Surface electron accumulation and effective mass anisotropy in wurtzite structure InN

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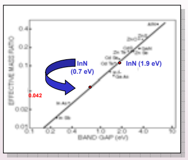
Our message

- MO generalized ellipsometry measurements show evidence for a thin electron accumulation layer and corroborate HREELS and C-V data
- bulk and surface electron concentration follow power law dependencies as a function of the InN layer thickness
- strong deviation of scaling factors of the true bulk electron concentration and counted dislocation densities suggests evidence for a new defect related doping mechanism – most likely point defects, previously thought to be thickness independent
- neutralization of surface donors might be easier for low background concentrations
- experimental evidence for α-InN Γ-point effective electron mass value for polarization perpendicular to c-axis: $m_\perp = 0.050 \pm 0.03\ m_0$ and $m_{||} = 0.037 \pm 0.03\ m_0$

Motivation: electronic properties of InN

Band gap

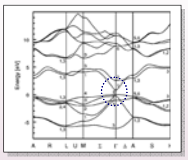
Experimental and theoretical evidence for E_g(InN)~0.7eV – Γ-point effective mass has been overestimated!



B.R. Nag PSS (b) **237**, R1 (2003)
H. Lu et al., APL 77, 2548 (2000)

$m_{||} \neq m_\perp$

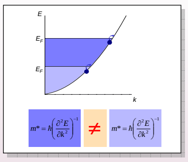
Anisotropic Γ-point effective mass predicted



D. Fritsch *et al.* PR **B 69**,165204(2004);
P. Carrier and S.-H. Wei JAP 97 (2005)

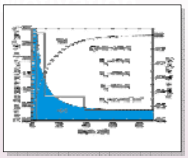
Non-parabolic cond. band

Non-parabolic conduction band – effective mass depends on the free-charge-carrier concentration



Surface accumulation

Electron surface accumulation obscures electrical, contact-based measurements – true bulk electron concentration is unknown



H. Lu et al. APL 82, 1736 (2003)
I. Mahboob et al. PRL 92, 036804 (2004)

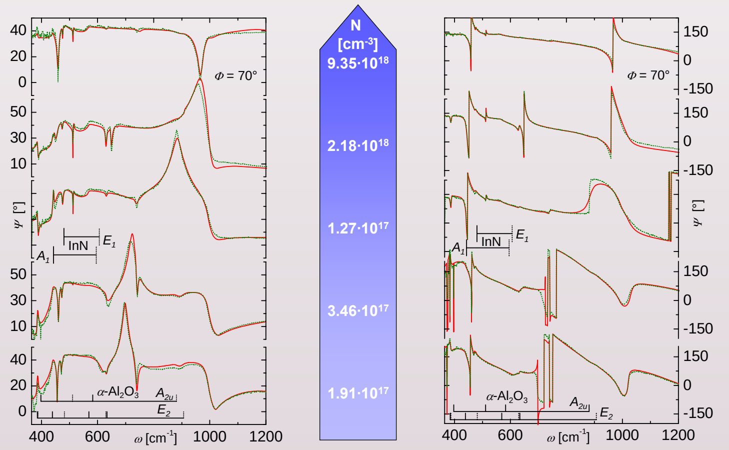
Far-infrared magnetooptic generalized ellipsometry

contact less, non-destructive determination of phonon and free-charge-carrier parameters (concentration, effective mass, mobility) in thin layer samples by stratified dielectric model calculation.

Recent publications on mo generalized ellipsometry:

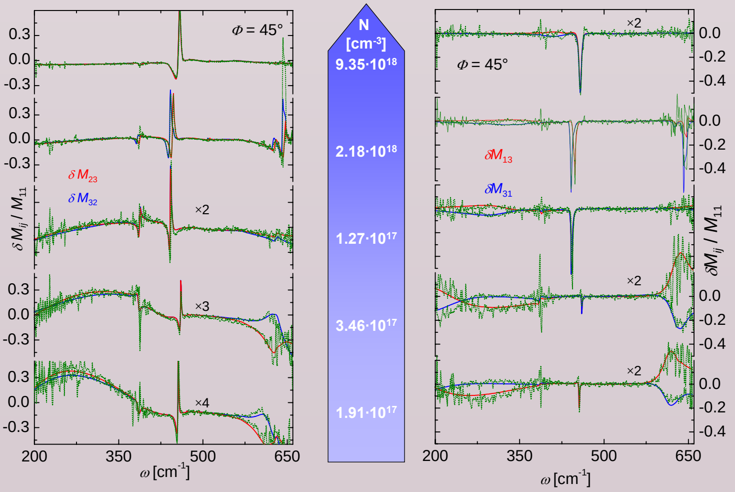
T. Hofmann et al. Appl. Phys. Lett. , (2007)
T. Hofmann et al. Rev. Sci. Instrum. **77**, 063902 (2006)
M. Schubert et al. Thin Solid Films **455-456**, 563-570 (2004)
T. Hofmann et al. Mat. Res. Soc. Symp. Proc. **744**, M5.32.1-6 (2003)
T. Hofmann et al. Appl. Phys. Lett. **82**, 3463-3465 (2003)
M. Schubert et al. J. Opt. Soc. Am. A **20**, 347-356 (2003)

Standard ellipsometry (zero-magnetic-field)



Zero-field ellipsometry spectra reveal thickness, phonon mode frequency and broadening parameters, static dielectric constants, plasma frequency and plasma broadening parameters of InN and GaN layers.

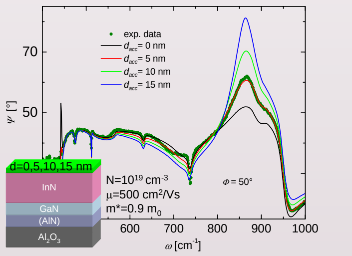
Magnetooptic generalized ellipsometry



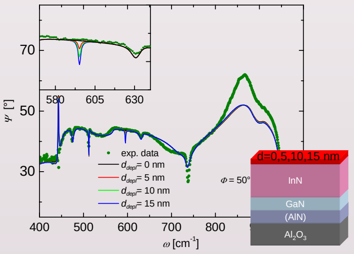
Differences between Mueller matrix data (chiral elements M_{13}, M_{31}, M_{32}, and M_{23}) measured magnetic fields of +4.5T and -4.5T. The non-chiral elements M_{12}, M_{21}, M_{22}, and M_{33} vanish.

Electron surface accumulation or depletion?

Electron accumulation

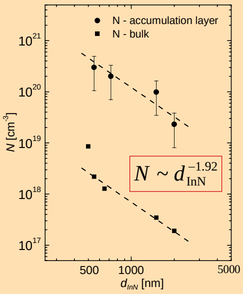


Electron depletion



Fingerprints of a thin electron accumulation/depletion layer in wurzite InN. Model calculations show distinct changes in the ellipsometric spectra if a charge depletion or accumulation layer is present. HREELS and C-V measurements have been reported in the literature. PR B **69**, 201307(R) (2004); JCG **269**, 29 (2004); PRL **92**, 036804 (2004); APL **82**, 1736 (2003)

Bulk- and surface carrier properties

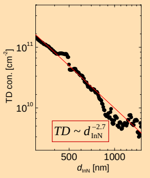


Bulk- and surface carrier concentration follow the same power-law dependencies as a function of the InN layer thickness

The observed scaling factor deviates strongly from the scaling factor for threading dislocations the most dominant thickness dependent donor:

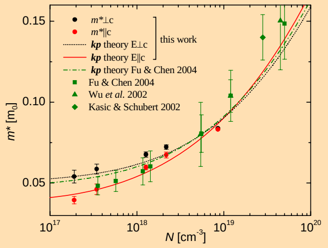
$$\alpha_{N-MOGE} = -1.92 \neq -3.7 = \alpha_{N-TD}$$

other thickness dependent donors must be present!



V. Cimalla et al. APL 89, 172109 (2006)

Anisotropic Γ-point effective mass



Anisotropy corresponds with recent ab initio band-structure calculations:
P. Carrier and S-H. Wei JAP 97 (2005):
P. Rinke et al. APL 89 (2006)

Calculated: 14 %
this-work: 17 %

Application of Kane's two-band model:

$0.050 = m^*_\perp > m^*_{||} = 0.037$

4th International Conference on Spectroscopic Ellipsometry, Stockholm, June 11-15 2007