Fast, low-power, all-optical switch

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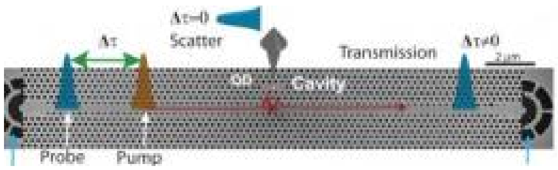

This is the setup of a waveguide made from a photonic crystal. A quantum dot (QD) is placed inside a tiny zone (cavity) clear of holes. Light is sent into and out of the waveguide via endcaps (the semi-circular structure at both ends, indicated by green arrows). If properly timed (the synchronicity time, tau, being less than about 100 ps), a pump (control) laser pulse will allow an accompanying probe pulse to exit out the side. If the probe and pump beams are not aligned, the probe beam will exit out the far end of the waveguide. Credit: Ranojoy Bose, JQI

An optical switch developed at the Joint Quantum Institute (JQI) spurs the prospective integration of photonics and electronics. What, isn't electronics good enough? Well, nothing travels faster than light, and in the effort to speed up the processing and transmission of information, the combined use of light parcels (photons) along with electricity parcels (electrons) is desirable for developing a workable opto-electronic protocol.

The JQI switch can steer a beam of light from one direction to another in only 120 picoseconds (120 trillionths of a second), requiring very little power, only about 90 attojoules (90 x 10-18 joules). At the wavelength used, in the near infrared (921 nm), this amounts to about 140 photons. These new results are being published in an upcoming issue of the journal *Physical Review Letters*.

The centerpiece of most electronic gear is the transistor, a solid-state component in which a gate signal is applied to a nearby tiny conducting pathway, thus switching on and off the passage of an information signal. The analogous process in photonics would be a solid-state component which acts as a gate, enabling or disabling the passage of light through a nearby waveguide, or as a router, for switching beams in different directions.

In the JQI experiment, prepared and conducted at the University of Maryland and at the National Institute for Standards and Technology (NIST) by Edo Waks and his colleagues, an all-optical switch has been created using a quantum dot (the equivalent of a gate) placed inside a resonant cavity. The dot, consisting of a nm-sized sandwich of the elements indium and arsenic, is so tiny that electrons moving inside can emit light at only discrete wavelengths, as if the dot were an atom. The quantum dot sits inside a photonic crystal, a material that has been bored with many tiny holes. The holes preclude the passage of light through the crystal except for a narrow wavelength range.

Actually, the dot sits inside a small hole-free arcade which acts like a resonant cavity. When light travels down the nearby waveguide some of it makes its way into the cavity, where it interacts with the quantum dot. And it is this interaction which can transform the waveguide's transmission properties. Although 140 photons are needed in the waveguide to produce switching action, only about 6 photons actually are needed to bring about modulation of the QD, thus throwing the switch.

Previous optical switches have been able to work only by using bulky nonlinear-crystals and high input power. The JQI switch, by contrast, achieves high-nonlinear interactions using a single quantum dot and very low power input. Switching required only 90 aJ of power, some five times less than the best previous reported device made at labs in Japan , which itself used 100 times less power than other all-optical switches. The Japanese switch, however, has the advantage of operating at room temperature, while the JQI switch requires a temperature of around 40 K.

Continuing our analogy with electronics: light traveling down the waveguide (the equivalent of the conducting pathway in a transistor) in the form of an information-carrying (probe) beam can be switched from one direction to another using the presence of a second pulse, a control (pump) beam. To steer the probe beam out the side of the device, the slightly detuned pump beam needs to arrive simultaneously with the probe beam, which is on resonance with the dot. The dot lies just off the center track of the waveguide, inside the cavity. The temperature of the quantum dot is tuned to be resonant with the cavity, resulting in strong coupling. If the pump beam does not arrive at the same time as the probe, the probe beam will exit in another direction

So, is this quantum-dot switch an "optical transistor"? Not quite, says JQI scientist Ranojoy Bose. "Our waveguide-dot setup can't yet be used to modulate a beam of light using only a weak control pulse of light---what we would call a low-photon-number pulse.

But Bose says he expects an improvement (reduction) in the number of photons needed to switch the resonant cavity on and off. In the meantime, the JQI switch represents a great start toward creating a usable ultrafast, low-energy on-chip signal router. "Our paper shows that switching can be achieved physically by using only 6 photons of energy, which is completely unprecedented. This is the achievement of fundamental physical milestones—sub-100-aJ switching and switching near the single photon level," Bose says.

More information: *Physical Review Letters*, in press