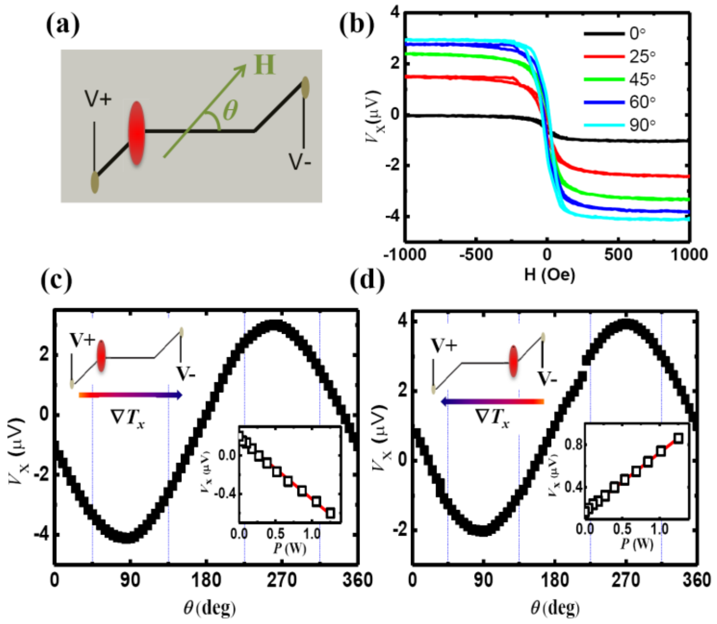
熱激發自旋電子學（Spin Caloritronics）

本所李尚凡副研究員、美國約翰霍浦金斯大學天文與物理系錢嘉陵教授、與台大凝態中心郭瑞年主任部分由國科會龍門計畫支持組成的跨國研究團隊，在新興研究領域“熱激發自旋電子學”（Spin Caloritronics）獲得突破性的重大研究成果。藉由建立溫度差來控制熱流、電荷與自旋電流目前主流的研究方式是希望藉由平行膜面的溫度差，驅動自旋電流，當自旋向上與自旋向下電子數不相等時，自旋極化電流便因應而生。然而室溫下藉由熱激發所產生的自旋電動勢與外加磁場呈非對稱關係。目前尚無法解釋為何在遠大於自旋擴散長度，且物理性質完全不同的材料中，得到類似的結果。

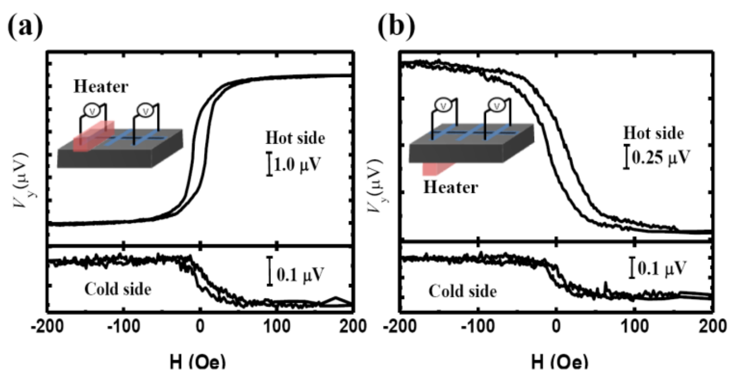
我們的研究團隊首次以實驗證實，藉由熱激發的非對稱自旋電動勢也可經由垂直膜面的溫度差來驅動，系統化地翻轉熱自旋電動勢。在沒有基板的磁性箔片可確保只有水平方向的溫度梯度存在，實驗發現熱電動勢為對稱的行為。此重要發現有助了解熱激發自旋電子學的機制與過程，並為相關研究領域提供一個全新的思考方向。本研究成果論文將發表於標竿期刊《物理評論通訊》(Physical Review Letters, **107**, 216604 (2011))。

A team lead by Dr. Shang-Fan Lee, Prof. C. L. Chien of Department of Physics and Astronomy in the Johns Hopkins University, and Prof. J. Raynein Kwo in CCMS of NTU, also supported by the Dragon Gate Program under the NSC, has important results on the newly developed ‘Spin Caloritronics’. Most studies of spin caloritronic effects to date, including spin-Seebeck effect, utilize thin films on substrates. We use patterned ferromagnetic thin film to demonstrate the profound effect of a substrate on the spin-dependent thermal transport. With different sample patterns and on varying the direction of temperature gradient, both longitudinal and transverse thermal voltages exhibit asymmetric instead of symmetric spin dependence. This unexpected behavior is due to an out-of-plane temperature gradient imposed by the thermal conduction through the substrate and the mixture of anomalous Nernst effects. Only with substrate-free samples have we determined the intrinsic spin-dependent thermal transport with characteristics and field sensitivity similar to those of the anisotropic magnetoresistance effect. The result has been published in Physical Review Letters, **107**, 216604 (2011).



圖一、(a)鎳鐵奈米線與熱電動勢的量測示意圖；(b)不同角度下熱電動勢對外加磁場的關係；(c)由左至右與(d)由右至左的平行膜面溫度差下，熱電動勢與角度的關係。

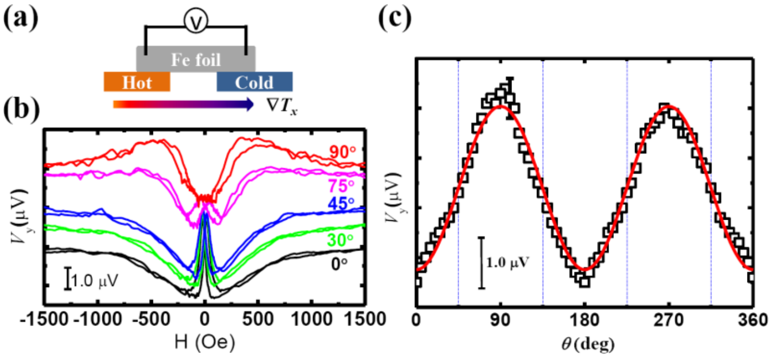
Fig.1. (a) Schematic diagram of a Py wire sample for the thermal measurement with voltage leads on two sides, heat source indicated by the large oval, and magnetic field direction at angle θ. (b) field dependence of thermal voltage at different angle θ. Angular dependence of thermal voltage when heater is on the (c) left, and (d) right of the wire. Insets show power dependence of thermal voltage.



圖二、(a)由上至下與(b)由下至上的垂直溫度差下，熱電動勢與外加磁場在熱端與冷端的關係。

Fig. 2. (a) Schematic diagram of the Hall bar sample used for the thermal transport measurement with the heater on one side, transverse voltages measured at three locations (hot, cold, middle). (b) Field dependence of thermal voltage at the hot side and the cold side at θ =0. (c) Angular dependence of thermal voltage at cold side. (d)

Field dependence of thermal voltage at the hot side and the cold side with a closer heater position at $\theta = 0$.



圖三、(a)微米鐵箔與熱電動勢的量測示意圖；(b)不同角度下熱電動勢對外加磁場下的關係；(c) 在平行溫度差方向下量測時，熱電動勢與角度的關係。

Fig. 3. Field dependence of thermal voltage on the hot side (top panel) and cold side (bottom panel) of Hall bar Py sample with heater placed on (a) top; and (b) bottom of the sample. Results of same measurements with a 10-nm Pt layer on top of 300-nm Py are shown in (c) and (d).