Researchers develop first-of-its-kind optic isolator

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Researchers at the Technion-Israel Institute of Technology have constructed a first-of-its-kind optic isolator based on resonance of light waves on a rapidly rotating glass sphere. This is the first photonic device in which light advancing in opposite directions moves at different speeds.

"Essentially, we developed a very efficient photonic isolator, which can isolate 99.6% of the light," said research team leader Professor Tal Carmon. "Namely, if we sent 1,000 light particles, the device will effectively isolate 996 photons and will miss only 4. Such isolation efficiency is necessary for applications that include quantum optics communication devices and building high-powered lasers. The isolator we developed here fulfills several additional requirements: it also works well when light from both opposing directions is simultaneously perceived, it is compatible with standard optical-fiber technology, it can be scaled down and it does not change the color of the light."

Just as swimming downstream is faster than swimming upstream and riding a bicycle with the wind behind you is faster than riding against the wind, light also changes its speed with "tailwinds" or "counter-flow," in response to the medium in which it is moving. The speed of light in glass, for instance, is slower than its speed in air. Also, two beams of light advancing in opposite directions in glass, or any other material, will advance at the same speed.

"At the Technion, I also learned that the speed of light depends on the speed of the medium in which it is moving," said Professor Carmon. "Precisely like a swimmer in a river – the speed of light against the movement of the medium is slower than its speed with the movement of the medium."

This effect was already described in 1849 by the French scientist Armond Fizeau, who showed, that like a swimmer in a river, the speed of light down a current is faster than light going up a current. Fizeau's discovery had a significant impact on the development of Einstein's theory of Special Relativity.

The Fizeau drag may lead to significant applications in optics and computers, as its unique ability to differentiate between the speeds of light for counter-propagating beams can generate an optic isolator – a device into which light entering on one side is blocked, while the light entering from another side is transmitted. Until now, a device in which opposing light beams advance at different speeds, had not be constructed.

But now, for the first time, Technion researchers have succeeded in constructing such a device. The spherical optic device rotates at a high speed. Light beams are delivered into it from opposite directions via a nearby tapered fiber. The light approaching from the right moves along the circumference of the ball, in the direction of the rotation of the sphere, while the light approaching from the left turns opposite the direction of the rotation and therefore moves at a slower speed.

The novel device constitutes an optic isolator – it transmits light approaching from the left and turns off light coming from the right. Another effect that is relevant here is resonance. Just like a musical instrument that resonates at a specific frequency, light circumferentially circulating in the sphere resonantly echoes. Yet, the different speeds for counter-circulating light forces these counter-circulating light to have different colors. This way, light entering from one side

echoes inside the sphere while circulating thousands of times in the sphere, until it is absorbed. In contrast, light entering from the opposing side of the isolator is nonresonating and hence passes through the device practically undisturbed. In other words, the light moving with the device, resonates and is shut off, while the light moving against the device is transmitted and continues on."

Professor Carmon noted that the device was constructed at the Technion glass blowing workshop. It was constructed from a glass rod whose tip was melted to a 1 millimeter-radius ball. The light enters the isolator from both sides of a standard optical fiber, tapered at the vicinity of the sphere to a diameter 100-time smaller than that of a hair, and positioned several nanometers away from the sphere. The sphere, which serves as the resonator, rotates at an ultra-fast speed – the tip of the ball moves at a speed of 300 kph – and the light coming from the fiber rotates within it thousands of times.

One of the engineering challenges the research group faced was maintaining the ultra-short distance between the fiber – via which light is provided – and the spherical resonator constant.

"Maintaining an accurate distance is a true challenge, even when the device is not moving, and is an enormous challenge when the sphere is rotating at such a high speed," said Prof. Carmon. "Therefore, we sought a means of forcing the fiber to move together with the sphere, despite the fact that the fiber and sphere are not connected. We finally achieved this by designing the fiber to float on the wind generated by the rotation of the sphere. In this way, if the device wobbles – which it does due to the rapid rotation – the fiber will wobble with it and the distance between them will be preserved. In fact, the fiber is actually flying above the rotating sphere at a constant and self-alighted nano-elevation"

The photo shows the fiber (the empty circle), the tip of the rotating sphere (at the bottom, in grey), and the flow of wind between them, upon which the fiber floats. The fiber floats above the sphere while maintaining a distance of several tens of nanometers.

Professor Carmon hopes this nano-seperated paves a path toward a novel type of mechanical device based on relatively unexplored forces that dominates at nano-scale separation.

"The forces acting at such distances include Casimir and Van der Waals forces – very strong forces originating from quantum effects, which, to date, have barely been exploited in mechanical devices, in general, and in mechanical oscillators, in particular," he said. "We recently demonstrated, for the first time, lasers in which water waves mediate laser emission; and also, for the first time, micro-lasers where sound mediates laser emission."

In the future, the researchers may be able to generate such lasers that are based on vibrations where the restoring force is Casimir or Van der Waals. Using their self-aligned nano separation method might also allow micro electro mechanical devices [MEMS] where Casimir and Van der Waals forces will be used.

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