CHEMNITZ UNIVERSITY
OF TECHNOLOGY

# Clustering Effects in Ga(AsBi)

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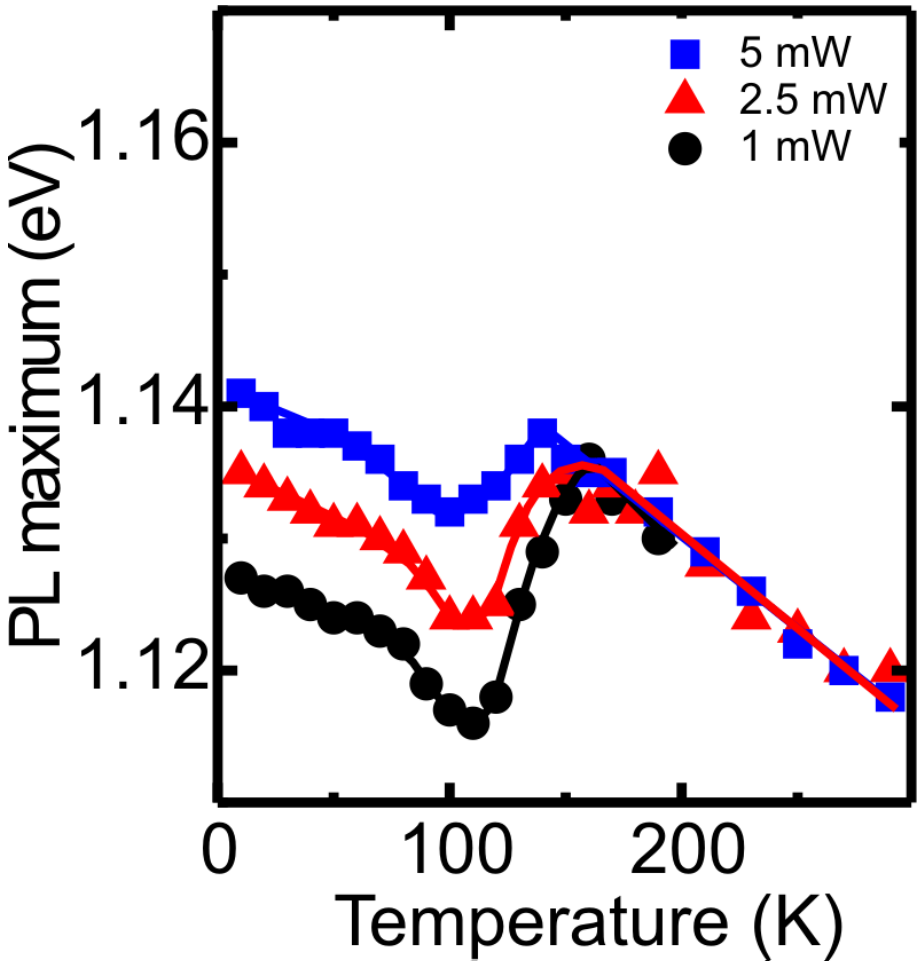
# Motivation: S-Shape

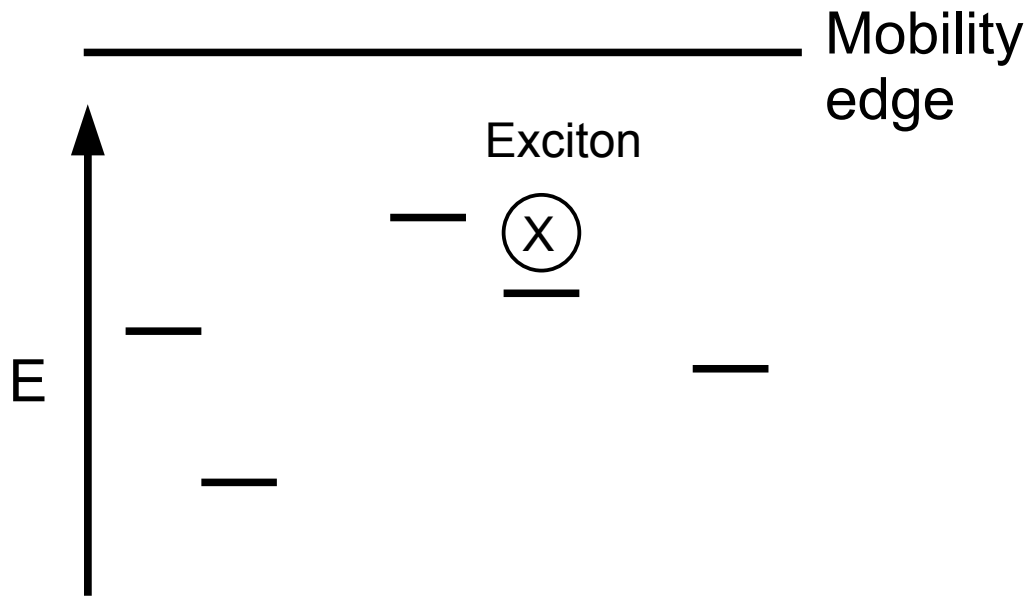



Imhof et al., Appl. Phys. Lett. 96, 131115 (2010)

# Outline

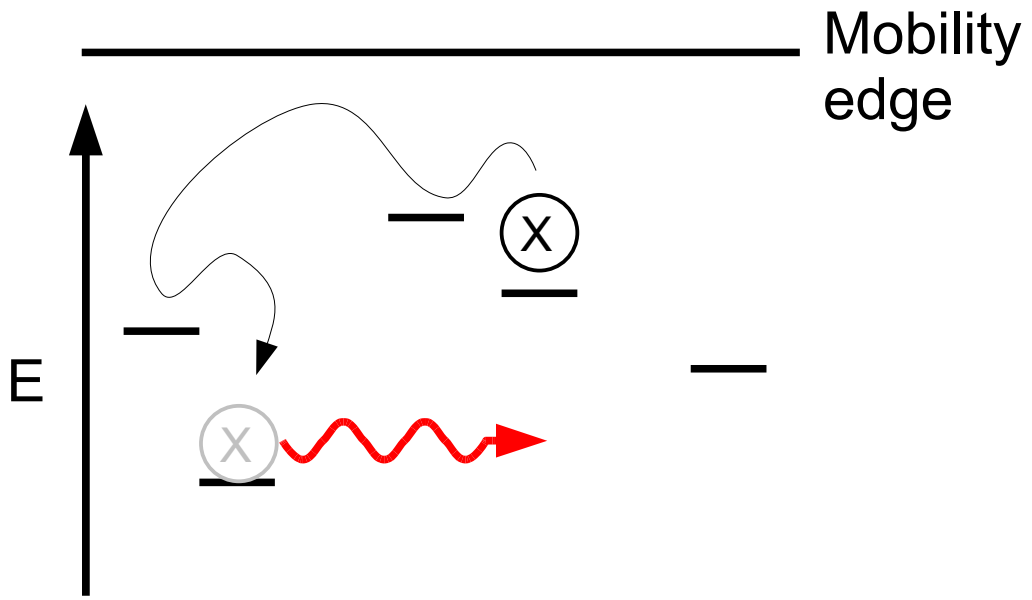
- Photoluminescence in disorderd semiconductors
- Kinetic Monte-Carlo simulation
- Experimental results
- Two scale approach for Ga(AsBi)
- Conclusion and outlook

# Disorder Model



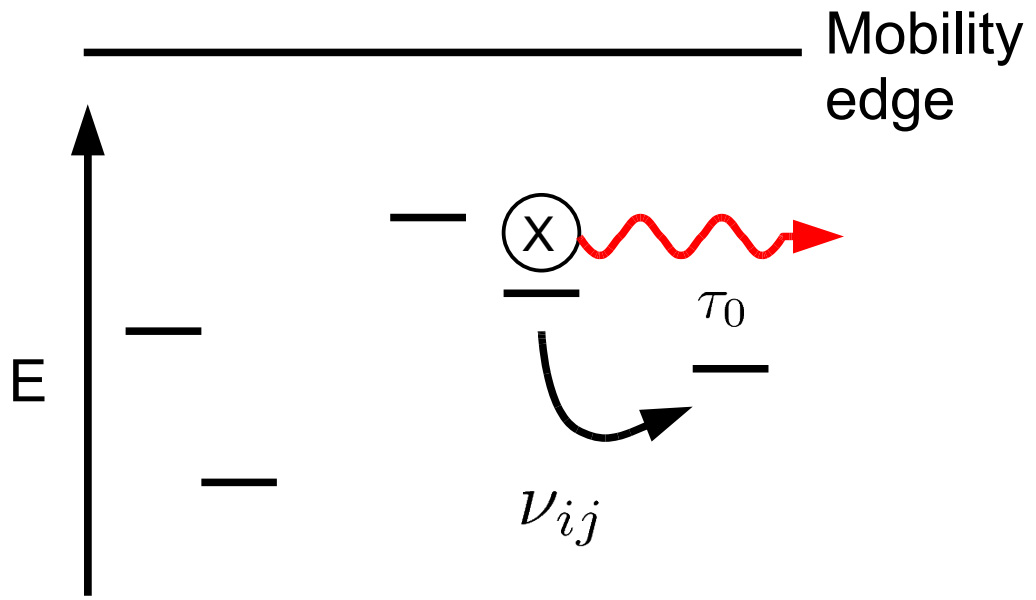

- Localized states randomly distributed in space
  - $N_0$: Area density of localized states
  - α: Exciton localization radius
- Energies given by a certain distribution function

# Hopping of Excitons




- Excitons can move among localized states
- Motion of excitons independent in the case of low densities
- Excitons can decay radiatively

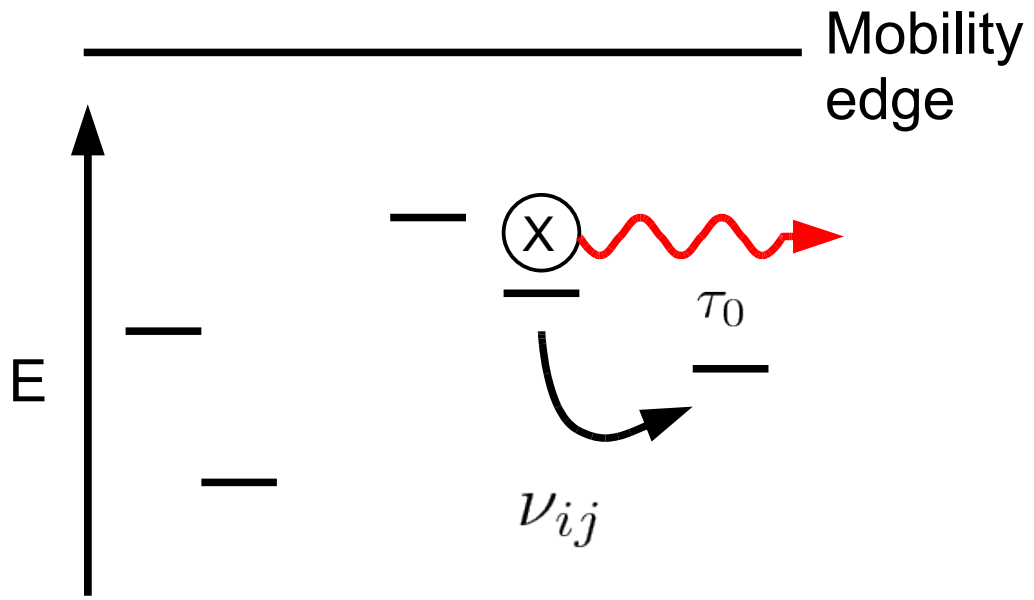
# Hopping of Excitons




- Hopping transition given by Miller-Abrahams Indices
- Excitons can decay with life time $\tau_0$

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

# Hopping of Excitons




- Hopping transition given by Miller-Abrahams Indices
- Excitons can decay with life time $\tau_0$
- Decay rate of exciton on ith site:

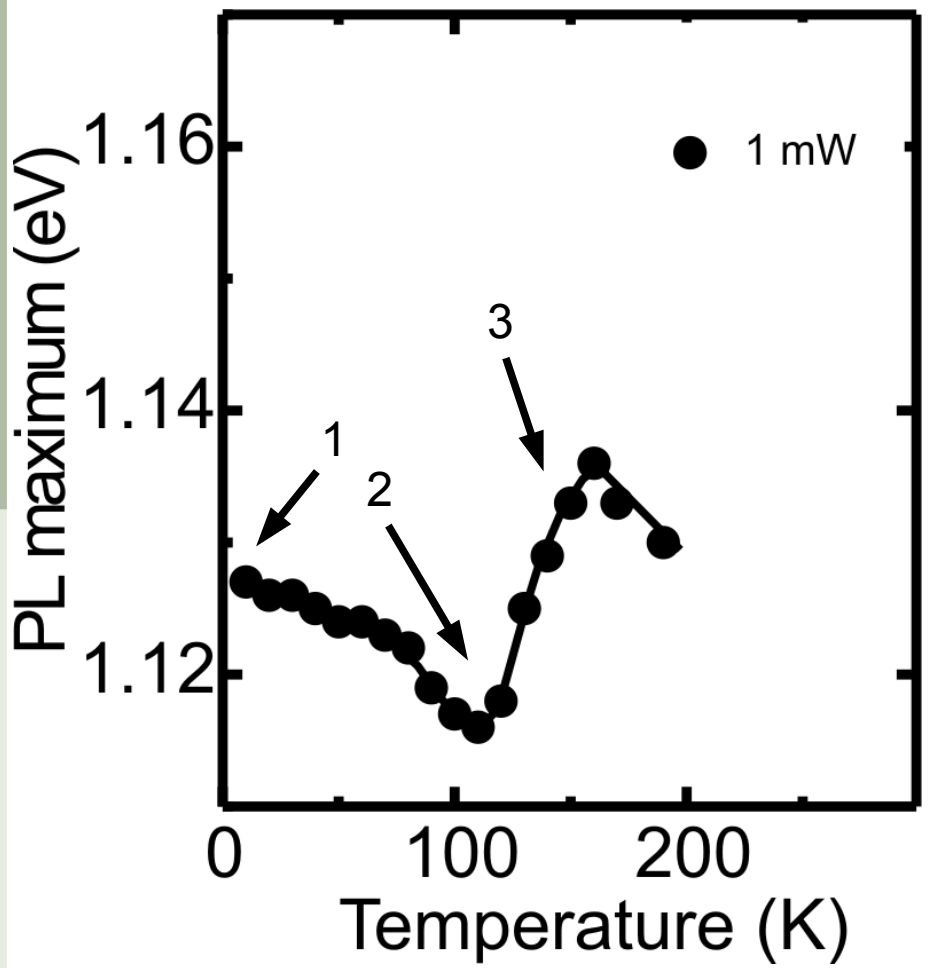
$$\nu_i = \tau_0^{-1} + \sum_j \nu_{ij}$$

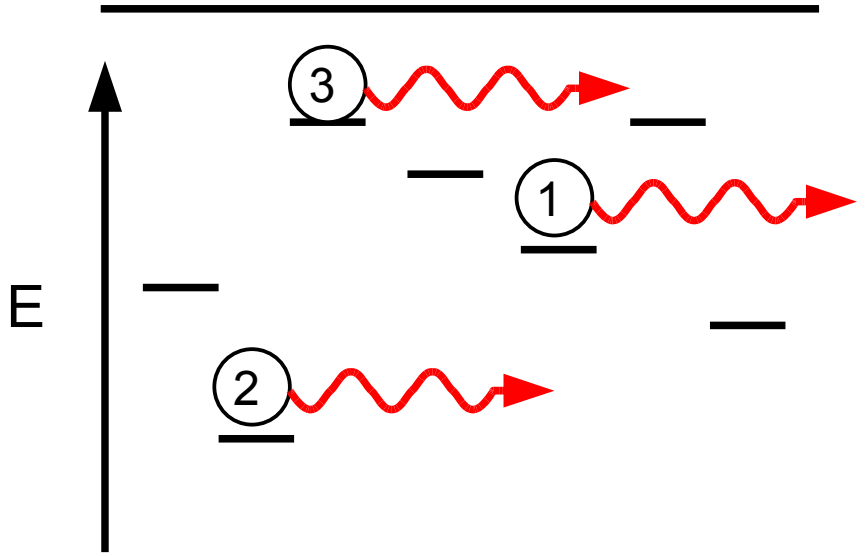
- Dynamic of exciton:

$$t_i^{-1} = -\nu_i \ln \xi$$

- Spectra depend on three parameters: $\nu_0\tau_0,\ \epsilon_0,\ N_0\alpha^2$

# Explanation of the S-Shape



# Kinetic Monte-Carlo Simulation

1. Calculate energies and positions of localized states
2. Choose start position of exciton randomly
3. Calculate hopping rates
4. Decide whether exciton decays or performs a hop
   - Decay: save the energy and restart with a new exciton
   - Hopping transition: Go to step 3

# Ga(AsBi) Sample Properties

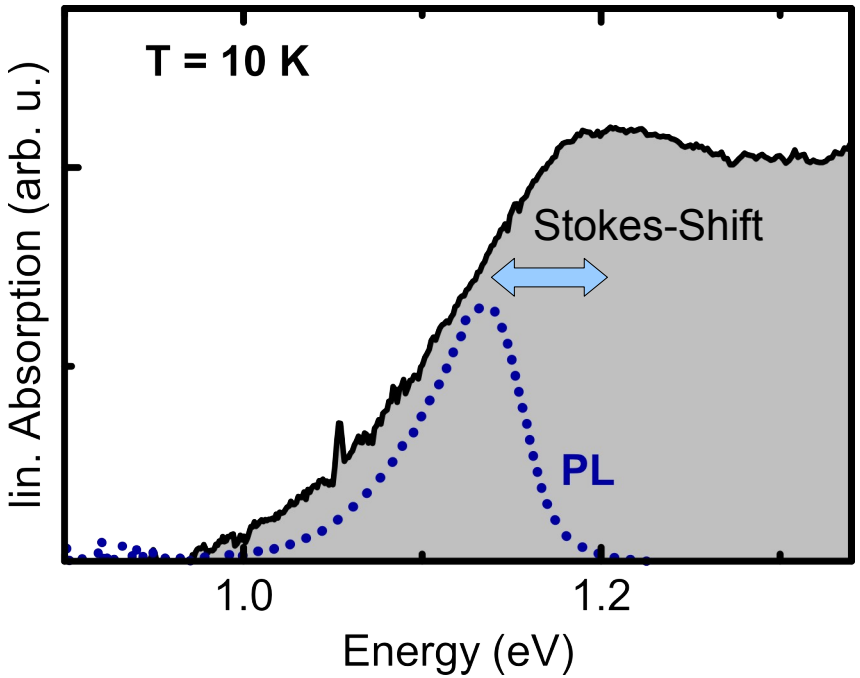
- Thickness ~30nm
- Bi content: 4% - 5%
- Substrate: GaAs
- MBE-grown

Grown by:
D. Beaton
*Univ. of British Columbia, Kanada*

X. Lu
*Arizona State University, USA*

T. Tiedje
*Univ. of Victoria, Kanada*

# Experimental results I

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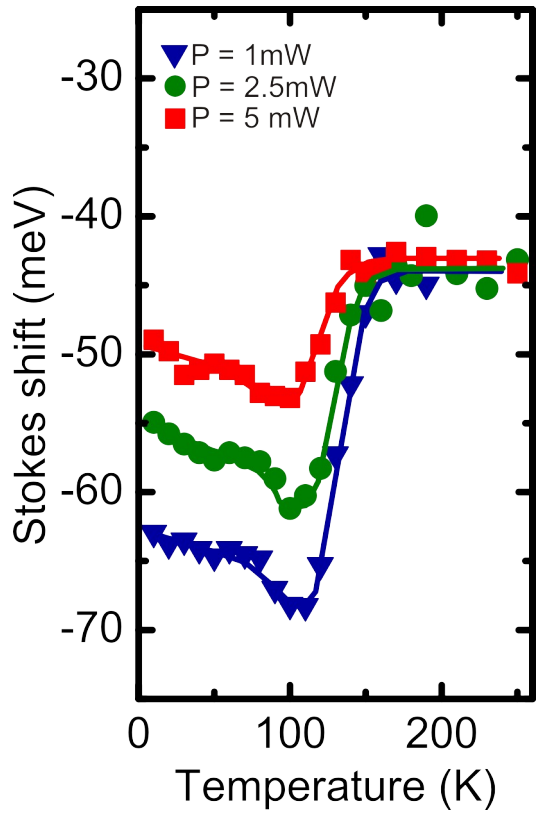
- Band gap from linear absorption spectrum around 1.2 eV
- Gaussian shaped density of states at low energy tail

Experiments done by
A. Chernikov, K. Kolata, N. Köster, M. Koch, S. Chatterjee
*Philipps University Marburg, Germany*

# Experimental results II

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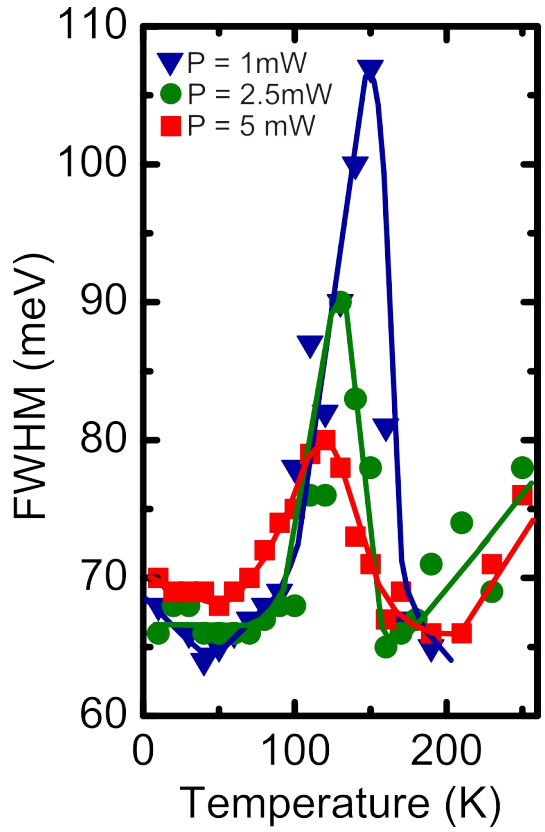
- Zero-temperature Stokes-shift excitation power dependent
- Maximal Stokes-shift around 110 K
- Finite Stokes-shift at high temperatures
  - Disorder effects still present at high temperatures

# Experimental results III

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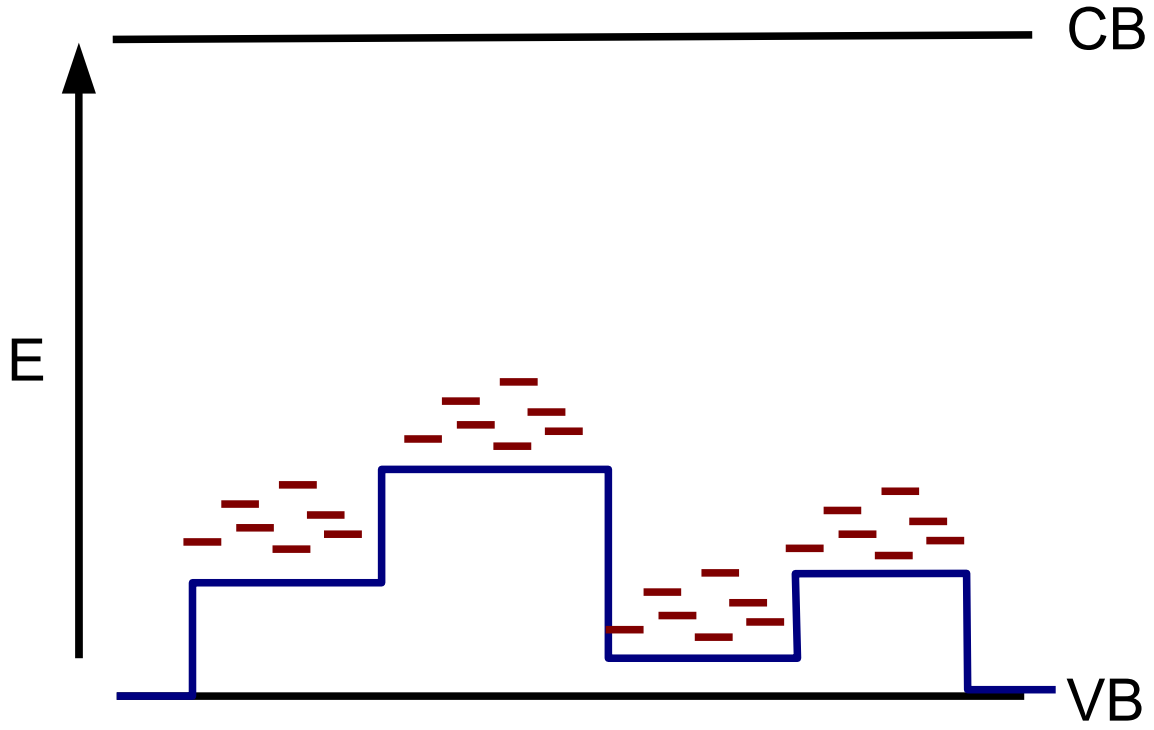
- Very broad PL spectra, FWHM at T=0 around 70meV
- PL linewidth at T=0 excitation power independent
- FWHM has maximum at 140 K
  - Sign of exponential DOS

# Summary: Experimental results

- Gaussian shaped low energy tail of linear absorption spectra
  - Sign of Gaussian DOS
- Maximum Stokes-shift at T=110 K and maximum FWHM at T=140 K
  - Sign of exponential DOS with energy scale of 11 meV
- Disorder effects still present at high temperatures
  - Inconsistent with energy scale of 11 meV

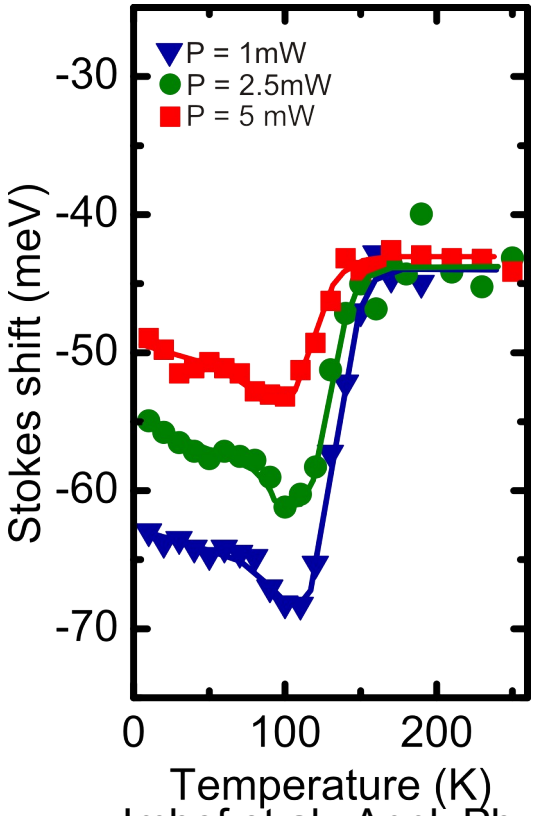
# Two energy scales



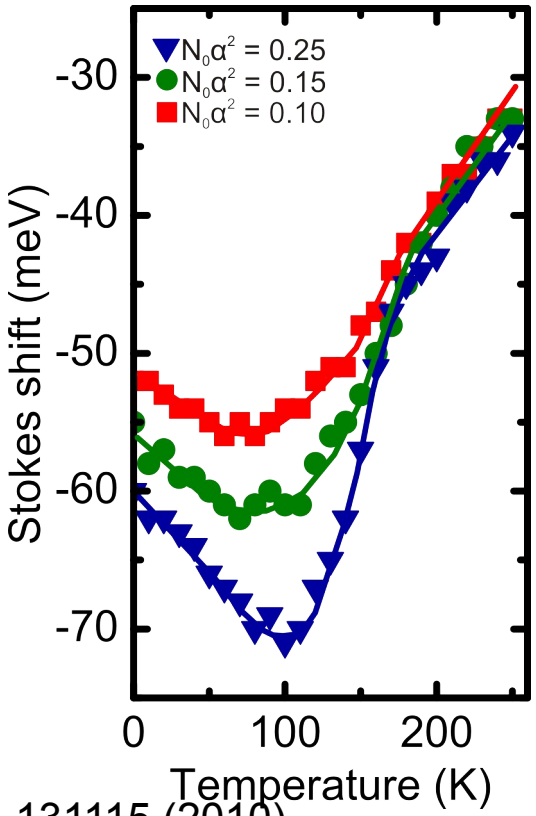

- Alloy disorder of Bi only affects the valence band
  - Gaussian distribution
- Additional Bi-Cluster sites beyond the valence band
  - Exponential distribution

# Experiment-Theory Comparison Stokes-Shift

Experiment




Theory

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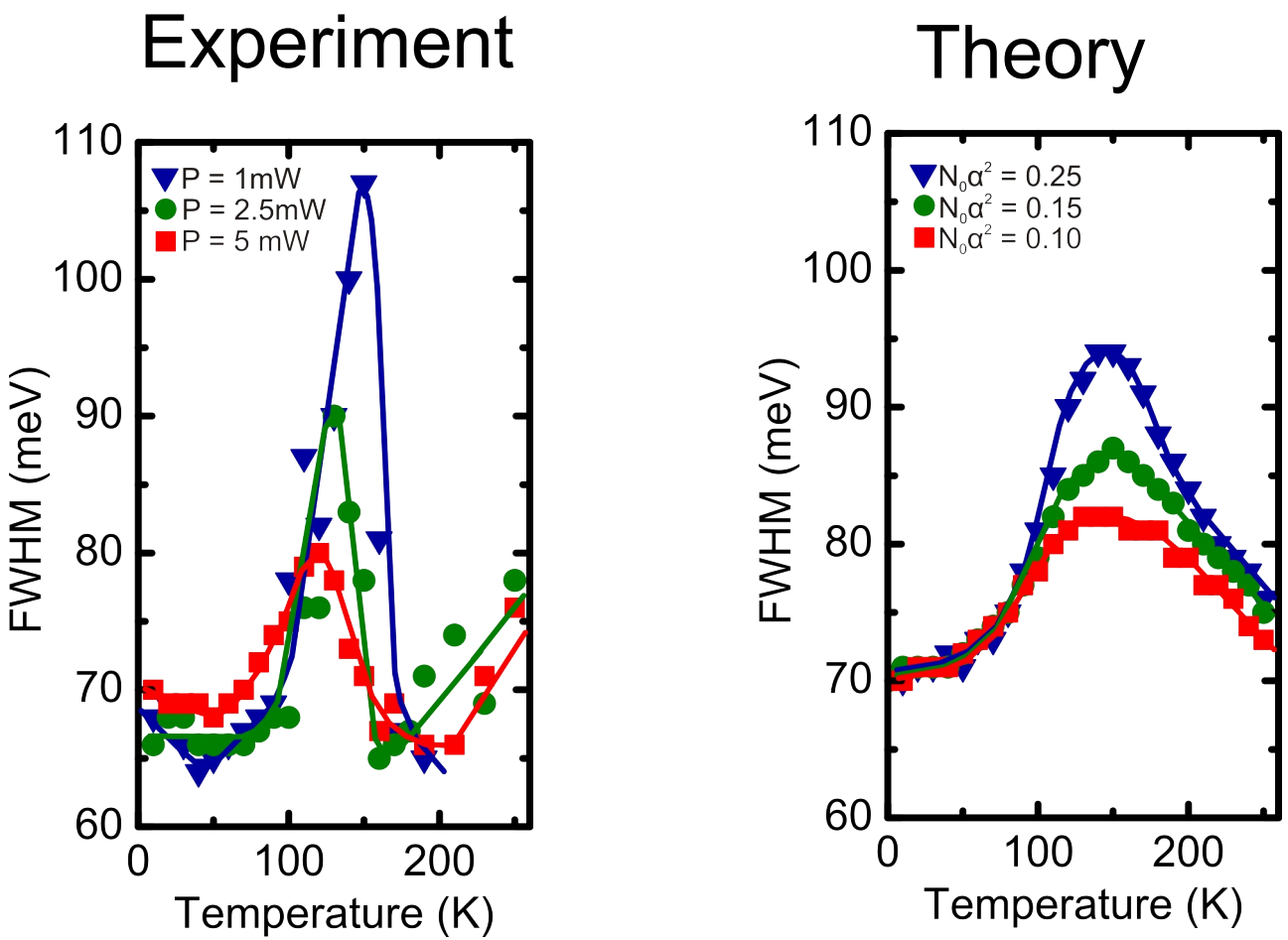
# Experiment-Theory Comparison FWHM

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# Conclusion and Outlook

- Experimental spectra show both, Gaussian and exponential behavior of DOS
- Spectra can be fitted using the approach of two energy scales
- Next steps:
  - Time dependent photoluminescence spectra
  - Analysis of systematic sample series

# Acknowledgements

C. Wagner and A. Thränhardt
*Chemnitz Technical University, Germany*

A. Chernikov, K. Kolata, N. Köster, M. Koch, S. Chatterjee and S.W. Koch
*Philipps University Marburg, Germany*

X. Lu and S. Johnson
*Arizona State University, USA*

D. Beaton
*University of British Columbia, Kanada*

T. Tiedje
*University of Victoria, Kanada*

O. Rubel
*Lakehead University, Kanada*

Further Details:
Imhof et al., Appl. Phys. Lett. 96, 131115 (2010)