Spectroscopic Ellipsometry and optical Hall-Effect studies of free-charge carriers in In-polar p-type InN:Mg

Stefan Schöche1, Tino Hofmann1, Nebiha Ben Sedrine2, Vanya Darakchieva2, Bo Monemar2, Xinqiang Wang2, Akihiko Yoshikawa4, and Mathias Schubert1

1 Department of Electrical Engineering and Nebraska Center for Materials and Nanoscience, University of Nebraska-Lincoln, U.S.A.
2 Department of Physics, Chemistry and Biology, Linköping University, Sweden & Instituto Tecnológico e Nuclear, Lisbon, Portugal
3 State Key Laboratory of Artificial Microstructure and Mesoscopic Physics, Peking University, Beijing, China
4 Graduate School of Electrical and Electronics Engineering, Venture Business Lab, Chiba University, 1-33 Yayoicho, Inage-ku, Chiba 263-8522, Japan

Our Message

- Confirmation of successful p-type doping in In-polar InN:Mg by means of IR spectroscopic ellipsometry (SE) and FIR optical Hall-effect (OHE)
- p-type doping was found in a Mg-concentration window between 1.1x10^{18} cm^{-3} and 2.9x10^{19} cm^{-3}
- Characteristic peak in the IRSE spectra due to weak longitudinal optical phonon-plasmon coupling
- Decrease of carrier-induced birefringence in OHE data due to higher effective mass and significantly lower mobility of holes
- Urbach-tail below the band gap indicating increasing number of defect states within band gap
- Determination of hole concentration and mobility by assuming a hole effective mass of 0.42 m_e

Electron accumulation in p-InN

Electrical methods

- electron accumulation on surface and at interface between InN and GaN buffer [1]
- only surface accumulation is probed by standard electrical methods
- buried p-type channel is not detected due to higher resistivity
- electrolyte capacitance-voltage measurements or thermo-power determine only carrier concentration and/or carrier type

IR Ellipsometry: FIR optical Hall-effect

- penetration of light through the whole sample stack including substrate and buffer layers
- contribution of each individual layer by reflection at interfaces or phase-shift within layers
- in general determination of free-charge carrier concentration, mobility, effective mass and carrier type (electron/hole) possible for each individual layer by combining spectroscopic ellipsometry with magnetic fields (optical Hall-effect)

Theory

Standard IR Ellipsometry

LO phonon-plasmon coupling (Kukharski-model) [2]:

\[ \varepsilon_{sLPP} = \varepsilon_{s0} + \frac{a_0^2}{a_0^2 + a_1^2} \left( \varepsilon_{sLO} - \varepsilon_{s0} \right) \]

2 branches: LPP+ and LPP-

\[ a_0^2 = \frac{N q^2}{m^* c^2} \]

plasma frequency: \( \omega_p = \sqrt{\frac{4 \pi e^2 N}{m^*}} \)

plasma broadening: \( \gamma = \frac{\omega_p}{m^*} \)

FIR optical effect

Magnetic field \( H \) causes non-symmetric properties of the IR dielectric function tensor [3,4,5]:

\[ \varepsilon_{\omega} = \frac{N q^2}{m^*} \]

Plasma (frequency) tensor

\[ \left( \omega_p^2 \right) = N \frac{q^2}{m^*} \]

Cyclotron (frequency) tensor

\[ \left( \omega_c^2 \right) = H \frac{q^2}{m^*} \]

Experimental Results

NIR-VIS-UV-VUV SE

- determination of layer thickness
- modeling of electronic band-band transitions

IRSE

- no shift of transition energies with increasing [Mg]
- decreasing absorption strength, increasing broadening and increasing surface roughness with increasing [Mg]
- Urbach tail below band gap for increasing [Mg]
- Burstein-Moss shift for very high Mg concentration

Characteristic peak in the IRSE spectra due to weak longitudinal optical phonon-plasmon coupling (LPP) for smaller mobility and higher effective mass of holes

References