Oral | Material, processing, and characterization

Wed. Jul 30, 2025 1:30 PM - 2:35 PM JST | Wed. Jul 30, 2025 4:30 AM - 5:35 AM UTC Convention Hall(300, 3F)

[O11] Emerging Magnets

Session Chair: Dr. Konstantin Skokov (Technical University of Darmstadt)

Invited

1:30 PM - 1:50 PM JST | 4:30 AM - 4:50 AM UTC

[O11-1]

Origin of high coercivity in post-sinter annealed Cu-doped $Sm(Fe,Ti,V)_{12}$-based sintered magnets

*JIASHENG ZHANG[1], Xin Tang[1], Tadakatsu OHKUBO[1], Kazuhiro Hono[1], SEPEHRI-AMIN Hossein[1] (1. National Institute for Materials Science (Japan))

1:50 PM - 2:05 PM JST | 4:50 AM - 5:05 AM UTC

[O11-2]

The effect Ag on phase transformation and magnetic properties in SmFe12-based composition

Maria Takeuchi[1], Aaron Dextre Zamalloa[1], Esmaeil Adabifiroozjaei[2], Leopoldo Molina-Luna[2], Oliver Gutfleisch[1], *Pelin Tozman[1] (1. Functional Materials, Institute of Materials Science, Technische Universität Darmstadt, 64287 Darmstadt (Germany), 2. Advanced Electron Microscopy Division, Institute of Material Science, Technical University of Darmstadt, 64287 Darmstadt (Germany))

2:05 PM - 2:20 PM JST | 5:05 AM - 5:20 AM UTC

[O11-3]

Additive Manufacturing of Hard Magnetic Materials $Nd_2Fe_{14}B$ and $Sm(Fe,Ti,V)_{12}$

*Alexey S. Volegov[1,2], Sergey V. Andreev[1], Oksana A. Golovnia[1], Aleksandra A. Golubyatnikova[1], Ilia A. Ivanov[1], Viktoria E. Maltseva[1], Dmitriy S. Neznakhin[1], Andrey V. Protasov[1,2], Nadezhda V. Selezneva[1], Elena A. Stepanova[1], Arkadiy N. Shalaginov[1] (1. UrFU (Russia), 2. IMP UB RAS (Russia))

2:20 PM - 2:35 PM JST | 5:20 AM - 5:35 AM UTC

[O11-4]

In-Depth investigation of the sub-micronic equiaxed grain microstructure of a NdFeB permanent magnet fabricated by Laser Powder Bed Fusion

*Aymeric Wolz[1], Jean-Paul Garandet[1,2], Camille Flament[1], Olivier Tosoni[1] (1. CEA (French Alternative Energies and Atomic Energy Commission) (France), 2. UGA (Grenoble Alpes University) (France))

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[O11-1] Origin of high coercivity in post-sinter annealed Cu-doped $Sm(Fe,Ti,V)_{12}$-based sintered magnets

*JIASHENG ZHANG[1], Xin Tang[1], Tadakatsu OHKUBO[1], Kazuhiro Hono[1], SEPEHRI-AMIN Hossein[1] (1. National Institute for Materials Science (Japan))
Keywords：1:12 sintered magnets、Post-sinter annealing、Intergranular phase、Coercivity

Research on $SmFe_{12}$-based (1:12) compounds has been revived due to their excellent intrinsic magnetic properties [1]. However, how to transfer the intrinsic magnetic properties to the high extrinsic performance in bulk 1:12 magnet is still a major problem. Recent studies have been demonstrated coercivities of 0.8 – 1.0 T in textured 1:12 sintered magnets [2, 3]. Note that the reported coercivity is still less than 10% of the anisotropy field of the 1:12 phase. By introducing Cu, a record high coercivity of 1.4 T was obtained due to the formation of Cu-rich intergranular phases between 1:12 grains [4]. Therefore, microstructure engineering is essential to further increase the coercivity. Post-sinter annealing (PSA) is effective in forming the continuous intergranular phase in Nd-Fe-B sintered magnets [5]. The question is whether PSA can have a similar influence in $SmFe_{12}$-based sintered magnets to further increase the coercivity.

In this work, $Sm_8Fe_{77}Ti_5V_8Al_2$ at. % (named Cu-free) and $Sm_8Fe_{76.5}Ti_5V_8Al_2Cu_{0.5}$ at. % (named Cu-doped) sintered magnets were prepared by conventional powder processing method. The magnets were prepared by sintering at 1100 °C for 1.5 h, and followed by PSA at 500 - 1100 °C for 1.5 h. The coercivity of the Cu-doped magnet was significantly enhanced from 0.9 T to 1.48 T by PSA at 1100 °C for 1.5 h, compared to 0.93 T to 1.05 T in the referenced Cu-free magnet (Fig. 1a). Detailed microstructure characterizations were conducted to understand the origin of the coercivity increase. The existence of ferromagnetic $SmFe_2$ in post-sinter annealed Cu-free sample was observed by XRD, TEM, and Lorentz microscopy while it could be fully eliminated in the optimally annealed Cu-doped sample. Moreover, thick and continuous Sm-rich intergranular phase with an excellent interconnection was observed in the optimally annealed Cu-doped magnet (Fig. 1b). Formation of thick Sm-rich intergranular phases can reduce the exchange-coupling between 1:12 grains resulting in a coercivity enhancement. This work indicates that the addition of Cu is beneficial to realize a large coercivity in optimally annealed 1:12 sintered magnets by suppressing the $SmFe_2$ phase and forming the Sm-rich intergranular phase.

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[3] J. Zhang, et al. Acta Mater., 217 (2021) 117161.
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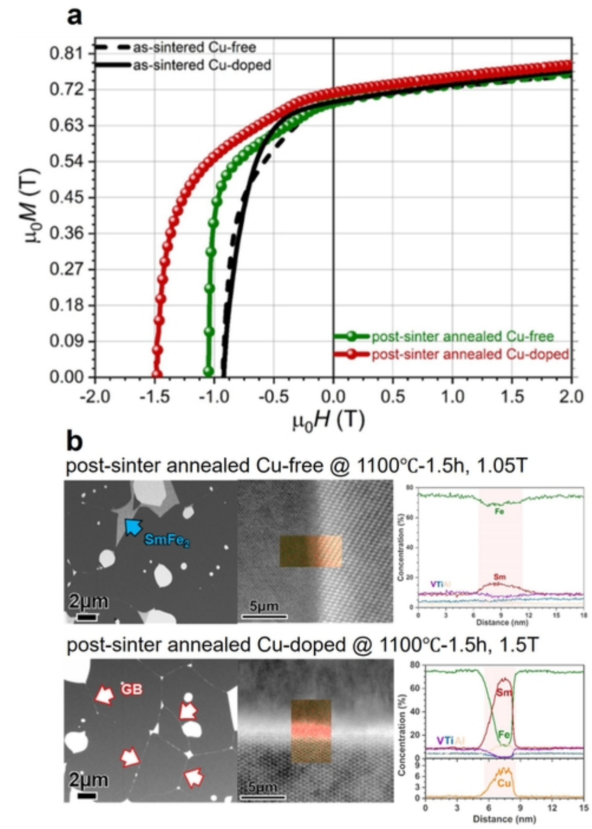

Fig. 1 (a) Demagnetization curves for Cu-free and Cu-doped magnets, (b) high magnification backscattered electron (BSE) SEM images, high-resolution HAADF-STEM images and the corresponding composition line profiles for the optimal annealed Cu-free and Cu-doped magnets.

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[O11-2] The effect Ag on phase transformation and magnetic properties in SmFe12-based composition

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Keywords：SmFe12-based、Intergranular phase、Melt spinning、Structure

The renewed interest in SmFe12-based compounds is driven by their superior intrinsic magnetic properties, making them a promising candidate for replacing Nd-Fe-B magnets, particularly in high-temperature applications [1]. However, a key challenge for these compounds is achieving an optimal microstructure in which hard magnetic grains are isolated by an intergranular phase while maintaining a minimal amount of phase stabilizer within the hard magnetic grains to preserve high magnetization [2]. Overcoming these challenges is particularly difficult due to the lack of equilibrium between the hard magnetic 1:12 phase and low-melting-point phases in the Sm-Fe-V phase diagrams, especially in the M-lean region where the M content is below 15 at.%.Therefore, in this study, we selected V over Ti in our composition design, as V promotes less twin formation, which helps higher coercivity [3]. The V content was kept below 15 at.% to maximize the magnetization, while Zr was substituted at the Sm site to maintain the 1:12 phase stability. Additionally, Ag was introduced to form a non-ferromagnetic Sm-Ag intergranular phase, which does not enter the 1:12 crystal structure [4].In the first part, we will discuss the effects of annealing and composition on phase formation, as well as the optimal composition for stabilizing the 1:12 phase, as illustrated in Fig. 1. In the second part, we will examine the impact of wheel speed, annealing, and composition on phase formation and extrinsic magnetic properties. For instance, reducing the V content results in Ms between 0.8T and 1T, while the Sm-Ag intergranular phase contributes to achieving μ0Hc of 0.6T–0.77T. Interestingly, ribbons predominantly containing the SmFe3-type phase also exhibit a moderate coercivity of 0.76T. Furthermore, machine learning algorithms are applied to optimize the experimental process, maximizing extrinsic magnetic properties and identifying desirable phases to enhance coercivity.

Fig. 1 The XRD and BSE image of Sm15.4Zr1.4Fe71.5V9.23Ag2.85 ingot.

References: [1] P. Tozman et al, Scr. Mater. 194 (2021) 113686. [2] J. S. Zhang et al., Acta Mater. 238 (2022) 118228.[3] P. Tozman et al., Scr. Mater. 258 (2025) 116491[4] O. Takeda et al., J. Magn. Magn. Mater. 542 (2022) 168.

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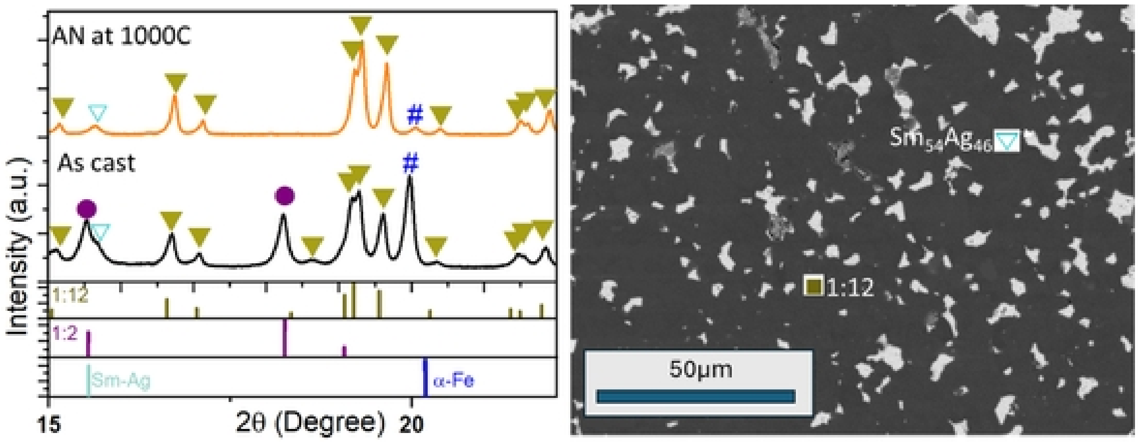

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[O11-3] Additive Manufacturing of Hard Magnetic Materials $Nd_2Fe_{14}B$ and $Sm(Fe,Ti,V)_{12}$

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Keywords：additive manufacturing、Nd2Fe14B、Sm(Fe、Ti、V)12、permanent magnet

The development of power engineering and robotics, miniaturisation of high-tech devices containing electric motors and actuators, and electric transport require either a significant improvement in the magnetic hysteresis properties of permanent magnets or a change in approaches to the fabrication of magnetic systems. One approach to changing the design and fabrication of magnetic systems is to fabricate them by additive manufacturing. This approach is advantageous in that it eliminates the use of magnetically soft materials as magnetic cores, thereby reducing the mass of magnetic systems utilised, for instance, as components of electric motors or small generators.
The primary challenge associated with the printing of functional materials pertains to the acquisition of a microstructure that facilitates the attainment of designated magnetic properties, or properties analogous to those of samples fabricated through conventional methodologies. A notable benefit of additive technologies is the capacity to modulate magnetic properties in three dimensions by manipulating the chemical composition, grain size, or grain orientation.
In the talk approaches to the additive manufacturing of magnetically hard materials from alloys based on $Nd_2Fe_{14}B$ and $Sm(Fe,Ti,V)_{12}$ compounds, as well as the results of studies of microstructure and magnetic hysteresis properties will be described. The employment of these techniques has enabled the fabrication of permanent magnets exhibiting coercivity of up to 19.5 kOe for the primary phase of $Nd_2Fe_{14}B$ and 5.5 kOe for the $Sm(Fe,Ti,V)_{12}$ phase. The report will be provided, encompassing the detailed outcomes of the phase composition, microstructure, and magnetic properties analysis of the obtained samples.
The work was financially supported by the Ministry of Science and Higher Education of the Russian Federation FEUZ-2024-0060.

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[O11-4] In-Depth investigation of the sub-micronic equiaxed grain microstructure of a NdFeB permanent magnet fabricated by Laser Powder Bed Fusion

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Keywords：Laser Powder Bed Fusion (LPBF)、Additive manufacturing、NdFeB、Microstructure investigation、Columnar to equiaxed transition (CET)

Laser Powder Bed Fusion (LPBF) has been identified as an interesting technique for the manufacturing of high coercivity NdFeB magnets thanks to the emergence of sub-micronic microstructures [1]. However, most studies have focused on commercial MQP-S powder whose chemical composition is not optimized for the formation of a Nd-rich intergranular phase, thus resulting in poor magnetic properties [2]. In this work, magnets have been elaborated using a specific and unique powder fabricated with an in-house experimental pilot line allowing to adapt both the size (in the case of this study a narrowly-distributed powder with a volumic D_{50} of 40 µm) and the chemical composition of the material as desired.

The microstructure of the magnets has been characterized down to the nano-scale using TEM analyses. It is composed of sub-micronic $Nd_2Fe_{14}B$ grains ranging from 100-200 nm to 1-2 µm and multiple Nd-rich phases at grain boundaries. Interestingly, there seems to be a NdO_x phase (*Fm3m* structure) mainly present at the triple junctions (TJ) with a lattice parameter of circa 5.5 angstroms, while the fine grain boundaries are composed of metallic Nd with traces of Cu and Ga. As for sintered magnets, non-homogeneous grain boundaries have been identified in the as-built materials, which prevents high coercivity to be obtained. However, the magnetic properties can be improved by annealing heat treatments around 500-600°C that allow the grain boundary phase to reorganize. This effect is made possible thanks to the presence of addition elements (in particular Cu and Ga) which lower the melting temperature of the Nd-rich phase [3].

Multiple precipitates have been observed inside of the grains sizing from 10 to 100 nm. They have been identified either as NdO_x *Fm3m* but this time with a lattice parameter of circa 5.2 angstroms, either as Nd_2O_3 $P6_3/mmc$. These results agree with reference works on sintered magnets [4].

In this context, the origin of the formation of an almost fully equiaxed microstructure has been investigated. Indeed, in LPBF fabrications, the formation of columnar grains is generally preponderant, as the formation of equiaxed grains is not expected due to the strong thermal gradients generated during the process. Using both a numerical model to provide information on the cooling conditions of the alloy during LPBF [5] and experimental observations on crystallographic orientations between Nd oxide precipitates and $Nd_2Fe_{14}B$, it has been suggested that the oxides could act as nuclei for the formation of the $Nd_2Fe_{14}B$ phase.

Such a result could be of strong interest for future optimization of the LPBF process for $Nd_2Fe_{14}B$ magnets as Nd oxides are naturally present in the alloy due to fabrication conditions of the powder, and as sub-micronic grains are beneficial for the formation of high coercivity magnets.

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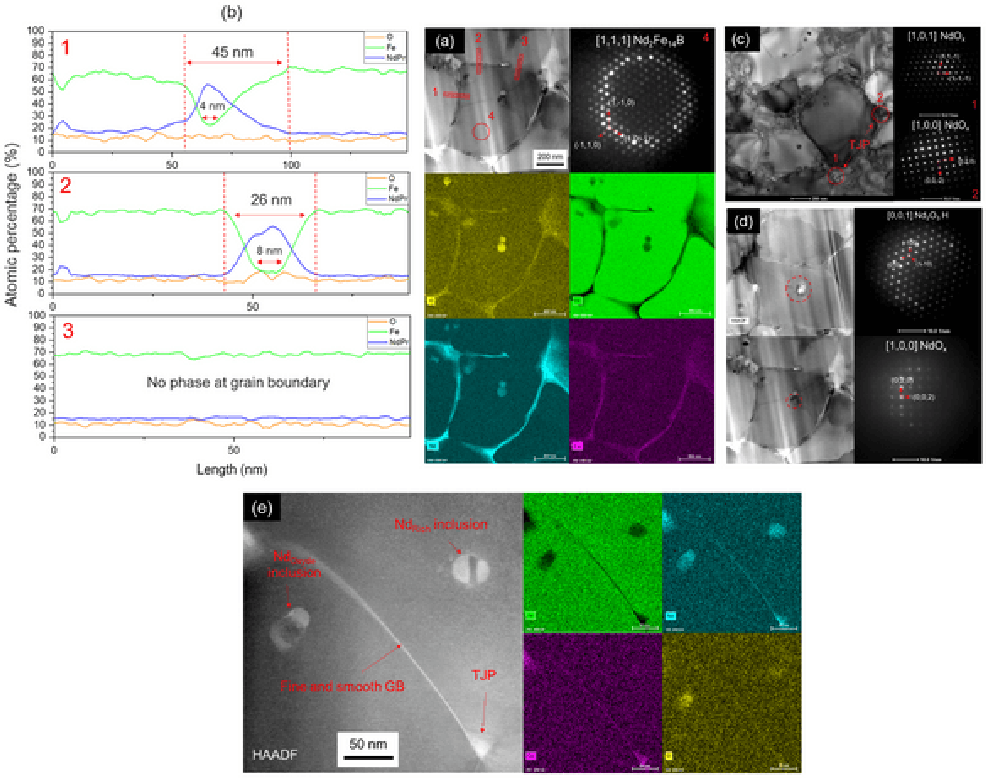

Additional Figure: *(a) Observation of a sub-micronic $Nd_2Fe_{14}B$ grain in a sample fabricated by LPBF ; (b) STEM EDS line profiles of the inhomogeneous grain boundary (GB) phase ; (c) Identification of the triple junction phase (TJP) ; (d) identification of Nd oxide precipitates ; (e) observation of a fine and smooth Nd-rich GB after annealing heat treatment ;*