Modeling ultrashort mid-infrared laser pulses

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Propagation of ultrashort, off-resonant optical pulses in atomic gases produces a broad range of extreme nonlinear optical effects including high-harmonic generation [1], synthesis of attosecond pulse forms [2], and optical filamentation [3]. While it is generally accepted that the origin of these phenomena resides in the quantum mechanical nature of light-matter interaction, the standard approach of modeling these effects is phenomenological in nature. With the new availability of ultrashort pulse laser sources in the mid-infrared wavelength region, we ask to what extent does the current set of modeling equations capture the nonlinear optical phenomena seen in the mid-infrared region.

We begin by presenting the main nonlinear optical phenomena seen in laser propagation experiments and discuss the modeling equations that capture them. From here, we present three research avenues towards accessing the validity of and possibly extending the standard modeling equations to the mid-infrared region.

The first research avenue is the use of quantum resonant states [4] to provide a self-consistent description of the nonlinear polarization, the rate of ionization, and effects due to weakly bound electrons. Although this approach performs well for both near- and mid-infrared pulse scenarios, and consolidates several of the currently used phenomenological terms, many of their fundamental properties are still unknown.

The second avenue is to quantify the nonlinear optical properties of gaseous media using time-dependent density functional theory (TDDFT). Extracting low-order susceptibilities and absorption spectra due to a wide range of mid-infrared laser pulses, we investigate to what extent these quantities depend on the laser properties.

The third avenue involves modeling new experimental results involving the propagation of mid-infrared laser pulses. For example, a recent experiment demonstrates that the phase of the underlying carrier electric field may play a role in the generation of harmonic spectrum. We investigate whether it is possible for the current modeling equations to reproduce this and if a modification to the theory is necessary.

From these three approaches, we aim to access the applicability of the standard modeling equations to the mid-infrared wavelength region and suggest modifications to the theory if necessary.

References

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