Excitonic Devices

Transistors, Traps, and Stirring Potentials

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**Introduction to indirect excitons**

**Exciton**: bound electron – hole pair

**Indirect exciton**: electron and hole are confined to spatially separated quantum well layers

**Properties of indirect excitons**
- Increased lifetime
- Increased transport distances
- Allows for cooling to low temperatures
- Are oriented dipoles:
  - Repulsive interaction screens disorder
  - Exciton energy is controllable by voltage $E = edF_z$

**Excitonic Devices**

**Physics of Cold Bosons in Materials**
Excitonic devices

- Traps for excitons
  - A.A. High et al, PRL 2009
  - Y.Y. Kuznetsova et al, APL 2010

- Lattices for excitons
  - M. Remeika et al, PRL 2009
  - M. Remeika et al, APL 2012

- Excitonic conveyer, CCD

- Excitonic circuits
  - J.R. Leonard et al, APL 2012
Overview

• Excitonic Transistors
• Snowflake Traps for Excitons
• Stirring Potentials for Excitons
Excitonic transistors

- Geometry similar to FET
- Time delay between signal processing and optical communication is effectively eliminated
- Compact footprint

Exciton optoelectronic transistor

Source and drain are photonic;
Exciton flux from source to drain is controlled by voltage on gate electrode

A.A. High et al, Optics Lett. 2007
A.A. High et al, Science 2008

All-optical excitonic transistor

Source and drain are photonic.
Light changes voltage at gate electrode, controlling exciton flux from source to drain.

Y.Y. Kuznetsova et al, Optics Lett. 2010
Crossed-Ramp Excitonic Transistor

(a)

P. Andreakou et al, APL 2014
Control of Exciton Energy by Electrode Density

Excitonic Ramp

Ramp: exciton transport in the direction of lower potential energy

→ realizes directed transport of excitons analogous to a diode for electrons

Higher electrode density corresponds to higher electric field in z direction
→ lower exciton energy

Shape of electrode calculated to give a linear potential energy profile for excitons

Y.Y. Kuznetsova et al, APL 2010

J.R. Leonard et al, APL 2012
Reduced electrode density in crossing region to keep linear potential.

Crossed ramp potentials for indirect excitons

$U_{\text{ramp}}$ (meV)

P. Andreakou et al, APL 2014
Crossed-Ramp Excitonic Transistor

Light controls light by using excitons as an intermediate medium.

- Single-electrode design prevents heating by in-plane electron currents

Crossed-Ramp Excitonic Transistor

Light controls light by using excitons as an intermediate medium.

- Single-electrode design prevents heating by in-plane electron currents
- Also operates as a router

Crossed-Ramp Excitonic Transistor

- On/Off ratio reaches 300
- Low intensity gate beam controls high intensity output

Overview

• Excitonic Transistors
• Snowflake Traps for Excitons
• Stirring Potentials for Excitons
Diamond-Shaped Trap

- Creates canoe-shaped confining potential for excitons in small area

- Only small number of excitons can be trapped

- Condensate of ~1000 excitons can be collected

A.A. High et al, PRL 2009
Nano Lett. 2012
Realization of 2D Snowflake Trap

- Confining potential in large area

- 2D Snowflake trap collects excitons from all directions to trap center

- Realization of high-density exciton gas in trap center

Outlook: Study high-density condensates in 2D snowflake traps
Overview

• Excitonic Transistors
• Snowflake Traps for Excitons
• Stirring Potentials for Excitons
Moving Lattice: Conveyer

Electrode schematic

connecting electrodes

conveyer electrodes

Works as exciton CCD

A.G. Winbow et al, PRL 2011
Stirring Potential for Indirect Excitons (Carousel)

- Stirring potentials can be used to generate vortices.

- Vortices are studied for various collective states, which range from superconductors to BEC.

**Control of Stirring Potential:**

- Angular velocity is controlled by AC frequency

- Wavelength is determined by electrode periodicity

- Potential amplitude is controlled by AC amplitude
Design of Stirring Potential for Excitons (Carousel)
Design of Stirring Potential for Excitons (Carousel)

Carousel electrodes

Insulating layer with openings for connections
Design of Stirring Potential for Excitons (Carousel)

Carousel electrodes

Insulating layer with openings for connections

Connecting electrodes
Stirring Potential for Excitons at Different Radii

Angle (Degrees)

Potential (meV)

-45
-40
-35
-30
-25
0
90
180

R = 15um
R = 10um
R = 5um

0
90
180
Carousel Results

Exciton Emission

Angle

OFF
ON

First Moment of Angle Shift (degrees)

Excitation Spot

OFF
ON

Excitation Spot

OFF
ON

First Moment of Angle Shift (degrees)

First Moment of Angle Shift (degrees)

Excitation Power (µW)

Amplitude of Stirring Potential (mV)
Conclusions

• Demonstrated an all-optical excitonic transistor and router

• Demonstrated a 2D snowflake trap for excitons

• Demonstrated a stirring potential for excitons