Research Group for Mechanical Control of Materials and Spin Systems

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Spintronics is a subject of great current interest that will be essential in next-generation electronics. Spintronics exploits an electronic charge and spin simultaneously so as to produce novel function and electronic property devices. A central concept of the spintronics is a flow of an electronic angular momentum called spin current. In our research group, a mechanical angular momentum and nuclear angular momentum are focused on as new angular momentum source interacting with spin currents.

Observation of Barnett fields in solids by nuclear magnetic resonance

Angular momentum conversion between spins and mechanical rotation is a promising candidate of a mechanism for micro driving devices. Fundamental phenomena of the angular momentum conversion are the Einstein-de Haas effect (body rotation due to its magnetizing) [1], and the Barnett effect (magnetizing by body rotation) [2]. The Barnett effect implies that an effective magnetic field arises in a rotating body. The emergent field B_{Ω}, called Barnett field, can be derived theoretically from rotational coordinate transformation into the body-fixed frame. B_{Ω} acting on a particle is linearly depends on the angular velocity of rotation Ω:

$$B_{\Omega} = \frac{2m}{gq}\Omega,$$

where m, q, and g are mass, charge and g-factor of the particle.

To measure the Barnett field by nuclear magnetic resonance (NMR) method, the detection has to be done on the rotating frame same as the body. The reason for this is that, if there are relative velocity between the signal detector and the body (signal emitter), an extrinsic NMR frequency shift arises from the relative velocity (rotational Doppler effect). To overcome the difficulty, we developed a new detection method in NMR, and directly measured the Barnett field [3]. The detection on the rotating frame was realized by the newly developed tuning circuit that consists of a sample and detection coil both installed in the same rotor.

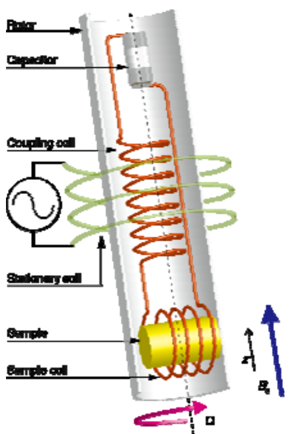

Fig. 1 An illustration of the experimental assembly.

Figure 1 shows the schematic illustration of the experimental assembly. The assembly comprises two components: the stationary coil placed along external field B_0 and connected to an NMR spectrometer, and a high-speed rotor consisting of a cylindrical capsule in which a specially arranged tuning circuit is installed. This circuit is composed of two small coils placed perpendicularly and connected in series, and a small capacitor. One of the two coils is arranged parallel to the stationary coil to establish a coupling by a mutual inductance between the tuning circuit and the stationary coil (coupling coil). The other, the sample coil, holds a sample inside. The RF field in the coupling coil is transmitted to the sample coil and generates an oscillating RF field to induce an NMR signal. Under this configuration, the sample coil rotates at exactly the same angular velocity as the sample. The rotor is put inside the stationary coil and, during measurements, it is rotated up to $|\Omega/2\pi|$=10 kHz.

In Fig. 2, we plot the ^{115}In NMR spectra at various values of the angular velocity Ω. Clearly, the NMR frequency increases linearly with Ω. Furthermore, by reversing the rotation direction, the direction of the NMR shift is also reversed; thus, the sign of B_{Ω} is reversed. The sign of the g-factor of ^{115}In is known to be positive; that is, the nuclear magnetic moment is parallel to its angular momentum. Next we measured the shifts for nuclei with negative g-factors. From the NMR spectra for ^{29}Si having negative g-factor, the direction of the NMR shift is clearly opposite to that for ^{115}In, indicating that the emergent Barnett field is opposite in direction to that for ^{115}In. These results mean that the nuclei feel additional magnetic field to the external field. It is a direct evidence for the existence of Barnett field.

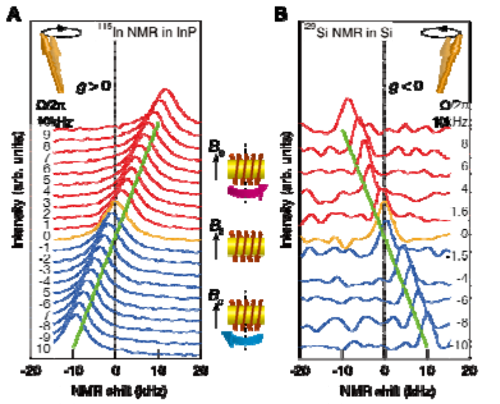

Fig. 2 NMR spectra for positive and negative g-factors. Spectra for (A) ^{115}In and (B) ^{29}Si NMR obtained at various angular velocities.

References

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[2] S. J. Barnett, Phys. Rev. **6**, 239 (1915).
[3] H. Chudo *et al.*, Appl. Phys. Eepress 7, 063004 (2014).