From Earth to Mars: Transporting spin information at the speed of light !

Scientists have successfully modulated magnetic information using electrical pulses while converting it into a polarized light signal. This discovery, described in the journal Nature, could revolutionize long-distance optical telecommunications.

In spintronics, recognized by its success with magnetic computer hard drives and magnetic memories, information is represented by electron spin and by its proxy, the direction of magnetization. Ferromagnets such as iron or cobalt have a finite magnetization, because unequal numbers of their electrons' spins are oriented either along or against the magnetization axis, representing binary information 0 and 1. While electrons with spin along the magnetization travel smoothly across a ferromagnet, those with opposite spin orientation are bounced around, just as a player in a football match dealing with the member of his own or the opposing team. The resulting change of the resistance with the spin orientation-magnetoresistance, is the key principle for spintronic devices. As we know, the fridge magnet does not need power to remain stuck to the fridge door. Its magnetic state, which can be considered as stored information, is maintained indefinitely.

However, by taking electrons out of the ferromagnet, akin to taking fish out of the water, the spin information is quickly lost and cannot travel far. This major limitation can be overcome by utilizing light through its circular polarization or handedness, also known as helicity*, as another spin carrier. Just as recognized for centuries that written information would be carried faster and farther by pigeons, the trick would be to transfer electron spin to photon spin, the quantum of light. The presence of spin-orbit coupling, which is also responsible for the spin information loss outside of the ferromagnet, makes such transfer of spin from electron to photon possible. The crucial missing link is then to electrically modulate the magnetization and thereby change the helicity of the emitted light.

The group of scientists from the Jean Lamour Institute (CNRS/University of Lorraine, France) in collaboration with Laboratoire Albert Fert (France), Université de Toulouse (France), Université Paris-Saclay (France), Ruhr-Universität Bochum (Germany), Institute of Semiconductors and Institute of Physics (Chinese Academy of Sciences), National Institute of Advanced Industrial Science and Technology (Japan), University of Minnesota (USA), National Renewable Energy Laboratory (USA), and University at Buffalo (USA) have chosen circular polarization of light to carry the electron's spin information. They successfully switched the magnetization of a spin injector by an electrical pulse using the spin-orbit torque. The electron's spin is rapidly converted into information contained in the helicity of the emitted photons enabling a seamless integration of magnetization dynamics with photonic technologies.

This electrically controlled spin-photon conversion is now achieved in the electroluminescence of light-emitting diodes. In the future, through the implementation in semiconductor laser diodes, so-called spin-lasers, this highly-efficient information encoding could pave the way for rapid communication over interplanetary distances since polarization of light can be conserved in space propagation, potentially making it as the fastest mode of communication between Earth and Mars. It will also greatly benefit the development of various advanced technologies on Earth, such as optical quantum communication and computation, neuromorphic computing for artificial intelligence, ultrafast and high-efficient optical transmitters for data centers or Light-Fidelity (LiFi) applications. More perspectives can be found in the journal Nature.

* It represents the rotation direction of the electrical component of light (clockwise or counterclockwise) around its propagation axis and is related to the spin state of the photons.

Collaborators' comments on this work:

"It is great to see spin-orbit-torque materials that can be part of the enablers to demonstrate the first spin-laser. We are glad to be part of this large team to try out different SOT materials", said by Jian-Ping Wang, Distinguished McKnight University professor and Robert Hartmann Chair in Electrical and Computer Engineering at the University of Minnesota.

"The realization of spin-orbit-torque spin injectors is a decisive step that will greatly advance the development of ultrafast and energy-efficient spin lasers for the next generation of optical communication and quantum technologies. It has been a pleasure to be part of this great activity and team.", said by Nils Gerhardt, professor at the Chair of Photonics and Terahertz Technology at the Ruhr University in Bochum, Germany.

“For decades we were dreaming of and predicting room-temperature spintronic devices beyond magnetoresistance and just storing information. With this team's discovery, our dreams became reality,” noted Igor Žutić, State University of New York Distinguished Professor of Physics, University at Buffalo.

"The concept of spin LEDs was initially proposed at the end of the last century. However, for the transition into a practical application, it must meet three crucial criteria: operation at room temperature, no need of magnetic field, and the ability for electrical control. After more than 15 years of dedicated work in this field, our collaborative team has successfully conquered all obstacles. We are very happy to push this technology towards another important spintronic application beyond the magnetoresistance effect.", stated by Yuan Lu, senior CNRS researcher at Institut Jean Lamour, University of Lorraine, France.

“The room-temperature (RT) spintronics devices of Spin LED (this work) together with other previous reported spin resonant tunneling diode (Spin RTD), not only can be controlled by the voltage (electric field) and laser (optical field), but also can be controlled by the spin (magnetic field). Such distinct developments have important scientific significance and application values in the RT spin quantum manipulation and device applications. These experimental works landmark both the Spin LED and Spin RTD devices at RT and open the “quantum” era for the classic spintronics.”, emphatically pointed out by Prof. Xiufeng Han, Institute of Physics (Chinese Academy of Sciences).

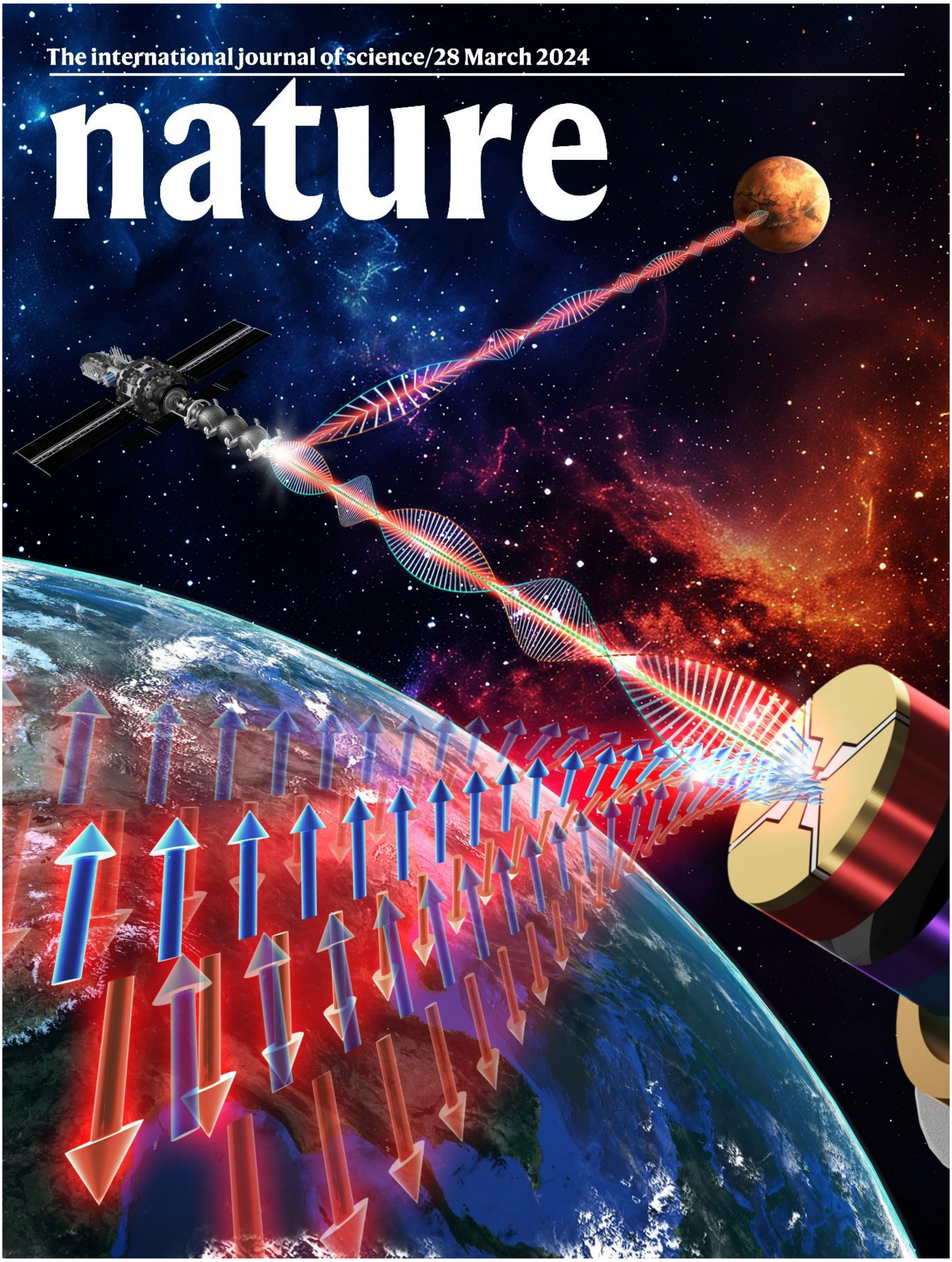
Reporter: CARTIER DIT MOULIN Christophe (christophe.cartier@cnrs-dir.fr)

Reference:

Pambiang Abel Dainone *et al.*
Controlling the helicity of light by electrical magnetization switching
Nature 627, 783-788 (2024). Published online 27 March, 2024.
https://www.nature.com/articles/s41586-024-07125-5
read article on https://rdcu.be/dCFs3

Contact:

Yuan Lu, CNRS researcher at l'Institut Jean Lamour (CNRS/Université de Lorraine)
Email: yuan.lu@univ-lorraine.fr


The international journal of science/28 March 2024
nature