Rigorous Quality Factor Calculation in Contemporary Optical Resonant Systems

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Accurate approaches on calculating the quality factor of contemporary optical resonant systems, involving dispersive dielectrics, metals, and 2D materials, are systematically presented. Such resonant systems exhibit high material dispersion and important ohmic and/or radiation losses, rendering typical *Q*-factor calculation methods, roughly accurate in conventional dielectric resonators, principally erroneous.

Q-factor calculation techniques

The quality factor *Q*, a measure of the overall cavity loss, specifies the spectral bandwidth, the energy decay rate, and the possible enhancement of a nonlinear resonator's response [1]. Thus, its correct calculation is of outmost importance, being extensively used in linear and nonlinear temporal coupled-mode theory (CMT) frameworks [2] to easily assess resonators' complex response without resorting to cumbersome full-wave simulations.

Here, we collectively present the available methods on calculating the quality factor of nanophotonic resonant systems, computationally simulated using commercially available frequency-domain finite-element method (FEM) software. Specifically, we present the correct approaches to calculate *Q* using either eigenvalue or time-harmonic simulations, employing: (i) the complex eigenfrequency, (ii) the complex eigenmode, (iii) the actual field spatial distribution, or (iv) the resonator's spectral response. Although well established for conventional dielectric resonators [Fig. 1(a)], the four above techniques should be carefully applied to contemporary nanophotonic resonant systems, such as graphene-comprising resonators, dielectric metasurfaces, and plasmonic nanoparticles [Figs. 1(b)-(d)], to correctly account for the material dispersion, ohmic loss, and light leakage effects. We systematically discuss on the appropriate modifications that should be introduced for the correct *Q*-factor calculation and demonstrate a remarkable, almost 100% error when applying conventional methods to highly dispersive systems (graphene tubes, plasmonic nanoparticles, etc.). Furthermore, the applicability limits of each modified approach are consistently highlighted.

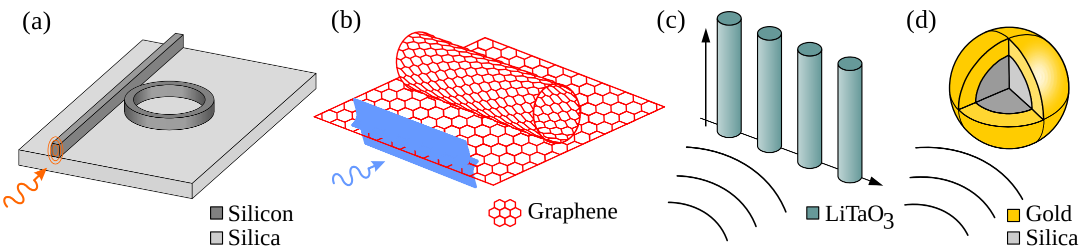

Fig. 1 *Optical resonant systems: (a) Silicon microring resonator, (b) graphene tube resonator, (c) dielectric rod metasurface, and (d) plasmonic core-shell nanoparticle.*

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