

Near-field multi-probe diagnosis of subwavelength-scale optoelectronics functionalities

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The fundamental processes of near-field optical or electronic diagnosis of optoelectronic functionalities in nanometer-scales rely on macroscopic transport of photons or electrons in non-equilibrium open-system controlled by local interactions and dissipations in a coupled system of oscillating electric multipoles and local environment. In the entire system of diagnosis, the local environment takes the role of temporal reservoir buried in a hierarchical structure of dissipation extended to effective reservoirs governing the macroscopic transport, which in turn produces multi-scale correlations between the local dissipation processes. Such hierarchy nature is one of the origins of complexities generated in optoelectronics functionalities of subwavelength scales, and would bring us with innovative applications to construct intelligent optoelectronic processors beyond von Neumann architecture. The near-field interactions of oscillating electric multipoles are well described based on the angular-spectrum representations of scattered electromagnetic fields based on the half-space boundary problems, for which the triplet-modes are defined as the basis of second quantization. Regarding a transport process between the Left- and Right-half spaces, each of which either a source or a sink is attached, we should consider the problems of normal-mode transformation between two different orthogonal complete sets of mode descriptions, so called Triplet-modes and Detector-modes including both Transverse-electric, TE, and transverse-magnetic, TM, polarizations. The transitions between the normal-modes should inevitably be assisted by momentum or angular momentum dissipations into the local environments. When the role of the optical source and sink are reversed, the different combinations of Right- and Left- Triplet- and Detector- modes should be employed, so that reciprocity of optical processes, in general, could not stand for such electromagnetically disconnect half-space problems. Further, near-field optical interactions in strongly confined transport channel involve broad spectra of transverse momentum and pseudo-angular momentum of evanescent waves, so that the interaction and transport manifold greatly increases the complexity of functionalities.

For multi-aspect diagnosis of optoelectronics functionalities of subwavelength scales, we have developed several different types of multi-probe diagnosing apparatus, such as an STM-controlled scanning near-field optical microscope, STM-SNOM, with counter two probes enabling an observation of front-to-back transport of local optoelectronic excitation through a functional multilayered quantum structure operating at low temperature under applied magnetic field up to 9T, a three-probe SNOM system which enables us with tracing paths of excitation transfer, and a hole-array system revealing concurrent correlations between local events. We present the details of each apparatus and applications based operation mechanism and expected functionality diagnosis of hierarchical features of optoelectronics interactions in nanometer scales.