Theory of ultrafast and ultrastrong processes in solids

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The advent of sources of ultrashort and strong laser pulses opened up pathways to investigate light-induced excitation and charge-carrier transport on the natural, the attosecond (10^{-18}s) timescale. While for atoms a direct solution of the time-dependent Schrödinger equation, in some cases even numerically exact, is possible, methods to describe systems with huge numbers of particles are necessarily subject to strong approximations and have to be validated by comparison with experimental results.

In all processes discussed in this tutorial (heating/melting is not included as it happens on much longer timescales) the production of pairs of charge carriers through the absorption of light in the material is the fundamental interaction starting complicated multi-particle dynamics. A short introduction in selected methods used to simulate the interaction of ultrashort and strong laser pulses with extended systems will be presented together with examples of applications of these methods including high-harmonics generation in dielectrics, the generation of electron pulses confined in time and space, the switching of the direction of electric currents with the help of light fields, the speed limit of optoelectronics, or the timing of the photoexcitation process in solids providing, in turn, benchmarks for the validity of the simulation methods.

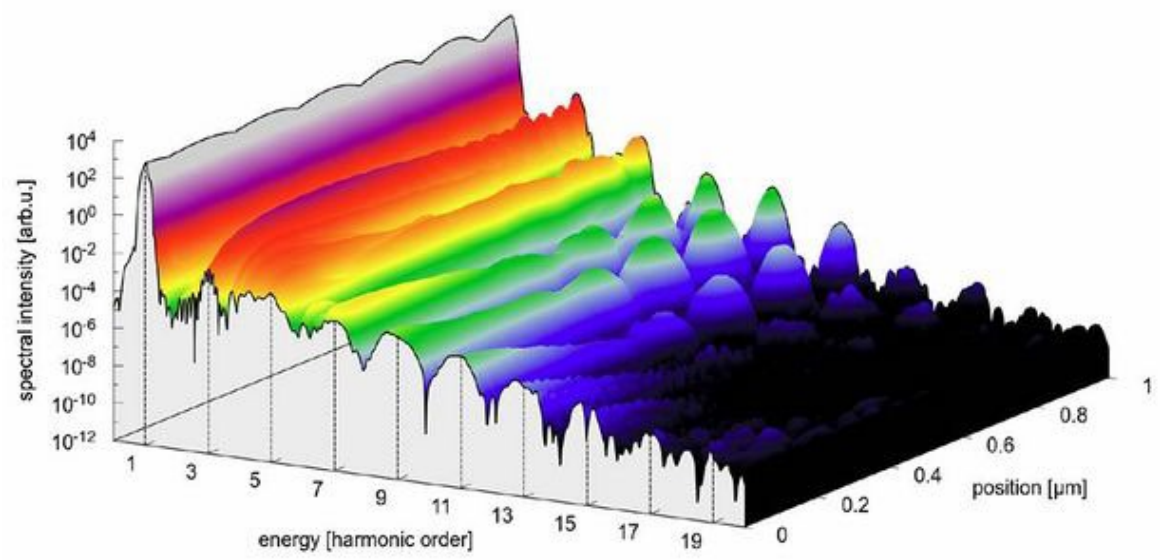

Figure 1: High harmonic spectrum generated in diamond by a linearly polarized few-cycle laser pulse as a function of the position along the propagation direction inside a 1 μm thick diamond crystal. This figure is the result of a multi-scale simulation combining time-dependent density functional theory for the simulation of electron dynamics in a crystal unit cell (small scale) with a solution of Maxwell's equations for the propagating light wave (large scale).