Poster | Applications: Motors and others

Mon. Jul 28, 2025 4:30 PM - 6:00 PM JST | Mon. Jul 28, 2025 7:30 AM - 9:00 AM UTC Blue zone, Conference rooms 101 and 102(1F)

[P1] Applications

Session Chair: Dr. Imants Dirba (Technical University of Darmstadt, Germany), Dr. Tae-Hoon Kim (Korea Institute of Materials Science, Korea)

[P1-39]

Dynamic evaluation in motors of variable magnetic flux magnets

*Kenji Takeda[1], R. Fujiwara[1], T. Shinji[1], S. Miyazaki[1], T. Kajita[1], Y. Enokido[1], K. Akatsu[2] (1. Technology and Intellectual Property HQ, TDK Corporation (Japan), 2. Department of Faculty of Engineering, Yokohama National University (Japan))

[P1-40]

High Magnetic Flux Rotor Core for IPM Motor through Partial Non-Magnetic Improvement of Silicon Steel

*Norihiko Hamada[1], Hironari Mitarai[1], Katsunari Oikawa[2], Satoshi Sugimoto[2] (1. Aichi Steel Corporation (Japan), 2. Tohoku University (Japan))

[P1-41]

Development of 200,000rpm SPM small motor using rare earth anisotropic bonded magnets

Takenobu Yoshimatsu[1], *Chisato Mishima[1], Eiki Kikuchi[1], Yoshinobu Honkura[1], Junichi Asama[2] (1. MagDesign corporation (Japan), 2. Shizuoka University (Japan))

[P1-42]

A new magnetization methods that supports high-performance magnets applied to IPMSMs for EV/HEV and new motors such as spoke type motor

*Michitaka Hori[1], Naoya Tomita[1], Kazuki Akiyama[1] (1. Nihon Denji Sokki Co., LTD. (Japan))

[P1-43]

Advantages of Manufacturing Radially Oriented Ring Magnets through Hot Forming and the Impact on Electrical Machines

*Martin Krengel[1], Stefan Schmülling[1], Lukas Schäfer[2], Semih Ener[2], Burçak Ekitli[2], Oliver Gutfleisch[2] (1. WILO SE (Germany), 2. TU Darmstadt / Functional Materials (Germany))

[P1-44]

Design Considerations for Post Assembly Magnetising of Permanent Magnet Rotors

*Matthew Joseph Swallow[1] (1. Bunting Magnetics Ltd (UK))

[P1-45]

Formation of ferromagnetic clusters affecting the first-order phase transition in off-stochiometric Fe-Rh

*Alex Aubert[1], Konstantin Skokov[1], Andrei Rogalev[2], Alisa Chirkova[1], Benedikt Beckmann[1], Fernando Maccari[1], Fabrice Wilhelm[2], Esmaeil Adabifiroozjaei[3], Leopoldo Molina-Luna[3], Gabriel Gomez[4], Benedikt Eggert[4], Katharina Ollefs[4], Heiko Wende[4], Oliver Gutfleisch[1] (1. Functional Materials, TU Darmstadt (Germany), 2. ESRF (France), 3. Advanced Electron Microscopy, TU Darmstadt (Germany), 4. CENIDE, University of Duisburg-Essen (Germany))

[P1-46]

A Compact 4 Tesla Permanent Magnet Field Source with Reduced Structural Complexity

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[P1-47]

Development strategy of Fe-Cr-Co alloy powder for high-performance microwave absorbers and noise suppression sheets

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[P1-48]

Development of $RE_2(Fe,Co)_{14}B$ (RE = rare-earth) compounds for transverse thermoelectric applications

*Babu Madavali[1], Fuyuki Ando[1], Zulfa Hilmi Kautsar[1], Takamasa Hirai[1], Ken-ichi Uchida[1,2], Xin Tang[1], Hossein Sepehri-Amin[1] (1. National Institute for Materials Science (NIMS) (Japan), 2. The University of Tokyo, Kashiwa (Japan))

[P1-49]

Coercivity mechanism of rare earth-free Cr substituted $Mn_{1-x}Cr_xAlGe$ for “thermoelectric permanent magnet” applications

*Andres Martin-Cid[1], Babu Madavali[1], Fuyuki Ando[1], Yuya Sakuraba[1], Ken-ichi Uchida[1,2], Hossein Sepehri-Amin[1] (1. National Institute for Materials Science (NIMS) (Japan), 2. Department of Advanced Materials Science, Graduate School of Frontier Sciences, The University of Tokyo (Japan))

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Session Chair: Dr. Imants Dirba (Technical University of Darmstadt, Germany), Dr. Tae-Hoon Kim (Korea Institute of Materials Science, Korea)

[P1-39] Dynamic evaluation in motors of variable magnetic flux magnets

*Kenji Takeda[1], R. Fujiwara[1], T. Shinji[1], S. Miyazaki[1], T. Kajita[1], Y. Enokido[1], K. Akatsu[2] (1. Technology and Intellectual Property HQ, TDK Corporation (Japan), 2. Department of Faculty of Engineering, Yokohama National University (Japan))

Keywords：motors

The variable magnetic flux permanent magnet synchronous motor (VMF-PMSM) is one of the next-generation technologies to improve the efficiency of PMSM. The VMF-PMSM is expected to achieve high efficiency over a wide operating range by switching the magnetization states of the VMF-magnet, which has a low coercive field, through the application of the magnetic field from an armature coil. Achieving the desired torque in the VMF-PMSM requires to accurately grasp the relationship between the electrical control of the motor and the operating point of the magnet embedded in a rotating rotor, which is difficult to be measured. This presentation will show the approach for directly measuring the operating point of the VMF-magnet.

The VMF-PMSM with the system for real-time measurement of the magnetic field and the temperature of the rotor magnet was constructed (Fig. (a)). The rotor magnet consisted of a series lamination of the VMF-magnet [1] and the high coercive field magnets. The sensor probe with a Hall element and an NTC thermistor on a flexible printed circuit board was fixed on the surface of the rotor magnet and was electrically connected to a signal conditioner mounted on the rotor shaft, which includes a micro-controller and a Bluetooth module, enabling measurement and wireless communication. For driving the VMF-PMSM, a DSP (PE-Expert3) and an inverter unit (MWINV-2022A) manufactured by Myway Plus Corporation were used.

Figure (b) shows the current angle β dependence of torque during 3 Arms load rotation after magnetizing and demagnetizing the VFM-magnet with a d-axis current of ±60 A and an energizing time of 50 ms during a 600 rpm rotation at 26℃. The magnet torque in the magnetized state at β = 0° after a field weakening operation up to β = 90° decreased by 3.8% compared to before. This corresponded to a 4% decrease in the magnetic field of the rotor magnet, which was measured simultaneously during the same operation as mentioned above. In the presentation, the relationship between the electrical control of the motor and the operating point of the VMF-magnet will be considered using the measurement results of the torque and the magnet field.

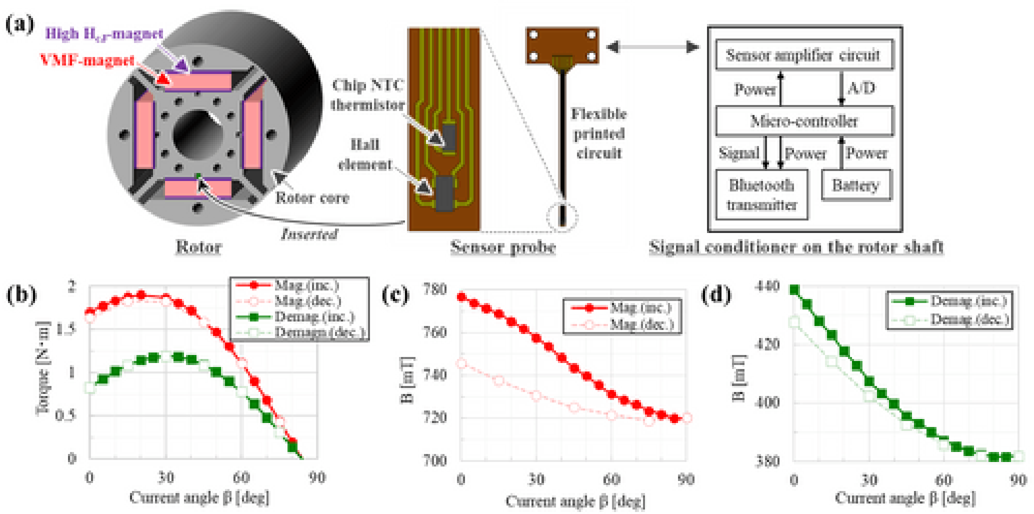

Figure: (a) Overview of the VMF-PMSM with the real-time measurement system. The current angle β dependence of torque (b), and the magnetic field of the rotor magnet in the magnetized state (c) and the demagnetized state (d).

[1] K. Takeda, S. Miyazaki, T. Kajita and Y. Enokido, IEEE Transaction on Magnetics, 59, 8203105 (2023).

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[P1-40] High Magnetic Flux Rotor Core for IPM Motor through Partial Non-Magnetic Improvement of Silicon Steel

*Norihiko Hamada[1], Hironari Mitarai[1], Katsunari Oikawa[2], Satoshi Sugimoto[2] (1. Aichi Steel Corporation (Japan), 2. Tohoku University (Japan))

Keywords：interior permanent magnet(IPM) motor、rotor core、leakage flux、partial non-magnetic improvement、Nd-Fe-B magnet

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Leakage flux in the rotor core of a bridge remains a persistent issue for interior permanent magnet motors and has yet to be resolved. It is well-established that partial non-magnetization of the bridges reduces magnetic flux leakage, resulting in a rotor with higher magnetic flux [1]. In a preliminary experiment [2], we attempted to melt and mix the bridges of the rotor core with a Ni-Cr alloy wire using laser heating, based on the Schaeffler diagram [3]. This method produced a rotor with partial non-magnetization of the bridges. However, due to welding defects and the coupling of laminated bridges, these rotors were unsuitable for practical applications. To address this, we pre-treated the silicon steel sheets–intended to become the rotor bridges–by partially non-magnetizing them before laminating them to form the rotor core. We then evaluated the performance of the fabricated rotor.

Partial non-magnetization treatment involved mixed and melt with silicon steel sheets and Ni-Cr-B alloy powder by laser. A rotor (8 poles, 80 mm outer diameter, and 30 mm height) was produced by pressing and laminating the silicon steel sheets. Two types of permanent magnets were used for the experiments: one was an Nd anisotropic bonded magnet with a residual flux density (Br) of 0.77 T, and the other was an Nd sintered magnet with a Br of 1.3 T.

Magnets were inserted into the rotor, and the surface magnetic flux density at the center of the pole was measured. A conventional rotor was also fabricated for comparison, and the same evaluation was performed. The results, shown in Figure 1, indicate that the surface magnetic flux density of the sintered magnet was higher than that of the bonded magnet. However, both magnets experienced similar flux increases, as the amount of magnetic leakage in the bridge was the same for both types of magnets.

[Acknowledgement]
This research was supported by a Green Innovation Fund subsidy project (JPNP21026) of the New Energy and Industrial Technology Development Organization, which is a national R&D agency.

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[2] N. Hamada et al., Mater. Trans., 64 (2023) 1058.
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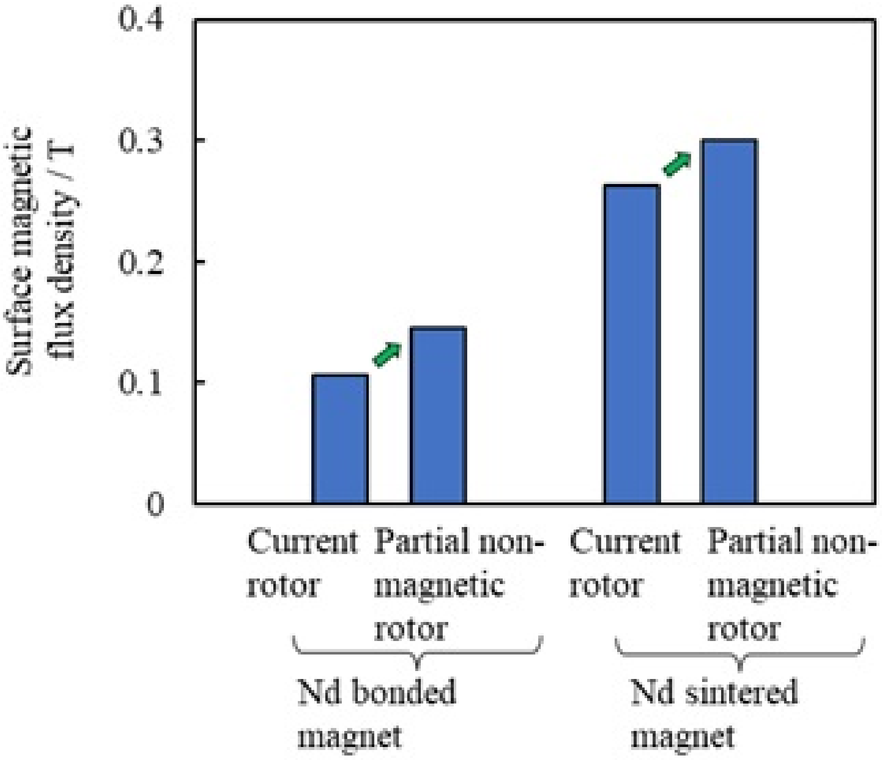

Fig. 1 Surface magnetic flux density of non-magnetic improved rotors using various magnets, compared with current rotor.

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[P1-41] Development of 200,000rpm SPM small motor using rare earth anisotropic bonded magnets

Takenobu Yoshimatsu[1], *Chisato Mishima[1], Eiki Kikuchi[1], Yoshinobu Honkura[1], Junichi Asama[2] (1. MagDesign corporation (Japan), 2. Shizuoka University (Japan))
Keywords：SPM motor、anisotropic bonded magnet、High speed rotation

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1.Background
With the expansion of the robotics and medical industries, increasing the efficiency and weight reduction of small SPM (Surface Permanent Magnet) motors has become an important issue. High speed rotation of motors is an important to achieve this, but when NdFeB-based sintered magnets are used, it is difficult to achieve high speeds due to the large eddy currents loss. We have found that a coreless distributed winding SPM motor using rare earth anisotropic bonded magnets with a motor structure of 200,000rpm, can achieve twice the performance of a conventional motor.

2.Experiment method
1) Prototype SPM type rotor
Rare earth anisotropic bonded magnets were integrally molded into a steel rotor shaft using a vertical injection molding machine and a magnetic molding die. The molding temperature was 275°C and the molding pressure was 1425Pa. Polar anisotropic orientation and magnetization of anisotropic bonded magnets were performed simultaneously during injection molding using polar anisotropic molds made from permanent magnets. To improve the centrifugal force resistance, the rotor shaft surface was knurled, shot blasted, and coated with adhesive. The 200,000rpm test was performed using a high-speed rotary tester with an air turbine.
2)Computer design of SPM motors
The motor diameter, magnet diameter, magnet length, rotation speed, current density, and clearance were set to 18mm,8mm, 15mm,200,000 rpm, 6Arms/mm^2 and 0.3 mm, respectively, and the motor structure (with and without core, winding method), yoke material, and rare earth anisotropic bonded magnetic material were examined for the optimum combination and optimal motor performance was investigated.

3.Experimental results
3.1 Shaft surface processing and integral molding
The rotor shaft surface used in this study was knurled to withstand centrifugal force at high-speed rotation, followed by shot blasting and adhesive coating (Fig.1). Figure 2 shows the results of surface observation by SEM (scanning electron microscope). An anisotropic bonded magnet was integrally molded into this rotor shaft and investigated in

a high-speed rotation test apparatus (Fig.3).

3.2 Polar Anisotropic Molds Using Permanent Magnets

Figure 4 shows a pole-anisotropic mold designed with Nd sintered magnets. The number of poles is four, and the magnetic circuit is designed so that the magnetic field flows pole-anisotropically. The distribution of the magnetic flux density of the magnet after integral molding was evaluated, and a roughly sinusoidal flux density was obtained (Fig.5).

3.3 High-speed Rotation Results

Figure 6 shows the results of a 200,000rpm high-speed rotation test of the above integrally molded rotor shaft. As a result, it was found that the shaft maintained a rotation speed of more than 200,000 rpm.

3.4Computer design result of motor

The calculation results show that a small SPM motor with a motor output of 140 W and a motor efficiency of 97% can be realized by using a coreless partial winding, a rare earth anisotropic bond magnet with a (BH)max of 12 MGOe(3mm thick, 4 pole anisotropic magnetization)for the magnet, and an amorphous ribbon for the yoke material. Note, the size of a commercial motor with the same output using Nd sintered magnets is twice, with a diameter of 18mm and a length of 30mm.

4.Summary

1)The performance of 200,000rpm rotation type SPM motor using rare earth anisotropic bonded magnets((BH)max12MGOe) instead of Nd sintered magnets((BH)max50MGOe) was found to achieve twice the torque for the same size.

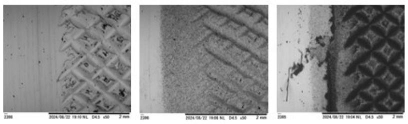
2)A four-pole anisotropic magnetized magnet was successfully molded into the rotor.

3)We succeeded in creating a rotor that can withstand the centrifugal force of 200,000 rotations.

4)Future plan: We will fabricate a motor and confirm consistency with simulation results, and aim for practical application.

Acknowledgements: This development was supported by the NEDO Energy Saving Technology Development Program (JPNP21005), and we would like to express our gratitude.

Fig.1 Rotor shaft surface processing



After knurling process After shot blasting process After adhesive coating

Fig.2 Surface observation by SEM after processing each shaft

Fig.3 Prototype rotor shaft

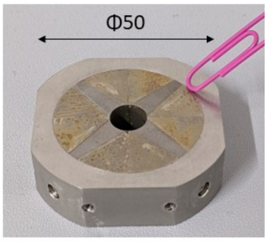


Fig.4 Polar anisotropic molds using Nd sintered magnets

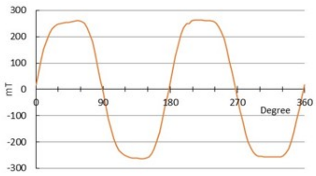


Fig.5 Magnetic flux density in sinusoidal waveform after integral molding

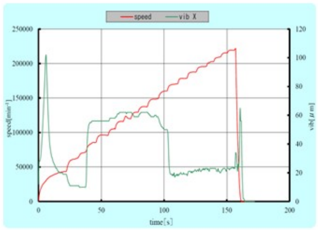


Fig.6 High-speed Rotation Test Results

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[P1-42] A new magnetization methods that supports high-performance magnets applied to IPMSMs for EV/HEV and new motors such as spoke type motor

*Michitaka Hori[1], Naoya Tomita[1], Kazuki Akiyama[1] (1. Nihon Denji Sokki Co., LTD. (Japan))
Keywords：magnetization method、high performance magnets、EV/HEV、IPMSM、spoke type motor

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Recently, the trend toward electrification of automobiles, aircraft, and other vehicles has accelerated due to regulations on carbon dioxide emissions. The interior permanent magnet synchronous motor (IPMSM) is used as the main electric motor. The permanent magnets used in IPMSMs require improved performance because the motors are used at extremely high speeds and high temperatures. Permanent magnets, the main material in EV/HEV main motors, often use neodymium sintered magnets, but there has been an issue with the reduction in coercivity due to high temperatures, including the effects of eddy currents. In addition, there is a risk of an unstable supply of heavy rare earth materials due to resource issues.

For these reasons, there is an acceleration in the development of neodymium sintered magnets, such as improving the coercivity by reducing the crystal grain size, and of samarium magnets. Along with magnet development, motor development is also being promoted to improve motor efficiency by even 1% as a measure against global warming. For IPMSMs, models with various magnet arrangements have been developed. One of these, the spoke-type motor, is attracting attention.

When magnetizing the magnets of IPMSM, there are two methods: a pre-magnetization method, in which a magnet is magnetized alone and then embedded in the rotor, and a post-magnetization method, in which an unmagnetized magnet is embedded in the rotor and then magnetized; however, the post-magnetization method is considered better from the perspective of efficiency in the production process.

However, in the case of the post-magnetization method, depending on the arrangement of the magnets, if the magnetizing magnetic field has an angle θ with respect to the orientation direction of the magnet, only the cosθ component of the magnetizing magnetic field is effective [1], so a larger magnetizing magnetic field is required.

Due to this industrial background, post-magnetization of magnets in IPMSMs is becoming more difficult every year, and the durability of the equipment used for magnetization is also becoming an issue. As one method to solve these problems, we have reported that magnetization of heated hot-deformed neodymium magnets can be performed sufficiently with a practical magnetizing magnetic field through basic experiments [2].

In this study, we propose a post-magnetization method in which IPMSMs rotors with high-performance permanent magnets are rapidly heated using induction heating, and report on the feasibility of introducing this method to rotor mass production lines based on experimental results. As shown in Figure 1, the magnetic field strength required for magnetization is reduced by 42% compared to the conventional method, and the magnetizing current required for magnetization is also significantly reduced by 73%, making it possible to improve magnetization and the durability of the magnetizer.In spoke-type motors, magnets are arranged radially toward the center of the rotor, making it difficult to magnetize them using conventional methods. For this reason, we propose a new magnetization method from the inside and outside as shown in Figure 2, making effective use of the magnetizing magnetic field that is simultaneously generated from the inner circumference using a flux barrier placed on the rotor.

In the industrial world, magnet and motor development is accelerating due to environmental and resource issues, and we will report on the latest trends in magnetization technology, which is an important element in the production process. We hope that this report will be of help in the research and development of permanent magnets and motors.

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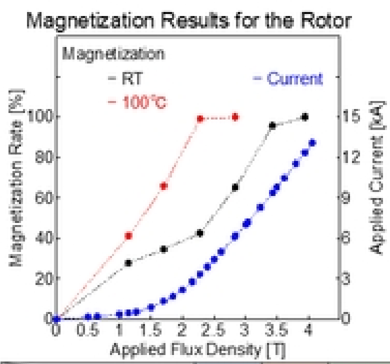
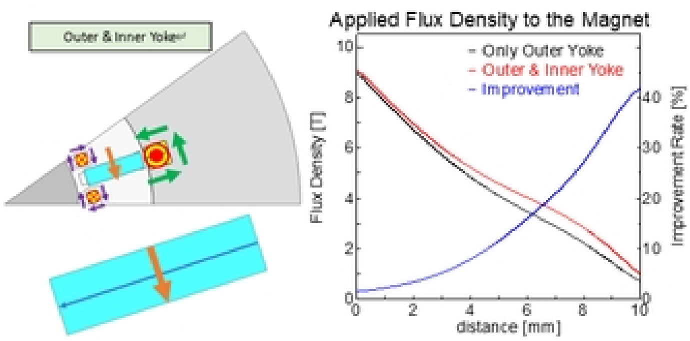
[2]. M.Hori, "Heat magnetizing method for high-performance neodymium magnets for EV and HEV motors", IEEE, Intermag, Permanent Magnet Machines IV, Permanent Magnet Machines I .2023



	RT	100°C	Reduction
Applied flux density [T]	3.95	2.28	42%
Applied Current [kA]	12.4	3.3	73%

Figure1. Experimental results showing the effect of heated magnetization (The relationship between the magnitude of magnetic flux density required for magnetization when the magnet temperature is room temperature and 100°C and the magnetization rate, and the required magnetization current at that time are shown.)



	Only Outer	Outer & Inner	Increase
Applied Flux Density [T]	0.77	1.08	41%

Figure2. Simulation results showing the effect of magnetizing the magnets of a spoke-type motor from the inside and outside

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[P1-43] Advantages of Manufacturing Radially Oriented Ring Magnets through Hot Forming and the Impact on Electrical Machines

*Martin Krengel[1], Stefan Schmülling[1], Lukas Schäfer[2], Semih Ener[2], Burçak Ekitli[2], Oliver Gutfleisch[2] (1. WILO SE (Germany), 2. TU Darmstadt / Functional Materials (Germany))
Keywords：NdFeB ring magnets、Hotforming、Synchronous Motor、Cogging torque

This paper examines the innovative manufacturing process of hot pressing and hot forming in detail. The focus is on the unique features of this process, which arise from the fact that the anisotropy or orientation of the magnetic materials is not achieved through an external magnetic field in a press, as is conventionally done. Instead, a thermo-mechanical orientation is applied, which can be varied through a specially chosen pressing direction. Instead of the usual forward or backward extrusion, this paper employs transverse pressing relative to the cylinder axis. Figure 1 illustrates this setup.

This distinctive approach allows the creation of magnet geometries that are oriented in such a way, through the selection of punch geometry that they induce extraordinary effects in air gap induction (Examples of punches in Figure 2). These effects are particularly advantageous for use in high-performance electrical machines, as they can significantly enhance the efficiency and performance of these devices.

Figure 3 shows the two-dimensional cross section of a small electric motor with a rated power of 90W for heating applications. The stator has 6 slots and 3 phases. It is equipped with a tooth coil winding providing a fundamental 4-pole flux distribution. The rotor consists of an anisotropic ring magnet and back iron, pressed onto a stainless-steel shaft. The radially oriented ring provides a rectangular flux distribution within the airgap region. The advantage of those magnets is a higher power density compared to injection moulded or compression moulded isotropic solutions. Due to the rectangular flux density cogging torque and noise often becomes a problem. A common measure to reduce noise and vibration is skewing. Skewing allows to reduce harmonics but also effects the peak torque and efficiency of a motor.

Figure 4 shows the same motor with a special shaped anisotropic ring. This ring can be manufactured by transverse hot forming (c.f. Fig. 1 and Fig. 2). The stator shows no major difference in flux distribution. Nevertheless, the airgap induction becomes more sinusoidal without loss of performance. While keeping the motor performance constant, the shape provides significant reduction in cogging torque and vibration. While the overall torque is reduced by 3% from 400 mNm to 388 mNm, cogging torque is reduced by 163%.

Transverse hot forming offers many possibilities to affect the properties of magnets directly. On possibilities is to improve the motor behaviour regarding noise and vibration by improving the shape of a ring magnet.

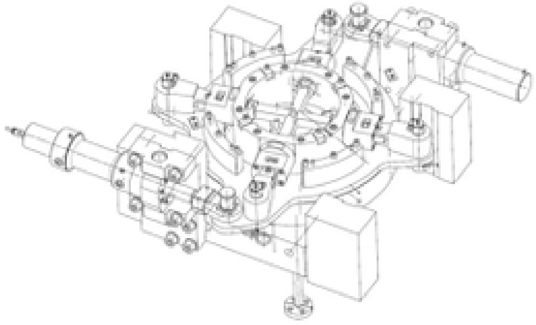

Fig. 1: Transversal pressing device with 4 punches

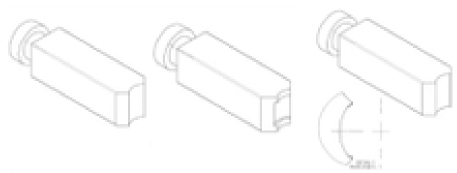

Fig. 2: Various examples of transverse pressing punch contours

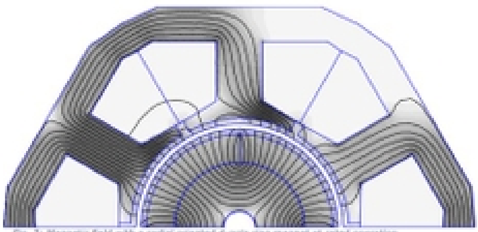

Fig. 3: Magnetic field with a radial oriented 4-pole ring magnet at rated operation

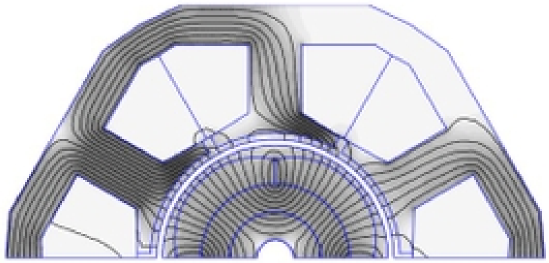

Fig. 4: Magnetic field with a special shaped 4-pole ring magnet at rated operation

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[P1-44] Design Considerations for Post Assembly Magnetising of Permanent Magnet Rotors

*Matthew Joseph Swallow[1] (1. Bunting Magnetics Ltd (UK))
Keywords：Magnet、Magnetising、Rotor、NdFeB

This presentation details the design considerations and the influence of magnetic material choice on the ability to magnetise a permanent magnet assembly. Initially the presentation focuses on the magnetisation characteristics of NdFeB and SmCo. This is followed by the impact of the way that the permanent magnets are arrayed and the influence that this has on the required electromagnetic field. Finally a series of examples derives a general rule for the magnetising of rotating magnetic assemblies in either NdFeB or SmCo.
The paper is presented by Matthew Swallow, The Technical Product Manager for Bunting Magnetics and former Chair of the UK Magnetics Society

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Presentation Content

1. Introduction - Bunting Magnetics
2. Post Assembly Magnetisation – What are the Issues?
3. Saturation Field of Permanent Magnets
4. Modelling of unsaturated regions
5. IPM and Halbach Rotor Examples
6. Conclusions

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[P1-45] Formation of ferromagnetic clusters affecting the first-order phase transition in off-stochiometric Fe-Rh

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Keywords：Magnetocaloric application、First order phase transition

First-order phase transitions (FOPT) materials have a great potential for magnetic refrigeration application, provided a reduction of their thermal and magnetic hysteresis [1,2]. Among the magnetocaloric materials with FOPT, FeRh is usually considered as a reference system because it is a "simple" binary system with CsCl structure exhibiting large adiabatic temperature change [3]. Recently, ab-initio theory predictions have shown that slight changes in the stoichiometry of FeRh has a strong influence on the FOPT characteristics [4]. However, this theoretical prediction was never clearly shown experimentally. Here, we investigate the composition dependence of the transitional hysteresis in FeRh. We compare phase pure bulk samples produced in a similar way in order to neglect the effect of microstructure, phases, synthesis process and strain. It is shown that a Fe excess of only 1 at. % induces a ferromagnetic state in the whole temperature range (from 5 K up to T_c) for a minor portion of the sample (≈10%), while 5 at. % is enough to completely eliminate the FOPT. Element-specific X-ray magnetic circular dichroism (XMCD) measurements suggest that this ferromagnetic contribution arises from residual FeRh ferromagnetic regions. This was observed in party thanks to a novel instrument designed for advanced magnetic study, installed at the ID12 beamline of the European Synchrotron Radiation Facility in Grenoble, France. This instrument offers the unique capability to simultaneously measure element-specific microscopic and macroscopic properties related to the magnetic, electronic and structural characteristics of materials [5]. Using this capability, we probed the FOPT in FeRh, revealing the presence of residual ferromagnetic regions. Mössbauer spectroscopy further suggests that Fe antisite defects are responsible for their formation, as it demonstrates the presence of Fe atoms occupying the 1b (Rh) sites in the CsCl-type structure (see Figure). As a consequence, compared with the equiatomic composition, the slightly Fe-rich sample exhibits completely different FOPT properties, influencing the magnetocaloric performances. Thus, our study sheds light on the origin of the remarkable stoichiometric sensitivity of the FOPT behavior in FeRh. These insights have broader implications for understanding FOPT dynamics and the role of residual ferromagnetic domains [6].

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Acknowledgement
This work was supported in part by the German Federal Ministry of Education and Research (BMBF) under Grant BMBF-Projekt05K2019 and in part by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Project 405553726-TRR270.

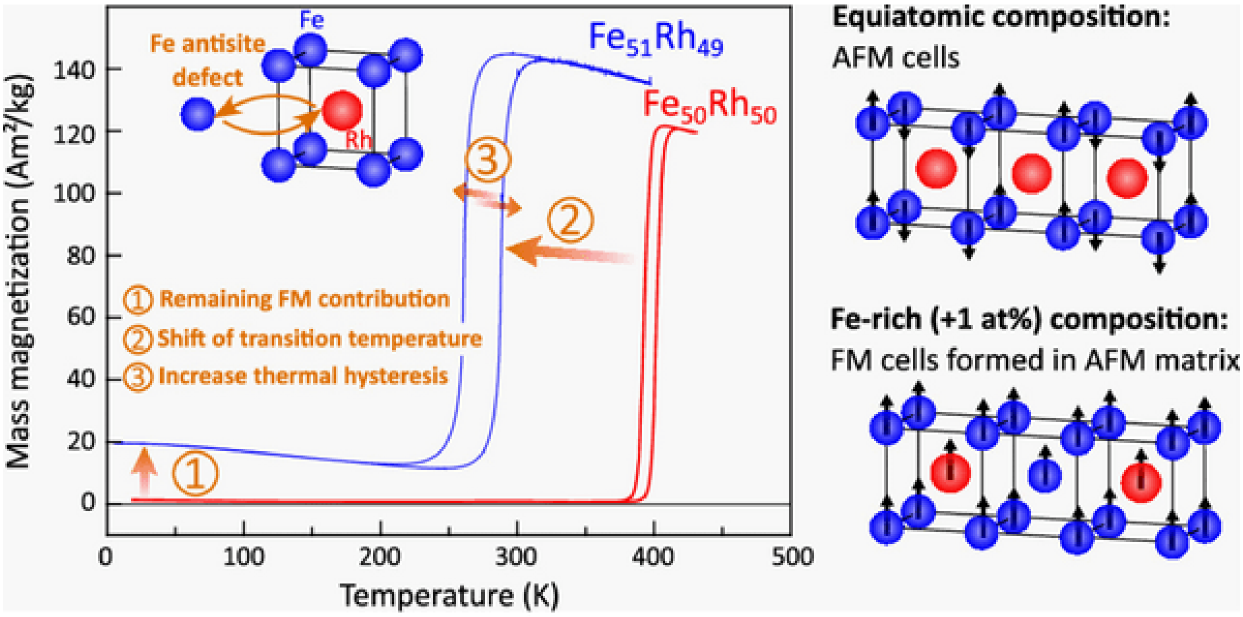

Figure: Thermal dependence of the magnetization for various Fe–Rh compositions under applied fields of 1 T and the origin of such difference

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[P1] Applications

Session Chair: Dr. Imants Dirba (Technical University of Darmstadt, Germany), Dr. Tae-Hoon Kim (Korea Institute of Materials Science, Korea)

[P1-46] A Compact 4 Tesla Permanent Magnet Field Source with Reduced Structural Complexity

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Keywords：Magnetic Field Source、Permanent Magnet Structure、Magnetic Flux Concentration、High Magnetic Field Generation、Finite Element Analysis (FEA)、Nd-Fe-B Magnet Application、Rare Earth Permanent Magnet Application

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Permanent magnet structures play a crucial role in generating magnetic fields for various applications [1]. Previous designs combining rare-earth permanent magnets and high-saturation soft magnetic materials have achieved measured fields up to 5.16 Tesla in a 2 mm gap using a 900 kg structure, which included 340 kg of permanent magnets [2]. A subsequent study theoretically predicted that a similar design with 350 kg of permanent magnets could generate a 7.4 Tesla field in a 2 mm gap [3]. More compact designs have demonstrated 4 and 5 Tesla fields in 1.5 mm (Φ6 mm) and 0.15 mm (Φ6 mm) gaps, respectively, using a 120 mm Nd-Fe-B magnet sphere composed of 192 segments, along with Fe-Co pole pieces and sample access apertures [4, 5].

We present a novel permanent magnet structure utilizing high performance Nd-Fe-B magnets (remanence: 1.45 T, normal coercivity: 1110 kA/m) and Fe-Co alloy (saturation magnetization: 2.3 T), optimized via finite element analysis (FEA) [6]. This compact design consists of 18 permanent magnet pieces and 6 Fe-Co pole pieces, with a form factor of $50\times50\times120$ mm^3 and a total weight of just 2.1 kg. Our simulations indicate magnetic fields of 4.20 Tesla in a 1.5 mm air gap ($3\times3\times1.5$ mm^3 volume) and 3.96 Tesla in a 2.0 mm air gap ($3\times3\times2.0$ mm^3 volume), as shown in Fig. 1. Compared to prior work, this design achieves a high field strength with significantly reduced size and structural complexity.

The potential applications of this compact high magnetic field source include small-sample MRI for biomedical research, magnetic manipulation of biological materials, and quantum computing/spintronics for qubit control. It may also support material and component testing, diagnostics, and magnetic field research for fusion reactor processes, among other possibilities.

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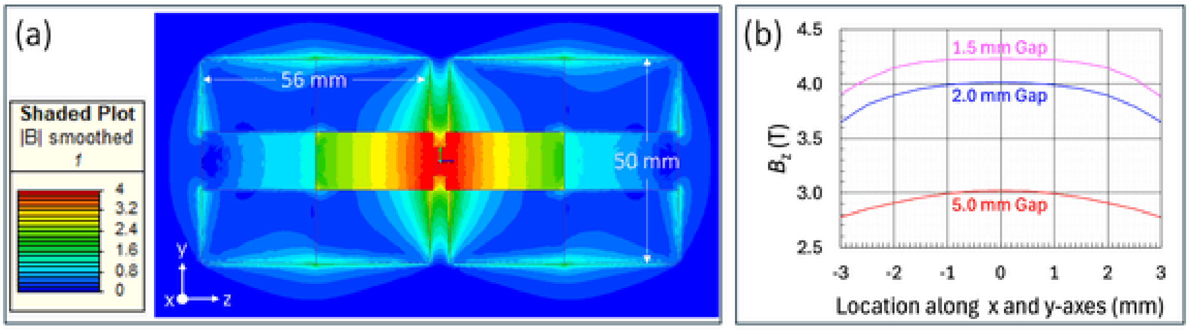

Fig. 1. (a) Magnetic flux density map of B_z in the (x=0, y=0) central planes with a 1.5 mm air gap of the compact 4T permanent magnetic field source. (b) Magnetic flux density B_z in the air gaps of 1.5 mm, 2.0 mm, and 5.0 mm as a function of location along the x and y-axes.

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[P1] Applications

Session Chair: Dr. Imants Dirba (Technical University of Darmstadt, Germany), Dr. Tae-Hoon Kim (Korea Institute of Materials Science, Korea)

[P1-47] Development strategy of Fe-Cr-Co alloy powder for high-performance microwave absorbers and noise suppression sheets

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Keywords：Fe-Cr-Co、Microwave absorption、Noise suppression、permeability、core-shell

One way to suppress electromagnetic interference is to use microwave absorption materials (MAMs) and noise suppression sheets (NSSs) made from magnetic materials [1]. Although spinodal decomposition material of Fe-Cr-Co alloys have been extensively studied as permanent magnetic materials, there have been no report to date concerning the utilization of Fe-Cr-Co alloy as microwave absorbers. We have proposed Fe-Cr-Co alloy powder as an alternative material for MAMs and NSSs [2-4]. This study outlines the development strategy of Fe-Cr-Co alloy for producing high-performance MAMs and NSSs, ranging from spherical powders to flakes, to core/shell structured flaky Fe-Cr-Co/Co ferrite powders.

Spherical gas-atomized powder (< 45 μm) of Fe-25mass%Cr-12mass%Co-1.5mass%Ti was subjected to a step-aging treatment consisting of heat treatment at 655°C for 80 min, continually at 620°C for 1 h and 600°C for 2 h, then subsequently quenched in ice water (denoted as Sphere). The step-aged sample was ball-milled at 200 rpm for 3 h to produce optimal flaky shape powder (Flake). To fabricate the core/shell structured powder, cobalt ferrite was deposited onto flaky Fe-Cr-Co powder (Flake/Co-ferrite) by sputtering. Consequently, Sphere, Flake, and Flake/Co-ferrite were mixed with epoxy resin, respectively, with volume ratio of 56:44 to fabricate resin composite samples for evaluation of their microwave absorption and noise suppression properties. The power dissipated in a magnetic material is due to magnetic loss can be expressed as P = $\omega\mu_r{}^2H^2$ [5], H is external magnetic field and ω is angular frequency ($\omega = 2\pi f$). Herein, the parameter $\omega\mu_r{}^2$ was used to evaluate the noise suppression properties in the frequency range of 0.1–40 GHz.

In our previous study, it is demonstrated that the relative permeability (μ_r) of the resin composites of spherical Fe-Cr-Co alloy powders can be tuned by step aging at different final aging temperatures, which is contributed by ferromagnetic FeCo-rich (α_1) phase particles with single-domain structure induced by spinodally decomposed Fe–Cr–Co alloy powder [2]. However, the value of μ_r decreased with the decrease of step-aging temperature. To improve the μ_r, we flattened the spherical powder into flakes, which significantly improved the μ_r and enhanced the microwave absorption [3] resulting from

the microstructural changes in both the powder and α_1 phase owing to the excellent ductility of the Fe-Co-Co alloy [6]. Recently, we have successfully fabricated the resin composites of flake/Co-ferrite powders with core/shell structures, aimed at further improving microwave absorption performance [4].

The noise suppression performance using magnetic loss represented by $\omega\mu_r^2$ was shown in Fig. 1. Compared with the resin composite of sphere, the resin composite of flake exhibited higher $\omega\mu_r^2$ between 0.1-15 GHz, suggesting higher magnetic loss ability in this frequency range. On the other hand, the resin composite of flake/Co-ferrite showed enhanced $\omega\mu_r^2$ values at 5-40 GHz. It can be attributed to the combination of microstructural changes in the Fe-Cr-Co flake and the high magnetic anisotropy of the shell of Co-ferrite. This promising finding demonstrates the potential of using Fe-Cr-Co alloy powders for microwave absorption and noise suppression up to 40 GHz.

Acknowledgements
This work was supported by JSPS KAKENHI Grant No. JP19H05620 and the Development of Technical Examination Services Concerning Frequency Crowding program, MIC, Japan.

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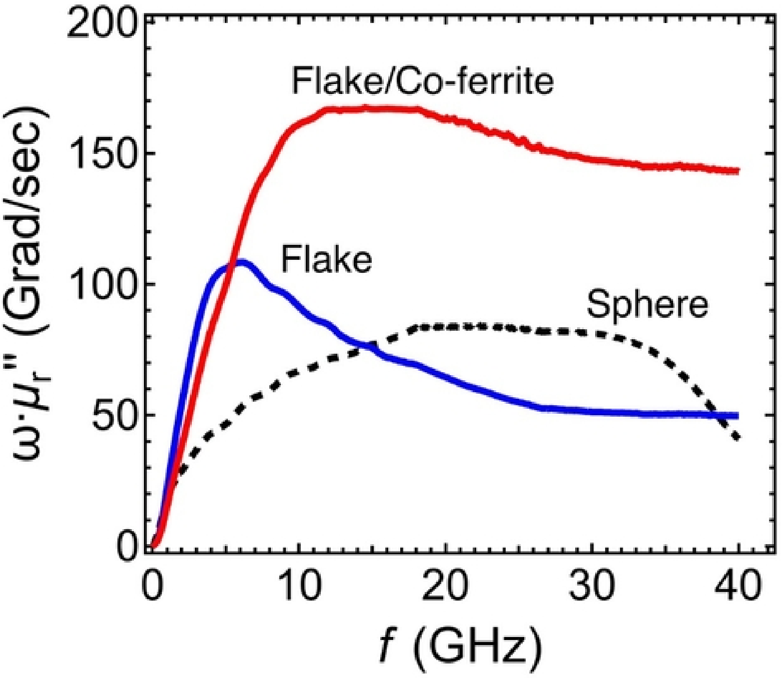

Fig. 1. Frequency dependence of $\omega\mu_r''$ for resin composites using Fe-Cr-Co alloy powder with spherical (Sphere), flaky (Flake), and core/shell structures (Flake/Co-ferrite), respectively.

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[P1] Applications

Session Chair: Dr. Imants Dirba (Technical University of Darmstadt, Germany), Dr. Tae-Hoon Kim (Korea Institute of Materials Science, Korea)

[P1-48] Development of $RE_2(Fe,Co)_{14}B$ (RE = rare-earth) compounds for transverse thermoelectric applications

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Keywords：permanent magnets、anomalous Nernst/Ettingshausen effect、transverse thermoelectrics

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Development of new permanent magnets are in high demand for the use in transverse thermoelectric generation (TEG), as their strong remanent magnetization and high coercivity allow TEGs to operate without requiring an external magnetic field. Recently, TEGs based on the anomalous Nernst effect (ANE) has received much interest because of simple lateral device structures and its intriguing physical mechanisms [1-3]. Moreover, the performance of transverse thermoelectrics has improved significantly by developing a multifunctional composite magnet (MCM) using $SmCo_5/Bi_{0.2}Sb_{1.8}Te_3$ multilayers, with the resulting MCM thermopile module generating a maximum power of 204 mW at a temperature difference of 152 K, comparable to commercial thermoelectric modules utilizing the Seebeck effect [4]. These findings strongly motivate further exploration of new materials design and investigations into the application of permanent magnets for transverse thermoelectric conversion.

In this work, we have explored the potential of $RE_2Fe_{14}B$ (RE=Tb, Dy, Ho, and Nd) and $Nd_2(Fe_{1-p}Co_p)_{14}B$ (p = 0 - 1) compounds and systematically investigated the transverse thermoelectric properties at room temperature. The detailed crystal structure and chemical composition analyses of the alloys showed the polycrystalline 2:14:1 as the main phases in all samples with some minor secondary phases such as α-Fe or RE-rich phases for all the samples [5]. The transverse thermoelectric signals were measured by a lock-in thermography technique with external magnetic field of ±1 T. We obtained the negative anomalous Nernst coefficient S_{ANE} for all the $RE_2Fe_{14}B$ alloys regardless of the RE element and the highest negative $S_{ANE(14T)}$ of -0.67×10^{-6} VK^{-1} for $Tb_2Fe_{14}B$ among them, which is comparable to that of the commercial $Nd_2Fe_{14}B$ sintered permanent magnets with an optimized microstructure [2]. The substitution of Co for Fe site in $Nd_2(Fe_{1-p}Co_p)_{14}B$ alloys causes sign reversal (from negative to positive) of S_{ANE} values. The transverse thermoelectric conductivity is responsible for the sign change in S_{ANE} values. As a result, the $Nd_2(Fe_{0.4}Co_{0.6})_{14}B$ alloy shows the highest positive $S_{ANE(14T)}$ of $+1.87\times10^{-6}$ VK^{-1}, revealing that the RE and 3d transition metal elements play the distinct roles on the transverse thermoelectric performance in $RE_2(Fe,Co)_{14}B$ compounds.

Furthermore, we have developed the $Nd_2(Fe_{0.4}Co_{0.6})_{14}B$ permanent magnet to realize the high coercivity for zero field ANE device operations. The hot-pressed magnets were processed through the grain boundary diffusion process (GBDP) using $Pr_{80}Cu_{20}$ (~5wt.%) as a diffusion source for $Nd_2(Fe_{0.4}Co_{0.6})_{14}B$ alloys at optimized heat-treatment conditions. The GBDP samples had a fine grain with rare-earth (RE) rich IGP phases at grain boundaries. The formation of such non-ferromagnetic IGP reduces the intergranular exchange coupling, which results in increase in coercivity [6]. The GBDP sample shows $S_{ANE\ (0T)}$ of $+2.33\times10^{-6}$ VK^{-1} measured at remanent state, which is higher than that of the ingots. These developed $Nd_2(Fe_{0.4}Co_{0.6})_{14}B$ permanent magnets excelled the promising transverse thermoelectric properties, which can be scale-up the zero field ANE power generation applications [3].

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[P1] Applications

Session Chair: Dr. Imants Dirba (Technical University of Darmstadt, Germany), Dr. Tae-Hoon Kim (Korea Institute of Materials Science, Korea)

[P1-49] Coercivity mechanism of rare earth-free Cr substituted $Mn_{1-x}Cr_xAlGe$ for “thermoelectric permanent magnet” applications

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Keywords：Rare earth free magnet、Transverse thermoelectric、Coercivity mechanism

Permanent magnets are crucial materials for the decarbonization of society, being used in key applications such as electric motors and electric generators. Since their discovery, the permanent magnet market has been dominated by high-performance rare earth (RE) based magnets using RE elements such as Nd, Dy, and Tb. However, the increasing demand and scarcity of some heavy RE elements have raised interest in the development of alternative magnets for specific applications that are low in and/or free of RE elements.

Recently, a new application has been reported for permanent magnet materials related to efficient thermal management making use of the thermoelectric cooling effect [1]. For this, an artificially tilted multilayer device combining a thermoelectric material such as $Bi_{88}Sb_{12}$ with an anisotropic permanent magnet such as $Nd_2Fe_{14}B$ can achieve high transverse thermoelectric conversion performance, reaching record high normalized power density among transverse thermoelectric modules [2]. The use of permanent magnets with finite remanence and coercivity has eliminated the need for an external magnetic field to operate transverse thermoelectric generation based on the anomalous Nernst effect (ANE). Based on this new application, there is room to explore the potential of permanent magnets that are not necessarily among the commercially available permanent magnets but have excellent thermoelectric properties.

In this study, we investigated the potential of bulk MnAlGe-based compound for the “thermoelectric permanent magnet” application. This system is one of the only four uniaxial ferromagnetic materials reported until now with a negative anomalous Nerst coefficient at room temperature, together with $Nd_2Fe_{14}B$-type, MnGa-type [3], and MnBi-type magnets [4]. The MnAlGe system has been shown to have an enhanced uniaxial anisotropy from 2.5×10^5 J/m^3 up to 7.3×10^5 J/m^3 in thin films by Cr substitution of Mn [5]. This material has also been reported to have an increasing negative anomalous Nerst coefficient of up to -0.5 μV/K with the substitution of Mn by Cr in thin films [3]. However, there is no report on their performance in the bulk form.

In this work, we explored the development of permanent magnet properties of the bulk $Mn_{1-x}Cr_xAlGe$ system for x ranging from 0 to 0.5 and its transverse thermoelectric properties. The bulk isotropic magnets were produced by induction melting and casting the pure constituents followed by melt-spinning, hammer-milling, and hot pressing to obtain nearly fully dense magnets. The parameters of each process were kept the same for all compositions to better compare the effect of Cr substitution in the final properties. X-ray diffraction confirmed that the hot-pressed magnets are composed of a single phase identified as the C38 MnAlGe phase. SEM-EDS analysis verified the target Cr-Mn ratio; however, all samples exhibited a slight Ge depletion. Based on SEM observations, it has been confirmed that the samples exhibit a comparable microstructure characterized by a broad range of grain sizes extending from less than 1 μm to up to 10 μm.

An analysis of the transverse thermoelectric properties by lock-in thermography shows an increase of the ANE coefficient when substituting Mn by Cr, having a maximum value of -0.74×10^{-6} VK^{-1} for $x = 0.1$, decreasing with further substitution of Cr by Mn. On the other hand, the Seebeck coefficient presents a maximum value of 18.5×10^{-6} VK^{-1} for $x = 0.2$. SQUID-VSM measurements show a trend of the coercivity with Cr content similar to that of the Seebeck coefficient, reaching a maximum value of 1.18 T for $x = 0.2$, followed by a decrease for higher concentrations of Cr. The saturation magnetization presents a similar trend to the coercivity, while the remanent magnetization is almost constant for all compositions around 50% of the saturation magnetization, as expected from isotropic magnets. Focusing on the curve of first magnetization, samples with a Cr concentration of 0.2 or greater show a kink, typically associated with magnetic domain pinning, which was studied based on detailed microstructure characterizations and magnetic domain observations. In this talk, we will discuss the transport properties of bulk $Mn_{1-x}Cr_xAlGe$ magnets along with their coercivity mechanism.

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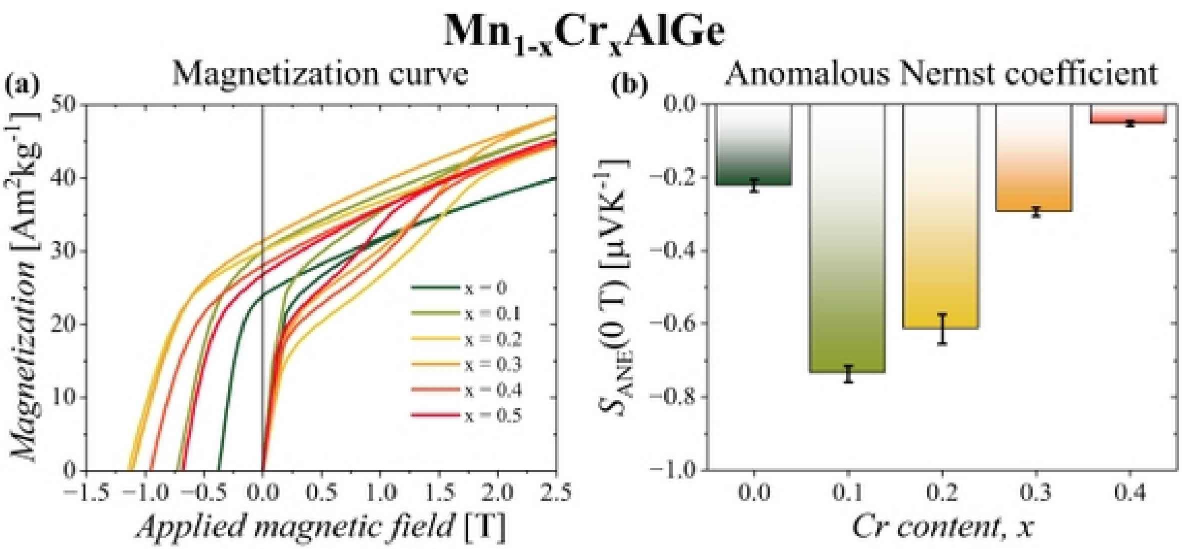

Figure 1- Curve of first magnetization and demagnetization curve (a) and the ANE coefficient (b) for the Cr substituted MnAlGe magnets.