Orbitronics: The Future's Energy-Efficient Technology

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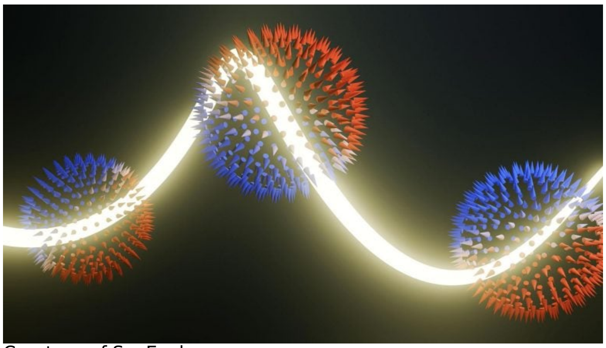

Courtesy of SynEvol
Credit: Paul Scherrer Institute

The next generation of environmentally friendly technologies may process information using different electron characteristics than electronics, which rely on electron charge for data transport. Spintronics has been the leading candidate for an alternative kind of "tronics" until recently. In this case, information is sent via the electron's spin.

In a developing subject known as orbitronics, scientists are also investigating the potential applications of the orbital angular momentum (OAM) of electrons circling their atomic nucleus. This area has a lot of potential for memory devices, especially since it may be possible to create substantial magnetization with comparatively tiny charge currents, which would result in devices that require less energy. The key topic at hand is which materials are best suited to produce flows of OAMs, which are necessary for orbitronics.

An international research team now demonstrated that chiral topological semi-metals, a new class of materials discovered at PSI in 2019, have properties that make them a highly viable option for generating currents of OAMs. The team was led by scientists from Paul Scherrer Institute PSI and Max Planck Institutes in Halle and Dresden in Germany.

In the hunt for suitable materials for orbitronics, steps ahead have already been made utilizing conventional materials such as titanium. Nevertheless, chiral topological semi-metals have emerged as a compelling candidate since their discovery five years ago. These materials' helical atomic structure lends them a natural "handedness" akin to the double helix of DNA and may equip them with OAM flow-facilitating textures or patterns.

Michael Schüler, an assistant professor of physics at the University of Fribourg and group leader in the PSI Center for Scientific Computing, Theory and Data, says, "This offers a significant advantage to other materials because you don't need to apply external stimuli to get OAM textures—they're an intrinsic property of the material." Schüler co-led the recent study. "This could simplify the process of producing steady and effective OAM currents without the need for particular circumstances."

Researchers have been particularly interested in OAM monopoles, a specific OAM texture that has been postulated in chiral topological semi-metals. OAM extends outward from a central point at these monopoles, resembling the spikes of a frightened hedgehog curled into a ball.

OAM is isotropic, meaning that it is uniform in all directions, which is why these monopoles are so alluring. According to Schüler, this is a very helpful feature since it allows for the generation of OAM flows in any direction.

OAM monopoles are attractive for orbitronics, but up until this most recent work, they were only a theoretical possibility.

Circular Dichroism in Angle-Resolved Photoemission Spectroscopy, or CD-ARPES, is a technique that uses circularly polarized X-rays from a synchrotron light source to study them experimentally. However, in the past, a discrepancy between theory and experiment has made it difficult for researchers to understand the data. "The data may have been available to researchers, but it was buried with evidence supporting OAM monopoles," Schüler claims.

Electrons are ejected from a substance in ARPES when light shines on it. The material's electrical structure can be inferred from the angles and energy of these expelled electrons. The incident light in CD-ARPES has a circular polarization.

According to Schüler, "it is a natural assumption that you are measuring something that is directly proportional to the OAMs if you use circularly polarized light." The issue is that, as our research demonstrates, this turns out to be a quite naive assumption. In truth, it's really more complex."

In their investigation, Schüler and colleagues tested two types of chiral topological semi-metals at the Swiss Light Source SLS: those constructed of palladium and gallium or platinum and gallium. With a strong desire to uncover the OAM textures concealed in the intricate network of CD-ARPES data, the team applied rigorous theory to question every presumption.

Then, they carried out an odd but essential additional experimental step in which they changed the photon energies. "The facts didn't make sense at first. According to Schüler, the signal appeared to be fluctuating all over the place.

After carefully separating out the various factors that affected OAM calculations from CD-ARPES data, they discovered that, contrary to what was previously thought, the CD-ARPES signal rotated around the monopoles as photon energy varied. They established the existence of OAM monopoles and closed the gap between theory and experiment in this way.

After successfully seeing OAM monopoles, Schüler and associates demonstrated that a crystal with a mirror image chirality could be used to change the polarity of the monopole, or whether the OAM spikes point inside or outward. According to Schüler, "ortronics devices could potentially be created with different directionality, so this is a very useful property."

With theory and experiment finally coming together, the research community at large may now investigate OAM textures in a range of materials and maximize their orbitronics applications.