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Pointing Light

Without the vast, nearly infinite web of crisscrossing electromagnetic waves that travel invisibly through the air, the modern world would cease to exist. Transmitting digital data and sensing and returning information about the environment at the speed of light, these waves are important in many emerging applications, including autonomous vehicles, Lidar and holographic displays, where the ability to direct and steer light beams over time is crucial to mapping surroundings or to immersion in an augmented reality.

UC Santa Barbara engineer Jon Schuller aims to manipulate specialized semiconductor materials and devices to control light without using mechanically moving parts — an achievement that could have wide-ranging applications. He is pursuing ways to use sub-wavelength interactions involving any element smaller than the wavelength of light (about one micron) to not only steer light, but also to enable faster, more efficient sensing. He also hopes to shrink the size of the system and improve its performance — all at a lower cost.

In a paper in the journal Nature Communications, Schuller, an assistant professor, and his UCSB collaborators — Chris Palmstrøm, a professor of electrical and computer engineering and of materials, and graduate students Mihir Pendharkar and Prasad P. Iyer — describe a technique for applying heat to the semiconductor indium antimonide (InSb) to form an ideal material for controlling the phase of light necessary to achieve tunability.

“Sub-wavelength elements are essentially active mirrors, reflecting light with a controllable phase, and are able to generate and modulate the light when it interacts with matter,” said Schuller, a faculty member in UCSB’s Department of Electrical and Computer Engineering. “Our focus is on steering the beam. When multiple objects emit light, the different phases cause them to add up constructively in certain directions and destructively in others.”

One way to encode digital data is to turn a laser on and off rapidly, which can be achieved by splitting the laser into two waves, shifting the phase of one 180 degrees and recombining them. As the parallel beams travel through space, the waves align as mirror images of each other. The peaks of one wave line up with the troughs of the other, canceling out the signal. By switching the phase between 0 degrees (on) and 180 degrees (off) millions of times per second, information is encoded into the ones and zeroes of a digital data sequence.

To cause such phase shifts at the micron scale of light is much more difficult than doing so at the millimeter or centimeter scale. “At that scale, the phase-shifting device is so small that the light travels very little distance and therefore has very little time to interact with the material,” Schuller explained. “We need to find a much larger and more extreme light-matter interaction that can occur over such a small distance and time.”

For example, a material’s refractive index can be changed from 10^{-3} to 10^{-4} — one-tenth of a percent to one-hundredth of a percent — a significant increment in scientific terms. However, this research investigates effects that are one to 10,000 times bigger. The refractive index tells a lot about how light behaves in a material, such as its speed, its effective wavelength and the angle at which light rays bend as they enter or exit the material.

One type of modulation involves changing the number of mobile electrons in the material to alter its optical properties, which in turn affects the phases. It is possible to change electron density simply by changing the temperature of InSb without having to run a current through it.

Ultimately, the UCSB team is trying to broadcast or direct optical (infrared-frequency) waves in a particular direction with a high degree of control at an extremely high frequency. Traditionally, antennas have operated in the domain of gigahertz or megahertz; Schuller’s group is working at the scale of tens of terahertz, or 1 trillion cycles per second in the optical frequency range.

For now, the researchers are using their new thermal free-carrier method — employing heat to tune the number of electrons — to solve the challenges of optical tuning. Eventually, their goal is to activate InSb electrically, which — while faster and offering more benefits — poses another complex challenge. That makes the thermal approach even more valuable, permitting the researchers to experiment with the material without having to create an electrical system to activate it.

“Our temperature technique is a clever way to look at the basic physics of this problem — the basic optical materials science questions — and get all the complexities of the ultimate application that will use electricity,” said Schuller.

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