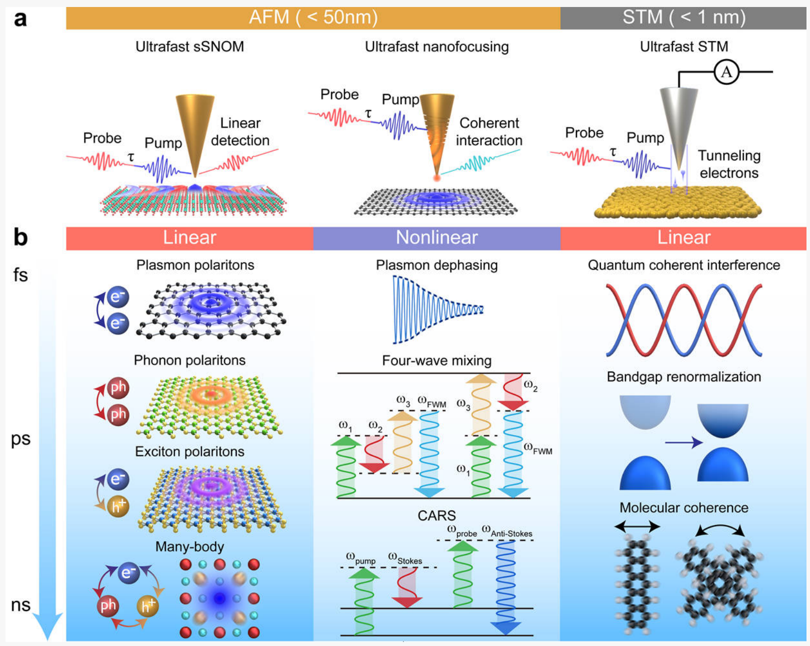
Applications of ultrafast nano-spectroscopy and nano-imaging

GA, UNITED STATES, January 13, 2025 /EINPresswire.com/ -- This review focuses on the applications of cutting-edge ultrafast nano-spectroscopy and nano-imaging based on diverse tip-based microscopy techniques. These advanced techniques simultaneously achieve sub-diffraction spatial resolution facilitated by a subwavelength tip apex and high temporal resolution enabled by electromagnetic pulses. This spatiotemporally resolved capability enables real-time visualization of light-matter interactions, uncovering phenomena like polaritons, quantum phases, and many-body effects across various materials, including 2D, molecular, and hybrid systems.



a, diagrams for the three main ultrafast tip-based microscopy techniques discussed in the review. b, exploration of physical processes through the techniques described above, sorted on the basis of their characteristic times.

Optical microscopy has long been a fundamental tool for scientific discovery. Yet, traditional far-field techniques are limited by diffraction, restricting their resolution to hundreds of nanometers, which can be inadequate for capturing phenomena in quantum and solid-state materials. With the emergence of tip-based microscopy capable of achieving atomic-scale spatial resolution, near-field optical nano-spectroscopy and nano-imaging have evolved into versatile tools for characterizing the optical properties of materials at the nanoscale. When further combined with ultrafast pump-probe methods, these techniques enable both atomic-scale spatial and femtosecond-level temporal resolutions, offering unprecedented insights into ultrafast dynamics. This breakthrough permits observing fleeting quantum states and complex phenomena like polaritons and phase transitions, which were previously unobservable in real time.

In the recent review published in eLight, scientists from Tongji University, the University of

Colorado Boulder, and ITMO University provide a comprehensive overview of the applications of ultrafast nano-spectroscopy and nano-imaging, focusing on the three major branches of ultrafast tip-based microscopy: ultrafast scattering-type scanning near-field optical microscopy (s-SNOM), ultrafast nanofocusing, and ultrafast scanning tunneling microscopy (STM).

· Ultrafast s-SNOM has been widely applied to characterize the dynamics of light-matter interactions in the linear optical regime, offering compatibility with a broad range of optical wavelengths and materials.
· Ultrafast nanofocusing, facilitated by a grating coupler on the plasmonic tip, enables background-free coherent detection in the nonlinear optical regime, reaching temporal resolution down to a few femtoseconds.
· Ultrafast STM, typically supported by an ultrahigh vacuum environment, can achieve spatial resolution down to the sub-ångström scale under optimal conditions.

“Building on the various SPM techniques capable of breaking the diffraction limit, further integration with ultrafast techniques has enabled the simultaneous achievement of high spatial and temporal resolutions,” they said.

“This integration enables real-time observation of electronic, vibrational and magnetic dynamics at the nanoscale, which advances the exploration of ultrafast interaction processes characterized by ultrashort lifetimes ranging from femtosecond to nanosecond time scales.” They added.

“Three representative techniques in ultrafast tip-based microscopy, ultrafast s-SNOM, ultrafast nanofocusing and ultrafast STM, have greatly advanced the understanding of underlying physical mechanisms, enabling the direct observation of dynamic processes at the atomic scale. Continued progress in this field promises to further enhance the ability to investigate complex physical phenomena, driving both advanced scientific discovery and the development of cutting-edge techniques.” The scientists forecast.

DOI
10.1186/s43593-024-00079-1

Original Source URL
https://doi.org/10.1186/s43593-024-00079-1

Funding information
This work was supported by the National Natural Science Foundation of China (62175188, 62475194, 61925504, 62305249, 62192770, 62192772) and the Science and Technology Commission of Shanghai Municipality (23190712300, 23ZR1465800), the Priority 2030 Federal Academic Leadership Program, the National Science Foundation (NSF) Science and Technology Center on Real-Time Functional Imaging (STROBE) under Grant DMR 1548924 for ultrafast pump-probe nanoimaging instrument development, the National Science Foundation (NSF Grant No. CHE2108009) for strong light-matter coupling, and the U.S. Department of Energy, Office of Basic

Sciences, Division of Material Sciences and Engineering, under award no. DESC0008807 for coherent nanoimaging of quantum materials.

Lucy Wang
BioDesign Research
email us here
