THz generation at optical breakdown of gases by two-color laser fields: one more demonstration of the SFA insufficiency

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Abstract

We present the results of theoretical and experimental study of THz generation at optical breakdown of gases by two-color laser pulses. It is shown that, in contrast to the predictions of strong-field approximation, the optimal phase shift between components of a two-color laser field is dependent on the laser intensity. This dependence is explained by taking into account the Coulomb interaction between the detached electron and the parent ion.

Terahertz radiation (THz) is of interest thanks to its applicability for identification of substances, biomedical diagnostics, tomography, security, etc. Optical methods are now widely used for THz generation with the use of femtosecond laser pulses whose peak intensity is sufficient for the optical breakdown of a gas. Terahertz radiation generated in such schemes is a subpicosecond pulse with the waveform of the electric field that contains only one or two oscillations and has a very broad spectrum. Here we will focus on the most popular and efficient two-color scheme, in which the gas is irradiated by a combination of the laser fields at the fundamental frequency and its second harmonic.

The frequency conversion in the plasma-based sources is closely related to the excitation of macroscopic quasi-dc currents whose excitation efficiency determines to a large degree an efficiency of the generation of THz waves. The well-known photocurrent model [1, 2] explains the mechanism of ionization-induced directional macroscopic currents in gases on the basis of strong-field approximation (SFA). This model predicts strictly defined optimal phase shift of the second harmonic with respect to the fundamental frequency component of a two-color field. However, in different independent experiments and numerical calculations, different values of the optimal phase shift were obtained [1-5].

The above-mentioned conflicting results lead to the conclusion that a simple picture of the mechanism of a directional current generation given on the basis of SFA is not accurate enough missing some fundamentally important factors. Among these factors may be the effect of the Coulomb potential of the parent ion on the escaping electron. Actually, after escaping from the well, the electron continues to be influenced by the Coulomb potential, which can lead to an additional change in the electron drift velocity.

In [6] we have theoretically shown that Coulomb effects actually change the optimal phase between the fundamental field and its second harmonic in the two-color scheme of THz generation. We have demonstrated that, in contrast to the SFA predictions, this phase strongly depends on the laser intensity. More recently, we have performed experimental study to address the laser intensity dependence of the above-mentioned optimal phase shift [7].

Figure 1 provides a comparison of our experimental and theoretical curves for the optimal phase shift vs. the laser intensity. Good agreement between experimental and theoretical results in a wide intensity range indicates that the optimal phase shift can indeed be interpreted as the manifestation of the Coulomb interactions in laser ionization of gas particles.

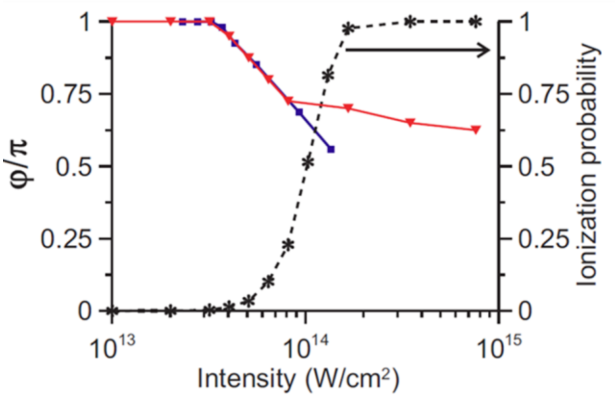

Fig. 1. Optimal phase of the second harmonic versus the intensity of a two-color laser pulse: numerical calculations (red line) and experimental data (blue line) are presented. Black dashed line presents the probability of gas ionization during the pulse.

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