Spin hydrodynamic generation

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Spin current, a flow of spins, is a key concept in spintronics. Spin-current generation has been achieved by using angular momentum conversion among magnetization, photon, orbital motion of electron, and spin angular momentum. Recently, an alternative scheme has been proposed, wherein the interconversion from mechanical angular momentum into electron spins is exploited. In this study, we have theoretically proposed mechanical generation of spin current due to the interconversion between fluid angular momentum and electron spin and experimentally confirmed it by electric voltage measurement using a liquid metal flow in a narrow pipe.

Let us introduce the spin-vorticity coupling:

$$H = -S\cdot\omega/2, \quad (1)$$

where S is the electron spin and ω is vorticity of fluid given by $\omega = \nabla\times v$, with fluid velocity v. It can be interpreted as the Zeeman interaction due to the effective magnetic field since Eq. (1) can be rewritten as $H = -S\cdot\gamma B_\omega$, with $B_\omega = \omega/2\gamma$ and $\gamma = e/m$. The spin-vorticity coupling emerges universally in a rotating object [1,2] as well as local rotation motion induced in an elastic material [3] and a liquid metal [4], and plays a crucial role in the angular momentum conversion between mechanical rotation and spin. In particular, the electron spins in a liquid metal can be manipulated by the spin-dependent force due to the spin-vorticity coupling:

$$F_s = -\nabla H = S\cdot\nabla\omega/2. \quad (2)$$

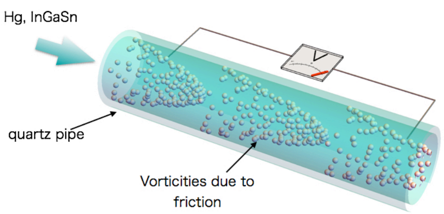

Fig.1 Experimental setup. Spin current is generated along the vorticity gradient, which is induced perpendicular to the flow velocity by applying a pulsed pressure. The spin current is converted into the charge current due to the inverse spin Hall effect. Then, the electric voltage is generated along the flow velocity.

This means that spin current can be generated along the vorticity-gradient, grad omega. This is the mechanical analogue of the Stern-Gerlach effect.

In the presence of the spin-vorticity coupling, the spin-diffusion equation is extended to the following form:

$$\left(\nabla^2 - \lambda^{-2}\right)\delta\mu_s = -\frac{4e^2\xi}{\sigma_0\hbar}\omega, \quad (3)$$

where $\delta\mu_s$ is the spin accumulation, λ is the spin diffusion length, σ_0 is the conductivity, and ξ is the conversion rate of angular momentum [4]. By solving this equation, the generated spin current is obtained as $J_s = (\sigma_0/e)\nabla\delta\mu_s$.

To confirm the spin-current generation, we used liquid metal flows of Hg and GaInSn in a narrow quartz pipe. When applying a pulsed pressure, vorticity fields are induced. The spin current is generated along the vorticity gradient, and is converted into the electric voltage due to the inverse spin Hall effect. The induced voltages are measured by the nano-voltmeter attached to the pipe.

In our setup, the solution of Eq. (3) leads to the scaling law of the voltage:

$$(r_0/L)V_{SHD} = (4e/\hbar)\times\left(\theta_{SH}\lambda^2/\sigma_0\right)\times\xi\times\left(v_*^2/\kappa\right), \quad (4)$$

where L is the pip length, r_0 is the pipe radius, κ is the Karman constant, θ_{SH} is the spin Hall angle, v_* is the friction velocity. Equation (4) indicates that the scaled signal $(r_0/L)V_{SHD}$ is proportional to v_*^2, and is fitted by a single parameter, $\theta_{SH}\lambda^2\xi$. The friction velocity dependence of the signal shows good agreement with the theoretical prediction as shown in Fig. 2.

From application points of view, the observed voltage

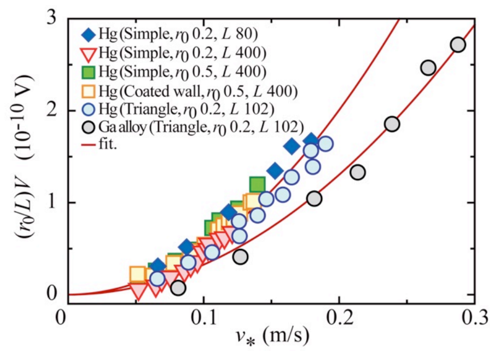

Fig.2 Scaling law of the electric voltage.

generation will be used to make an electric generator and a spin generator without using magnets. We anticipate that observed phenomena will bridge the gap between spintronics and fluid science.

References

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