Nonlinear and quantum nano-optics with atomically-thin materials

Joel D. Cox[1,2]

1. POLIMA—Center for Polariton-driven Light–Matter Interactions, University of Southern Denmark, Campusvej 55, DK-5230 Odense M, Denmark
2. Danish Institute for Advanced Study, University of Southern Denmark, Campusvej 55, DK-5230 Odense M, Denmark
E-mail: cox@mci.sdu.dk

Abstract: We explore the ways strong light-matter interactions in atomically-thin materials can trigger nonlinear optical phenomena that enable spectral control of light by light, atomic bistability, and single-photon-level nonlinear optical interactions on the nanoscale.

Coherent control of light and atomic systems enables fundamental explorations of quantum physics while promising disruptive applications in diverse fields, ranging from information and communications technologies to optical sensing and metrology. In this context, the intrinsically strong and actively tunable light-matter interactions available in atomically-thin materials, such as graphene and ultrathin noble metals, offer unique opportunities to trigger nonlinear and quantum optical phenomena on the nanoscale by invoking their supported polaritons and/or near field interaction with proximal quantum light emitters [1]. Here we discuss the excellent nonlinear optical response associated with plasmons in ultrathin crystalline noble metal films [2], with thickness-dependent properties and potentially lower loss than their amorphous counterparts, as well as 2D plasmon polaritons in graphene [3], characterized by strong optical confinement, electrical tunability, and mechanical flexibility. In particular, we will explore the ways that synergetic interactions between different plasmon resonances in graphene heterostructures can drive intense plasmon-assisted harmonic generation, which we show can be further catalyzed by nonlocal light-matter interactions (see Fig. 1) [4]. Finally, we will discuss recent proposals to harness strong light-matter interactions in atomically-thin platforms to optically drive atomic systems into actively-tunable bistable states and mediate single-photon-level nonlinear optical interactions on the nanoscale [5,6].

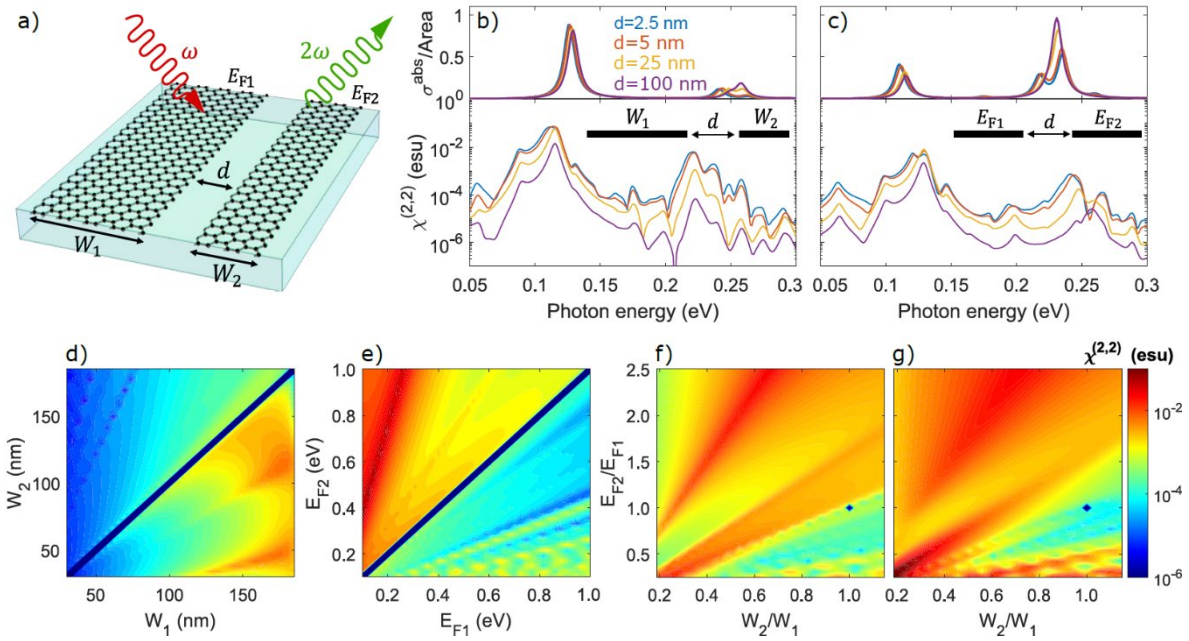

Fig. 1 Second-harmonic generation in co-planar asymmetric graphene nanoribbon pairs. (a) Schematic illustration of second-harmonic generation (SHG) in two co-planar graphene nanoribbons separated by a distance d and characterized by widths W_j and Fermi energies E_{Fj} for j ∈ {1,2}. (b) For a dimer formed by arranging ribbons of width W_1=160 nm and W_2=40 nm at the same doping E_{Fj}=0.4 eV, such that the frequency of the lowest-order dipolar plasmon resonance in ribbon j=1 is half of that in ribbon j=2, the effect of inter-ribbon interaction is explored in both the linear absorption cross-section (upper panel) and the SHG susceptibility (lower panel) by varying the separation distance d. (c) Similar to (d), but for ribbons of equal width W_j=100 nm and different doping E_{F1}=0.2 eV and E_{F2}=0.8 eV. (d-f) SHG from co-planar ribbons spaced d=25 nm apart when: (d) the ribbons have the same doping E_{F1}=E_{F2}=0.4 eV and varying widths W_j; (e) equal widths W_1=W_2=100 nm and varying doping E_{Fj}; (f) both the width and doping of ribbon j=2 are changed. (g) Similar to (f), but for a small ribbon separation d=2.5 nm. In panels (d-g) the impinging light frequency is maintained at the lowest-order dipolar plasmon resonance frequency.

References

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