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Wavelength scaling of THz emissions by two-color filaments in air

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Producing terahertz (THz) radiation by ultrashort laser pulses has become an active field of research because of its promising applications in, e.g., spectroscopy and medical imaging [1]. Efficient THz emitters can be obtained by focusing into air a two-color femtosecond light pulse, composed of fundamental (FH) and second (SH) harmonics, in order to create a plasma channel that acts as a frequency converter [2]. Recent studies [3,4] showed that increasing the pump wavelength enhances the THz energy. However, there is no consensus on the gain factors expected when pushing the FH wavelength, λ_0 , from the near-IR to the mid-IR range. Clerici *et al.* [3] reported THz energy yields scaling like $\lambda_0^{4.6}$ in the range 0.8 - 1.8 μm . By contrast, according to the local-current model [2,4], the largest THz energy attained by two colors with $\pi/2$ relative phase should follow a scaling in λ_0^2 only.

Here we address this apparent contradiction by performing two distinct experiments scanning the wavelength range 1.2 - 2.6 μm . The experimental campaigns used two different OPA systems (TOPAS). Figure 1(a) summarizes the THz signals recorded with a pyroelectric detector. Despite the different wavelength ranges investigated, the fitting curves of this figure underline impressive growths in λ_0^α with powers α not only exceeding ~ 4.6 [3], but also reaching up to almost 15 in the highest wavelength ranges. We also observe a decrease in the pyroelectric signal beyond specific λ_0 values, which may indicate some optimum wavelengths where maximum THz generation is achieved. Such a behavior is present in the data points of Ref. [3] as well, recalled by the gray symbols and line.

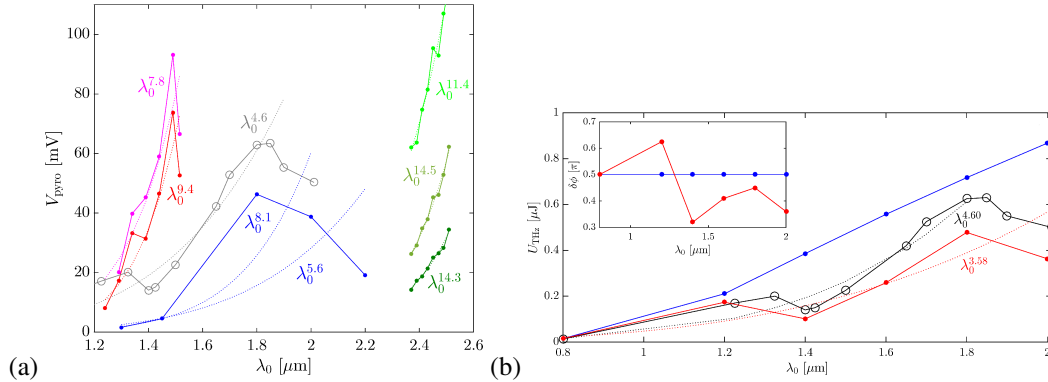


Figure 1 (a) Pyroelectric detector signals vs FH wavelength in the frequency window $\nu < 20$ THz for the two experimental campaigns. The average input power of the pump beam is constant for each curve, namely, 720-840 mW (red), 300 mW (blue), 348-420-558 mW (green curves). Dotted curves are fitting curves in λ_0^α . Gray circles recall the data of Ref. [3]. (b) THz energy yield computed with the 3D UPPE model (red dots) for the experimental data of [3] (black circles) with the initial phase shifts specified in inset. The blue curve is associated to $\pi/2$ phase angle at the exit of the doubling crystal.

Here we show that such impressive growths can be explained by changes in the laser parameters as the FH wavelength is increased. Comprehensive 3D simulations combining both computations of the SH/FH energy ratio from the doubling crystal and a unidirectional numerical solver [6] are performed using the experimental values of the beam diameters and pulse durations. They reproduce reasonably well the behaviors of THz energies reported from the experiments, that is, not only a global growth in $\sim \lambda_0^\alpha$, but also the occurrence of optimum FH wavelengths beyond which efficiency in THz generation drops [Fig. 1(b)]. We demonstrate that the latter effect strongly depends on the phase angle between the two colors exiting the crystal, which varies with λ_0 for a fixed distance separating the plasma zone from the doubling crystal. In particular, drops in the THz signal around specific wavelengths ($\lambda_0 = 1.4$ and 2.0 μm) are due to variations in the relative phase. A constant phase angle of $\pi/2$ at the crystal exit renders the THz energy increase monotonous (blue curve).

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