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Electromagnetic density of states in complex plasmonic systems

R. Carminati[a,*], A. Cazé[b], D. Cao[a], F. Peragut[a], V. Krachmalnicoff[a], R. Pierrat[a], Y. De Wilde[a]

[a]*ESPCI ParisTech, PSL Research University, CNRS, Institut Langevin, 1 rue Jussieu, F-75238 Paris, France*
[b]*Department of Mathematics, University of Michigan, Ann Arbor, MI 48109, USA*

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Abstract

Nanostructured materials offer the possibility to tailor light–matter interaction at scales below the wavelength. Metallic nanostructures benefit from the excitation of surface plasmons that permit light concentration at ultrasmall length scales and ultrafast time scales. The local density of states (LDOS) is a central concept that drives basic processes of light–matter interaction such as spontaneous emission, thermal emission and absorption. We introduce theoretically the concept of LDOS, emphasizing the specificities of plasmonics. We connect the LDOS to real observables in nanophotonics, and show how the concept can be generalized to account for spatial coherence. We describe recent methods developed to probe or map the LDOS in complex nanostructures ranging from nanoantennas to disordered metal surfaces, based on dynamic fluorescence measurements or on the detection of thermal radiation.

Keywords: Local density of states; Plasmonics; Spontaneous emission; Thermal radiation; Spatial coherence; Cross density of states

Contents

*Corresponding author.
E-mail address: remi.carminati@espci.fr (R. Carminati).

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1. Introduction

Plasmonics couples surface plasmon excitations [1,2] with nanostructures in view of enhancing and controlling light emission and absorption at small length and time scales. This field of research has become an important branch of nano-optics [3,4], and several reviews have been published, describing developments towards applications in integrated subwavelength photonics [5–7], light concentration and manipulation at the nanoscale [8–10] including the design of optical antennas [11], active [12] and quantum plasmonics [13]. Our goal here is not to present another review of the field of plasmonics, but rather to revisit fundamental aspects based on the unifying concept of density of states. Measuring and engineering the electromagnetic local density of states (LDOS) in plasmonic structures is a major issue, since the LDOS drives basic processes of light–matter interaction such as spontaneous emission (fluorescence), thermal emission and absorption. New possibilities are emerging for the design of efficient sources and absorbers of visible and infrared radiation, for optical storage and information processing with ultrahigh spatial density, or for the development of nanoscale markers for biomedical imaging and therapy. In the last decade, methods have emerged that enable us to map the LDOS on nanostructured surfaces, or to engineer the LDOS in order to control light emission by single quantum sources. On the theoretical side, the concept of LDOS itself has been clarified to better account for specific features of the optics of metal surfaces, for example regarding the electric and magnetic contributions, or the splitting into radiative and non-radiative components. The purpose of this review article is to give a self-contained presentation of the concept of LDOS and of the connection between the LDOS and real observables in optics, and a state-of-the-art description of the methods permitting to probe or map the LDOS in real structures (from nanoantennas to complex disordered surfaces). The extension of the concept of density of states to include a description of spatial coherence, through the introduction of a cross density of states (CDOS), is also introduced. The concepts of LDOS and CDOS allow us to connect different aspects of plasmonics in complex structured geometries. They also help establishing connections with other fields of wave physics, in which wave–matter interaction is controlled by similar quantities.

2. Electromagnetic local density of states

2.1. Non-absorbing closed cavity: a canonical example

The concepts of density of states (DOS) and local density of states (LDOS) can be introduced starting from the textbook situation of a non-absorbing and non-dispersive medium embedded in a closed cavity with volume $V = L^3$ (it is usually