Max-Planck-Innovation

Technology Offer

Rare Earth Metal-free Hard Magnets

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Abstract

This technology pertains to rare earth metal-free hard magnets with hexagonal or trigonal crystal symmetry. The magnets consist of ternary intermetallic compounds with the general composition $X_aX'_bY_cZ_d$, where X and X' are 3d transition metals, Y is a 4d or 5d transition metal, and Z is a main group element of groups 13, 14 and 15. The compounds exhibit high uniaxial magnetocrystalline anisotropy, making them suitable for permanent magnetic materials with high coercive fields. These magnets offer an environmentally friendly alternative to current rare-earth-based magnets while maintaining desirable magnetic properties.

Background

Rare-earth-based magnets, such as Sm-Co and Nd-Fe-B, are the most widely used permanent magnets due to their high performance. However, they rely on rare earth elements, which are limited in availability and subject to political constraints. Additionally, these magnets face issues like corrosion susceptibility and limited service temperatures. Existing alternatives, including ferrites, ALNICO, and MnAl-based magnets, offer limited performance, such as lower coercivity and mechanically stability. Therefore, developing high-performance, rare-earth-free hard magnetic materials is crucial to overcome these challenges and meet the increasing demand for advanced magnetic materials.

Technology

This technology involves the creation of rare earth metal-free hard magnets using ternary intermetallic compounds with hexagonal or trigonal crystal structures. The compounds follow the general formula $X_aX'_bY_cZ_d$, where X and X' are 3d transition metals (e.g., Mn, Fe, Co, Ni), Y is a 4d or 5d transition metal (e.g., Ru, Pt, Pd, Pt, Ir, Ag, Au, Nb, Ta), and Z is a main group element of group 13, 14 and 15 (e.g., Al, Ga, In, Ge, An, As, Sb, Bi). Adjusting the sum of the composition parameters a, b, c and d between 3.0 and 4.0 provides high uniaxial magnetocrystalline anisotropy, crucial for strong magnetic performance.

These magnets are produced using a sputtering technique, depositing thin films onto substrates in a vacuum chamber. After deposition, the thin films are vacuum-annealed to enhance their crystal structure and magnetic properties, followed by slow cooling to room temperature. To protect the films from oxidation, a 2 to 3 nm aluminum layer is deposited. By adjusting the deposition parameters, the crystal structure can be tuned, with lower temperatures favoring a hexagonal structure and higher temperatures promoting a tetragonal half-Heusler phase. Epitaxial growth on substrates like sapphire (Al_2O_3) ensures the desired crystal orientation. This method enables the production of high-coercivity magnetic films ($B_c = \mu_0 H_c \geq 0.05$ T) with tunable magnetic properties.
Depending on the composition, sintering or bonding methods can also produce bulk magnets. Sintered magnets are formed through pressure molding and heating, while bonded magnets involve mixing the intermetallic compounds with binders and molding at elevated temperatures.

Various materials have already been successfully synthesized. For instance, $Mn_{2.6-x}Fe_xGa_{1.4}$ films were epitaxially grown on STO substrates, as shown in Fig. 1 (a). Figure 2 demonstrates the magnetization and coercivity as a function of iron concentration, highlighting the direct impact of compositional variations on the magnetic behavior as well as the competitiveness of the material.[1]

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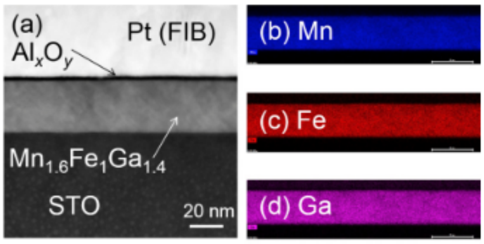

Fig. 1. (a) Cross section STEM image, and corresponding elemental mapping of (b) Mn, (c) Fe, and (d) Ga.[1]

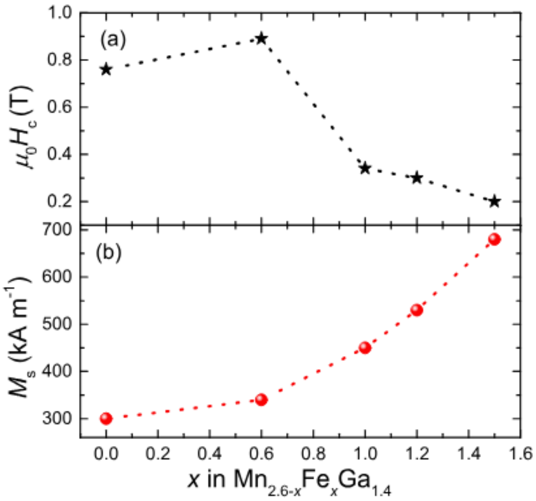

Fig. 2. Dependence of saturation. Magnetization Ms and coercivity µ0HC at 300 K in Mn2.6-xFexGa1.4 upon the Fe substitution x.[1]

Advantages

- Free of rare earth elements, reducing supply risk and environmental impact.
- High uniaxial magnetocrystalline anisotropy, suitable for advanced magnetic applications.
- Tunable magnetic properties through compositional adjustments.
- Compatible with thin-film fabrication for integration into micro-scale devices.
- Suitable for high-temperature applications with minimal degradation in magnetic performance.

Potential applications

- Spintronics: Suitable for devices requiring high perpendicular magnetic anisotropy.
- Electric Vehicle Motors: Providing efficient, environmentally friendly alternatives to rare-earth magnets.
- Wind Turbine Generators: Offering high-performance magnets for renewable energy applications.
- Data Storage: Integration into magnetic data storage devices requiring stable and strong magnetic fields.
- Aerospace: Lightweight, high-performance magnets for advanced aerospace technologies.

Patent Information

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Publications

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