Envelope and phase reconstruction of ultra-short pump lasers by optical rectification measurements

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Abstract: In this paper, we present a technique to retrieve the temporal properties of ultra-short pump lasers by optical rectification measurements. The technique is based on the measurement of the electric field of the THz wave generated by the pump laser. The THz field is characterized by its envelope and phase, which can be retrieved by analyzing the generated THz field at a detector. This work shows that the technique can be used to retrieve the THz field characteristics, which are important for many applications, including THz-based particle acceleration.

Nonlinear wave equation for the THz field generated via optical rectification:

\[ \nabla^2 E_{THz} - \frac{\varepsilon}{c^2} \frac{\partial^2 E_{THz}}{\partial t^2} = \frac{1}{\varepsilon c^2} \frac{\partial^2 P_{OR}}{\partial t^2} \]

Fourier transform with respect of the time variable:

\[ \nabla^2 \mathcal{E}(\omega, z) - \frac{\omega^2 \varepsilon(\omega)}{c^2} \mathcal{E}(\omega, z) = -\frac{4d^2}{c^2} \left( E_p \ast E_p^* \right)(\omega) e^{-\alpha z} \]

The THz electric field as function of the medium optical characteristics:

\[ \mathcal{E}(\omega, z) = \frac{2d^2 \varepsilon(\omega) k(\omega)^3}{\varepsilon_y + i\alpha - k(\omega)} \left( E_p \ast E_p^* \right)(\omega) \]

Generic pump electric field:

\[ E_p(\omega) = E'_p(\omega - \omega_0) \cdot \exp \left[ \frac{1}{2} \left( \frac{(\omega - \omega_0)^2}{\Delta \omega^2} + \frac{1}{3} \left( \omega - \omega_0 \right)^3 \right) \right] \]

Correction to transfer function for the reconstruction:

\[ TF_{\text{corr}} = r \cdot TF_{\text{meas}}(\omega, z) \times TF_{\text{pump}}(\omega) \times TF_{\text{det}}(\omega) \times TF_{\text{z}}(\omega, z) \]

By modulating the electric field of the THz wave it is possible to retrieve the intensity profile and the phase of the pump laser. We test our technique on the experimental results of Ref [6,7] where Terahertz spectrum emitted by DAST, DSTMS and OH1 were measured (THz Michelson interferometer).

THz shaping

By modulating the non-linear phase of the pump laser field it is possible to dynamically modulate the polarization of the THz electric field. This technique is particularly useful for THz-based acceleration processes. Simulation of a single-cycle THz pulse using a laser pump of: λ=1000nm, 100 fs FWHM and a crystal of DSTMS 1mm thick.

Conclusion: We have presented a non-intersecting, single-shot technique to retrieve the temporal profile of ultra-short pump lasers (100 fs and below) used to produce THz pulses via OPC. We have shown experimental examples of THz production and how to reconstruct the pump temporal profile and phase. Finally we discussed the effects of the second and third order dispersion of the pump pulse on the THz production and temporal shaping. The shaping of THz pulses could be of great utility for many applications, including the most recent ones related to electron acceleration experiments Ref[10]. Therefore this work paves the way to the possibility dynamically control the acceleration process by opportune shaping the THz field.