MINIATURE TERAHERTZ TIME-DOMAIN SPECTROMETRY

by

Brian Schulkin

An Abstract of 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: PHYSICS

The original of the complete thesis is on file
in the Rensselaer Polytechnic Institute Library

Examining Committee:

Xi-Cheng Zhang, Thesis Adviser

Sang-Kee Eah, Member

Zhaoran Rena Huang, Member

Michael Shur, Member

Masashi Yamaguchi, Member

Rensselaer Polytechnic Institute
Troy, New York

December, 2008

ABSTRACT

This thesis focuses on the design, development and evaluation of novel concepts which enable the miniaturization of terahertz (THz) time-domain spectrometry. Portable THz spectrometry is applied to research and industrial domains for immediate, short and long term applications in nondestructive evaluation, homeland security, and biomedicine respectively.

Due to the previous limitation of THz devices for public uses, in particular, the lack of access to a THz spectrometer, applications of THz science and technology have only recently expanded beyond the laboratory. There is an urgent need for compact, even handheld THz time-domain spectrometry (THz-TDS) platforms which can carry out proven-to-be-useful applications developed and tested in laboratory conditions.

There are three major challenges restricting THz-TDS to laboratories. Atmospheric absorption severely limits the propagation distance of the THz beam and confines systems to low-moisture environments. The sample's surface roughness, grain size and geometry severely limit the bandwidth of the measurement. Physical size and weight of THz systems are generally limited by large laser sources and optomechanics.

The sensitivity and selectivity of THz-TDS systems are the two most significant parameters used to describe the quality of the system. Sensitivity is directly related to the Signal-to-Noise Ratio (SNR) and dynamic range, which may be improved by either lowering the noise floor or increasing the THz signal. On the other hand, selectivity is far more complex as it is related to the sensitivity, sample preparation, baseline correction, and selection method. Sensitivity is gauged using industrial statistical methods, such as Gauge Repeatability and Reproducibility (GR&R), and can transform a not-so-useful SNR value to an extremely useful measure of the minimum detectable amount of a certain material. It is shown that the GR&R value is inversely proportional to the square root of the number of averaged waveforms, which supports that sensitivity is related to SNR, and can be improved. Selectivity is judged using a set of contingency tables with false positive and negative rates, along with a sample library which is designed to rigorously test the correlation and Partial-Least-Squares (PLS) selection methods. Samples were chosen to cover the entire useable bandwidth and contain real-

world complications such as saturation, similar peak positions, and a range of different baselines.

Besides spectrometry, THz systems may be used for pulsed Time-of-Flight (TOF) measurements, in which the THz pulse position is critically important for most nondestructive evaluation applications. The quality of the pulse position is gauged in the same manner as sensitivity. The materials used to assess TOF measurements are specifically chosen to range from low to high scattering. It is shown that in normal operating conditions GR&R is not directly related to SNR, as it should only be dependant on the optical delay stage performance, thermal expansion, and atmospheric conditions.