Electrostatic conveyer for excitons

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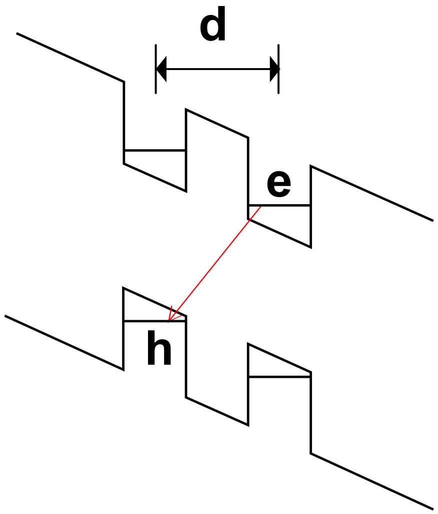
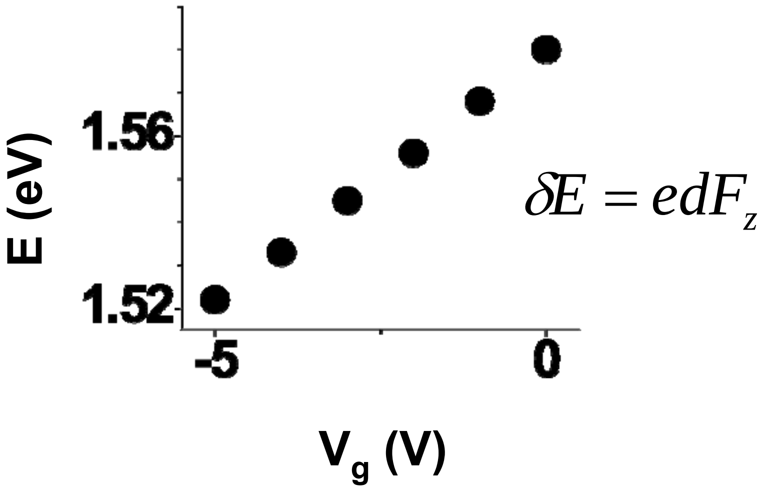
APS March Meeting

arXiv:1102.5329

Indirect Excitons in GaAs CQW





$$\delta E = edF_z$$

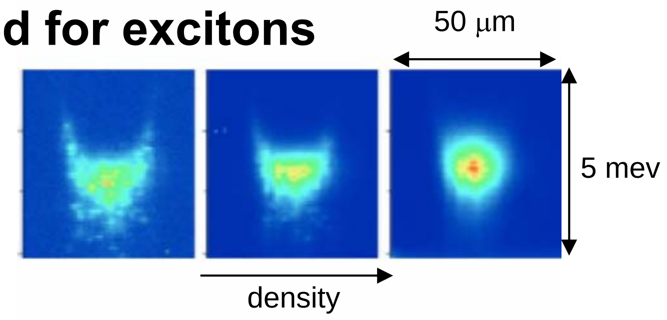
Spatial separation between electron and hole layers → Long Lifetime
→ Controllable Energy

Excitonic devices

Ability to control exciton energy via V_g
→ a variety of potential landscapes can be realized for excitons

Traps:

- **Diamond traps**
- **Elevated traps**
- **Snowflake traps**



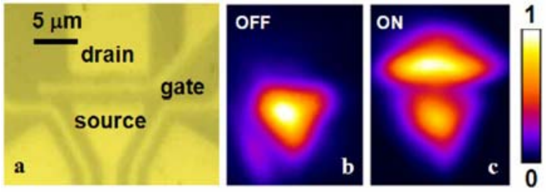
A.A. High, A.T. Hammack, L.V. Butov, L. Mouchliadis, A.L. Ivanov, M. Hanson, A.C. Gossard, Nano Lett., 9, 2094 (2009)

A.A. High, A.K. Thomas, G. Grosso, M. Remeika, A.T. Hammack, A.D. Meyertholen, M.M. Fogler, L.V. Butov, M. Hanson, A.C. Gossard, PRL, 103, 087403 (2009).

Y.Y. Kuznetsova, A.A. High, and L.V. Butov, APL, 97, 201106 (2010).

Circuit Devices:

- **Exciton optoelectronic transistor**
- **All optical excitonic transistor**
- **Exciton integrated circuit**



A.A. High, A.T. Hammack, L.V. Butov, A.C. Gossard, Optics Lett., 32, 2466 (2007).

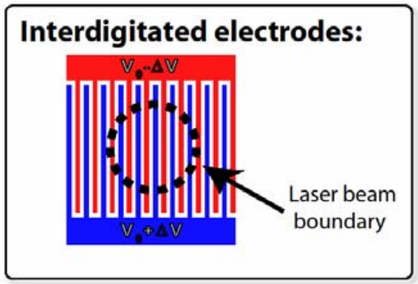
A.A. High, E.E. Novitskaya, L.V. Butov, A.C. Gossard, Science, 321, 229 (2008).

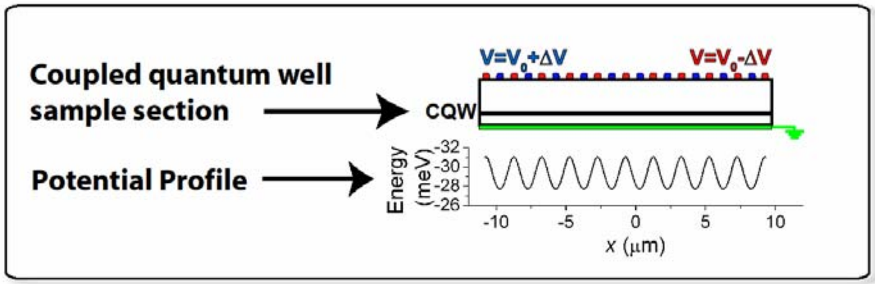
G. Grosso, J. Graves, A.T. Hammack, A.A. High, L.V. Butov, M. Hanson, A.C. Gossard, Nat. Photonics, 3, 577 (2009).

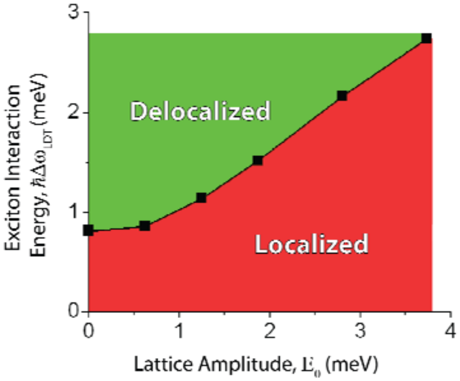
Y.Y. Kuznetsova, M. Remeika, A.A. High, A.T. Hammack, L.V. Butov, M. Hanson, A.C. Gossard, Optics Lett., 35, 1587 (2010).

Electrostatic lattices

Linear Lattices





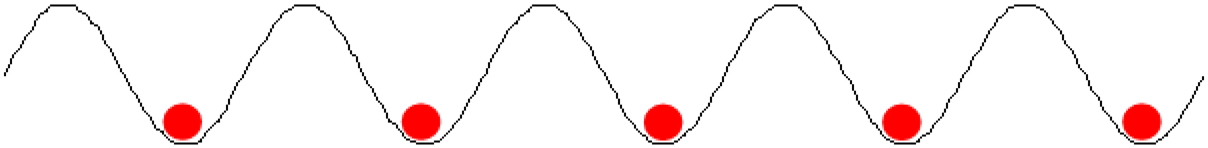


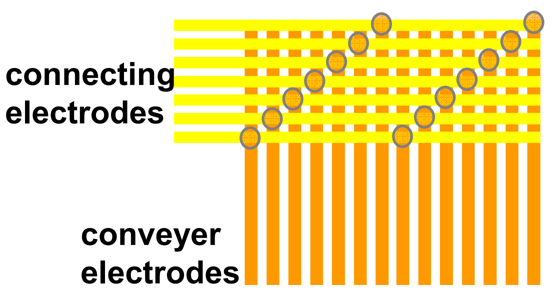
M. Remeika, J.C. Graves, A.T. Hammack, A.D. Meyertholen, M.M. Fogler, L.V. Butov, M. Hanson, A.C. Gossard, PRL, 102, 186803 (2009).

2D Lattices

See talk, M. Remeika, “Two-Dimensional Electrostatic Lattices for Excitons,” 1:03 PM, Thursday, Room: D223/224, P32.

Moving lattices: conveyer





Electrode schematic

Study dynamical Localization-Delocalization Transition (dLDT) as a function of

- **Exciton density ← controlled by laser**
- **Conveyer amplitude ← controlled by AC voltage**
- **Conveyer velocity ← conveyer by AC frequency**

Exciton conveyer is the exciton counterpart of CCD.

↳ controlled exciton transport

↳ controlled electron transport

G.E. Smith, RMP 82, 2307 (2010).

Exciton, exciton-polariton and e-h transport via surface acoustic waves → transport velocity determined by SAW velocity, v_{saw}~3 μm/ns.

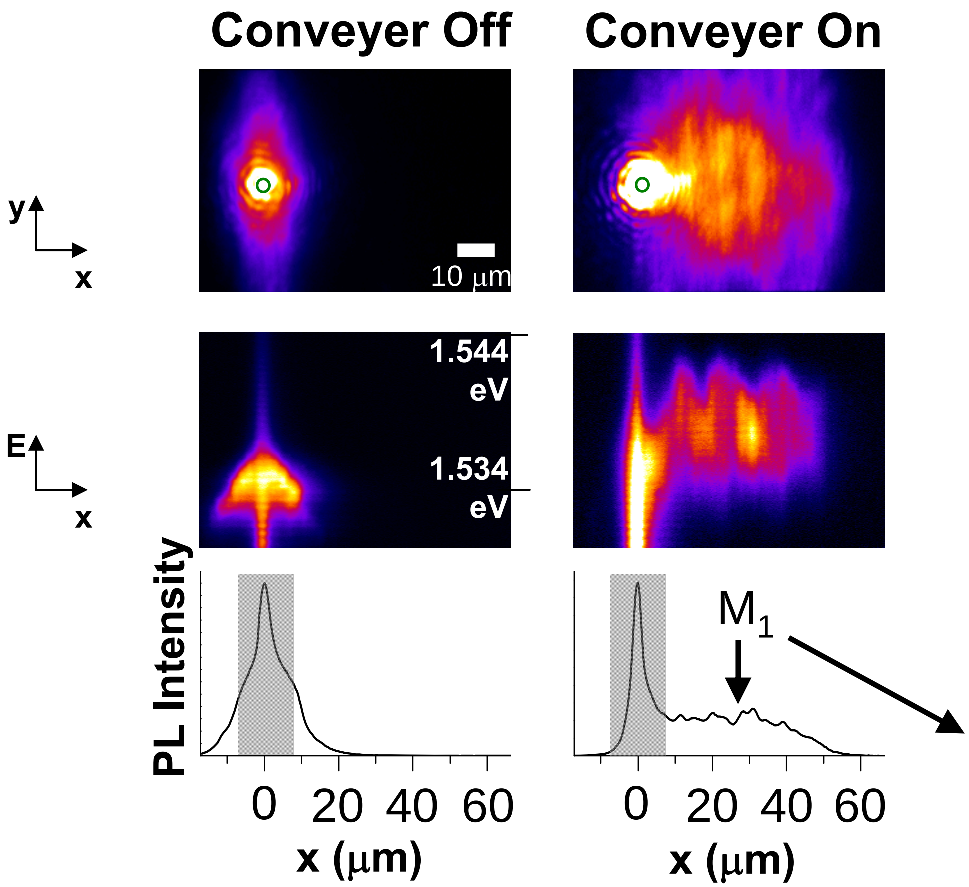
C. Rocke, S. Zimmermann, A. Wixforth, J.P. Kotthaus, G. Böhm, G. Weimann, PRL 78, 4099 (1997).

J. Rudolph, R. Hey, P.V. Santos, PRL 99, 047602 (2007).

S. Lazić, P.V. Santos, R.Hey, Physica E 42, 2640 (2010).

E.A. Cerda-Méndez, D.N. Krizhanovskii, M. Wouters, R. Bradley, K. Biermann, K. Guda, R. Hey, P.V. Santos, D. Sarkar, M.S. Skolnick, PRL 105, 116402 (2010).

x-y and x-energy Images



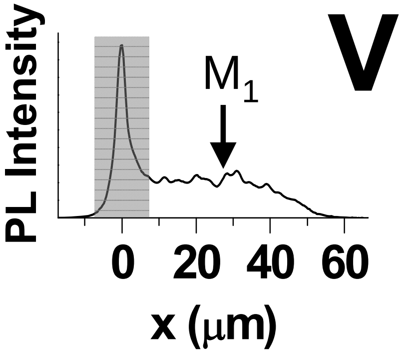
x-y images

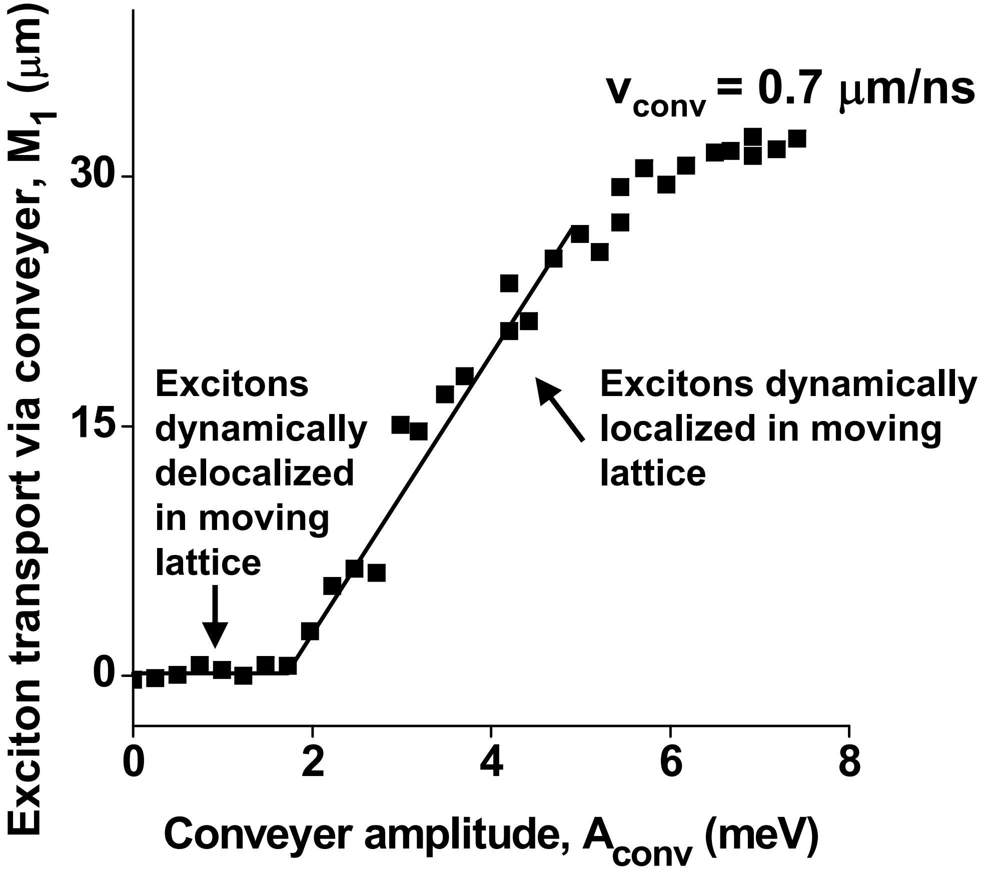
x-energy images

I(x) PL intensity profile

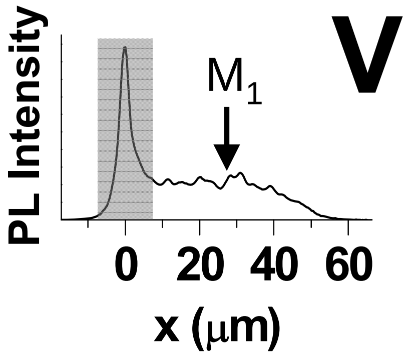
Average distance of exciton transport via conveyer

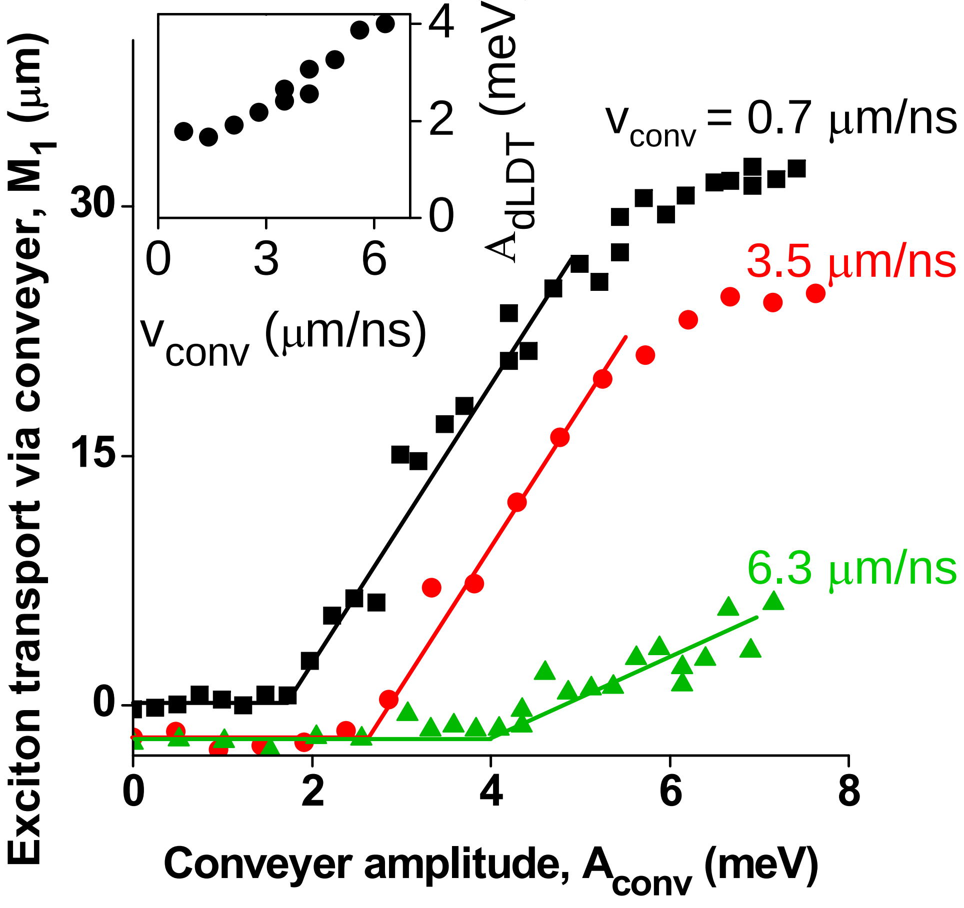
Conveyer Amplitude and Velocity Dependence





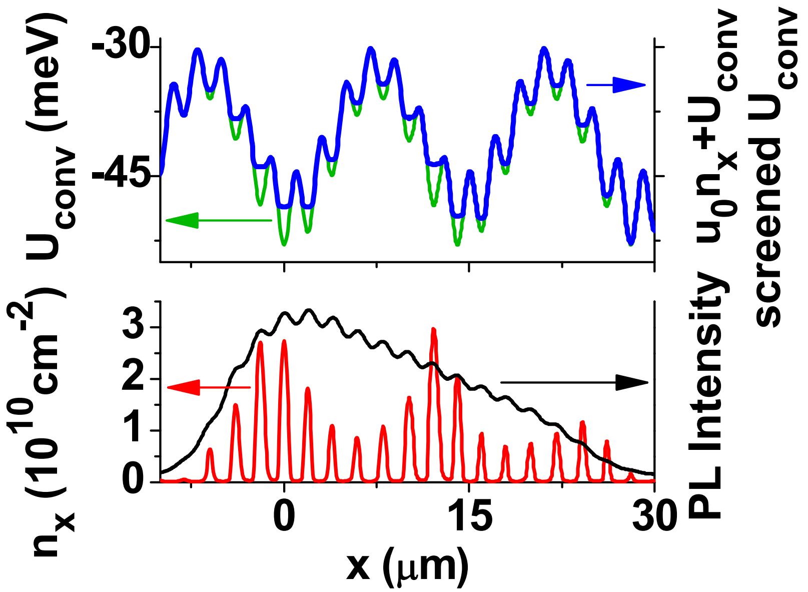
Conveyer Amplitude and Velocity Dependence





- **dynamic Localization-Delocalization Transition**
- **Exciton transport via conveyer is less efficient for higher v_{conv}**
- **A_{dLDT} increases with increasing v_{conv}**
- **No abrupt change as conveyer speed crosses the sound velocity**

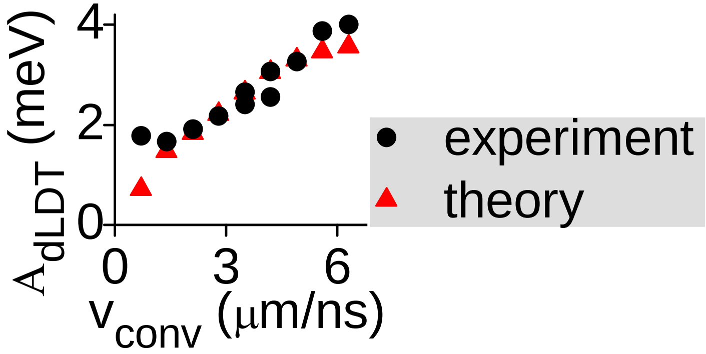
Numerical Simulations

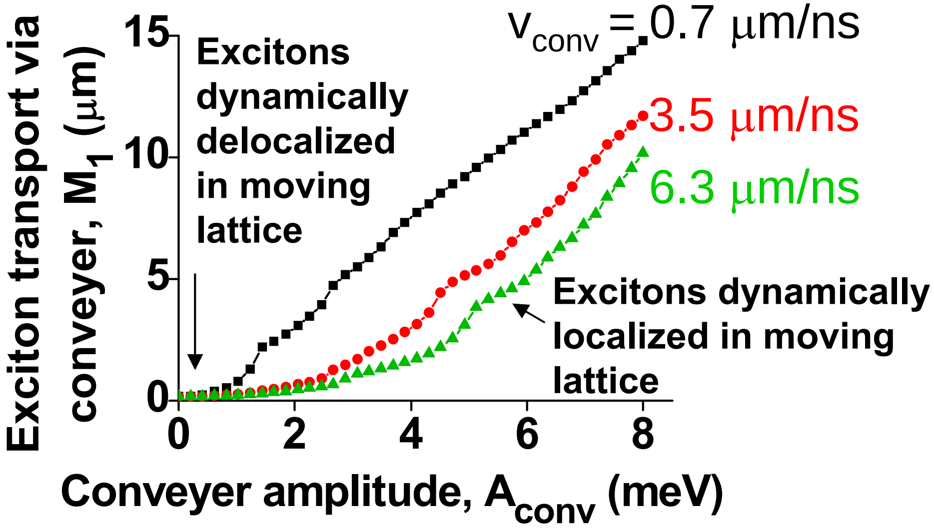


$$\frac{\partial n_x}{\partial t} = \nabla \cdot [\overbrace{D_x \nabla n_x}^{\text{diffusion}} + \overbrace{\mu_x n_x \nabla(\underbrace{u_0 n_x}_{\text{ex-ex interaction}} + \underbrace{U_{\text{conv}}}_{\text{conveyer potential}})}^{\text{drift}}] + \underbrace{\Lambda}_{\text{generation}} - \underbrace{n_x / \tau_{\text{opt}}}_{\text{recombination}}$$

U_{conv} = sinusoidal potential + ripples

controlled by electrode spacing

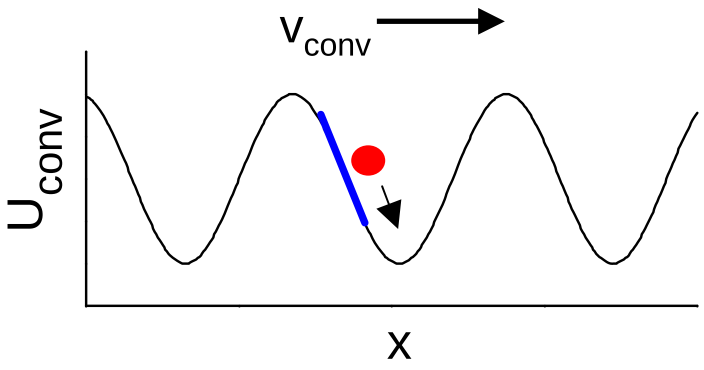




Simulations show:

- dLDT
- A higher A_{conv} is required for efficient transport via conveyer at higher v_{conv}
- Qualitative agreement with experimental data

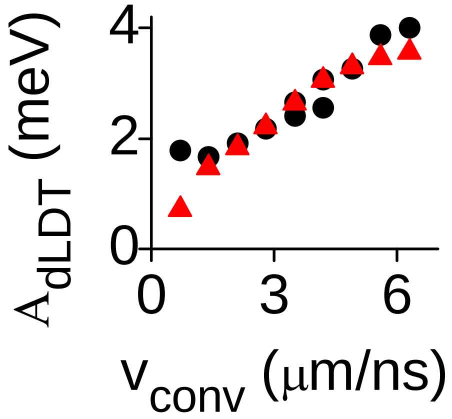
Qualitative Understanding

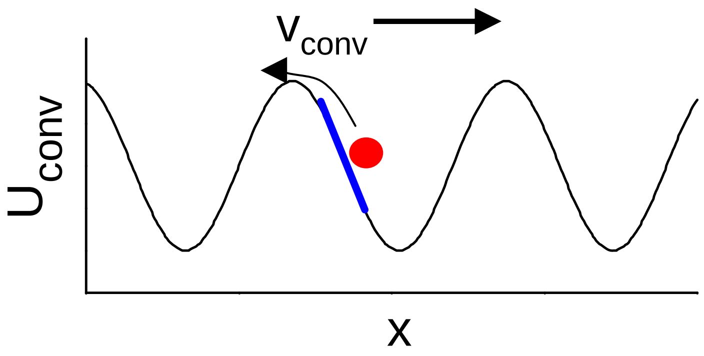


$$v_{\mathrm{drift}} = \mu_x \left(\frac{\partial U_{\mathrm{conv}}}{\partial x} \right)_{\max}$$

$$v_{\mathrm{drift}} \geq v_{\mathrm{conv}}$$

→ **Efficient exciton transport via conveyer**





$$v_{\mathrm{drift}} \leq v_{\mathrm{conv}}$$

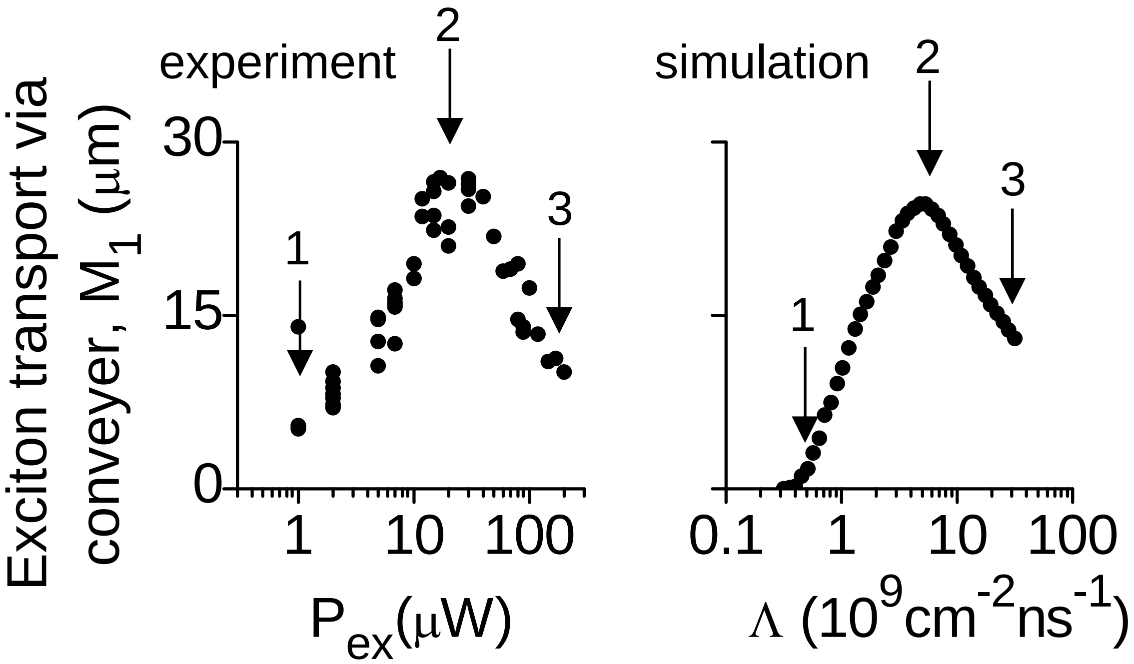
→ **Inefficient exciton transport via conveyer**

$$A_{\mathrm{dLDT}} \sim \frac{v_{\mathrm{conv}} \lambda_{\mathrm{conv}}}{\mu_{\mathrm{x}}}$$

A_{dLDT} is in qualitative agreement with the data.

No abrupt change at $v_{\mathrm{conv}} = v_{\mathrm{sound}}$ ← $v_{\mathrm{Thermal}} = \sqrt{\frac{2k_B T}{M_x}} \sim 15\ \mu\mathrm{m/ns} >> v_{\mathrm{sound}}$

Exciton Density Dependence



1. **Excitons localized in QW disorder → Inefficient exciton transport via conveyer**

2. **Excitons screen QW disorder and are dynamically localized in conveyer → Efficient exciton transport via conveyer**

3. **Excitons screen U_{conv} → less efficient exciton transport via conveyer → conveyer saturation**

Conclusions

- Realized exciton conveyer
- Observed dynamical Localization-Delocalization Transition with varying:
  - Conveyer Amplitude
  - Conveyer Velocity
  - Exciton Density

arXiv:1102.5329