Lock-in Thermoreflectance as a Tool for Investigating Spin Caloritronics

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Thermal management of spintronics devices is indispensable for further reducing power consumption and improving reliability. Generally, in electronic devices, heat is generated by Joule heating and thermoelectric effects when the electrical current is applied to the devices. In the case of spintronic devices, not only conventional thermoelectric effects but also thermo-spin conversion phenomena appear and change the temperature depending on the magnetic state of the devices.

In recent years, “spin caloritronics”, a fusion research field of thermal engineering and spintronics, has developed rapidly. To link spin caloritronics to the thermal management technique, thermal response of spintronics devices composed of nanoscale thin films has to be measured in wide frequency band and high spatial resolution. The conventional thermal measurement based on the lock-in thermography technique [1] can achieve high temperature resolution measurement. However, the spatial resolution achieved by the lock-in thermography is limited to several microns by the optical limit of the infrared light and it is difficult to measure the thermal response of spintronics devices operating at high speed.

In this work, we demonstrate that the lock-in thermoreflectance method is applicable to measuring the spin caloritronic phenomena. As shown in Fig. 1, thermoreflectance method is used for measuring temperature by the intensity change of the reflected light from a sample. By using visible light and lock-in technique at the frequency of the applied current, highly-sensitive temperature measurements with the sub-micron spatial resolution can be achieved [2]. Here, by means of the lock-in thermoreflectance method, we successfully observed the temperature modulation induced by the spin Peltier effect (SPE), one of the representative spin-caloritronic phenomena, in a ferromagnet/heavy metal hybrid system and revealed its high-frequency response that cannot be achieved by the conventional methods. Our experiments show that the temperature resolution of the lock-in thermoreflectance reaches the level of several mK in a wide frequency range, confirming the usefulness of this method in spin-caloritronics studies.

[1] S. Daimon, *et al*., *Nature Communications*, 7, 13754 (2016)

[2] C. A. Paddock and G. L. Eesley, *J. Appl. Phys.*, 60, 285 (1986)

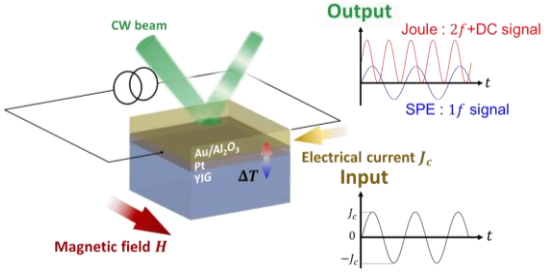

Fig. 1 Schematic image of measurement principle