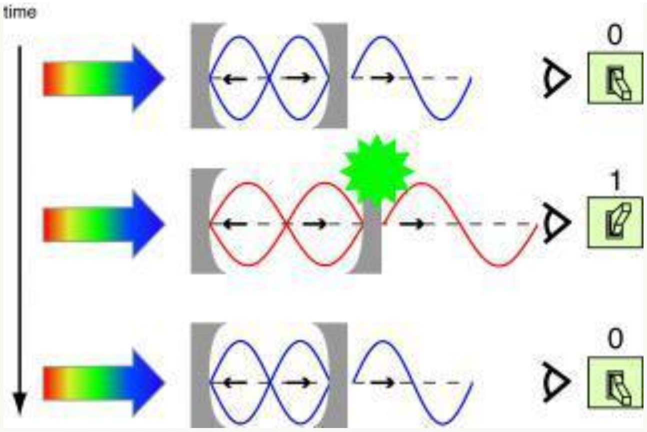
SEMICONDUCTOR OPTICAL SWITCHES REACH THE SPEED OF LIGHT

Fibre optic cables transmit information so fast because they can make use of the unique properties of light and transmit many data channels at the same time. The digital 1s and 0s the light beams carry are imprinted onto the beams by semiconductors that in quick succession turn the light beam on and off. Unfortunately, that also puts a limit on the possible data rate, as materials switch slower than light. There are all-optical switches operating at the speed of light using special crystals, but what is needed are solutions that can be fabricated on a chip.

This is made possible now. Georgios Ctistis, Willem Vos, Jean-Michel Gérard and colleagues from the University of Twente and the FOM-Institute Amolf in the Netherlands, and the Institute for Nanoscience and Cryogenics in Grenoble in France have demonstrated that using a material to switch light is not a drawback anymore. They are able to switch a light beam within a semiconductor device at speeds of 0.3 picoseconds, where a picosecond is a millionth of a millionth second. That’s so fast that it approaches the limit set by the speed of light.



The principle of the ultimate optical switch. Top: a microcavity blocks the transmission of the red signal beam. Middle: in the presence of a control beam the cavity changes its properties and lets the beam pass. Bottom: as the control beam is off again, the switch also turns off. Figure provided by the authors.

In a conventional optical switch, a light beam (or an electrical voltage), is used to excite electrons in a semiconductor. These electrons then change the material’s optical properties in a way that switches the signal beam on or off. But this is a comparatively slow process. The idea here is to separate the optical effects from materials properties, which would only slow the device down. “The key advance is that both the switch-on and -off times of the semiconductor microcavity is completely determined by the properties of light itself,” says Vos.

The way this works is to use a microcavity, where light is confined between two mirrors. The mirrors as well as the microcavity are made of precisely controlled layers of the semiconductors GaAs and AlAs, because these work particularly well for the wavelengths used in telecommunications.

The switching process involves two laser beams. It is important that these two lasers, the signal beam as well as the control beam that triggers the switching, have energies that are below the bandgap energy of the semiconductors. That way, the photons in the laser beam can’t excite electrons in the semiconductor, which as mentioned would slow down the switching. In fact, the energy of the signal beam is even less than half of the bandgap energy, so that there is not even the chance of two photons combining together to excite an electron.

Switching occurs only for that brief moment where the signal and the control beam come together. In that moment, the semiconductor microcavity, which normally would block the signal beam, lets it pass. This is due to an nonlinear optical effect, the so-called electronic Kerr effect. Again, electrons are not really relevant here, as the combined energy of signal and control beam isn’t enough to excite electrons above the bandgap. Rather, the increased light intensity, through the Kerr effect, modifies the refractive index of the semiconductors. This change in materials parameters changes the resonance frequency of the microcavity, so that light that otherwise would be trapped can escape.

Being a non-linear optical effect means that the laser intensities remain quite large says Vos. Therefore, he says, the next step now is to “switch to tiny micron-sized cavities (e.g. micropillars, photonic crystal) with weak pulses from on-chip lasers.” Smaller cavities require less switching power.

Either way, switching speeds on the order of a picosecond correspond to signal frequencies in the THz regime, which is what next generation optoelectronic switches need to achieve. However, at this stage the researchers did not yet show successive switching at such frequencies. That’s one of their next tasks, comments Vos. “We are working hard to demonstrate repetitive switching where consecutive switch events occur every ps or so.” It won’t get much faster than that.

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