THz Ellipsometry in Theory and Experiment

Daniel Dietze, Damien P. Kelly, Juraj Darmo and Karl Unterrainer
Vienna Technical University, Photonics Institute, 1040 Vienna, Austria

Abstract—**In this work, we discuss several versions of ellipsometry in the THz spectral region and present the underlying theory. A THz TDS ellipsometry setup is demonstrated experimentally, which is suited for industrial applications on non-destructive semiconductor characterization.**

I. Introduction And Background

NON-DESTRUCTIVE testing methods are highly demanded in the semiconductor industry which allow the characterization of semiconductor material and device parameters. Conductivity measurements are usually performed through Hall measurements which yield good results, but require the fabrication of contacts on the semiconductor surface. Therefore, only few wafer samples are typically tested on the production line.

This limitation could be overcome by the use of optical methods. Ellipsometry is a well established technique in the visible and infrared spectral region, which exploits the change in the polarization of a linearly polarized beam of light after reflection from the sample surface. It can be used for a variety of measurements on semiconductor properties[1, 2].

In addition, terahertz (THz) radiation is a good candidate for non-destructive material characterization for several reasons. First, the energy of the photons is low enough not to excite photocarriers in the semiconductor and thereby altering the outcome of the measurement. Second, the characteristic frequencies of the samples under study, like the carrier plasma frequency, lie well within the accessible frequency range of THz waves. This was already demonstrated successfully with a THz TDS setup in transmission geometry[3].

The fruitful combination of THz TDS and ellipsometry was recently demonstrated by Nagashima et al.[4] for one specific setup, but no systematic and detailed exploration of THz ellipsometry was pursued.

II. Results

In this work, we discuss several different schemes of realizations of THz ellipsometry and present the underlying theory. Furthermore, we demonstrate a THz TDS ellipsometry setup based on biased dipole antennas grown on LT-GaAs.

The emission characteristic of dipole antennas is known to be highly linear polarized with only small quadrupolar contributions[5]. The chosen alignment of the emitter and detector antenna (see fig. 1) provides the incident radiation on the sample consisting of equal contributions of s- and p-polarized light. In this way, one wire-grid polarizer in front of the sample is enough to select pure s- or p-polarization. The relative amplitude of the orthogonal polarized component lies below 1%. This value corresponds to the degree of polarization we can achieve with our dipole antennas.

With our setup, we are able to measure the ellipsometric angles Ψ and Δ by using the relations[2]

$$\rho = \tan(\Psi)\ e^{i\Delta}$$

and

$$\rho = \left(\frac{E_{\mathrm{ref,\ p}}}{E_{\mathrm{ref,\ s}}}\right) / \left(\frac{E_{\mathrm{sam,\ p}}}{E_{\mathrm{sam,\ s}}}\right)$$

where $E_{ref,\,p}$ and $E_{ref,\,s}$ are the amplitudes of the pulses reflected from a reference sample (gold mirror) and $E_{sam,\,o}$ and $E_{sam,\,s}$ are the amplitudes of the pulses reflected from the sample surface in p- and s-polarization, respectively.

The results of our measurements on slabs of Si, GaAs and AlGaAs/GaAs heterostructures are found to be in good agreement with simple models.

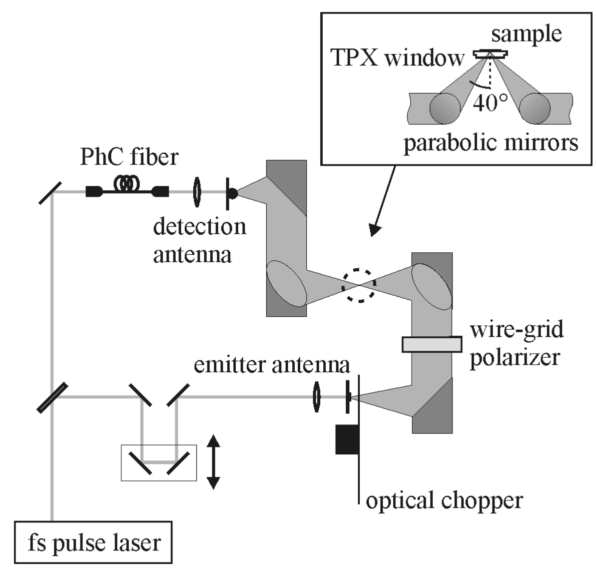

Figure 1: Schematic diagram of the THz TDS ellipsometry setup. The THz radiation is incident on the sample under 40 degrees. The sample is placed on top of a TPX window to allow easy operability.

References

[1] R. M. A. Azzam and N. M. Bashara, *Ellipsometry and Polarized Light*, North Holland, Amsterdam (1977).
[2] M. Schubert, *Infrared Ellipsometry on Semiconductor Layer Structures*, Springer Tracts in Modern Physics, Volume 209, Springer, New York (2004).
[3] D. Grischkowsky, S. Keiding, M. van Exter and C. Fattinger, J. Opt. Soc. Am. B **7**, 2006 (1990).
[4] T. Nagashima and M. Hangyo, Appl. Phys. Lett. **79**, 3917 (2001).
[5] J. V. Rudd, J. L. Johnson and D. M. Mittleman, Opt. Lett. **25**, 1556 (2000).

978-1-4244-2120-6/08/$25.00 ©IEEE.