**Motivation**

- understanding of fundamental electronic and lattice processes in highly excited semiconductors:
  - band-filling, bandgap renormalization
  - exciton screening, Mott transition
  - separate electron/hole thermalization and cooling, hot-phonon effects
- comparison to doping, useful for ablation dynamics and material reflection with light
- experimentally: either amplitude or phase information from bare or transmission experiments
  - solution: spectroscopic ellipsometry (also handling of optically anisotropic samples possible)
  - probe of joint density of states affected by occupation of states

---

**Sub-picoscords**

- Hot charge carriers: high electron/hole temperatures and separated quasi-Fermi levels due to excess energy and different effective masses
- Hole scattering in Bi2: within 200 fs, faster than electron scattering (600 fs), enabling inter-VB absorption
- Absorption fine-structure: passivation of surface-defects and scattering of their electric field

**Picoseconds**

- Absorption bleaching: blocking of near-band edge transitions along with reduced refractive index
- Exciton persistence: absorption peaks present despite a χ pair density larger than Mott density
- Hot-phonon effects: large non-thermal optical phonon distribution created from excess energy, obviating of EPC, carrier cooling slowed down
- reduced number of e-h pairs due to recombination

**Nanosseconds**

- remaining passivated surface defects
- Heating: redshift of absorption edge

---

**Transistion optical properties of ZnO structures studied with femtosecond-time-resolved spectroscopic ellipsometry**

O. Herrfurth1, S. Richter2, M. Rebarz1, S. Espinoza, M. Kloz3, S. Zollner4, Å. Andreasonsson5 and R. Schmidt-Grund1

1. Universität Leipzig, Felix Bloch Institute for Solid State Physics, Linnestr. 5, 04103 Leipzig, Germany
2. ELLI-Beamlines, Institute of Physics, Czech Academy of Science, Na Slovance 2, 18221 Prague, Czech Republic
3. Department of Physics, New Mexico State University, Las Cruces, NM, USA
4. Chalmers University of Technology, Condensed Matter Physics, Department of Applied Physics, Göteborg, Sweden

* oliver.herrfurth@physik.uni-leipzig.de  http://polariton.physik.uni-leipzig.de  http://www.uni-leipzig.de/~hlp

---

**ZnO-based microresonator**

**Experimento info:**

- sample: 200 nm c-ZnO cavity between YSZ/Al2O3 DBR
- e-h pair density: \( n = 1 \times 10^{19} \text{cm}^{-2} \)

---

**c-ZnO thin film: hot carriers and phonons**

**Experimental info:**

- sample: 30 nm c-ZnO on glass substrate
- e-h pair density: \( 1 \times 10^{19} \text{cm}^{-2} \)

---

**m-ZnO thin film: transient birefringence and dichroism**

**Experimental info:**

- sample: 37 nm m-ZnO on m-sapphire orientation: parallel and perpendicular to optic axis
- e-h pair density: \( 2 \times 10^{19} \text{cm}^{-2} \)

---

**Pump-probe technique**

- amplified Ti:Sa laser (1 kHz, 6 mJ, 35 fs)
- pump: 3rd harmonic (266 nm / 4.67 eV)
- probe: CaF2 continuum white light (690 – 345 nm / 1.8 – 3.6 eV)
- prism spectrometer with fast CCD (1 kHz readout rate coupled to Ti:Sa)
- only reflective or thin transmission to suppress group velocity delay
- reflectance-difference in two-chopper scheme spectra for improved signal-to-noise ratio:
- 70 fs temporal resolution, 4 nm spectral resolution in UV

---

**Ellipsometry & dielectric function**

**working principle:**

- change of polarisation upon transmission / reflection
- thickness of thin layers
- optical constants \( n, \varepsilon \)
- indirect method (model necessary)

**linear dielectric response to EM wave**

\[
\hat{E} = \varepsilon_1 + i \varepsilon_2 = (\varepsilon_1 + \varepsilon_2) + i \varepsilon_2
\]

\( F \): electric field

\( \varepsilon \): tensor of dielectric function (DF)

**relation to refraction \( n \) & absorption \( k \)**

\[
\rho = \frac{\varepsilon}{\varepsilon_0} = (\varepsilon_1 + \varepsilon_2) + i \varepsilon_2
\]

**carrier distribution**

- \( T \) = 2800 K
- \( E_F,h = -0.3 \text{ eV} \)

---

**ZnO-based microresonator**

**Experimental info:**

- sample: 200 nm c-ZnO cavity between YSZ/Al2O3 DBR
- e-h pair density: \( n = 1 \times 10^{19} \text{cm}^{-2} \)

---

**Bandstructure taken from:** Schiele et al. PRB 80, 035112 2009

**Directions**

- Dipole operator representation
- Allowed transitions (selected)

---

**Transient dynamics:**

- decreased refractive index mode blue shift by 20 meV to fulfill the mode condition until 5 ps
- coexistence of blueshifted mode and original one
- effect of charge carrier depth gradient