Time-dependent ionization modeling for Maxwell solvers: application to the nonlinear femtosecond laser propagation in dielectrics

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Extended abstract

Optical materials such as silica or KDP (KH2PO4) are commonly used in laser systems for pulse shaping or may be structured, following the laser energy deposition, to obtain new optical functionalities as wave guides, nano-gratings, etc. These materials are dielectrics with a large bandgap which electronic properties may significantly evolve when interacting with intense femtosecond (fs) laser pulses. The modifications of electronic properties initiate with the photo-ionization stage. It is followed by the laser-assisted electron dynamics in the conduction band leading to the energy deposition into the material. The laser-pulse characteristics such as the frequency spectrum may also be strongly affected in the course of propagation. To evaluate accurately the energy deposition, it turns out that a modelling for the coupled electron and laser propagation dynamics is required.

In the case of short pulses of tens of fs, spectral broadening becomes significant and the assumption of a fixed monochromatic wave should be abandoned, i.e. time-dependent descriptions are required. The best way to describe the propagation of short laser pulses in dielectric materials under these conditions is to solve numerically the three-dimensional Maxwell equations [1]. Good candidates for modeling the primary ionization stage are the so-called Bloch-Volkov (BV) and optical Bloch (OB) approaches [2]. They have been shown to correctly account for the possible temporal evolution of the frequency spectrum through the time-dependent electric field, thus being able to describe consistently the simultaneous presence of various multiphoton orders due to a temporal chirp or a frequency conversion for instance. An illustration is provided by Fig. 1 with the following parameters: 413nm, 50TW/cm², and bandgap of 9eV. The electron density evolution consists of peaks corresponding to the absorption of different numbers of photons. This time-dependent ionization model has been coupled to a code solving the Maxwell’s equations to account for a temporal evolution of the pulse frequency spectrum [1]. An illustration of this effect is provided by Fig. 2 which shows the evolution of the maximum of the free-electron density as a function of the propagation distance in a frequency converter KDP crystal with parameters: 633nm, 7.5TW/cm², and bandgap of 7.8eV.