



Press Release

28 January 2026

Designing efficient magnets for electric motors

How defects determine the strength and stability of permanent magnets is now published in the journal Nature Communications

At a glance:

- **Research topic:** Researchers identified the atomic-scale features that make high-performance samarium-cobalt permanent magnets stronger and more stable.
- **Key finding:** The strongest magnets contain an ultra-thin copper-rich layer, just one to two atoms thick, at a critical internal phase.
- **Relevance:** This atomic-scale “perfect defect” suppresses demagnetisation, improving reliability and efficiency in electric motors and generators.
- **Approach:** The team combined atom probe tomography, magnetic measurements and computer modelling.

Rare-earth magnets are essential for electric motors in vehicles, drones, and trains, forming the backbone of modern, environmentally friendly mobility. The strength and stability of those magnets determine the efficiency and reliability of the motor or generator. An international research team led by the Technical University of Darmstadt and the Max Planck Institute for Sustainable Materials (MPI-SusMat) compared the microstructure of high- and medium performance samarium-cobalt magnets and revealed that ultra-thin layers of copper determine the strength of the high-performance magnets. They published their latest findings in the journal Nature Communications.

Atomic-scale copper layers increase magnetic properties

“We used atom probe tomography to compare the chemical composition of high- and medium performance samarium-cobalt magnets that appeared structurally similar. However, at the nanoscale differences showed up. We were able to reveal that the strongest magnets have an ultra-thin copper-rich layer located at a critical internal phase”, explains Prof. Baptiste Gault, group leader at MPI-SusMat and a corresponding author of the publication. Phases are tiny building blocks each with its own crystal structure, chemistry and physical properties. The copper-rich layer in the $\text{Sm}_2(\text{Co,Fe,Cu,Zr})_{17}$ magnets is only one to two atoms thick and acts as an effective pinning barrier, suppressing demagnetization and enabling reliable operation under extreme conditions.

Grain boundaries play a minor role for magnetic performance

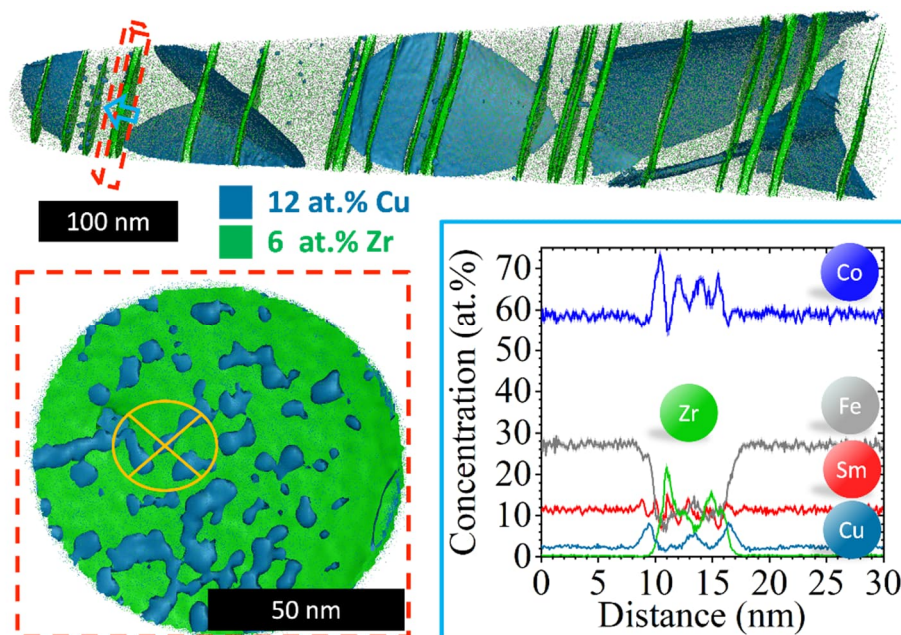
Another important finding concerns the so-called grain boundary, which separates regions within a crystal that have different orientations but otherwise the same crystal structure. For a long time, grain boundaries were considered to be the weak link at which demagnetization begins. Now, the researchers have discovered that grain

boundaries do not significantly impair magnetic performance. Rather, the real potential for improvement lies in the crystalline parts themselves. There, a carefully optimized, atomic-scale nanostructure leads to stronger, more stable magnets. Thus, even tiny changes in how atoms are arranged or how elements are distributed can significantly affect the overall magnet strength and it is the specific structural features at the atomic scale that lead to improved properties of the entire material.

By comparing laboratory observations with micromagnetic computer modelling, the researchers identified the specific microstructural features, known as 'perfect defects', that are responsible for the magnet's strongest and most stable state. These theoretical insights help to explain why some areas of the magnet perform better than others and will provide valuable guidance for designing even stronger and more efficient magnets in the future without the need for slow and costly trial-and-error testing.

Combination of disciplines and approaches is pivotal

The international research team works within the Collaborative Research Center "HoMMage" funded by the German Research Foundation. The study highlights how the combination of complementary expertise across institutions and disciplines was essential to achieve a holistic understanding of how magnets draw their properties from the interplay of structure and composition down to the atomic level. This work is the result of close scientific cooperation between academia and industry, involving the Technical University of Darmstadt, Max Planck Institute for Sustainable Materials, Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, University of Glasgow, VACUUMSCHMELZE GmbH & Co. KG, Center for Nanointegration Duisburg-Essen and the University Duisburg-Essen. The published manuscript is also a summary of a pilot project in the framework of the collaborative research centre.



Atom probe reconstruction showing the distribution of the main phase within a SmCo permanent magnet. In the red box is a close-up on one of the Z-phase plates, and the blue



isosurface shows the presence of Cu on the interface, which is also marked by arrows in the profile through this phase. The Cu partitions to the so-called 1:5 phase that helps with better separating the magnetic contributions of the individual grains of the so-called 2:17 hard magnetic phase, making the magnet stronger. Adapted from: Nature Communications 16 (2025) 11335. DOI: <https://doi.org/10.1038/s41467-025-67773-7>

Original Publication

S. Giron, N. Polin, E. Adabifiroozjaei, Y. Yang, A. Kovács, T. P. Almeida, D. Ohmer, K. Üstüner, A. Saxena, M. Katter, F. Maccari, I. A. Radulov, C. Freysoldt, R. E. Dunin-Borkowski, M. Farle, K. Durst, H. Zhang, L. Alff, K. Ollefs, B.-X. Xu, O. Gutfleisch, L. Molina-Luna, B. Gault, K. P. Skokov: Identifying grain boundary and intragranular pinning centres in $\text{Sm}_2(\text{Co,Fe,Cu,Zr})_{17}$ permanent magnets to guide performance optimisation. Nature Communications 16 (2025) 11335
<https://doi.org/10.1038/s41467-025-67773-7>

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