Spin Current and Magnetoresistance from the Orbital Hall Effect

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Overview

The Spin Hall Effect (SHE) generates spin current, spin torque, and magnetoresistance and is extensively used in spintronic devices, such as memory devices, magnetic sensors, and data storage media. However, strong SHE behavior mainly exists in heavy and expensive metals. Here we provide a novel method, the intrinsic Orbital Half Effect (OHE), to convert the orbital current to spin current by using a thin layer of heavy metals in a CMOS-compatible process, thus reducing the costs of the devices mentioned above.

Background and Unmet Need

The Spin Hall Effect (SHE) has been exploited for electrically-manipulating electron spin in a variety of spintronics applications, such as magnetoresistance devices for reading magnetically-encoded data storage media and magneto-resistive random-access memory for computers. Spin current involves an alignment of intrinsic electron spin and has a specified orientation. Notable materials which exhibit strong SHE behavior and provide spin current are heavy (and expensive) metals, e.g., Tungsten (W) and Platinum (Pt). It is desirable to reduce the dependence on heavy metals by utilizing ordinary metals to provide spin current in devices while reducing the extent of heavy metal required.

The Solution

Prof. Binghai Yan and his team invented a new method to convert the orbital current in the orbital Hall effect (OHE) to spin current via the spin-orbit coupling from a contact layer to the device, thus enabling the usage of ordinary metals like Al and Cu with only a thin layer of heavy metal.

Technology Essence

The intrinsic orbital Hall effect (OHE), the orbital counterpart of the spin Hall effect (SHE), was predicted and studied theoretically for more than one decade, yet to be observed in an experiment. Unlike the SHE, the OHE does not rely on the spin-orbit coupling (SOC); thus, it was predicted to exist in many materials with either weak or strong SOC. Heavy metals such as Platinum (Pt) and Tungsten (W) exhibit strong spin-orbital coupling, whereas ordinary metals such as Copper (Cu) and Aluminum (Al) exhibit weak spin-orbital coupling. Orbital current has a specific orientation, involves an alignment of the orbital motion of atomic electrons, and is distinct from the intrinsic spin of the electron. The conversion from orbital current to spin current is done in a very thin layer of heavy metal, capping ordinary metal planar components, thereby substantially reducing heavy metal requirements by replacing most of the heavy metal with ordinary metal. Spin current is generated by the conversion of out-of-plane orbital current arising from the OHE in ordinary metals. Furthermore, OHE can induce large nonreciprocal magnetoresistance when employing magnetic contact[1].

Applications and Advantages

- Use of lower amounts of heavy and expensive metal without degrading the quality of operation
- Reduces production costs dramatically
- Easily applies to existing CMOS fabrication technologies
- Magnetic field sensors
- Spintronic and spin-torque devices
- Memory devices and computational applications
- Independence of the Spin Hall Effect (SHE) in heavy metals
- Enables spin current using key metals in the semiconductor industry, such as Cu and Al

Development Status

Prof. Binghai and his team demonstrated the generation of spin currents from the orbital Hall effect taking place in pure Copper and Aluminum. Using a spin-orbit coupling of a thin Platinum layer introduced at the interface that converts the orbital current to a measurable spin current, the Aluminum possesses an orbital hall effect of opposite polarity in agreement with the theoretical predictions [2]. These results, obtained in die-level measurements, demonstrated spin- and orbit functionality for two important metals in the semiconductor industry beyond their use as interconnects.

Market Opportunity

- There are several potential applications in a range of markets, including:
- Data Storage: The ability to manipulate and control the spin of electrons could lead to new data storage technologies that are faster and more energy-efficient than existing ones. For example, spintronic devices based on magnetic tunnel junctions are already being used in hard disk drives to increase their storage density;
- Memory and Computing: Spin-based logic devices, known as spintronic logic, could revolutionize computing by providing faster and more energy-efficient alternatives to traditional electronic devices. This could enable new technologies such as quantum computing;
- Sensors: Spin-based sensors could be used for a range of applications, including biomedical sensing, environmental monitoring, and navigation. For example, spin-based magnetometers can be used to detect small magnetic fields, which can be useful in detecting anomalies in the brain or heart. Additional devices for sensing and manipulating magnetic fields based on spin current interactions in ordinary metals can be used.

References

1. Xiao, J., Liu, Y. & Yan, B. Detection of the Orbital Hall Effect by the Orbital-Spin Conversion. In Memorial Volume for Shoucheng Zhang (pp. 353-364).â€ https://doi.org/10.1142/9789811231711_0015 [1]
2. Rothschild, A. *et al.* Generation of spin currents by the orbital Hall effect in Cu and Al and their measurement by a Ferris-wheel ferromagnetic resonance technique at the wafer level. *Phys. Rev. B* **106**, 144415 (2022). DOI: 10.1103/PhysRevB.106.144415 [2]

Patent Status

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