Giant Tunability of Magnetoelasticity in Fe_4N System as a Platform to Unveil Correlation Between Magnetostriction and Magnetic Damping

Magnetoelastic properties of Fe_4N can be significantly varied by partially replacing Fe with Co or Mn. The high quality Fe_4N film exhibits large negative magnetostriction along the [100] direction (λ_{100}) of -121 ppm while $Fe_{2.3}Co_{1.7}N$ shows λ_{100} of +46 ppm. The correlation between λ_{100} and magnetic damping (α) is also found. Thanks to the tunability and the bipolarity of magnetoelasticity, magnetic nitrides are candidate materials for high-sensitive spintronic strain sensors.

Flexible electronic devices have rapidly become important in the coming trillion-sensor era. As we look at current flexible spintronics, miniaturized strain sensors exploiting the spintronic function have attracted much attention, where the magnetoelasticity linking magnetism and lattice distortion is a vital property for high-sensitive and multi-directional strain detection. Through the inverse magnetostriction effect, the magnetization vector of a magnetic material changes depending on the magnitude and the direction of mechanical stress applied to the magnet. Thus, large magnetoelastic materials and the elucidation of underlying physical mechanism are keys for the development of high-sensitive devices.

Fe_4N, a ferromagnetic iron nitride, exhibits the magnetostriction constant several times larger than that of typical ferromagnetic metals such as Fe, Co, and Ni. In addition, spintronic functions such as tunnel magnetoresistance effect have been reported for the systems with Fe_4N. These features make ferromagnetic nitrides a promising material group not only for spintronic devices, but also for flexible spintronic devices. Thus, it should be clarified to what extend the magnetoelasticity can be enhanced and controlled for the ferromagnetic nitrides in order to achieve best performance of flexible spintronic devices.

We demonstrated that the large negative magnetostriction along [100] (λ_{100}) can be achieved for the high-quality Fe_4N film, which was epitaxially grown employing the rf-assisted molecular beam epitaxy technique, and the value of λ_{100} can be significantly varied by partially replacing Fe with Co or Mn (Fig. 1). The magnitude of λ_{100} was modulated in a wide range from -121 to +46 ppm, indicating the giant tunability and bipolarity of magnetostriction in the ferromagnetic nitride [1].

We also found that the correlation between λ_{100} and magnetic damping experimentally and theoretically. The first-principles calculations

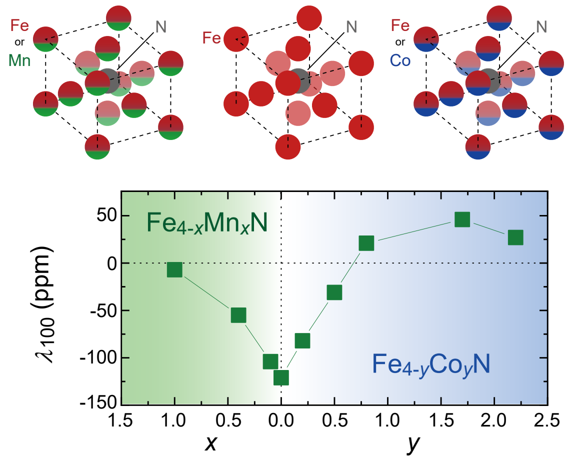

Fig. 1 Crystal structures of magnetic nitrides and the composition dependences of magnetostriction along [100] (λ_{100}) for $Fe_{4-x}Mn_xN$, Fe_4N and $Fe_{4-y}Co_yN$.

revealed that the density of states at the Fermi level [$D(E_F)$] was the leading term to determine the magnitudes for both intrinsic magnetic damping and λ_{100}, suggesting that appropriate control of $D(E_F)$ is indispensable for developing giant magnetoelastic materials. As for the correlation between extrinsic magnetic damping and λ_{100}, the magnetostriction is a source of the two-magnon scattering, resulting in the large extrinsic magnetic damping with increasing λ_{100}. We believe that the findings obtained on the Fe_4N research platform can give a guiding principle for exploring giant magnetoelastic materials, which is applicable to other ferromagnetic systems such as Co-Ni alloys [2].

References

[1] K. Ito, I. Kurniawan, Y. Shimada, Y. Miura, Y. Endo, and T. Seki, Commun. Mater. **6**, 53 (2025).

[2] I. Kurniawan, K. Ito, T. Seki, K. Masuda, and Y. Miura, Phys. Rev. B **112**, L100407 (2025).

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