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Published in:
Proceedings of 2019 URSI International Symposium on Electromagnetic Theory

Publication date:
2019

Document Version
Publisher's PDF, also known as Version of record

URSI EM Theory Symposium, EMTS 2019, San Diego, CA, 27 – 31 May 2019

Active Nano Particles for Enhanced and Directive Radiation and Scattering Phenomena

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Our ability to effectively tailor and control light-matter interactions at the nano-scale may have a profound impact on several nano-photonic fields of utmost societal importance, e.g., nano-sensors and lasers, solar cells and energy harvesting, optical communication and medicine, to mention a few. In this regard, nano-antennas (NAs) are the key enablers towards a successful realization of the required light-matter interactions. As a result, significant attention has been devoted recently to the field of NAs. Their realizations fall mainly into two categories. The first category is comprised of traditional NAs which simply are the scaled down versions of their traditional microwave counterparts. The second category consists of NAs based on a wide range of plasmonic and/or all-dielectric nano-particles (NPs) supporting the excitation of different multipoles. In most cases, the involved NP sizes were electrically small, making such NAs radiate as small dipoles. However, many emerging applications are in strong need of electrically small and directive NA that may enable strong power flows in preferred directions.

The purpose of this work is to review our previous and current research efforts in the promising area of directive NP-based NAs. Focus will be placed on both symmetric and asymmetric two-dimensional (2D) and three-dimensional (3D) passive as well as active cylindrical NPs with appropriate layer designs, perforations or eccentricities. Since these NPs contain, in most cases, silver as one of their constituent layers, the use of active medium is essential in order to overcome large losses at the optical frequencies of interest here. Specifically, we will illustrate how perforations (which introduce higher order modes) essentially only enhance the near-field radiation properties, while asymmetries introduced through the layer eccentricities also enhance the far-field radiation behaviors through a balanced excitation of dipole and quadrupole modes. As for the latter, we will also demonstrate that the over-all response can be effectively tailored (enhanced, reshaped, and steered) through appropriate changes of both the amount and the direction of the nano-core displacements (eccentricities). Furthermore, we will also describe how symmetric multi-layered cylindrical passive NPs with scattering coefficients tailored to follow e.g., the Dirac-delta and binomial distributions lead to super-directive and needle-like radiation patterns in both forward as well as backward directions. Our results will be illustrated by a variety of near-and far-field distribution results obtained either analytically and/or numerically with full-wave commercial packages. When relevant and possible, our efforts will be contrasted to the existing alternative approaches of achieving directive radiation and scattering phenomena from electrically small NAs.