Japan Academy Prize to:

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for "Pioneering Research on the Physics of Spin Current"

Outline of the work:

Dr. Eiji Saitoh has established the principle of directly detecting spin currents in solids. Furthermore, he discovered various novel and important phenomena related to spin currents, including the spin Seebeck effect. He has substantially contributed to the development of the field of physics of the spin current in solids and its applications.

Electronics is a technology that uses current and voltage for processing signals and information. The current and voltage are generated from the "charge" of an electron; however, the electron also has "spin" as an internal degree of freedom. Because the spin behaves as a minute magnetic moment, the direction of the spin can also be used as a signal and information. The field of electronics that uses the electron spin for processing signals and information are called spintronics. Recently, several spintronics devices have been realized, and they have received a great deal of attention.

The first example of spintronics applications is probably the use of the giant magnetoresistance effect discovered in multilayers comprising alternating ferromagnetic and nonmagnetic conductive layers. This magnetoresistance effect, in which the electrical resistance changes substantially with a magnetic field, has been used in magnetoresistive random access memory, and as read-heads for hard-disk drives, biosensors, and other devices. Another example of the spintronics applications is the tunnel magnetoresistance effect, which is also used as read-heads for hard-disk drives, etc.

A spin current can be generated in various ways. For example, it is generated when the direction of the electron motion differs depending on the spin direction. The spin current is a physical quantity and independent of the electric current due to the charge of electrons. When the spin current is used instead of the electric current, devices with a completely new function are realized. However, the spin current is not conserved in solids because of the presence of the spin–orbit interaction unlike the electric current, which satisfies the charge conservation law. Therefore, not until recently, the spin current did not attract so much attention.

In a magnetic field, electric current flows in a direction perpendicular to an applied electric field because of the Lorentz force. This phenomenon is well known as the “Hall effect.” Even in the absence of a magnetic field, moving electrons sometimes feel an “effective magnetic field” due to the spin–orbit interaction, and up-spin and down-spin electrons experience a force in opposite directions. Therefore, when an electric current flows, a spin current is generated in the perpendicular direction. This phenomenon is called the “spin Hall effect.” Because a method for directly detecting this spin current did not exist in the early stage, indirect methods, such as the observation of spatial change in the average spin direction (spin accumulation), were used for detecting the spin Hall effect.

Dr. Saitoh observed for the first time that a strong electric field is generated by a spin current through systematic experiments on a Pt thin film and later in various composite films, including NiFe and metal layers. The observed phenomenon corresponds to the reverse process of the spin Hall effect, and it is called the “inverse spin Hall effect.” This inverse spin Hall effect has enabled direct detection of the spin current, which has led to active research on the spin current globally.

Dr. Saitoh has made significant contributions to the research on spin current based on the aforementioned method of spin current detection. Furthermore, he observed several basic phenomena that are crucial in the field of the spin current physics and its applications, including the presence of spin currents in insulators, spin Seebeck effect, spin Hall magnetoresistance, and dynamic spin current generation. Among these, the discovery of the spin Seebeck effect is noteworthy. The conventional Seebeck effect is a phenomenon in which an electric current is generated by a temperature difference. When the current does not flow, a voltage is induced. Alternatively, temperature differences can be induced by the current.

The spin Seebeck effect is a phenomenon in which a spin current is generated by a temperature difference, and it is an energy conversion phenomenon between thermal energy and the spin current. The spin Seebeck effect can be observed even in an insulator, as long as it is a good conductor of the spin current. Because the spin current generates voltage through the inverse spin Hall effect, thermal power generation becomes possible using an insulator. Therefore, the spin Seebeck effect is interesting considering its applications, such as thermoelectric power generation and heat flow sensors.

The work of Dr. Eiji Saitoh has made outstanding contributions to the worldwide development of the physics of the spin current. The scope of solid-state physics has been enlarged through the studies of spin current, which provide a new perspective on the properties of materials.

List of Main Publications

1. E. Saitoh, H. Miyajima, T. Yamaoka, and G. Tatara, “Current-induced resonance and mass determination of a single magnetic domain wall”, Nature 432, 203–206 (2004).
2. E. Saitoh, M. Ueda, H. Miyajima, and G. Tatara, “Conversion of spin current into charge current at room temperature: inverse spin-Hall effect”, Applied Physics Letters 88, 182509 (2006).
3. K. Ando, S. Takahashi, K. Harii, K. Sasage, J. Ieda, S. Maekawa, and E. Saitoh, “Electric manipulation of spin relaxation using spin-Hall effect”, Physical Review Letters 101, 036601

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4. K. Uchida, S. Takahashi, K. Harii, J. Ieda, W. Koshibae, K. Ando, S. Maekawa, and E. Saitoh, "Observation of the spin Seebeck effect", Nature 455, 778–781 (2008).
5. Y. Kajiwara, K. Harii, S. Takahashi, J. Ohe, K. Uchida, M. Mizuguchi, H. Umezawa, H. Kawai, K. Ando, K. Takanashi, S. Maekawa, and E. Saitoh, "Transmission of electrical signals by spin-wave interconversion in a magnetic insulator", Nature 464, 262–266 (2010).
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7. K. Ando, S. Takahashi, J. Ieda, H. Kurebayashi, T. Trypiniotis, C. H. W. Barnes, S. Maekawa, and E. Saitoh, "Electrically tunable spin injector free from the impedance mismatch problem", Nature Materials 10, 655–659 (2011).
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9. H. Nakayama, M. Althammer, Y.-T. Chen, K. Uchida, Y. Kajiwara, D. Kikuchi, T. Ohtani, S. Geprägs, M. Opel, S. Takahashi, R. Gross, G. E. W. Bauer, S. T. B. Goennenwein, and E. Saitoh, "Spin Hall magnetoresistance induced by a nonequilibrium proximity effect", Physical Review Letters 110, 206601 (2013).
10. T. An, V. I. Vasyuchka, K. Uchida, A. V. Chumak, K. Yamaguchi, K. Harii, J. Ohe, M. B. Jungfleisch, Y. Kajiwara, H. Adachi, B. Hillebrands, S. Maekawa, and E. Saitoh, "Unidirectional spin-wave heat conveyer", Nature Materials 12, 549–553 (2013).
11. R. Takahashi, M. Matsuo, M. Ono, K. Harii, H. Chudo, S. Okayasu, J. Ieda, S. Takahashi, S. Maekawa, and E. Saitoh, "Spin hydrodynamic generation", Nature Physics 12, 52–56 (2015).
12. D. Hou, Z. Qiu, R. Iguchi, K. Sato, E. K. Vehstedt, K. Uchida, G. E. W. Bauer, and E. Saitoh, "Observation of temperature-gradient-induced magnetization", Nature Communications 7, 12265 (2016).
13. D. Hirobe, M. Sato, T. Kawamata, Y. Shiomi, K. Uchida, R. Iguchi, Y. Koike, S. Maekawa, and E. Saitoh, "One-dimensional spinon spin currents", Nature Physics 13, 30–34 (2017).
14. K. Uchida, S. Daimon, R. Iguchi, and E. Saitoh, "Observation of anisotropic magneto-Peltier effect in nickel", Nature 558, 95–99 (2018).
15. Z. Qiu, D. Hou, J. Barker, K. Yamamoto, O. Gomonay, and E. Saitoh, "Spin colossal magnetoresistance in an antiferromagnetic insulator", Nature Materials 17, 577–580 (2018).
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18. K. Harii, Y-J. Seo, Y. Tsutsumi, H. Chudo K. Oyanagi, M. Matsuo, Y. Shiomi, T. Ono, S. Maekawa, and E. Saitoh, "Spin Seebeck mechanical force", Nature Communications 10, 2616 (2019).
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R. Ramos, S. Takahashi, Y. Shiomi, Y. Tserkovnyak, and E. Saitoh, "Observation of nuclear-spin Seebeck effect", Nature Communications 12, 4356 (2021).

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