# Photons do the twist, and scientists can now measure it

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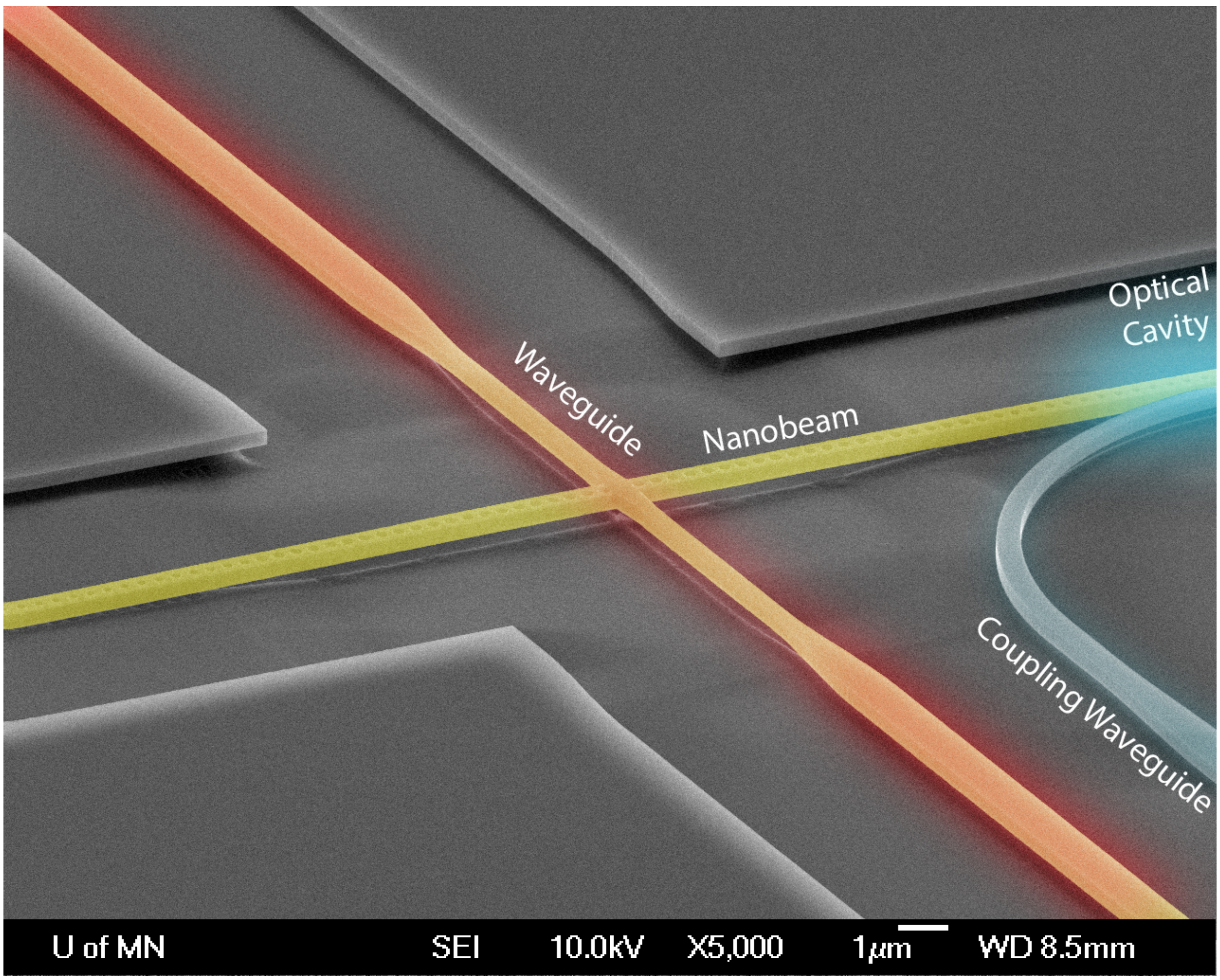


Measurement of the twisting force, or torque, generated by light on a silicon chip holds promise for applications such as miniaturized gyroscopes and sensors to measure magnetic field, which can have significant industrial and consumer impact. Credit: University of Minnesota

Researchers in the University of Minnesota's College of Science and Engineering have measured the twisting force, or torque, generated by light on a silicon chip. Their work holds promise for applications such as miniaturized gyroscopes and torsional sensors to measure magnetic field, which can have significant industrial and consumer impact.

The new study, entitled "Optomechanical measurement of photon spin angular momentum and optical torque in integrated photonic devices" was published in the American Association for the Advancement of Science's journal *Science Advances*. The authors are University of Minnesota Department of Electrical and Computer Engineering Associate Professor Mo Li, graduate student Li He, and postdoctoral associate Huan Li.

Torque, in the context of light, stems from the spin angular momentum of photons (particles of light), and its measurement is mechanical proof of the quantum nature of light. Although such measurements have been performed in much larger scale systems, the latest results were achieved within a micrometer-sized waveguide—a thin wire that guides light—and demonstrated the use of optical torque to induce rotational motion in a microscale mechanical device.

## Polarized light and optical torque

Light is an electromagnetic wave, and its electric field is free to oscillate in any direction. This is called the polarization of light. Your polarizing sunglasses and the goggles you wear to see 3D movies work by using the polarization properties of light.

In a type of polarization state called circular polarization, the electric field of light rotates in a circle because of which the photons have spin angular momentum. Theory suggests that such spin angular momentum will lead to a mechanical torque on the objects that interact with the circularly polarized light.

While optical forces such as radiation pressure have been studied and harnessed for a while, angular momentum and the force it induces, optical torque, have remained relatively unexplored. Polarization of light plays a critical role in optical communication. Each time the state of polarization changes, photons exchange angular momentum with the device thereby inducing an optical torque.

Measurement and exploitation of angular momentum and the resulting optical torque could give scientists new insights into controlling and manipulating light for new technologies.

To provide some historical context to the work carried out by Professor Mo Li and his team, consider this: the angular momentum of light was first measured in the mid-1930s (during the dawn of the quantum theory of light) by Richard Beth of Princeton University and Worcester Polytechnic Institute. His experiment measured optical torque and confirmed what had been thus far theoretically predicted: photons can have angular momentum. He set up his experiment to measure spin angular momentum of photons in high vacuum, with measurements based on the rotation of a two-inch diameter wave plate—a device that can alter the polarization state of light passing through it. As a testament to the technical difficulty of setting up the experiment, further experiments to measure optical torque and angular momentum have been few and far between.

## The measurement of angular momentum and optical torque

Professor Mo Li and his team fabricated an integrated optomechanical device on a silicon chip, with the core element of the device being a waveguide, measuring only 400 nm wide and 340 nm high (unlike the two inch diameter wave plate Beth used), suspended like a string from the substrate. The rectangular cross-section of the waveguide causes the light with horizontal polarization to travel slower than light with vertical polarization. Such an effect is called birefringence, and in this particular case is caused by the geometry of the waveguide rather than the material of the waveguide.

The waveguide works in the same way as a wave plate to change the polarization state of light. When circularly-polarized light is sent into such a waveguide, its polarization state continues to change as it propagates in the waveguide and consequently, the photons exchange spin angular momentum with the waveguide.

"Controlling polarization is critical for modern optical communication. We know from theory that when polarization is changed in an optical fiber or a silicon waveguide, a torque is applied on them," said Huan Li. "The mechanical effect is that the waveguide is twisted [by light] by a very tiny amount that has not been previously measured."

To measure this twisting caused by light, a small silicon beam inscribed with a high quality optical cavity is attached to the waveguide. This provides high measurement sensitivity to the rotation of the beam and the waveguide.

The silicon beam is like the board of a seesaw and the waveguide is like the shaft in the center. When light twists the shaft, the latter rotates and the seesaw tilts, and this is detected by the optical cavity. By changing the polarization of input light periodically, Professor Mo Li's team observed that the nanobeam rotated periodically as well, revealing the optical torque applied on the waveguide.

"From the measurement results, we were able to calculate the spin angular momentum carried by a single photon, which equals to the fundamental Planck constant multiplied by a factor that can be controlled by the waveguide geometry," said Li He. "Our experiment reveals the quantum mechanical property of light on a chip."

For Professor Mo Li and his team, it is exciting that their experiment provides the first unambiguous measurement of the spin angular momentum of photons and the optical torque generated in an integrated photonic device. The result of their experiment also demonstrates that optical torque is influenced by the geometric birefringence, in addition to the material of the waveguide. Also, since the angular momentum of photons is independent of the frequency of light (frequency is what gives light its different colors), the effect of optical torque is the same over the spectral band.

In an age where the power of light is being harnessed for a variety of different applications ranging from medicine to communication systems, exploring the characteristics and resulting effects of photons can be of far reaching impact for scientific devices, military technology, infrastructure, and consumer devices.

**More information:** L. He et al. Optomechanical measurement of photon spin angular momentum and optical torque in integrated photonic devices, *Science Advances* (2016). DOI: 10.1126/sciadv.1600485

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