Free-Charge Carrier Profiles of Iso- and Anisotype Si Homojunctions

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P2-10

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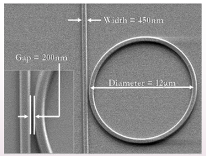
Our Message

- 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 determination of low (!) (~10^{15} cm^{-3}) free charge carrier concentrations in silicon bulk and layered structures.
- THz ellipsometry can be used to accurately find the location of an abrupt isotype (p+/p or n+/n) homojunction as well as the diffused carrier concentration profile.
- Simultaneous analysis of THz and FIR data allows contact-free, non-destructive measurement of complex semiconductor structures.

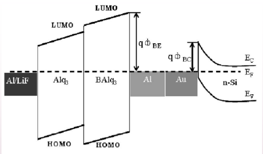
Motivation

- Optical sensitivity to low carrier concentration levels via THz resonance polaritons provides a new technique to study complex semiconductor structures
- Non-destructive, contact-free determination of semiconductor structure is key to developing future technologies



Cornell Nano Photonics Group
Electro-optical Modulator

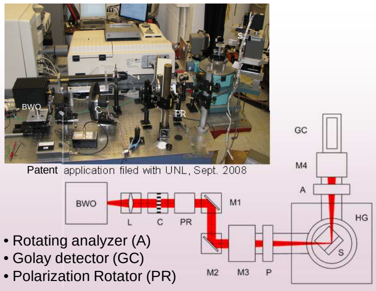
- Integrated Circuit waveguides for photonic computation and integration with optical fiber communications



M. Yi *et al.*, Appl. Phys. Lett. **92**, 243312 (2008)
High Mobility Isotype Transistor

- High mobility transistors
- Silicon homojunction interfacial workfunction internal photoemission (HIWIP) far-infrared detectors

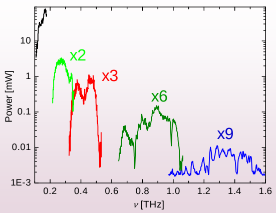
THz Ellipsometry Setup



Patent application filed with UNL, Sept. 2008

- Rotating analyzer (A)
- Golay detector (GC)
- Polarization Rotator (PR)

Backwards Wave Oscillator (BWO) Source



Output power of the BWO augmented with different Schottky diode multipliers

Model System

Spectral Features

- The low THz region is dominated by surface guided waves, present here at ~290 GHz and ~900 GHz.
- The FIR region is dominated by Fabry – Perot oscillations, which damp at high frequency.

Analytical Model

Analytical solution to Poisson equation of an isotype homojunction [1]:

$$E^2(\phi) = -2/(\varepsilon_0\varepsilon)\int \rho(\phi)\,d\phi$$

Assuming semi infinite boundary conditions and substituting the non-degenerate semiconductor expressions:

$$N(x) = N_D e^{[q\phi(x)/kT]} \qquad P(x) = N_A e^{[q\phi(x)/kT]}$$

Results in a simplified equation if $N_+ \gg N_-$, where $N(x)$ may be determined entirely in terms of N_+ and N_- and a characteristic lenth L!

$$\boxed{N_H(x) = N_+ e^{\left[-\frac{LN(N_+/N_-)}{1+\sqrt{N_+/N_-}}\right]e^{x/L}}}$$

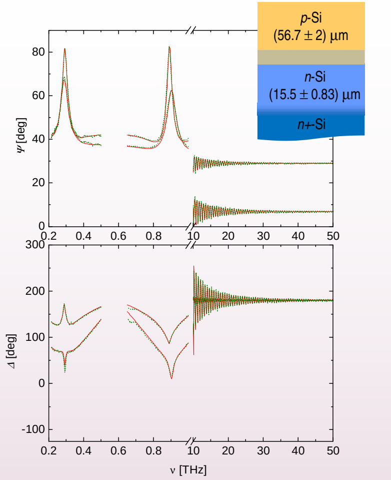
$$\boxed{N_L(x) = N_- e^{\left[LN\left(\frac{N_+}{N_-}\right)-2LN\left(e^{0.5}\left(1-\frac{N_-LN(N_+/N_-)}{N_+-N_-}\right)+x/L\right)\right]}}$$

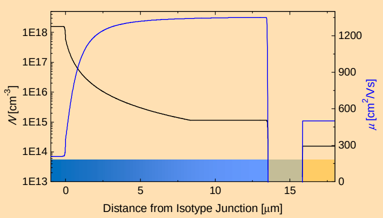
Separate solutions for each side of the abrupt dopant junction lead to an asymmetric carrier profile. Mobility is also given as a function of concentration [2].

$$\mu = \mu_{min} + \frac{\mu_{max}-\mu_{min}}{1+\left(\frac{N}{N_{ref}}\right)^{\alpha}}$$

[1] Z.T. Kuznicki, J. Appl. Phys. **69**, 6526 (1991)
[2] C. Jacoboni et al., Solid-State Electron. **20**, 77 (1976)

P/N/N+ Sample

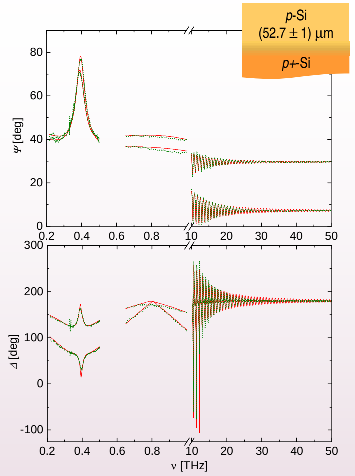


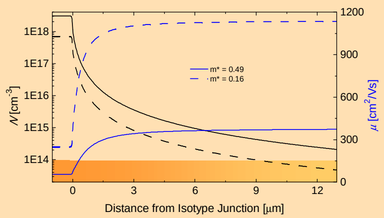


	d_P (μm)	d_N (μm)	ρ_{epi-P} (Ωcm)	ρ_{epi-N} (Ωcm)	ρ_{sub} (Ωcm)
Best-Model	56.7	15.5	80.4	4.19	0.016
As-Grown	71 - 85	22 - 28	60 - 90	3.0 – 5.0	<0.02

Silicon Iso- and Anisotype Example Systems

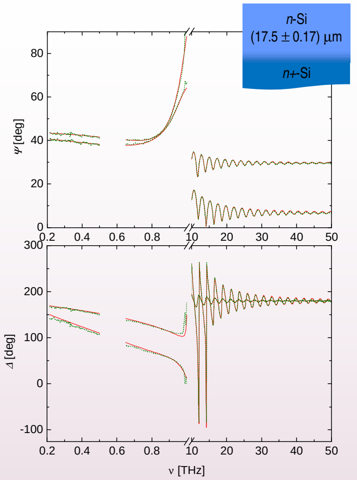
P/P+ Sample

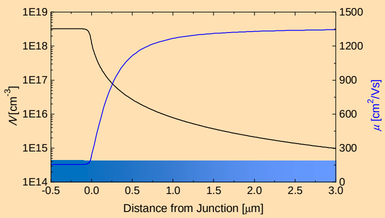




	d (μm)	ρ_{epi} (Ωcm)	ρ_{sub} (Ωcm)
Best-Model	52.7	34.8	0.014
As-Grown	48 - 58	56 – 78	0.008 – 0.02

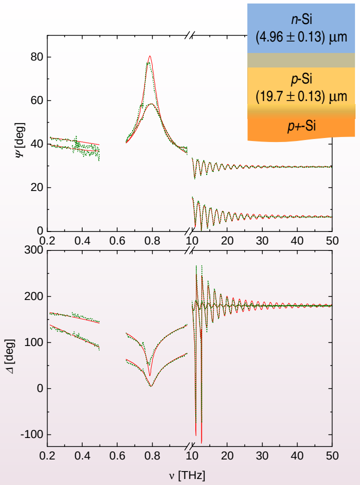
N/N+ Sample

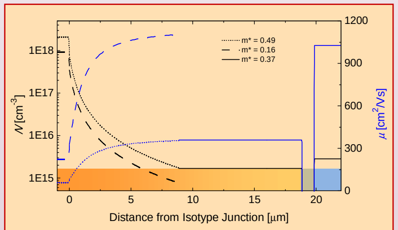




	d (μm)	ρ_{epi} (Ωcm)	ρ_{sub} (Ωcm)
Best-Model	19.7	6.17	0.012
As-Grown	17 – 22	5.0 – 6.8	0.005 – 0.013

N/P/P+ Sample





	d_P (μm)	d_N (μm)	ρ_{epi-P} (Ωcm)	ρ_{epi-N} (Ωcm)	ρ_{sub} (Ωcm)
Best-Model	19.7	4.96	10.3	2.1	0.016
As-Grown	11 - 13	11 – 13	4.0 – 7.0	1.6 – 1.9	0.008 – 0.02

5th International Conference on Spectroscopic Ellipsometry, Albany, NY, May 2010

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