“Hearing” Terahertz Electromagnetic Radiation

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I. Introduction

The enhancement of acoustic waves, from audible into the ultrasonic range, is a linear function of the terahertz (THz) intensity incident on a laser-induced plasma, making THz-enhanced acoustics (TEA) useful for THz detection. By using a dual-color laser field to produce the plasma detector, THz spectroscopic information can be encoded into the acoustic emission, making it possible to obtain the electric field profile of the THz pulse by simply “listening” to the plasma at a distance.

II. Goal

- Realize a method for performing remote THz spectroscopy that circumvents high intrinsic water-vapor absorption of THz in air

III. Experimental Method

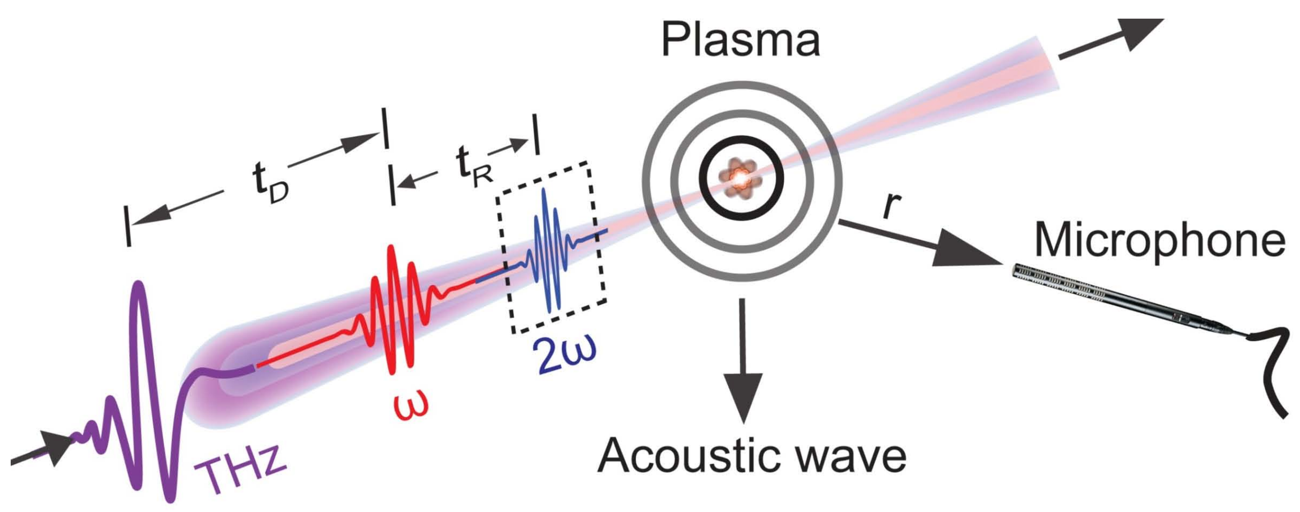

FIG. 1

- A femtosecond laser focused into air forms a plasma
- Nearly instantaneous heating of the gas emits a shock wave
- The shock wave relaxes into an acoustic wave which can be “heard”
- THz and optical pulse delays allow time resolved study of interactions

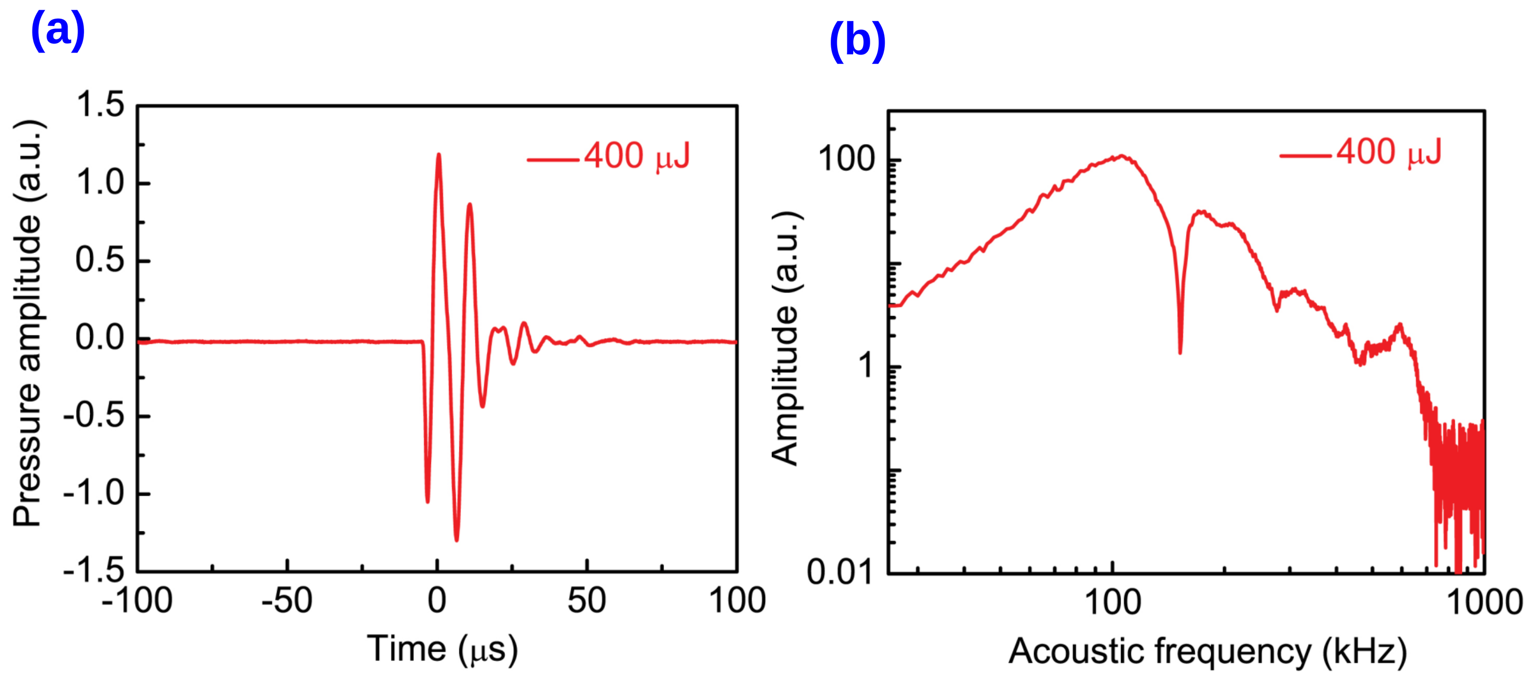

FIG. 2

2(a) Single acoustic pulse emitted from a laser-induced air-plasma.

2(b) Corresponding spectrum after Fourier transformation.

IV. Terahertz-Plasma Interaction

- A broadband THz pulse is focused collinearly onto a laser-induced plasma.
- THz field-induced energy transfer through acceleration of free electrons and the following electron-molecule collisions results in an enhanced acoustic emission from the plasma [1].

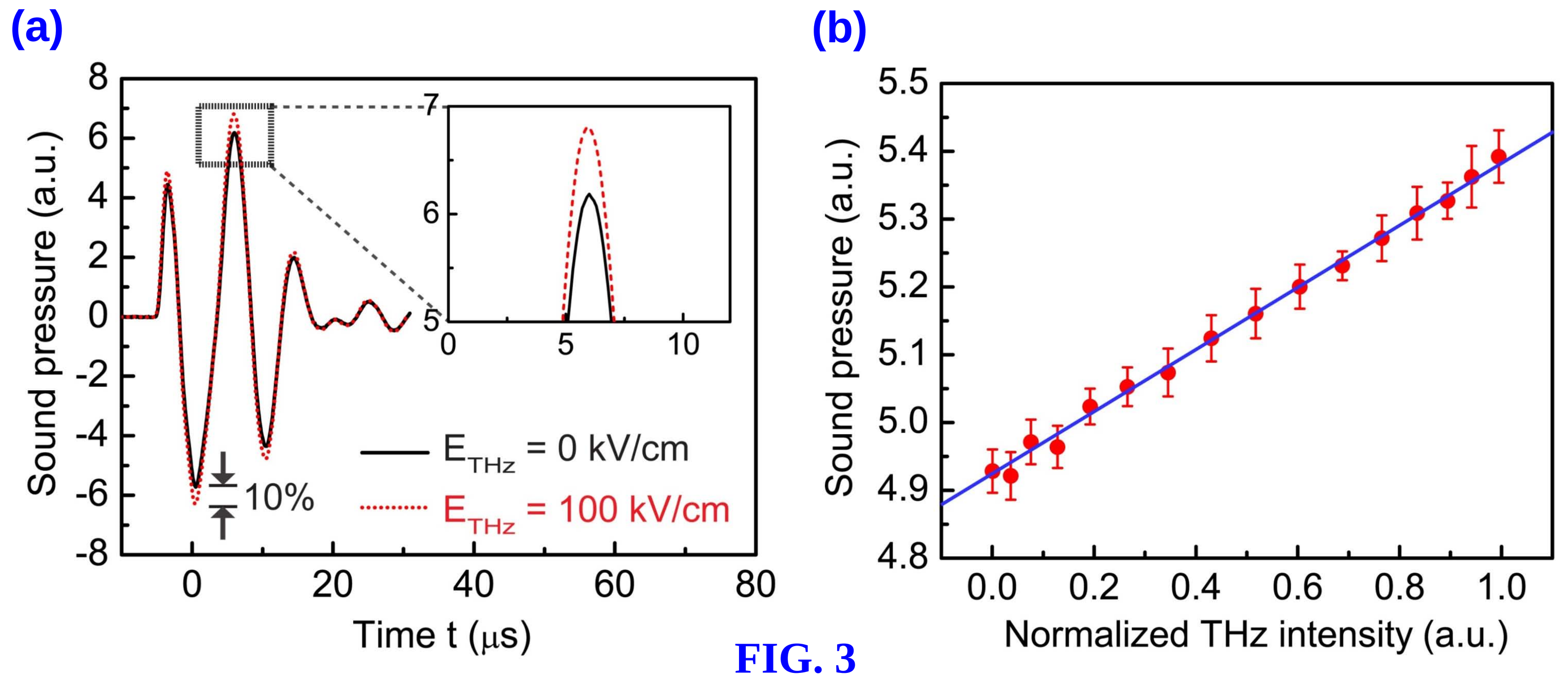

FIG. 3

3(a) Photoacoustic waveforms with and without THz field interaction.

3(b) Acoustic signal at 100 kHz for varied THz intensity incident on the plasma.

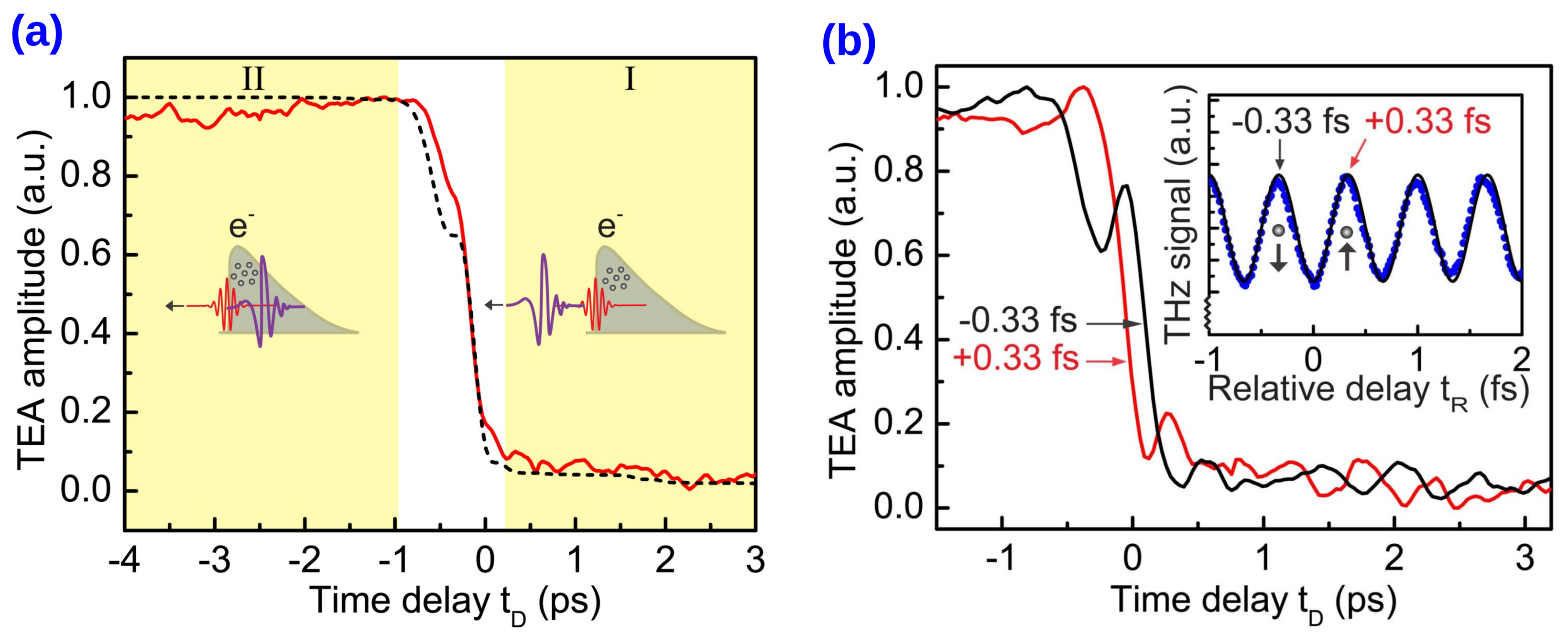

FIG. 4

4(a) TEA signal as the time delay, t_D, between the optical and THz pulse is scanned. Dotted line shows simulated energy transfer.

4(b) TEA signals obtained by scanning the time delay, t_D, for relative delays, t_R, of -0.33 fs, and +0.33 fs between ω and 2ω.

V. Coherent Detection

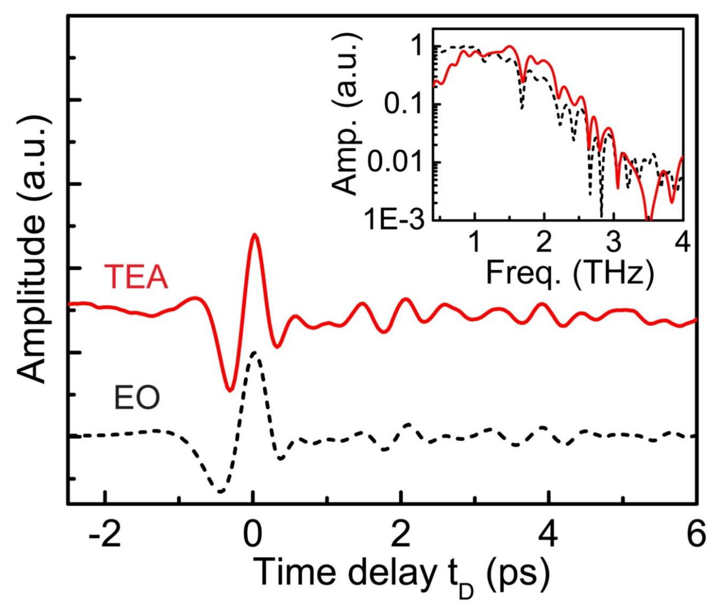

FIG. 5

- Subtracting the curves in **FIG. 4(b)** reveals the temporal THz electric field [2]:

$$E_{THz}(t) \propto \Delta p(-0.33\,fs) - \Delta p(+0.33\,fs)$$

- A dual-color laser-produced plasma allows manipulation of free electron drift
- TEA has the ability to coherently detect THz pulses and is compared with conventional electro optic (EO) sampling.

VI. Remote Sensing

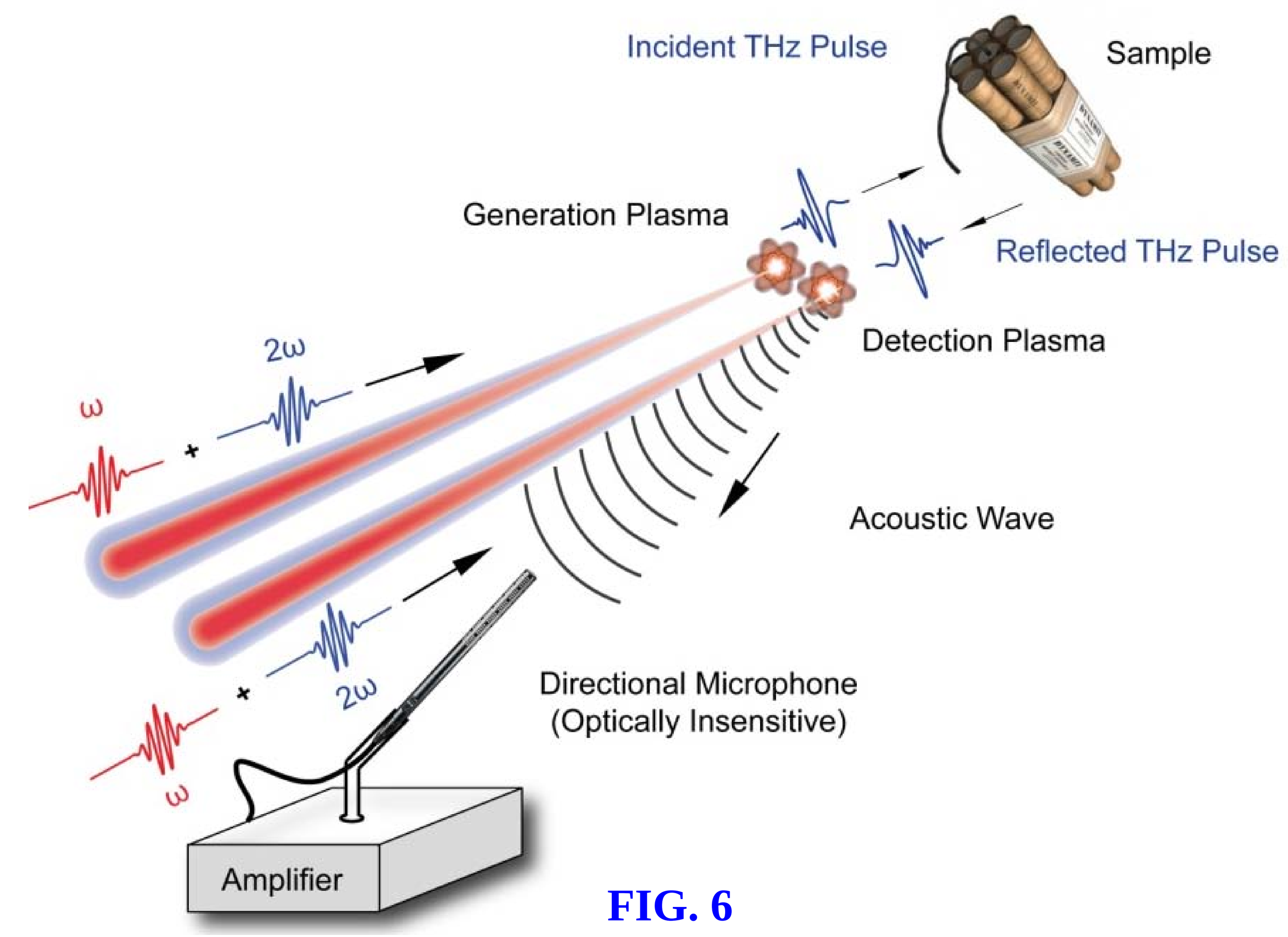

FIG. 6

- Cartoon demonstrating TEA detection at a remote distance

VII. Conclusions

- Acoustic waves from a laser-induced plasma are enhanced under single-cycle THz radiation.
- THz-enhanced acoustics (TEA) emission varies linearly with the THz intensity incident on the plasma.
- TEA can be attributed to THz plasma heating through energy transfer from the THz wave into translational motion of the gas molecules.
- These results provide a promising method for coherent THz wave detection at remote distances.
- This method circumvents the fundamental limitation of high THz absorption by water vapor in air by using acoustics to encode the THz spectral information which can be “heard” at a distance.

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References

[1] Clough, B., Liu, J. & Zhang, X. C. Laser-induced photoacoustics influenced by single-cycle terahertz radiation. *Opt. Lett.* ***35*, *3544-3546 (2010).***

[2] Liu, J., Clough, B. & Zhang, X. C. Enhancement of photoacoustic emission through terahertz-field-driven electron motions. *Physical Review E* ***82*, *066602 (2010).***