SCIENCE CHINA
Information Sciences

• LETTER •

September 2026, Vol. 69, Iss. 9, 199404:1–199404:2
https://doi.org/10.1007/s11432-026-4955-x

Giant orbit-to-charge conversion induced via the inverse orbital Hall effect

Renyou XU[1,2†], Hui ZHANG[1*†], Yuhao JIANG[1†], Houyi CHENG[1,2†], Yunfei XIE[3], Yuxuan YAO[1], Danrong XIONG[1], Zhaozhao ZHU[4,5], Xiaobai NING[1], Runze CHEN[1], Yan HUANG[1], Ao DU[1], Shijie XU[1,2], Jianwang CAI[4], Yong XU[1,2], Tao LIU[3], Jirong SUN[4,5] & Weisheng ZHAO[1,2*]

[1]*School of Integrated Circuit Science and Engineering, Beihang University, Beijing 100191, China*
[2]*Hefei Innovation Research Institute, Beihang University, Hefei 230013, China*
[3]*National Engineering Research Center of Electromagnetic Radiation Control Materials, University of Electronic Science and Technology of China, Chengdu 610054, China*
[4]*Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China*
[5]*Songshan Lake Materials Laboratory, Dongguan 523808, China*

Received 4 January 2026/Revised 27 February 2026/Accepted 28 April 2026/Published online 13 August 2026

Citation Xu R Y, Zhang H, Jiang Y H, et al. Giant orbit-to-charge conversion induced via the inverse orbital Hall effect. Sci China Inf Sci, 2026, 69(9): 199404, https://doi.org/10.1007/s11432-026-4955-x

Electrons carry not only spin angular momentum (SAM) but also orbital angular momentum (OAM). Spin transport and spin-charge interconversion are well established and underpin modern spintronic technologies. In contrast, orbital transport and orbit-charge interconversion have attracted increasing attention in recent years. In systems with strong spin-orbit coupling (SOC), charge-spin conversion occurs through mechanisms such as the spin Hall effect (SHE) and the Rashba-Edelstein effect, with their inverse processes enabling spin-charge conversion [1]. In parallel, orbitronics aims to exploit the generation, transport, and detection of OAM. In particular, charge-to-orbit conversion driven by the orbital Hall effect (OHE) has been shown to generate efficient torques and may offer advantages over spin-based mechanisms, including reduced material constraints [1]. The reciprocal process, namely the inverse orbital Hall effect (IOHE), is expected to enable efficient orbit-charge conversion [2,3]. However, experimental studies of IOHE remain scarce. Reported signals are generally weak, and the diffusion and detection of orbital currents are not yet well understood. This challenge arises from the strong coupling among spin, orbital, and charge degrees of freedom, which makes it difficult to isolate purely orbital contributions. As a result, establishing clear experimental signatures of IOHE and disentangling its underlying mechanisms remain outstanding issues.

Here, we investigate orbit-charge conversion in YIG/Pt/NM heterostructures using the longitudinal spin Seebeck effect (SSE) and spin pumping (SP). By introducing a Ru capping layer, both SSE and SP signals are significantly enhanced and increase with Ru thickness before reaching saturation. A diffusion model reproduces the thickness dependence and indicates that the enhancement originates from IOHE in the NM layer. Similar behavior is observed for other NM materials, suggesting that IOHE is a general effect. These results establish a clear route to probe orbital transport and demonstrate its potential for spin-orbitronic applications.

Results and discussion. SSE and SP measurements are performed to probe spin and orbital transport in YIG/Pt/Ru heterostructures. Structural characterization confirms the high crystalline quality and sharp interfaces of the samples (Supplementary Note S2). Figures 1(a) and (d) illustrate the physical processes under thermal and ferromagnetic resonance excitations, respectively. In both cases, a spin current is injected from the YIG layer into the Pt layer. Due to the strong SOC in Pt, part of the spin current is converted into an orbital current during diffusion. As a result, spin and orbital currents coexist in Pt and propagate along the out-of-plane direction.

The spin current generates a transverse charge current via the inverse spin Hall effect (ISHE), while the orbital current gives rise to an additional charge current through IOHE. Since the Pt thickness is comparable to its diffusion length, both spin and orbital currents are not fully relaxed and can be further injected into the Ru layer. In Ru, the orbital current is efficiently converted into charge current via IOHE, providing an additional contribution to the measured signal. This unified transport picture applies to both SSE and SP.

Figure 1(b) shows the SSE signals for YIG/Pt and YIG/Pt/Ru samples. Upon introducing a thin Ru layer, the SSE signal increases by nearly an order of magnitude. A similar enhancement is observed in SP measurements (Figure 1(e)), where the generated charge current under ferromagnetic resonance exhibits the same trend. The agreement between SSE and SP indicates that

* Corresponding author (email: huizh@buaa.edu.cn, weisheng.zhao@buaa.edu.cn)
† These authors contributed equally to this work.

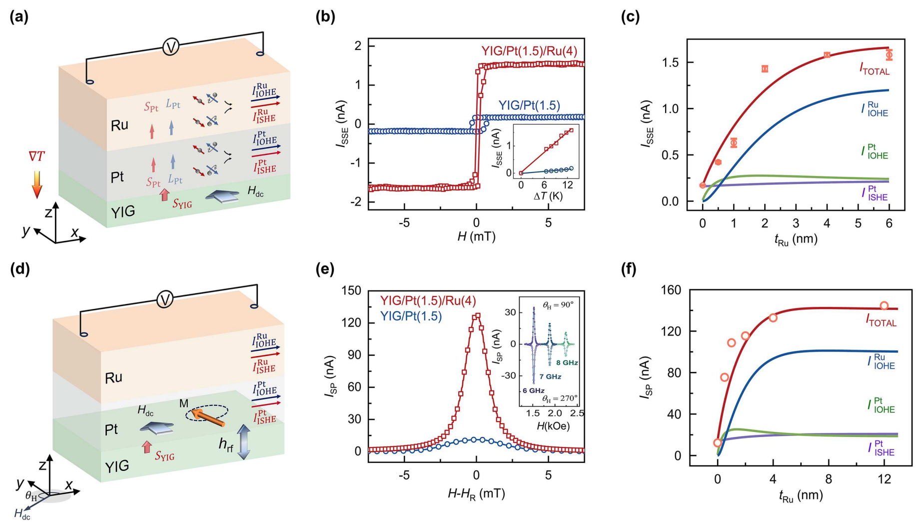

Figure 1 (Color online) SSE and SP measurements in YIG/Pt/Ru trilayers. Schematics of (a) the longitudinal spin Seebeck effect (SSE) and (d) spin pumping (SP), where spin current injected from YIG into Pt is partially converted into orbital current, contributing to charge generation via ISHE and IOHE. (b) SSE and (e) SP signals for YIG/Pt(1.5) and YIG/Pt(1.5)/Ru(4), showing nearly one-order-of-magnitude enhancement after introducing Ru. Insets show temperature-dependent SSE amplitude and representative SP spectra. Thickness dependence of (c) SSE and (f) SP signals in YIG/Pt(1.5)/Ru($t_{\rm Ru}$). Red circles are experimental data; purple, green, and blue lines denote ISHE in Pt, IOHE in Pt, and IOHE in Ru, respectively. The red solid line shows the total fitting, indicating dominant IOHE contribution in Ru.

the enhancement originates from a common transport mechanism rather than the excitation method.

To further elucidate the origin of this enhancement, we examine the dependence of the SSE and SP signals on the Ru thickness. As shown in Figures 1(c) and (f), both signals increase rapidly with increasing Ru thickness and gradually approach saturation at larger thicknesses, indicating a diffusion-limited process.

To quantitatively describe this behavior, we employ a coupled spin-orbital diffusion model (Supplementary Note S1). In this framework, both spin and orbital chemical potentials and their interconversion are explicitly considered, allowing simultaneous treatment of ISHE and IOHE contributions across the multilayer. The calculated total charge current shows excellent agreement with the experimental data. The fitting results reveal that the enhancement of the signal is dominated by IOHE in the Ru layer. As shown in Figures 1(c) and (f), the IOHE contribution from Ru (blue line) increases rapidly with Ru thickness and eventually becomes the dominant component, accounting for the overall increase and saturation of the measured signals (red circles). In contrast, the ISHE contribution from Pt (purple line) shows only a slight variation, indicating a minor role of conventional spin-to-charge conversion. The IOHE contribution from Pt (green line) also increases with Ru thickness, reflecting enhanced orbital transport across the Pt/Ru interface, but remains smaller than that in Ru. The ISHE contribution from Ru is negligible and therefore not shown.

In addition, the insertion of the Ru layer suppresses the reflection of orbital current at the Pt interface, giving rise to an orbital sink effect. This effect enhances both the IOHE contribution in Ru (blue line) and the orbital contribution in Pt (green line), leading to the observed overall signal amplification.

Additional measurements with different NM layers (Ta, W, and Cu) are presented in Supplementary Note S7. Remarkably, a significant enhancement is also observed in Cu, a light metal with weak SOC, indicating that strong SOC is not a prerequisite for the observed effect. Furthermore, Ta and W, whose spin Hall conductivities have opposite signs to that of Pt, also exhibit pronounced signal enhancement. This behavior is inconsistent with a purely ISHE-based mechanism but can be naturally explained by IOHE, whose contribution dominates and shares the same sign across these materials. These results further support the generality of IOHE in orbit-charge conversion.

Conclusion. In conclusion, this work presents an efficient approach for generating charge current via the OAM channel. We demonstrate that a Ru layer with negligible SOC can significantly enhance the inverse charge signal through orbit-to-charge conversion, as evidenced by SSE and SP measurements. Compared with previous studies of IOHE, our work combines thickness-dependent measurements with theoretical analysis, enabling the separation of IOHE from ISHE contributions and revealing the presence of an orbital sink effect. These findings provide new insights into the interplay among charge, spin, and orbital degrees of freedom and offer potential opportunities for advancing spin-orbitronic applications, such as magnetoelectric spin-orbit (MESO) logic and spin-based terahertz emitters.

Acknowledgements This work was supported by National Key Research and Development Program of China (Grant No. 2022YFB4400200), National Natural Science Foundation of China (Grant Nos. 92164206, 52261145694, 52072060, 52121001), and Beihang Hefei Innovation Research Institute Project (Grant Nos. BHKX-19-01, BHKX-19-02). All authors sincerely thank Hefei Truth Equipment Co., Ltd. for assistance with film deposition. This work was also supported by the Tencent Foundation through the XPLORER PRIZE.

Supporting information The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

References

1 Ding S, Kang M G, Legrand W, et al. Orbital torque in rare-earth transition-metal ferrimagnets. Phys Rev Lett, 2024, 132: 236702
2 Santos E, Abrão J E, Go D, et al. Inverse orbital torque via spin-orbital intertwined states. Phys Rev Appl, 2023, 19: 014069
3 Xu R, Ning X, Cheng H, et al. Terahertz generation via the inverse orbital Rashba-Edelstein effect at the Ni/CuO$_x$ interface. Phys Rev Res, 2025, 7: L012042