# Transport of Indirect Excitons in a Potential Energy Gradient

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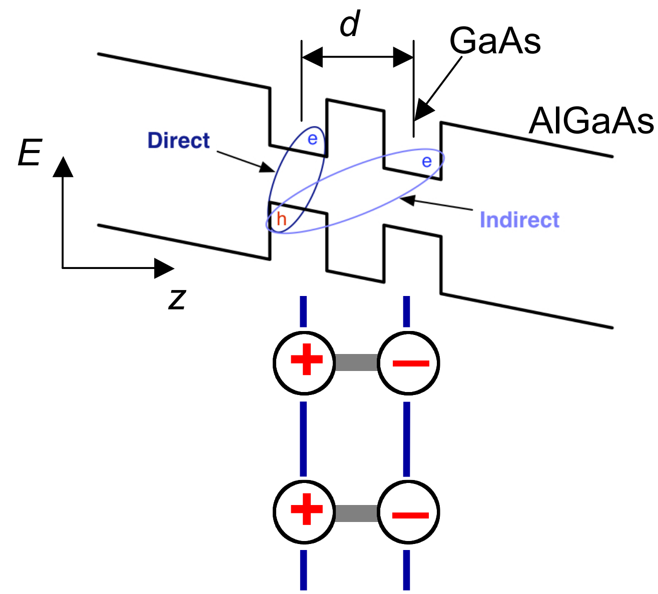
# Indirect excitons



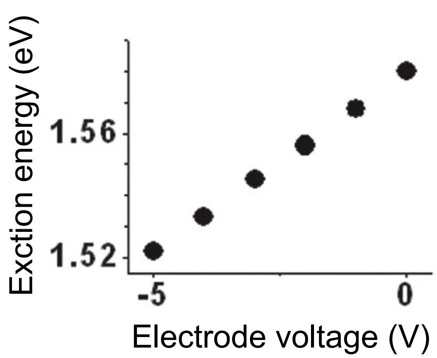

An exciton is a bound electron-hole pair.

*Indirect excitons: e* and *h* are confined to spatially separated quantum wells.

Properties of indirect excitons:

- increased lifetime and transport distance

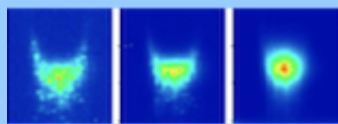
- oriented dipoles → repulsive interaction → excitons screen disorder
- oriented dipoles → exciton energy controllable by applied voltage




$\delta E = edF_z$

# Excitonic devices

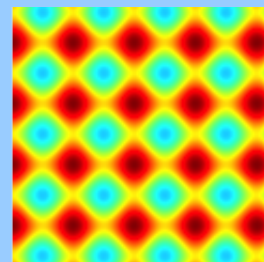
Electrostatic traps for excitons



A.A. High *et al, Nano Lett.* 10.1021 (2012).

A.A. High, session FS 1
4/8, 5:15 PM, rm. A4

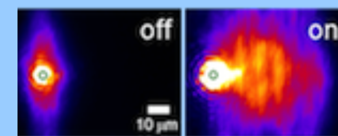
Electrostatic lattices for excitons



M. Remeika *et al, APL* **100**, 061103 (2012).

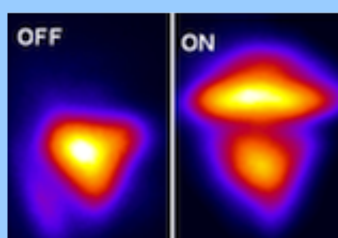
M. Remeika, session FS 4
4/7, 12:15 PM, rm. A7

Electrostatic conveyer for excitons



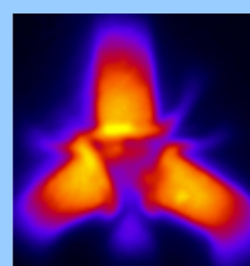

A.G. Winbow *et al*, *PRL* **106**, 196806 (2011).

Exciton transistors



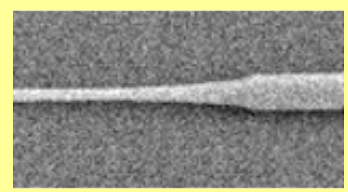

Y.Y. Kuznetsova *et al, Optics Lett.* **35**, 1587 (2010).

Exciton integrated circuits



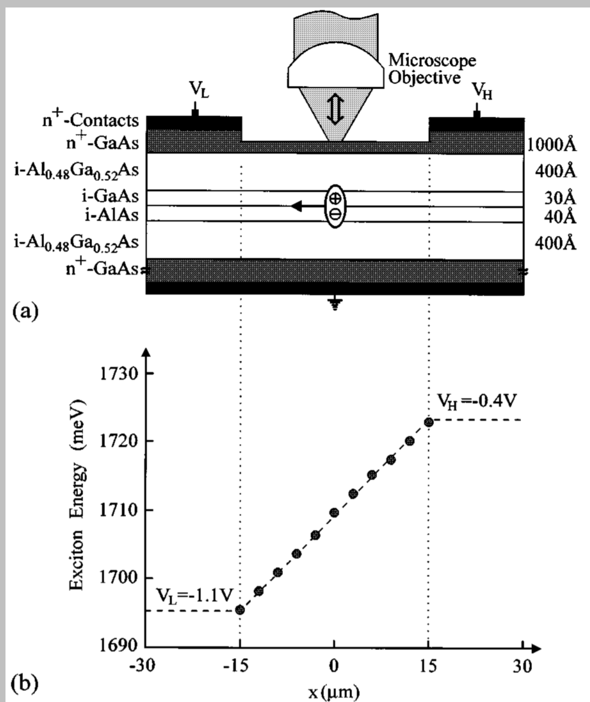
A.A. High *et al, Science* **321**, 229 (2008).

New device:
Exciton ramp (diode)



J.R. Leonard *et al,* arXiv:1203.6239v1 (2012).

# Earlier realizations of exciton ramps used voltage gradients




M. Hagn, A. Zrenner, G. Böhm, G. Weimann, *APL* **67**, 232 (1995)

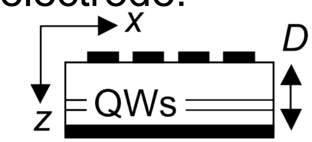
A. Gartner, A.W. Holleitner, J.P. Kotthaus, D. Schuh, *APL* **89**, 052108 (2006)

# New approach: Control of excitons by electrode density

Exciton energy landscape is controlled by using a single voltage on a single shaped electrode:

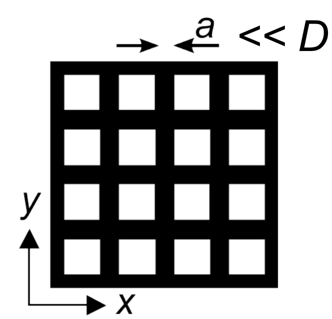
electrode pattern at voltage

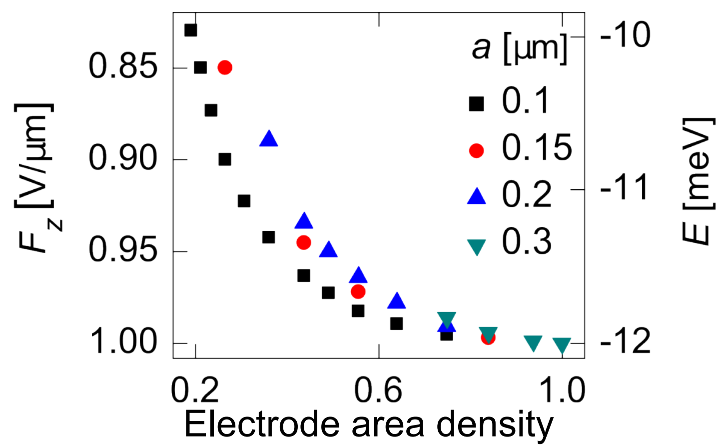
ground plane




$$\delta E = edF_z$$

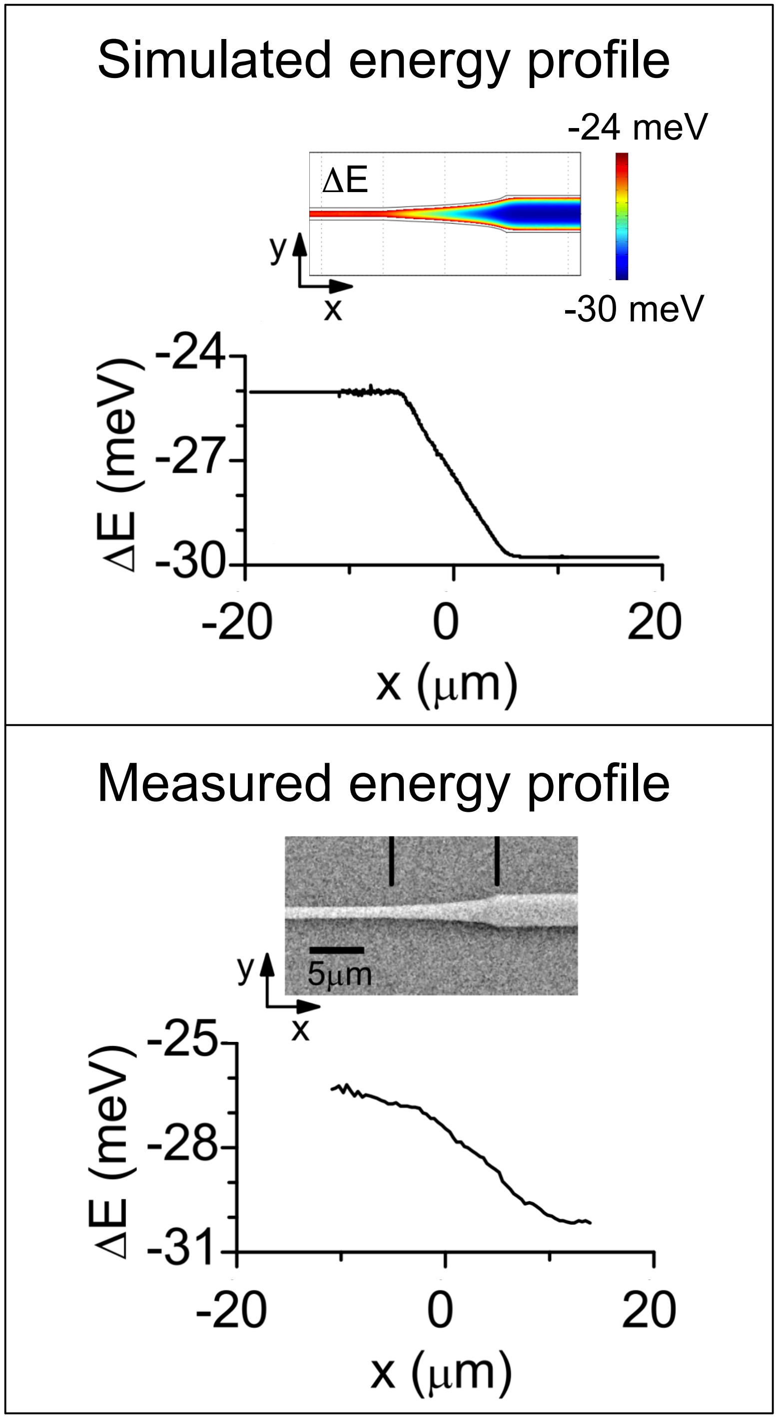
shaping the top electrode reduce $F_z$ due to fringing field




*Advantage:* suppression of heating by electric currents in electrodes

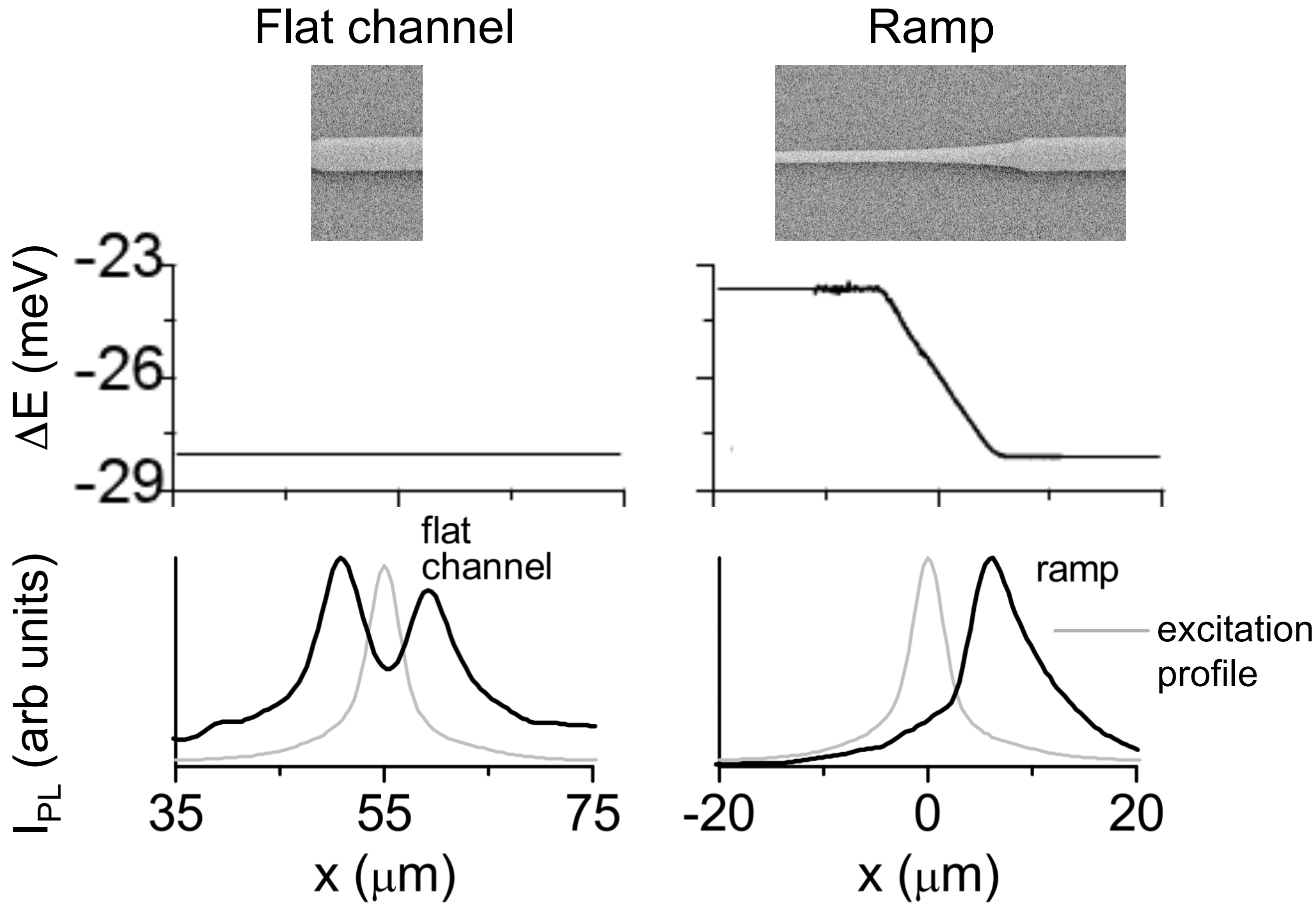
Y.Y. Kuznetsova, A.A. High, L.V. Butov, *APL* 97, 201106 (2010)




# Exciton ramps

- Width of electrode varies from 1 μm to 3 μm
- Electrode shape calculated to give a linear potential energy profile for excitons

# Exciton transport in a ramp

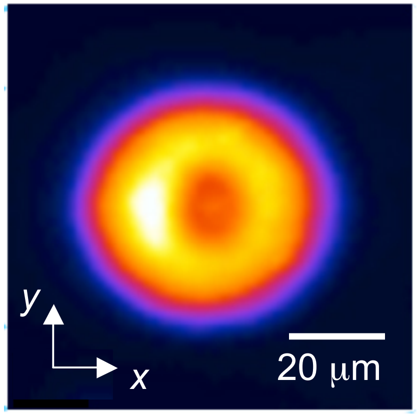



**Flat channel:** exciton transport symmetric about the excitation spot

**Ramp:** exciton transport only in the direction of lower potential energy

➡ realizes directed transport of excitons as a diode realizes directed transport of electrons.

# Formation of the exciton inner ring




excitons cool as they travel away from the excitation spot

↓

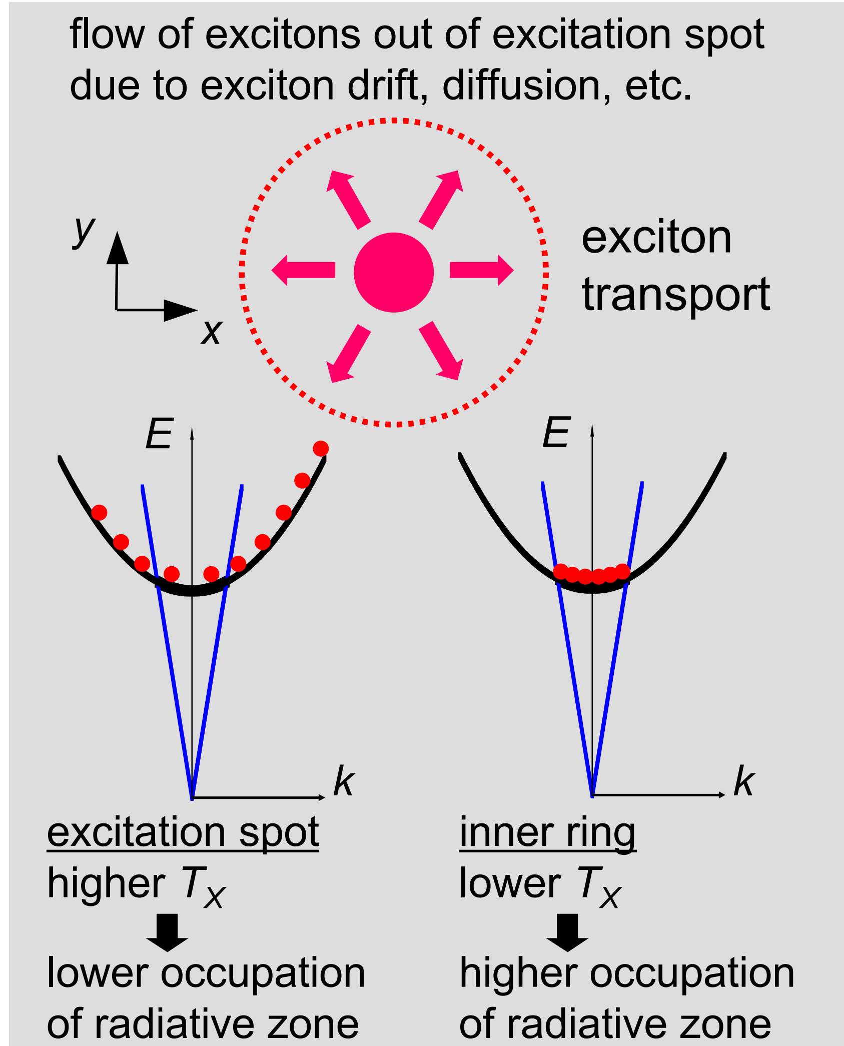
increased occupation of radiative zone

↓

enhancement of PL intensity

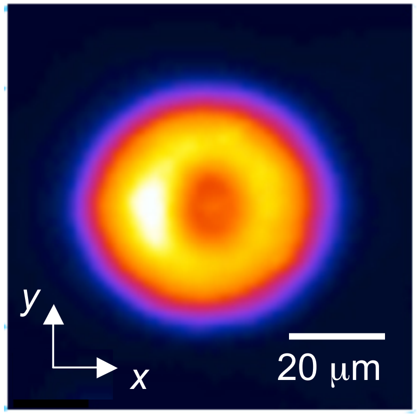
↓

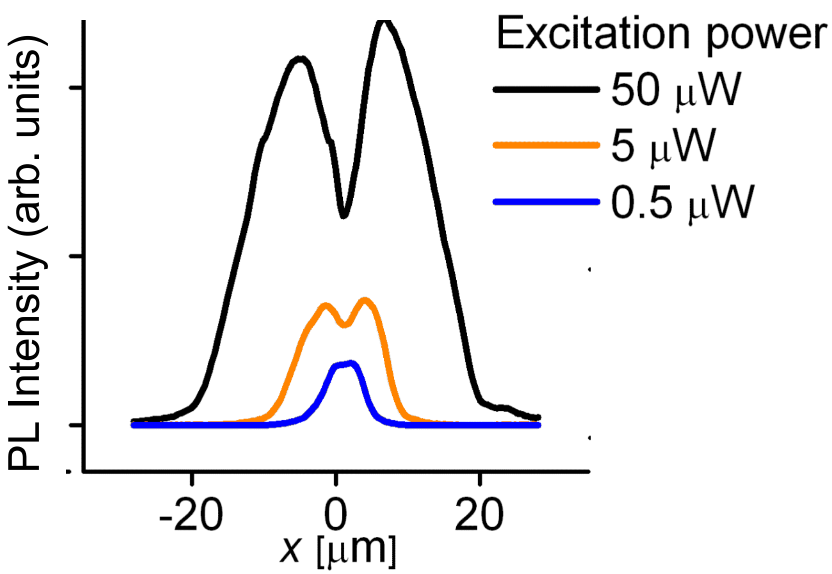
inner ring

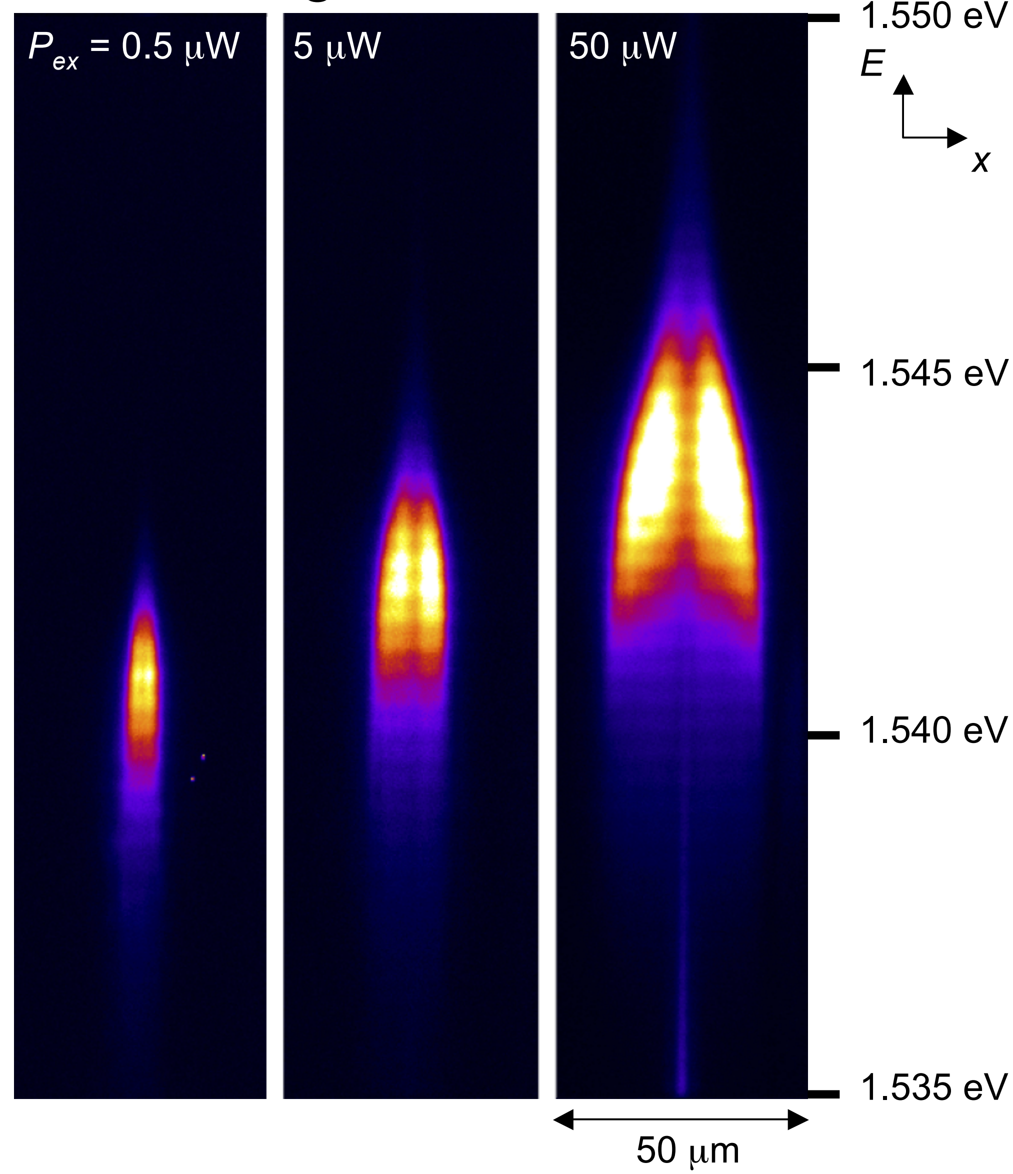



Y.Y. Kuznetsova, J.R. Leonard, L.V. Butov, J. Wilkes, E.A. Muljarov, K.L. Campman, A.C. Gossard, *PRB* **85**, 165452 (2012)

# Exciton inner ring




$E_{ex}$ = 1.588 eV
T = 1.5 K
excitation spot at x = 0 with
FWHM = 2.8 μm

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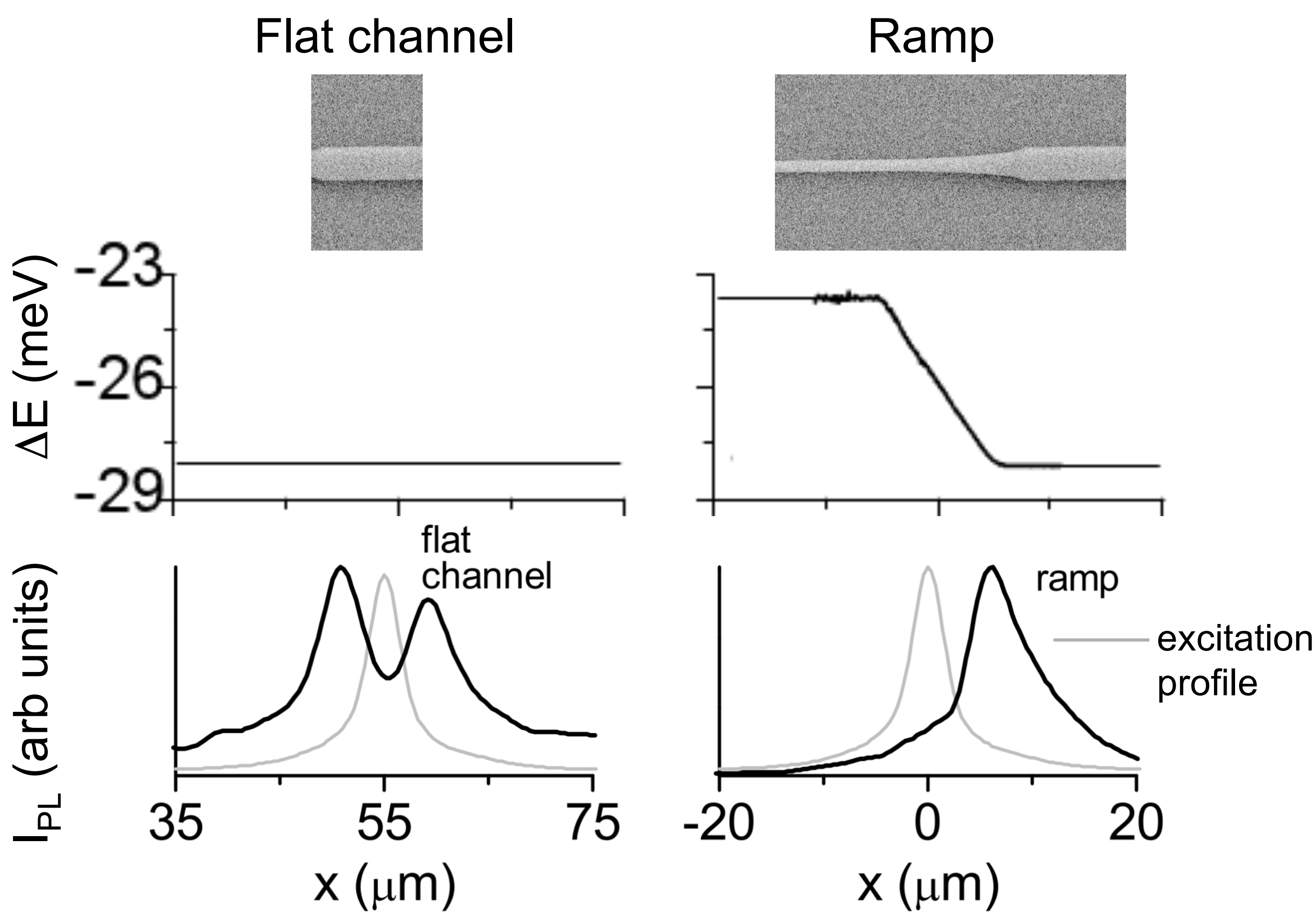
# Exciton transport in a ramp

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**Ramp:** exciton transport only in the direction of lower potential energy

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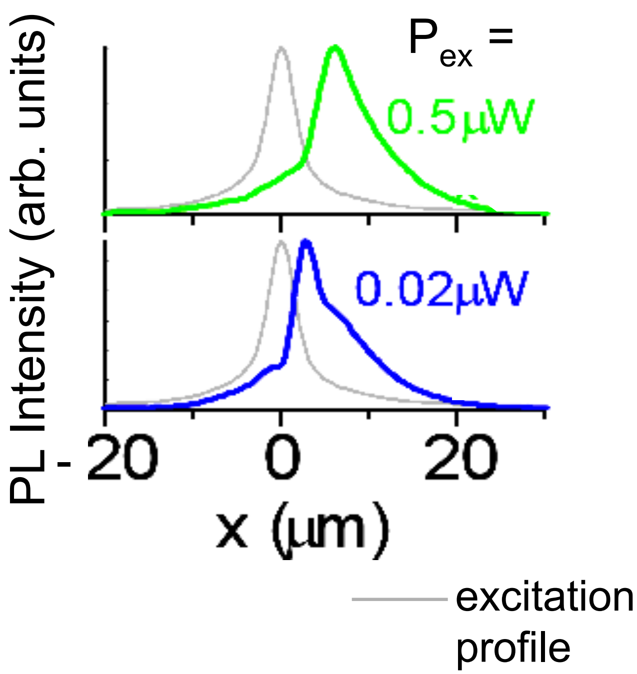
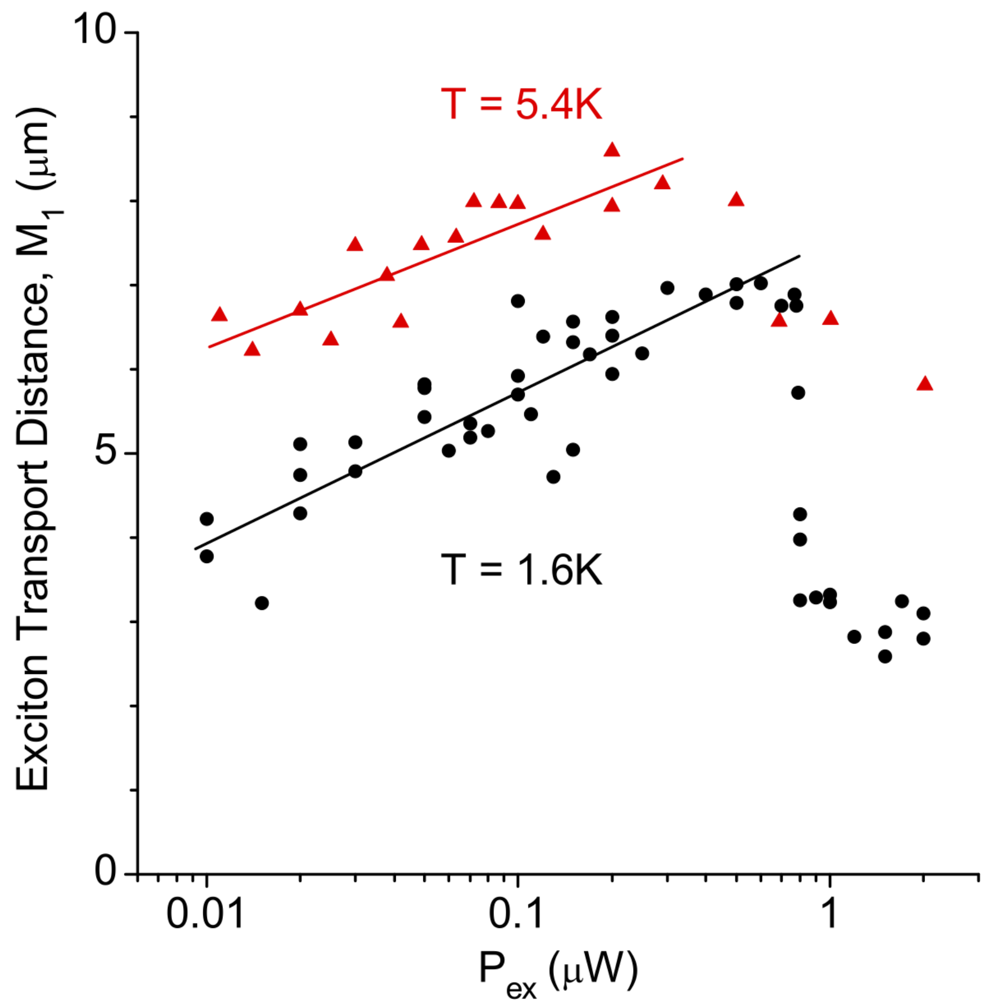
# Density dependence of exciton transport in ramps




higher excitation power

↓

higher exciton density

↓

better disorder screening

↓

longer transport distances

# Numerical simulations

The system was modeled by solving coupled differential equations:

drift-diffusion equation

$$\nabla\left[D_x \nabla n_x + \mu_x n_x \nabla\left(u_0 n_x + U_{ramp}\right)\right] - n_x/\tau_{opt} + \Lambda = 0$$

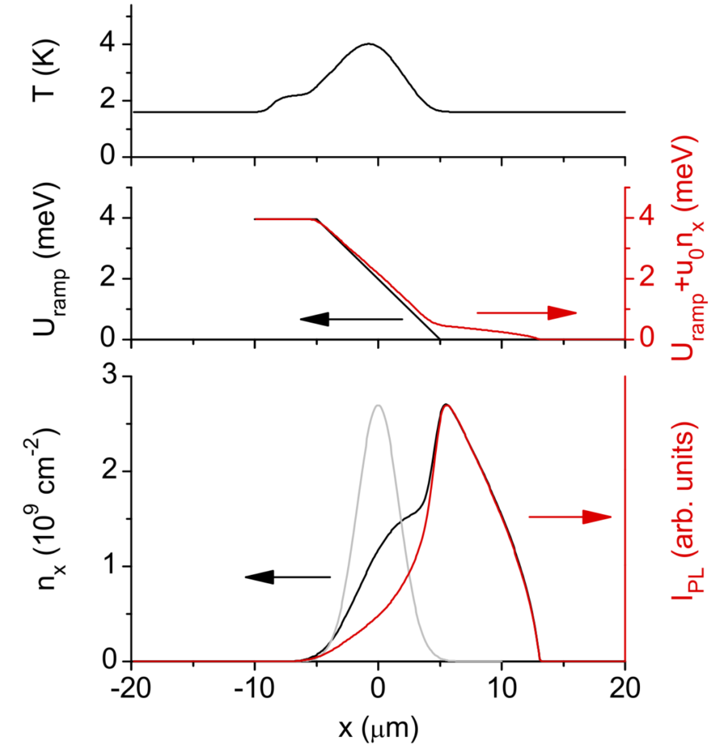
diffusion — drift — optical decay — exciton generation

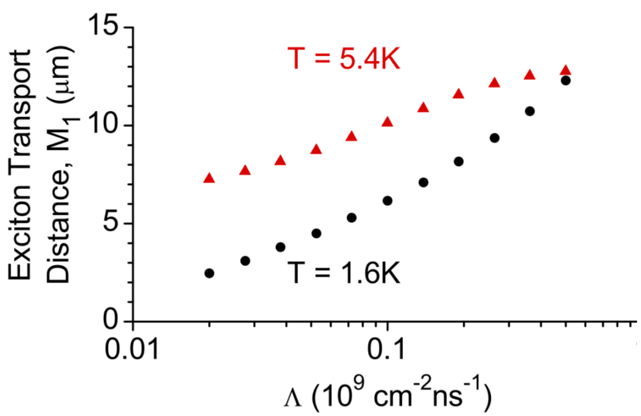
and heat balance equation

$$S_{phonon}\left(T_0, T\right) = S_{pump}\left(T_0, T, \Lambda, E_{inc}\right)$$

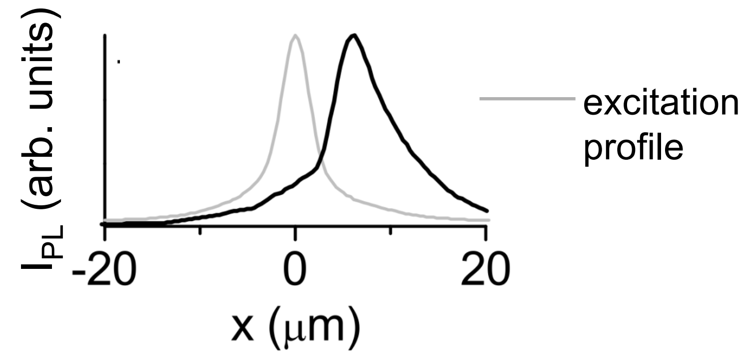
cooling through phonons — heating due to laser

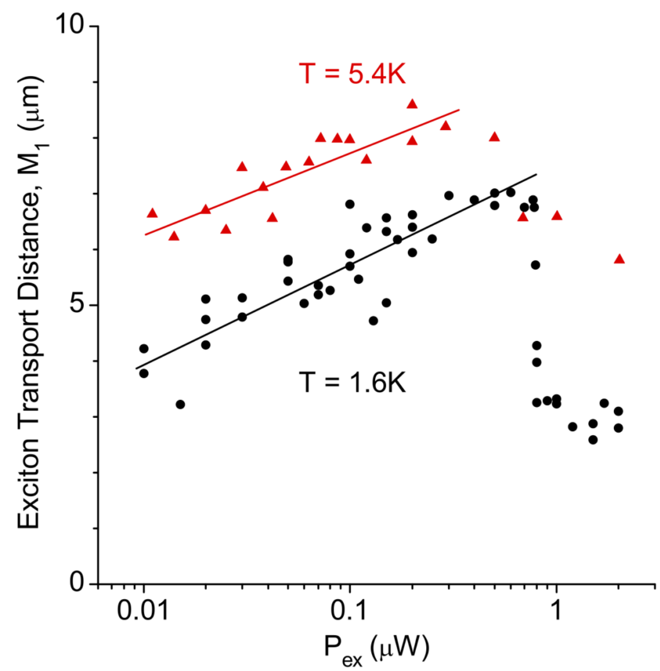
# Numerical simulations




# Experimental results



# Conclusions

- We realized a linear potential energy gradient (ramp) for indirect excitons using a shaped electrode at constant voltage.
- The excitonic ramp realizes directed transport of excitons as a diode realizes directed transport of electrons.
- We studied transport of indirect excitons along the ramp and observed that the exciton transport distance increases with increasing density and temperature.

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