Photon spintronics or spin properties of light or could enable integrated electronic, optoelectronic and magnetoelectronic devices

Spin electronics (also called spintronics, magnetoelectronics or magnetronics) is “A branch of physics concerned with the storage and transfer of information by means of electron spins in addition to electron charge as in conventional electronics.” Spin-based electronics focuses on devices whose functionality is based primarily on the spin degree of freedom of the carriers. This is in contrast to conventional electronics, which exploits only the charge of the carriers.

One advantage of spin over charge is that spin can be easily manipulated by externally applied magnetic fields, a property already in use in magnetic storage technology. Less energy is needed to change spin than to generate a current to maintain electron charges in a device, so spintronics devices use less power.

A new discovery links the spin and momentum of light waves, and could mean a major advance in the development of new photonic and spintronic devices. Scientists from Purdue University have discovered a property of light waves called “spin-momentum locking,” which means that a rotating electric field accompanying light moves in a certain direction according to the photons’ momentum. In other words, light waves spinning counterclockwise move only “forward,” those
It’s a significant discovery, because it means that light—formerly used in technology merely for communication purposes—can now be harnessed for memory and logic operations in computers, for instance, by using photonic spin.

The University of Pennsylvania’s (Penn) Agarwal Group, headed by professor Ritesh Agarwal, seeks to understand how light interacts with small-scale nanostructures. The group then uses that understanding to engineer useful and innovative optoelectronic devices.

Ultimately this could lead to “In fact, the spintronics dream is a seamless integration of electronic, optoelectronic and magnetoelectronic multifunctionality on a single device that can perform much more than is possible with today’s microelectronic devices,” says Sharma.

Unfortunately, the spin only lasts for a very short time, making it (as yet) difficult to exploit in electronics. Researchers from the Kavli Institute of Nanoscience at TU Delft, working with the Netherlands Organisation for Scientific Research’s AMOLF institute, have now found a way to convert the spin information into a predictable light signal at room temperature. The discovery brings the worlds of spintronics and nanophotonics closer together and might lead to the development of an energy-efficient way of processing data, in data centres, for example.
In a recent article in Nature Communications, a team of researchers from Linköping University and the Royal Institute of Technology in Sweden have designed a new device that can effectively transfer information carried by electron spin to light when at room temperature.

**New Discovery May Allow Us to Harness the Power of a Photon’s Spin**

Photonic technology could also be coupled with “spintronics,” in which the spin as well as charge of electrons is utilized. The question,” explains Zubin Jacob, one of the authors of the new study appearing in the journal Optica, “is how to interface photonics and spintronics. We would have to use some of these spin properties of light to interface with spintronics so that we might use both photons and electrons in devices.”

“Researchers had noticed intriguing effects related to directional propagation of light coupled to its polarization,” Jacob continues. “What we have shown is that this is a unique effect related to the spin and momentum of light analogous in many ways to the case of spin-momentum locking which occurs for electrons. We showed there is a very simple rule that governs this spin and momentum locking. And it’s a universal property for all optical materials and nanostructures, which makes it potentially very useful for photonic devices. This universality is unique to light and does not occur for electrons.”
Agarwal Group Puts Spin on Photons

Silicon-based photonic device that is sensitive to the spin of the photons in a laser shined on one of its electrodes. Light that is polarized clockwise causes current to flow in one direction, while counter-clockwise polarized light makes it flow in the other direction.

One area the researchers at Penn’s Department of Materials Science and Engineering is focusing on is photon “spintronics,” a variation of electron-based spintronics but applied to measuring photon spin for applications in optical devices and circuits.

“Current electronic devices work by measuring the number of electrons that flow in a circuit. In spintronics, the idea is to encode more information in electron spin,” Agarwal said. “Analogously, if we can engineer properties of materials via an interplay of symmetry, geometry, and topology, then we can encode more information in photon spin. Recently, by using materials called topological Weyl semimetals, we were able to detect on-chip the spin of the photon, and the next step we are currently working on is to also design photodetectors sensitive to what are called the orbital angular degrees of freedom of light.”

Agarwal told Photonics Media that the idea behind the photon spin is to encode and extract more information in optical circuits. “We showed that even in a material like silicon, which has all the mirror symmetries, we can still make the material chiral by engineering its geometrical properties,” he said. “For example, by cutting the material in a particular direction, by applying electrical fields, we broke all the
mirror symmetries in silicon. By doing so we were able to detect the photon spin using Si, a workhorse material for electronics and photonics.”

The Penn researchers’ focus with photon spin is to make silicon photonics work at the same length scales as silicon-based electronics.

In a typical computer chip that is opened up, there are features that are 20 to 40 nanometers in diameter; these are basically silicon based electronic transistors. However, to make optical devices that are comparable to the size of the optical wavelength, they have to be many microns in size.

“If you want to integrate electronics with photonics, and your optical devices are two or three orders of magnitude larger in size than your electronics, then there is a size mismatch,” Agarwal said. “What we’ve been trying to focus on is trying to reduce the length scale of silicon-based photonics down to tens of nanometers.”

The Agarwal Group has created silicon-based detectors that can detect photon spin very reliably and with very high fidelity. They’re also trying to make modulators and silicon-based Raman lasers at the same length scale as silicon-based electronic devices. The researchers say they can extend the same idea of photon spin in commercial silicon-based single-photon detectors and make them sensitive to photon spin.
Spintronics and nanophotonics combined in 2-D material

The research revolved around a nano-construction consisting of two components: an extremely thin silver thread and a 2D material called tungsten disulfide. The researchers attached the silver thread to a slice of tungsten disulfide measuring just four atoms in thickness. Using circularly polarised light, they created what are known as ‘excitons’ with a specific rotational direction. The direction of that spin could be initialized using the rotational direction of the laser light.

Excitons are actually electrons that have bounced out of their orbit. With this technique, the laser beam ensures that the electrons are launched into a wider orbit around a positively charged ‘hole’, in much the same way as a hydrogen atom. The excitons thus created want to return to their original state. On their return to the smaller orbit, they emit an energy package in the form of light. This light contains the spin information, but it emitted in all directions.

To enable the spin information to be put to use, the Delft researchers returned to an earlier discovery. They had shown that when light moves along a nanowire, it is accompanied by a rotating electromagnetic field very close to the wire: it spins clockwise on one side of the wire, and anti-clockwise on the other side. When the light moves in the opposite direction, the spin directions change too. So the local rotational direction of the electromagnetic field is locked one-to-one to the direction with which the light travels along the wire. ‘We use this phenomenon as a type of lock combination,’ explains Kuipers. ‘An exciton with a particular rotational direction can only emit light along the thread if
the two rotational directions correspond.’

**Opto-electronic switches**

And so a direct link is created between the spin information and the propagation direction of the light along the nanowire. It works almost perfectly: the spin information is ‘launched’ in the right direction along the thread in 90% of cases. In this way, fragile spin information can be carefully converted into a light signal and transported over far greater distances. Thanks to this technique, which works at room temperature, you can easily make new optoelectronic circuitry. Kuipers: ‘You don’t need a stream of electrons, and no heat is released. This makes it a very low-energy way of transferring information.’

The discovery clears the way for combining the worlds of spintronics and nanophotonics. Kuipers: ‘This combination may well result in green information processing strategies at the nanoscale.’

**Researchers from both Linköping University and the Royal Institute have devised an interface that’s efficient in spin-light technology.**

Team of researchers from both Linköping University and the Royal Institute have devised an interface that’s efficient in spin-light technology. “This interface can not only maintain and even enhance the electron spin signals at room temperature. It can also convert these spin signals to corresponding chiral light signals traveling in the desired
direction,” says Chen.

The problem is that when the temperature rises the electrons are more at risk of losing their spin orientations. “A key element for future spin-light applications is efficient quantum information transfer at room temperature, but at room temperature, the electron spin orientation is nearly randomized,” explains Weimin Chen at the Department of Physics, Chemistry and Biology, IFM, at Linköping University.

The device itself is made up from tiny disks of gallium nitrogen arsenide (GaNAs) stacked on top of one another with a thin layer of gallium arsenide (GaAs) placed in-between. And the way it will work is to enhance spin signals so that they’re efficient enough to drain unwanted electrons while preserving those with the correct spin orientation. Hopefully, this device will spur on the likes of other spin-light interfaces and the world of opto-spintronics itself.

References and Resources also include:

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