Size dependences III-nitride nanowires

R. Calarco 1,2

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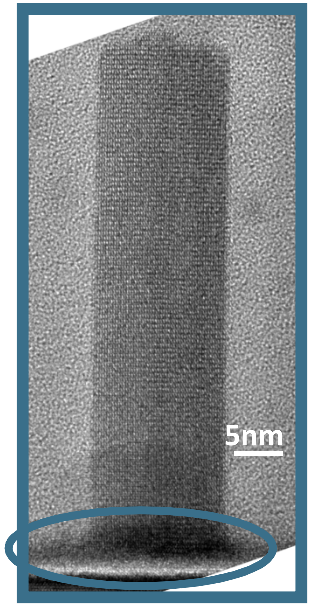
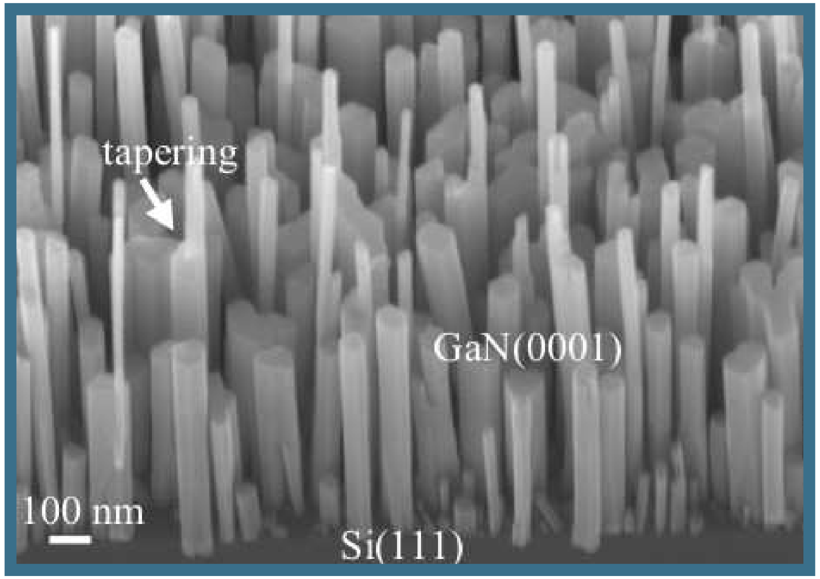
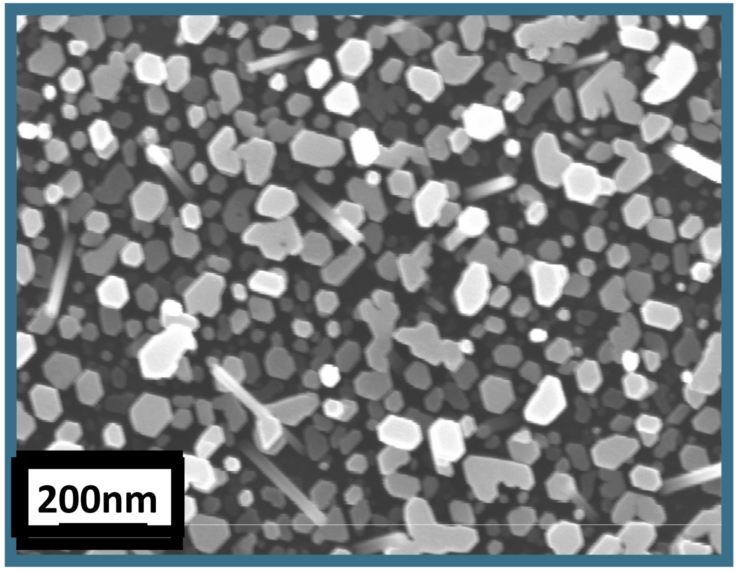
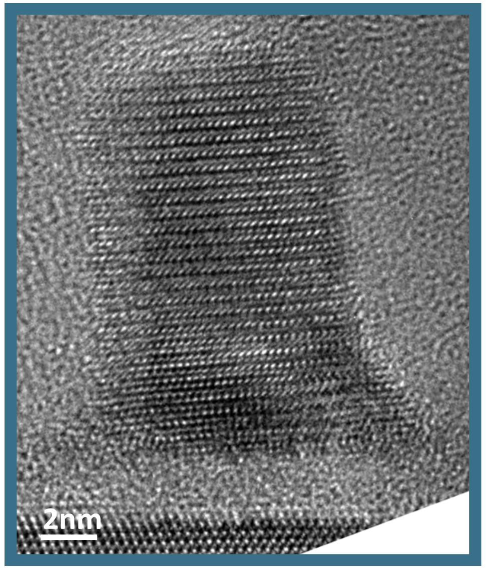
Crystalline quality









MBE-grown NWs in N-rich conditions

Hexagonal shape

Growth direction // GaN [0001]

Length: 0.3 - 2 µm

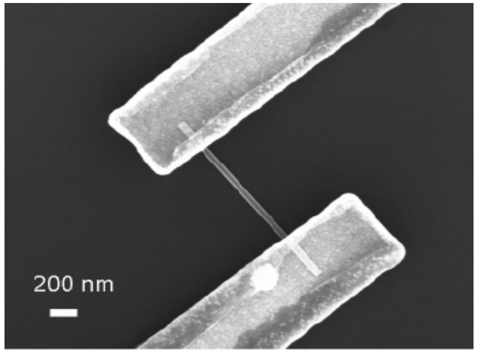
Diameter: 20-500 nm

Interface: amorphous layer

T. Stoica et al. Small 4, 751 (2008)

R. Meijers et al. J. of Cryst. Growth 289, 381 (2006)

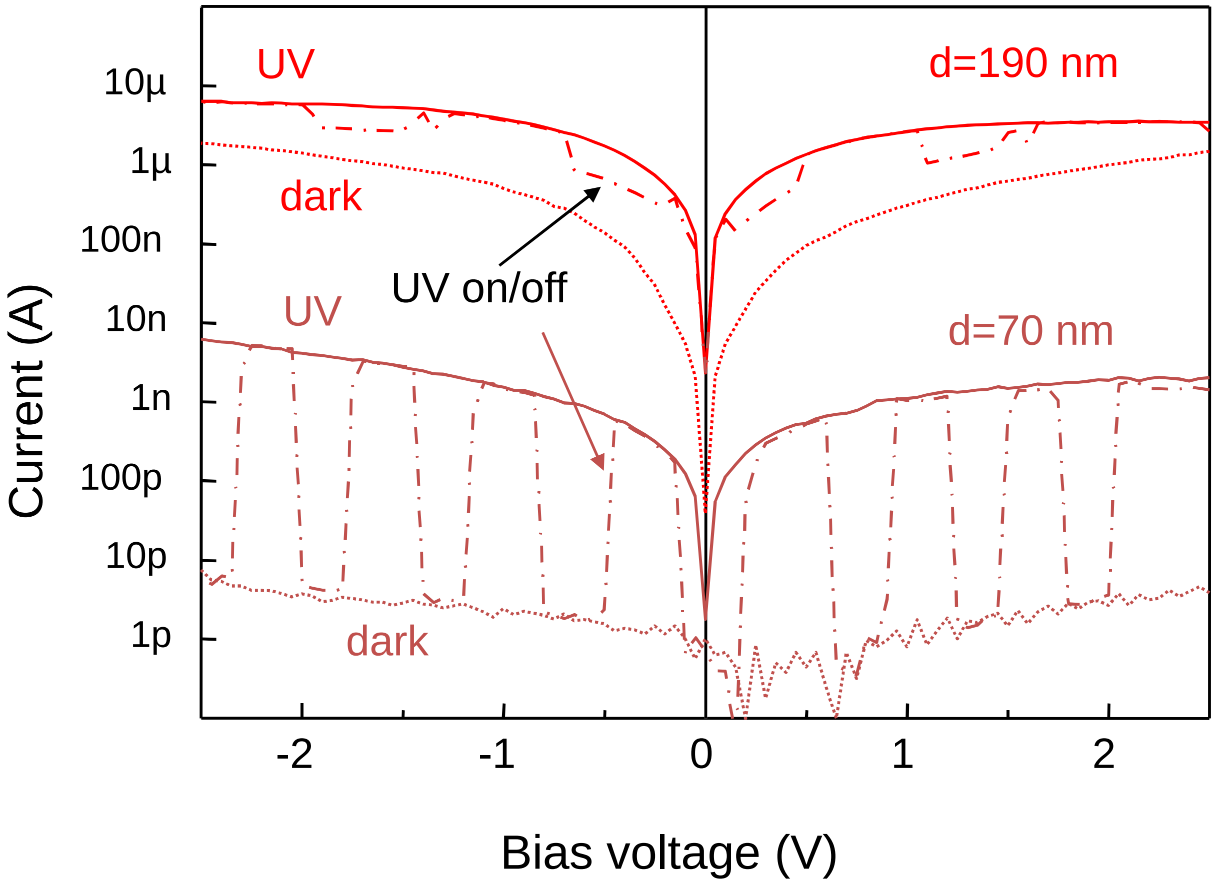
Electrical transport



• currents decrease strongly for small diameters

• significant relative increase for small diameters under UV illumination

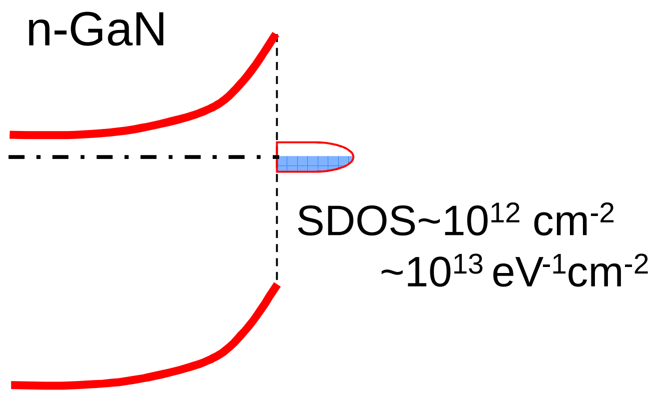
•PPC after switching off UV light



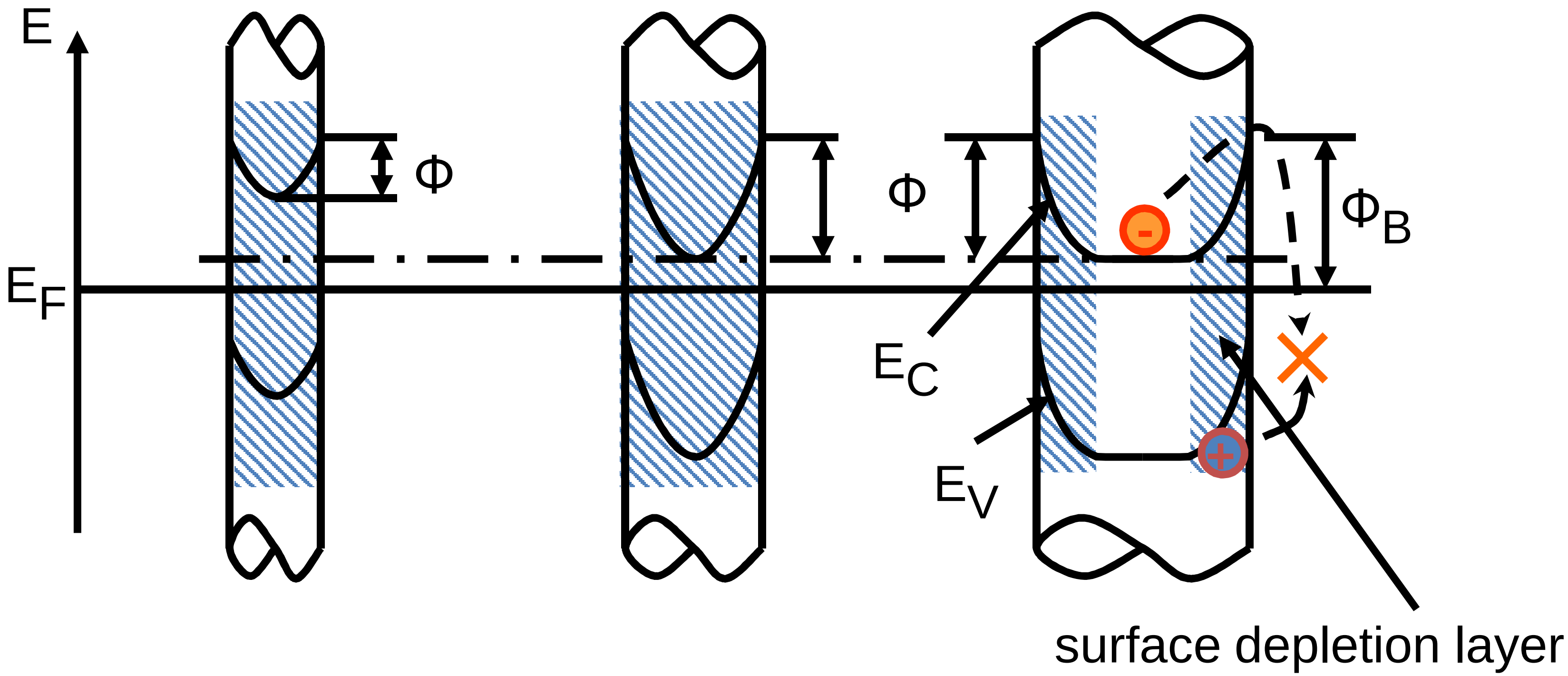
R. Calarco et al. Nano Letters 5, 981 (2005)

L. Polenta et al. ACS Nano 2, 287 (2008)

Recombination model



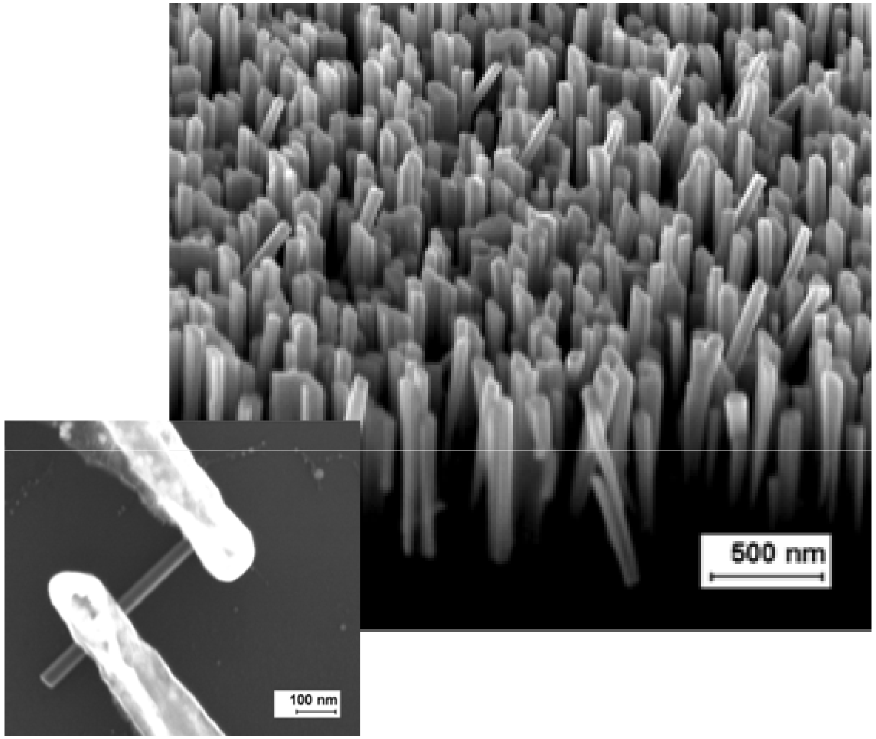
Pinning of E_F
at the surface
$\Rightarrow$ depletion

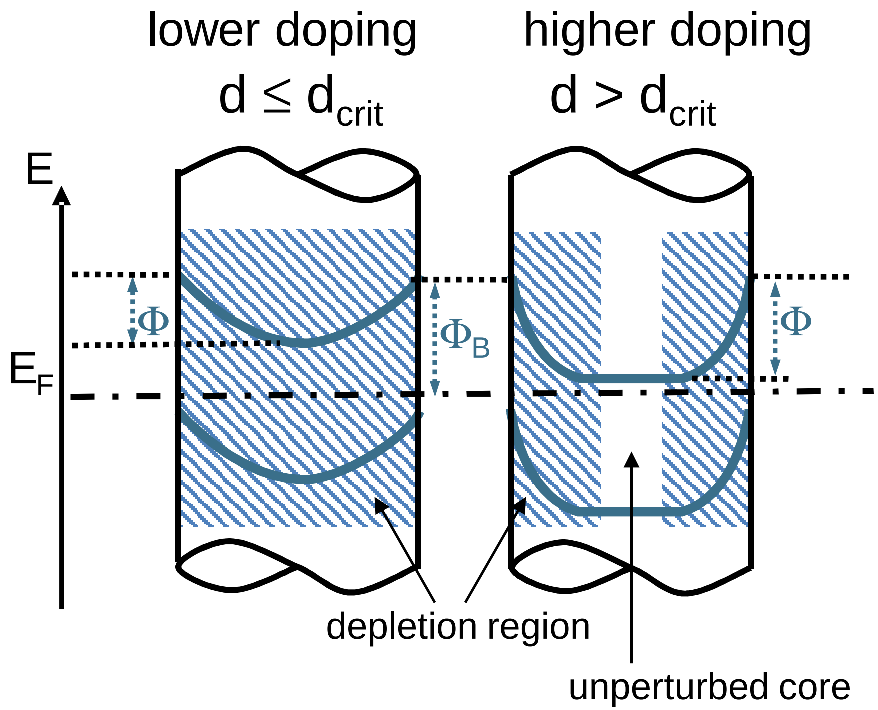


R. Calarco et al. Nano Letters 5, 981 (2005)

Si-doped GaN NWs

$$PC \sim d / \exp(-\Phi/kT)$$

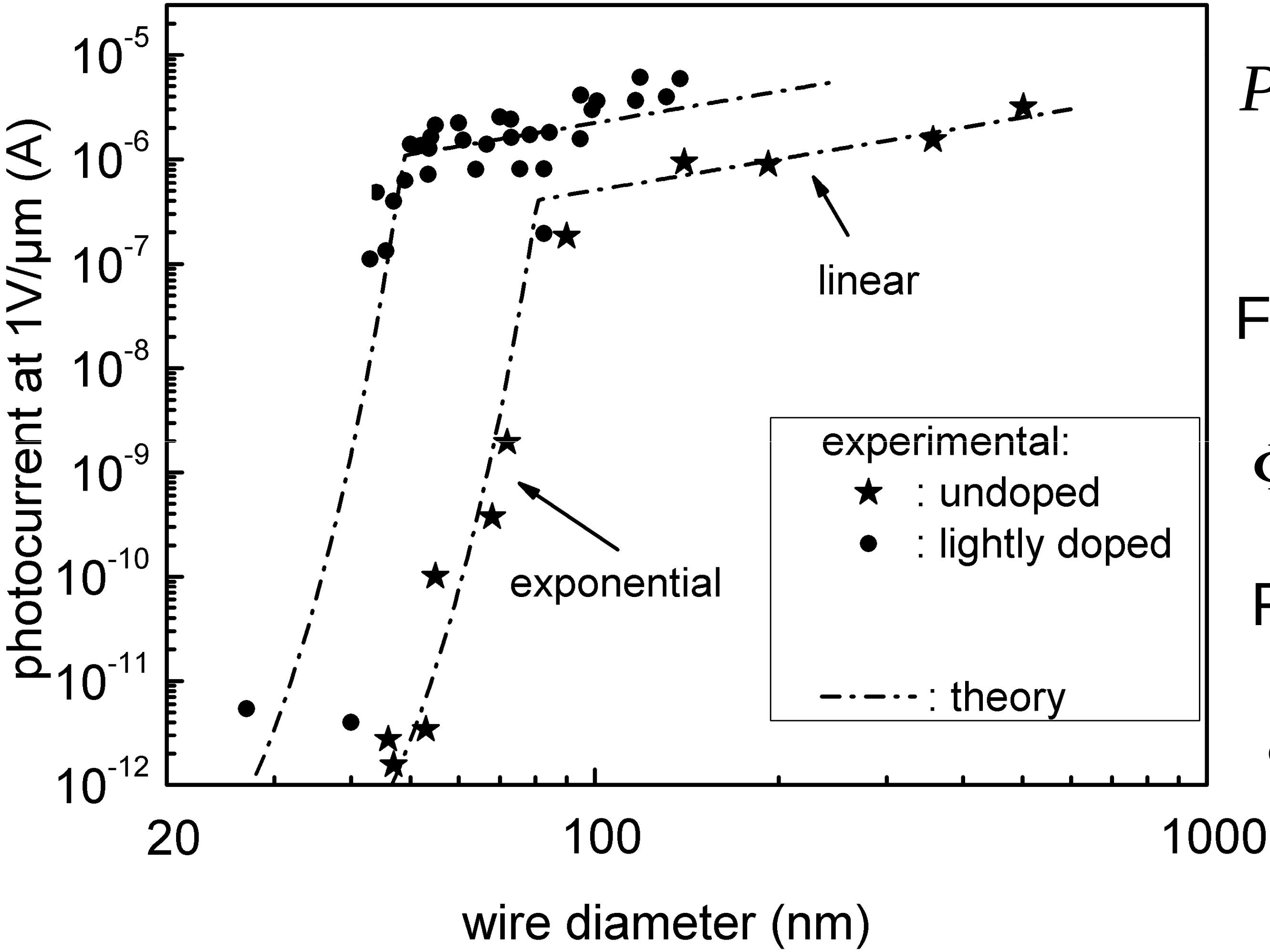




	carrier concentration	critical diameter
undoped	6.2×10^{17} cm^{-3}	80 nm
doped	1.8×10^{18} cm^{-3}	50 nm

T. Richter et al. Nano Letters 8(9); 3056 (2008)

Size-dependent photoconductivity



$$PC \propto d \Big/ \exp\left(-\Phi / kT\right)$$

For $d<d_{crit}$

$$\Phi = eN_D d^2 / 16\varepsilon\varepsilon_0$$

For $d>d_{crit}$

$$\Phi = eN_D d_{crit}^2 / 16\varepsilon\varepsilon_0$$

R. Calarco et al. Nano Letters Vol. 5, , 981, (2005)

T. Richter et al. Nano Letters 8(9); 3056 (2008)

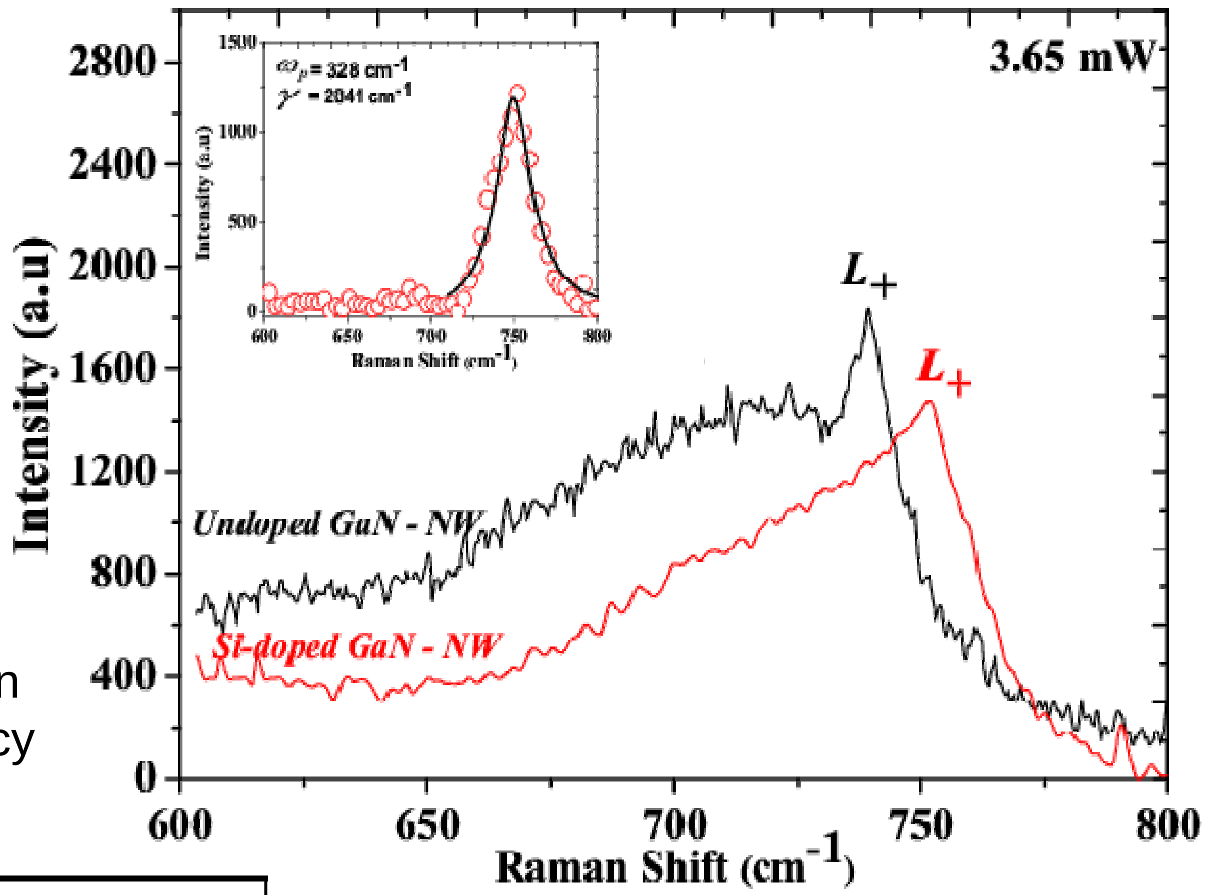
Si-doped GaN NWs: Raman

L+ mode shifts to higher frequency and broadens with increasing carrier concentration.

$$\omega_p^2 = \frac{\pi n e^2}{\varepsilon_\infty m^*}$$

plasmon frequency

$m^*=0.2m_e$

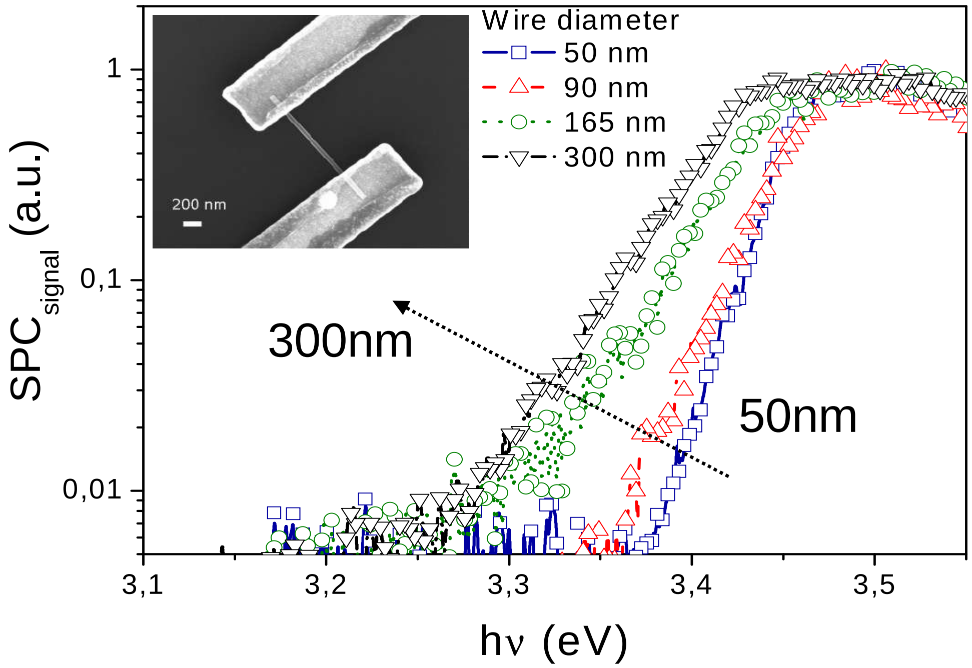


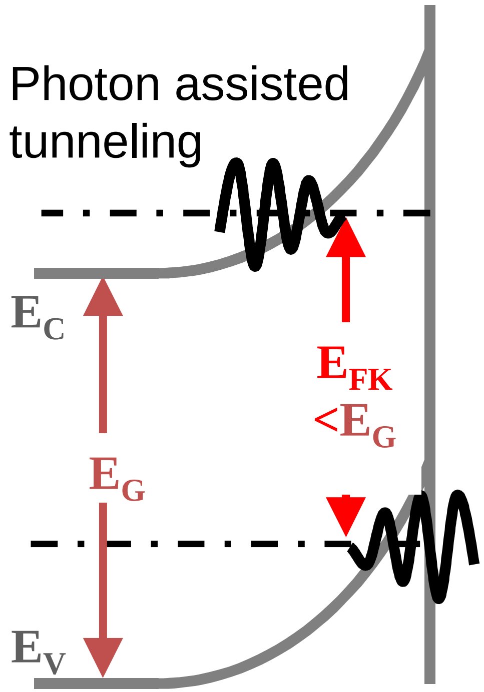
	carrier concentration
undoped	2.0×10^{17} cm^{-3}
doped	1.8×10^{18} cm^{-3}

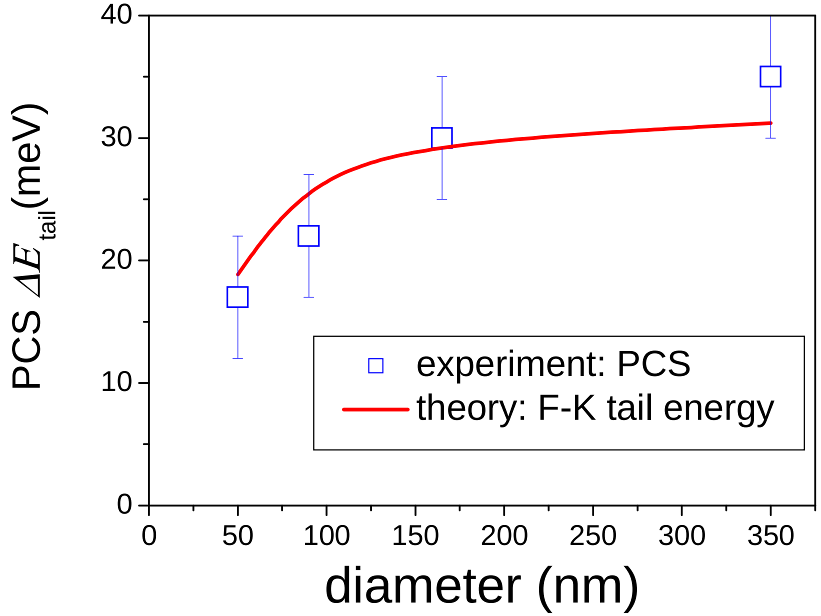
mobility=460 cm2V-1s-1

K. Jeganathan et al. JAP , 105, 123707 (2009)

Spectral photocurrent: Franz-Keldysh effect



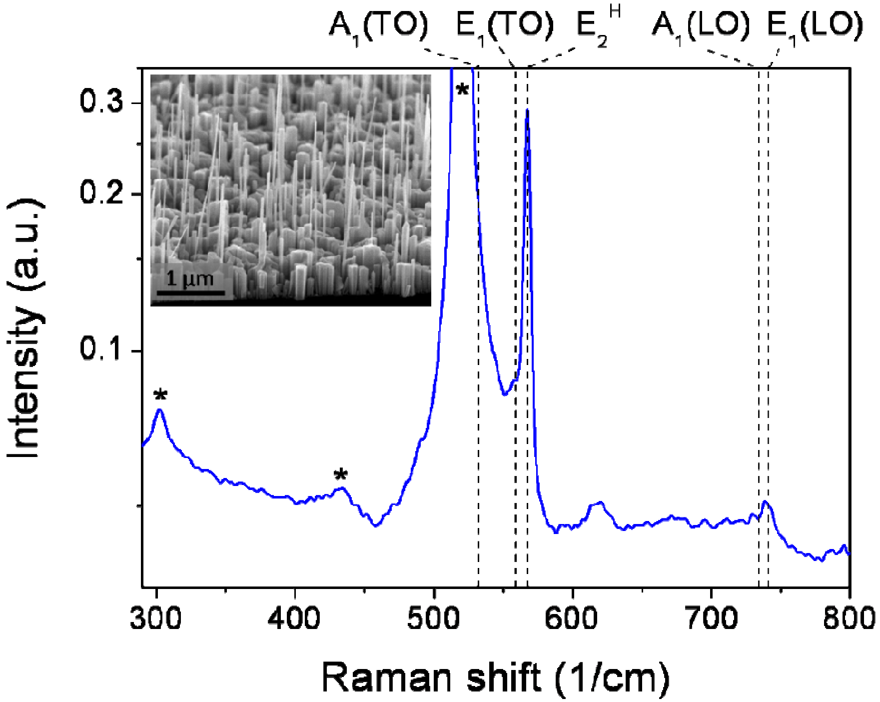


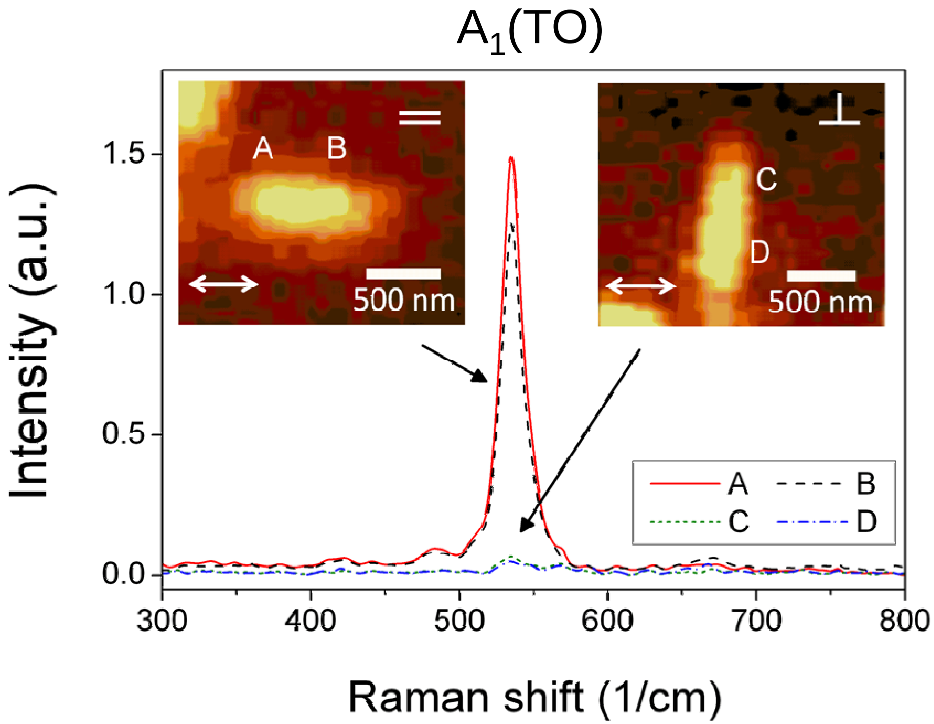


PC ~ α ~ exp(hν/Δ*E*$_{tail}$)
absorption coefficient α

A. Cavallini et al. Nano Letters, 7 (2007), 2166

GaN NWs: Raman





quasi backscattering geometry

Frequencies consistent with strain free values from literature

A_1(TO) suppressed if laser polarization perpendicular to NW axis.

FWHM(E_2^{high}) = 2.8 cm^{-1}
=> good crystalline quality

penetration of the laser light and Raman scattering in isolated GaN nanowires thinner than 100 nm is governed by size effects

E. O. Schäfer-Nolte, et al.App. Phys. Lett. ***96*** *091907 (2010)*

PAMBE grown InN NWs on Si(111)

Growth under N-rich conditions:

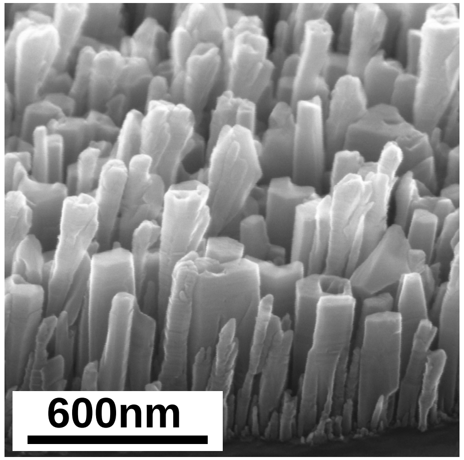
Φ_N= 4 sccm
P_{RF} = 500 W

Distinctive property :

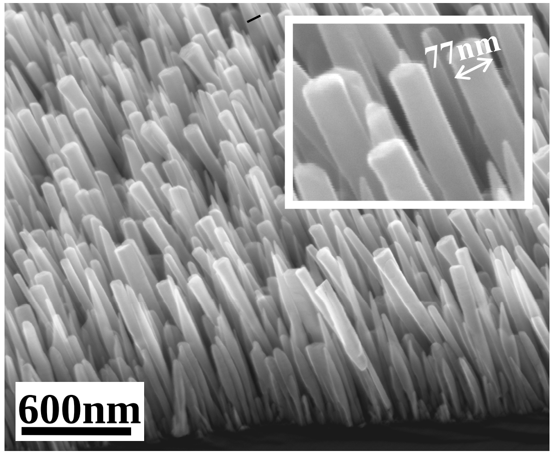
→InN decomposes at relatively low temperatures

Effect of substrate temperature on morphology

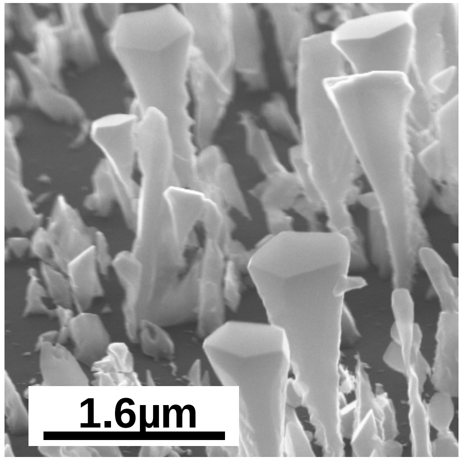
T_{sub}=440°C



T_{sub}=475°C



T_{sub}=525°C

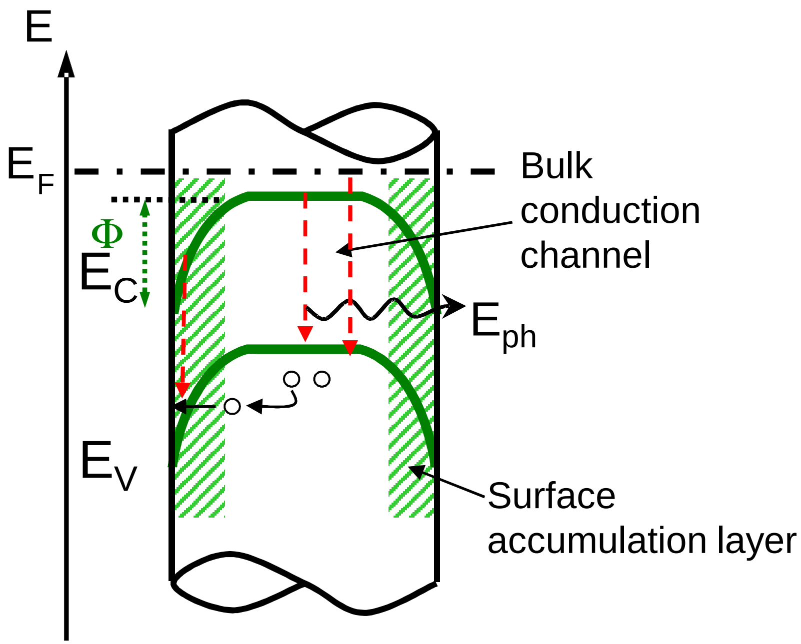


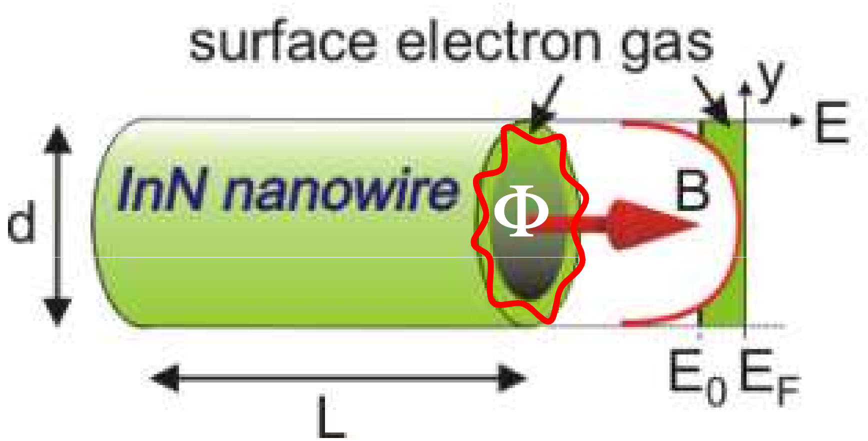
Φ_{in} = 3.9 x 10^{-8} mbar

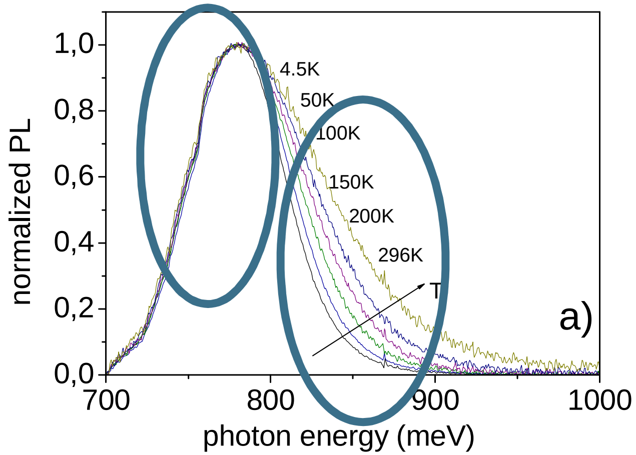
T. Stoica et al. J. Cryst. Growth, 290(1), 241-247, (2006)
T. Stoica et al. Nano Letters, 6(7), 1541-1547, (2006)

"III-Vs review the advanced semiconductor magazine" vol.19, no 3, pg.45 (2006)

InN a degenerated semiconductor





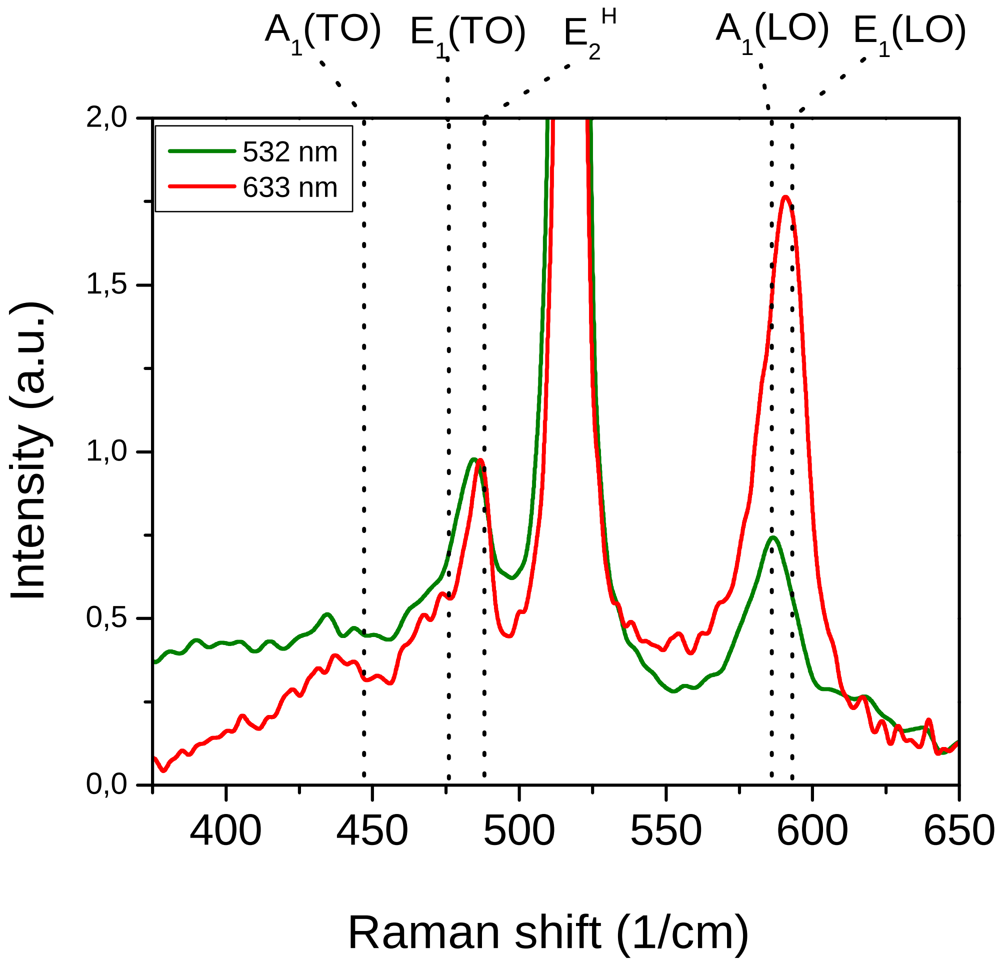


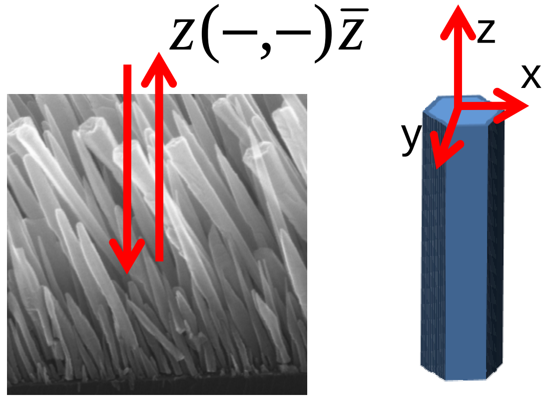
magnetoconductance oscillations attributed to the occurrence of single magnetic flux quantum periodicity induced by phase-coherent circular states

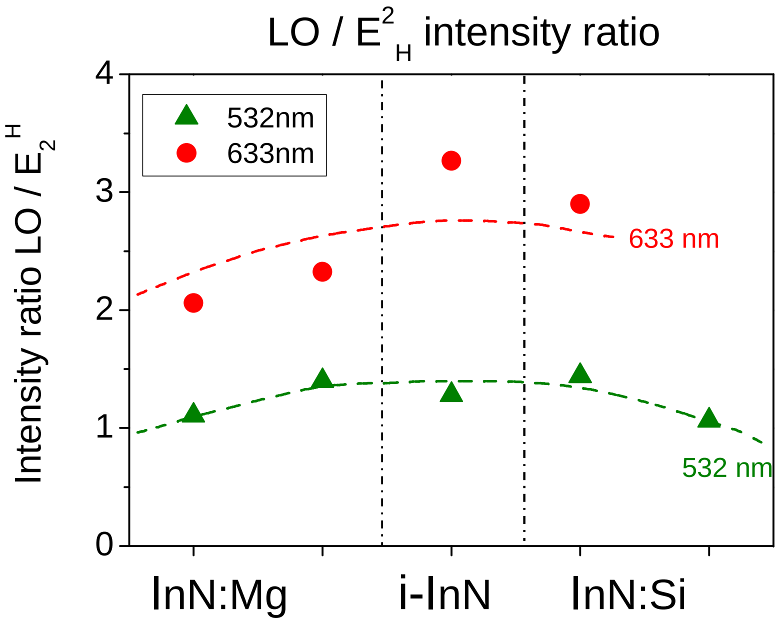
T. Stoica et al. Nano Letters, 6(7), 1541-1547, (2006)

T. Richter et al., Nano Letters 8, 2834 (2008)

Raman – nanowire ensemble







→ Strong increase in LO intensity for 633 nm excitation wavelength

T. Stoica et al. Nanotechnology 21, 315702 (2010)

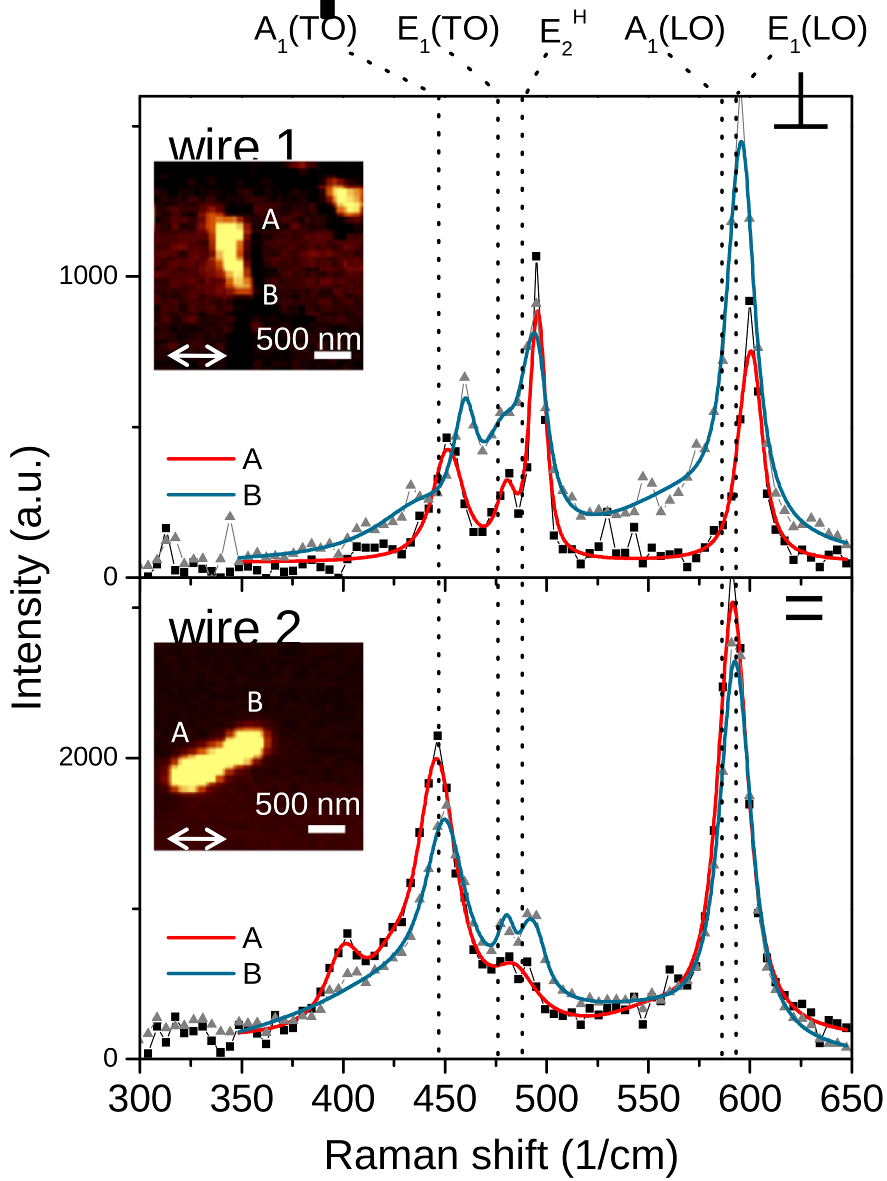
Similar for thin films in Kuball et al., PSSa (2005)

Polarization dependency of single NW Raman spectra

intense symmetry-forbidden LO mode

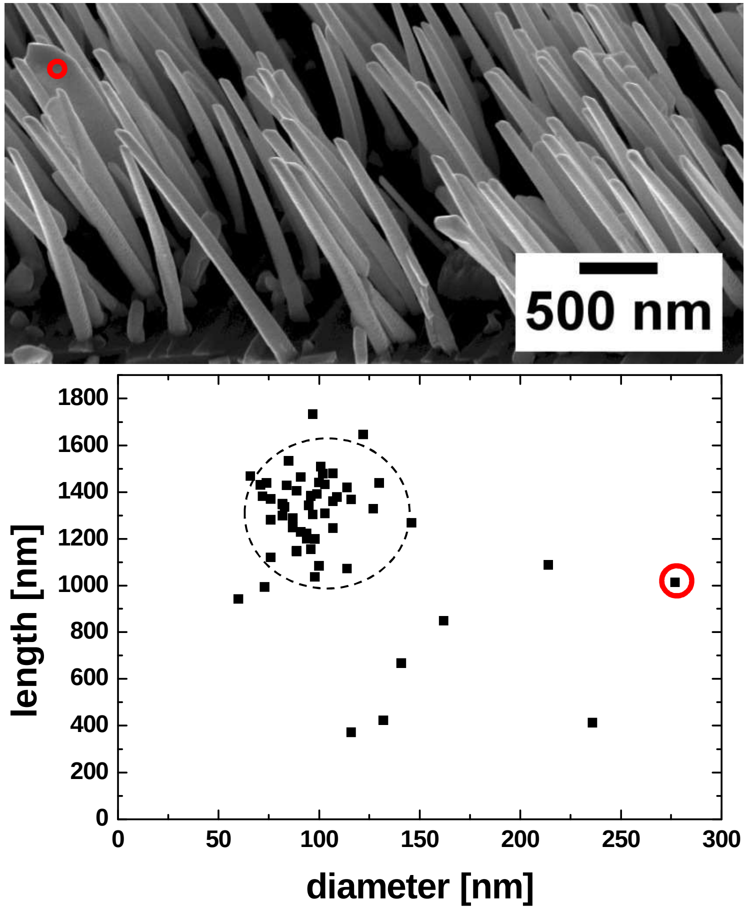
relative intensities of A_1(TO) and E_2^H strongly depend on nanowire orientation

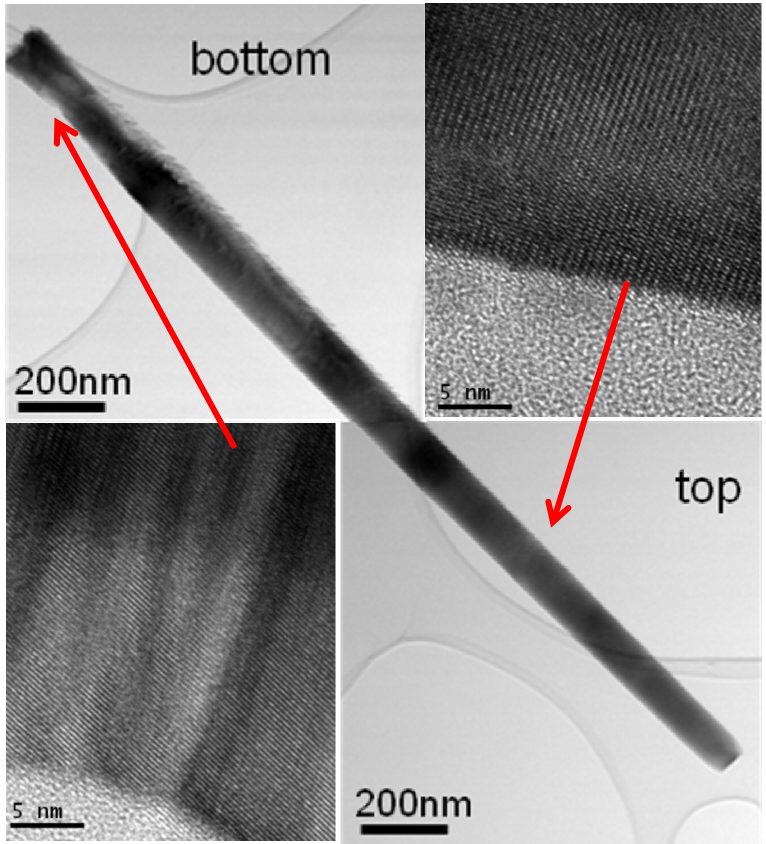
	Configuration	Phonon modes
⊥	$x(y,y)\bar{x}$	$A_1(TO), E_2$
=	$x(z,z)\bar{x}$	$A_1(TO)$
=,⊥	$x(z,y)\bar{x}$	$E_1(TO)$



T. Stoica et al. Nanotechnology 21, 315702 (2010)

InN:Si Optimal growth





- Density: 6.8 x 10^{8} cm^{-2}
- Small fluctuation of diameter and length
- Aspect ratio: 14

- Smooth lateral surfaces
- Good crystalline quality

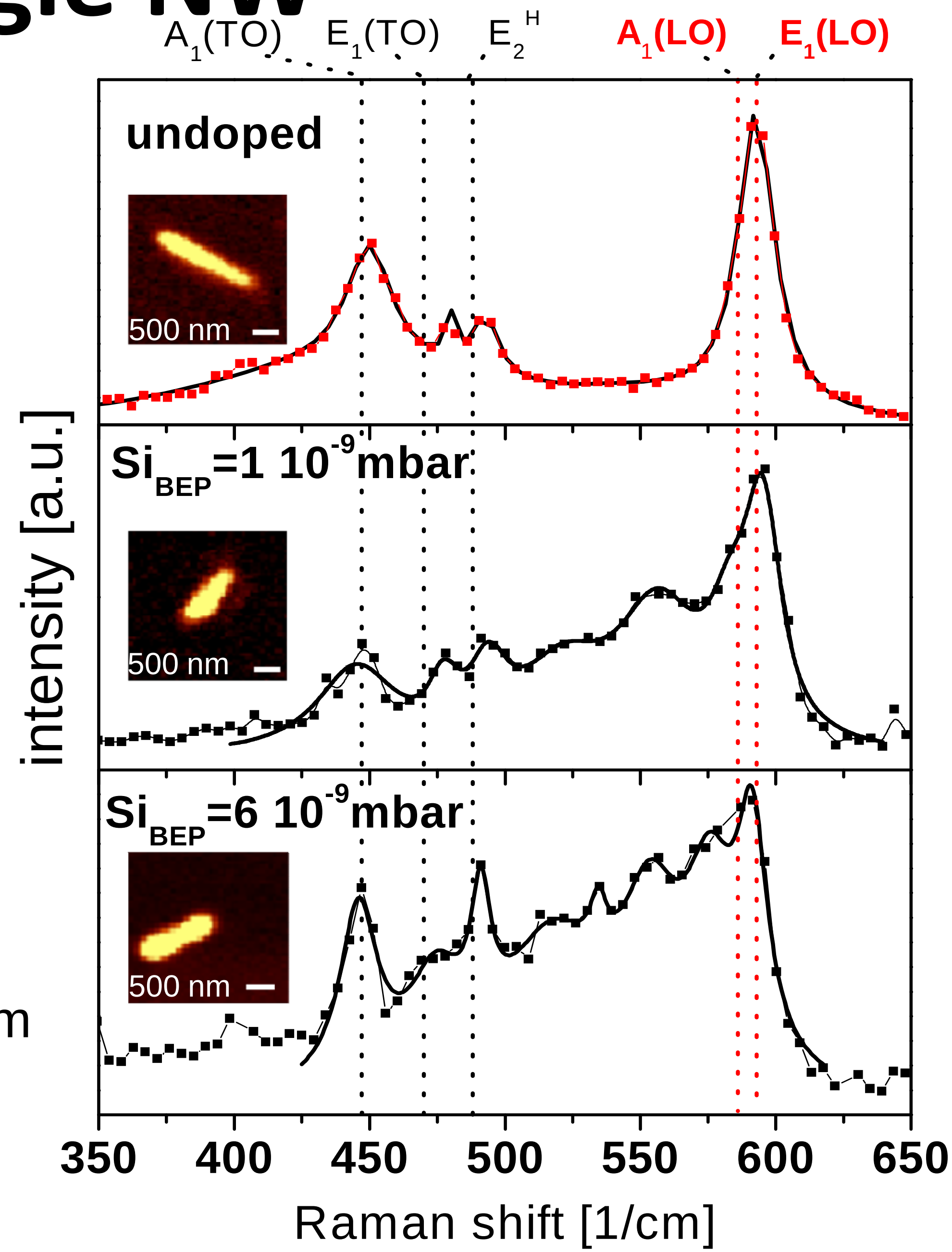
T. Gotschke et al. accepted Nanotechnology 2011

Raman - single NW

Occurrence of uncoupled LO mode and its scattering mechanism are still under discussion in literature

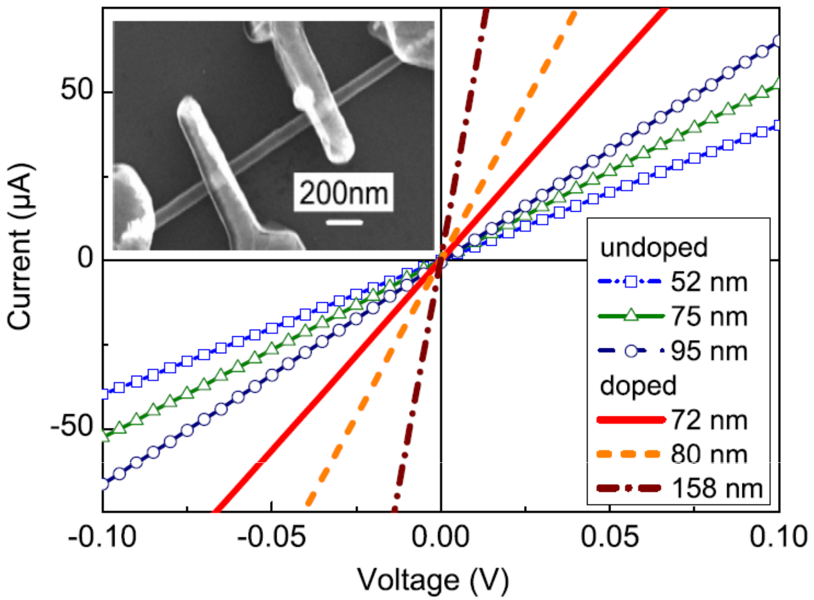
strong LO even both A1(LO) and E1(LO) are symmetry-forbidden

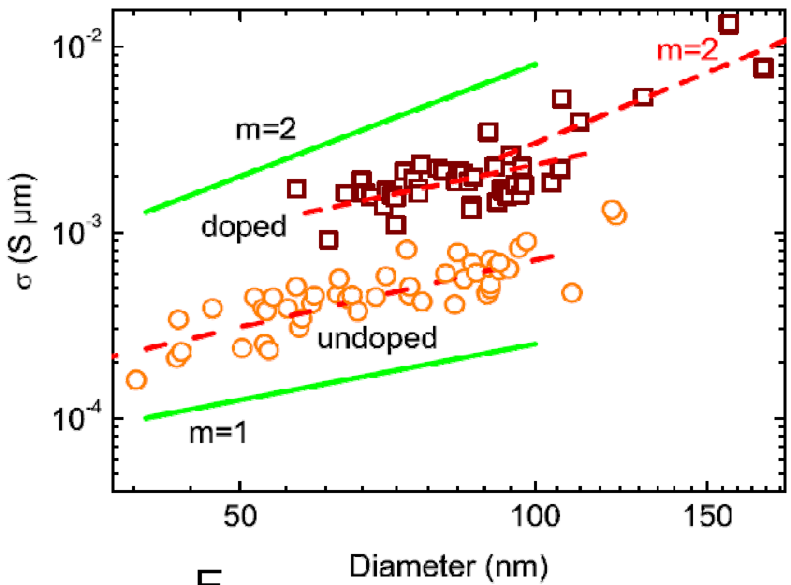
emerging low energy tail of the LO mode with doping due to interaction with electronic subsystem

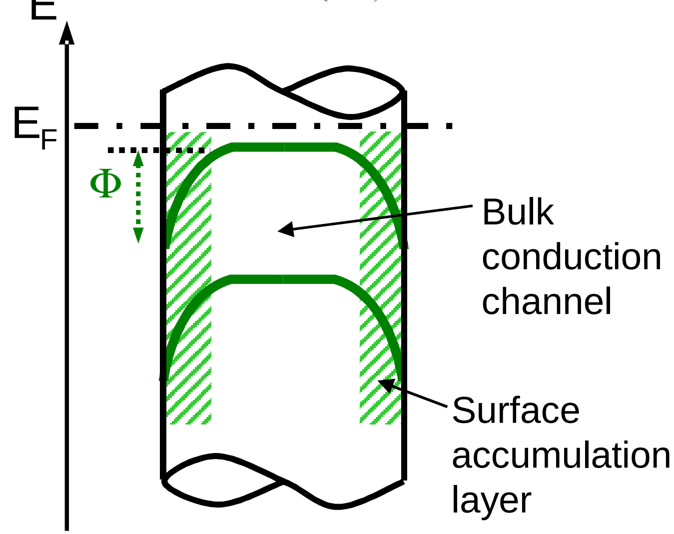


T. Stoica et al. Nanotechnology 21, 315702 (2010)

Electrical characterization





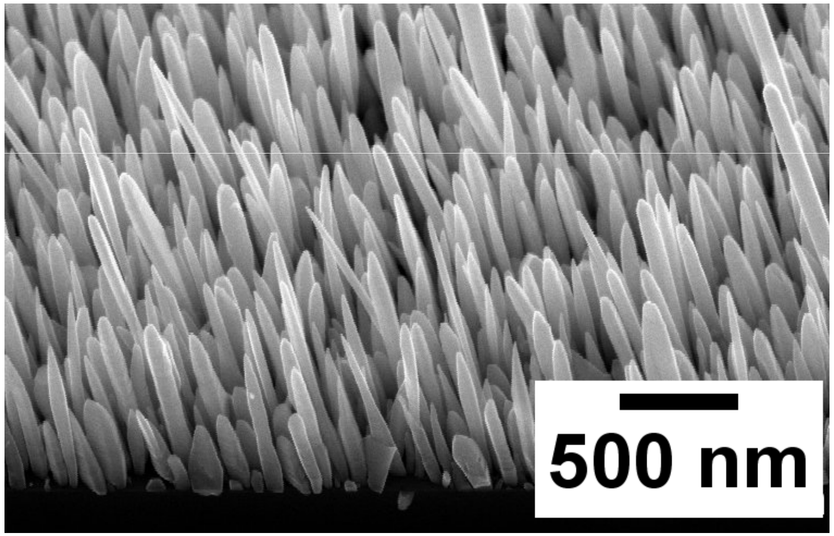


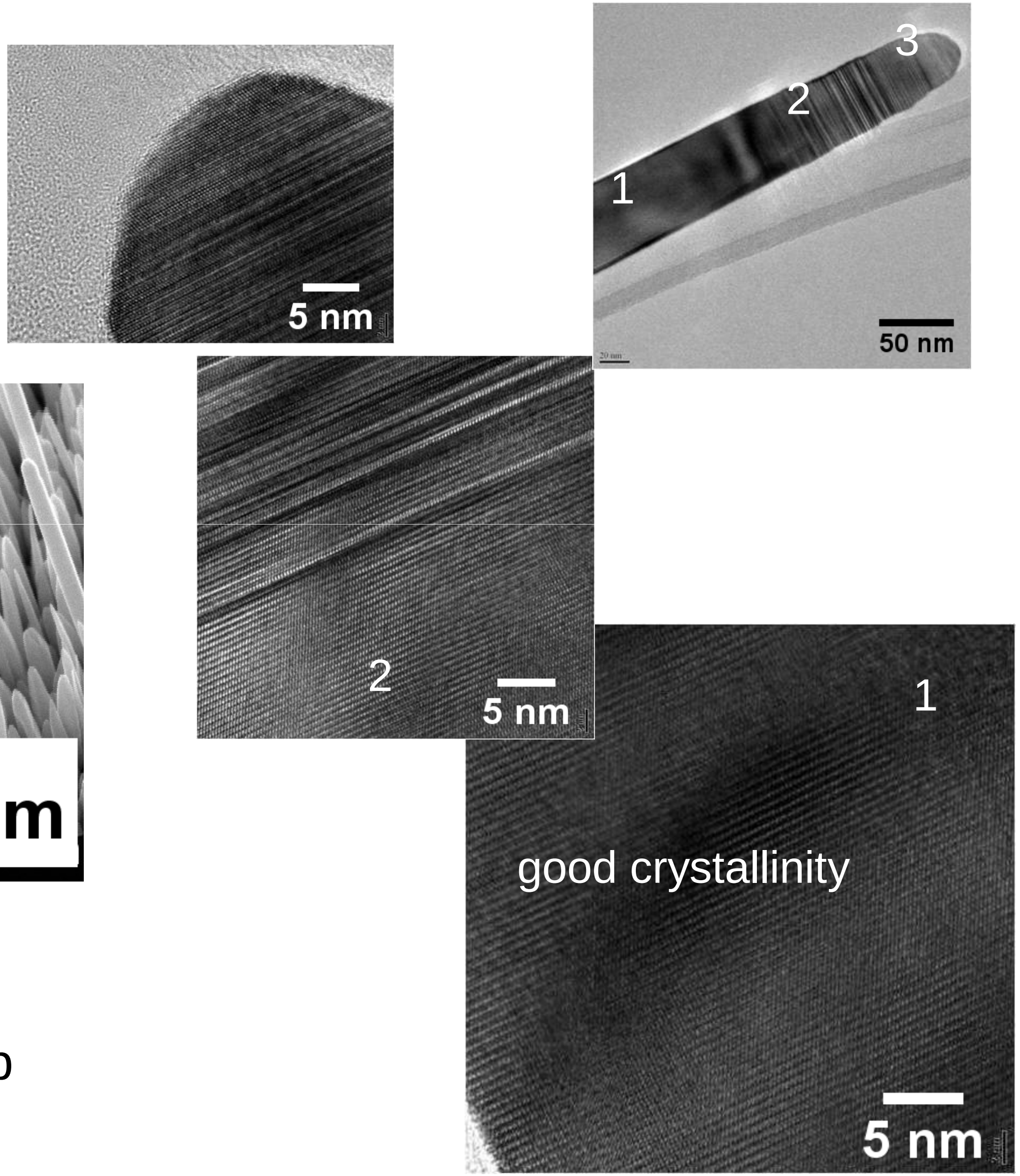
- Major carrier transport mechanism occurs in a tube-like surface accumulation layer
- Successful Si doping

T. Richter et al., Nanotechnol. 20, 405206 (2009)
T. Richter et al., Nano Lett. 8, 2834 (2008)

TEM investigation of InN:Mg

Φ_{In} = 4 x 10^{-8} mbar
Φ_{Mg} = 0.5 x 10^{-9} mbar
T_{sub} = 487℃



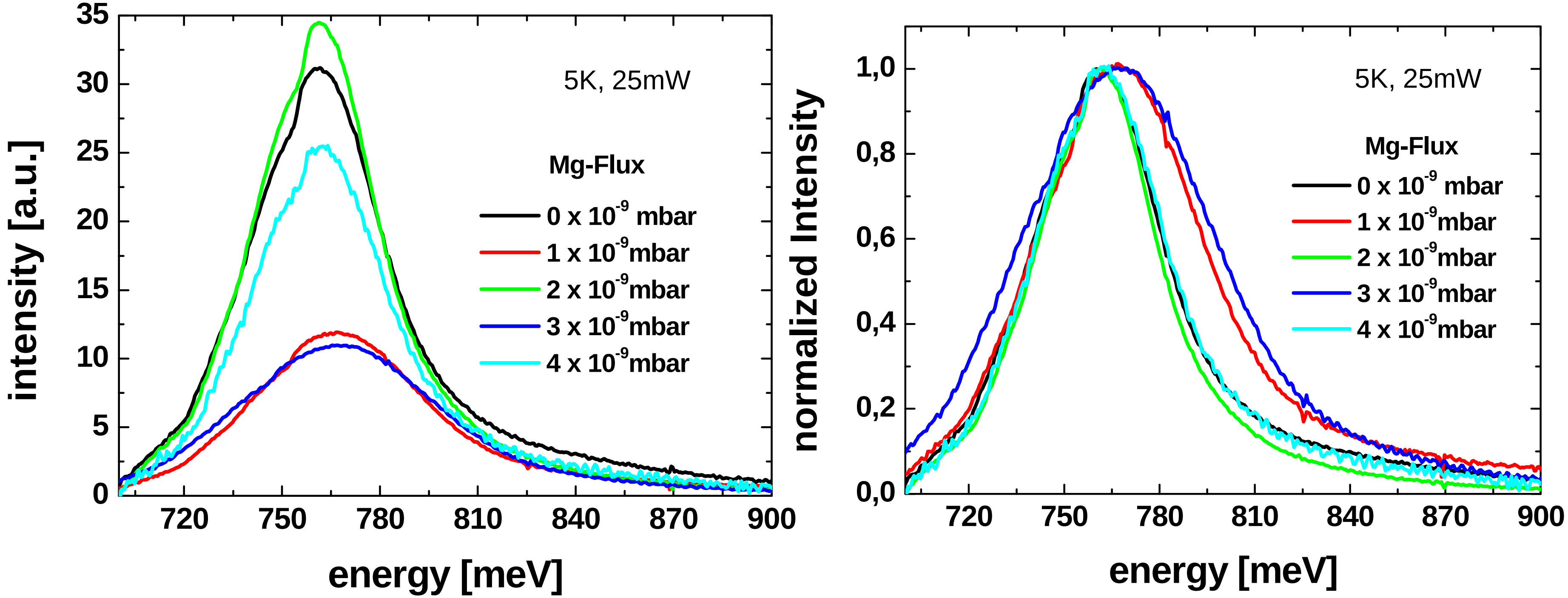


- Good crystalline quality
- Stacking faults at the top

T. Gotschke et al. in preparation

Influence of the Mg-flux on PL

Φ_{In} = 2 x 10^{-8} mbar ; T_{sub} = 494 °C

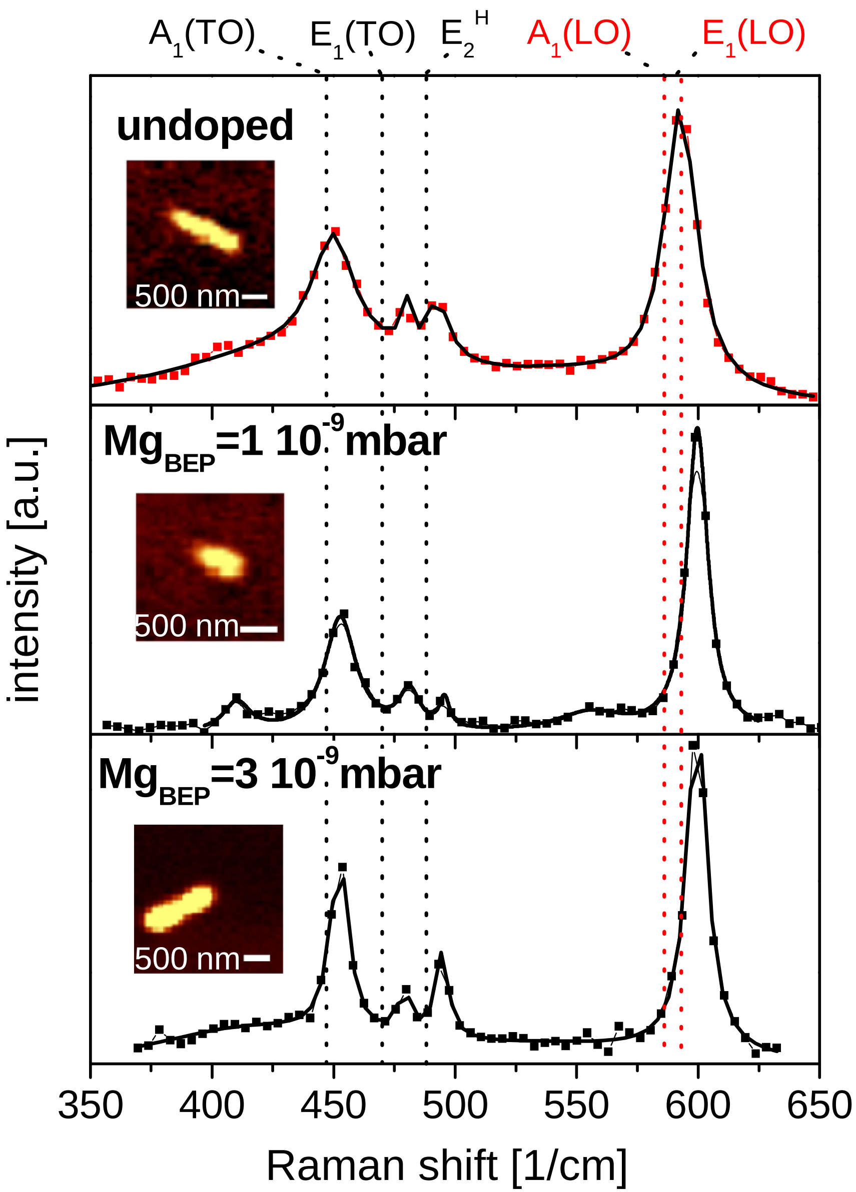


- Fluctuation of peak energy and intensity

For thin films:
X. Wang et al, Appl. Phys. Lett., 90, 201913 (2007)
N.Khan et al. Appl. Phys. Lett. , 91, 012101 (2007)

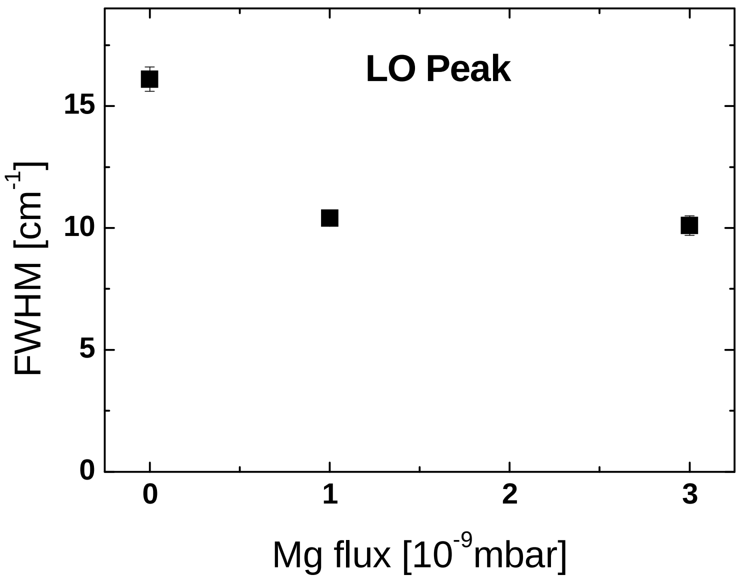
T. Gotschke et al. in preparation

Mg doped - single NW Raman



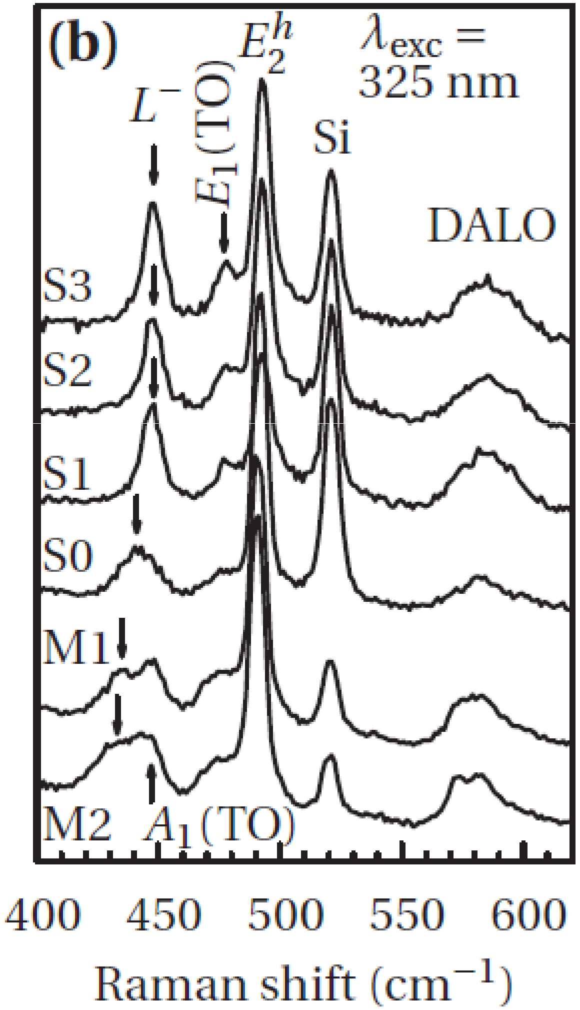
LO shifted to higher energies

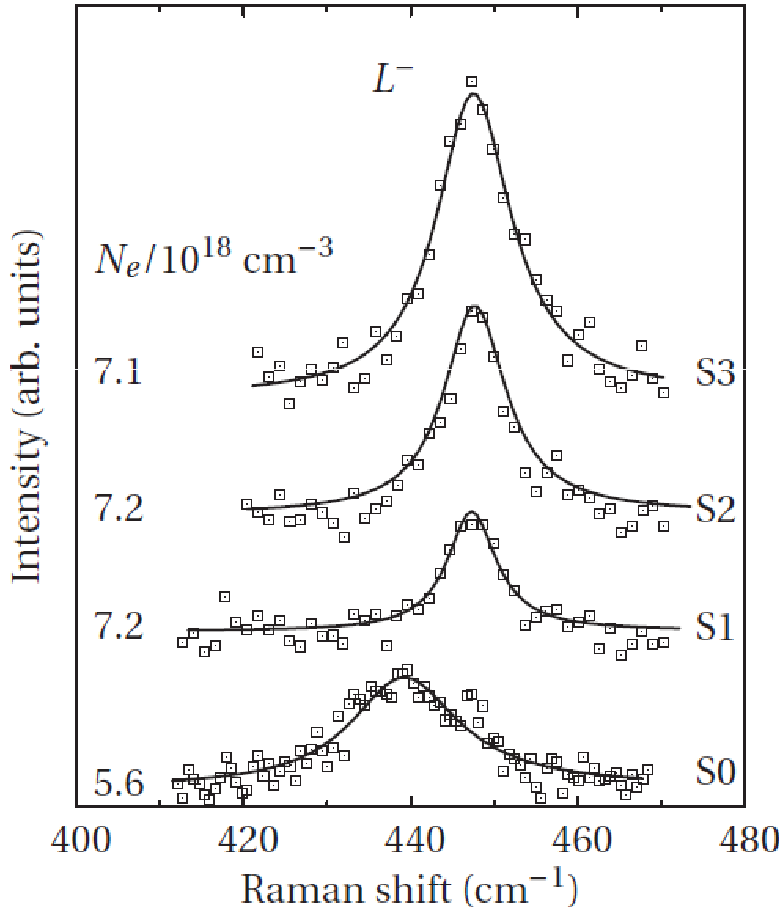
Sharper peaks in Mg doped samples



T. Stoica et al. Nanotechnology 21, 315702 (2010)

Raman: determination of carrier concentration

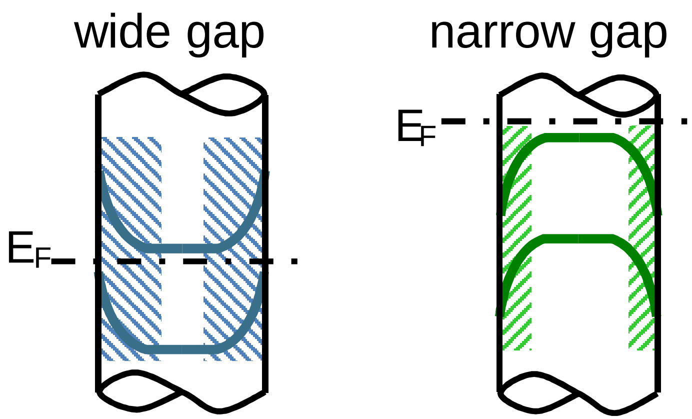




R. Cuscó, N. Domenech-Amador, and L. Artús T. Gotschke, K. Jeganathan, T. Stoica, R. Calarco, ***Appl. Phys. Lett. 97****, 221906 (2010)*

Conclusions

AIM:
understanding size dependences electrical and optoelectrical properties



Thank you for your attention

Bundesministerium
für Bildung
und Forschung

Project QPENS
Project EPHQUAM

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R. Caterino

T. Schumann