Ultrafast beam-steering breakthrough

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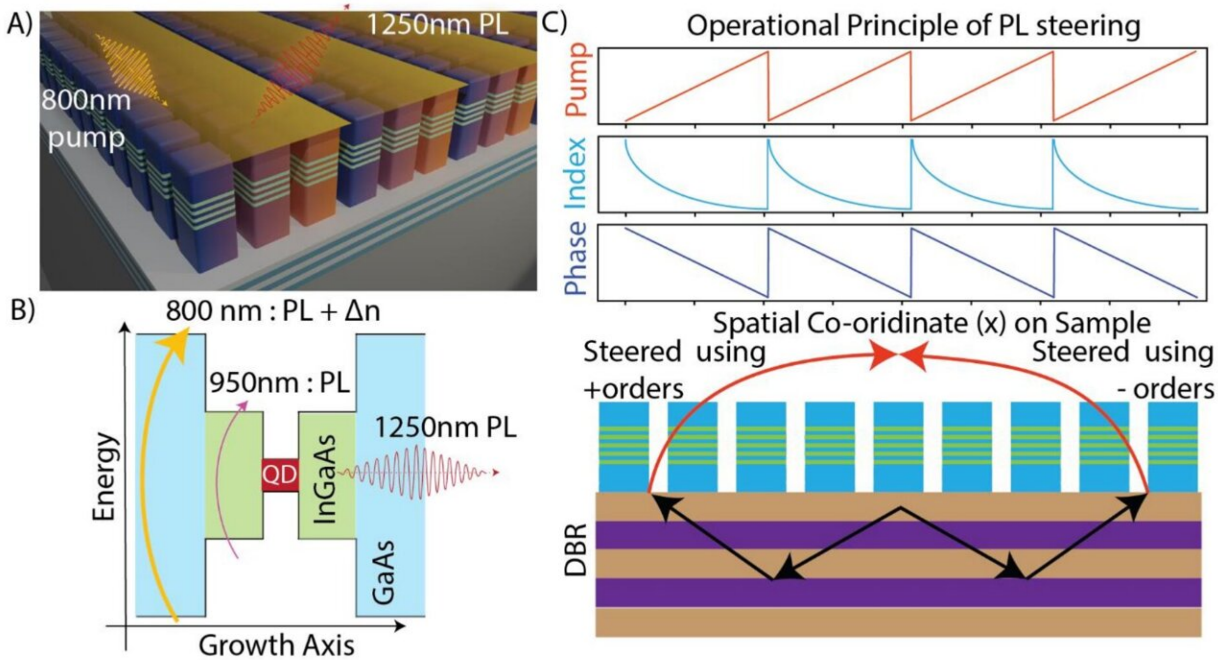

A) Schematic of the GaAs metasurface containing InAs QDs embedded inside $In_{0.15}Ga_{0.85}As$ quantum wells grown on a DBR stack using molecular beam epitaxy on GaAs wafer. The schematic shows the spatially structured (800 nm) pump beam (as a yellow periodic gradient) causing a refractive index's shift of the resonators, colored as indigo for a low |Δn|, to orange for a high |Δn|). B) Band-structure sketch of the MBE grown III-V resonators highlighting the influence of 800 nm pump (producing an index shift, Δn. and PL) and the 950 nm second pump which only excites the QDs for PL emission. C) Operation principle for steering PL from dielectric metasurfaces using structured pumping. The top three panels show the effect of a spatial pump profile on the refractive index and the spatial phase profile of the metasurface. The spatial refractive index grating produces a spatial phase profile inside the resonators introducing a momentum kick to the PL. This momentum kick steersthe light emitted from the metasurface. Credit: *Nature Photonics* (2023). DOI: 10.1038/s41566-023-01172-6

In a major breakthrough in the fields of nanophotonics and ultrafast optics, a Sandia National Laboratories research team has demonstrated the ability to dynamically steer light pulses from conventional, so-called incoherent light sources.

This ability to control light using a semiconductor device could allow low-power, relatively inexpensive sources like LEDs or flashlight bulbs to replace more powerful laser beams in new technologies such as holograms, remote sensing, self-driving cars and high-speed communication.

"What we've done is show that steering a beam of incoherent light can be done," said Prasad Iyer, Sandia scientist and lead author of the research, which was reported in the current issue of the journal *Nature Photonics*.

Incoherent light is emitted by many common sources, such as an old-fashioned incandescent light bulb or an LED bulb. This light is called incoherent since the photons are emitted with different wavelengths and in a random fashion. A beam of light from a laser, however, does not spread and diffuse because the photons have the same frequency and phase and is thus called coherent light.

In the team's research, they manipulated incoherent light by using artificially structured materials called metasurfaces, made from tiny building blocks of semiconductors called meta-atoms that can be designed to reflect light very efficiently. Although metasurfaces had previously shown promise for creating devices that could steer light rays to arbitrary angles, they also presented a challenge because they had only been designed for coherent light sources.

Ideally, one would want a semiconductor device that can emit light like an LED, steer the light emission to a set angle by applying a control voltage and shift the steering angle at the fastest speed possible.

The researchers started with a semiconductor metasurface that had embedded tiny light sources called quantum dots. By using a control optical pulse, they were able to change, or reconfigure, the way the surface reflected light and steer the light waves emitted from the quantum dots in different directions over a 70-degree range for less than a trillionth-of-a-second, marking a significant success.

Similar to laser-based steering, the steered beam restrained the tendency of incoherent light to spread over a wider viewing angle and instead produced bright light at a distance.

Taming light

A feat previously considered impossible, the team's proof-of-principal work paves the way for developments in the fields of nanophotonics and ultrafast optics. The ability to dynamically control incoherent light sources and manipulate their properties offers a wide range of applications.

One low-power use would be to brighten military helmet screens used to overlay maps or blueprints over ordinary vision. "In applications where space is valuable," Iyer said, "steering light emission with low-size-and-weight metasurface-LED displays could be made possible in the future with this technology. We can use the light emitted in a better way rather than just turning them off and on."

The technique could also provide a new kind of small display that can project holographic images onto eyeballs using low-power LEDs, a capability of particular interest for augmented and virtual reality devices. Other uses could be in self-driving cars where LIDAR is used to sense objects in the path of the car.

In terms of expressions of interest, the team has had several inquiries from commercial sources, said Sandia researcher Igal Brener, a paper author and lead scientist on the project. "A commercial product could be 5-10 years out, especially if we want to have all the functionality on-chip," Brener said.

"You wouldn't use a control optical pulse to impart the changes in the metasurface needed to steer the light, but rather you would do this control electrically. We have ideas and plans, but it's still early. Imagine an LED light bulb that can emit light to follow you. Then you wouldn't waste all that illumination where there's nobody. This is one of the many applications that we dreamed about with DOE years ago for energy efficiency for office lighting, for example."

Similarly, tamed light may one day offer benefits in scenarios where focused illumination is only needed in a specific area of interest, such as surgery or in autonomous vehicles.

More information: Prasad Iyer, Sub-picosecond steering of ultrafast incoherent emission from semiconductor metasurfaces, *Nature Photonics* (2023). DOI: 10.1038/s41566-023-01172-6. www.nature.com/articles/s41566-023-01172-6

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