Thermal spin generation

Gyung-Min Choi[1,2*], Chul-Hyun Moon[2,3], Byoung-Chul Min[2],
Kyung-Jin Lee[3,4], and David G. Cahill[1]

[1]Department of Materials Science and Engineering, University of Illinois, Urbana, Illinois 61801, USA

[2]Center for Spintronics, Korea Institute of Science and Technology, Seoul 136-791, Korea

[3]Department of Materials Science and Engineering, Korea University, Seoul 136-701, Korea

[4]KU-KIST Graduate School of Converging Science and Technology, Korea University, Seoul 136-701, Korea

The coupling of spin and heat gives rise to new physical phenomena in nanoscale spin devices. In particular, spin transfer torque (STT) driven by passing heat currents through magnetic layers provides a new way to manipulate local magnetization. Hatami *et al*. theoretically predicted thermally-driven STT in metallic spin valves [1]; Slonczewski suggested the initiation of thermally-driven STT in ferrite/metal structures and predicted a greatly enhanced quantum efficiency compared to charge-current-driven STT [2]. These new phenomena, namely, “thermal STT” rely on the transport of thermal energy, in contrast to the transport of electrical charge, and provide a new way to manipulate magnetization [1, 2]. To fully realize the envisioned advantages of thermal STT, it is important to observe thermal STT directly and quantify its sign and magnitude. Although thermal spin injections in ferromagnetic metal (FM)/normal metal (NM) [3], ferrite/NM [4], and FM/semiconductor [5] have been achieved, direct and conclusive evidence of thermal STT has remained elusive.

Here I provide direct evidence of thermal STT in metallic spin valves with the structure Pt/FM1/Cu/FM2. Heating by the ultra-fast pump optical pulse generates spin currents in the structure by two distinct mechanisms: i) volume spin generation in the FM1 layer by ultrafast heating and associated ultrafast demagnetization of FM1 [6]; ii) interfacial spin generation at the Pt/FM1 and FM1/Cu interfaces by heat current passing through the FM1 layer [7]. The spin-dependent Seebeck effect (SDSE) of FM1 converts the heat current into spin current. Both demagnetization-driven and SDSE-driven spin generation on FM1 can diffuse to FM2 and exert STT on FM2 magnetization.

The demagnetization-driven spin generation is due to thermal transport between electrons and magnons of FM1 and angular momentum conservation of electron-magnon coupling of FM1 [6]. The demagnetization-driven spin generation is significant for only the first ~3 ps after the pump optical pulse; 3 ps is approximately the time required for electrons, magnons, and phonons of FM1 to equilibrate.

The SDSE-driven spin generation is due to thermal transport between FM and NM at FM/NM interface. In contrast to ultrafast demagnetization, the heat current passing through FM1 persists for a much longer time, ~100 ps, the time required for the various layers in the structure (Pt, FM1, Cu, and FM2) to equilibrate. The amount of SDSE can be controlled by the composition of FM1, which is a spin source layer, and thickness of Cu, which is a heat sink layer.

References

[1] M. Hatami*et al*. *Phys. Rev. Lett.* **99**, 066603 (2007).

[2] J. C. Slonczewski, *Phys. Rev. B* **82**, 054403 (2010).

[3] A. Slachter*et al. Nature Phys.* **6**, 879 (2010).

[4] K. Uchida*et al*. *Nature Mater.* **9**, 894 (2010).
[5] J.-C. Le Breton*et al. Nature* **475**, 82 (2011).
[6] G.-M. Choi*et al. Nature Commun*. **5**, 4334 (2014).
[7] G.-M. Choi *et al*. *Nature Phys*. **11**, 576 (2015).