Special issue on spin caloritronics Preface

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PREFACE

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Preface

Special issue on spin caloritronics

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The field of spin caloritronics, or spin-caloric transport, addresses the interplay between spin current phenomena and thermal properties. Though originally explored in metallic systems where spins can be transported by moving electrons, the field has played a key role in demonstrating spin transport by spin waves, the elementary excitations of magnetically ordered materials whether ferro-, ferri-, or antiferromagnetic.

We have known for almost two centuries that heat and charge currents are coupled, causing the phenomenon of thermoelectricity. Prominent examples are the Seebeck effect and its inverse, the Peltier effect. These are related by the Onsager–Kelvin relations and employed in devices such as thermocouples, power generators, and coolers. Only recently have researchers realized that these concepts must be re-considered by including the spin, generating completely new spin-related properties. These include effects at work in bulk materials and those explicitly occurring at interfaces between materials that are often realized in small structures and devices.

In recent years, a zoo of spincaloritronic effects have been discovered, which are spin-dependent generalizations of the classical Seebeck, Peltier or Nernst-Ettingshausen effects in bulk materials. Spin dependent thermal spin injection into normal metals by ferromagnetic contacts has been measured. Reciprocity in linear transport implies that each effect has an inverse with transport coefficients governed by Onsager relations.

The discovery of the completely new (longitudinal) spin Seebeck effect has caused much excitement. Here a temperature gradient over a metallic contact on a magnetic insulator interface generates spin currents that can be detected via the inverse spin Hall effect as a transverse voltage. The Onsager reciprocal spin Peltier effect was indeed detected a few years later.

This special issue with high-level research papers from leading scientists proves that spin caloritronics continues to be a hot field with many new research directions.

Below we briefly summarize the contents of this special issue on spin caloritronics.

Historically, the spin Seebeck effect has been discussed in two variations, distinguished by the orientation of the direction of heat flow with respect to the interface involved in detection of the spin transport. These longitudinal and transverse spin Seebeck effects, are perhaps the most prominent examples of spincaloritronic phenomena. The former is routinely observed in magnetic insulator (such as yttrium iron garnet, YIG)/heavy metal bilayers (but not in all-metallic samples since it cannot be separated from the anomalous Nernst effect). After its initial discovery, the scientific emphasis has turned to the engineering of the effect. Here, Yuasa *et al* [1] report on the YIG/Ru system, while Kirihara *et al* [2] focus on all-oxide hetero-structures. The diffusion of magnons in bulk magnetic insulators as studied theoretically by Rezende *et al* [3] (also for antiferromagnets) and Basso *et al* [4] is an important mechanism affecting spin pumping, the spin Seebeck, and related effects. Adachi *et al* [5] address theoretically the suppression of the spin Seebeck effect close to the Curie temperature.

The magnons generated at and in proximity of the contact can diffuse in the ferromagnet and can be detected by another contact to study non local magnon transport. Magnons can be injected not only thermally, but also by spin pumping or electrically via the spin Hall effect. Here nonlocal magnon transport experiments using tantalum and platinum spin injection/detection electrodes are presented by Liu *et al* [6]. Noack *et al* [7] predict ballistic transport of quasi-acoustic magnons in high quality YIG. The transverse spin Seebeck effect in metallic systems is difficult to detect because of the anomalous Nernst effect with similar symmetry. However, the latter is of considerable interest in itself (Seki *et al* [8]) and can be used as a microscopic detection method of domain walls (Scarioni *et al* [9]).

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Other classes of well-studied phenomena are the spin-dependent Seebeck effect and the related tunnel magneto-Seebeck effect that rely on metallic materials. Kuschel *et al* [10] review the experimental progress in spin dependent electron tunneling under temperature gradients. Popescu *et al* [11] give an overview of the methods of computational materials science to compute spincaloritronic properties of metals with emphasis on the effects of spin–orbit interactions and heterojunctions. The tunnel magneto-Seebeck effect can be used to measure the thermal conductivity of thin insulating films, see Huebner *et al* [12] or as a microscopic tool on atomic length scales; see Friesen *et al* [13]. Juarez-Acosta *et al* [14] model heat transport through metallic magnetic interfaces while Chen *et al* [15] calculate the spin currents through quantum dot spin valves. The spin-dependent Seebeck effect, where the thermal gradient exists on the length scale of the spin diffusion length at an interface of a ferromagnet and a non-magnetic metal, has typically been viewed as a purely electronic phenomenon. Beens *et al* [16] present theory that argues that magnons play a significant role.

Spin caloritronics is increasingly being studied on novel materials such as antiferromagnets; see Cramer *et al* [17] (experimental) and Białek *et al* [18] (theory), fully compensated ferrimagnets; see Yagmur *et al* [19] and magnetic oxide/metal multilayers (Ramos *et al* [20]). Gomonay *et al* [21] predict that the spin Peltier effect should exist in an antiferromagnetic insulator. Moreover, magnetic nanostructures (Asam *et al* [22], Michel *et al* [23], Cansever *et al* [24]) as well as III–V semiconductors (Göbbels *et al* [25]) become accessible. Theoretical aspects of spin caloritronics in exotic materials are studied theoretically by Wang and Wang [26] (topologically non-trivial spin lattices), Tatara *et al* [27] (insulating chiral magnets) and Kurpas *et al* [28] (black phosphorus and phosphorene).

Optical experiments have an increasing impact on the field. Brillouin light scattering has proven to be an efficient detection method for spin waves in temperature gradients (Langner *et al* [29]) and, more generally, to perform magnon and phonon thermometry; see the review by Olsson *et al* [30]. Increasing the sensitivity of magneto-optic Kerr effect microscopy (Liu *et al* [31]) is another potential route for probing interactions of heat and ferromagnets. Microcalorimeters have been optimized for the detection of thermo-electric properties in thin magnetic films; see Wesenberg *et al* [32] and Srichandan *et al* [33]. Furthermore, THz spectroscopic techniques allow for a fast and reliable detection of the spin Hall effect in metallic bilayers; see Seifert *et al* [34]. Shen *et al* [35] present theory underlying spatiotemporal Kerr microscopy, which is unique method to study the coupled magnetization and lattice dynamics of thin magnetic films induced by the heat generated by a pulsed and focussed laser beam.

The collection of papers published in this special issue demonstrates the growing breadth and fundamental importance of spin caloritronics, and provides a vibrant picture of the field as it enters its second decade. We hope that this special issue will inform those new to the field and point toward new directions for spin technologies, whether generated by heat or simply affected by it, continuing toward wider use in our world.

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References

[1] Yuasa H, Nakata F, Nakamura R and Kurokawa Y 2018 *J. Phys. D: Appl. Phys.* **51** 134002
[2] Kirihara A *et al* 2018 *J. Phys. D: Appl. Phys.* **51** 154002
[3] Rezende S M, Azevedo A and Rodríguez-Suárez R L 2018 *J. Phys. D: Appl. Phys.* **51** 174004
[4] Basso V, Ansalone P and Piazzi M 2018 *J. Phys. D: Appl. Phys.* **51** 214006
[5] Adachi H, Yamamoto Y and Ichioka M 2018 *J. Phys. D: Appl. Phys.* **51** 144001
[6] Liu J, Cornelissen L J, Shan J, van Wees B J and Kuschel T 2018 *J. Phys. D: Appl. Phys.* **51** 224005
[7] Noack T B *et al* 2018 *J. Phys. D: Appl. Phys.* **51** 234003
[8] Seki T, Iguchi R, Takanashi K and Uchida K 2018 *J. Phys. D: Appl. Phys.* **51** 254001

[9] Scarioni A F, Krzysteczko P, Sievers S, Hu X and Schumacher H W 2018 *J. Phys. D: Appl. Phys.* **51** 234004
[10] Kuschel T, Czerner M, Walowski J, Thomas A, Schumacher H W, Reiss G, Heiliger C and Münzenberg M 2019 *J. Phys. D: Appl. Phys.* **52** 133001
[11] Popescu V *et al* 2018 *J. Phys. D: Appl. Phys.* **52** 073001
[12] Huebner T, Martens U, Walowski J, Münzenberg M, Thomas A, Reiss G and Kuschel T 2018 *J. Phys. D: Appl. Phys.* **51** 224006
[13] Friesen C, Osterhage H, Friedlein J, Schlenhoff A, Wiesendanger R and Krause S 2018 *J. Phys. D: Appl. Phys.* **51** 324001
[14] Juarez-Acosta I, Olivares-Robles M A and Chanona-Perez J J 2018 *J. Phys. D: Appl. Phys.* **51** 294002
[15] Chen X, Yuan J, Tang G, Wang J, Zhang Z, Hu C-M and Guo H 2018 *J. Phys. D: Appl. Phys.* **51** 274004
[16] Beens M, Heremans J P, Tserkovnyak Y and Duine R A 2018 *J. Phys. D: Appl. Phys.* **51** 394002
[17] Cramer J, Ritzmann U, Dong B-W, Jaiswal S, Qiu Z, Saitoh E, Nowak U and Kläui M 2018 *J. Phys. D: Appl. Phys.* **51** 144004
[18] Białek M, Bréchet S and Ansermet J-P 2018 *J. Phys. D: Appl. Phys.* **51** 164001
[19] Yagmur A, Iguchi R, Geprägs S, Erb A, Daimon S, Saitoh E, Gross R and Uchida K 2018 *J. Phys. D: Appl. Phys.* **51** 194002
[20] Ramos R, Lucas I, Algarabel P A, Morellón L, Uchida K, Saitoh E and Ibarra M R 2018 *J. Phys. D: Appl. Phys.* **51** 224003
[21] Gomonay O, Yamamoto K and Sinova J 2018 *J. Phys. D: Appl. Phys.* **51** 264004
[22] Asam N, Yamanoi K and Kimura T 2018 *J. Phys. D: Appl. Phys.* **51** 224004
[23] Michel A-K *et al* 2017 *J. Phys. D: Appl. Phys.* **50** 494007
[24] Cansever H *et al* 2018 *J. Phys. D: Appl. Phys.* **51** 224009
[25] Göbbels S, Güntherodt G and Beschoten B 2018 *J. Phys. D: Appl. Phys.* **51** 214003
[26] Wang X S and Wang X R 2018 *J. Phys. D: Appl. Phys.* **51** 194001
[27] Tatara G 2018 *J. Phys. D: Appl. Phys.* **51** 254002
[28] Kurpas M, Gmitra M and Fabian J 2018 *J. Phys. D: Appl. Phys.* **51** 174001
[29] Langner T, Bozhko D A, Bunyaev S A, Kakazei G N, Chumak A V, Serga A A, Hillebrands B and Vasyuchka V I 2018 *J. Phys. D: Appl. Phys.* **51** 344002
[30] Olsson K S, An K and Li X 2018 *J. Phys. D: Appl. Phys.* **51** 133001
[31] Liu H, McLaughlin R, Sun D and Vardeny Z V 2018 *J. Phys. D: Appl. Phys.* **51** 134003
[32] Wesenberg D, Hojem A, Bennet R K and Zink B L 2018 *J. Phys. D: Appl. Phys.* **51** 244005
[33] Srichandan S, Kronseder M, Vogel M, Back C H and Strunk C 2018 *J. Phys. D: Appl. Phys.* **51** 294006
[34] Seifert T S *et al* 2018 *J. Phys. D: Appl. Phys.* **51** 364003
[35] Shen K and Bauer G E W 2018 *J. Phys. D: Appl. Phys.* **51** 224008