Rigorous modal analysis of micro or nanoresonators

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***Abstract*— The most general motion of a system is a superposition of its normal modes, or eigenstates. We report our recent developments of a rigorous modal analysis of electromagnetic resonators, which is accurate even for geometries that have not been analyzed so far, e.g. 3D resonators made of dispersive media and placed in non-homogeneous backgrounds (on a substrate or an optical thin film stacks).**

***Keywords*— Computational electromagnetic methods, Resonators, Quasinormal mode, Microcavity devices, plasmonic nanoresonator, inverse design**

I. Introduction

Modes are central in physics, chemistry ... In optics, modes are self-consistent electromagnetic field distributions in waveguides, optical resonators or in free space (plane waves, Hermite–Gaussian modes …). In waveguide and free space, they are well documented in the literature, as shown by several textbooks on Fourier optics and optical waveguide theory (Vassalo, Snyder & Love, Marcuse, Collin).

Textbook on the modal theory of resonators are quite rare [1], although nanoresonances play an essential role in current developments in nanophotonics, e.g., optical metasurfaces, integrated optics, optical sensing, photovoltaic devices... The reason is due to mathematical difficulties, see details in the recent review articles [2], and especially to the fact that optical resonators are non-Hermitian systems; their physics is not driven by classical normal modes, but by quasinormal modes (QNMs) with complex frequencies $\tilde{\omega}$. The QNM theory of plasmonic resonators (with huge damping due to strong absorption and leakage) has made considerable progress since one decade [3,4]. This conference contribution will review recent achievements in my group, with an emphasize on theoretical [5-7] and numerical issues [8,9], including the development of the freeware MAN (Modal Analysis of Nanoresonators) [10]..

II. Example of result

Figure 1 illustrate the capability of the theoretical/numerical tool that has been developed [Yan18], for a “nanobulet” antenna placed on a metal substrate (to our knowledge, it is the first time that a modal formalism is capable to analyze nanoresonators placed on a substrate). In (a) we show the 600 QNMs computed with the solver in the complex frequency plane. In (b), we consider the field scattered by the resonator under illumination by a plane wave, and compare the field reconstructed with the modal method with the field computed with a classical frequency-domain method. It is important to remark that, once the resonance modes are computed, the resonator response to any driving field is analytically known at all frequencies, and considerable computational-speed improvement, compared to classical Maxwell’s equations solvers, is achieved.

Additionally, the QNM expansion provides key clues towards understanding the physics underlying the optical response, especially when several modes are excited together.

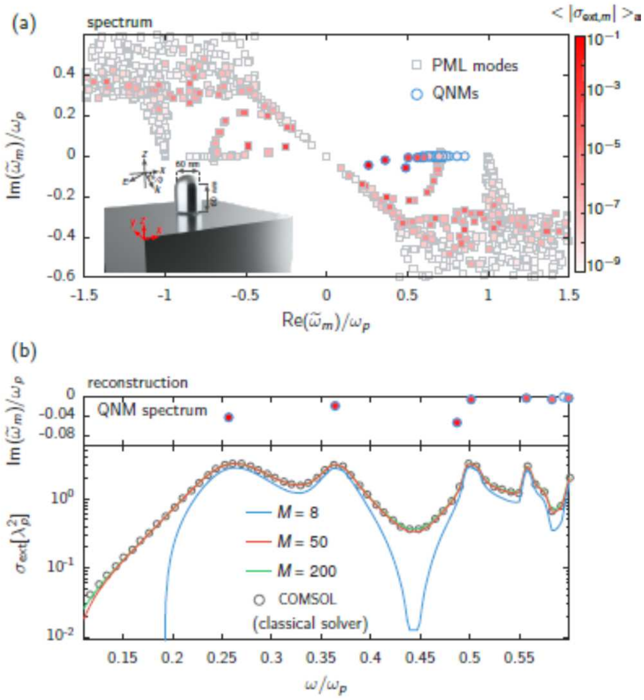

Fig. 1. (**a**) PML modes and QNMs (true resonance mode) of a Ag nanobullet placed on a gold substrate. $Re(\tilde{\omega})$ and $Im(\tilde{\omega})$ represent the resonance frequency and decay rate. (**b**) Extinction cross section spectra computed analytically over 5 octaves with the present modal method for $M = 8$, 50 and 200 QNMs retained in the computations and compared with results obtained with a classical frequency-domain method.

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