TOWARD REMOTE SENSING WITH BROADBAND TERAHERTZ WAVES

by

Benjamin W. Clough

A Thesis Submitted to the Graduate

Faculty of Rensselaer Polytechnic Institute

in Partial Fulfillment of the

Requirements for the degree of

DOCTOR OF PHILOSOPHY

Major Subject: ELECTRICAL ENGINEERING

Approved by the
Examining Committee:

____
Xi-Cheng Zhang, Thesis Adviser

____
Partha Dutta, Member

____
Zhaoran Rena Huang, Member

____
Masashi Yamaguchi, Member

____
Ning Xiang, Member

Rensselaer Polytechnic Institute
Troy, New York

March 2012
(For Graduation May 2012)

ABSTRACT

Terahertz electromagnetic waves, defined as the frequency region between 0.1 and 10 terahertz on the electromagnetic spectrum, have demonstrated remarkable usefulness for imaging and chemical identification with the ability to penetrate many optically opaque barriers. Photon energies at these frequencies are relatively small (meV), which means the radiation is non-ionizing and therefore considered biologically innocuous. With the growing list of applications and demand for terahertz technology, there is a need to develop innovative terahertz sources and detectors that can overcome existing limitations in power, bandwidth, and operating range.

Although terahertz radiation has demonstrated unique and exceptional abilities, it has also presented several fundamental challenges. Most notably, the water vapor absorption of terahertz waves in air at habitable altitudes is greater than 100 dB/km. There is an immediate push to utilize the material and vapor identification abilities of terahertz radiation, while extending the effective distances over which the technology can be used. Remote terahertz detection, until recently, was thought to be impossible due to the high water content in the atmosphere, limited signal collection geometries, and solid state materials necessary for generation and detection.

This dissertation focuses on laser air-photonics used for sensing short pulses of electromagnetic radiation. Through the ionization process, the very air that we breathe is capable of generating terahertz field strengths greater than 1 MV/cm, useful bandwidths over 100 terahertz, and highly directional emission patterns. Following ionization and plasma formation, the emitted plasma acoustics or fluorescence can be modulated by an external field to serve as omnidirectional, broadband, electromagnetic sensor.

A deeper understanding of terahertz wave-plasma interaction is used to develop methods for retrieving coherent terahertz wave information that can be encoded into plasma acoustic and fluorescence wave emission; the ultimate goal aimed at overcoming fundamental limitations of the current terahertz technology. A synthesized bichromatic field-induced laser plasma is used to study effects of electron velocity redistribution inside the plasma filament, and a technique for obtaining a direct correlation between the terahertz field and the plasma acoustic or fluorescence emission is engineered.

This dissertation presents significant advances in terahertz air photonics that help to close the "THz gap" once existing between electronic and optical frequencies, and the acoustic and fluorescence detection methodologies developed provide promising new avenues for extending the useful range of terahertz wave technology.