'Game-changer' for photonics applications: Researchers demonstrate record optical nonlinearity

April 28 2016

Credit: Petr Kratochvil/public domain

Work by an internationally renowned University of Rochester professor may offer an alternative to the way in which researchers have approached some photonics applications.

Photonics applications rely greatly on what physicists call nonlinear optics - the different way in which materials behave depending on the intensity of light that passes through them. The greater the nonlinearity, the more promising the material for real-life applications. Now a team, led by Robert W. Boyd, Professor of Optics and Physics at the University of Rochester and the Canada Excellence Research Chair in Quantum Nonlinear Optics at the University of Ottawa, has demonstrated that the transparent, electrical conductor indium tin oxide can result in up to 100 times greater nonlinearity than other known materials.

"This result is a game-changer for photonics applications," said Boyd. "It rests on the core of what I've worked on for over 30 years at Rochester. I find it very rewarding that even after all this time there are still fundamental questions to be answered in the field of nonlinear optics."

The result will be published online by the journal *Science* on Thursday, April 28, 2016.

Photonics uses light to transmit information. Photonics also uses light to perform logical operations, just as electronics does with electrons. A key aspect to being able to exert control over light is to be able to control a specific property - the refractive index - of the material that is transmitting the light.

Tweaking the refractive index of a material, which leads to light travelling faster or slower, is the key way in which photonics applications control light. When the refractive index is different for different light intensities, the material is described as being optically nonlinear.

When a pulse of light is sent through the material, the refractive index changes according to that intensity. The refractive index of the material is changed for only a few femtoseconds - a few millionths of a billionth of a second. For some potential applications, it is possible to send a second pulse through the material before it has time to recover for the first pulse. This second pulse then "sees" the material as having the refractive index as modified by the first pulse.

In general though, it is the quickness with which the material recovers as well as the range of values that the refractive index can take - how strongly nonlinear the material is - that makes this system particularly attractive to photonics applications.

Boyd, his PhD student at Ottawa, M. Zahirul Alam, and then research associate Israel De Leon (currently a professor in Monterrey, Mexico) were able to improve on the previous record for optical nonlinearities by a factor of 100. This improvement took place because these researchers exploited the unusual optical properties of a material that occurs under certain conditions, what is known as the epsilon-near-zero region.

"It was surprising that showing such a strong optical nonlinearity in a known metal was this easy," said Boyd. "This material has been around for many years, but until now the community had overlooked the potential that the 'epsilon-near-zero' region of materials offered."

"The optical nonlinear response that we have observed introduces a new paradigm in nonlinear optics," said De Leon, now a professor at Tecnologico de Monterrey, Mexico. "The common knowledge had always been that nonlinear effects are tiny compared with the linear ones; but in our work we have measured a nonlinear response that is 170% larger than the linear response."

The result opens the door for more careful study of this region of materials, with a view to finding a material that can offer just the right properties for certain photonics applications.

The 'epsilon-near-zero' region for this material is linked to light of a specific frequency, roughly a wavelength of 1.2 micrometers. This wavelength is of interest because it is in between that of visible light and light of wavelength 1.5 micrometers. This wavelength is of particular interest to optical communications, which uses devices such as fiber optics to transmit information in light.

It is possible that changes in the chemical composition of the material could lead to a change in the frequency at which epsilon near zero occurs, thus bringing this frequency closer to that used by optical communications.

More information: "Large optical nonlinearity of indium tin oxide in its epsilon-near-zero region" *Science*, DOI: 10.1126/science.aae0330

Provided by University of Rochester