Graphene-Based Nonlinear Resonators for Optical Bistability: A Coupled Mode Theory Approach

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Abstract: Graphene exhibits interesting properties in the THz frequency band and more specifically it has a surface conductivity consisting of both a linear and a third-order nonlinear contribution. The linear term has a significant negative imaginary part, allowing for the support of surface plasmon polaritons, while the third-order nonlinear term is, according to the literature, purely imaginary and of substantial magnitude, introducing a Kerr-type nonlinearity without extra nonlinear losses.

The combination of these unique properties of graphene with a simple travelling-wave resonator scheme providing feedback [Fig. 1(a),(b)], leads to optical bistability; a situation where the output power can potentially acquire two different states for a given input, depending on the history of the system [1].

To analyse this situation, we develop a framework combining first-order perturbation theory and temporal coupled mode theory (CMT). The framework is general, taking into account the inherent dispersion of graphene conductivity, expanding the available theory by additionally incorporating its nonlinearity. Importantly, we show that dispersive graphene can store energy due to the current density distribution on its surface. When dispersion is neglected, the stored energy on graphene becomes zero despite the fact that it still consumes reactive power produced by electric and magnetic fields.

To validate the framework developed, we compare the obtained results with full-wave nonlinear vectorial finite element method (NL-VFEM) simulations, while special care is taken to correctly model the current boundary conditions introducing graphene physically as a 2-D material [2]. Fig. 1(c) demonstrates excellent agreement between the two approaches.

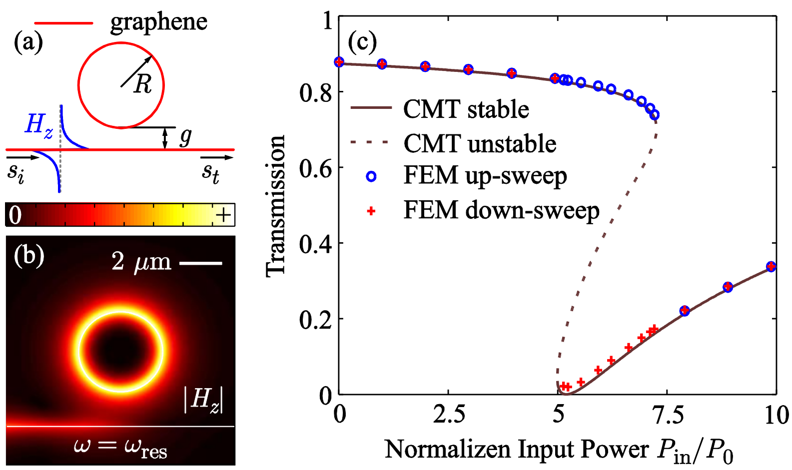

Figure 1. (a) Schematic of a graphene-based travelling-wave resonator, side-coupled with a graphene-based bus waveguide. **(b)** Magnetic field distribution on resonance (linear regime), revealing a travelling wave with zero transmission, since the resonator is critically coupled to the waveguide. **(c)** Bistability curve obtained both from CMT and NL-VFEM, indicating excellent agreement between the two.

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