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Published in:
EPJ Web of Conferences

Link to article, DOI:
10.1051/epjconf/201819503011

Publication date:
2018

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):

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Resonant Effects in Terahertz Generation with Laser-Induced Gas Plasmas

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Research on intense terahertz (THz) electromagnetic sources has received an increasing attention owing to numerous applications, for example, in time-domain spectroscopy, biomedical imaging or security screening [1]. Among the various techniques employed to generate THz radiation, focusing intense two-color femtosecond pulses in air or noble gases provides interesting features like absence of material damage, large generated bandwidth (up to ~100 THz) and high amplitudes of the emitted THz pulses (> 100 MV/m) [2]. First reported by Cook et al. [3], THz emission from intense two-color pulses was initially attributed to optical rectification via third-order non-linearity. However, it was shown later that the plasma built-up by tunneling photoionization is necessary to explain the high amplitudes of the THz field [4], and a quasi-de plasma current generated by the temporally asymmetric two-color field is responsible for THz emission [5].

Numerous experimental results show that the laser-induced free electron density has a strong impact on the THz emission [4,6,7]. While it is frequently observed that a larger free electron density leads to broader THz spectra, the origin of the effect remains controversial. In [6,7], homogeneous plasma oscillations were proposed as an explanation, even though those oscillations are in principle non-radiative [8,9]. Moreover, nonlinear propagation effects have been held responsible for THz spectral broadening as well [10].

On the other hand, the gas plasma produced by the fs laser pulse is a finite conducting structure with a lifetime largely exceeding the fs time scale. Thus, one can expect that the gas plasma features plasmonic resonances which may have a strong impact on the THz emission profile [11]. However, no direct evidence of plasmonic effects in laser-induced gas-plasmas was observed so far: To make an evidence of plasmonic effects, those need to be distinguished from nonlinear propagation effects. Also from the theoretical point of view capturing plasmonic effects is not trivial: plasmonic effects require at least a full two-dimensional Maxwell-consistent description, and reduced models like the unidirectional pulse propagation equation [12], which are frequently used to describe plasma-based THz generation [5,7,10], are by construction not capable of capturing such resonant effects.

In this work, we consider the two-color-laser-induced plasma as a plasmonic structure, and investi-
Fig. 2. Experimental THz spectra for qTE (a) and qTM (b) polarization (see text for details). Corresponding on-axis THz waveforms are shown as insets. The dashed lines specify the estimated maximum plasma frequency.

References