A New Era in Nanophotonics Is Unlocked by Tiny Polaritons

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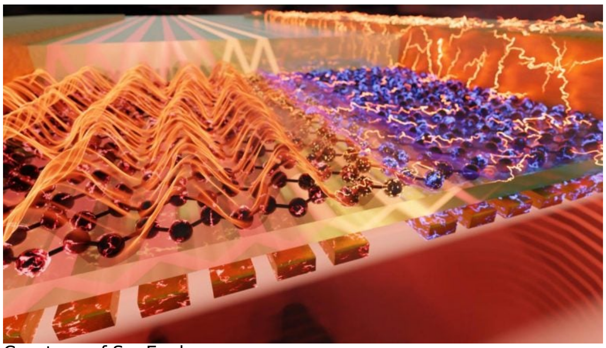

Courtesy of SynEvol
Credit: ICFO/ David Alcaraz Iranzo

When electromagnetic waves couple with charged particles or vibrations in a material's atomic structure, they produce polaritons, which are special excitations. Their ability to restrict light in extremely small spaces, down to nanometer-sized volumes, is essential for improving interactions between light and matter, which is why they play a significant role in nanophotonics. Polaritons can be produced very efficiently in two-dimensional materials that are only one atom thick. Compared to bulk materials, these 2D materials provide better tunability, less energy loss (increasing polariton lifetimes), and extreme light confinement.

Researchers employ nanoscale structures called nanoresonators to improve polaritonic characteristics and further refine light confinement. A nanoresonator's material and geometry shape the polaritons that oscillate and resonate at particular frequencies when light interacts with it. This creates new opportunities for sophisticated optical manipulation by enabling extremely accurate control of light at the nanoscale.

Although the application of polaritons for light confinement is well-established, techniques for exploring them can yet be improved. Optical measurements have gained popularity in recent years, but their large detectors need additional equipment. This limits the miniaturization of the detection system and the signal clarity (known as the signal-to-noise ratio) one can obtain from the measurements, which in turn hinders the application of polaritonic properties in areas where these two features are essential, such as molecular sensing.

In a recent article published in Nature Communications, researchers from the University of Ioannina, Universidade do Minho, the International Iberian Nanotechnology Laboratory, Kansas State University, the National Institute for Materials Science (Tsukuba, Japan), POLIMA (University of Southern Denmark), URCI (Institute of Materials Science and Computing, Ioannina), ICFO Dr. Sebastián Castilla, Dr. Hitesh Agarwal, Dr. David Alcaraz, Dr. Roshan Krishna Kumar, and ICREA Prof. Frank Koppens led the team.

For the first time, spectrally resolved electrical detection of 2D polaritonic nanoresonators is made possible by the integrated device, which also represents a major advancement in device shrinking.

The team applied electrical spectroscopy to a stack of three layers of 2D materials, specifically, an hBN (hexagonal boron-nitrate) layer was placed on top of graphene, which was layered on another hBN sheet. Researchers discovered a number of benefits of electrical spectroscopy over commercial optical methods during the studies. With the former, the spectral range covered is significantly broader (that is, it spans a wider range of frequencies, including the infrared and terahertz ranges), the required equipment is significantly smaller, and the measurements present higher signal-to-noise ratios.

Two key characteristics of this electro-polaritonic platform make it a breakthrough in the area. First, most optical techniques no longer require an external detector for spectroscopy. The system can be further reduced in size because a single device can function as both a polaritonic platform and a photodetector. Secondly, the integrated device effectively gets over the drawback that increasing light confinement generally degrades the quality of this confinement (e.g., reducing periods of light trapping). "Our platforms are of outstanding quality, attaining optical lateral confinement records and high-quality factors of up to 200, roughly." The photodetection efficiency is greatly increased by graphene's remarkable level of confinement and purity, according to Dr. Sebastián Castilla, the article's first co-author.

Furthermore, very tiny 2D polaritons (with lateral diameters of about 30 nanometers) can be probed using the electrical spectroscopy method. "The imposed resolution limitations made it extremely difficult to detect using traditional techniques," he continues.

Castilla now considers what new insights their new strategy might yield. This electro-polaritonic integrated platform could be useful for applications in optical spectrometry, hyperspectral imaging, and sensing. On-chip electrical detection of molecules and gasses, for example, may become feasible in the sensing situation, he says. "I am confident that our efforts will pave the way for numerous applications that have been impeded by the large size of conventional commercial platforms."