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Modulation of two-color laser-induced filament terahertz emission by effective length variation

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Terahertz (THz) radiation is of great scientific interest for its applications in spectroscopy and imaging [1]. Terahertz generation in femtosecond filament in gases has the specific features as compared with other THz sources [2, 3]. As the gaseous media are self-healing, one can use high-energy laser pulse focusing into small volumes without concern about material damage. Here one of the most effective ways to produce THz radiation is to use two-color (usually fundamental and second harmonics of fs-laser) laser pulse focusing for plasma creation [3]. However, in this case the efficiency of optical-to-terahertz conversion is highly dependent on mutual phase difference between harmonics. Moreover, for long filaments this difference varies along plasma channel. It has been demonstrated previously that this effect leads to off-axis peak in spatial THz distribution [4] and to possibility of waveform control by initial phase shift adjustment between harmonics [5]. In atmospheric air the distance for π phase walk-off between fundamental and second harmonic of Ti:Sapphire laser is about 25 mm.

In this paper, we show strong influence of phase matching between harmonics on overall THz power output and demonstrate that screening of a part of THz emission allows increasing the output power up to 20% of that for undisturbed emission. We also demonstrate the possibility of spectral modulation by means of π-retarder screens for a distinct THz frequency.

We use Ti:Sapphire laser system with following characteristics: 800 nm central wavelength, 40 fs pulse duration, 2.8 mJ pulse energy, ∅12 mm ($1/e^2$ level), 1 kHz repetition rate. A Glan-Taylor polarizer with a half-wave plate to control laser pulse energy is used.

A lens (∅25.4 mm, 1000 mm focal length) focuses laser radiation to create a filament in ambient air. A BBO crystal (SHG, 10x10x0.2 mm^3, I-type) converting part of radiation into second harmonic is placed on the optical pump path before the plasma. After the SHG a group delay compensator plate (TP) and a dual-wave plate (λ/2@800 nm+λ@400 nm) may be placed to provide more powerful THz generation due to use of collinear polarizations of harmonics in two-color pulse. The SHG and plates are mounted on a moving table to change air path of two-color pulse before the filament and so the initial phase difference between harmonics.

To collect THz radiation a system of two PTFE-lenses (first: ∅50 mm, 150 mm focal length; second: ∅50 mm, 100 mm focal length) is used. Laser pulse duration is lengthened up to ~120 fs by adding positive chirp to maximize THz output [6]. The length of visible plasma string is approximately 80 mm for maximal laser pulse energy of 2.3 mJ.

A metallic iris diaphragm with a ~1 mm diameter aperture centered at filament is mounted to screen THz radiation emitted before its position. Another moving table is utilized to control the position of the iris along the filament. Corresponding scheme is de-

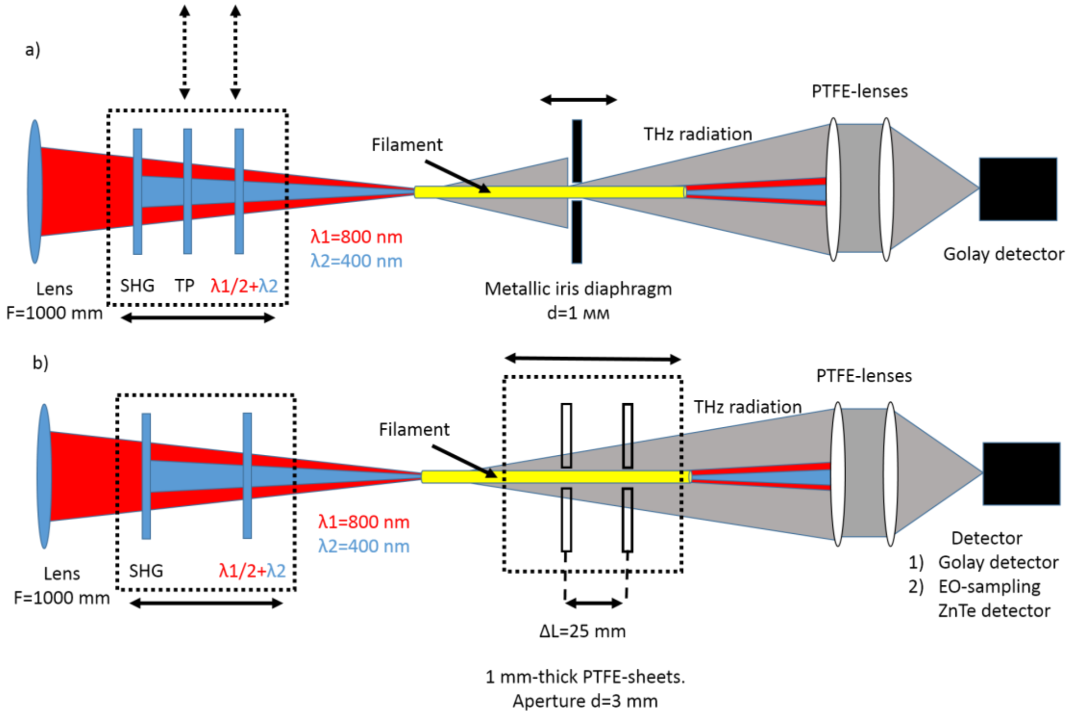

Fig. 1. Experimental schemes for: **(a)** screening of a part of the THz radiation with a metallic iris diaphragm; **(b)** spectral modulation by π-retarder PTFE-screens.

picted on Fig.1 (a).

The second thing we want to realize is spectral and spatial modulation of the emitted THz radiation. The idea is to make the THz emission collected by PTFE-lenses from all the points along filament interfere constructively for a distinct THz frequency. So one need to insert additional π-retardation for the part of the THz radiation that has previously interfered destructively. Ideally, there should be also a non-zero on-axis value in THz power distribution in this case. Thus, instead of the metallic iris diaphragm we place a 1 mm-thick (π-retardation for ~0.7 THz) PTFE-sheet with ~3 mm diameter aperture or a set of 2 such screens with a 25 mm distance between them (the distance corresponding to π walk-off in the air). Scheme is depicted on Fig.1 (b).

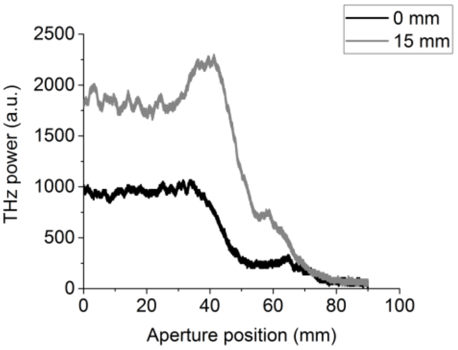

Fig. 2. Terahertz power dependence on iris diaphragm position along the filament created by 2.3 mJ laser-pulse for two positions of second harmonic crystal (SHG).

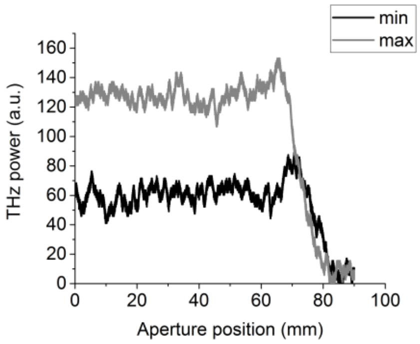

Fig. 3. Terahertz power dependence on iris diaphragm position along the filament created by 1.0 mJ laser pulse for two positions of second harmonic crystal (SHG).

For THz power measurements, a Golay cell (Tydex GC-1P) is used. For THz field measurements a standard electro-optical sampling scheme with ZnTe crystal (3x3x1 mm^3, <110> cut) is applied.

We measure THz power dependence on the iris diaphragm position along the two-color filament for different laser pulse energies from 1.0 to 2.3 mJ and for different initial phase difference between fundamental and second harmonics (SHG positions). We see strong influence on overall THz power due to constructive and destructive interference of THz emission from different parts of filament. For optimal initial phase and screening diaphragm position one can achieve significant increase in THz power. Examples of such dependencies for 2.3 mJ laser pulse with co-polarized harmonics are given on Fig. 2.

However, for short filament (low laser pulse energy) the effect of phase walk-off along plasma channel is sufficiently decreasing. See dependencies for 1.0 mJ laser pulse with co-polarized harmonics on Fig. 3.

For the experiment on spectral modulation, we collected waveforms of THz pulses and THz power value for different positions of π-retarder screen/set of screens. Thereafter waveforms are processed with fast Fourier transform to get spectra of THz pulses. Here one can see significant narrowing of spectrum for some position of the screens with peak amplitude on 0.7 THz frequency, that corresponds to the thickness of the PTFE-sheets used. There is also a bright peak on the doubled frequency ─ 1.4 THz. However, spectral change is accompanied with a dramatic drop in emitted THz power, so that even the amplitude on peak frequency is lower than that in spectrum with no screens placed. On Fig. 4 are given spectra of THz pulses for different positions of the set of two PTFE-screens: 0 mm position corresponds to undisturbed emission (screens placed before the whole filament), 40 mm position corresponds to significant influence of the π-retarders on emitted THz radiation.

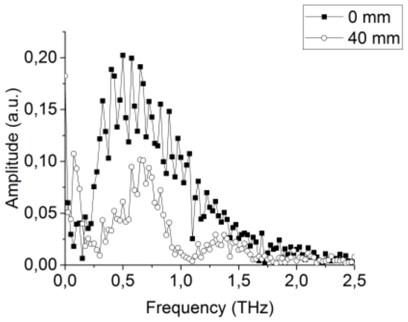

Fig. 4. Terahertz pulse spectra for two PTFE-screens positions.

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