Toward Standoff Distance Terahertz Wave Sensing

Jianming Dai[a], Nicholas Karpowicz[a], Qian Song[a, b], Cunlin Zhang[b], and X.-C. Zhang[a]
[a] Rensselaer Polytechnic Institute, 110 8th Street, Troy, NY 12180, USA
[b] Capital Normal University, No. 105 XiSanHuan BeiLu, Beijing 100037, China

***Abstract*—For standoff distance terahertz wave generation by mixing a 800 nm pulse and its second harmonic (400 nm) in air, a phase compensator, incorporated with a small-angle wedge pair, is used to pre-compensate the temporal walk-off between the 800 and 400 nm pulses due to the normal dispersion of the ambient air. With the phase compensator, we are able to generate intense terahertz waves by sending the two optical pulses 116 meters away and focusing them locally.**

I. Introduction And Background

As a promising nonlinear optical medium, femtosecond-laser-induced plasma in gases has been studied intensively over the past several years. It is not only used to generate tunable ultrashort laser pulses and coherent, extreme, ultraviolet radiation via phase-matched high-order difference-frequency mixing [1, 2], but also used to generate, and amplify, and detect terahertz (THz) waves [3-10]. Recent studies show that, using air as both THz wave emitter and detector with heterodyne detection, we can achieve extremely broad THz bandwidth covering the entire THz gap. The bandwidth is only limited by the femtosecond pulse duration [11, 12]. One of the potential applications of using air as the THz emitter and detector is THz wave remote sensing and identification by sending optical beams instead of a THz beam to the target and generating and detecting the THz wave remotely, utilizing the lower attenuation at the visible range (<0.01 dB/km) from air. However, due to the normal dispersive nature of the ambient air, the 800 and 400 nm pulses will temporally walk off with the 800-nm pulse leading after they travel in the atmosphere. Therefore, a phase compensator with high stability and precise tunability is necessary to compensate this temporal walk-off.

II. Results

Experimentally, a Ti:sapphire regenerative amplifier is used as the femtosecond laser source. The phase compensator is essentially based on a Michelson interferometer, similar to the configuration described in reference [13]. However, instead of directly changing the phase delay between the fundamental pulse (ω) and its second-harmonic (2ω) through a piezo translation stage, we used a pair of fused silica wedges with wedge angle of 2.8 degrees as the delay line. By changing the insertion of one of the wedges, the relative phase can be more precisely controlled, as illustrated in Fig. 1. The THz signal was measured by monitoring the peak THz signal of the THz time-domain waveform while scanning the relative phase between ω and 2ω. Fig. 2 shows the THz signal versus the relative phase (i.e. a phase scan). In Fig. 2, the step size of the phase delay is 0.055π (corresponding to 11.1 nm in space or 37 attoseconds in time).

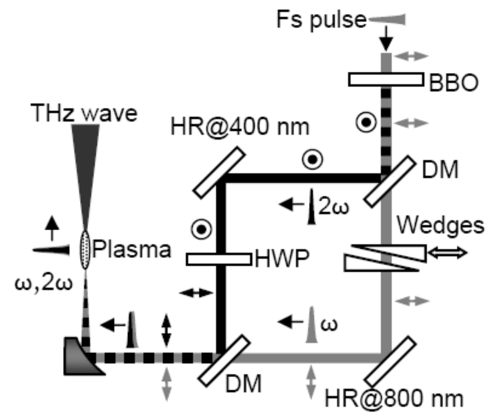

Fig. 1. Schematic illustration of the phase compensator incorporated with a wedge pair: DM, dichroic mirror used to separate or re-combine ω and 2ω beams; HWP, half wave plate used to control the polarization of the 2ω beam.

The capability of precise phase control enables us to generate intense THz waves at standoff distances by simultaneously sending ω and 2ω pulses over 116 meters away and focusing them locally using a parabolic mirror with an effective focal length of 8 inches. Fig. 3 shows phase scans at different optical distances obtained by scanning the relative phase between ω and 2ω pulses while monitoring the THz average power with a pyroelectric detector.

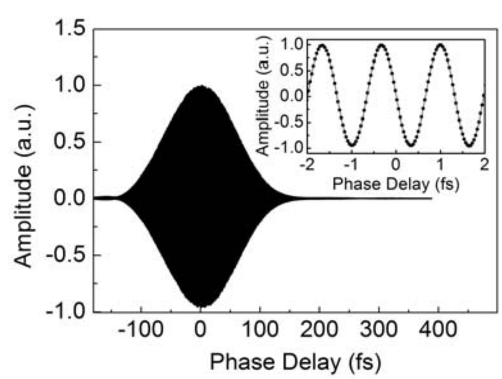

Fig. 2. Phase scan obtained by continuously changing the insertion of the fused silica wedge pair. The inset shows a zoomed-in portion of the phase scan.

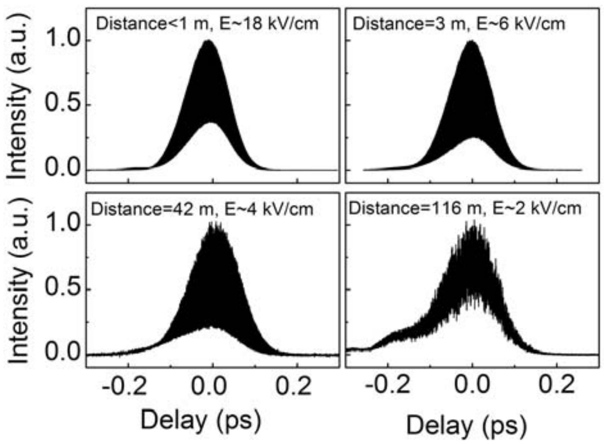

Fig. 3. Phase scan at different distances obtained by continuously changing the insertion of the fused silica wedge pair while monitoring the THz average power with a pyroelectric detector. The optical beams (ω and 2ω) are focused locally with an 8-inch parabolic mirror after traveling in the air at different distances.

Fig. 4 shows a typical THz waveform generated at a distance of 116 m with local electro-optic detection using a 0.3-mm GaP crystal. The inset in Fig. 4 shows the corresponding spectrum. The experimental result shown in Fig. 4 indicates that the peak signal/noise ratio can still be greater than 100, despite of the strong air turbulence existing in the experimental environment.

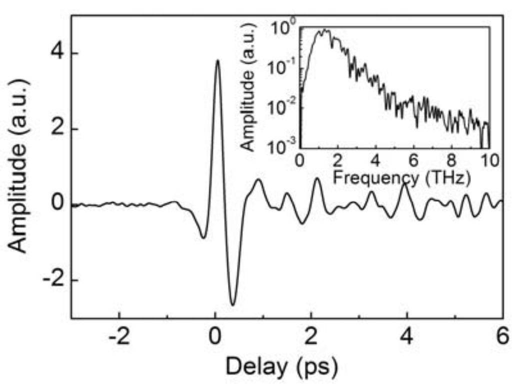

Fig. 4. THz waveform and spectrum (inset) generated by sending ω and 2ω beams about 116 meters away and focusing them locally using a parabolic mirror with a focal length of 8 inches. The peak signal/noise ratio of the spectrum can still be over 100.

These results verified the feasibility of remote generation of broadband intense THz waves using air or laser-induced air plasma as the emitting medium, which is one of most important steps toward standoff THz sensing and identification.

REFERENCES

[1] F. Théberge, N. Aközbek, W. Liu, A. Becker, and S. L. Chin, "Tunable ultrashort laser pulses generated through filamentation in gases", *Phys. Rev. Lett.* **97**, 023904 (2006).

[2] S. Meyer, H. Eichmann, T. Menzel, S. Nolte, and B. Wellegehausen, "Phase-matched high-order difference-frequency mixing in plasmas", *Phys. Rev. Lett.* **76**, 3336 (1996).

[3] T. Bartel, P. Gaal, K. Reimann, M. Woerner, and T. Elsaesser, "Generation of single-cycle THz transients with high electric-field amplitudes", *Opt. Lett.* **30**, 2805 (2005).

[4] H. Hamster, A. Sullivan, S. Gordon, W. White, and R. W. Falcone, "Subpicosecond, electromagnetic pulse from intense laser-plasma interaction", *Phys. Rev. Lett.* **71**, 2725 (1993).

[5] S. Tzortzakis, G. Méchain, G. Patalano, Y.-B. André, B. Prade, M. Franco, A. Mysyrowicz, J.-M. Munier, M. Gheudin, G. Beaudin, and P. Encrenaz, "Coherent sub-terahertz radiation from femtosecond infrared filaments in air", *Opt. Lett.* **27**, 1944-1946 (2002).

[6] D. J. Cook, and R. M. Hochstrasser, "Intense terahertz pulses by four-wave rectification in air", *Opt. Lett.* **25**, 1210-1212 (2000).

[7] M. Kress, T. Töffler, S. Eden, M. Thomson, and H. G. Roskos, "Terahertz-pulse generation by photoionization of air with laser pulses composed of both fundamental and second-harmonic waves", *Opt. Lett.* **29**, 1120-1122 (2004).

[8] T. Löffler, M. Kress, M. Thomson, and H. G. Roskos, "Efficient Terahertz Pulse Generation in Laser-Induced Gas Plasmas", *Acta Phys. Pol.* A **107**, 99 (2005).

[9] J. Dai, X. Xie, and X.-C. Zhang, "Terahertz wave amplification in gases with the excitation of femtosecond laser pulses", *Appl. Phys. Lett*. **91**, 211102 (2007).

[10] J. Dai, X. Xie, and X.-C. Zhang, "Detection of broadband terahertz waves with a laser-induced plasma in gases", *Phys. Rev. Lett.* **97**, 103903 (2006).

[11] N. Karpowicz, J. Dai, X.-C. Zhang *et al*, "Coherent heterodyne time-domain spectrometry covering the entire "Terahertz gap", *Appl. Phys. Lett.* **92**, 011131 (2008).

[12] N. Karpowicz, J. Chen, T. Tongue, and X.-C. Zhang, "Coherent millimeter wave to mid-infrared measurements with continuous bandwidth reaching 40 THz", Elec. Lett. **44**, 544 (2008)

[13] X. Xie, J. Dai, and X.-C. Zhang, "Coherent Control of THz Wave Generation in Ambient Air", *Phys. Rev. Lett.* ***96***, 075005 (2006).

978-1-4244-2120-6/08/$25.00 ©IEEE.