Enhancement of temperature change induced by anomalous Ettingshausen effect in ferromagnetic metal films on suspended membrane substrates

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In the field of spin caloritronics, magneto-thermoelectric and thermo-spin effects in magnetic materials and junctions have attracted much attention [1]. Despite the fact that these magneto-thermoelectric effects are known for a long time and possibly beneficial for thermoelectric applications, there are several drawbacks which has to be optimized. For example, the thermoelectric conversion output of these phenomena is still much smaller than that of conventional Seebeck/Peltier devices. Therefore, proper optimization of these devices is necessary to realize practical applications. Here, we focus on demonstrating the enhancement of temperature modulation due to the anomalous Ettingshausen effect (AEE) by modifying the substrate design. Due to AEE, when a charge current $\mathbf{J}_c$ is applied to a ferromagnet in the direction perpendicular to the magnetization **M**, a transverse heat current $\mathbf{J}_q$ is generated in the direction perpendicular to both $\mathbf{J}_c$ and **M**. In 2018, Seki et al. [2] demonstrated that, in perpendicularly-magnetized thin films on bulk substrates, the magnitude of the AEE-induced temperature modulation depends not only on the thermoelectric conversion properties of the films but also on thermal properties of the substrates, where a large amount of the heating/cooling power generated in the films is dissipated to the substrates [3]. They also suggested that, if the heat loss is reduced, a large temperature modulation can be achieved in the perpendicularly-magnetized configuration. Here, we first experimentally demonstrate that the temperature modulation induced by AEE in a perpendicularly-magnetized Ni films can be significantly enhanced by using suspended membrane substrates. Our experimental results show that the AEE signal for the Ni film on the 200-nm-thick SiN membrane substrate is more than 20 times greater than that on the bulk glass substrate in a nearly steady state, indicating the important role of substrates in thin-film-based AEE devices. We also demonstrate that the temperature modulation can be further enhanced by using a simple suspended thermopile structure. We thus anticipate that the experimental demonstrations shown in this paper will be a guideline for future application studies towards thermal management of nanoscale spintronic devices.

[1] G. E. W. Bauer et al., *Nat. Mater.* **11**, 391 (2012).
[2] T. Seki et al., *Appl. Phys. Lett.* **112**, 152403 (2018).
[3] R. Das et al., *Phys. Rev. Appl.* **11**, 034022 (2019).