TuP C01

UNIVERSITÄT LEIPZIG

Infrared ellipsometry on wurtzite ZnO-based alloy thin films: Crystal structure, free charge carrier and phonon properties

C. Bundesmann#,1 , N. Ashkenov[1], M. Schubert[1], M. Lorenz[1], E. M. Kaidashev[1], M. Grundmann[1], A. Kasic[2], B. Monemar[2], N. Oleynik[3], A. Dadgar[3], A. Krost[3]

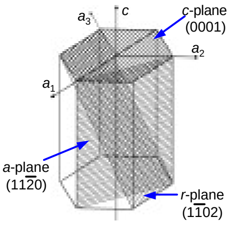
[1]*Institut für Experimentelle Physik II, Universität Leipzig, Germany*
[2]*Department of Physics and Measurement Technology, Linköping University, Sweden*
[3]*Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg, Germany*

bundesm@physik.uni-leipzig.de
http:\\www.uni-leipzig.de\ellipsometrie

Our Message

Infrared spectroscopic ellipsometry (IRSE) is a versatile, contactless and non-destructive method for characterization of free charge carrier (electrical properties) and phonon mode (composition, structural quality) parameters of wurtzite-type ZnO and ZnO-based thin films and heterostructures.

Introduction



ZnO has wurtzite-type structure,
i.e. optically uniaxial

Model dielectric function

Electronic contribution	Polar lattice contribution	Alloy-induced modes (TO-LO << TO, LO)	Free charge carrier contribution

$$e_j(w) = e_{\infty,j} \cdot \prod_{i=1}^{l} \frac{w^2 + ig_{LO,ij}w - w_{LO,ij}^2}{w^2 + ig_{TO,ij}w - w_{TO,ij}^2} \cdot \prod_{k=1}^{m} \left(1 + \frac{idg_{kj}w - dw_{kj}^2}{w^2 + ig_{AM,kj}w - w_{AM,kj}^2}\right) - \frac{w_{p,j}^2 e_{\infty,j}}{w(w + ig_{p,j})}$$

For uniaxial materials: *j* = “||”, “⊥” *c*-axis

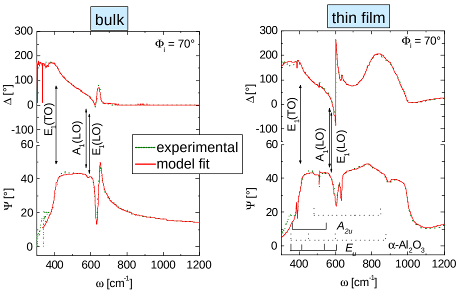
$w_{p,j} \propto z_j = (N/m_j)^{0.5}$ $g_{p,j} \propto x_j = (m_j \mu_j)^{-1}$

ZnO – an interesting semiconductor

ZnO and ZnO based compounds are promising wide band gap semiconductors for UV and VUV optoelectronic applications

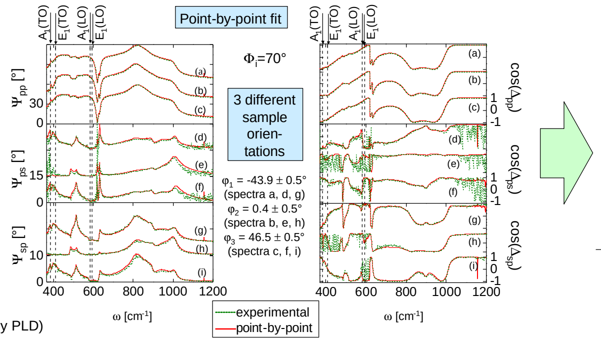
Advantages compared to GaN
- Exciton binding energy at room temperature 60 meV
- Higher optical gain
- Higher radiation hardness
- High-quality bulk single crystals available

c-plane ZnO



Comparison of dielectric functions, phonon modes and static dielectric constant between *c*-plane oriented ZnO bulk and thin film
N. Ashkenov et al., J. Appl. Phys. **93**, 126 (2003).

a-plane ZnO: Generalized Ellipsometry

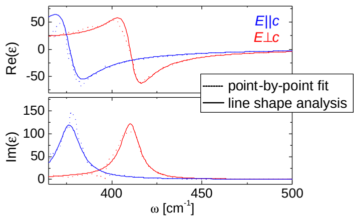


3 different sample orientations

φ_1 = -43.9 ± 0.5° (spectra a, d, g)
φ_2 = 0.4 ± 0.5° (spectra b, e, h)
φ_3 = 46.5 ± 0.5° (spectra c, f, i)

(Grown by PLD)

ZnO infrared dielectric functions



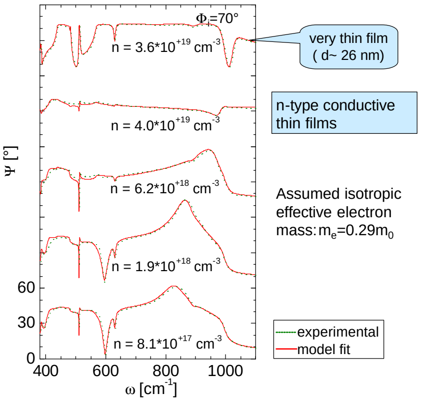
Phonon mode parameters

	ε_∞	ω_{TO} [cm^{-1}]	ω_{LO} [cm^{-1}]	γ [cm^{-1}]
A_1 (*E*||*c*)	3.60 (0.02)	376.5 (0.1)	574.1 (0.4)	15.1 (0.2)
E_1 (*E*⊥*c*)	3.53 (0.02)	410.7 (0.2)	590.4 (0.6)	10.7 (0.5)

Free charge carriers

ZnO doped with Ga

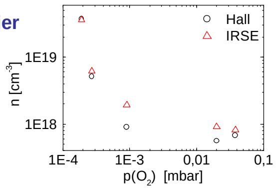
(Grown by PLD)



n-type conductive thin films

Assumed isotropic effective electron mass: m_e=0.29m_0

Free charge carrier concentration



Good agreement between IRSE and Hall data

Free charge carrier mobility

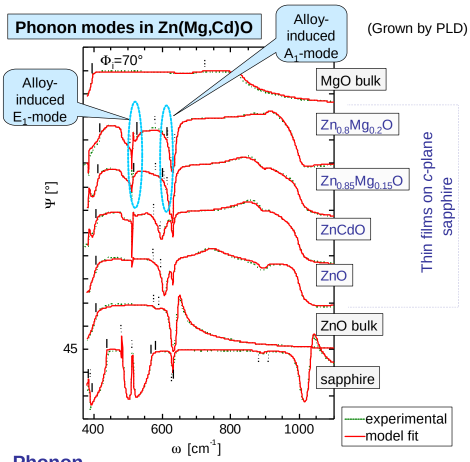
$\mu_{E\perp c} > \mu_{E\parallel c}$

Hall measurements have no sensitivity to anisotropy of mobility in *c*-plane films

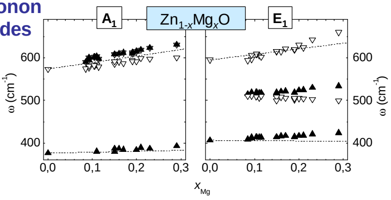
Alloying

Phonon modes in Zn(Mg,Cd)O

(Grown by PLD)



Phonon modes



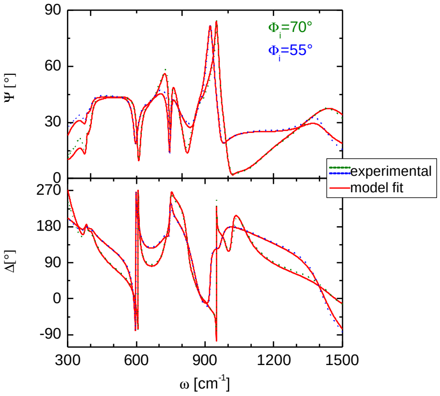
Composition dependent phonon mode frequencies

C. Bundesmann et al., Appl. Phys. Lett. **81**, 2376 (2002)
R. Schmidt et al., Appl. Phys. Lett. **82**, 2260 (2003)

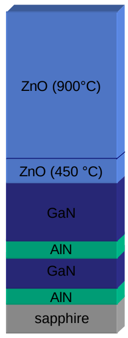
Heterostructures

ZnO grown on AlN/GaN

(Grown by MOVPE)



Thickness and free carrier concentration



d = 2780 nm
d = 200 nm, N = 2.95·10^{19} cm^{-3}
d = 930 nm, N = 1.8 ·10^{17} cm^{-3}
d = 12 nm
d = 700 nm, N = 1.8 ·10^{17} cm^{-3}
d = 140 nm

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