Light at the Nano-Scale: Imaging, Spectroscopy and Beyond

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Abstract

Light–matter interactions have long been central to exploring fundamental and technologically relevant physical phenomena ranging from nanoscience to astrophysics. In particular, when used in a non-invasive way, these interactions provide a powerful means of probing the structure and properties of materials, revealing information about the electronic structure, lattice vibrations, chemical composition, quasiparticle properties etc.

With the rapid development of nanotechnology and miniaturised devices, our ability to investigate light–matter interactions and optical response at the nanoscale becomes crucial for observation and characterisation of different materials, structures and phenomena. However, the diffraction limit of light restricts conventional far-field optical techniques from resolving spatial features smaller than approximately half of the illumination wavelength λ.[1] This fundamental challenge prompted the development of several far-field nanoscopy techniques in order to circumvent the diffraction limit, such as stimulated emission depletion microscopy, photoactivated localisation microscopy, and stochastic optical reconstruction microscopy.[1,2] Although these methods allow for routine nanoscale optical imaging, they are limited by the requirement for fluorescent labels. For materials in which labelling is not feasible or informative, other nanoscale optical imaging and spectroscopy techniques are needed.[2]

Scanning near-field optical microscopy (SNOM) is a term that encompasses different techniques which solve this problem and allow for label-free, high-resolution, submicron-scale spatial imaging and spectroscopy.[2,3] Of special importance is a technique called scattering-type SNOM (s-SNOM), which enables nanoscale imaging across a broad range of frequencies from visible light to sub-terahertz radiation.[2] Specifically, this technique yields optical properties (e.g., dielectric constants) with compatible spectroscopic capability and temporal sensitivity.[4] It can also detect mobile carrier oscillations (plasmons), lattice and molecular vibrations (phonons) and excitons in the visible range. With these capabilities, s-SNOM is a powerful tool for obtaining information about local conductivity, crystallinity, chemical composition, electronic band structure and optical properties in various types of matter.[2]

Keywords: light-matter interactions, diffraction limit, nanoscale optical imaging, scanning near-field optical microscopy

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