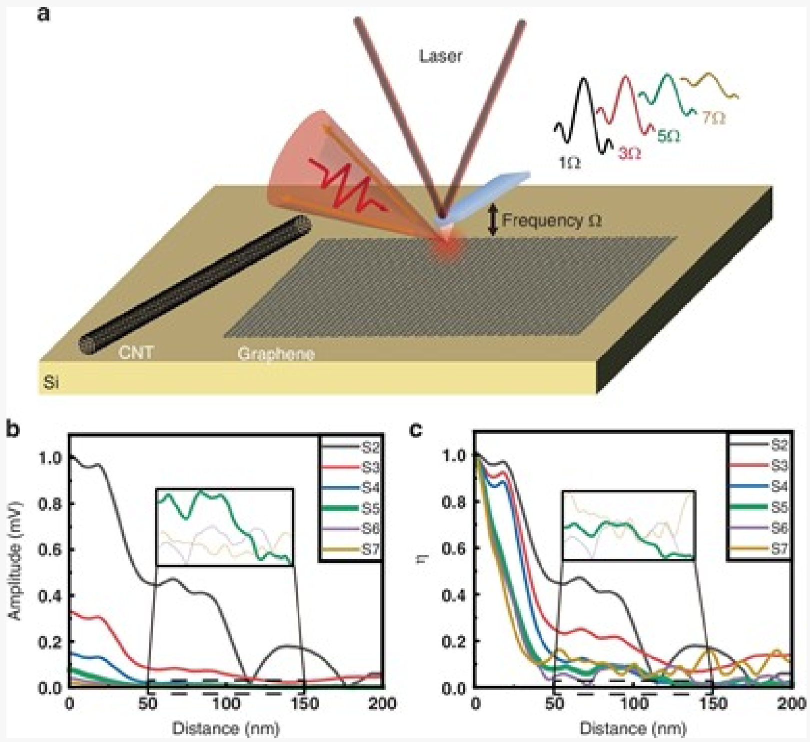
Zooming into the nanoworld: how high-order signals clarify the invisible

GA, UNITED STATES, August 1, 2025 /EINPresswire.com/ -- A newly refined near-field optical imaging method is offering researchers a clearer look at low-dimensional materials like graphene and carbon nanotubes. By tuning into fifth-order optical signals at infrared wavelengths, the technique minimizes background interference and enhances image contrast, revealing nanoscale structures that traditional approaches often miss. The method captures subtle plasmonic effects and material interfaces with high fidelity, surpassing the resolution of standard atomic force microscopy. This development provides researchers with a more precise and stable way to study light-matter interactions at the nanometer scale, with broad implications for nanophotonics, optoelectronics, and materials science.



Schematic of s-SNOM principle and comparison of higher-order signals (2nd–7th). a The schematic diagram of the measurement principle of s-SNOM. b The electric field strength from the 2nd to the 7th order. c Signal-to-noise ratio (SNR) values from the 2nd

Conventional optical microscopes are limited by diffraction, making it difficult to observe structures smaller than half the wavelength of light. Scattering-type scanning near-field optical microscopy (s-SNOM) overcomes this barrier by detecting light scattered just nanometers from a material's surface. However, its effectiveness depends heavily on signal clarity, which is often compromised by background noise—particularly when imaging ultra-thin or nanoscale samples. While interferometric techniques can suppress some noise, they introduce complexity and stability issues. Given these challenges, there is a growing need for a more reliable and higher-resolution approach to near-field imaging that can reveal fine structural and plasmonic details in low-dimensional materials.

Researchers at Xi’an Jiaotong University have developed an enhanced imaging method using fifth-order near-field signals to sharpen visualization of nanoscale materials under infrared light. The study, published June 5, 2025, in Microsystems & Nanoengineering, demonstrates how this technique reveals surface plasmon behavior and fine structural features in graphene, carbon nanotubes, and gold nanoparticles. By addressing key limitations in traditional near-field imaging, the research team provides a more stable and accurate path toward observing optical phenomena at nanometer scales.

To refine near-field optical imaging, the team simulated light scattering at different infrared wavelengths and signal orders using finite-difference time-domain methods. They identified 1550 nm as the optimal excitation wavelength for enhancing plasmonic signals in graphene and carbon nanotubes. Experiments showed that fifth-order demodulated signals (S5) offered the best balance of signal strength and noise suppression.Using this approach, researchers captured near-field images of graphene-silicon (Gr-Si) interfaces, revealing distinct plasmonic waves and sharp material boundaries—features not visible in atomic force microscopy. Similarly, single multi-walled carbon nanotubes (MWCNTs) were imaged with striking detail, with stronger light scattering observed along the tube axis, indicating surface plasmon propagation.In another test, the method resolved features between gold nanoparticles spaced just 10 nanometers apart on a gold film. Compared to AFM, which showed blurred outlines and wider gap measurements, the high-order imaging offered more precise resolution, reducing tip-sample convolution effects. These findings underscore the advantages of higher-order signal isolation in revealing nanoscale structures with greater contrast and spatial accuracy.

“Traditional s-SNOM often struggles with background interference that masks delicate optical signals,” explained Prof. Shuming Yang, who led the study. “By harnessing higher-order harmonics—particularly the fifth order—we’re able to suppress unwanted noise and clearly observe nanoscale plasmon behavior. This enables us to track light-matter interactions in materials like graphene with much greater clarity and confidence. Our approach doesn’t just enhance imaging—it improves understanding.”

This high-order imaging method provides a more refined tool for exploring nanoscale optical properties in low-dimensional materials. Its ability to detect fine variations in material composition and plasmonic behavior makes it valuable for advancing research in nanophotonics, biosensing, and flexible optoelectronics. Because the technique requires no structural modification of the sample, it may also be integrated into real-time imaging workflows or adapted for use with machine learning-assisted analysis. As scientific interest in 2D materials and nanostructures grows, this approach offers a stable and accessible way to explore their optical responses with unprecedented resolution.

References
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