Terahertz pulse generation by multi-color laser fields with linear vs. circular polarization

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Terahertz (THz) radiation produced by ultrafast laser sources has recently become a hot topic with many innovative applications in molecular spectroscopy, medical imaging or homeland security [1]. Efficient THz emitters can be obtained by focusing into air a 2-colors femtosecond light pulse, composed of fundamental (FH) and second (SH) harmonics, in order to create a plasma spot that acts as a frequency converter [2].

On the one hand, recent studies [3,4] showed that increasing the number of laser harmonics (called colors) until shaping the laser temporal profile with a sawtooth waveform can lead to noticeable enhancement in the laser-to-THz conversion efficiency driven by photocurrents. On the other hand, changing the polarization state of the FH and SH components can also improve the THz performances of laser-plasma emitters. In particular, it was experimentally evidenced [5] that circularly-polarized 2-colors pulses with same helicity (CP-S) can deliver $\sim 3-5$ times higher THz powers than their linearly-polarized, parallel pulses (LP-P). In [6], theoretical evaluations showed that the direct dependency of the drift velocity acquired by photo-ionized electrons on the FH pump amplitude and longer ionization sequences explain this increase in THz power, which is refound below in Figs. 1(a,b) from a local current model and in Fig. 1(e) (dashed curves) from comprehensive 3D computations.

Here we combine the advantages of adding more colors (up to 10) arranged within a sawtooth wave shape and circular polarization to achieve much higher THz energy yields. In air, whose ionization of O_2 molecules saturates early along the pulse history, we report gain factors > 4 by using 10-colors LP-P sawtooth field and > 2 reached by 10-colors CP-S sawtooth pulses compared with their 2-colors counterparts [see Figs. 1(c,d) and 1(e)]. Surprisingly, the LP-P fields become more efficient than CP-S ones by increasing the number of colors above 6, which we attribute to larger electron drift velocities acquired at the ionization instants.

Figure 1 Electron density N_e/N_a (black curves), laser fields E_L/E_{max} (blue, red curves), electron drift velocity at ionization times (blue, red dots) and THz energy (green curves) versus time for 2-colors (a) LP-P; (b) CP-S pulses, and 10-colors (c) LP-P and (d) CP-S pulses ionizing air with 200 TW/cm^2 intensity, 1600 nm FH and 50 fs FWHM (local current model). Quantities are normalized to their maximum at constant number of colors [$E_{max} = 45$ and 64 GV/m in (a,b) and (c,d), respectively; $N_a = 5.4 \times 10^{18} \text{ cm}^{-3}$]. (e) shows the THz energy yield obtained from 3D unidirectional computations for the same pulses.

These performances being sensitive to the ionization dynamics, we shall address pulse configurations leading to different ionization yields, including those of nitrogen, argon, helium, and their multiply ionized states.

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