Time-Domain Analysis of Wideband Optical Pulse SHG in Layered Dispersive Material

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Time-domain analysis of Second Harmonic Generation (SHG) in modern optical devices provides an invaluable insight into the understanding and potential utilization of this phenomenon and wave-device interaction in general. For CW inputs or long pump pulses, it is quite sufficient to match the phase velocities of the propagating fundamental and second harmonic beams for optimum conversion. As the bandwidth of the pump (fundamental) pulse increases, the group velocity mismatch and wave packet spreading need to be taken into consideration. These effects become significant for pulse durations less than 100 femtoseconds. The earlier attempts to model and simulate pulsed SHG in second order materials involved 1-D approximations with high-order time derivatives and input depletion ignored to simplify the analysis. These attempts, in general, have ignored material dispersion. In this work, the analysis of ultrashort optical pulse propagation in dispersive second order nonlinear materials is introduced. The formulation of the problem involves incorporating the frequency-dependent material dispersion in the time-domain SHG model. For simulation purposes, explicit and uncoupled FDTD solution equations are obtained. The present model fully accounts for all temporal and spatial variations and takes the depletion of the input beam into consideration. The material is assumed to have the general Lorentzian dispersion relation of the form

$$\varepsilon_r(\omega) = \varepsilon_\infty + \frac{(\varepsilon_s - \varepsilon_\infty)\omega_o^2}{\omega_o^2 + 2j\omega\delta - (j\omega)^2}$$

where ε_s and ε_∞ are the static and optical values of the dielectric constant, respectively, ω_o is the material resonance frequency and δ is the damping factor. The frequency dependence in the dispersion relation is accommodated in the time domain model through an auxiliary differential equation relating the electric flux density to the field intensity. A symmetric AlGaAs-based dielectric slab waveguide is considered to test the proposed FDTD algorithm. It consists of a 0.44-μm thick guiding layer sandwiched between two 3-μm thick AlAs layers. The excitation field is a Gaussian-modulated CW signal at a fundamental wavelength of 1.064 μm. The transverse profile of the excitation corresponds to the first guided mode at the given operating frequency. Due to group velocity mismatch (GVM) phenomenon, the power exchange between the propagating input pulse and the generated second harmonic pulse diminishes along the propagation direction as shown in figure 1. Eventually the two pulses seize to interact. This behaviour is very clearly exhibited as the pulse duration is made shorter. The power exchange process becomes similar to the CW case for longer pulses. The generated second harmonic pulse breaks up after propagating a curtain distance along the waveguide. The higher frequency components travel slower and lag the fundamental pulse. This process takes around 40 μm to complete for a 15 fs input pulse, as shown in figure 2.

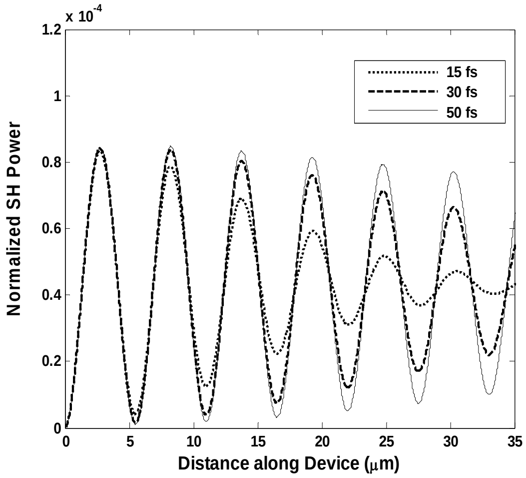

Figure 1. Normalized second harmonic power along the nonlinear, dispersive and lossless waveguide for different initial pulse waists.

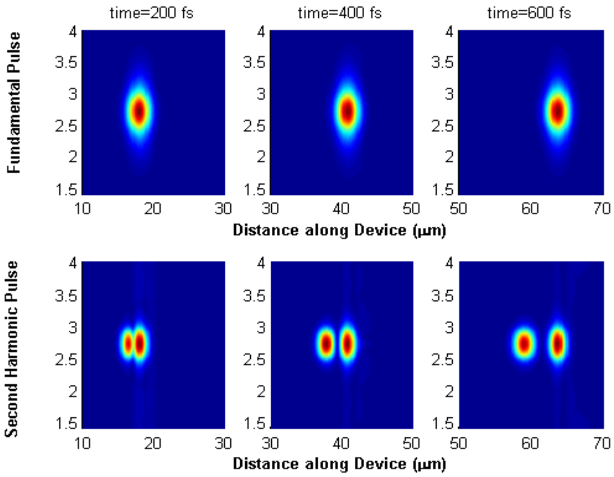

Figure 2. The fundamental and second harmonic fields inside the dispersive nonlinear waveguide. Initial pulse waist is 15 fs.

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