Oral | Material, processing, and characterization

Wed. Jul 30, 2025 9:00 AM - 10:35 AM JST | Wed. Jul 30, 2025 12:00 AM - 1:35 AM UTC Convention Hall(300, 3F)

[O9] RE Nitrides

Session Chair: Dr. Takahiko Iriyama(*Daido Steel Inc.*)

Plenary

9:00 AM - 9:30 AM JST | 12:00 AM - 12:30 AM UTC

[O9-1]

Novel High Frequency Magnetic Properties of Rare Earth-Transitional Metal Intermetallic Compounds

*Jinbo Yang[1], Wenyun Yang[1], changsheng wang[1], Fashen Li[2] (1. Peking University (China), 2. Lanzhou University (China))

Invited

9:30 AM - 9:50 AM JST | 12:30 AM - 12:50 AM UTC

[O9-2]

Process development of high-performance Sm-Fe-N permanent magnet

*Yusuke Hirayama[1], Shusuke Okada[1], Wataru Yamaguchi[1] (1. National Institute of Advanced Industrial Science and Technology (Japan))

9:50 AM - 10:05 AM JST | 12:50 AM - 1:05 AM UTC

[O9-3]

Particle size effects on degree of alignment in Ba-Cu doped $Sm_2Fe_{17}N_3$ sintered magnets

*Yuta Iida[1,2], Akihide Hosokawa[2], Wataru Yamaguchi[2], Yusuke Hirayama[2] (1. Niterra Co., Ltd. (Japan), 2. National Institute of Advanced Industrial Science and Technology (AIST) (Japan))

10:05 AM - 10:20 AM JST | 1:05 AM - 1:20 AM UTC

[O9-4]

Effect of Mn doping on the synthesis and properties of nearly spherical $Sm_2Fe_{17}N_3$ powders

Pengfei Yue[1], Dongsheng Shi[1], Jingwu Zheng[1], Wei Cai[1], Liang Qiao[1], Yao Ying[1], *Shenglei Che[1] (1. Research Center of Magnetic and Electronic Materials, College of Materials Science and Engineering, Zhejiang University of Technology, Hangzhou 310014, China (China))

10:20 AM - 10:35 AM JST | 1:20 AM - 1:35 AM UTC

[O9-5]

Low temperature densification of $Nd(Fe,Mo)_{12}$ nitrided samples

Gabriel Gomez Eslava[1], Patricia de Rango[2], *Sorana Luca[1] (1. Univ. Grenoble Alpes, CEA, Liten, F-38000 Grenoble (France), 2. Univ. Grenoble Alpes, CNRS, Institut Néel, 38000 Grenoble (France))

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[O9-1] Novel High Frequency Magnetic Properties of Rare Earth-Transitional Metal Intermetallic Compounds

*Jinbo Yang[1], Wenyun Yang[1], changsheng wang[1], Fashen Li[2] (1. Peking University (China), 2. Lanzhou University (China))

Keywords：Rare Earth-Transitional Metal Intermetallic Compounds、Magnetocrystalline anisotropy、high frequency、soft magnetic materials、nitrides

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Magnetocrystalline anisotropy, as one of the core foundations and applications of modern magnetic materials, determines the performance and use of most magnetic materials. For many years, the search for rare earth permanent magnet materials with strong uniaxial anisotropy has been the mainstream direction of research on rare earth-transition metal intermetallic compounds. However, there has been less attention paid to rare earth-transition metal intermetallic compounds with complex conical anisotropy or planar anisotropy. In particular, most rare earth-transition metal intermetallic compounds mainly exhibit easy-plane or easy-cone anisotropy, including hundreds of compounds, and their interstitial compounds can derive more systems. This provides a vast material library for emerging high-frequency magnetic materials and topological electronic materials, laying the foundation for obtaining high-performance magnetic material applications. This talk reports our recent work on using various element substitutions and interstitial atom effects to change the saturation magnetization, Curie temperature, and magnetocrystalline anisotropy of rare earth-transition materials, thereby achieving the design and application from permanent magnet materials to soft magnetic materials. In particular, for $R_2Fe_{17}N_3$ (R=Y, Ce, Pr, Nd etc.) materials, changing the ratio of the axial anisotropy field H_θ to the in-plane anisotropy field H_φ is expected to significantly increase its Snoek's limit. Further research and technological development could make it a new generation of high-efficiency electromagnetic wave absorption and soft magnetic materials, opening up new directions for the research and application of rare earth-transition metal intermetallic compounds.

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[O9-2] Process development of high-performance Sm-Fe-N permanent magnet

*Yusuke Hirayama[1], Shusuke Okada[1], Wataru Yamaguchi[1] (1. National Institute of Advanced Industrial Science and Technology (Japan))

Keywords：Sm2Fe17N3、powder metallurgy

Sm-based compounds have great potential as permanent magnet compounds. For example, the stable phase $Sm_2Fe_{17}N_3$ compound[1,2] , the metastable phase $TbCu_7$-type Fe-rich SmZrFeCoN compound[3] , and the non-nitride SmZrFeCoNbB compound[4] are promising post-neodymium magnets. However, no process has been developed that can fully utilize the potential of any compound. In this presentation, we will focus on the following two compounds and report on the high properties achieved by optimizing the powder synthesis process. $Sm_2Fe_{17}N_3$ compoundWe are working on improving the process for $Sm_2Fe_{17}N_3$ single crystal powder using the jet mill and reduction diffusion methods, which are pulverization methods. By optimizing the process parameters in the jet mill process, we have succeeded in synthesizing powder with a much narrower particle size distribution than conventionally obtained powders. The magnetic properties of the powder showed an improvement of more than 7% in both coercivity and remanence. In contrast, the reduction diffusion method had a problem of poor orientation due to strong necking between particles[5]. By properly crushing using a wet jet mill, we succeeded in synthesizing powder with a BHMAX exceeding 370 kJ/m3, which had not been achieved until now. In addition to these powder synthesis process developments, we would like to briefly introduce the sintered $Sm_2Fe_{17}N_3$ magnet by liquid phase sintered that we have been working on recently. $TbCu_7$ type Fe-rich Sm-Fe-N compounds Because of a metastable phase, single crystal powder rather than polycrystal is difficult to obtain. At present, processes using low-temperature reduction diffusion[6] or thermal plasma[7] have been reported. However, neither process has been able to prepare a Fe-rich compound. Therefore, following the report that achieved Fe-richness by replacing Zr or Y with Sm[3,8], we attempted to synthesize Fe-rich SmZrY-Fe-N compounds using a thermal plasma process. From the XRD measurement results, the peak positions also suggested that the Fe/Sm (at%) ratio was greater than 8.5, so we succeeded in synthesizing Fe-rich SmZrY-Fe-N compound single crystal powder. There is still room for developing permanent magnets using Sm-based compounds, and it is highly significant to continue developing this process. Iriyama, T., *et al.*, *Magnetics, IEEE Transactions on* (1992) **28** (5), 2326 Coey, J. M. D., *et al.*, *Journal of Applied Physics* (1991) **69** (5), 3007 Sakurada, S., *et al.*, *J. Appl. Phys.*

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[O9-3] Particle size effects on degree of alignment in Ba-Cu doped $Sm_2Fe_{17}N_3$ sintered magnets

*Yuta Iida[1,2], Akihide Hosokawa[2], Wataru Yamaguchi[2], Yusuke Hirayama[2] (1. Niterra Co., Ltd. (Japan), 2. National Institute of Advanced Industrial Science and Technology (AIST) (Japan))
Keywords：Sm2Fe17N3、sintered magnet、magnetic alignment

The $Sm_2Fe_{17}N_3$ compound is one of prospective candidates for next generation permanent magnets because of its high saturation magnetization and coercivity as well as high Curie temperature [1], but $Sm_2Fe_{17}N_3$ has not been sintered densely due to the constraints of decomposition temperature (620°C). Recently, we have developed the novel sintering aid containing alkaline earth metals, which successfully enhanced the volume fraction of main phase and magnetization [2, 3]. Although the energy product could be increased by doping the sintering aid, the magnetic properties should be further improved for practical applications. Then we investigated the factors that could improve the degree of alignment (DOA) of $Sm_2Fe_{17}N_3$ anisotropic sintered magnets. Although it has been reported that the DOA in powder tends to decrease when the average particle diameter of $Sm_2Fe_{17}N_3$ is near 1 μm [4], few studies have quantitatively evaluated the DOA in sintered magnet. Therefore, in this study, we have investigated the influence of particle diameter on the DOA of $Sm_2Fe_{17}N_3$ sintered magnets in details.
The manufacturing process of sintered magnets was carried out in a glove box with the oxygen concentration controlled below 0.5 ppm. $Sm_2Fe_{17}N_3$ coarse powder (provided from Sumitomo Metal Mining Co., Ltd.) was pulverized to D_{50}≒1.5 μm (referred to as Powder A, hereafter) and 3.0 μm (Powder B) using jet-milling. Ba-Cu alloy with a eutectic point of 440 °C was selected as a sintering aid. Both pulverized $Sm_2Fe_{17}N_3$ powders of A and B were coated with 2 wt.% $Ba_{80}Cu_{20}$ (at.%) using the magnetron sputtering technique while the powder was stirred. The coated powders were put in the mold made of nonmagnetic WC-FeAl and magnetically aligned with a static magnetic field of 2 T at room temperature. The aligned powders were sintered at 400 – 500 °C for 2 minutes under the vacuum below 0.5 Pa with a pressure of 1200 MPa. The magnetic properties of sintered magnets were evaluated by using VSM (DynaCool, Quantum Design inc.) with the maximum field of 9 T. The DOA of sintered magnets were estimated by measuring the pole-figure around (003) plane using synchrotron X-ray diffraction in Aichi Synchrotron Center.
A relative density of over 90% was obtained for both the sintered magnets of A and B. By measuring the demagnetization curves of sintered magnets, the remanence and the energy product of the sintered magnet B were higher than those of the sintered magnet A,

although the sintered magnet B had lower coercivity because of its larger particle size. To discuss the difference in remanence between A and B, the pole figures of sintered magnets were measured. The shape of the pole figures was an ellipse vertically elongated in this paper, which coincides with the actual direction of pressure applied during pressure sintering. In the sintered magnet B, the shape of the high-intensity region of the pole-figure became closer to a circle, suggesting that the alignment degree was improved. The DOA of the sintered magnets A and B were estimated to be 71.9% and 83.6%, respectively from these pole figures. The particle size distribution measurements of the pulverized powder showed that the frequencies of fine particles under 1 μm in the powders of A and B were approximately 30% and 10%, respectively. Therefore, it seems conclusive that the DOA of the $Sm_2Fe_{17}N_3$ sintered magnets are dependent on the crystal grain size, and it would be expected that remanence could be further improved by controlling the particle size (and its distribution) of the pulverized powder.

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[2] Niterra Co., Ltd., AIST, press release "Development of high-density technology for $Sm_2Fe_{17}N_3$ permanent magnet" (2024)
[3] Y. Iida, A. Hosokawa, W. Yamaguchi, Y. Hirayama, Abstractbooks MMM InterMag 2025, p.97 (2025)
[4] A. Hosokawa, W. Yamaguchi, K. Suzuki, K. Takagi, *J. Alloy. Compd.* **869** (2021) 159288.

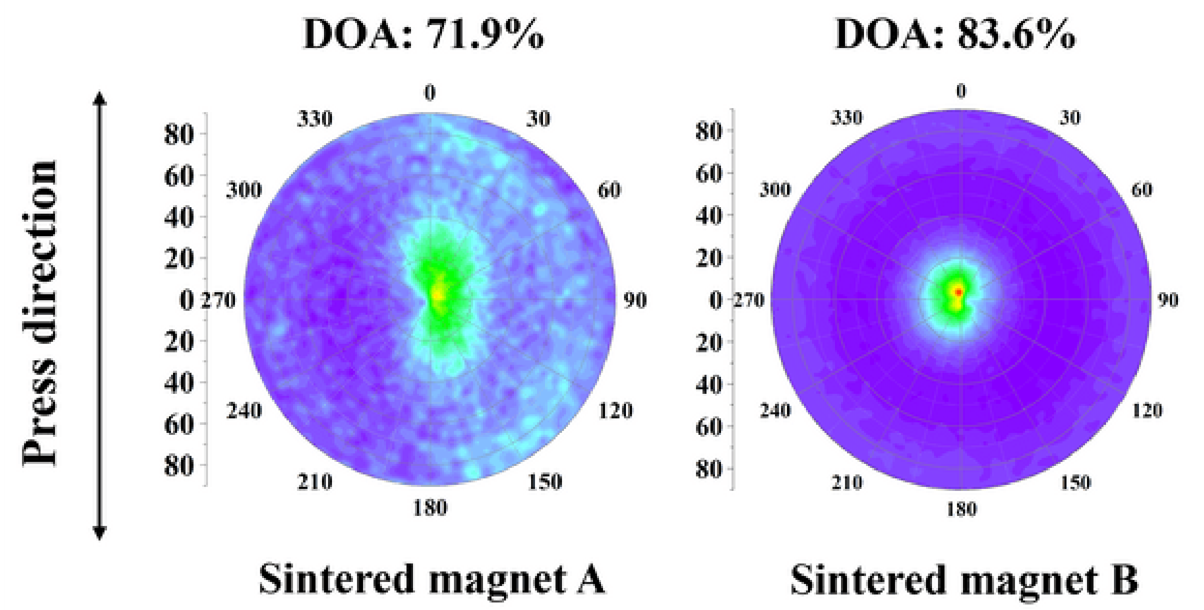

Fig.1 Pole figures of Ba-Cu doped $Sm_2Fe_{17}N_3$ sintered magnets

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[O9-4] Effect of Mn doping on the synthesis and properties of nearly spherical $Sm_2Fe_{17}N_3$ powders

Pengfei Yue[1], Dongsheng Shi[1], Jingwu Zheng[1], Wei Cai[1], Liang Qiao[1], Yao Ying[1], *Shenglei Che[1] (1. Research Center of Magnetic and Electronic Materials, College of Materials Science and Engineering, Zhejiang University of Technology, Hangzhou 310014, China (China))
Keywords：Sm-Fe-N、Mn doping、Ultrasonic spray pyrolysis、magnetic particle

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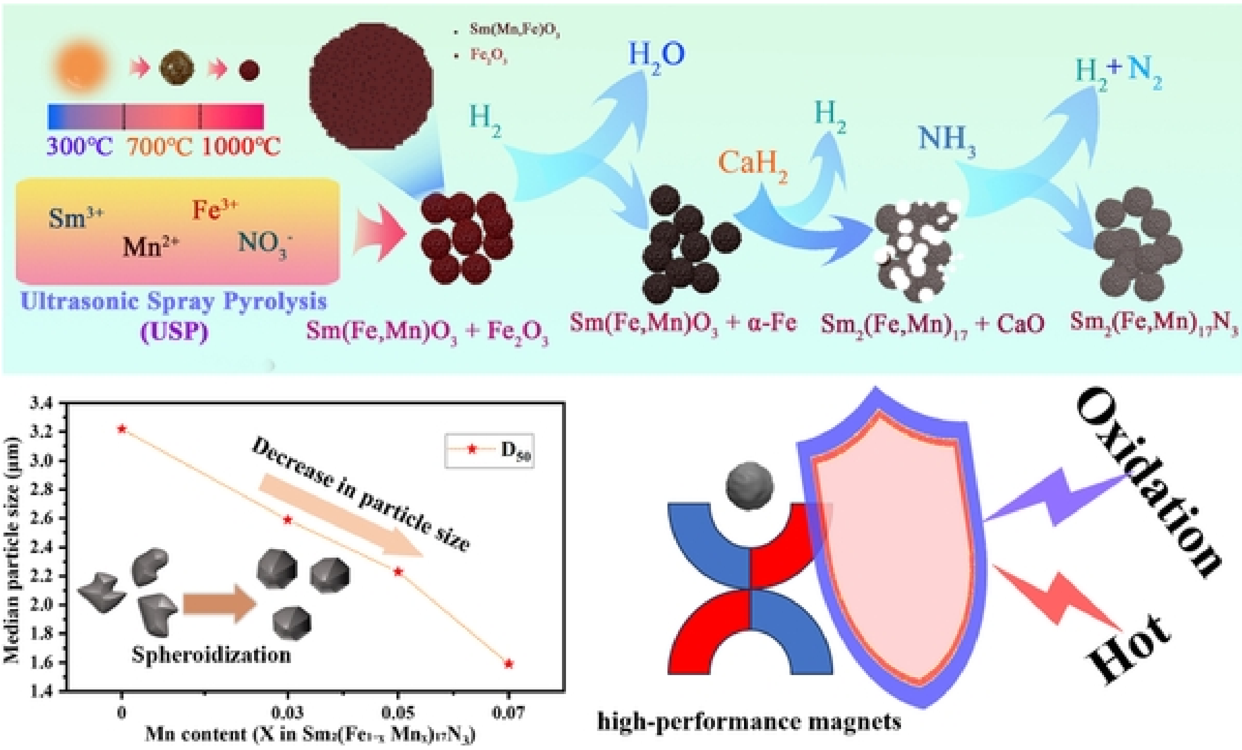
To achieve smaller particle sizes of $Sm_2Fe_{17}N_3$ magnetic powders, crushing is often applied to the obtained powders. However, this process introduces more angular edges and increases the risk of oxidation. In this study, nearly spherical $Sm_2(Fe,Mn)_{17}N_3$magnetic powders with controllable particle sizes and strong oxidation resistance were prepared eliminating the need for crushing, using a combined ultrasonic spray pyrolysis-reduction diffusion method. The results show that appropriate Mn doping facilitates particle size refinement. Mn substitution of Fe increased lattice expansion without altering crystal structure. The optimal coercivity occurred at a 5 at.% Mn substitution. Furthermore, as the Mn doping level increased, the proportion of adsorbed oxygen decreased, slowing the occurrence of further oxidation reactions and impeding the transformation of metallic elements into higher-valence oxides, thereby enhancing oxidation resistance. The addition of Mn improved the thermal stability and magnetic properties of $Sm_2Fe_{17}N_3$magnets, offering a promising method for producing high-performance permanent magnets.


Sm(Mn,Fe)O3
Fe2O3
300℃ 700℃ 1000℃
Sm3+
Fe3+
Mn2+
NO3-
Ultrasonic Spray Pyrolysis
(USP)
H2
H2O
CaH2
H2
NH3
H2+N2
Sm(Fe,Mn)O3 + Fe2O3
Sm(Fe,Mn)O3 + α-Fe
Sm2(Fe,Mn)17 + CaO
Sm2(Fe,Mn)17N3
Median particle size (μm)
Decrease in particle size
D50
Spheroidization
Mn content (X in Sm2(Fe1-x Mnx)17N3)
high-performance magnets
Oxidation
Hot

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[O9-5] Low temperature densification of $Nd(Fe,Mo)_{12}$ nitrided samples

Gabriel Gomez Eslava[1], Patricia de Rango[2], *Sorana Luca[1] (1. Univ. Grenoble Alpes, CEA, Liten, F-38000 Grenoble (France), 2. Univ. Grenoble Alpes, CNRS, Institut Néel, 38000 Grenoble (France))

Keywords：TR-Fe12 compounds、low temperature densification、eutectic alloys

The family of intermetallics with general formula RE-Fe12 (RE = rare-earth) is considered as the strongest candidate for alternative high performance permanent magnet. Among all the existent compounds, the Nd-based ones are of particular interest due to their high saturation magnetization, high magnétocristalline anisotropy and Curie temperature in the nitrided powders. However, the nitrided Nd-based 1:12 phase decomposes at 650°C [1], making the densification of a permanent magnet a challenging task. To overcome this limitation, we developed low temperature densification processes for the $Nd(Fe,Mo)_{12}$-based powders, thanks to the Grain Boundary (GB) low temperature eutectic alloys. Therefore, the insertion of low temperature eutectic alloys is a fundamental piece of the puzzle. Several binary eutectic alloys were identified, i.e., La-Cu and Al-Cu, that respond to two fundamental requirements: (i) their constituents have limited or none solubility in the 1:12 phase and (ii) their eutectic temperature should be lower than the decomposition temperature of the 1:12 phase. Our preliminary studies had shown that Cu is not soluble into the 1:12 $Nd(Fe,Mo)_{12}$ phase, and forms eutectic alloys with the excess of RE [2]. In addition, no 1:12 phase can be stabilized with La at the RE site [3]. In the case of Al, it is a possible stabilizing element of the 1:12 phase, which is in any case already stabilized by the presence of Mo. It is thus expected that at low temperatures it will not substitute Mo. Infiltration experiments of the above mentioned alloys were carried out, by putting in contact the binary alloys (powder or flakes) with Cu-rich $Nd(Fe,Mo)_{12}$ SC flakes. The thermal treatment for infiltration was performed in vacuum below 600°C, during 12 h. No significant changes in the microstructure of the SC flake was detected. Infiltration of the La-Cu has been evidenced by SEM-EDX mapping, on all the flake's thickness (~150 µm). SEM images and compositional maps acquired by EDX analysis of an Al-Cu infiltrated sample are presented in fig. 1. The only modification of the microstructure is the appearance of thin grain boundary layers separating adjacent grains, even in the regions where initially no grain boundary was observed. EDX compositional maps reveal the presence of Al only at the GB region all across the SC flake, together with Cu and Nd/Pr. This promising result suggest that Al could be used for the production of low temperature eutectic phase at the GB's. In addition, Nd/Pr – rich GB phase with a low Fe content suggests the formation of non-magnetic GB phase, which is beneficial for the magnetic decoupling of 1:12 adjacent grains.

Spark Plasma Sintering (SPS) experiments were carried out by mixing the nitride SC powders and Al-Cu powders at different volume ratios. Parts produced at 600°C – 70 MPa with 25 vol% of Al-Cu powder show good mechanical stability, with density of 5.13 g/cm^3 that represents 73% of the theoretical density, which could be improved by high pressure SPS. Densification at 83% was obtained in a first test at 1.7 GPa at room temperature that can be improved by densifying at higher temperatures. Microstructural analysis and magnetic properties of aligned densified samples will be reported at the conference. Our promising results show that low temperature densification of nitrided $NdFe_{12}$-based compounds are feasible by the inclusion of eutectic alloys. Powder-to-powder method combined with high pressure SPS could lead to an improved density in the final parts. In a second step, we aim to including the identified components, i.e. Ga, La, Cu and Al, during the preparation of the SC ribbons, in order to improve the microstructure and simplify the low-temperature densification process.

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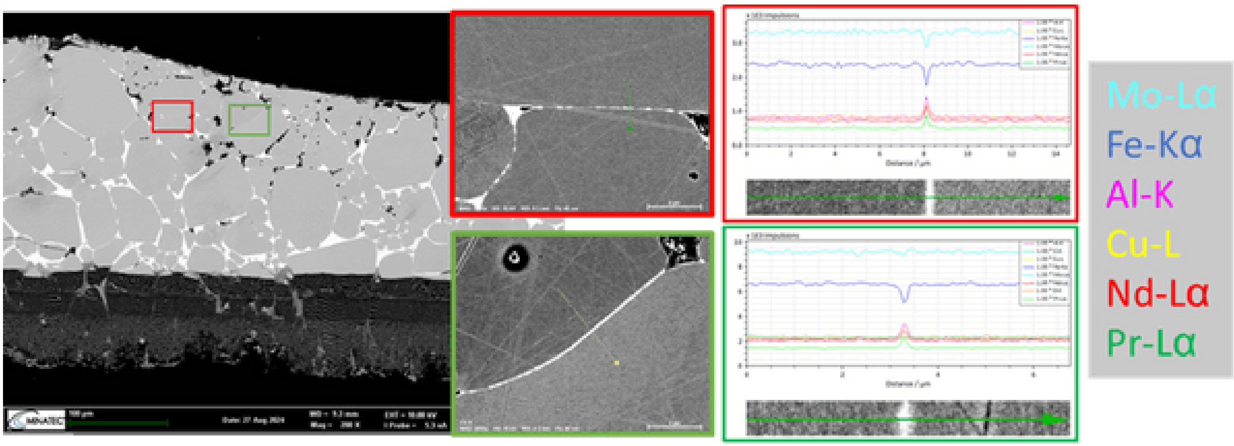

Figure 1. SEM images and EDX compositional profile across a grain boundary of Al-Cu infiltrated $(Nd,Pr)_{1.25}Fe_{10.5}Mo_{1.5}Cu_{0.1}$ SC flake.