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Nonlinear Optics

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INTRODUCTION

Nonlinear science, i.e., the study of systems capable of generating new frequencies, is ubiquitous and fascinating; as opposed to linear science, where we often have well known tools to tackle a specific problem, when nonlinearity comes into play, and the whole can be more than the sum of its parts, we can seldom resort to standard techniques. Even in the non stochastic framework, the field is often unpredictable: the emergence of qualitatively new phenomena is anticipated and made welcome, offering incredible outcomes for basic and applied sciences.

Nonlinear optics is a particular and rich subset of nonlinear science. Although nonlinear effects in optics are known since a very long time, modern nonlinear optics was born with the invention of the optical maser, today known as the laser. In a seminal paper by Franken and co-workers in 1961, second harmonic generation was demonstrated by tightly focusing a pulsed ruby optical maser into crystalline quartz (Franken et al., 1961). In the following years a plethora of nonlinear effects in light-matter interaction were experimentally demonstrated and often rapidly found their way to market applications in several different fields, ranging from telecommunications to imaging for health care and characterization.

Due to the short interaction lengths between light and matter, in the early stage, nonlinear optical effects were often associated with very low efficiencies; for this reason, a very important milestone has been set moving from bulk nonlinear optics to guided wave nonlinear optics. The flourishing field of nonlinear guided wave optics started shortly after the optical fiber became a popular transmission medium (Stolen et al., 1974). This gave an incredible boost to the efficiency of nonlinear optical effects, because light-matter interaction lengths could be increased by several orders of magnitude (from few centimeters to tens of kilometers). The richness of new physics, which since then has appeared, has deeply fed this research area and, in turn, the field has given back incredible success to the researchers. For all these reasons, nonlinear optics could quickly move into the field of extreme events; just to mention only a few of the remarkable outcomes of this part of the history of nonlinear optics: the field of solitons is strongly indebted to nonlinear optics and viceversa, since optical fibers gave an ideal playground where to observe and test the properties of these fascinating waves, which were first predicted in water waves and then became, in the sixties, one incredible chapter of modern mathematical physics (Zakharov and Shabat, 1970). This is, still today, a rich and flourishing research field with important, and sometimes surprising, outcomes for optical communications and optical sensing with new fascinating phenomena like rogue waves (Dudley, 2019).

In line with what Richard Feynman said at the annual American Physical Society meeting in 1959, *there is still plenty of room at the bottom*, nonlinear optics, in the last 20 years, deeply dived into nanotechnologies and nanophotonics (Kauranen and Zayats, 2012; Shcherbakov et al., 2014; Carletti et al., 2015). Anelastic scattering from metallic and non metallic nanoparticles (**Figure 1**) is now a very hot research topic for both basic and applied

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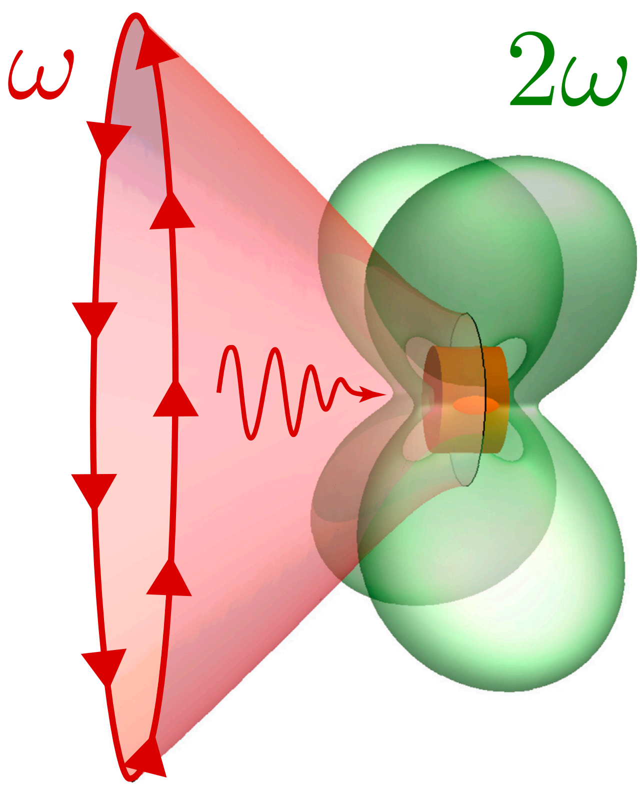

FIGURE 1 | Artistic view of the second-harmonic field generated from a subwavelength dielectric nanoparticle pumped by an azimuthally polarized beam at the Bound State in the Continuum (BIC) conditions (Carletti et al., 2018).

science (Koshelev and Kivshar, 2020). In this framework, the interplay between periodicity and nonlinearity is a huge and still largely unexplored research field where possible applications ranges, for example, from telecommunications to healthcare and energy harvesting.

Some keywords of today Grand Challenges in nonlinear optics are: Nonlinear guided-wave optics; Nonlinear scattering from nanoparticles; Nonlinear optics in metamaterials and metasurfaces; Nonlinear optics in dissipative systems; Nonlinear optics in time dependent media; Nonlinear topological phenomena and PT-symmetric photonic structures; Nonlinear optomechanical and optothermal coupling; Nonlinear optical circuits for machine learning and artificial intelligence; Dielectric and hybrid nanophotonics for nonlinear devices and systems: Statistical behavior, coherence, and turbulence in nonlinear optics; Quantum optics including the generation, manipulation and detection of nonclassical light via nonlinear optical interactions; Non-perturbative nonlinear optics; Ultrafast phenomena and high harmonics generation; Extreme events in nonlinear optics, including solitons, modulational instability and rogue waves; Theoretical and computational methods in nonlinear optics.

This fascinating research area is at the hearth of many key enabling devices for a plethora of applications driven by societal challenges and needs; here we aim at a holistic approach to address the theoretical, computational, physical, and engineering aspects of modern nonlinear optics.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.