Optical properties of free-standing Nanowires

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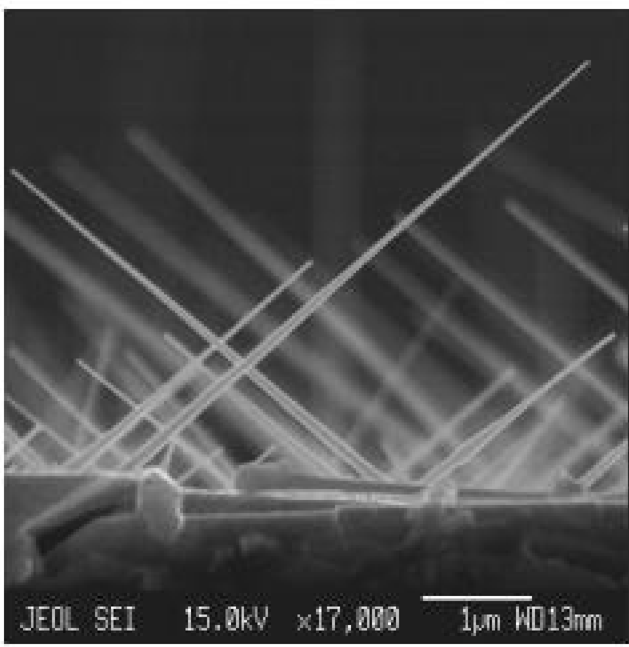
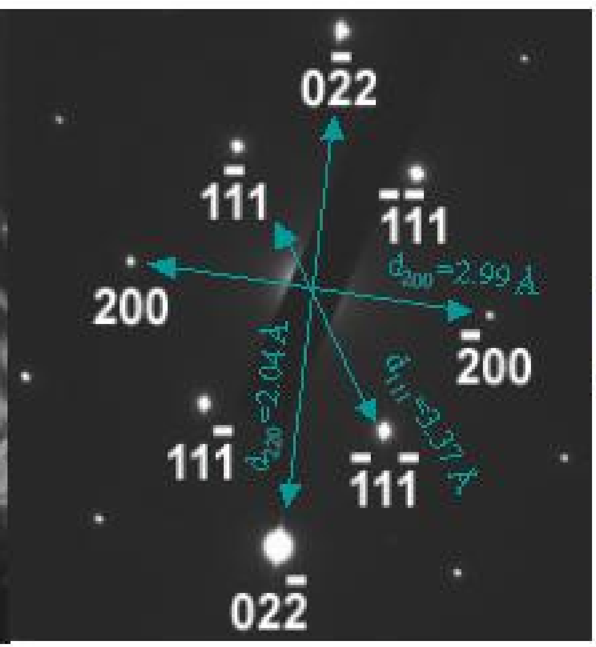
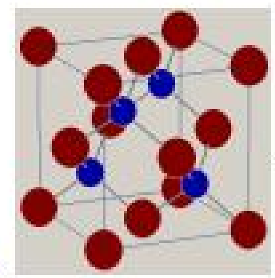
Samples

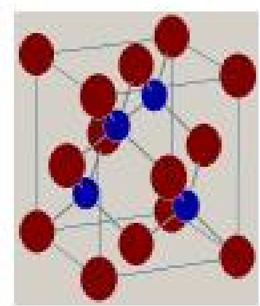
InP NW´s were synthesized by the Vapor-liquid-Solid growth method in a Chemical Beam Epitaxy reactor (CBE), using 20 nm gold nanoparticles as catalysts. The free-standing InP NW´s exhibit a slight conical shape with average diameter of 38 nm, a mean length of 5 μm, and a distorted zinc-blend crystal structure.





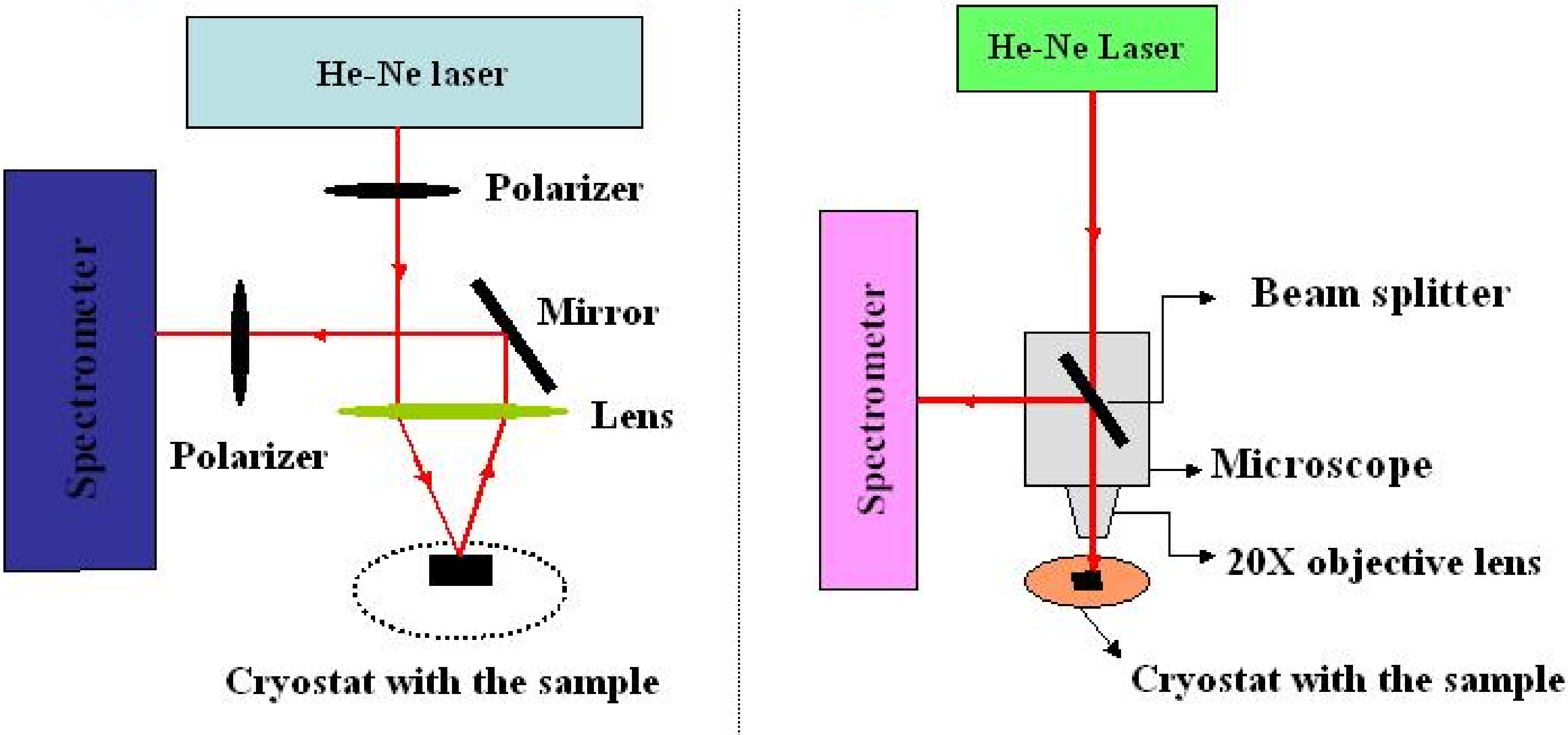


InP Bulk
Cubic
A=b=c=5.86 Å



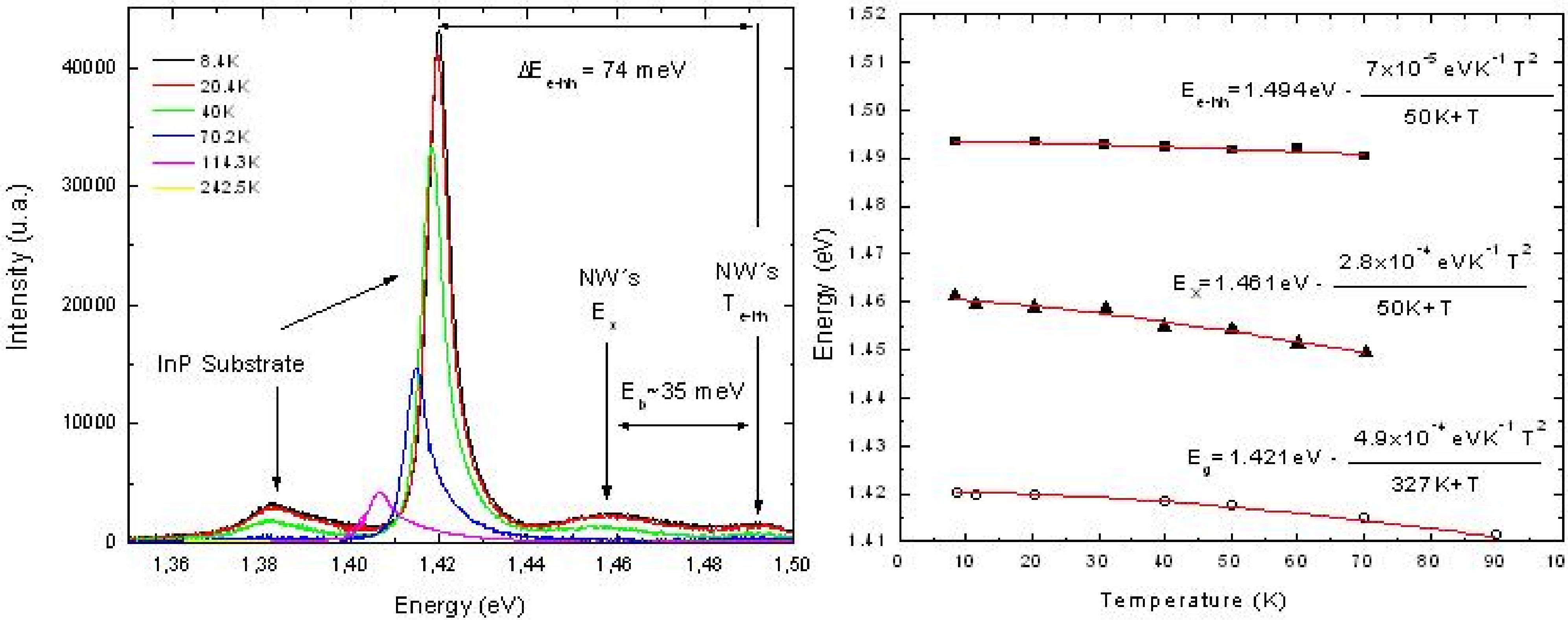
InP NW´s
Tetragonal
a=b=5.75 Å
c=5.95 Å

Experimental Set up



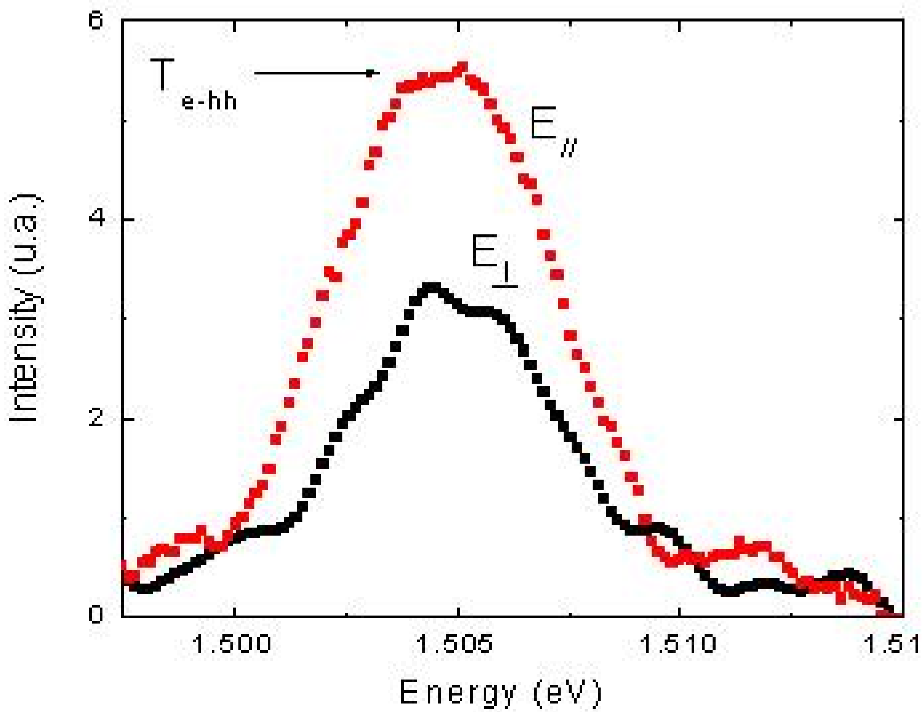
Experimental setup used for PL and μ-PL spectroscopy of NW´s.

Experimental Results: macro-PL

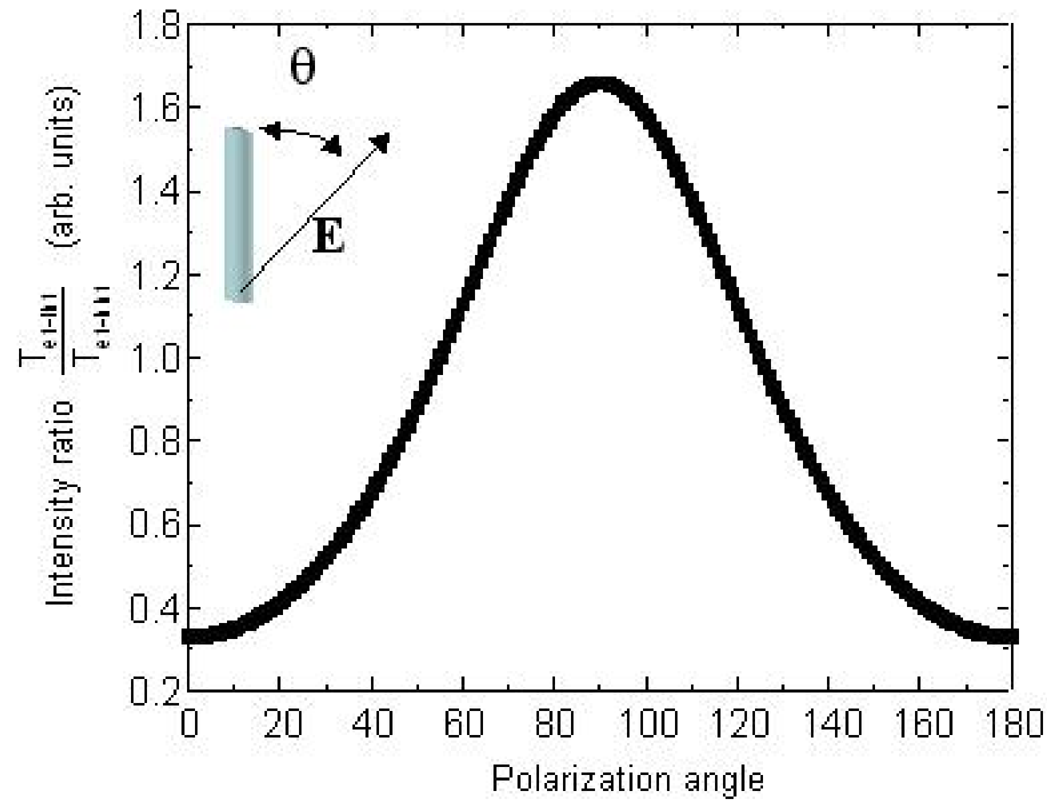


Temperature dependence of InP NW´s PL emission

Macro-PL: polarization

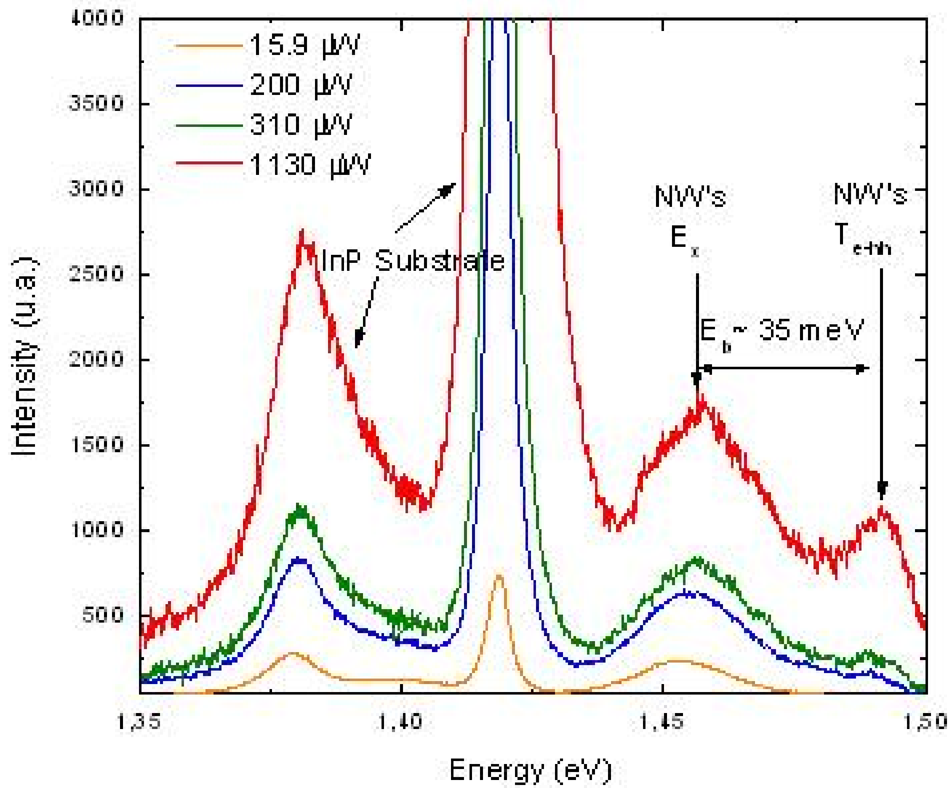


Polarization dependence of the InP NW´s PL at 10 K



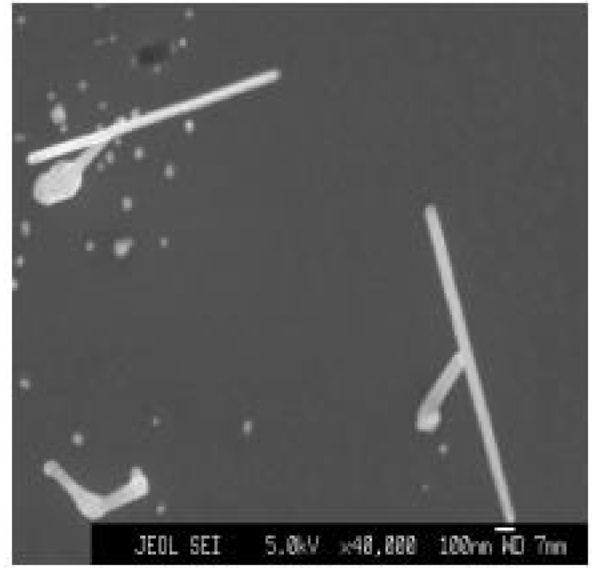
Theoretical dependence of the transition strength with the polarization angle

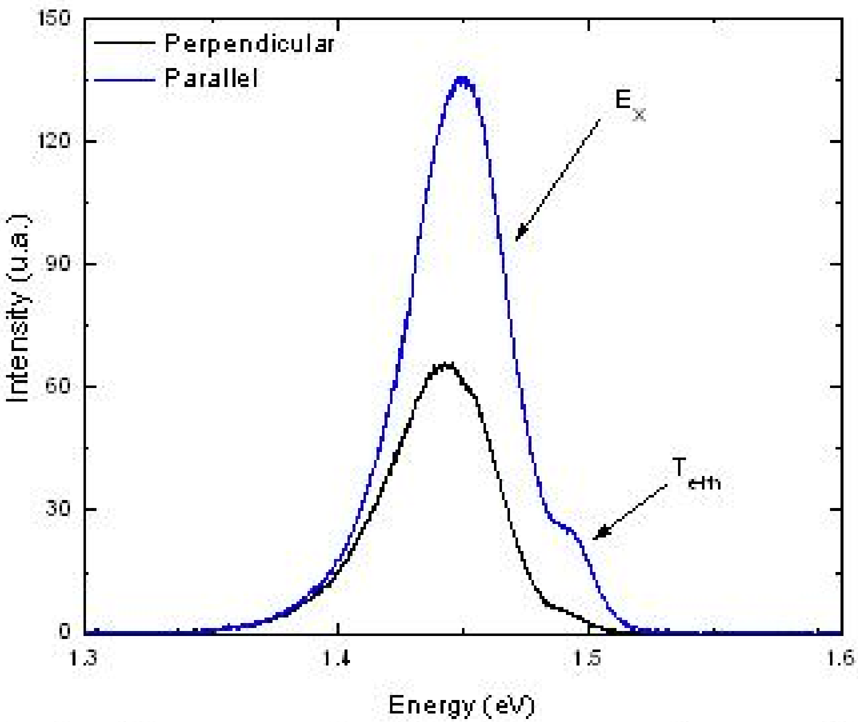
Experimental Results: macro-PL



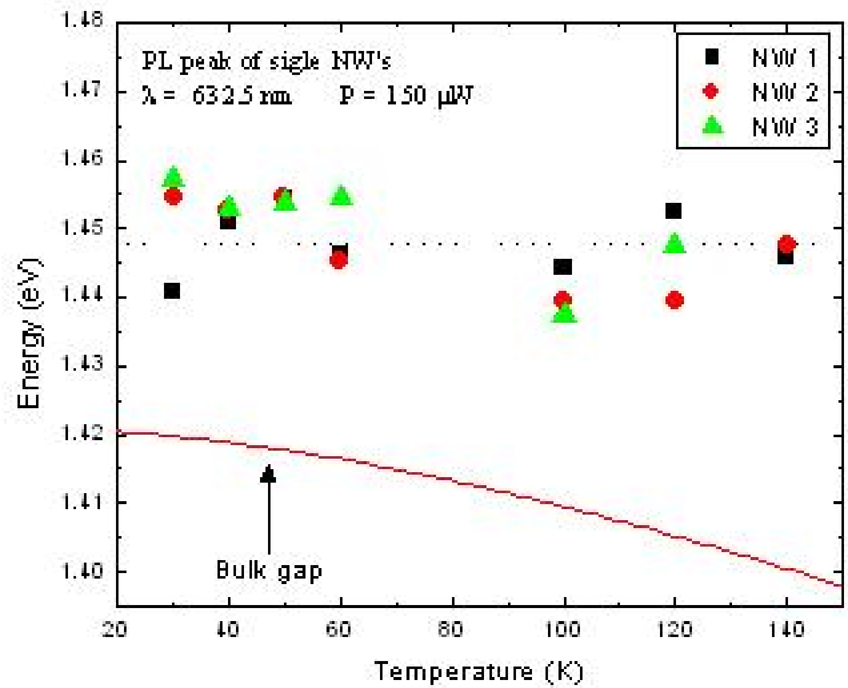
Power dependence of the InP NW´s PL at 10 K

Micro-PL



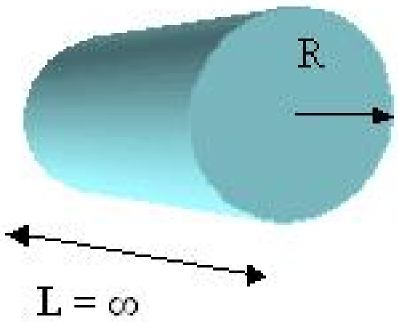


Polarization resolved μ-PL spectrum of a single InP NW.



Temperature dependence of the excitonic emission for three individual InP NW's.

Model: Cylindrical well with infinitely high walls



$$\frac{-\hbar^2}{2m}\left(\frac{\partial^2}{\partial r^2}+\frac{1}{r}\frac{\partial}{\partial r}+\frac{1}{r^2}\frac{\partial^2}{\partial \theta^2}\right)\psi = E\psi$$

$$\psi(r,\theta) = u(r)\phi(\theta)$$

Radial equation:

$$r^2\frac{d^2u}{dr^2}+r\frac{du}{dr}+[(kr)^2-l^2]u=0$$

$$\psi_l(r,\theta) = AJ_l(ka)e^{il\theta}$$

Wave function and energy eigenvalues

$$\psi_{nl}(r,\theta) = AJ_l\left(\frac{j_{ln}r}{a}\right)e^{il\theta} \qquad E_{nl} = \frac{\hbar^2 j_{ln}^2}{2ma^2}$$

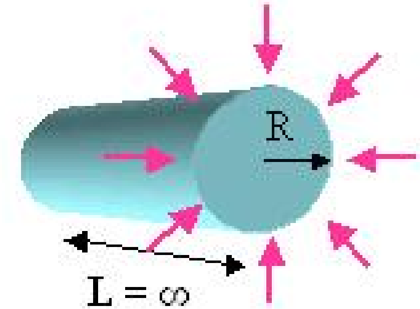
$$E_{n-hh} = E_g + \frac{\alpha_n^2 \hbar^2}{2R^2}\left(\frac{1}{m_e} + \frac{1}{m_{hh}}\right)$$

$$E_{n-lh} = E_g + \frac{\alpha_n^2 \hbar^2}{2R^2}\left(\frac{1}{m_e} + \frac{1}{m_{lh}}\right)$$

For: R= 17 nm, we have:

$E_{el\text{-}hh_1} \sim 9$ meV

$E_{el\text{-}lh_1} \sim 19$ meV



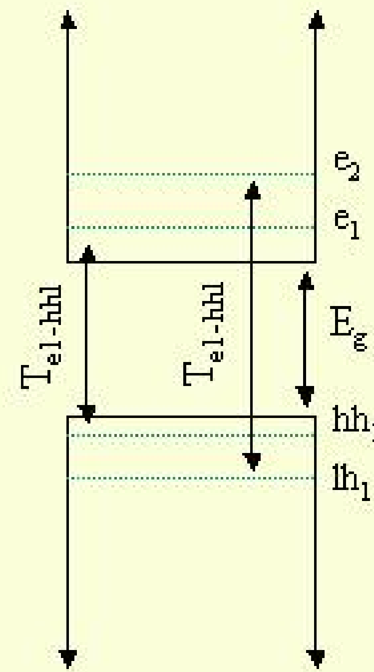
Adding a biaxial strain in the inward radial direction, and uniaxial longitudinal strain:

$$T_{n-hh(lh)} = E_{n-hh(lh)} + \Delta E(\varepsilon)$$

$$\Delta E(\varepsilon) = \left(2a\frac{C_{11} - C_{12}}{C_{11}} - b\frac{C_{11} + 2C_{12}}{C_{11}}\right)\varepsilon$$

$$T_{el-hh1} - E_g \sim 9 \text{ meV} + 65 \text{ meV} = 74 \text{ meV}$$

$$T_{el-lh1} - E_g \sim 19 \text{ meV} + 65 \text{ meV} = 84 \text{ meV}$$



Dielectric confinement for excitons (variational method):

$$E_x(a) = \frac{\hbar^2}{4\mu}a^2 + \frac{2e^2}{\varepsilon_b}\frac{a}{\sqrt{\pi}}\left[\ln\left(\frac{a \cdot R}{2}\right) + \frac{1}{2}C - \frac{\varepsilon_b/\varepsilon_w}{4}\right]$$

$$E_x(R = 19 \ nm) \sim 39 \ meV$$

Conclusions

• The optical properties of high crystalline quality and strained InP NW's were studied.

• Polarization-resolved PL and μ-PL experiments were used to identify the origin of the optical transitions observed in the sample.

• This experiments revealed a strong dielectric confinement of the excitons in the NW's and a large blue shift of 74 meV for the first electron-to-heavy hole optical transition, that cannot be solely explained by quantum confinement effects.

• A simple theoretical model including both quantum confinement and strain effects consistently describes the actual energy position of the InP NW´s optical emission. A variational method was satisfactorily used to calculated the effects of the dielectric confinement of the excitons in the NW´s.

References:

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