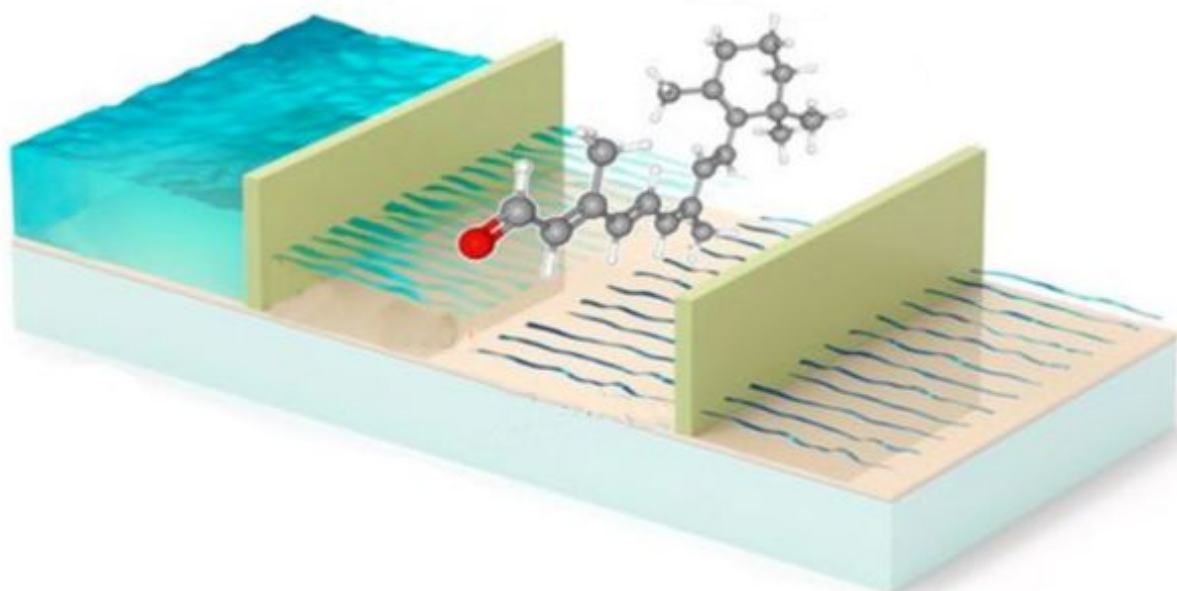




Chemically identifying molecules through ballistic electron energy losses

A study by ICFO researchers reports on a new approach that uses 2D materials and electron energy losses to detect molecules at the zeptomole level.

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Infrared absorption spectroscopy is a technique used to detect minute concentrations of molecules by analyzing and studying the molecule's vibrational and electronic excitations. Such method has proven to be an excellent candidate for applications in areas such as medical diagnosis and detection of hazardous substances. Additionally, all-optical techniques based on Raman and infrared (IR) absorption spectroscopies are widely used for this purpose and can reach single-molecule sensitivity when enhanced by the near-field light amplification of optical hot spots associated with plasmons-conduction electron excitations-localized at corrugated metal surfaces. However, because the wavelength of the infrared light used to detect the molecules is several microns, while the target measures only

a few nanometres, molecular vibrations are excited by light with low efficiency, thus limiting these techniques in spatial resolution.

In a separate development, recent advances in electron energy-loss spectroscopy (EELS) have pushed the combined space/energy resolution to unprecedented levels, enabling the detection and spatial imaging of nanoscale optical excitations. However, this technique requires high vacuum and produces structural damage, which hinders applications to in vivo samples. In addition, this structural damage also limits the acquisition of visible and IR spectra from structures consisting of only a few molecules.

In a recent study published in Science Advances, ICFO researchers Renwen Yu and ICREA Prof. at ICFO Javier Garcia de Abajo report on a novel approach that can chemically identify amounts of molecules at the zeptomol level (one 10-21th part of a mole, or about 600 molecules of a substance). In their approach, they propose a device that uses ballistic electrons moving within a 2D semiconductor to analyze the device. Instead of using photons to interact with the molecules, they use electron that moving ballistically in the semiconductor.

They inject electrons with well-defined energies through the device and have them interact with the analyte molecules placed close to the 2D-material. The interaction produces energy losses, which are directly associated with the fingerprints of the molecules. The 2D material is basically used for this purpose because it already provides vertical confinement of the electrons without the need of a vacuum chamber to run the experiment. The energy losses produced by interactions between the incident electrons and the analyte are then analyzed in energy to generate a spectrum in the IR range, which exhibits the fingerprints of the molecules. More specifically, they analyze the molecules' spectrums in terms of their polarizabilities, and demonstrate, with the help of these inelastic scatterings, that the device provides enough spectral resolution to distinguish between molecules.

The results of the theoretical study prove a new approach towards the identification of molecules at the zeptomol level. Their realistic simulations reveal a sensitivity down to the zeptomol level within a device of $\sim 1 \mu\text{m}^2$ footprint, which could be integrated for massive multiplexing using currently available technology.