Ferromagnetic Interface Engineering of Spin-Charge Conversion in RuO_2

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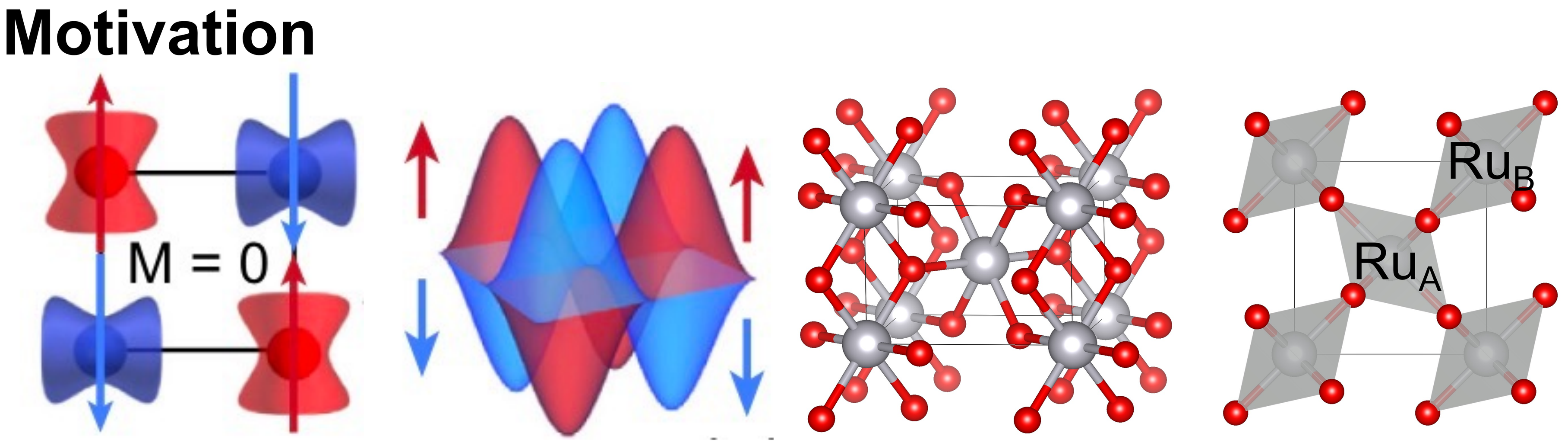
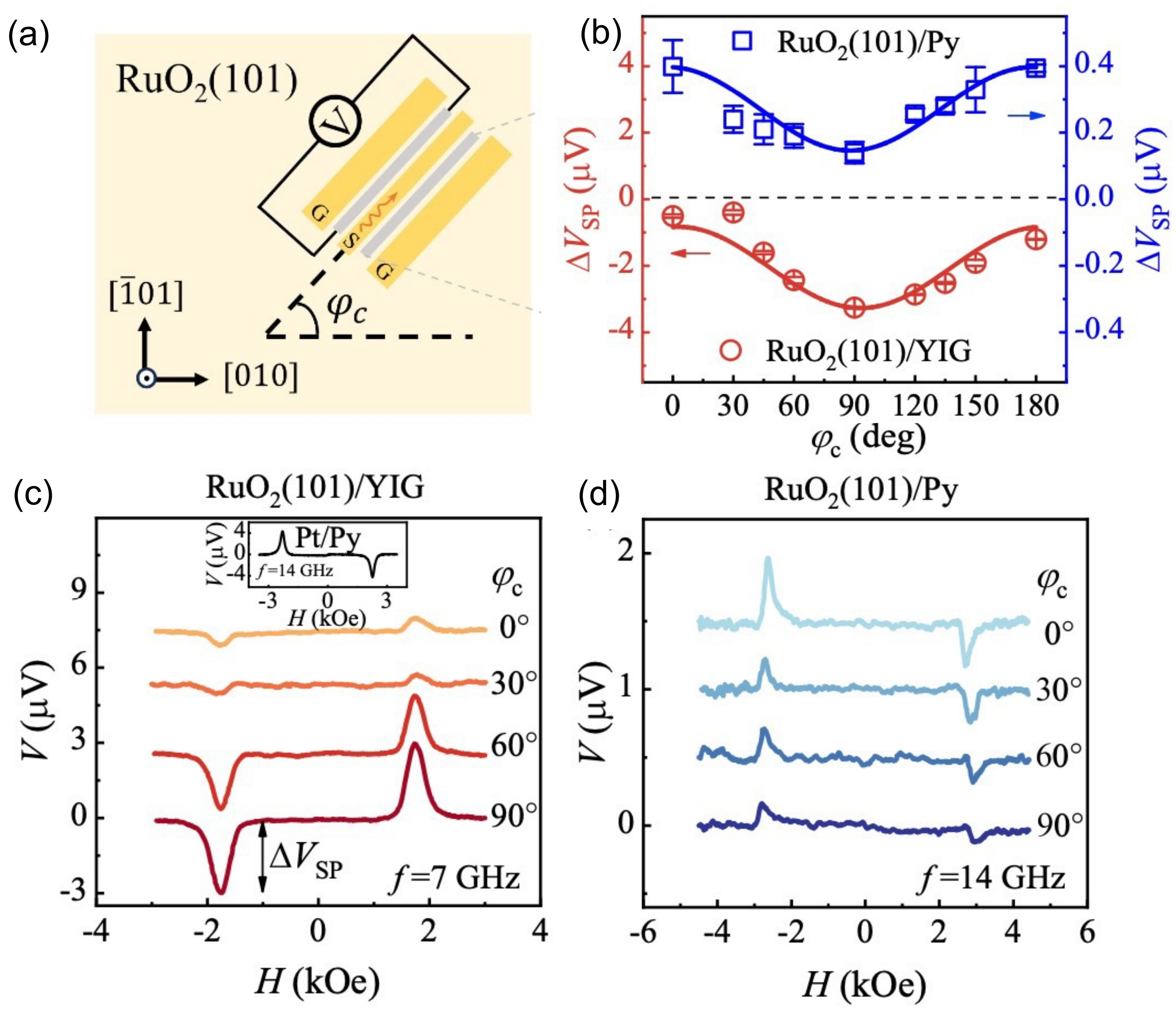
Abstract: Spin-orbit torque efficiency is conventionally fixed by bulk materials. *D*-wave altermagnets introduce an additional nonrelativistic spin-charge conversion channel beyond the inverse spin-Hall effect. Using prototypical candidate RuO_2 as an example, we show that the adjacent ferromagnet alone can dictate both the magnitude and sign of spin-charge conversion. Spin-pumping measurements on RuO_2/$Y_3Fe_5O_{12}$(YIG) and RuO_2/$Ni_{80}Fe_{20}$(Py) bilayers yield opposite effective spin-Hall angles that persist across crystalline and polycrystalline RuO_2. Inserting an ultrathin Au spacer at the RuO_2/YIG interface reverses the signal, evidencing a dominant interfacial inverse Rashba-Edelstein effect, whereas RuO_2/Py is governed by the bulk inverse spin-Hall effect. First-principles calculations trace this dichotomy to interface-selective band hybridization: Rashba surface states survive at the insulating YIG contact yet are quenched by metallic Py. Our findings establish ferromagnetic interfacing as a deterministic knob for tailoring spin-charge conversion in altermagnetic oxides, paving the way to field-free, low-dissipation spintronic memory devices.

Motivation



Challenge: The spin-Hall angle (SHA) of altermagnetic candidate RuO_2 shows conflicting signs in literature (positive with Py, negative with YIG). **ASSE? ASHE? Additional contributions?**

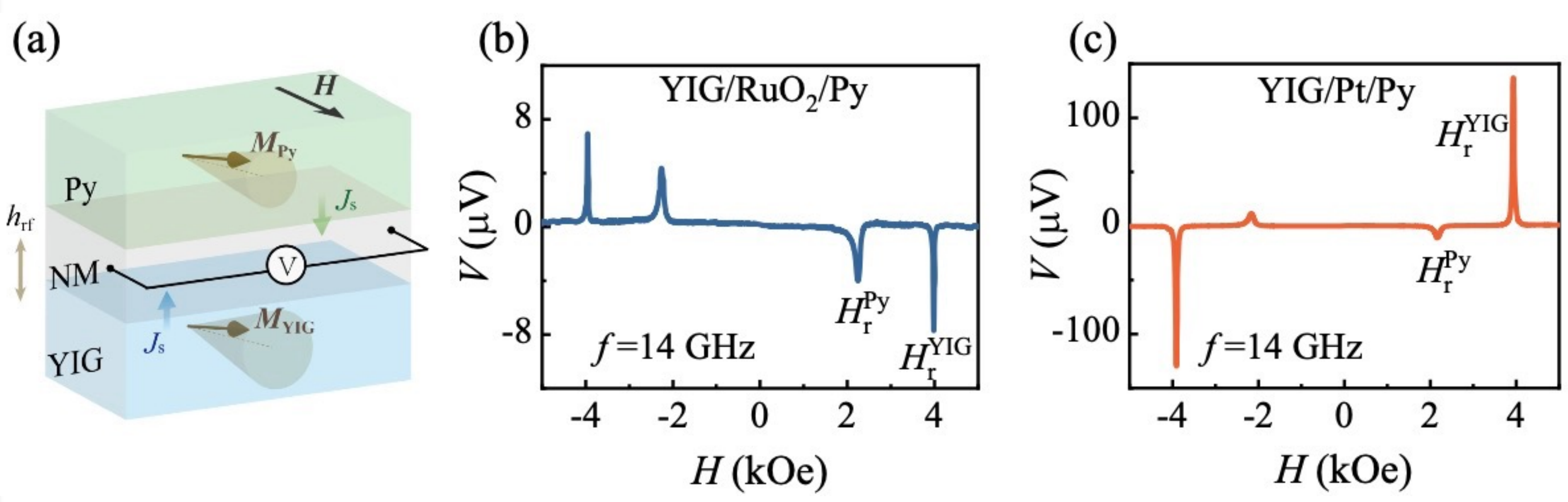
Spin Pumping in RuO_2/FM Bilayers



The sign discrepancy dictates that **competing spin-charge conversion mechanisms** are at play.

Polycrystalline measurement

Inverse ASSE ✗ ISHE in bulk RuO_2 ✓ Interfacial IREE ?

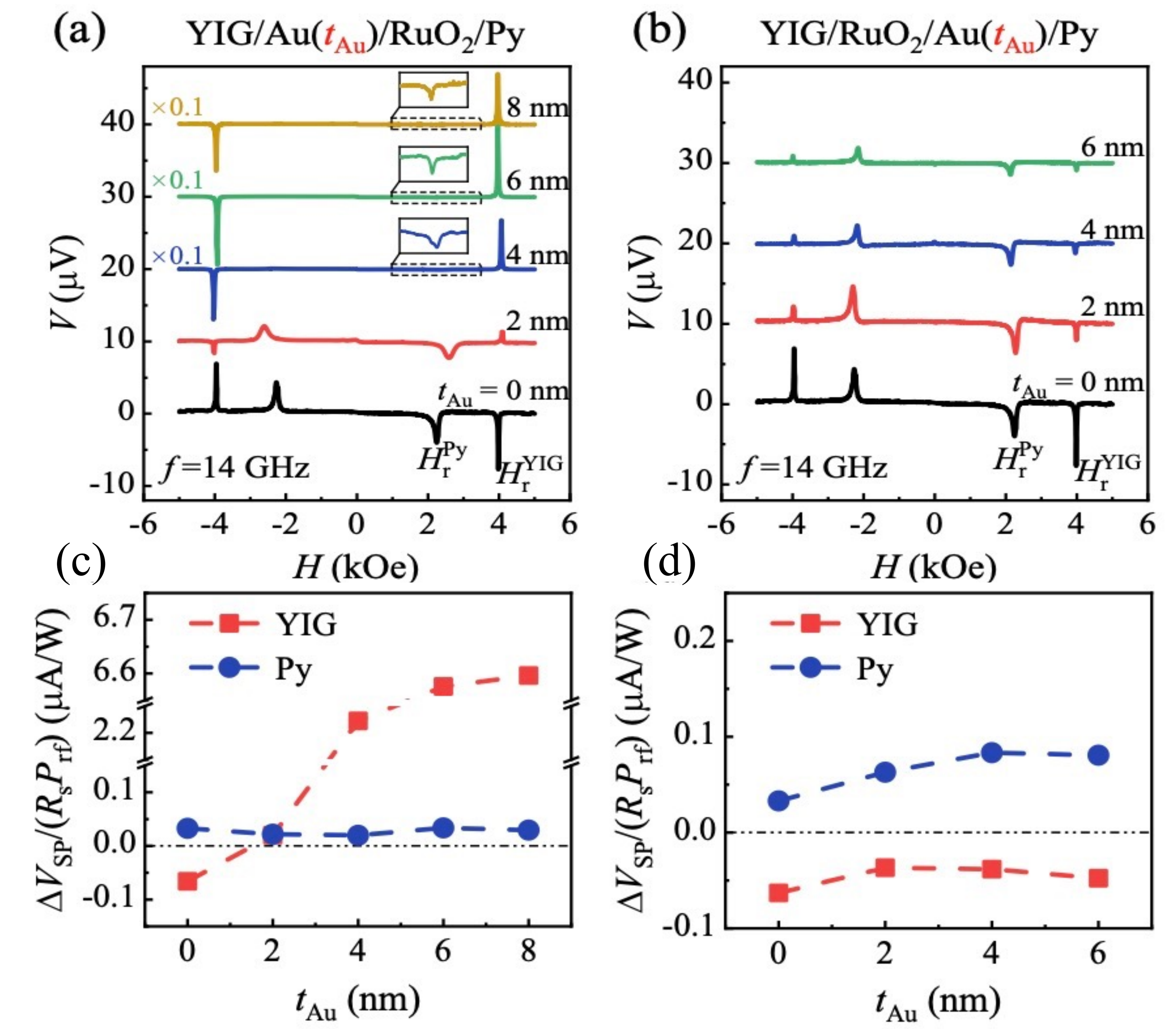


Interfacial IREE ✓

double- peak profile

peak-and-dip profile

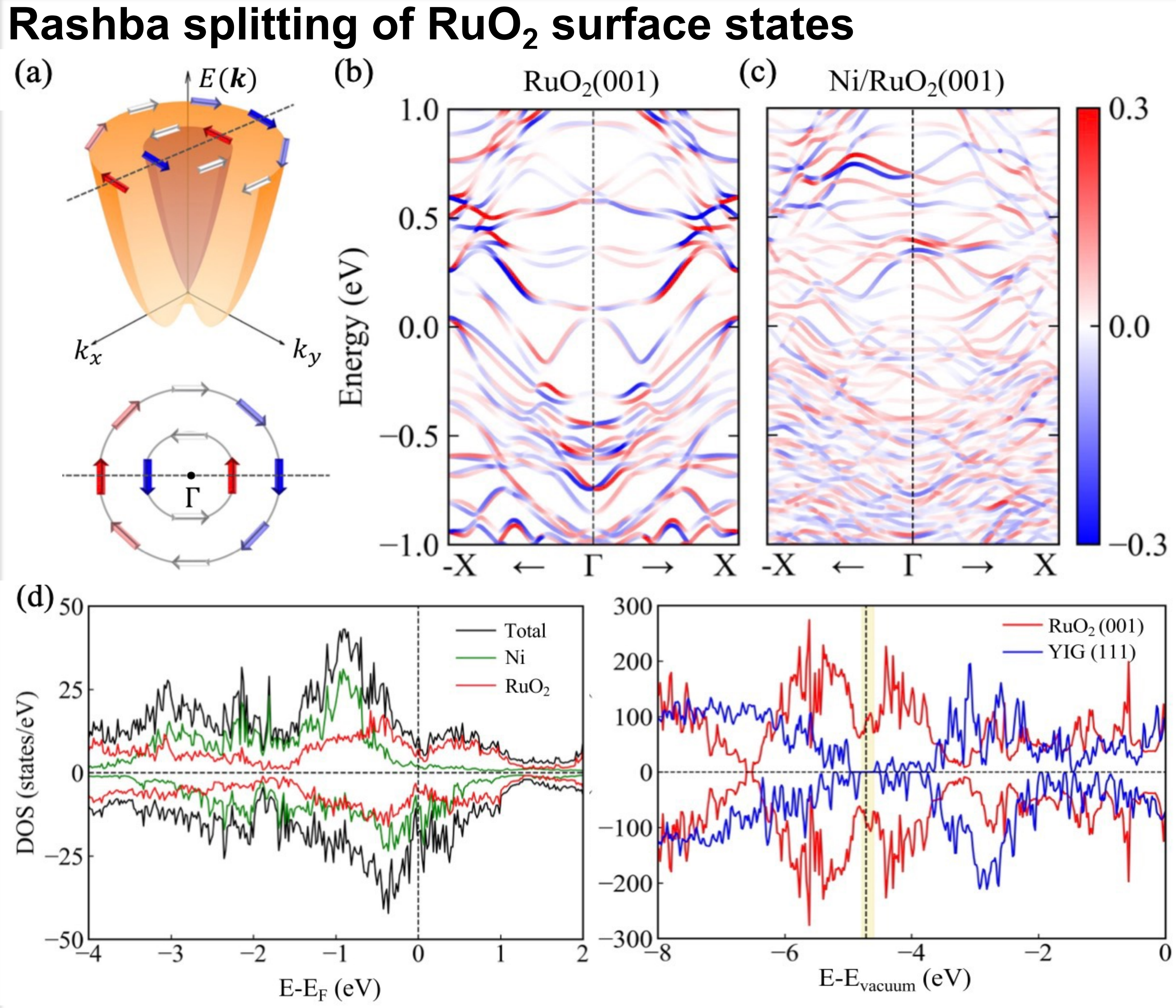
Isolating the Interfacial IREE (Au Insertion)



RuO_2/YIG reverses the spin-pumping voltage, IREE dominates

RuO_2/Py causes no sign reversal, bulk ISHE dominates

Rashba splitting of RuO_2 surface states



Pristine RuO_2: Rashba splitting via SOC.

RuO_2/YIG: Weak hybridization preserves Rashba → Strong IREE.

RuO_2/Py: Strong hybridization quenches Rashba → Bulk ISHE.

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