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

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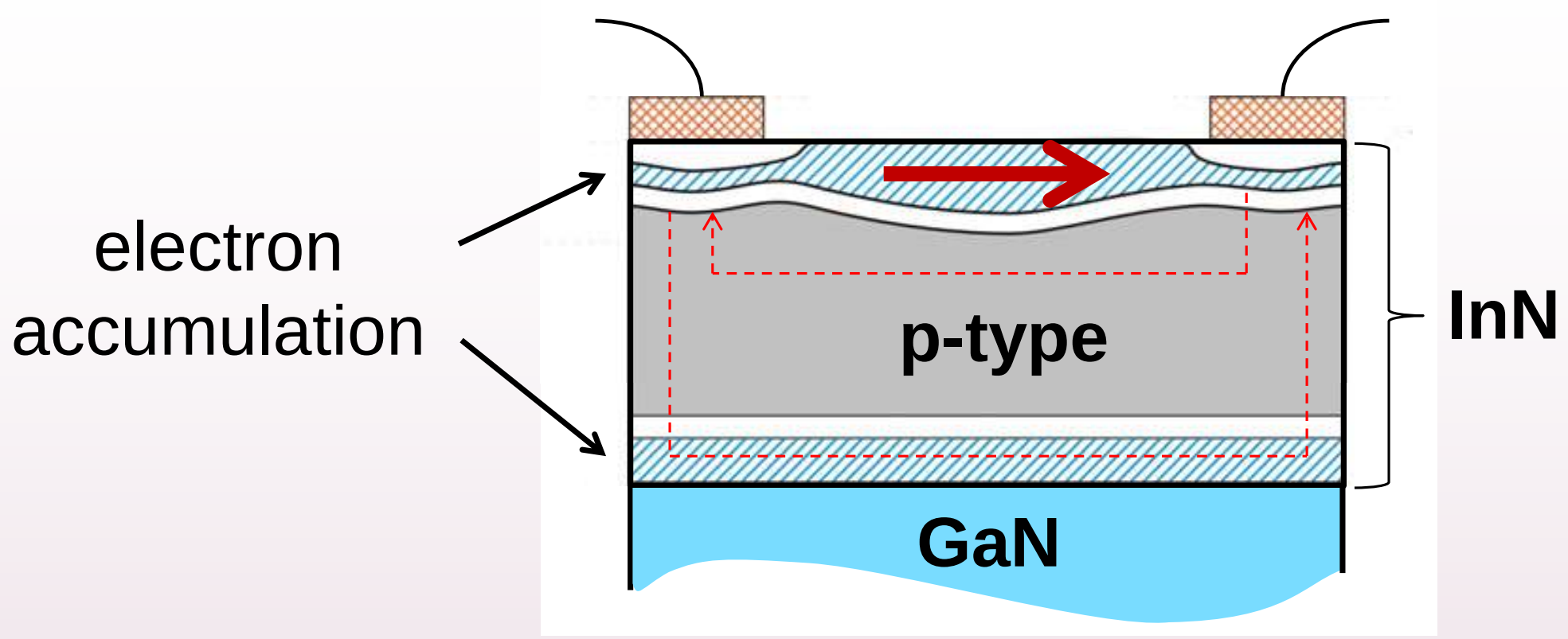
Our Message

- 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 1.1×10^{18} cm^{-3} and 2.9×10^{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

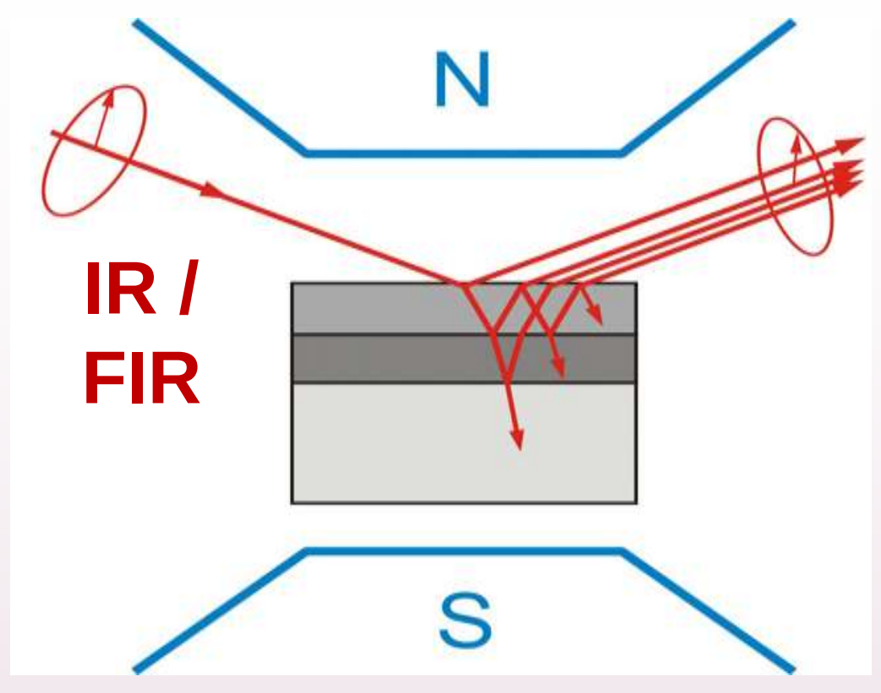
Electron accumulation in p-InN

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

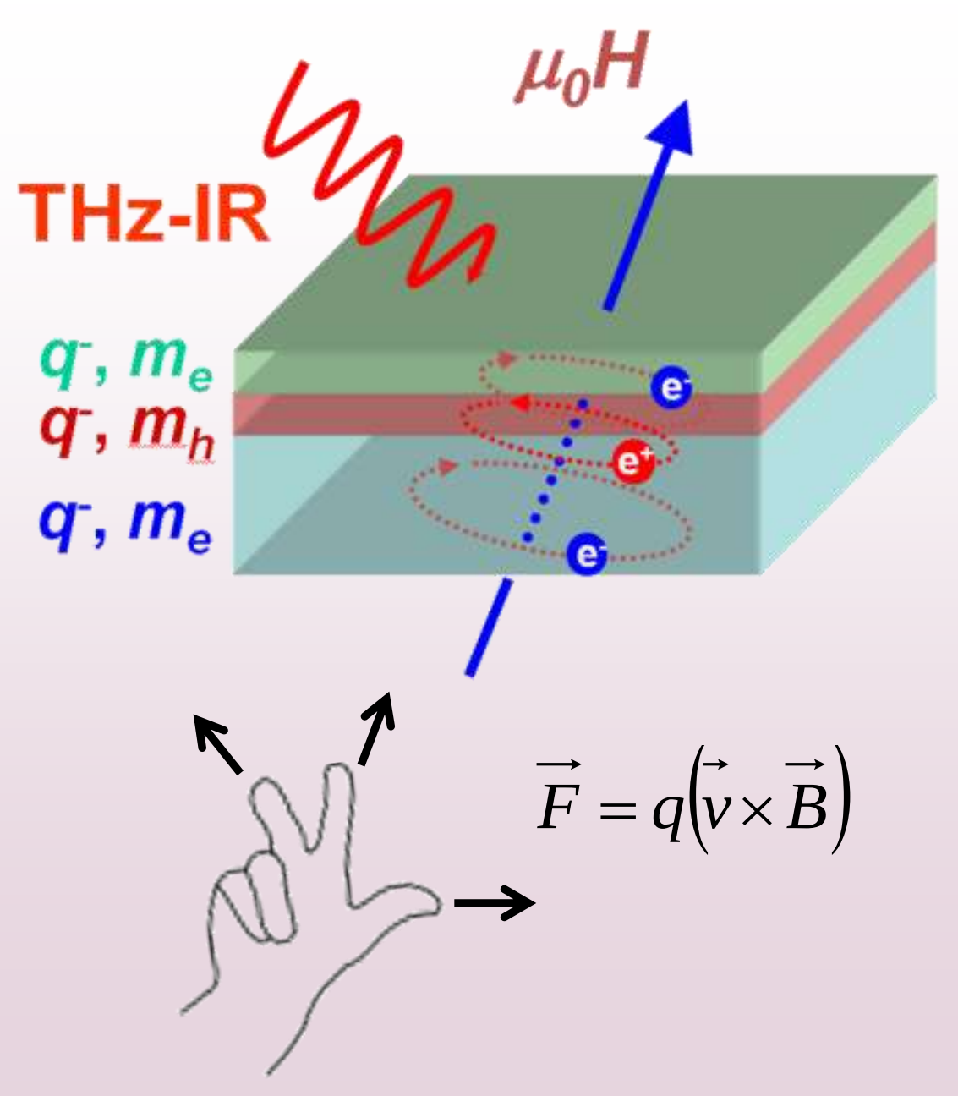
LO phonon-plasmon coupling (Kukharskii-model) [2]:

$$\varepsilon_{\perp,\|}(\omega)=\varepsilon_{\perp,\|;\infty}\frac{(\omega^2+i\gamma_{LPP-;\perp,\|}\omega-\omega^2_{LPP-:\perp,\|})\cdot(\omega^2+i\gamma_{LPP+;\perp,\|}\omega-\omega^2_{LPP+:\perp,\|})}{\omega(\omega+i\gamma_{P;\perp,\|})\cdot(\omega^2+i\gamma_{TO;\perp,\|}\omega-\omega^2_{TO:\perp,\|})}$$

2 branches: LPP$^+$ and LPP$^-$

$$\omega_{LPP-/+}=\left\{\frac{1}{2}\left[\omega_p^2+\omega_{LO}^2\pm\sqrt{(\omega_p^2+\omega_{LO}^2)^2-4\omega_p^2\omega_{TO}^2}\right]\right\}^{1/2}$$

plasma frequency: $\omega_p^2=N\frac{q^2}{m^*\varepsilon_0\varepsilon_\infty}$ **plasma broadening**: $\gamma_p=\frac{e}{m^*\mu}$



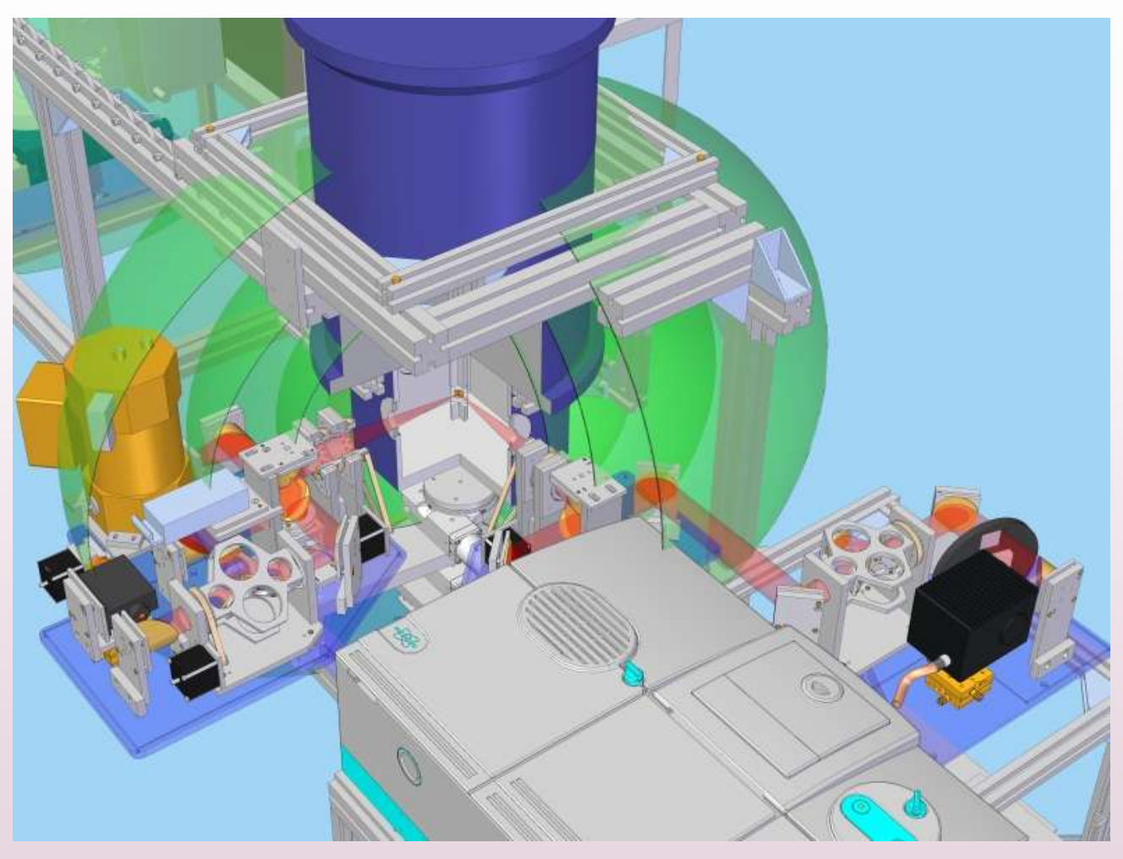
FIR optical Hall-effect

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

$$\varepsilon^{(FC-MO)}(\omega,\boldsymbol{H})=-\left\langle\omega_p^{*2}\right\rangle\left[(\omega^2+i\omega\boldsymbol{\gamma})\boldsymbol{I}-i\omega\langle\omega_c\rangle\begin{pmatrix}0&-h_3&h_2\\h_3&0&-h_1\\-h_2&h_1&0\end{pmatrix}\right]^{-1}$$

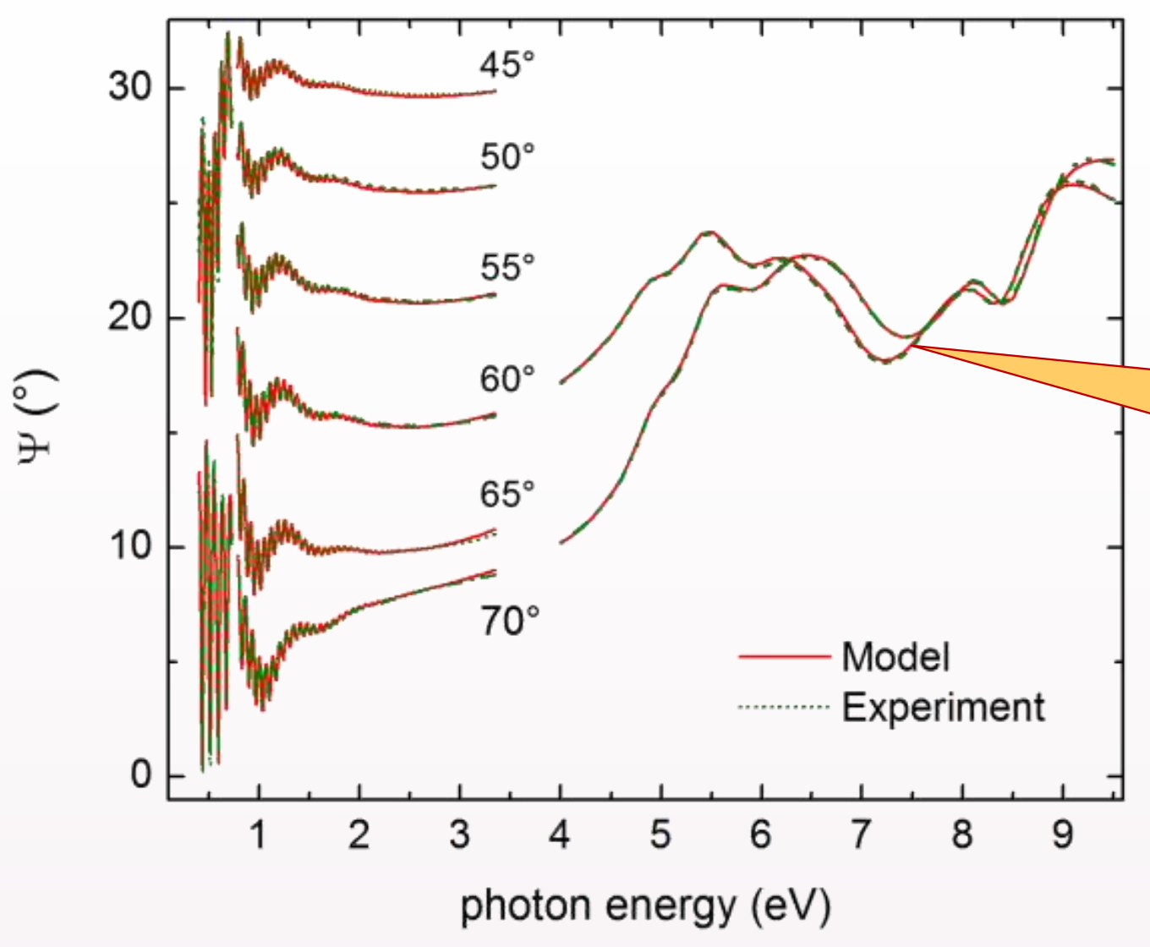
Plasma (frequency) tensor $\left\langle\omega_p^{*2}\right\rangle\equiv N\frac{q^2}{m_e}\boldsymbol{m}^{-1}$

Cyclotron (frequency) tensor $\langle\omega_c\rangle\equiv H\frac{q}{m_e}\boldsymbol{m}^{-1}$

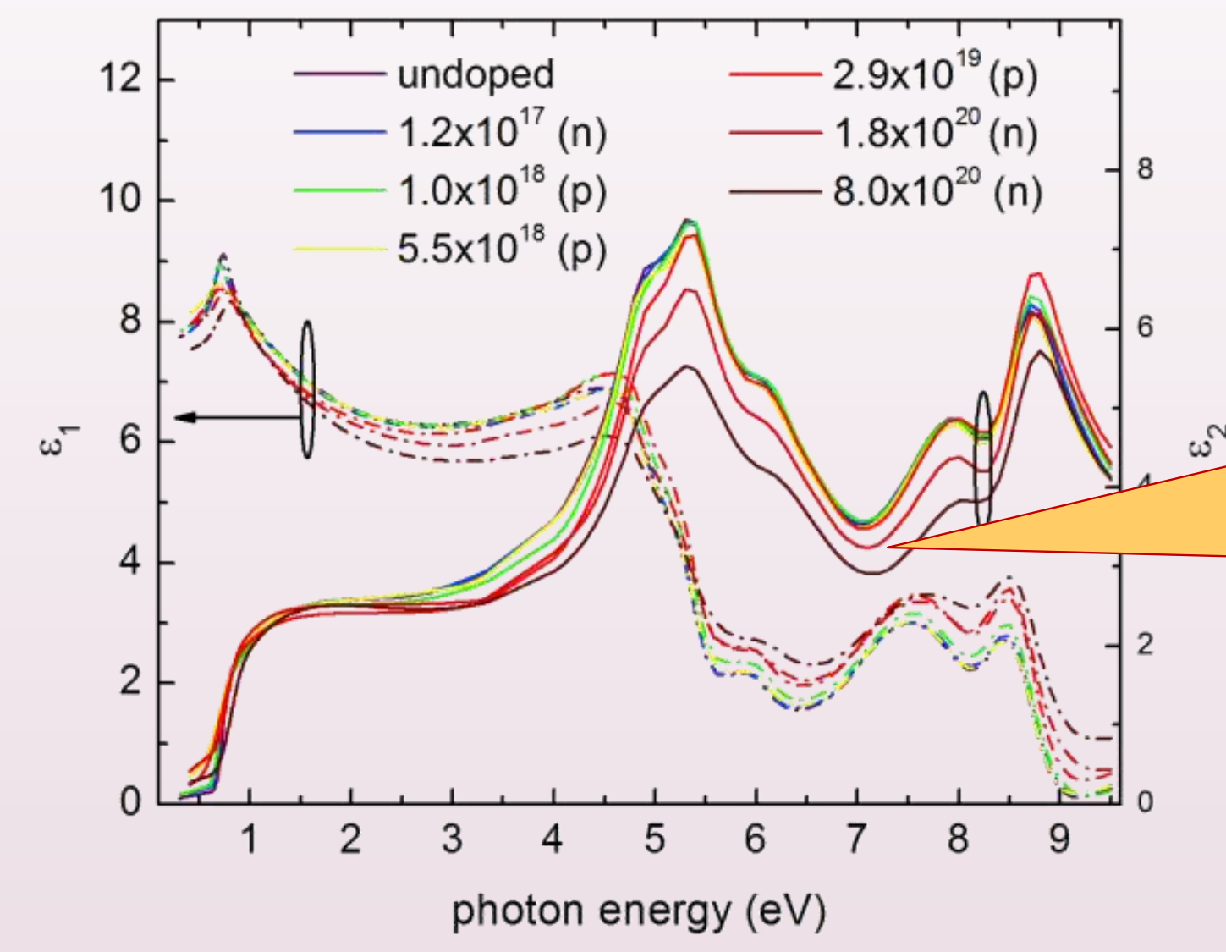


Experimental Results

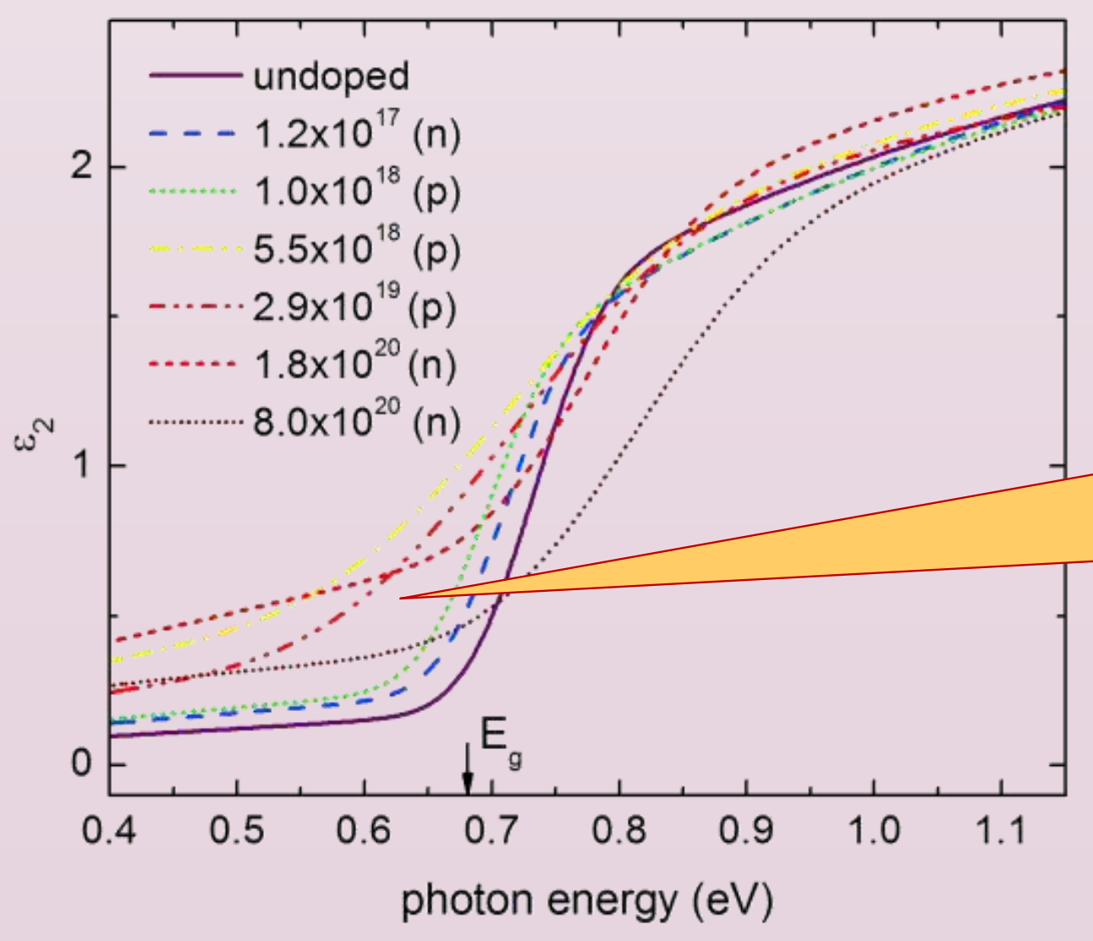
NIR-VIS-UV-VUV SE



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

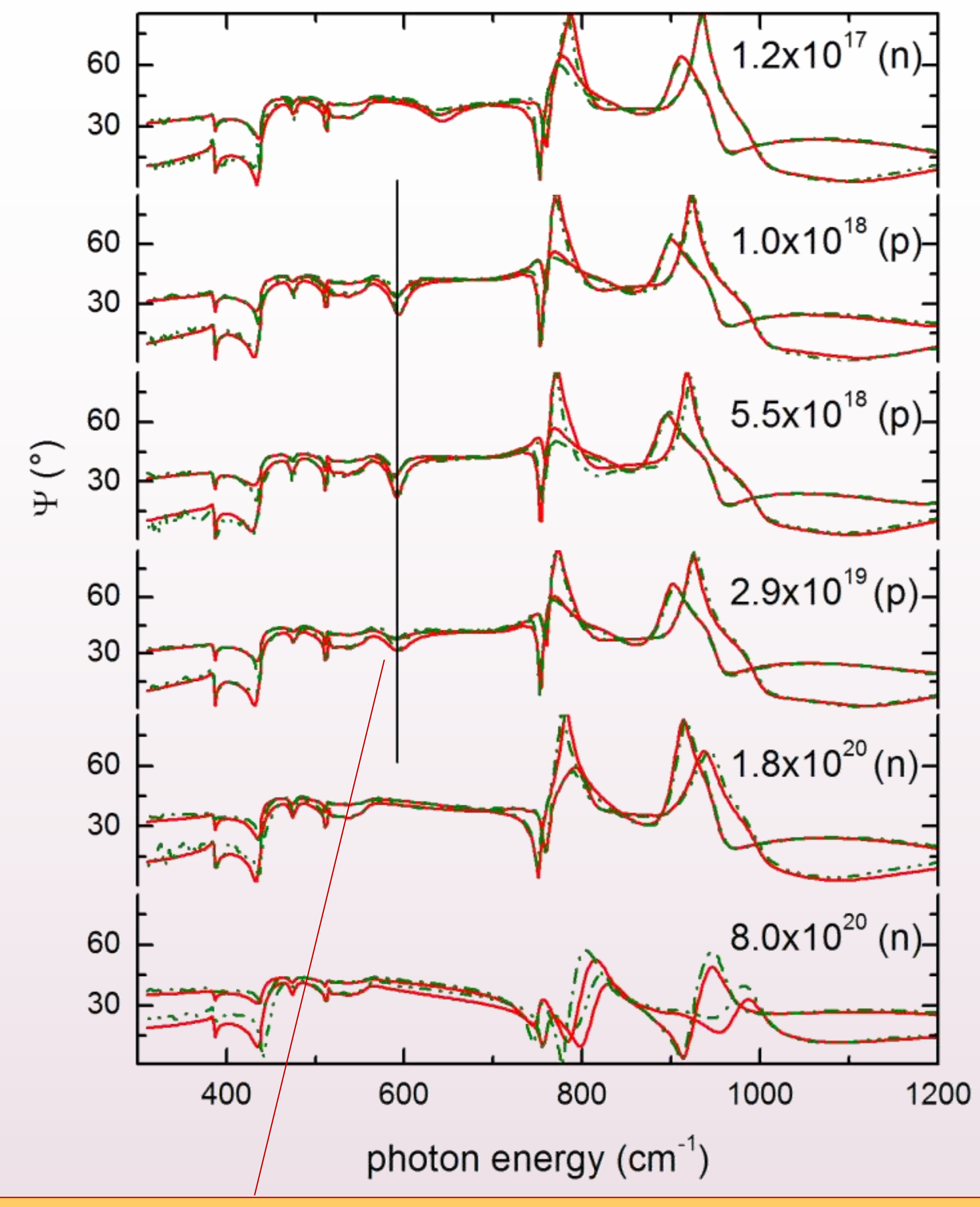


- no shift of transition energies with increasing [Mg]
- decreasing absorption strength, increasing broadening and increasing surface roughness with increasing [Mg]

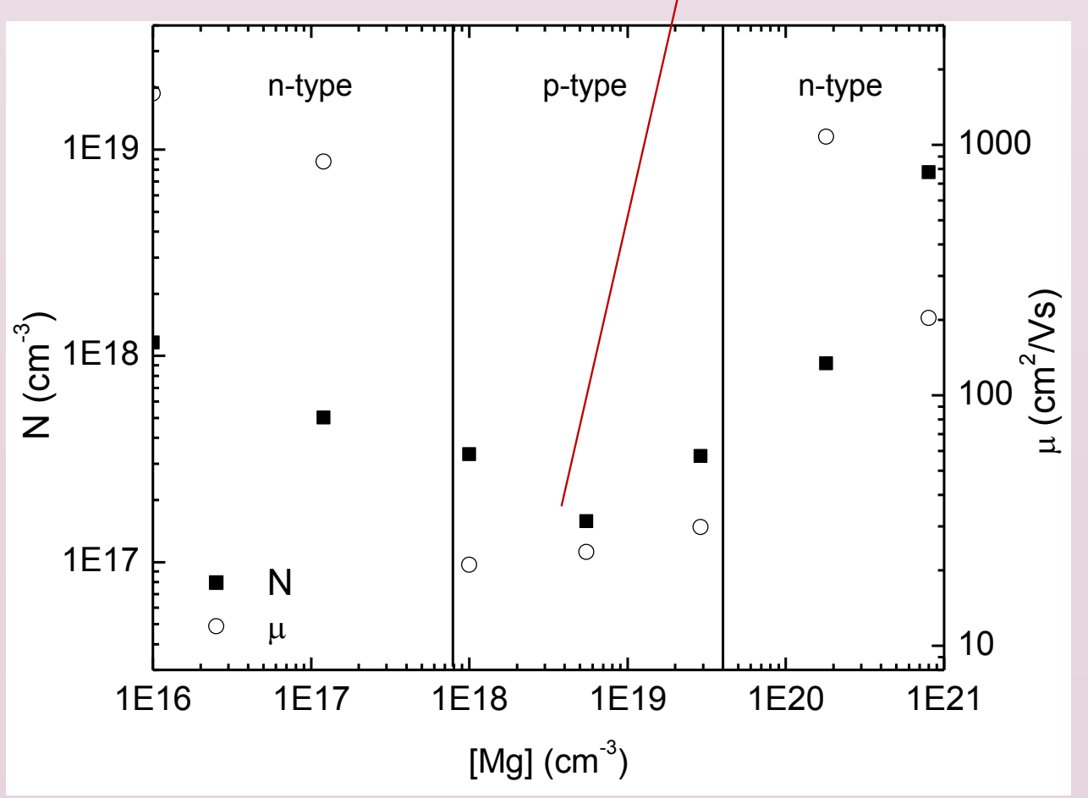


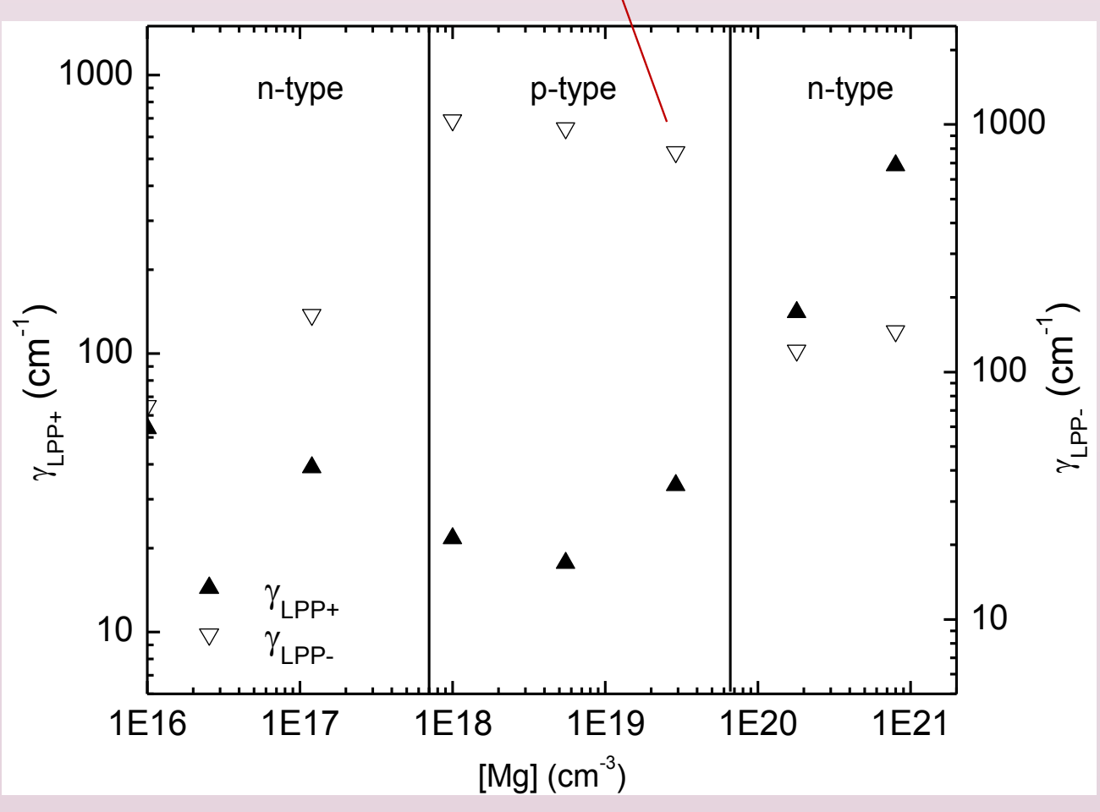
- Urbach tail below band gap for increasing [Mg]
- Burstein-Moss shift for very high Mg concentration

IRSE

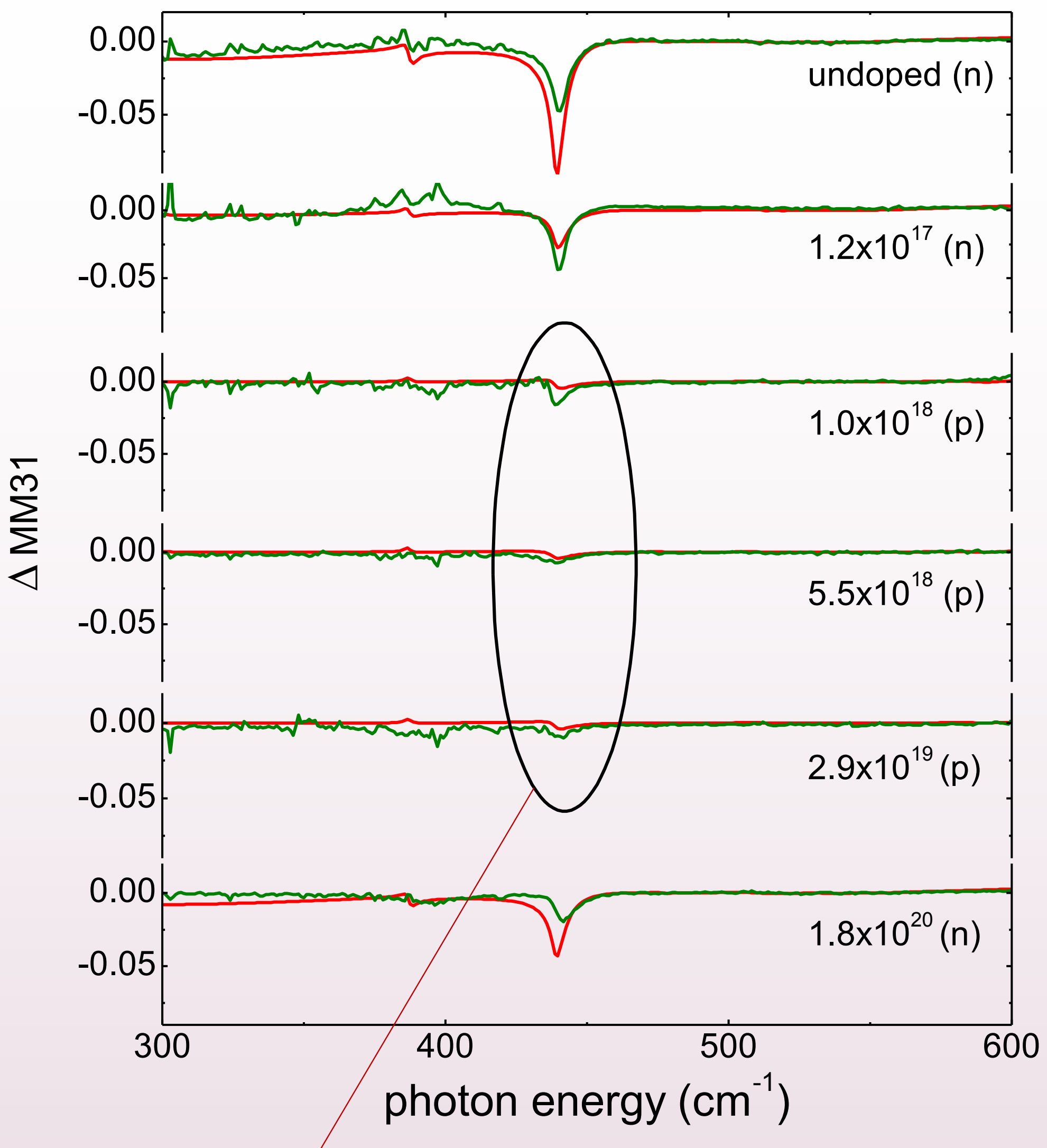


characteristic peak in the IRSE spectra due to weak longitudinal optical phonon-plasmon coupling (LPP) for smaller mobility and higher effective mass of holes





FIR-Optical Hall-Effect



Decrease of carrier-induced birefringence in OHE data due to higher effective mass and significantly lower mobility of holes

References

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