Light interaction with nanoresonators: mode volume and quasinormal mode expansion

Philippe Lalanne[1]

[1] LP2N, Institut d'Optique Graduate School, CNRS, Univ. Bordeaux, 33400 Talence, France
philippe.lalanne@institutoptique.fr

Microcavities and nanoresonators are characterized by their modes, called quasinormal modes because of they are the eigensolution of non-Hermitian operators. In contrast to waveguide and free space modes, quasinormal modes are not well documented in the literature, although nanoresonances play an essential role in current developments in nanophotonics. The reason is due to mathematical difficulties, see details in the recent review article [1], and especially to the fact that quasinormal modes cannot be normalized by their energy.

Quasinormal modes are characterized their quality factors Q and mode volumes V. While Q can be unambiguously defined and interpreted [1], there are still questions on V and in particular on its complex-valued character, whose imaginary part is linked to the non-Hermitian nature of open systems.

Mode Volume. The concept of complex V's [Phys. Rev. Lett 110, 237401 (2013)] is recent. It seems to be rooted in important phenomena of light-matter interactions in non-Hermitian open systems [1]. For instance, the ratio Im(V)/Re(V) quantifies the spectral asymmetry of the mode contribution to the modification of the spontaneous emission rate of an emitter weakly coupled to a cavity. For strong coupling, it modifies the usual expression of the Rabi frequency by blurring and moving the boundary between the weak and strong coupling regimes. Despite these strong roots, complex V are often seen as a mathematical abstraction.

Helped by cavity perturbation theory, see related earlier work in [2], and near field experimental data, we clarify the physics captured by the imaginary part of V and show how a mapping of the spatial distribution of both the real and imaginary parts can be directly inferred from perturbation measurements. This result shows that the mathematically abstract complex mode volume in fact is directly observable.

Quasinormal mode expansion. The modal theory of optical resonators has recently achieved very important improvements, to such an extend that we may say future works we mostly on refinements rather than on fundamental developments. At the conference, we will show state of the art reconstruction of the field scattered by resonators in their quasinormal mode basis [4].

References

[1] P. Lalanne, W. Yan, K. Vynck, C. Sauvan, and J.-P. Hugonin, Laser Photonics Rev. 12, 1700113 (2018). "Light interaction with photonic and plasmonic resonances"
[2] J. Yang, H. Giessen, P. Lalanne, Nano Lett. 15, 3439 (2015). "Simple Analytical Expression for the Peak-Frequency Shifts of Plasmonic Resonances for Sensing"
[3] K. G. Cognée, W. Yan, F. La China, D. Balestri, F. Intonti, M. Gurioli, A. F. Koenderink, and P. Lalanne, Optica 6, 269 (2019). "Mapping Complex Mode Volumes with Cavity Perturbation Theory"
[4] W. Yan, R. Faggiani, P. Lalanne, Phys. Rev. B **97** 205422 (2018). "Rigorous modal analysis of plasmonic nanoresonators"