# A New Drift in Spin-Based Electronics

**A symmetry-breaking mechanism allows researchers to produce and observe a directed current of magnons in a magnetic insulator, opening new possibilities in magnon-based electronics.**

By **Arabinda Haldar** and **Anjan Barman**

Demand for miniaturized, energy-efficient, and ultrafast information-processing devices continues to rise, but manufacturers are approaching the fundamental limits of the prevailing technology, which is based on complementary metal-oxide semiconductors (CMOS). One of the main barriers to progress is Joule heating: as CMOS components become faster and smaller, they suffer more from the heat that builds up because of the flow of electronic charge. Researchers have proposed circumventing this problem by doing away with moving charges altogether. Instead, information processing could be accomplished by manipulating "magnons"—quasiparticles of electron-spin excitations—in a magnetic medium. Now, Richard Schlitz at the Swiss Federal Institute of Technology (ETH), Zurich, and colleagues have taken an important step toward such a technology by showing that a magnon drift current can be induced to flow in a magnetic heterostructure [**1**].

Just as phonons represent the coherent propagation of lattice vibrations, magnons represent the collective precession of electrons' magnetic moments. In both cases, these quasiparticles move through a material even though the excitations that sustain them remain fixed within the lattice. The possibility of on-chip data processing based on magnons is stimulating a new frontier in physics called "magnonics," where a magnon current replaces the spin or charge current used in spintronic or electronic devices, respectively [**2**, **3**]. This is not a straightforward replacement, however. Whereas an electron drift current is the physical motion of charge, a magnon current represents only the propagation of the phase of collective spin precession. This difference means that the interaction of magnons with a magnetic field is not analogous to the interaction of electrons with an electric field. Rather than driving magnons through a circuit, a magnetic field only causes a change in their frequency. Instead, magnon drift currents must be manipulated by mechanisms that result from breaking the inversion symmetry of the magnetic medium.

One such mechanism is the Dzyaloshinskii-Moriya interaction (DMI), which can occur at the contact between a ferromagnetic layer and a nonmagnetic layer with large spin-orbit coupling. This interfacial DMI (iDMI) is an antisymmetric, three-site exchange interaction, where the spins of two ferromagnetic atoms interact via a nonmagnetic atom belonging to the nonmagnetic layer at the other side of the interface. As a result, the DMI vector lies in the plane of the interface, producing an asymmetric magnon dispersion that can be directly probed using an optical magnon-spectroscopy technique [**4**]. However, this probing technique cannot differentiate "pure" magnon drift currents induced by the iDMI from diffusive magnon currents driven by magnon chemical potential. As a result, clean observations of magnon drift currents have not been reported.

In a new study, Schlitz and his colleagues propose a theory of magnon transport in which the drift current contribution is added to the diffusive magnon current by including an additional asymmetric term in the equation that describes the system. The effect of this additional term is to create an anisotropy in the magnon velocity, which the team used as a way of disentangling the two contributions experimentally. They sputter-deposited a $Y_3Fe_5O_{12}$ (YIG) thin film on a (111)-oriented $Gd_3Ga_5O_{12}$ (GGG) substrate. YIG is a popular

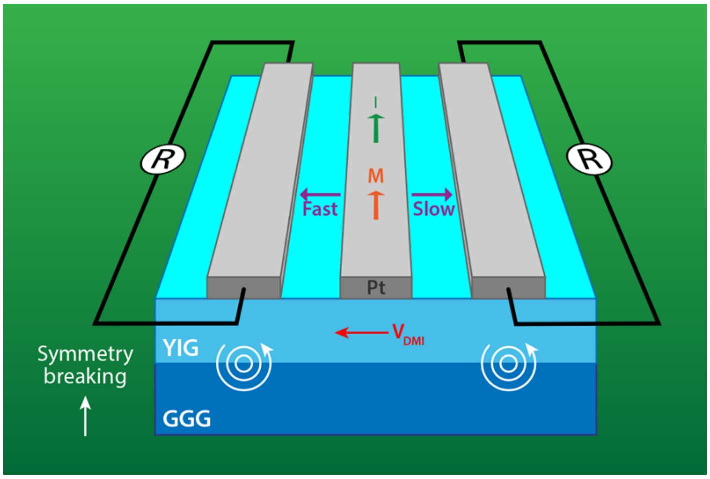

**Figure 1:** Schematic showing the experimental setup used to measure the magnon drift current. A current (I) flowing in the central platinum (Pt) wire generates a spin current in the YIG layer via the spin Hall effect. Dzyaloshinskii-Moriya interaction at the YIG-GGG interface produces an asymmetry in the propagation velocity of drift magnon current ($V_{DMI}$), which can be controlled by aligning the magnetization vector (**M**). The asymmetry is revealed as an unequal resistance measured by the two detector wires on either side of the current-carrying wire.

**Credit: A. Barman/S. N. Bose National Centre for Basic Sciences; A. Haldar/Indian Institute of Technology Hyderabad; adapted by APS/Alan Stonebraker**

ferrimagnetic oxide for such studies, as it allows long-range spin-wave propagation, while the YIG-GGG interface has been shown to generate iDMI [**5**]. Where the team's setup deviated from prior experiments is in their innovative nonlocal measurement technique. Usually, such nonlocal electrical measurements of a material are made using two physically separated contact pads. Current is sent into the material through one of the contact pads, and the material's resistance is calculated by measuring the voltage at the other contact pad. As the voltage is measured away from the current-carrying contact pad, the calculated resistance carries information on the transport properties of the material upon which the contact pads are fabricated. The problem is that the nonlocal resistance, as described by a simplified magnon transport model, arises because of the combination of both diffusion and drift magnon current in the material. As such, there is no way to tease the two effects apart in experiments.

To avoid the limitations of this conventional two-contact approach, Schlitz and his colleagues fabricated three equally spaced, parallel platinum wires on top of the YIG film (Fig. **1**). By driving an oscillating current in the central wire, they induced a magnon current in the lower YIG layer through the spin Hall effect (SHE). The SHE generates a pure spin current as a result of the flow of charge current in materials with large spin-orbit coupling, such as platinum and other heavy metals. Its inverse effect—known as ISHE—is the generation of a voltage due to the conversion of spin current to charge current. In the absence of a magnon drift current, the diffusive magnon current would generate an equal voltage at each wire, with the size of the voltage dependent on the magnetic-field strength and orientation. But a drift current would produce a voltage asymmetry. Indeed, the team found that the ISHE-induced voltage at each wire was different and that these voltages varied asymmetrically as the magnetic-field orientation was changed. From this asymmetry, the researchers were able to calculate the drift current contribution in isolation.

Schlitz and colleagues' clear demonstration of a magnon drift current is a proof-of-principle of an important phenomenon in magnonics. As such, the result opens up new possibilities, such as improved magnon-based logic and communication devices. A goal for the future will be to find material combinations that generate a stronger DMI effect than the YIG-GGG interface, which would enhance the magnon drift current. Such materials must also exhibit low levels of Gilbert damping—a phenomenon that causes spin excitations to dissipate—to allow for significant magnon propagation. But DMI might not be the only game in town: Other mechanisms of inversion symmetry breaking—such as an asymmetric or nonuniform field [**6**] and the Rashba effect [**7**]—can also be utilized to realize large magnon drift currents, and we look forward to the demonstration of such ideas.

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