When near-field plasmonic tip meets quantum technologies

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Abstract:

The ability to probe, manipulate, and engineer quantum states at the nanometer scale is essential for the development of next-generation quantum technologies. A sharp metallic tip provides a unique platform for this purpose by concentrating optical fields into a nanoscale volume and dramatically enhancing local light–matter interactions. Importantly, the plasmonic tip can function not only as a near-field imaging probe, but also as a dynamically tunable nanoantenna and optical cavity that actively modifies the quantum system beneath it. In this talk, I will discuss how tip-enhanced nano-spectroscopy can be used to investigate and control excitons, localized emitters, defects, and other quantum states in low-dimensional materials. Tip-induced field enhancement and cavity coupling can generate exotic hybrid light–matter states, modify radiative and nonradiative decay pathways, and enable the nanoscale tuning of strong-coupling conditions. For quantum emitters, the confined plasmonic field can substantially enhance emission intensity and provide active control over single-photon generation, polarization, and photon statistics. The extreme spatial confinement and sensitivity of the tip-enhanced interaction also offer new opportunities for quantum sensing. Local electric and magnetic fields, charge fluctuations, strain, vibrational modes, and dielectric variations can be detected through their influence on nanoscale quantum states. Extending these concepts to soft matter and biological interfaces may ultimately enable quantum-enhanced optical sensing of biomolecules, membranes, and cellular environments with nanometer-scale resolution. Finally, I will present emerging directions in ultrafast, nonlinear, cryogenic, and device-integrated tip-enhanced spectroscopy. These developments illustrate how the near-field plasmonic tip can evolve from a passive characterization tool into a versatile nanoscale platform for creating, controlling, and reading out quantum states.