Magnon Valve Effect Between Two Magnetic Insulators

Recently, a group headed by Prof. HAN Xiufeng at the State Key Laboratory of Magnetism under the Institute of Physics (IOP), Chinese Academy of Sciences reported in *Physical Review Letters* a novel type of magnon valve effect in a magnon-valve based on ferromagnetic insulators, rather than ferromagnetic metals as conventionally fabricated spin-valve structures.

Spin-valves are vital for spin-based electronic devices, such as magnetic memory and spin logic, which promise opportunity in developing smaller micro-electronic components of better reliability, lower energy consumption and higher speeds. It generally comprises a sandwich structure with a non-magnetic spacer layer imbedded between two layers of ferromagnetic metals. In this structure, the relative orientation of the two outer layers can regulate the resistance of the whole structure via influencing the spin polarized electrons transporting between the two layers of ferromagnetic metals.

Relying on spin information transport, spin-valve based structures, such as giant magnetoresistance (GMR in 1988) effect and tunneling magnetoresistance (TMR in 1995) effect have been widely used for decades in hard disk drives (HDD), magnetic random-access memory (MRAM), and magnetic sensors. The discoverers of the GMR effect, Profs. A. Fert and P. Grünberg were awarded the Nobel Prize in Physics in 2007 due to their contributions.

Magnons are quantized quasi-particles derived from the collectively excited spin wave, and each magnon carrying one unit of spin angular momentum equal to the Planck constant. Compared with conduction electrons in traditional metals, magnons have some advantages. For example, their transportation is Joule-heating free, and this is favorable for spin information propagation in long distance. Their properties as waves offer possibility in manipulating in both phase degree of freedom and magnitude, and this might further offer opportunities to break through the logic and framework set by the von Neumann architecture and hence might herald a revolution in information transport and processing beyond the Moore's law. Moreover, emerging new phenomena based on magnons, such as spin superfluid, spin superconductor, magnon Bose-Einstein Condensation, magnon Josephson Junctions and so on, are becoming hot points of research in the field of condensed matter physics. Given the key role and potential of magnons in large-scale integrated circuits, it is important to understand their spin-excited state, and develop methods to produce, manipulate and detect them.

From 2012 to 2016, the group headed by Prof. HAN Xiufeng experimentally fabricated a new spin valve type structure where a thin magnetic insulator (MI) is sandwiched by two heavy metallic (HM) layers of Pt. The MI layer was made of YIG, and the HM was Pt (HM/MI/HM). In this structure they observed the same magnon-mediate current drag effect as theoretically proposed by Prof. ZHANG Shufeng at University of Arizona: due to the magnon excitation and propagation in YIG, the spin/charge current in either of the Pt layers drags another spin/charge current in the other Pt layer.

This work demonstrated that spin information could be carried by magnons in magnetic insulators [H. Wu and X. F. Han, *et al.*, *Phys. Rev*. B 93, 060403(R) (2016)].

Based on this work, they further overcome challenges and creatively fabricated a high-quality magnon valve structure based on magnetic insulator with a layer of metal Au sandwiched by two layers of YIG: YIG/Au/YIG (MI/NM/MI). For the first time, they reported the detection of magnon valve effect in a heterogeneous system dominated by insulators: the effective magnon current transmission coefficient across the magnon valve could be controlled by the relative magnetic orientation of the two YIG layers.

They used the spin Seebeck effect (SSE) to excite the magnon current in YIG, and inversed spin Hall

Effect (ISHE) to detect the magnon current across the magnon valve. They interpreted the magnon valve effect by the angular momentum conversion and propagation between magnons in two YIG layers and conduction electrons in the Au layer. The temperature dependence of magnon valve ratio (Magnon Valve Ratio, MVR) showed approximately a power law, supporting the above magnon-electron spin conversion mechanism. By fitting the Au thickness dependence of MVR, a 15.1 nm spin diffusion length of Au was obtained, which was close to the value by spin pumping measurement. [H. Wu and X. F. Han *et al*., Magnon Valve Effect between Two Magnetic Insulators, *Phys. Rev. Lett.* 120 (2018) 097205, DOI: https://doi.org/10.1103/PhysRevLett.120.097205, Editors' suggestion & Featured in Physics].

This work conceptually proved the possibility of using magnon valve structures to manipulate the magnon current in magnetic insulators, which could be a basic building block for future magnon spintronics and could be potentially applied in magnon based circuit, logic, memory, diode, transistors, magnon waveguide, and on-off switching devices, and so on.

This study entitled "Magnon Valve Effect Between Two Magnetic Insulators" has been published on *Phys. Rev. Lett*. and was also highlighted in the journal's Editors' Suggestion and Featured in Physics.

Physics, a journal of the American Physical Society, comments on the discovery of magnon valve effect in YIG/Au/YIG sandwich structure.

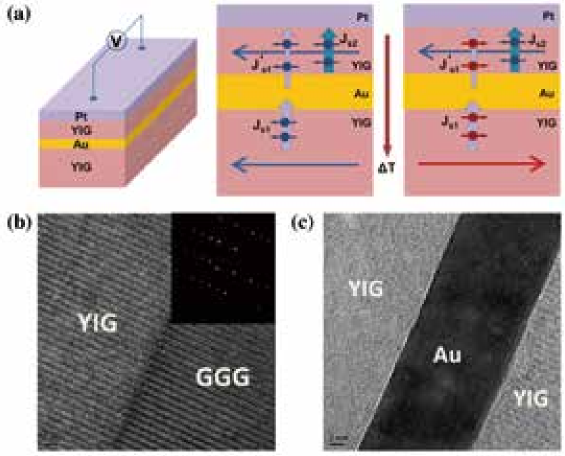

Fig. 1 (a) Illustration of the magnon valve effect. (b) The cross-sectional scanning transmission electron microscopy (STEM) of GGG/YIG interface. (c) The cross-sectional high-resolution transmission electron microscopy (HRTEM) of YIG/Au/YIG region.

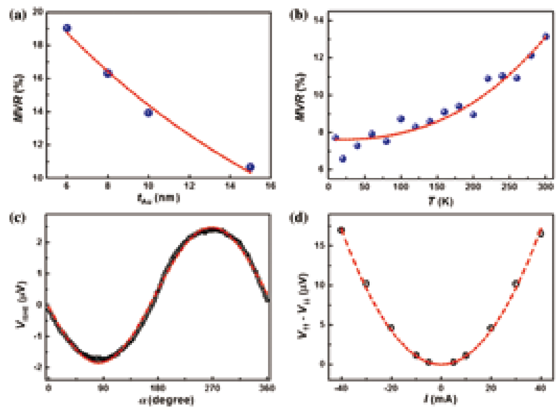

Fig. 2 (a)-(d) Thickness, temperature, magnetization direction, and heating current dependences of the magnon valve effect.

Editor of *Physics*, a journal of the American Physical Society, also commented: "Three new transistors (i.e. magnon valve) for spin-based currents may lead to a new type of circuitry that is faster and more efficient than traditional electronics." [*Physics* 11 (2018) 23]

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