Quantum Physics Discovery May Bring About Changes in Optical Communication

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Results from experiments conducted at the University of California, Santa Barbara may lead to profound changes in optical communications. The discovery is reported in the October 28th edition of the journal *Science*.

Physicist Mark Sherwin at UCSB explained that as information technology advances, scientists are intent on transmitting information much more quickly. "We are working toward sending information 100 times faster than it can be sent now," he said. His research group has spent five years on this project. The experiments were performed using the university's room-sized, free-electron laser.

"We took an existing semiconductor device that is essentially an electrically controlled shutter and we have tried to open and close the shutter at the rate of three trillion times a second," he explained. "We found that in addition to opening and closing the shutter we are making the shutter itself vibrate."

Those vibrations of the shutter may enable the shutter to be opened and closed with weak light beams rather than strong voltages, said Sherwin. In optical communications there are different channels of communications, so these light beams could correspond to different channels. "It would be a way of changing channels really fast," he added. "Right now it is a very slow process to change channels in optical communications.

Sherwin explained that electronics are much slower than optics and that one optical fiber could transmit information more than 1,000 times as fast as the information could be put on it by an electronic device like a computer.

"What we have here at UCSB is a special source of radiation, the free-electron laser, that can generate electromagnetic oscillations at the rate of a few trillion per second," said Sherwin. "We found that when you drive the modulator, or shutter, that fast it acts in a peculiar way. Rather than absorbing light near a single frequency, it can absorb light near a second frequency as well. This opens the possibility of a new type of cross modulation, where a beam of light at one of the absorption frequencies can turn on or off the light of the other."

Sherwin said that light has been used to send information rapidly over long distances for more than 3000 years. The ancient Greeks, for example, used large fires to flash signals from mountain top to mountain top, as described by Homer in the Iliad. In order to send information, light must be modulated—that is, one must be able to turn the light beam on and off. In World War II, ships communicated with one another in code using searchlights that sailors modulated manually with shutters. Modern modulators for light are controlled by electrical voltages, explained Sherwin.

"In an electro-absorption modulator, light near a particular frequency, the carrier frequency, can be blocked or transmitted by tuning a material oscillation in or out of resonance with the carrier frequency," said Sherwin. "A common electro-absorption modulator is made of a semiconductor quantum well, a thin layer of a semiconductor with a relatively small "band gap" (or a relatively large affinity for negatively charged electrons and positively charged holes) sandwiched between two layers with a larger band gap."

Sherwin explained that when light of the correct frequency is incident on a quantum well, it creates bound electron-hole pairs called excitons and is absorbed. An electric field applied perpendicular to the plane of the quantum well shifts the frequency of the excitonic absorption so that light resonant with the zero-field excitonic resonance is no longer absorbed. Quantum well electro-absorption modulators are currently used to modulate light at rates exceeding 10 billion bits per second.

In this article, the scientists report that a quantum well electro-absorption modulator has been strongly driven at frequencies exceeding one Terahertz (1 trillion cycles). This is more than 100 times faster than quantum well modulators are usually operated. At these extremely high frequencies, internal quantum-mechanical oscillations of the excitons themselves were excited. When the strong Terahertz drive was resonant with the excitonic oscillations, the absorption spectrum of weak light near the excitonic absorption of the quantum well was transformed from a single peak to a double peak, or doublet. This doublet is a signature that light with frequency near the excitonic absorption can no longer simply create an exciton in its lowest-energy state, but must create a quantum mechanical superposition of an exciton in its ground and excited states.

A potential application for optical communication is that two arbitrarily weak light beams separated by the frequency of the Terahertz drive could modulate one another. "Usually, such cross-modulation occurs only when light beams have power exceeding a certain threshold," said Sherwin.

On a separate note, Sherwin said, "In atomic gases, the doublet observed here has been the first step toward creating a system that could greatly slow or even stop the propagation of light. The ability to slow or stop light in a semiconductor would also enhance the toolbox for optical communications and computation. However, in order to achieve slowing or stopping of light, the mechanisms for energy dissipation in the quantum well modulator would have to be significantly reduced."

The Science article, "Quantum Coherence in an Optical Modulator," was co-authored by S. G. Carter, who worked on the experiments at UCSB and then moved to the University of Colorado; V. Birkedal, from UCSB; C. S. Wang, from UCSB; L. A. Coldren, from UCSB; A. V. Maslov, from the Center for Nanotechnology at the NASA Ames Research Center; and, D. S. Citrin from the Georgia Institute of Technology and Georgia Tech Lorraine in Metz, France.

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