From heat to spin to electricity: Understanding spin transport in thermoelectric devices

January 28 2021

Thermoelectric materials will allow the efficient conversion of waste industrial heat into electricity. But to create effective thermoelectric materials, their underlying physics must be well understood. Credit: Macrovector on Freepik

Thermoelectric materials, which can generate an electric voltage in the presence of a temperature difference, are currently an area of intense research; thermoelectric energy harvesting technology is among our best shots at greatly reducing the use of fossil fuels and helping prevent a worldwide energy crisis. However, there are various types of thermoelectric mechanisms, some of which are less understood despite recent efforts. A recent study from scientists in Korea aims to fill one such gap in knowledge.

One of these mechanisms mentioned earlier is the spin Seebeck effect (SSE), which was discovered in 2008 by a research team led by Professor Eiji Saitoh from Tokyo University, Japan. The SSE is a phenomenon in which a temperature difference between a nonmagnetic and a ferromagnetic material creates a flow of spins. For thermoelectric energy harvesting purposes, the inverse SSE is especially important. In certain heterostructures, such as yttrium iron garnet—platinum (YIG/Pt), the spin flow generated by a temperature difference is transformed into a current with an electric charge, offering a way to generate electricity from the inverse SSE.

Because this spin-to-charge conversion is relatively inefficient in most known materials, researchers have tried inserting an atomically thin layer of molybdenum disulfide (MoS_2) between the YIG and Pt layers. Though this approach has resulted in enhanced conversion, the underlying mechanisms behind the role of the 2-D MoS_2 layer in spin transport remains elusive.

To tackle this knowledge gap, Professor Sang-Kwon Lee of the Department of Physics at Chung-Ang University, Korea, has recently led an in-depth study on the topic, which has been published in *Nano Letters*. Various colleagues from Chung-Ang University participated, as well as Professor Saitoh, in an effort to understand the effect of 2-D MoS_2 on the thermoelectric power of YIG/Pt.

To this end, the scientists prepared two YIG/MoS_2/Pt samples with different morphologies in the MoS_2 layer, as well as a reference sample without MoS_2 altogether. They prepared a measurement platform in which a temperature gradient can be enforced, a magnetic field applied, and the voltage difference caused by the ensuing spin flow monitored. Interestingly, they found that the inverse SSE, and in turn the thermoelectric performance of the whole heterostructure, can be either enhanced or diminished depending on the size and type of MoS_2 used. In particular, using a holey MoS_2 multilayer between the YIG and Pt layers yielded a 60% increase in thermoelectric power compared with YIG/Pt alone.

Through careful theoretical and experimental analyses, the scientists determined that this marked increase was caused by the promotion of two independent quantum phenomena that, together, account for the total inverse SSE. These are called the inverse spin Hall effect, and the inverse Rashba-Edelstein effect, which both produce a spin accumulation that is then converted into a charge current. Moreover, they investigated how the holes and defects in the MoS_2 layer altered the magnetic properties of the heterostructure, leading to a favorable enhancement of the thermoelectric effect. Excited about the results, Lee remarks: "Our study is the first to prove that the magnetic properties of the interfacial layer cause spin fluctuations at the interface and ultimately increase spin accumulation, leading to a higher voltage and thermopower from the inverse SSE."

The results of this work represent a crucial piece in the puzzle of thermoelectric materials technology and could soon have real-world implications, as Lee explains: "Our findings reveal important opportunities for large-area thermoelectric energy harvesters with intermediate layers in the YIG/Pt system. They also provide essential information to understand the physics of the combined Rashba-Edelstein effect and SSE in spin transport." He adds that their SSE measurement platform could be of great help to investigate other types of quantum transport phenomena, such as the valley-driven Hall and Nernst effects.

Let us hope that thermoelectric technology progresses rapidly so that we can make our dreams of a more ecofriendly society a reality!

More information: Won-Yong Lee et al, Enhanced Spin Seebeck Thermopower in Pt/Holey MoS2/Y3Fe5O12 Hybrid Structure, *Nano Letters* (2020). DOI: 10.1021/acs.nanolett.0c03499

Provided by Chung Ang University