Disorder Effects in Ga(AsBi)

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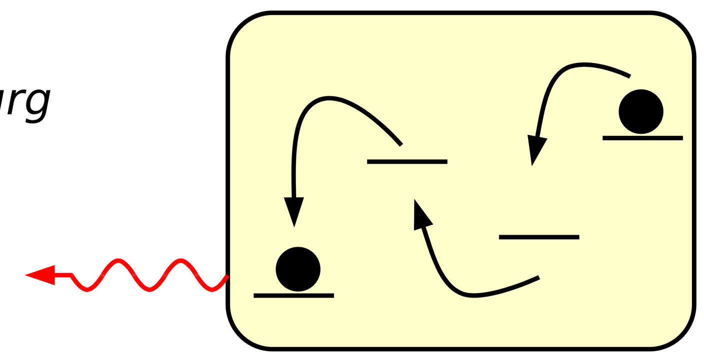


Motivation

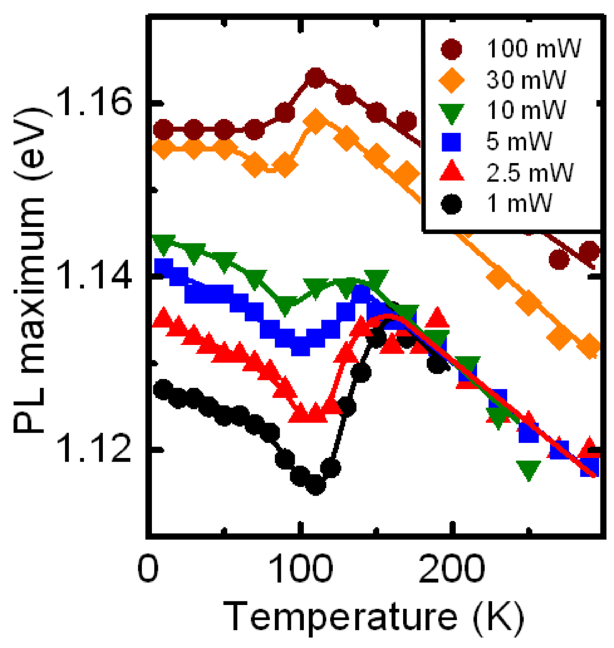
- Incorporation of Bi into GaAs reduces the band gap 60-80meV per percent Bi
- Wide wavelength range in near and middle infrared region can be reached in the Ga(AsBi) system
- Suitable for laser applications e.g. emitting at the telecommunication wavelength 1.3microns
- Band structure described by a valence-band anticrossing-model
  ➡ Offers an independent valence band engineering
- Ga(AsNBi) can be grown lattice matched on GaAs
  ➡ Suitable for multilayer solar cells

Sample

- 30nm Ga(AsBi)/GaAs sample containing 4-5% Bi
- Sample grown by MBE
- Problems: Strong tendencies for Bi to surface segregate
- Technique can be used to grow samples containing up to 10.5% Bi

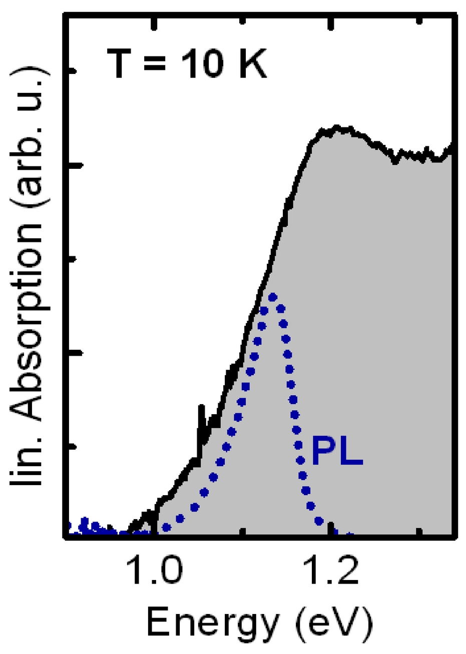
Experiment: PL

PL Peak Position



- PL shows an s-shape
- PL position depends on the excitation power for T<150K

Linear Absorption



- Band edge at 1.19eV
- Very broad excitonic signature
- Gaussian low-energy tail

➡ Typical Disorder Effects

Kinetic Monte-Carlo Simulation

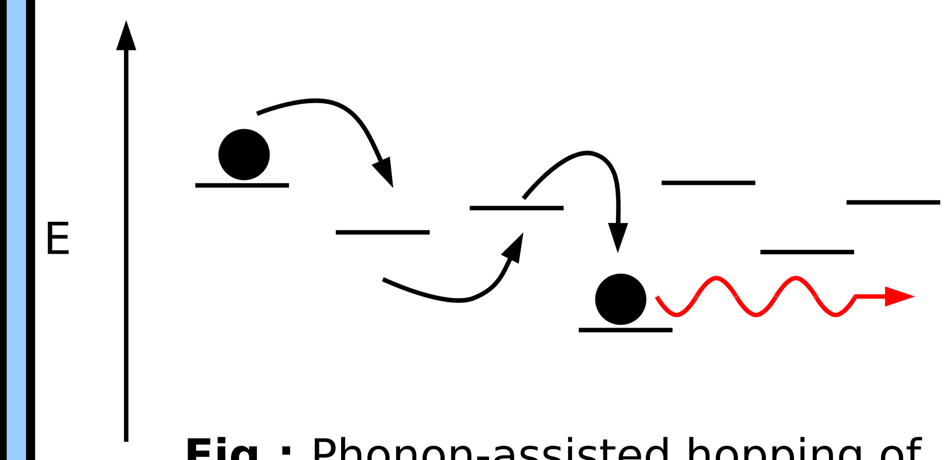


Fig.: Phonon-assisted hopping of excitons among a landscape of localized states

Transition rate:

$$\nu_{ij} = \nu_0 \exp\left(-\frac{2r_{ij}}{\alpha} - \frac{\epsilon_j - \epsilon_i - |\epsilon_j - \epsilon_i|}{2k_bT}\right)$$

ν_0: Attempt-to-Escape Frequency

Decay rate:

$$\nu_i = \tau_0^{-1} + \sum_{j\neq i} \nu_{ij}$$

τ_0: Exciton life time

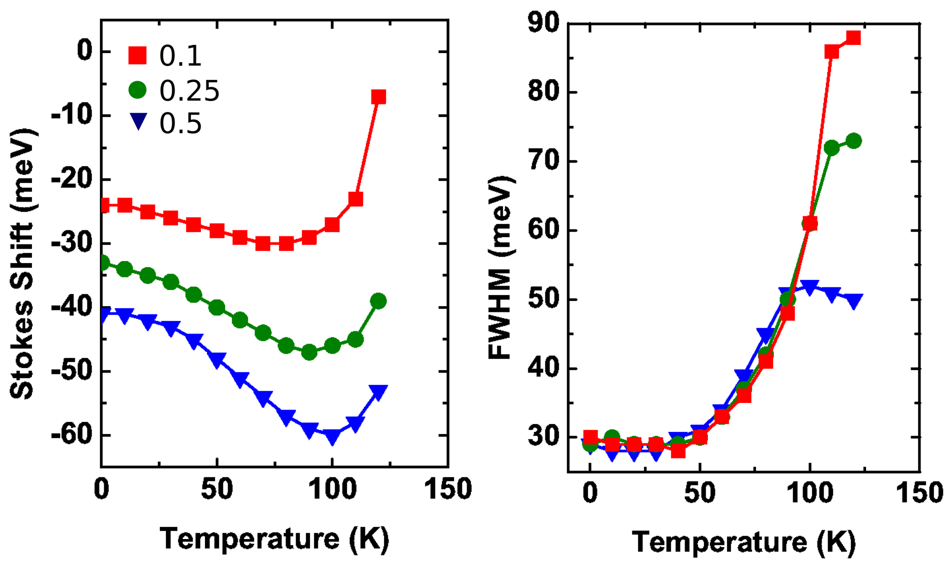
Spectra depend on:

- Density of states
- $N_0\alpha^2$, where N_0 is the area density of localized states and α is the exciton localization radius
- $\nu_0\tau_0$

Standard Hopping Model

- Single energy scale with exponential DOS
- Maximum Stokes shift: $k_BT \approx 0.6 - 0.8\epsilon_0 = 10 - 15\,\text{meV}$
- Maximum PL line width: $k_BT \approx 1.0 - 1.2\epsilon_0 = 10 - 15\,\text{meV}$
- Zero-temperature PL linewidth: $k_BT \approx 2.5\epsilon_0 = 28\,\text{meV}$

➡ Does not fit the experiment



Hopping on two Energy Scales

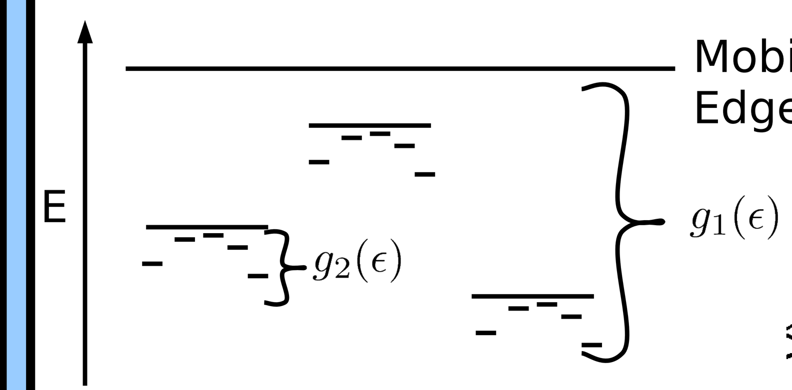


Fig.: Landscape of two energy scales

Alloy Disorder

$$g_0(\epsilon) = \exp\left[-\frac{\epsilon^2}{2\epsilon_0^2}\right]$$

Cluster states

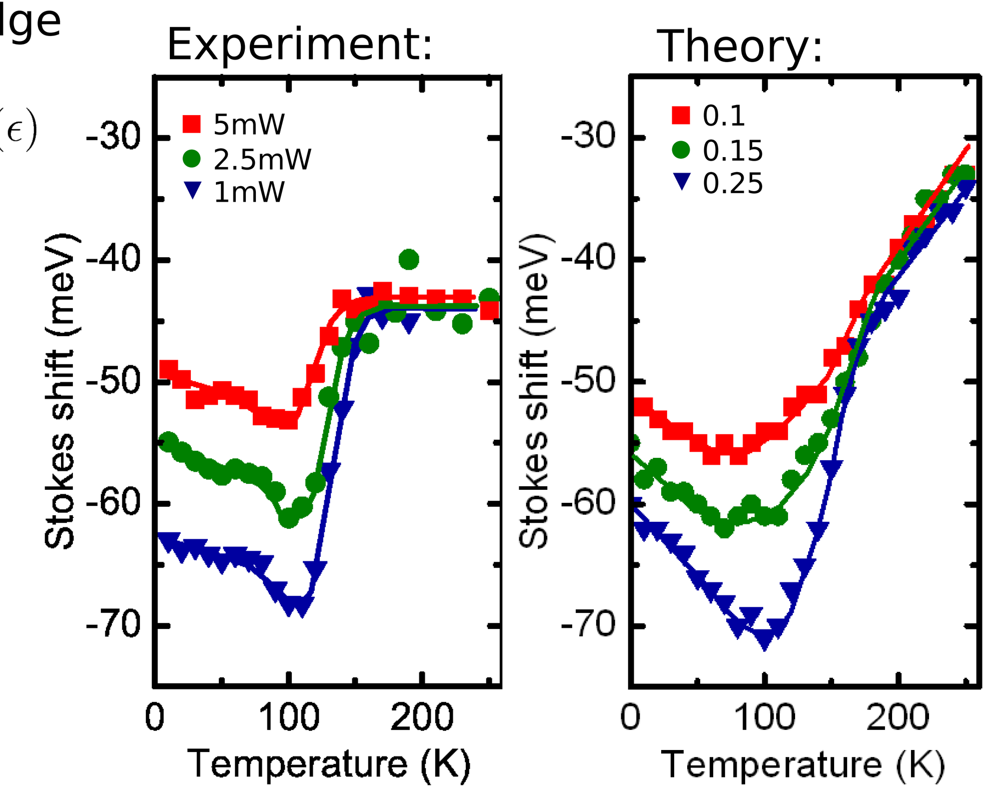
$$g_1(\epsilon) = \exp\left[-\frac{\epsilon}{\epsilon_1}\right]$$

Excellent agreement between experiment and theory using:

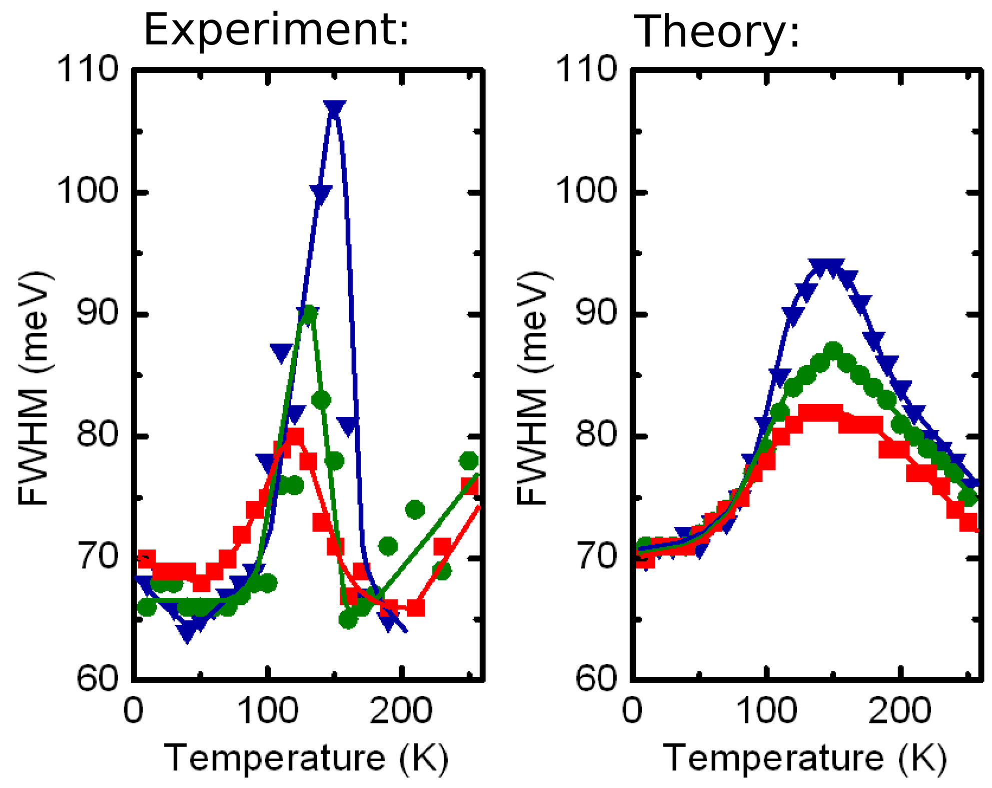
Alloy Disorder:
$N_1\alpha^2 = 0.01$
$\nu_1\tau_1 = 10^5$
$\epsilon_1 = 45\,\text{meV}$

Cluster states:
$\nu_2\tau_2 = 10^4$
$\epsilon_2 = 11\,\text{meV}$

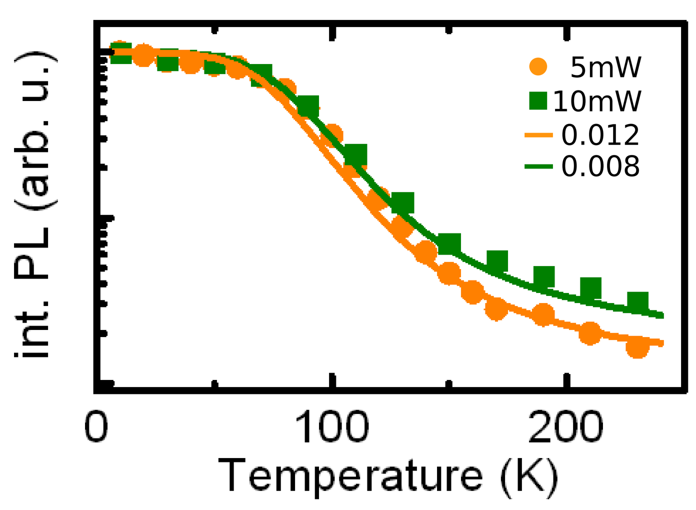
Stokes Shift



PL line width



Non-Radiative Recombination



- Squares/Dots: Measured PL intensity for P=5mW and 10mW
- Solid lines: Calculated PL intensity for $N_{nr}/(N_{nr}+N_r)$=0.012 and 0.008
- Very good agreement for a characteristic energy scale of 11meV

Conclusion

- Experimental results cannot be explained with the standard model
- Using a two-scale approach, an excellent agreement between experiment and theory is obtained

Acknowledgements

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