OPTO-ELECTRONICS

Laser Pulses Make Fast Work Of an Optical Switch

CAMBRIDGE, U.K.—Imagine controlling bullet trains with a railway switchman standing at the side of the track and pulling a lever. That's roughly what happens in modern fiber-optic communications. Signals race down optical fibers at the speed of light, then are ponderously shunted down one path or another by electronic switches. To speed things up, researchers have experimented with semiconductor switches controlled by pulses of light. Although an optical switch is faster for an isolated signal, it has to be left for a while to reset itself before it can deal with the next one—a serious handicap when the signals are arriving in quick succession.

But by refining the art of controlling semiconductors with light pulses, a team of scientists at the research labs of the Japanese electronics giant Hitachi, based at Cambridge University's Cavendish Laboratory, has come up with a way to turn a switch on with one pulse and turn it off with another. The speed is only limited by how fast they can fire two pulses at it—and thus far they have demonstrated speeds 10,000 times faster than switches that recover by themselves. "A key point is the fact that you don't really depend on the material properties anymore; you just depend on some basic physics of light interacting with a material," says team member Jeremy Baumberg. And the team's work has attracted a lot of attention among solid-state physicists. "It's really a big step forward," says Jürgen Kuhl of the Max Planck Institute for Solid-State Research in Stuttgart, Germany.

The team used a technique called "coherent control," which probes or manipulates a material by delivering multiple short laser pulses at precise intervals. Precise timing is the key to exploiting two wave properties of light: phase and coherence. If the peaks and troughs of two light waves coincide, the waves are said to be in phase; when they are exactly opposite each other, they are out of phase. Coherent waves may or may not be in phase, but they stay in step over time—their phase relationships are maintained.

"The idea of trying to use light pulses to control matter in some sense is not a new idea, but it's only in recent years that people have thought that one could really use the phase of the optical pulses in addition to the amplitude and other properties," says Jag Shah of AT&T Bell Laboratories in Holmdel, New Jersey. Researchers at Bell Labs pioneered the science of controlling electrons in semiconductors with laser pulses, and in the process exploited new laser technology and control electronics to produce brief, precisely timed laser pulses. Keith Nelson of the Massachusetts Institute of Technology helped turn this technology into an art form.

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> **—Jeremy Baumberg**

Now, says Nelson, "We can make nearly arbitrary femtosecond [10^{-15} second] pulse sequences, with the timing, phases, and amplitudes of the pulses all computer controlled—the user just specifies the desired optical wave form and out it comes."

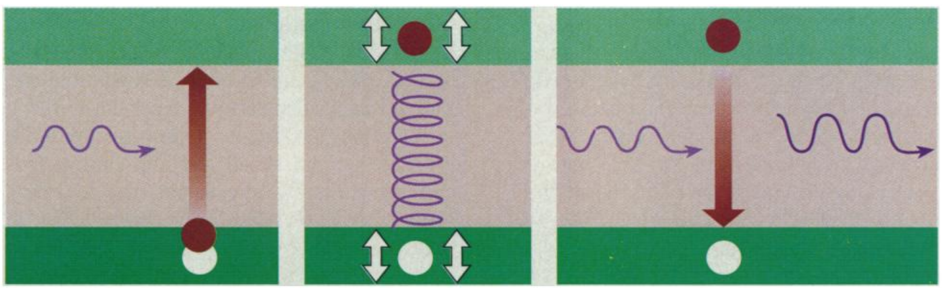
The Cambridge team uses such pulses to shuttle a semiconductor's electrons between different energy levels—the discrete ranges of energies available to electrons in the material. In their experiment, reported in last week's *Physical Review Letters*, the team fires a laser pulse at a sample of gallium arsenide, knocking electrons from a low-energy band into a higher energy one. Each electron excited by the laser pulse leaves behind a vacancy in the lower band, known as a "hole," and the electron-hole pair thus produced retains a memory of the light pulse that created it—in effect "ringing" like a bell.

A second pulse, cloned from the first using a beam splitter, is led to the sample by a slightly longer route so that it arrives a little later. Precise timing ensures that although it remains coherent with the first pulse, it is out of phase with it. Hence, it is also out of phase with the "ringing" electron. The moment the second pulse hits the electron, it stops ringing and drops back down from its excited state. The second pulse has switched off the excitation, a process the team has dubbed "coherent destruction." "The second light beam is behaving in rather an odd way," says Baumberg. "Instead of creating more electrons and holes it's actually creating less of them because the electron-hole pairs remember the phase of the light that originally excited them."

So how can this make an optical switch? Certain semiconductors actually change their optical properties when their electrons are excited to a higher level, so a semiconductor that is normally opaque may become transparent when its electrons are excited. Such a semiconductor could therefore block a data-carrying light beam until "switched on" by a laser pulse. But while the switch would normally reset itself only when electrons dropped down and filled the holes of their own accord—a process that takes about a million femtoseconds—resetting the device with a second coherent laser pulse reduces the delay by a factor of 10,000. And the Cambridge team is not stopping there. "We are at the moment constructing a laser system which produces pulses that are 10 times shorter, and we can see no problem with the effect working 10 times faster than we have it working already," says Baumberg.

The researchers will not be producing a workable commercial switch tomorrow, however. Their sample was made from expensive, ultrapure gallium arsenide layers, each a few tens of nanometers thick, cooled to –269°C. But the team has demonstrated an important principle, other researchers say. "They were the first group to demonstrate it was possible to manipulate the semiconductor excitation by external laser pulses on a time scale that is short compared to any intrinsic relaxation time of the system," says Kuhl. Adds Shah: "This is an exciting area of science currently." A lot of people, he says, will want a seat on this train.

–Andrew Watson



Light pulls a fast switch. A laser pulse excites an electron, creating an electron-hole pair that "rings" in phase with the light. A second pulse, out of phase with the first, knocks the electron back into the ground state, swiftly resetting the switch.

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