Open a path to development of new energy conversion technology

Generating spin current by irradiating light on insulator

Ken-ichi Uchida

(Institute for Materials Research, Tohoku University, Associate Professor)

PRESTO Phase Interfaces for Highly Efficient Energy Utilization "Creation of Innovative Energy Device Technology Based on Spin Currents" Researcher (2012-2018)

Eiji Saitoh

(WPI Advanced Institute for Materials Research/Institute for Materials Research, Tohoku University, Professor)

PRESTO Materials and Processes for Innovative Next-generation Devices "Spintronics Based on Spin Currents and Spin-photon Coupling in Dielectrics" Researcher (2007-2011)

CREST Creation of Nanosystems with Novel Functions through Process Integration "Generation of Nanointegration of Heat, Electricity and Motion by Spin Current" Representative Researcher (2010-2015)

SICP Combination region combining the material field and other field "Development of Thin-film Thermoelectric Devices by Utilizing Magnetic Nanostructures for Ubiquitous Thermoelectrics" Researcher (2011-2014)

ERATO "SAITOH Spin Quantum Rectification Project" Research Director (2014-2020)

Birth of completely new energy conversion principle

We now see world-wide approaches for a solution to environmental and energy issues aiming at a sustainable society. Among them, one of the most feasible trials is the one to utilize quite familiar items, such as light, heat, vibration and electromagnetic wave as an energy source. Power generation utilizing solar cells and thermoelectric devices is focused as energy conversion technology, which also is clean and highly reliable, so that it is a quite popular research subject.

Associate Professor Ken-ichi Uchida has succeeded in the conversion of optical energy into a spin current (magnetic flow) for the first time in the world by irradiating visible light to an insulator magnet *1 in which specific metal particles are embedded in the research of PRESTO; Phase Interfaces for Highly Efficient Energy Utilization. His former supervisor, Professor Eiji Saitoh, was honored by awards in the fundamental discovery of spin currents, who is actually regarded as the PRESTO of the field. Associate Professor Uchida, who was the member of the Saitoh laboratory at Keio University, discovered the spin Seebeck effect (phenomenon to cause spin currents from the temperature difference in a magnetic substance) for the first time in the world under Professor Saitoh. This discovery was published as his faculty graduation thesis in Nature in 2008.

Light/spin-current conversion realized by strong electromagnetic field

The conceptual diagram (Figure 1 <a>) shows the concept of PRESTO research of Associate Professor Uchida. A powerful electromagnetic field is formed adjacent to metal particles (Figure 1 <b>) embedded in an insulator magnet using the collective motion of electrons, which is called the surface plasmon*2 generated by the stimulus from light with a specific wavelength (Figure 1 <c>). This electromagnetic field has effectively driven the motion of spin to realize the light/spin-current conversion by an insulator magnet.

Here, he uses a device that is formed by jointing a thin film of platinum (Pt) on the surface of an insulating thin film called the magnetic garnet ($BiY_2Fe_5O_{12}$). The magnetic garnet layer of this device has gold (Au) particles with the size of a nanometer (nm, 1 nm is a one billionth of 1 m) embedded in it (Figure 1 <b>).

Irradiating light on it forms a powerful electromagnetic field adjacent to the particles only when the wavelength of the incident light meets the surface plasmon resonance condition. This means that the gold particles function as an antenna for the light (Figure 2<a>), and as a result, the motion of spins has obtained an external energy due to the powerful electromagnetic field, and the spin current is generated in the top layer of the platinum thin film (Figure 2<b>),

The conventional research regarding a light-spin conversion has always used a semiconductor. This research is based on the completely different physical principle, which for the first time has enabled the light/spin-current conversion with an insulator magnet.

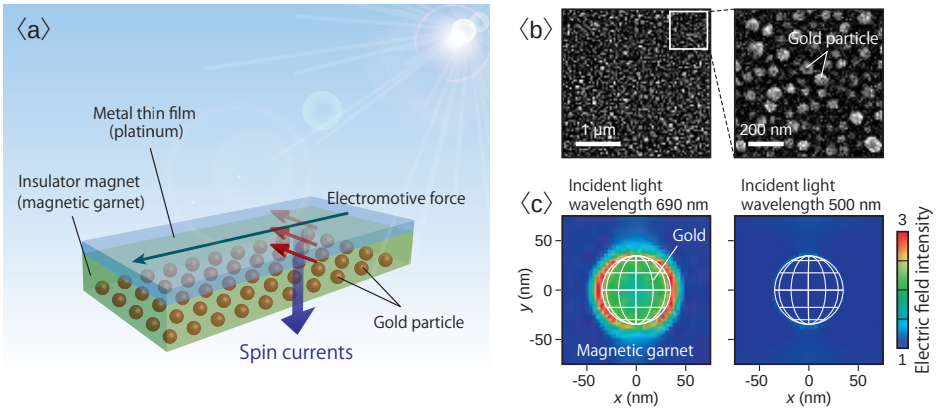

Figure 1 Light-spin conversion using surface plasmon

〈a〉 Conceptual diagram of research - Schematic diagram of the device used in this experiment

〈b〉 Gold particle captured by scanning electron microscope

〈c〉 Result of a simulation of electromagnetic field distribution adjacent to gold particles On the left; a powerful electromagnetic field is formed; on the right, no reinforcing effect of the electromagnetic field.

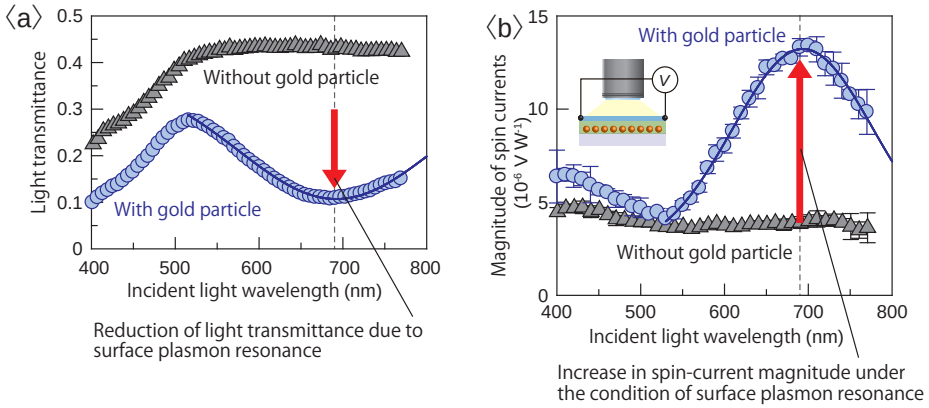

Figure 2 Wavelength dependency of the light transmittance and the spin-current magnitude for the device used in this experiment

Innovative characteristics such as a degree of freedom of device design and being enabled to utilize an insulator

The technology level of this energy conversion using spin currents has not reached the level of the existing energy conversion yet. However, it still has great characteristics compared to others, which includes a high degree of freedom for device design thanks to the simple thin film structure, being able to utilize an insulator that has been a mere substrate or container of devices, and being able to utilize various energy sources simultaneously. We see more and more increase in interest to the thermoelectric conversion technology with the new principle utilizing the spin Seebeck effect.

Expectation to contribution for formation and development of new fusion research field

The importance of this outcome is to indicate the possibility of converting various energy sources, such as light, heat, sound waves, and electromagnetic waves, into spin and electric currents, while we still have a subject to further increase efficiency.

The current critical subject is to secure a power source that is available full time in regards to the research development of the power source capable of a long-term energy provision without any need for recharging, exchanging, or refueling. The spin current capable of simultaneous utilization of various energy sources with a single device is a hope to pioneer in the future. This conversion principle that Associate Professor Uchida has discovered shall contribute greatly to the birth of a new research field fusing the surface plasmon and spin currents, and the research development of electric and magnetic devices without the need for any external power source.

*1 Collective term for substances that are not conductive. Professor Saitoh and his colleagues verified in 2010 that spins can flow in an insulator with the property of a magnet, such as a magnetic garnet.

*2 Free electrons' collective oscillation on the surface of a metal, excited by an optical electric field. A resonance phenomenon between an electric field excited by the oscillation of free electrons and an optical electric field is called surface plasmon resonance.