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Propagation Property of Femtosecond Laser Pulses in Air

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Abstract

Propagation properties of femtosecond laser pulses in air were investigated with 10fs optical pulses from a Ti:sapphire oscillator and 100fs optical pulses from a Ti:sapphire amplifier, respectively. For the 10fs pulse, the dispersion in the air has a severe effect on the pulse duration due to the broad bandwidth while the 100fs pulse duration does not undergo significant change over its 100 meter propagation in the air.

Introduction

Terahertz time-domain spectroscopy has long been applied in the fields of semiconductor, chemical, and biological characterization. Standoff distance THz sensing and imaging is expected to play a role in the new generation of security screening, remote sensing, biomedical imaging, and NDT [1]. To avoid the significant water absorption in air [2], it is crucial to employ the THz wave generation and detection in air [3,4]. We proposed that an amplified femtosecond laser can be used to generate a THz wave locally near a target in ambient air by focusing intense optical pulses to induce air plasma at stand-off distance.

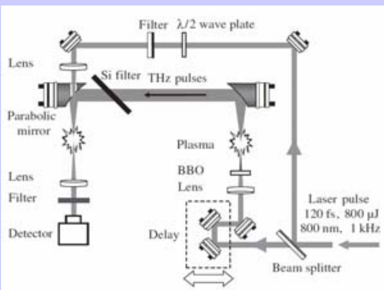

Fig. 1 Schematics of experimental setup for THz wave generation and detection in air

Understanding femtosecond laser pulse propagation properties and precise phase control in air are crucial to realizing standoff distance THz sensing and imaging.

10fs laser pulse propagation in air

The evaluation of the pulse propagation in air was done by using golden mirrors to reflect the laser pulse back and forth to increase the propagation distance along with using a spectrometer and a broadband optical autocorrelator to measure the spectrum and pulse duration. The pulse duration was measured at several distances to evaluate how the femtosecond pulse evolves in the air.

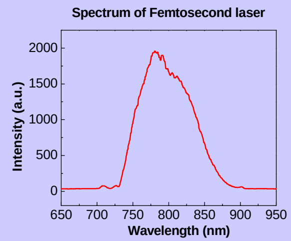

Fig. 2 Spectrum of 10 femtoseconds laser pulse. The central wavelength is 798nm., The HMFW is 99nm.

The central wavelength would be used to calculate the time period of the fringes later appearing in the autocorrelator. By being aware of the fringe period and the number of fringes, we can obtain the HMFW of the pulse autocorrelation.

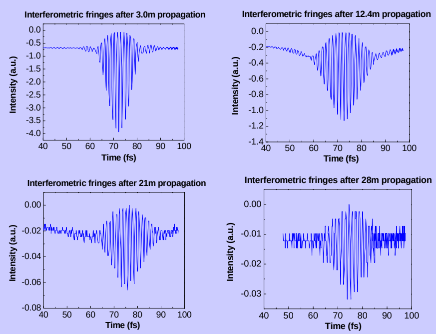

Fig. 3 Pulse interferometric fringes after different propagation distances

Above are the interferometric fringes measured by the autocorrelator at four different distances, 3.0m, 12.4m, 21.0m and 28.0m.

It can be easily noted that as the propagation distance increases, the shape of the autocorrelation fringes has become more distorted and the edge tails are no longer horizontal. At a distance of 28m, the distortion has become very severe. This is because the chirp by air dispersion has a dominant effect on this ultra short 10fs laser pulse with a band width as broad as 100nm. The severe chirp effect can be explained by experimentally measured air refractive indexes for different wavelengths (i.e. from 750nm to 850nm) [5].

100fs laser pulse propagation

The evaluation of the 100fs pulse propagation in air was done by using golden mirrors to reflect the laser pulse back and forth to increase the propagation distance along with using a FROG to measure the pulse duration.

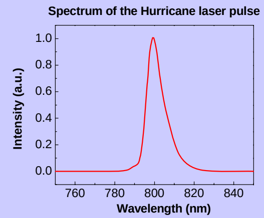

Fig. 4 Spectrum of Hurricane femtosecond laser. The central wavelength is 798nm., The HMFW is 9nm.

The spectrum and central wavelength are obtained by FROG. Below is a measured time vs frequency spectrogram; the pulse duration in time domain was measured by the FROG through the 2D spectral phase retrieval.

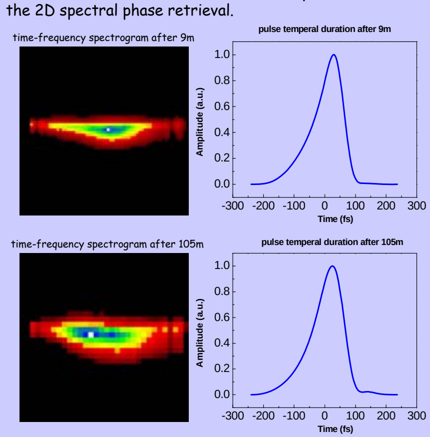

Fig. 5. Pulse time-frequency spectrogram and pulse duration after 9m and 105m propagation in the air.

The results show that the pulse duration changes very little within 100 meters. The frequency-time profile after 100 meters remains basically the same as it is after 9 meters. The effect of air dispersion on the 100fs pulse is very small.

Compared to the 10fs laser pulse, the 100fs pulse, with a relatively narrow bandwidth of 9nm, keeps the pulse duration from broadening too much over a long distance. This is ideal for standoff distance THz generation and detection.

Summary

The properties of femtosecond laser pulse propagation over a long distance (up to 100m) were studied for two different pulses with 10fs and 100fs initial chirp-free pulse durations. Air dispersion is the major factor causing the laser pulse chirp. The quantitative results provided by this study are very helpful for the future control of laser propagation over a long distance and ultimately THz standoff distance sensing and imaging.

Future Plan

1. Extend the propagation distance up to 200m or 400m.
2. Pre-set the negative chirp of the femtosecond laser pulse to compensate for the large air dispersion for broadband optical pulses.
3. Adjust the parameters of the pulse to control the standoff distance THz wave generation and detection in air.
4. Apply THz standoff distance technology to remote sensing and imaging of biological and chemical samples.

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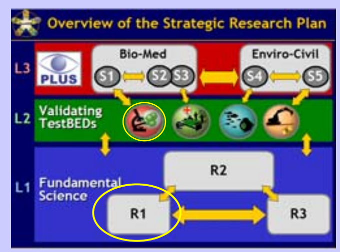

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