Plasmonic resonances affecting terahertz generation in laser-induced gas-plasmas

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Abstract— We demonstrate that plasmonic resonances can be used to broaden the terahertz emission spectrum from two-color laser-driven gas-plasmas. This effect can be controlled by changing the polarization properties of elliptically shaped driving laser-pulses.

I. INTRODUCTION

TERAHERTZ emission from two-color laser-induced gas-plasmas provide the possibility to generate effectively ultra-broadband THz pulses. By focusing two-color laser pulses composed of the fundamental and second harmonic frequency into a gas, a plasma is generated. The free electrons are accelerated in the electric field and produce a current leading to ultra-broadband THz emission.

Previous experiments have shown that the emission spectrum can be tuned by changing the gas pressure [1-3]. This effect is related to the generated electron density n_e in the plasma and it was proposed that the resonant excitation of plasmon polaritons (PPs) at specific frequencies can explain the broadening of the THz emission spectrum [4].

Fig. 1. THz emission from an ellipsoidal plasma (blue disc) induced by a two-color laser pulse. (a) Illustration of qTE polarization, (b) qTE spectrum, (c) illustration of qTM polarization, (d) qTM spectrum.

In this work, we consider elliptically shaped driving laser beams, which create plasmas with elliptically shaped transverse free electron density profiles, to control the excitation of plasmon resonances in the plasma. Depending on whether the laser polarization is oriented along the long beam axis (quasi transverse electric, qTE) or along the short beam axis (quasi transverse magnetic, qTM), plasmon-polariton-like resonances are triggered or not.

II. RESULTS

Based on 3D Maxwell simulations of strongly focused beams that produce micro plasmas, we show that the plasmonic resonances lead to a broadening of the spectrum. Figure 1 illustrates the ellipsoidal plasma (blue disc) induced by the two-color laser field (FH in red, SH in purple) and the two different situations for (a) qTE and (b) qTM polarization. We find dramatic differences in the waveforms which are presented as white lines in Fig. 1(a,c) demonstrating a significant shorter pulse duration for qTM polarization. Accordingly, the spectrum for qTM polarization is broadened up to 50 THz, which corresponds to the maximum plasma frequency $\nu_p^{\max} \propto \sqrt{n_e}$, while for qTE polarization no such broadening is found (Fig. 1(b,d)).

Furthermore, we demonstrate experimentally that this effect can also be observed under weaker focusing conditions and with longer plasmas. Therefore, we use a Ti:sapphire amplified laser system which produces laser pulses of 40 fs duration at 800 nm with 1 kHz repetition rate. The pulses become elliptically shape employing a pair of cylindrical lenses, they are focused by a lens and frequency doubled by a BBO-crystal. By rotating both cylindrical lenses we switch between the qTE and qTM polarization. The transients are recorded by using the air-biased coherent detection scheme [5]. The measured THz pulse duration for qTM is about 1.6 times shorter than for qTE and in agreement with the theoretical results, the qTM spectrum is significantly broader than the qTE spectrum. Thus, our experimental results support the hypothesis that plasmon-polariton-like resonances broaden the THz spectrum.

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