Applications for Terahertz Time-domain Spectroscopy

by ***R. Foltynowicz***

Motivation—Terahertz (THz) spectroscopy is emerging as a powerful technique to identify and characterize molecular species. Due to recent advances in femtosecond lasers and optical materials, the THz radiation band from 0.1 to 10THz is now routinely accessible. Spectroscopically, this is a new and unexplored portion of the spectrum that is rich in unique molecular information. As such, progress in this area requires fundamental measurements to determine molecular constants and extensive development of source and detector technologies. The fundamental work is closely tied to applications, which include sensing bio-chem agents, explosives, and byproducts of weapons of mass destruction (WMD) production. Our research interest lies in establishing a THz spectroscopy capability at Sandia to do fundamental spectroscopic characterizations of materials and to determine the feasibility of proposed THz applications that would be in the interest of our national security.

Accomplishment—We have built the first THz time-domain spectrometer at Sandia. Figure 1 shows a diagram of the experimental setup. THz generation is produced by optical rectification of an 800nm femtosecond laser pulse in a <110> ZnTe crystal. This process generates a broadband THz pulse with ~1ps period. The THz beam is detected via electro-optic sampling, which exploits induced polarization changes of the probe beam due to the THz interaction within a ZnTe crystal sensor. The polarization changes are proportional to the strength of the THz electric field; hence we measure the electric field strength of the THz radiation as a function of delay time. Currently, the detector bandwidth is 0.52 to 2.6THz with a spectral resolution of 1GHz (0.03 cm^{-1}). The spectral bandwidth is limited by laser power and crystal thickness. In the near future, we will integrate a regenerative amplifier with the THz spectrometer to produce high-energy THz pulses that will cover the entire THz bandwidth from 0.1 to 10THz.

Utilizing this spectrometer we measured the absorption spectrum of atmospheric water vapor shown in Fig. 2. If we are to conduct any type of molecular sensing through the atmosphere, it is important to know our background absorption. The measured data shows water resonances together with the transmission windows. In addition, we have observed and measured new water transitions. The majority of our measured lines match very well with published literature and NASA's JPL database. These same techniques and experimental configuration can be used to measure the absorption spectrum of a wide range of gases.

Significance—It is important to fully understand atmospheric water vapor resonance and non-resonance absorption behaviors if we want to do any type of remote or local sensing of molecules. Our results provide a map of the background absorption from the atmosphere as well as transmission windows. Having this information allows us to concentrate our molecular identification in the transmission windows. Next, we intend to measure spectral signatures of bio-chem, explosives, and WMD production byproducts and determine if any resonances lie in the atmospheric transmission window. Finally, we can prove the feasibility of molecular sensing through the atmosphere by determining if the line densities in the atmospheric windows are dense and specific enough to identify the molecule.

Sponsors for various phases of this work include: Nuclear Weapons/Science & Technology, Laboratory Directed Research & Development, and Work For Others

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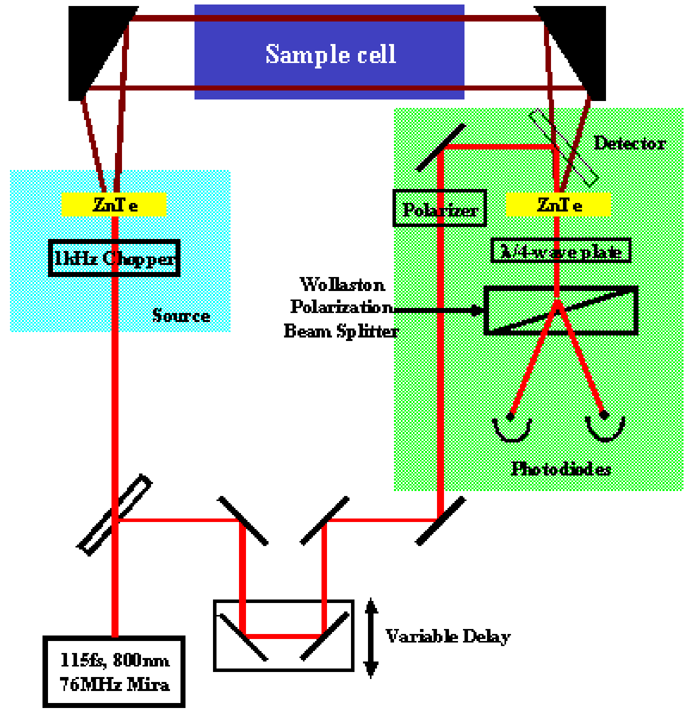

Figure 1. Diagram of the THz time-domain spectrometer. Femtosecond laser pulses chopped at 1KHz pump a <110> ZnTe crystal to produce THz radiation. The THz beam travels through the sample cell and collinearly propagates with an 800nm probe beam with horizontal polarization through a ZnTe sensor. The THz electric field strength is detected via polarization changes induced in the probe beam by the THz beam, inducing a change in the birefringence of the ZnTe sensor.

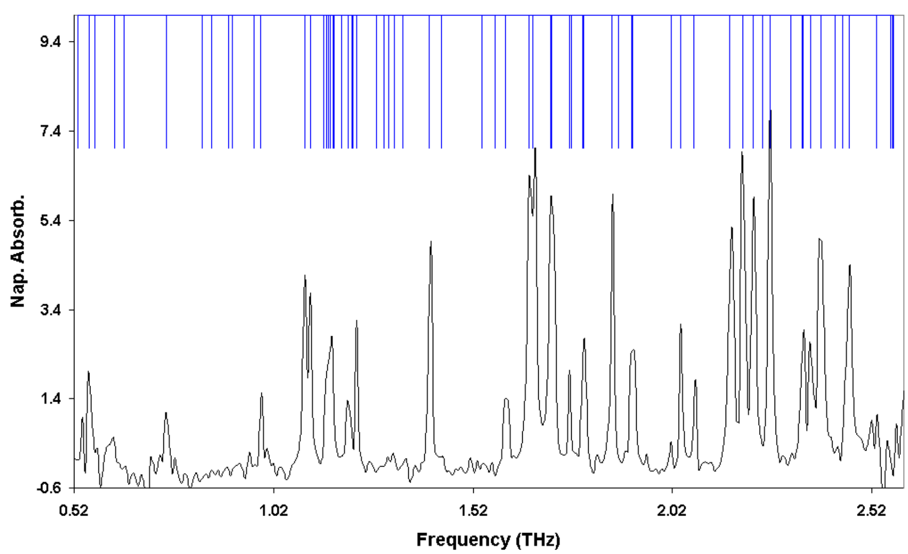

Figure 2. Water vapor absorption spectrum from 0.520 to 2.6THz. The blue ladders represent published lines in NASA's JPL database.