Spectral analysis of the optical pulses produced by the interaction of optical and THz pulses in a ZnTe crystal

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***Abstract* — The spectra of the optical pulses generated during the interaction of THz and optical pulses in a ZnTe crystal show that, besides sum and difference frequency mixing, spectral components associated to cross-phase modulation are produced.**

I. INTRODUCTION

Electro-optic sampling (EOS) is a widely used technique for the measurement of the electric field E_{THz} of a terahertz (THz) pulse, with subpicosecond time resolution [1]. The frequency description of EOS indicates that sum (SGF) and difference frequency generation (DFG) processes take place during the interaction between the optical and THz pulses [2]. Furthermore, it was shown [3] that during the interaction of an optical and an intense THz pulse in a <110> cut ZnTe crystal, the optical pulse experiences cross-phase modulation (XPM) resulting in a modification of its spectrum, which depends on the temporal derivative of the THz field. However, such a THz-induced XPM was only recorded at very high THz electric fields amplitudes, in the range of 10^7 $V.cm^{-1}$. We demonstrate hereafter that the evolution of the optical spectrum generated during EOS depends on the delay τ between the optical and THz pulses and can be evidenced for THz electric fields 1000 times smaller than shown previously. This experiment indicates that SFG, DFG and THz-XPM can be simultaneously at play during EOS of THz pulse.

II. EXPERIMENTAL SETUP

An amplified Ti: Sapphire regenerative amplifier yields 1.5 mJ pulses centered at 807 nm, at a 1 kHz repetition rate. The 60 fs pulse duration beam is split into pump and probe beams, respectively. The pump pulse generates an intense, linearly polarized THz pulse spanning the 0.3–7 THz frequency range, and whose amplitude reaches about 80 $kV.cm^{-1}$. It is emitted from air ionized by a two-color femtosecond laser field. This THz field is then collimated and focused onto a 320 µm thick and <110> cut ZnTe crystal by two off-axis paraboloidal mirrors with a 150 mm focal length. Within the ZnTe crystal, the probe and THz pulses propagate collinearly and are polarized along the <001> and <-110> axis, respectively. Without the THz pulse, the probe pulse transmitted by the crystal is blocked by a Glan-polarizer. However, when the probe and THz pulses are temporally and spatially overlapping in the crystal, their interaction within the ZnTe crystal generates a weak optical signal E_s, polarized perpendicularly to the probe field. It is therefore transmitted by the Glan-polarizer and recorded either by a photodiode coupled to a lock-in detection, or an optical spectrometer. A delay stage makes it possible to delay in time the probe and THz pulses.

III. RESULTS

We measured the evolution of the signal recorded by the photodiode as a function of the intensity of the THz electric field. It was found linear, which ensures that the signal transmitted by the Glan-prism results from EO interaction of the optical and THz pulses within the ZnTe crystal. Then we recorded the spectrum of this signal versus the delay τ: the evolution of some spectral components that are above or below the central wavelength of the optical pulse ($\lambda_c \approx 807$ nm) are displayed on Fig. 1, as well as $E_{THz}(t)$ (▼) and $\partial E_{THz}(t)/\partial t$ (▼). The temporal evolution of the spectral components close to λ_c is found to directly depend on the amplitude of $(E_{THz}(t))^2$.

However, a sensible deviation with respect to $(E_{THz}(t))^2$ is recorded in time, if one considers the temporal evolution of the spectral components below (Fig 1-a) or above (Fig. 1-b) λ_c. The maximum in amplitude for lower (resp. larger) wavelength components is shifted towards earlier (resp. later) time delay, with respect to the maximum of $E_{THz}(t)$. Such a trend is expected if the optical probe pulse experiences the cross-phase modulation induced by $E_{THz}(t)$ during its interaction with the THz pulse in the ZnTe crystal. However, the maximum of the THz cross-phase modulation is expected when the $\partial E_{THz}(t)/\partial t$ is maximum [3]. As shown in Fig. 1, that is not exactly the case in our experiment. We will show that SFG, DFG and THz-XPM may contribute together to the generation of these different spectral components, and detail their evolutions versus τ. This demonstrates that all these nonlinear processes may be recorded during conventional EOS of THz pulses.

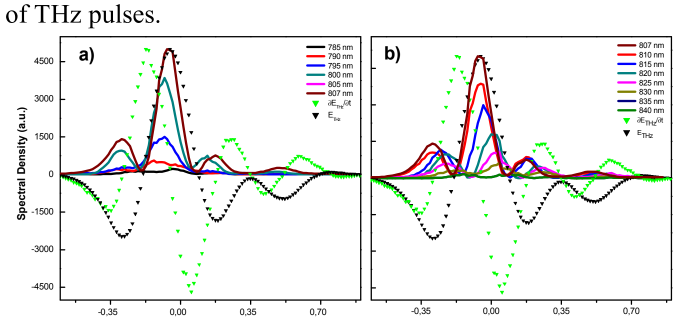

Fig. 1: Evolution of the optical spectral amplitude at different wavelengths **a)** below and **b)** above the central wavelength 807 nm, as a function of the time delay between the probe and the THz pulses. Comparison with $E_{THz}(t)$ and $\partial E_{THz}(t)/\partial t$.

REFERENCES

[1] Q. Wu and X.C. Zhang, "Ultrafast electro-optical field sensors," Appl. Phys. Lett, **68**, 1604-1606 (1996)

[2] G. Gallot and D. Grischkowsky, "Electro-optic detection of terahertz radiation," J. Opt. Soc. Am. B. **16**, 1204–1212 (1999)

[3]. Y. Shen, T Watanabe, D.A. Arena, C.C. Kao, J.B. Murphy, T.Y. Tsang, X.J. Wang and G.L.Carr, "Nonlinear cross-phase modulation with intense single-cycle terahertz pulses", Phys. Rev. Letters, Vol. **99**, 043901-043904 (2007)