An optical diode made with silicon technology can be used for quantum information

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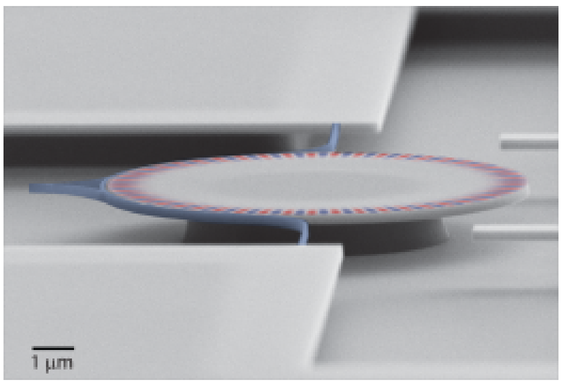


Image of an optical ring resonator, taken with a scanning electron microscope. CreditL: K. Srinivasan, NIST

(PhysOrg.com) -- Transistors, resistors, capacitors, and diodes. All of these are examples of common electrical circuit elements that can be found on a computer motherboard, for instance. Billions of transistors make up a processor, with each one being less than 100 nanometers in size. This is more than 10 times smaller than the diameter of a blood cell.

Electrons carry information over tiny distances in computer circuitry. Photons are commonly used to carry information over kilometer distances. Scientists are currently developing micron-scale optical devices to either replace or be compatible with their electronic counterparts.

Researchers from JQI and the Institute for Quantum Optics and Quantum Information (IQOQI) propose using ring resonators to construct a micro-optical diode. The technology is silicon-on-insulator, making it compatible with the CMOS (complementary metal-oxide-semiconductor) fabrication processes underlying today's computer circuits. Recently, other researchers have proposed and/or demonstrated optical technology to achieve this goal. This new approach, appearing this week in Optics Express,* has the advantage of being suitable for quantum information as it works with single photons.

Electrical elements called diodes are one-way streets for current, blocking backwards-moving electrons from passage. This property is called non-reciprocity. In optics, one-way travel for photons is typically created by using what's known as Faraday rotation. Here, a large magnetic field interacts with a crystal (i.e. yttrium iron garnet) such that light waves passing through the material get their polarization rotated. Polarization can be thought of as an orientation of the traveling light waves. For instance, polarized sunglasses can shield your eyes from light having certain orientations.

In this magnetic optical diode, light hits a polarizing element, which filters all but one type of wave orientation. Next, the waves travel through the magneto-optic material, which rotates the waves' polarization (faraday rotation). Now if that wave is reflected backwards, it is again rotated by the magneto-optic crystal. This reflected wave does not have the correct orientation to pass through the polarizer and is blocked. Thus an optical diode is achieved.

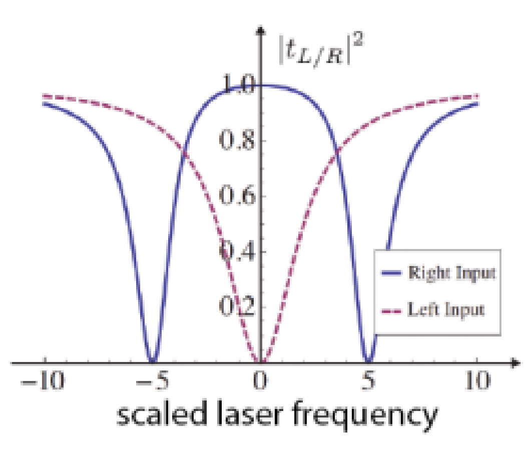
Optical isolation is used to protect lasers from damage due to reflected light. Tools for isolating light is also important for signal processing.

Scaling down this device to fit onto microelectronic chips is challenging due to the sizable magnetic field and difficulty integrating the magneto-optic crystals onto chips. However, Faraday rotation is not the only way to cause non-reciprocal behavior.

These researchers propose an opto-mechanical diode that works as follows. An optical pathway, called a waveguide, is connected to an opto-mechanical resonator that looks like a pedestal (see Figure 1).

The waveguide is the optical analog of a length of current-carrying wire. The mechanical resonator is the tool that will be manipulated to cause diode-behavior in the waveguide. Ring-shaped resonators act like a drum—they have a cavity in which light can bounce around, as well as floppiness. Like a timpani, the microring can vibrate in different ways. Here the scientists are interested in using the light circulating inside the cavity to make the resonator breathe radially.

Light from either direction can travel along the waveguide, and, depending on its' wavelength, will be absorbed or transmitted by the ring resonator (See Figure 2).



Theoretical calculation of light transmission (y-axis) through the waveguide when the optical resonator is operated as a diode. For a certain range of laser frequencies, the left moving light is attenuated, while light traveling from the right is transmitted. Credit: Figure courtesy of authors; a modified version appears in the article

Suppose that the light has the right frequency to both enter the resonator and excite its breathing motion. The vibrational motion is like a wave and will interfere with the light wave inside the resonator. But this is true whether the light travels right or left in the waveguide—the passage of light is still reciprocal. This is not an optical diode and, without modification, the light from either direction is only slightly affected by the vibrations.

To force the photons to travel one-way, the researchers propose to inject intense light (called a "pump") into one of the resonator pathways (here the clockwise path). The pump light enhances the clockwise-moving light's influence on the breathing. Now the vibrations are strong enough that the light is modulated. The result is that, at certain wavelengths, the clockwise light (light from the left) will transmit through the waveguide. However, light that travels counterclockwise does not excite vibrations and is still absorbed or blocked by the resonator. This is an optical diode.

This system has an advantage over the macroscopic faraday rotator—it can be easily switched on and off by adjusting the optical beam.

Depending on the parameters, the non-reciprocity can be manifested on the phase, instead of in the transmission/absorption through the waveguide. When waves travel through either pathway, they can be completely transmitted, but are imprinted with a phase. Phase can be thought of in terms of a time delay. For instance, when scientists look at the incoming wave and outgoing wave of a resonator, the intensity can be the same, but one wave may be shifted in time compared to the other.

The phase will be different depending on whether the light strongly excites vibrations. In this scheme, the clockwise moving light will acquire a different phase shift than the counterclockwise moving light.

Recently, other groups have proposed and demonstrated all-optical diodes. But this optical isolator can also work with single photons, in the quantum limit.

Author Mohammad Hafezi explains that, “Wave interference (here acoustic vibrations interfering with light waves) is non-quantum. But, scientists can cool micro-resonators to a temperature where quantum effects emerge.”

Additionally, researchers potentially can use an array of these micro-resonator diodes for simulating quantum many-body systems.

Hafezi describes the versatility of this proposal, “The outlook of this is an optical isolator that can be used on-chip, which is useful for photonics. On the other hand, it can be used as a non-reciprocal phase shifter so we can explore quantum Hall physics. We can exploit the non-linearity and non-reciprocity at the same time to simulate different quantum phenomena.”

More information: “Optomechanically induced non-reciprocity in microring resonators,” Mohammad Hafezi and Peter Rabl, *Optics Express*, 20, 7672, (2012)

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