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THz emissions by two-color filaments in air: Revisiting the wavelength scaling

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Abstract: We report impressive growths in the terahertz energies supplied by air plasmas created by two-color laser pulses whose fundamental wavelength is increased. Comprehensive 3D simulations reveal the crucial role of the two-color relative phase.

OCIS codes: (320.7110) Ultrafast nonlinear optics; (350.5400) Plasmas; (260.3090) Infrared, far.

1. Introduction

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.

2. Experimental campaigns vs numerical simulations

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.

We show that such impressive growths can be explained by changes in the laser parameters as the FH wavelength is increased [5]. 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 $2.0 \mu\text{m}$) 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).

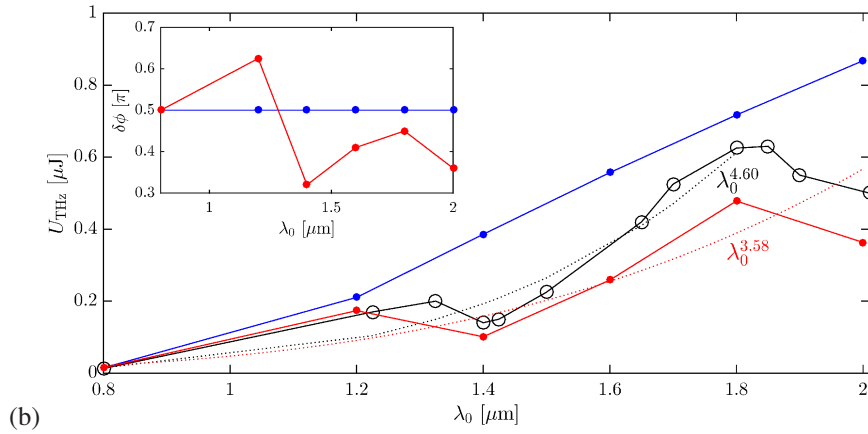
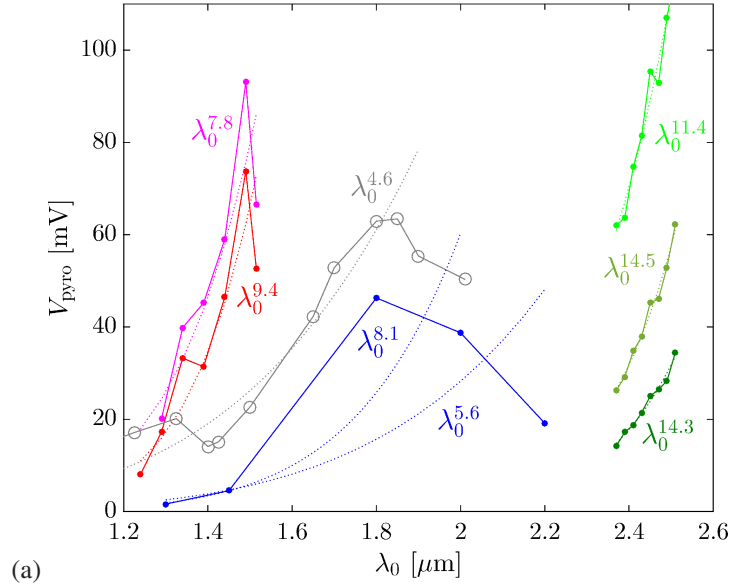


Fig. 1. (a) Pyroelectric detector signals vs FH wavelength in the frequency window $\nu < 20$ THz for the two experimental campaigns. The average input power of the pump beam is constant for each curve, namely, 720-840 mW (red/pink curves), 300 mW (blue curve), 348-420-558 mW (green curves). Dotted curves are fitting curves in λ^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.

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