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
- exciton energy controllable by applied voltage

\[
\delta E = edF_z
\]

[Graph showing exciton energy (eV) vs. electrode voltage (V)]

- repulsive interaction
- excitons screen disorder

GaAs

AlGaAs
Excitonic devices

Electrostatic traps for excitons
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

Exciton transistors

Exciton integrated circuits

New device: Exciton ramp (diode)
New approach: Control of excitons by electrode density

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

\[ \delta E = edF_z \]

shaping the top electrode reduce \( F_z \) due to fringing field

Advantage: suppression of heating by electric currents in electrodes


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

\( I_{PL}(\text{arb units}) \)

\( \Delta E \text{ (meV)} \)

\( x \text{ (\mu m)} \)
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

flow of excitons out of excitation spot due to exciton drift, diffusion, etc.

exciton transport

excitation spot higher $T_x$

inner ring lower $T_x$

lower occupation of radiative zone

higher occupation of radiative zone

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

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.
Density dependence of exciton transport in ramps

- Higher excitation power
  - Higher exciton density
  - Better disorder screening
  - Longer transport distances

PL Intensity (arb. units)

$x$ (μm)

$P_{ex} = 0.5 \mu W$

$P_{ex} = 0.02 \mu W$

Exciton Transport Distance, $M_1$ (μm)

$T = 5.4K$

$T = 1.6K$

$P_{ex} (\mu W)$
Numerical simulations

The system was modeled by solving coupled differential equations:

**drift-diffusion equation**

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

**heat balance equation**

\[
S_{phonon} (T_0, T) = S_{pump} (T_0, T, \Lambda, E_{inc})
\]

- **cooling through phonons**
- **heating due to laser**
Numerical simulations

Experimental results

I_{PL}(arb. units)

T (K)

U_{ramp} (meV)

n_x (10^8 cm^-2)

x (um)

I_{PL}(arb. units)

excitation profile

Exciton Transport Distance, M_x (mu m)

T = 5.4K

T = 1.6K

Lambda (10^9 cm^-2 ns^-1)

P_{ex} (mu W)

T = 5.4K

T = 1.6K
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.