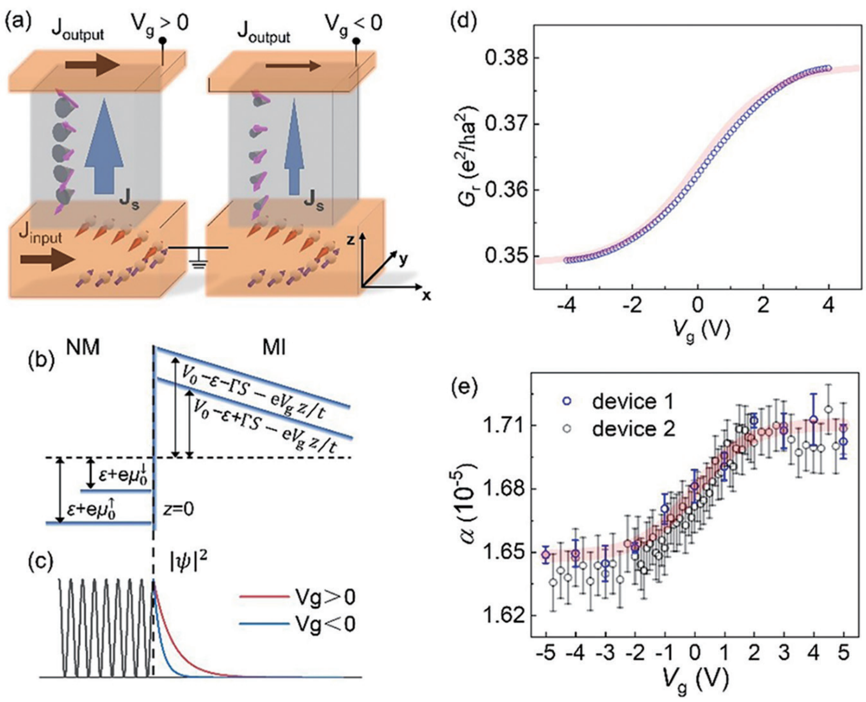
Unveil the Voltage-Controlled Magnon Transistor

Magnons, as the elementary excitations in magnetically ordered systems, are quasi-particles capable of carrying both angular momentum and phase information. They serve as ideal information carriers for the development of wave-based computing and Joule-heating-free microelectronic devices. The efficient manipulation of magnon flows, as the foundational technology for integrated magnonic circuits, has thus become a focal topic in the field of magnonics. The pursuit of efficient magnon transistors has been pioneered using magnetic fields, microwaves, stress and direct current. However, the nonlocality or significant energy consumption of the above methods hampers their usages as applicable gating sources for magnonic devices. The voltage gating method featured by its locality, low energy consumption and high CMOS and LSIC compatibility, become the optimal strategy for constructing magnon transistors. Nevertheless, the electrical neutrality of magnons hinders their direct coupling with electric fields, posing a long-term challenge in the field of magnonics for the construction of voltage-gated magnon transistors.

M02 research group from the National Key Laboratory of Magnetism at the Institute of Physics (IOP) of the Chinese Academy of Sciences (CAS), based on over a decade of magnonics studies, recently proposed an innovative solution to voltage control of magnon current. They theoretically demonstrated the physical principles of voltage-controlled magnon flow via tuning interfacial *s*-*d* coupling and experimentally inventing such a voltage-gated magnon transistor.

The proposed voltage-controlled magnon transistor



(a) Schematic diagram of the voltage-controlled magnon transistor. (b) Schematic diagram of the energy band at the bottom NM/MI interface under $V_g > 0$. (c) Schematic diagram of V_g controlled probability density of conduction electrons at the bottom NM/MI interface. (d) Numerically calculation results of V_g dependence of the real part of the spin-mixing conductance (G_r) at the bottom Pt/YIG interface and (e) experimentally measured V_g-controlled MECD efficiency (α) in Pt/YIG/Pt magnon transistor.

is based on a non-magnetic metal/magnetic insulator/non-magnetic metal (NM/MI/NM) sandwich structure, with the bottom and top NM electrodes serving as the source and drain of the transistor, respectively. An $\hat{\mathbf{x}}$ directional charge current in the source electrode is converted into a $\hat{\mathbf{z}}$ directional spin current due to the spin Hall effect. At the NM/MI interface angular momentum is then transferred from conduction electrons in NM to the local magnetic moment in MI via interfacial *s-d* coupling, thus magnons are activated. The produced magnons, driven by their density gradient, flow along the $\hat{\mathbf{z}}$ direction, forming a magnon spin current which is then converted into an $\hat{\mathbf{x}}$ directional electrical signal detected at the drain NM through the reverse spin Hall effect finally. A gating voltage at the NM/MI interface modulates the *s-d* coupling strength, thereafter influencing the spin-to-magnon conversion. In experiments, the efficiency of the magnon mediated electric current drag effect (or magnon current in $Y_3Fe_5O_{12}$) in the Pt (8)/$Y_3Fe_5O_{12}$ (80)/Pt (5 nm) magnon transistor can be controlled by applying a gate voltage between the top and bottom Pt electrodes. The controlling efficiency reaches 10%/(MV/cm), and the energy efficiency of magnon control by voltage is improved by 5 orders of magnitude compared to the previously reported direct current control methods. This prototype magnon transistor provides a novel solution for effective controlling of magnon transmission through gate voltage.

This study entitled "*Voltage controlled magnon transistor via tuning interfacial exchange coupling*" was published as "Editors' Suggestion and Featured in Physics" in *Phys. Rev. Lett.* **132** (2024) 076701 and reported as a focus story in the American Physical Society's *Physics* journal [February 16, *Physics* 17 (2024) 29]. Doctoral student WANG Yizhan is the first author of the paper, his supervisor Professor HAN Xiufeng and Associate Professor WAN Caihua are the co-corresponding authors. Doctoral students ZHANG Tianyi, DONG Jing, CHEN Peng, and Professor YU Guoqiang contributed to the theoretical and experimental aspects of this work.

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