Discovery of simple and versatile methods for spin current generation

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Electronics is indispensable in our daily life in the information society. As the next-generation technology, "spintronics" has attracted global interest. The "spin current" is the main ingredient of spintronics, and we have devised simple and versatile methods of generating spin current.

As the name implied, electronics is the art of controlling electrons in solids. The electron has two aspects: "charge" and "spin". The charge is the origin of electricity, and its flow leads to an electric (charge) current. On the other hand, the spin gives rise to magnetism and its flow is called a spin current. To date, developments in the field of electronics have been based solely on the charge current. Spintronics aims to improve the current technology by harnessing both charge and spin currents equally. It has been recognized, however, that it is quite a hard task to utilize spin currents unlike the case of charge currents. In this context, we have discovered new methods for generating spin currents.

Our method employs the spin transfer without charge transfer from a ferromagnet into an attached nonmagnetic conductor (metal or semiconductor), whose process is driven by the magnetization dynamics in the ferromagnet. When a magnetization in a ferromagnet is excited, it starts precession. Since a nonmagnetic conductor acts as a spin absorber, attaching a nonmagnetic conductor to the excited ferromagnet results in an emission of a certain amount of spins into the conductor as a result of the angular momentum conservation. Therefore, the spin current is generated in the nonmagnetic conductor without charge transfer across the interface of the ferromagnet/nonmagnetic conductor bilayers. This is a simple and versatile method because any perturbation exciting the magnetization dynamics enables this new type of spin current generation. We have demonstrated that this is indeed the case in the following ways.

First, we have shown that the spin current can be generated by sound waves. In a hybrid structure of a nonmagnetic metal (Pt) and an insulating ferromagnet ($Y_3Fe_5O_{12}$) as schematically shown in Fig. 1, a propagating sound wave is generated by a piezoelectric actuator attached to the ferromagnet. The sound wave then excites magnetization dynamics through the magneto-elastic coupling, thereby injects a spin current into the nonmagnetic metal. The spin current obtained is converted into an electric current via the spin-Hall effect. Thus, we have established a new route for generating spin and electric currents by ubiquitous sounds. This mechanism will be useful for constructing new spintronic and energy-saving devices.

Second, we have succeeded in injecting spin currents into semiconductors with a very high efficiency (10^3 times larger than before). So far, any attempt to generate spin currents in semiconductors has relied on the spin-polarized charge transfer from ferromagnets into semiconductors. However, the prevous attempts suffer from the so-called impedance mismatch problem arising from the extreme difference of the electric conductivity between ferromagnets and semiconductors. Using a hybrid structure of a semiconductor (GaAs) and a ferromagnet ($Ni_{81}Fe_{19}$) shown in Fig. 2 and by applying a microwave to the ferromagnet, we have shown that a high efficiency spin injection into GaAs is possible. This technique relies purely on the spin transfer caused by microwave-excited magnetization dynamics, and is free from the impedance mismatch problem that arises in the charge transfer. Since semiconductors are basic materials for conventional electronic devices, the impact of this finding on the spintronics community is astonishingly large.

A variety of such high-efficiency methods for spin current generation can make progress in spintronics, which in turn contributes to the development of energy-saving society as spintronics offers a route to reduce power consumption of solid-state logic devices.

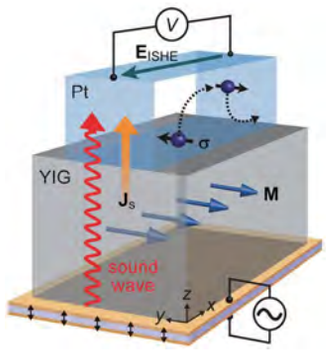

Fig. 1 Schematic illustration of the device structure to realize the new way of spin current generation by sound waves.

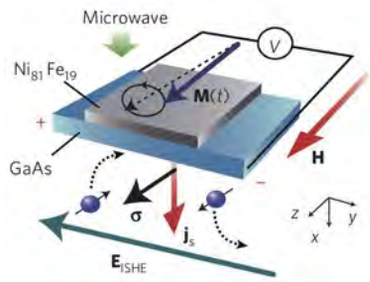

Fig. 2 Schematic illustration of the device structure to realize the new way of spin current generation by microwaves.

References

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[2] K. Ando *et al*., Nature Materials **10**, 655 (2011).