THz Ellipsometry Materials Characterization

UNIVERSITY OF NEBRASKA-LINCOLN

T. Hofmann[1], C.M. Herzinger[2], and M. Schubert[1]

[1] Department of Electrical Engineering and Nebraska Center for Materials and Nanoscience, University of Nebraska-Lincoln, U.S.A.
[2] J. A. Woollam Co. Inc., 645 M Street, Suite 102, Lincoln, NE 68508-2243, U.S.A

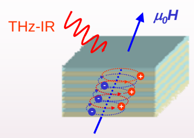
ellipsometry.unl.edu
thofmann@engr.unl.edu

Our Message

- **We demonstrate the first desktop THz ellipsometer in the frequency range from 0.1 to 1.5 THz (3 to 50 cm^{-1}) using a rotating analyzer configuration and a tunable backward wave oscillator source.**
- **THz ellipsometry enables optical and contact free determination of low (!) (~10^{15} cm^{-3}) free charge carrier concentrations in Si bulk and layered structures.**
- **THz ellipsometry may open new pathways for non-destructive investigation of the electrical properties of complex materials needed as building blocks for next generation nanoelectronics.**

Motivation: THz Spectroscopic Ellipsometry

2D Semiconductor & Semimetal

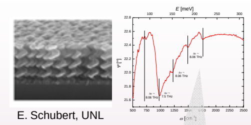


quantum confinement-effects in low dimensional systems

Generalized ellipsometry in combination with external magnetic fields:

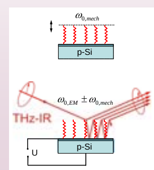
- Semiconductors: unbound charge carrier resonances in spatially confined structures in the THz frequency domain
- Highly oriented pyrolytic graphite: Landau level transitions, electron and hole contributions

Complex Metamaterials



E. Schubert, UNL

resonances in a sculptured Al thin Film on Si



new detector structures: quantum opto-mechanical couplers with Eigenresonances in the THz-IR domain

3D Nanostructure Networks

D. E. Scharett and R. E. Garrison Arm. Log. **37** (2005)

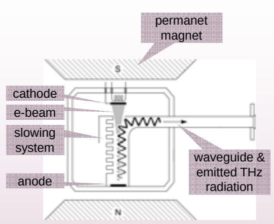
- future nanoelectronics will be assembled from nano-sized thin film structures and metamaterials
- new physical phenomena in these building blocks like quantum confinement and surface effects will alter the physical properties and need to be studied

optical metrology tools needed

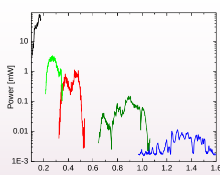
optical and mechanical Eigenresonances of these material fall in the THz domain

THz Spectroscopic Ellipsometry - Experimental Setup

Backward Wave Oscillator Source



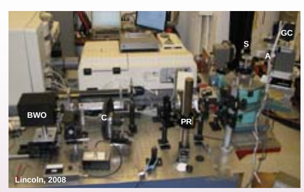
- acceleration voltage up to 3 kV
- cathode current ~20 mA
- base resonator frequency: 107 to 177 GHz
- full spectral range when augmented by Schottky diode multipliers: 0.1 to 1.5 THz



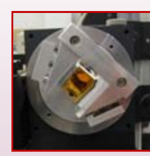
output power of the BWO augmented with different Schottky diode multipliers (x2, x3, x6, x9)

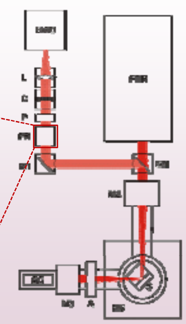
- peak power:
  0.1-0.18 THz: 0.1-0.01 W (!)
- base resonator bandwidth 2 MHz (!)
- emits linearly polarized light

Experimental Setup



Polarization rotator:



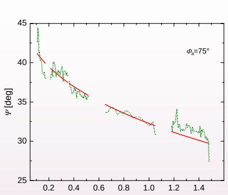


- rotating analyzer ellipsometry configuration
- employs polarization rotator to change the input polarization (PR)
- polyethylene substrate wire grid polarizer (A)
- Golay detector (GC)

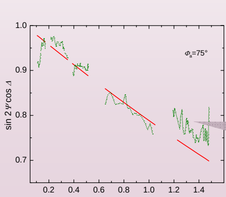
Patent application filed with UNL, Sept. 2008

Experimental Results

Highly Doped Si



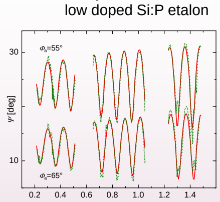
highly doped Si wafer used for single frequency system calibration
Drude best-fit model describes THz and MIR range consistently

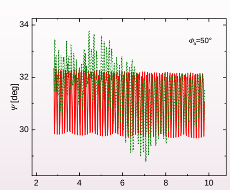


features are highly reproducible – refinement of the calibration model (wvl dependency) needed

Low Doped Si Etalon

Fabry-Pérot oscillations in a 384 μm thick low doped Si:P etalon



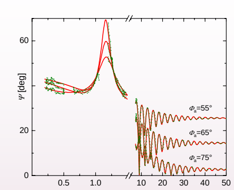


THz range model calculations excellently resemble residual Drude absorption!

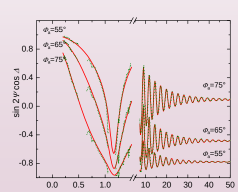
FIR region (80 to 333 cm^{-1}) is impaired by non-idealities in etalon and measurement system!

THz range analysis enables determination of bulk free charge carrier concentration N=1.3 10^{15} cm^{-3} and mobility μ=932 cm^2/(Vs) (m*=0.45; ρ=5 Ωcm and τ=239 fs)!

Low Doped Si Epi-Layer on Doped Si



THz range analysis reveals free charge carrier properties in Si epi-layer
N=2.8 10^{15} cm^{-3} and
μ=683 cm^2/(Vs)
(m*=0.45; ρ=3.9 Ωcm and τ=155 fs)



- consistent model describes the optical response from 0.2 to 50 THz (6 to 1667 cm^{-1}) (Si epi-layer thickness: 17μm, Si substrate: ρ = 0.012 Ωcm and τ = 4.5 fs)
- residual epi-layer doping remains undetected in MIR range (333 – 1667 cm^{-1})

5th Workshop Ellipsometry, Zweibrücken, March 2-4 2009

Support: STTR (D. Woolard, W911NF-08-C-0111), UNL Startup, NSF MRSEC, JAWF