Indirect Excitons in a Potential Energy Landscape Created by a Perforated Electrode

C. J. Dorow, Y. Y. Kuznetsova, J. R. Leonard, M. K. Chu, L. V. Butov
Department of Physics, University of California, San Diego

J. Wilkes
School of Physics and Astronomy, Cardiff University

M. Hanson, A. C. Gossard
Materials Department, University of California, Santa Barbara
Indirect Excitons

Exciton: bound electron-hole pair

**Indirect excitons:**
- $e$ and $h$ are confined to *spatially separated* quantum wells
- Increased lifetimes and transport distances
- Oriented dipoles → disorder screening

Indirect exciton energy controllable by applied voltage: $\delta E = -edF_z$
Excitonic Devices

Fundamental Physics

Electrostatic traps

Exciton Lattices

Electrostatic conveyer

Stirring potential

Circuit Devices

Exciton transistors:

Optoelectronic

All-optical

Exciton ramp (diode)

Exciton integrated circuits

more information: physics.ucsd.edu/~lvbutov
Control of Excitons by Electrode Density

electrode pattern at uniform voltage

ground plane

shaping the top electrode can control $F_z$ due to fringing field

$\delta E = -edF_z$

Advantage: suppression of heating by electric currents in electrodes

Important for
- creating devices with low energy consumption
- studies of ultra-cold exciton gasses

Earlier method: control of excitons by voltage gradient

A. Gartner et al, APL 89, 052108 (2006)
Directed Transport of Excitons

- Directs transport of excitons as a diode directs transport of electrons
- Potential energy gradient created by shaped electrode
- Exciton fluxes are limited by geometry

Ramp Created by Perforated Electrode Method

Electrode density modulation achieved with a perforated electrode

Increasing Electrode density
Decreasing Exciton energy

Perforated electrode method

- Opportunity to create versatile potential landscapes for indirect excitons
- Create channels for directing exciton fluxes with the required geometry and energy profile
- Exciton fluxes are not limited by geometry

Energy profile

Perforated electrode SEM

Ramp Created by Perforated Electrode Method

Flat channel, no preferred exciton transport direction

Similar to ring due to PL enhancement outside of excitation spot
Y.Y. Kuznetsova et al., PRB 85, 165452 (2012)

Ramp, directed exciton transport

Observed exciton transport distance increase with excitation power:

- higher excitation power
- higher exciton density
- better disorder screening
- longer transport distances
Numerical Simulations

The exciton system was modeled by solving coupled differential equations:

**drift-diffusion equation**

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

- **diffusion**
- **drift**
- **optical decay**
- **exciton generation**

**heat balance equation**

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

- **cooling through phonons**
- **heating due to laser excitation**
Control of Excitons: Perforated Electrode Method

Ramp: proof of principle demonstration of perforated electrode method for controlling exciton fluxes.

Outlook:
Apply method to other types of excitonic devices

Example:
Elevated trap potential created by a perforated electrode

Y.Y. Kuznetsova et al, APL 97, 201106 (2010)
Conclusion

• We realized a linear potential energy gradient (ramp) for indirect excitons using a **perforated electrode at constant voltage**.

• The excitonic ramp realizes **directed transport of excitons** as a diode realizes directed transport of electrons.

• The ramp provides an experimental **proof of principle for the perforated electrode method of controlling exciton transport** with electrode density gradients.

• The **perforated electrode method is non-dissipative**, important for
  – creating devices with **low energy consumption**
  – studies of **ultra-cold exciton gasses**