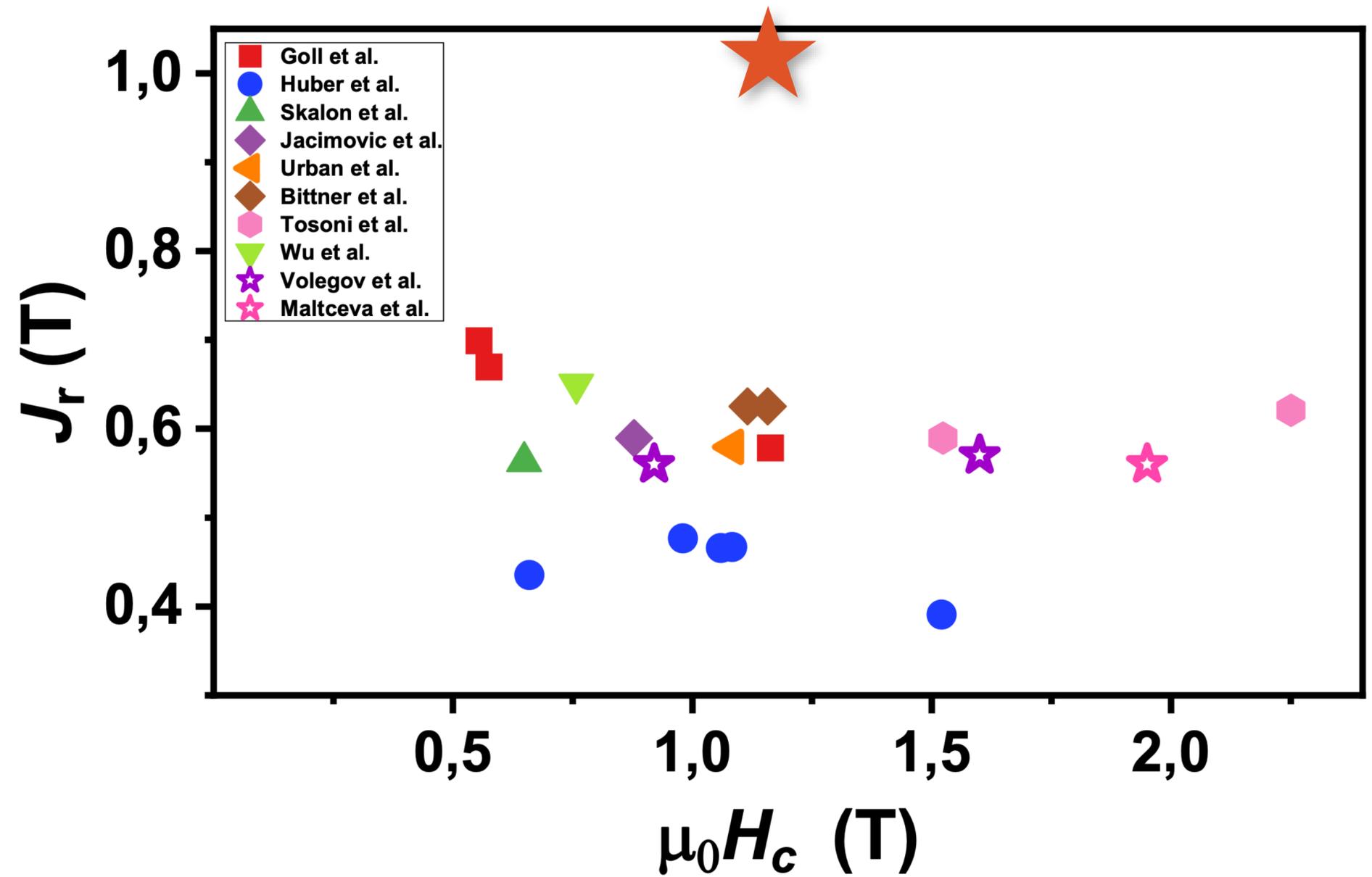
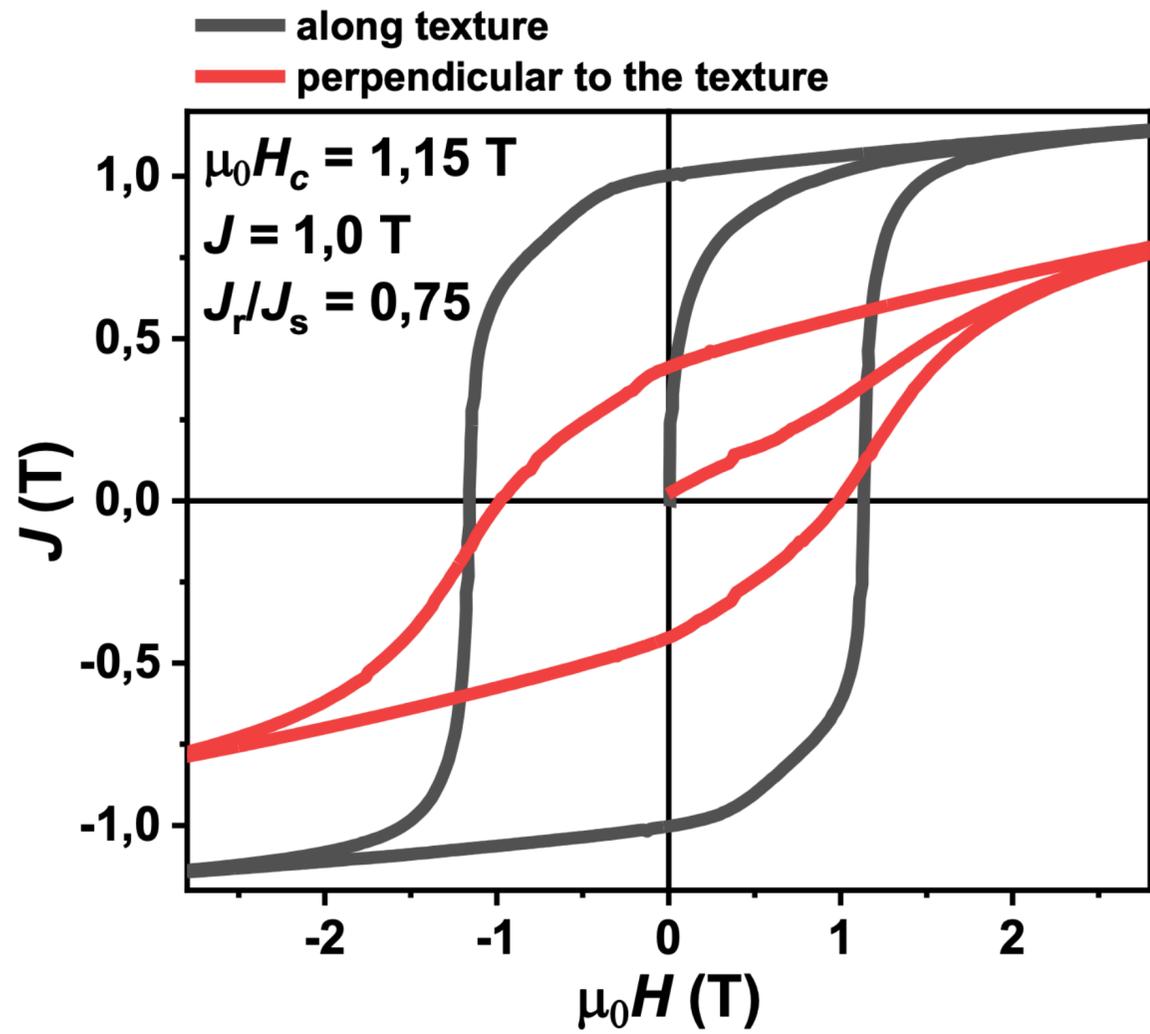
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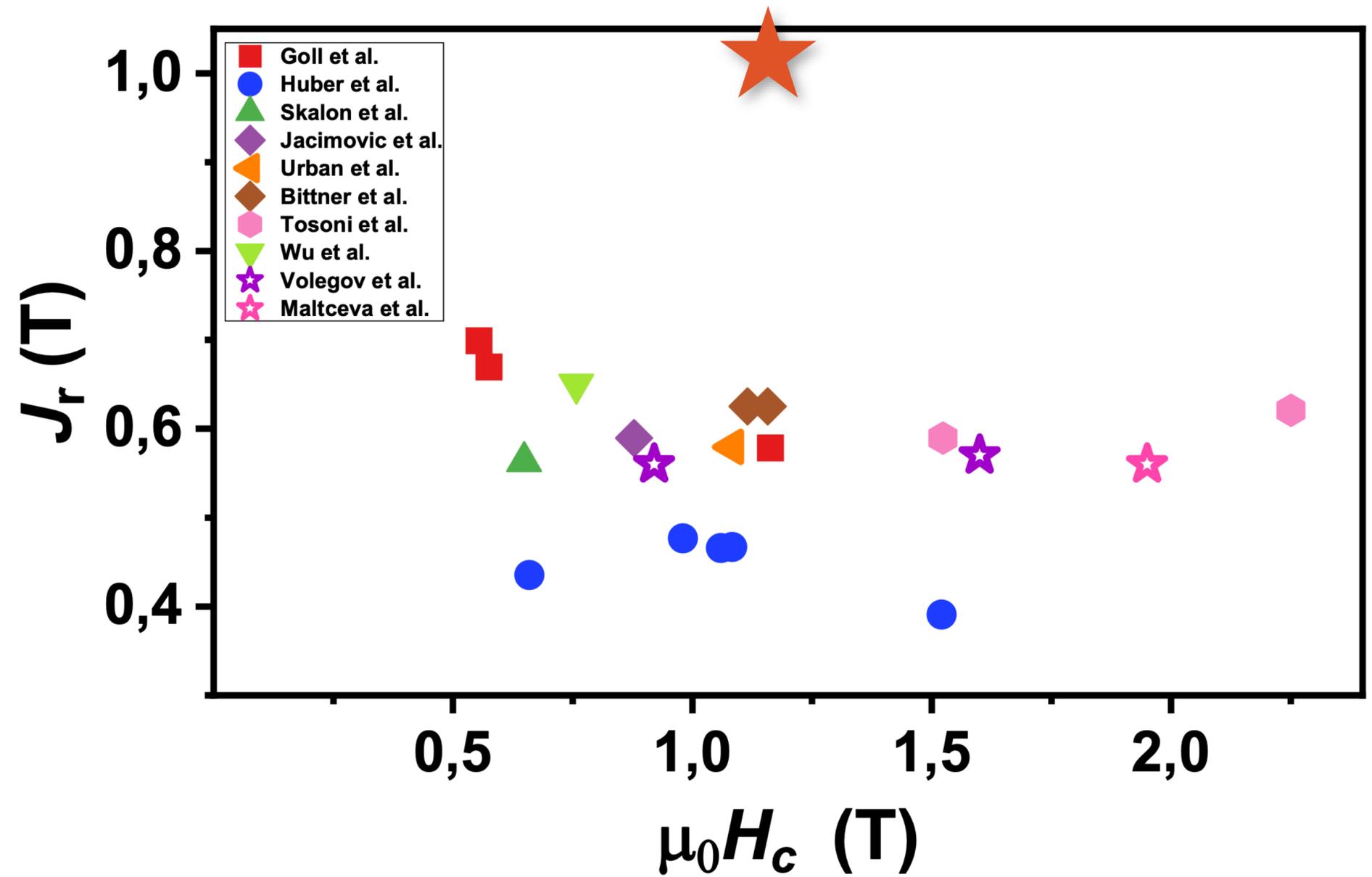
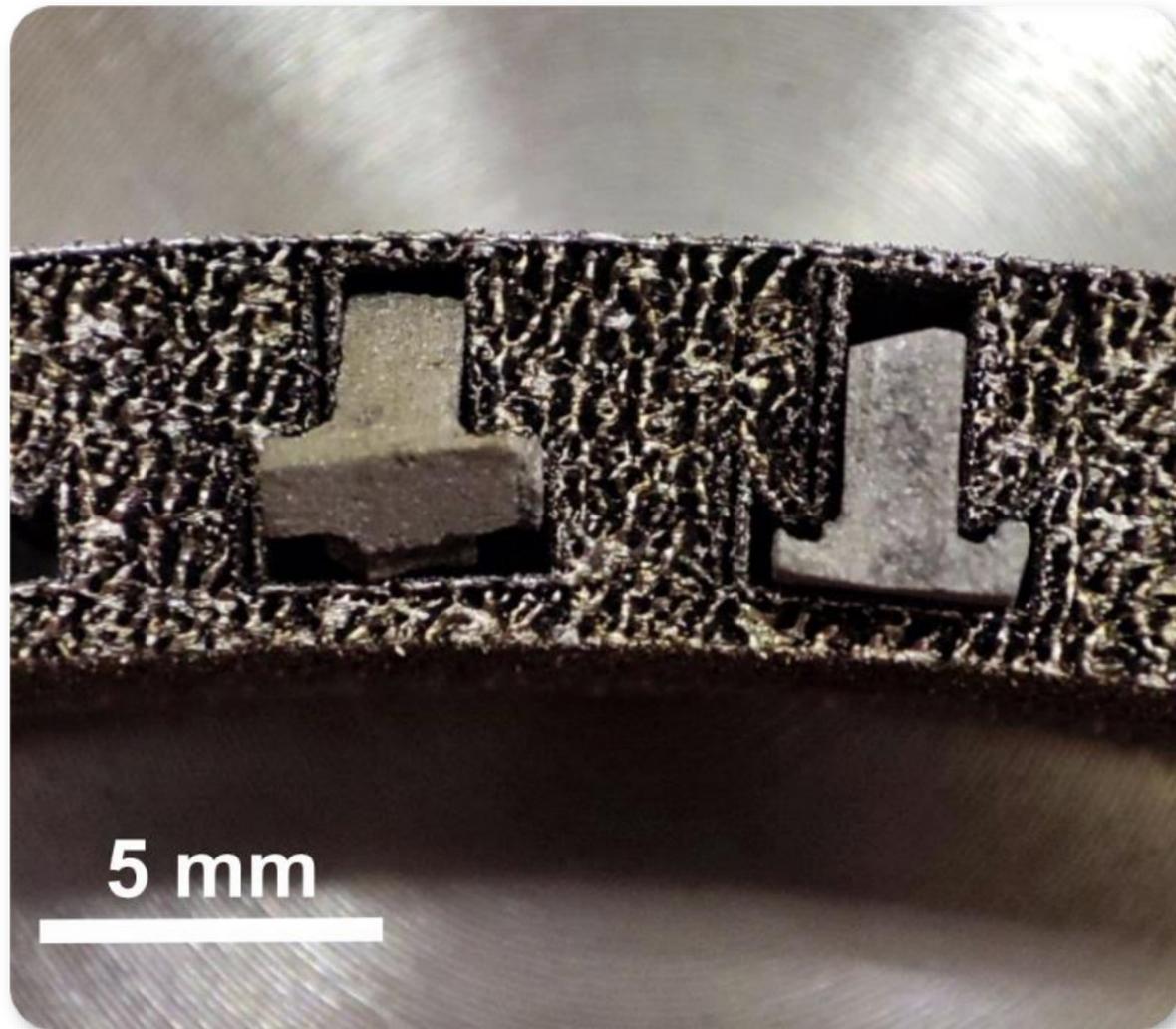




Benchmark



Benchmark



Closing Thoughts

- We have demonstrated anisotropic Nd-Fe-B magnet obtained using powder bed fusion with **coercivity 1.15 T**, **remanence 1.0 T** and **maximum energy product 175 kJ/m³**.
- Additive manufacturing of permanent magnets and magnetic systems holds attractive prospects, but to unlock them we need some time and creative solutions

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Sergey
Andreev



Nadezhda
Selezneva



Dmitriy
Neznakhin



Andrey
Urzhumtsev



Oksana
Golovnia



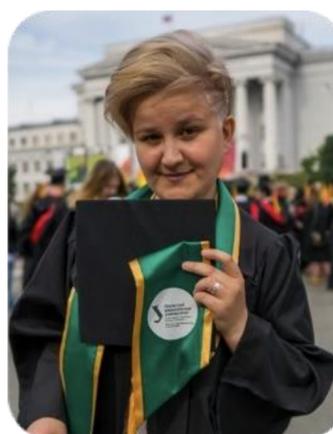
Elena
Stepanova



Ilya
Okulov



Andrey
Protasov



Viktoria
Maltseva



Arkadiy
Shalaginov



Ilya
Ivanov



Alexandra
Golubyatnikova



Natalia
Nosova

Thank you for your attention

ご清聴ありがとうございました。