Quantum Aspects of Nanoplasmonics

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Abstract

In 1959 Nobel Laureate Richard Feynman gave a celebrated speech called “There’s plenty of room at the bottom.” In that talk he outlined challenges we would face in manipulating individual atoms. Feynman’s talk marks the beginning of a quest to make things smaller and it inspires research directions that continue to this day. Nanotechnology tools have long passed the barrier to single atom manipulation, today devices are routinely fabricated using material engineering that exploit quantum mechanics.

Recent developments in metallic materials structured with nanometer scale features have spawned the field of nanoplasmonics; the word “plasmon” conjures up applications of free electron dynamics that are important in both electronic and photonic applications. Nanoplasmonic structures can be designed to concentrate electromagnetic intensity leading to scattering effects that are magnified by eight to twelve orders of magnitude. With new understanding of concentrating electromagnetic fields researchers have proposed new device designs with improved performance including molecular sensors, efficient energy harvesters and novel light sources.

While the classical theory applied to nanoplasmonic systems predicts an ever increasing field in the nanometer gaps between the metallic elements as it is made smaller, quantum theory places a limit on the electronic charge build up due to the electronic tunneling effect. Ultimately it is the quantum tunneling effect that will determine the optimal designs of new devices and sensors with nanoplasmonic materials. Incorporating quantum tunneling into the nanoplasmonic systems has only recently been done. Previous publications have used complex, large-scale computations to incorporate quantum tunneling effects into simple nanoplasmonic systems.

In a series of recent publications we have developed an electronic quantum tunneling approach that we call the Quantum Conductivity Theory (QCT), which is applied to survey the optical properties of metal-insulator-metal structures with sub-nanometer sized insulator gaps. QCT takes physical parameters from the literature and has no free fit parameters. The close proximity of metallic objects generates a tunneling, ac current density that endows the insulator gap region with additional linear and nonlinear conductivity coefficients. The quantum coefficients trigger electromagnetic scattering effects leading to linear and nonlinear absorption and second- and third-harmonic generation. Strong field localization inside the gap ensures that harmonic generation arising from the gap region overwhelms intrinsic second- and third-order nonlinearities of the composite materials. Experiments designed for nonlinear light scattering from nanoplasmonic structures can test critical aspects of QCT.