Excitonic Devices

Transistors, Traps, and Stirring Potentials

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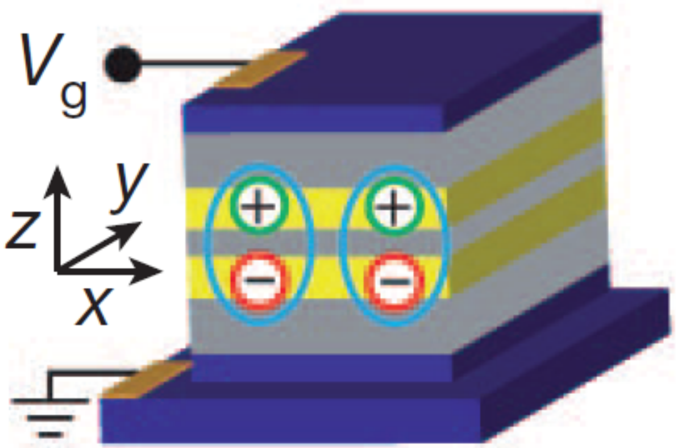
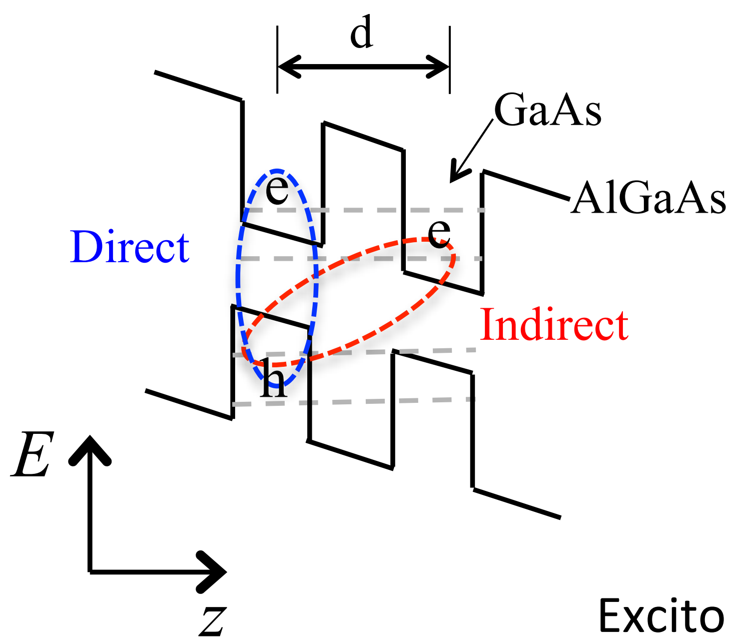
Introduction to indirect excitons



Exciton: bound electron – hole pair

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



Properties of indirect excitons

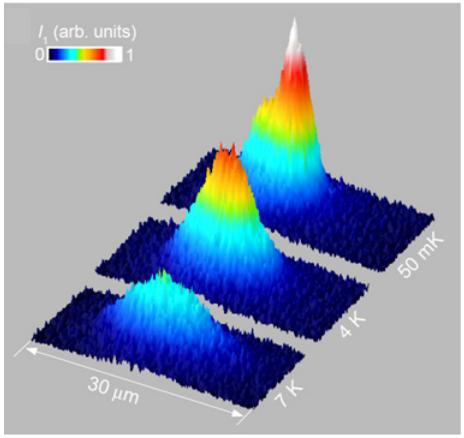
- Increased lifetime
  - Increased transport distances
  - Allows for cooling to low temperatures
- Are oriented dipoles:
  - -repulsive interaction screens disorder
  - -exciton energy is controllable by voltage $E=edF_z$

Excitonic Devices

Physics of Cold Bosons in Materials

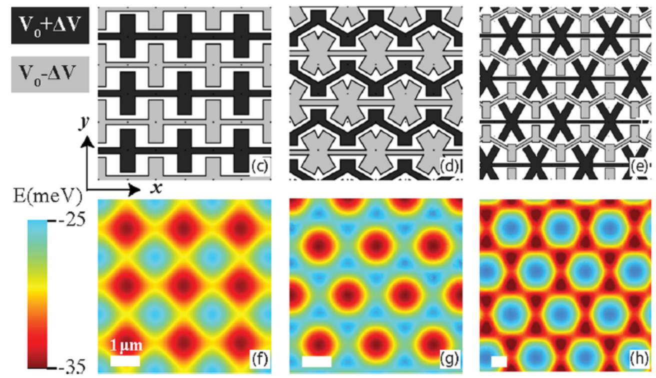
Excitonic devices

- Traps for excitons



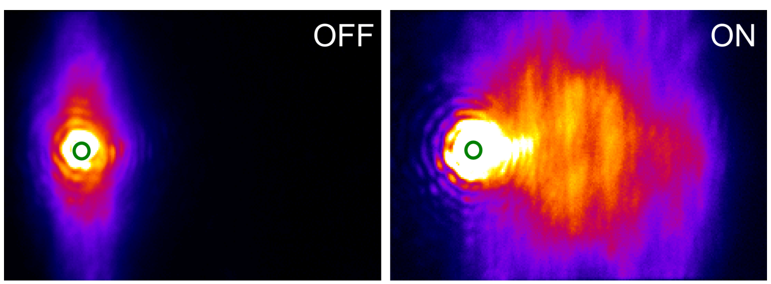
A.A. High *et al, PRL* 2009
A.A. High *et al, Nano Lett* 2009
Y.Y. Kuznetsova *et al, APL* 2010
A.A. High *et al, Nano Lett.* 2012

- Lattices for excitons



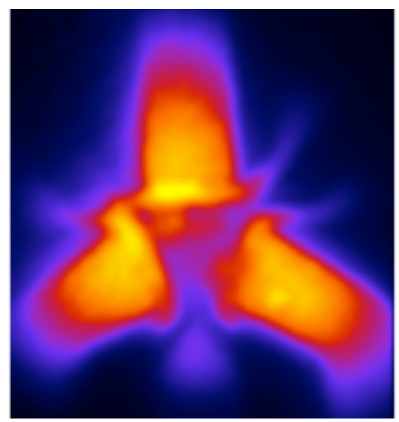
M. Remeika *et al, PRL* 2009
M. Remeika *et al, APL* 2012

- Excitonic conveyer, CCD



A.G. Winbow *et al, PRL* 2011

- Excitonic circuits



A.G. Winbow *et al, Nano Lett.* 2007
A.A. High *et al, Opt. Lett.* 2007
A.G. Winbow *et al, JAP* 2008
A.A. High *et al, Science* 2008
G. Grosso *et al, Nature Phot. 2009*
Y.Y. Kuznetsova *et al, Opt. Lett.* 2010
J.R. Leonard *et al, APL* 2012

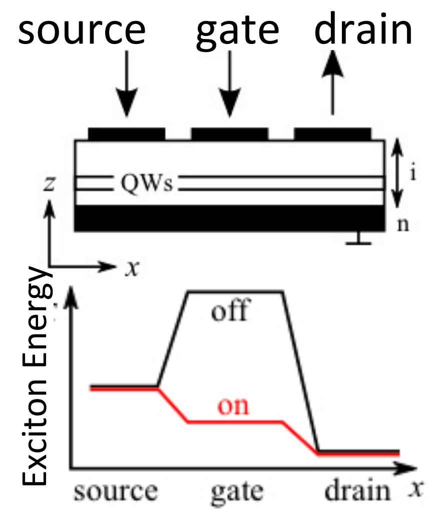
Overview

- Excitonic Transistors
- Snowflake Traps for Excitons
- Stirring Potentials for Excitons

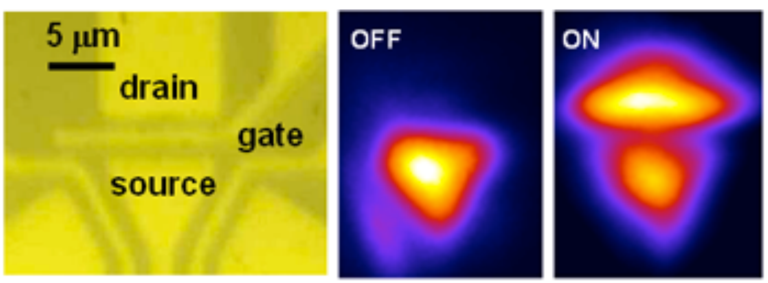
Excitonic transistors

- Geometry similar to FET

- Time delay between signal processing and optical communication is effectively eliminated
- Compact footprint



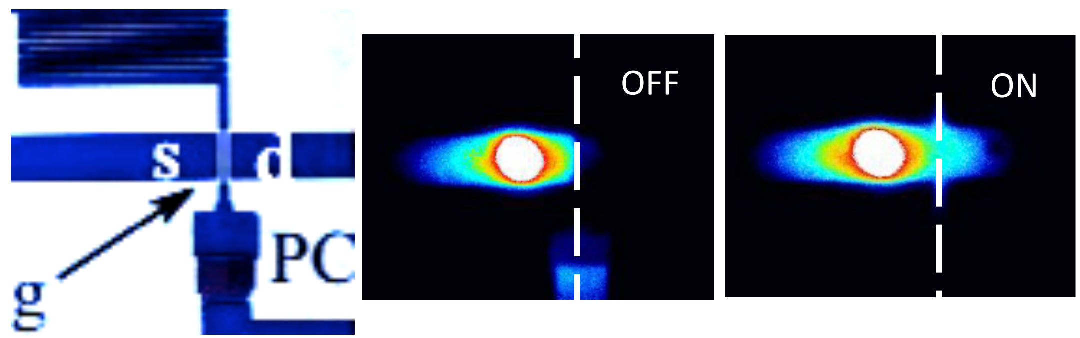
Exciton optoelectronic transistor



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
G. Grosso *et al*, *Nature Phot.* 2009

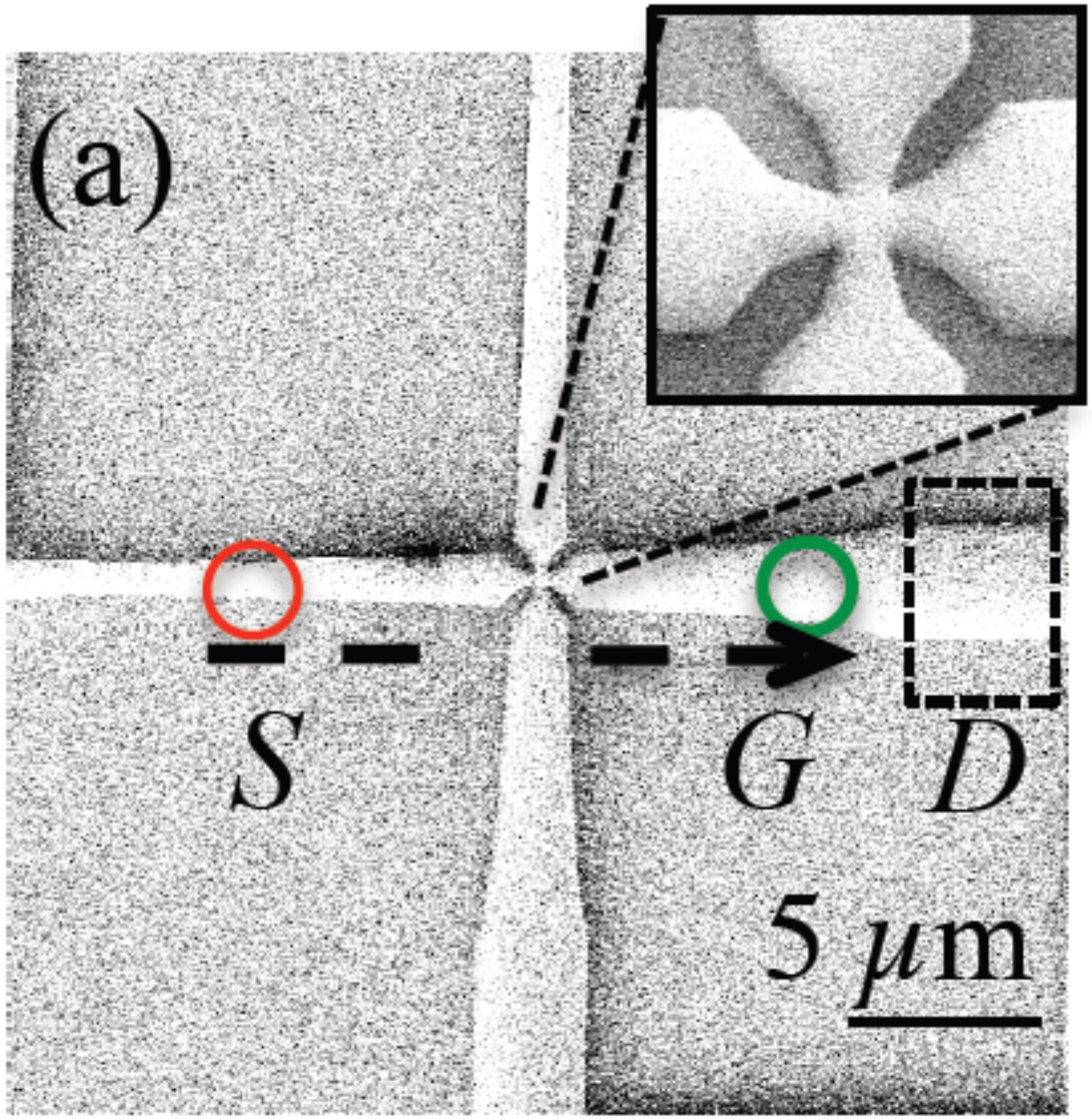
All-optical excitonic transistor



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

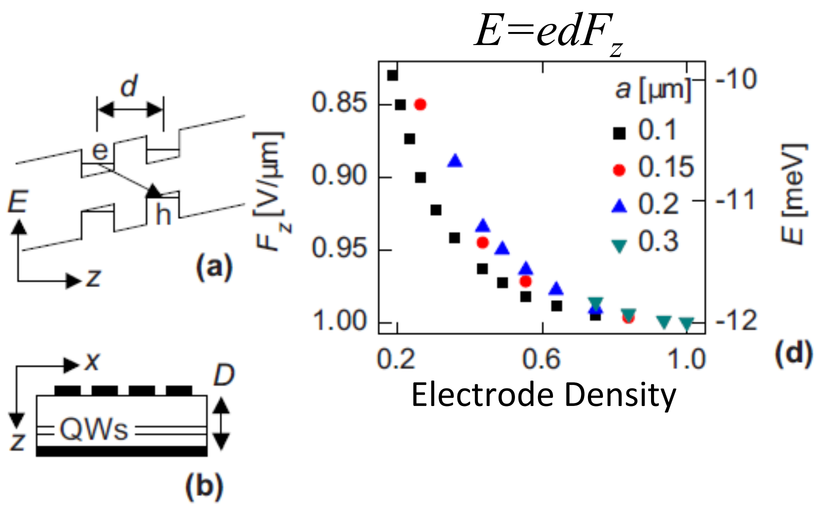
Y.Y. Kuznetsova *et al*, *Optics Lett*. 2010

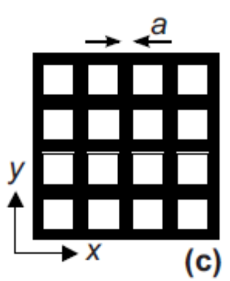
Crossed-Ramp Excitonic Transistor



P. Andreakou *et al, APL* 2014

Control of Exciton Energy by Electrode Density

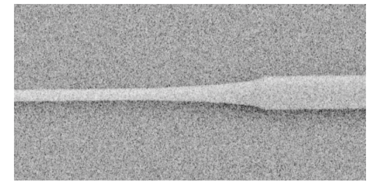




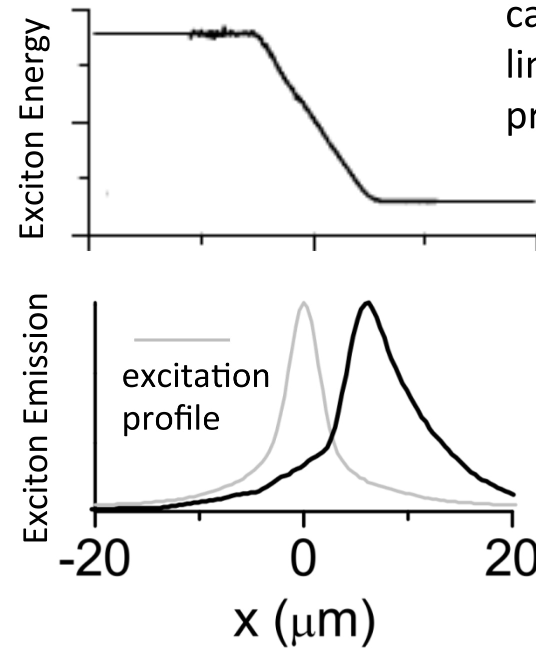
Higher electrode density corresponds to higher electric field in z direction
→ lower exciton energy

Y.Y. Kuznetsova *et al, APL* 2010

Excitonic Ramp



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

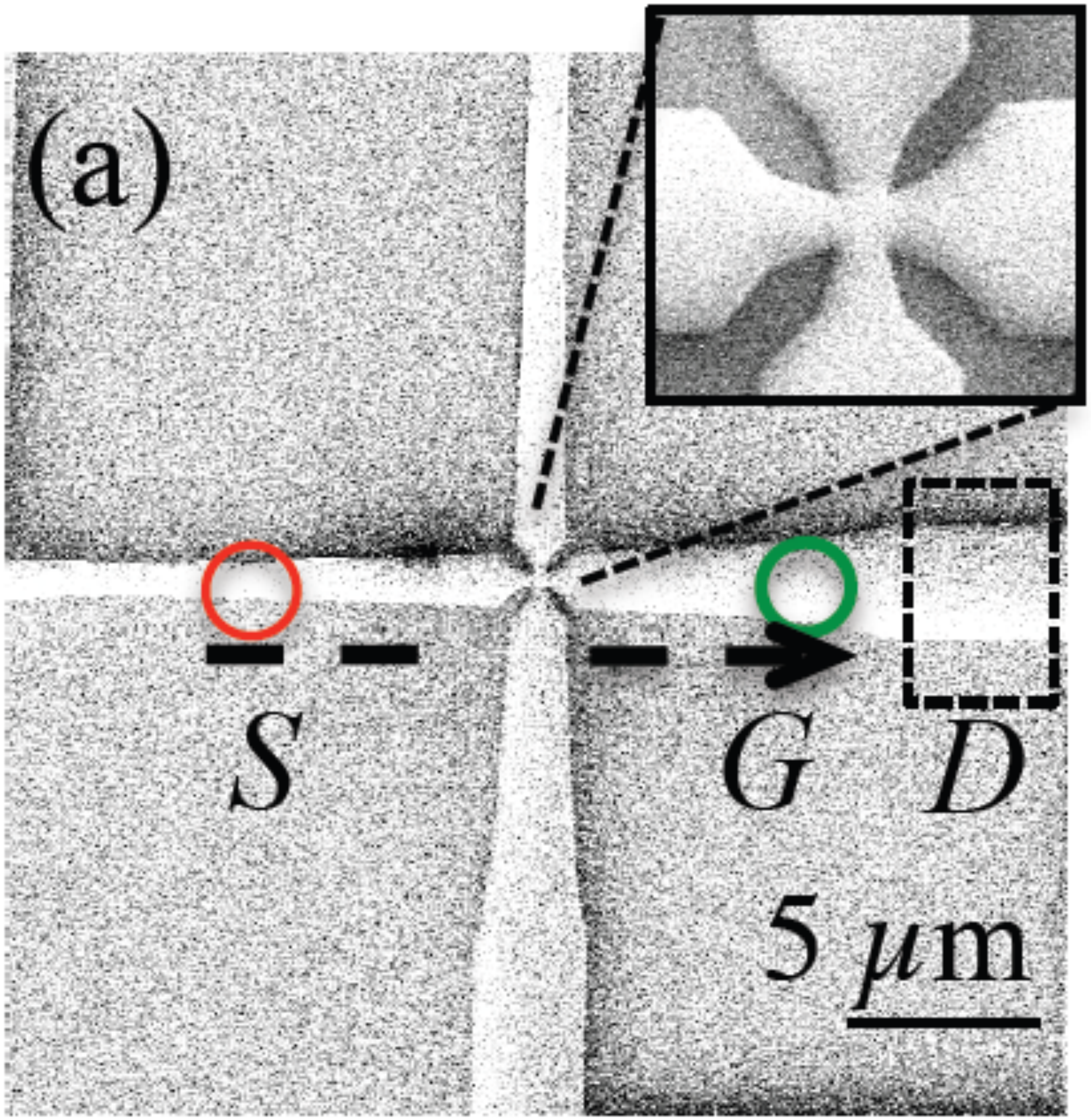


Ramp: exciton transport in the direction of lower potential energy

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

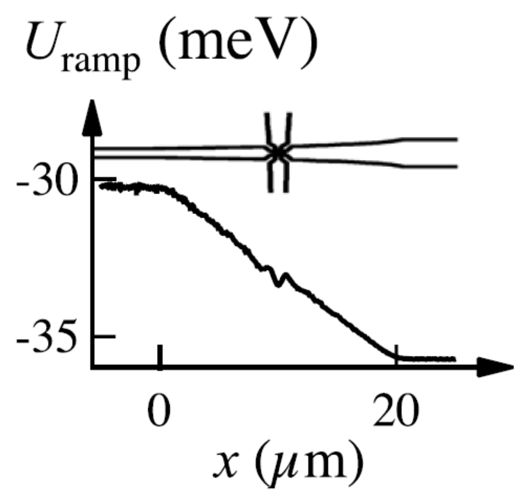
J.R. Leonard *et al, APL* 2012

Crossed-Ramp Excitonic Transistor



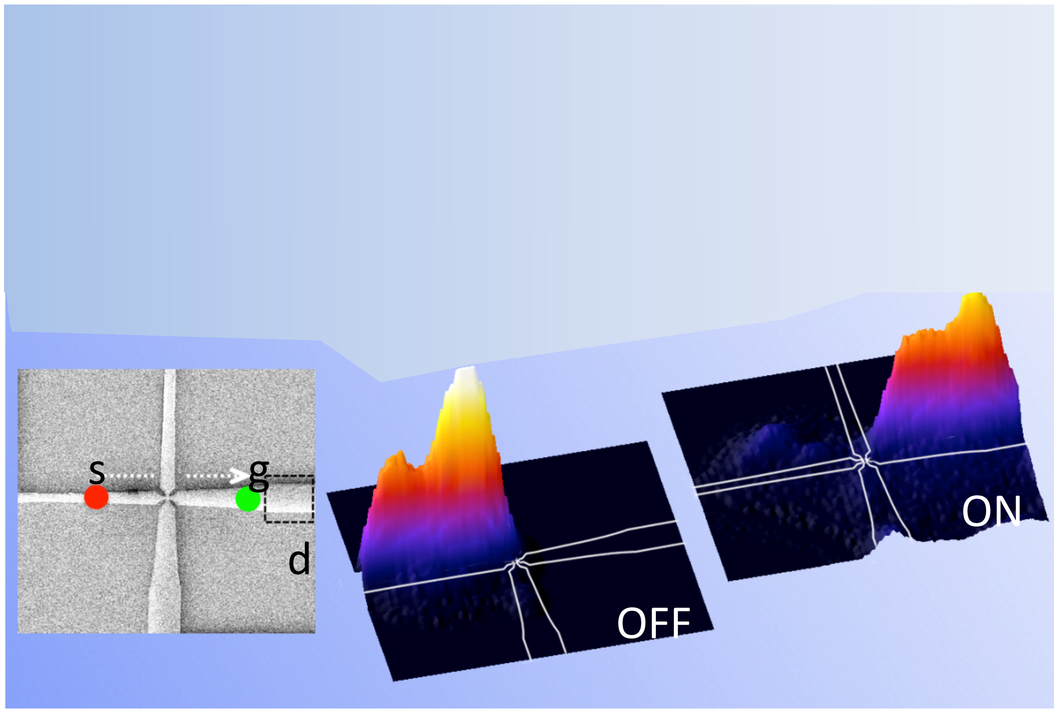
Reduced electrode density in crossing region to keep linear potential

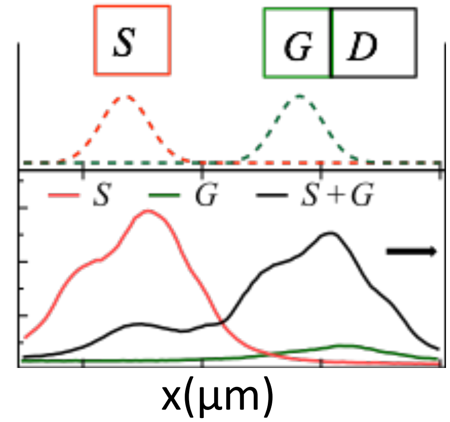
Crossed ramp potentials for indirect excitons



P. Andreakou *et al, APL* 2014

Crossed-Ramp Excitonic Transistor



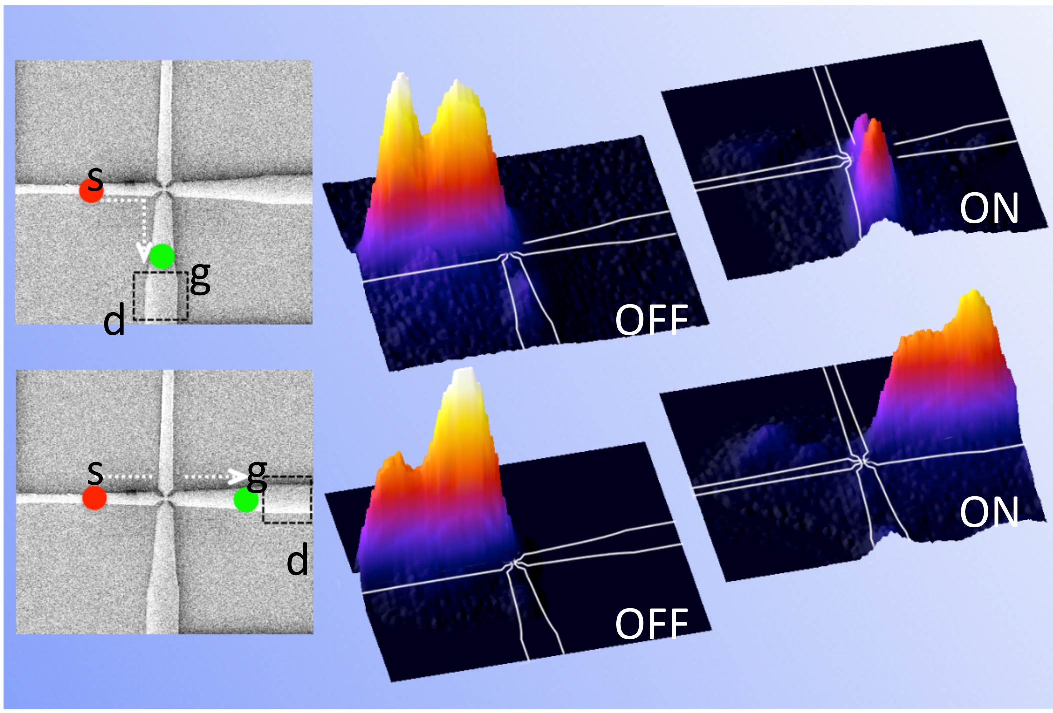


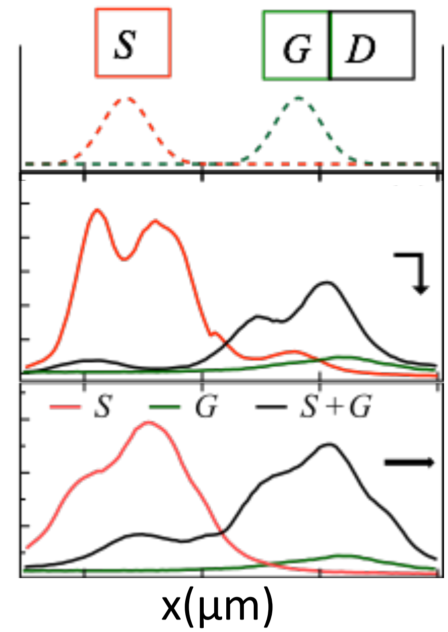
Light controls light by using excitons as an intermediate medium.

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

P. Andreakou, S.V. Poltavtsev, J.R. Leonard, E.V. Calman, M. Remeika, Y.Y. Kuznetsova, L.V. Butov, J. Wilkes, M. Hanson, A.C. Gossard, *Appl. Phys. Lett.* **104**, 091101 (2014)

Crossed-Ramp Excitonic Transistor



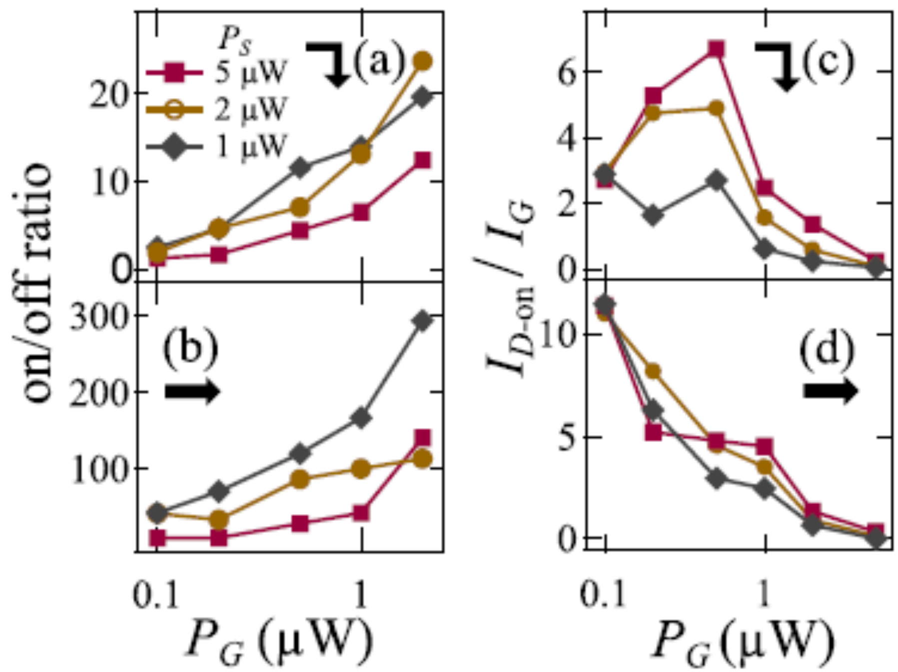


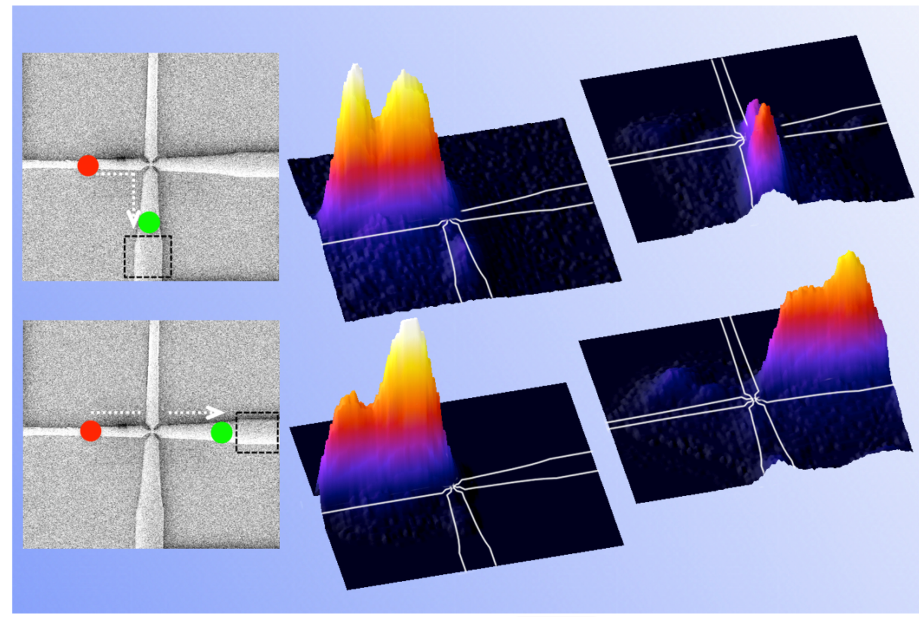
Light controls light by using excitons as an intermediate medium.

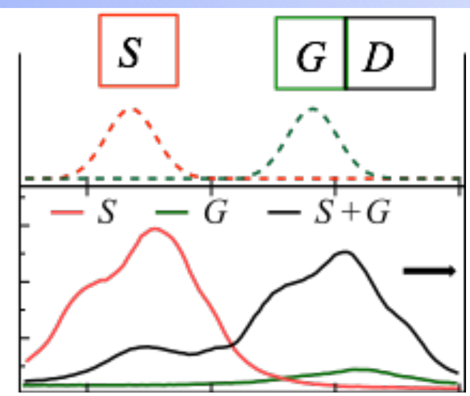
- Single-electrode design prevents heating by in-plane electron currents
- Also operates as a router

P. Andreakou, S.V. Poltavtsev, J.R. Leonard, E.V. Calman, M. Remeika, Y.Y. Kuznetsova, L.V. Butov, J. Wilkes, M. Hanson, A.C. Gossard, *Appl. Phys. Lett.* **104**, 091101 (2014)

Crossed-Ramp Excitonic Transistor







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

P. Andreakou, S.V. Poltavtsev, J.R. Leonard, E.V. Calman, M. Remeika, Y.Y. Kuznetsova, L.V. Butov, J. Wilkes, M. Hanson, A.C. Gossard, *Appl. Phys. Lett.* **104**, 091101 (2014)

Overview

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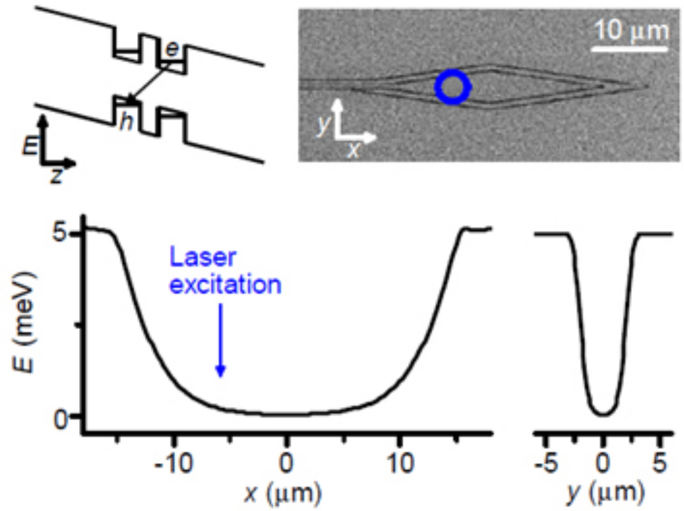
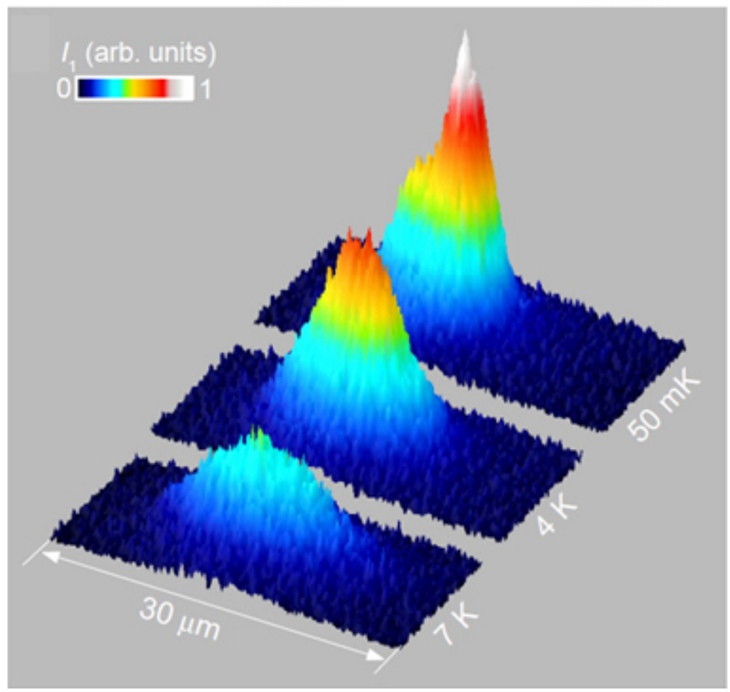
- Stirring Potentials for Excitons

Diamond-Shaped Trap





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

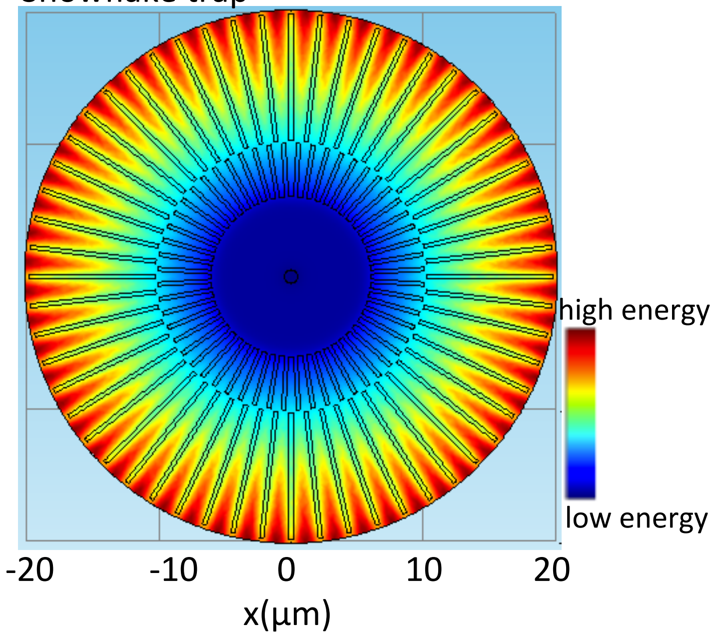
- Only small number of excitons can be trapped

- Condensate of ~1000 exictons can be collected

A.A. High *et al, PRL* 2009
Nano Lett. 2012

Realization of 2D Snowflake Trap

Exciton potential energy in 2D Snowflake trap

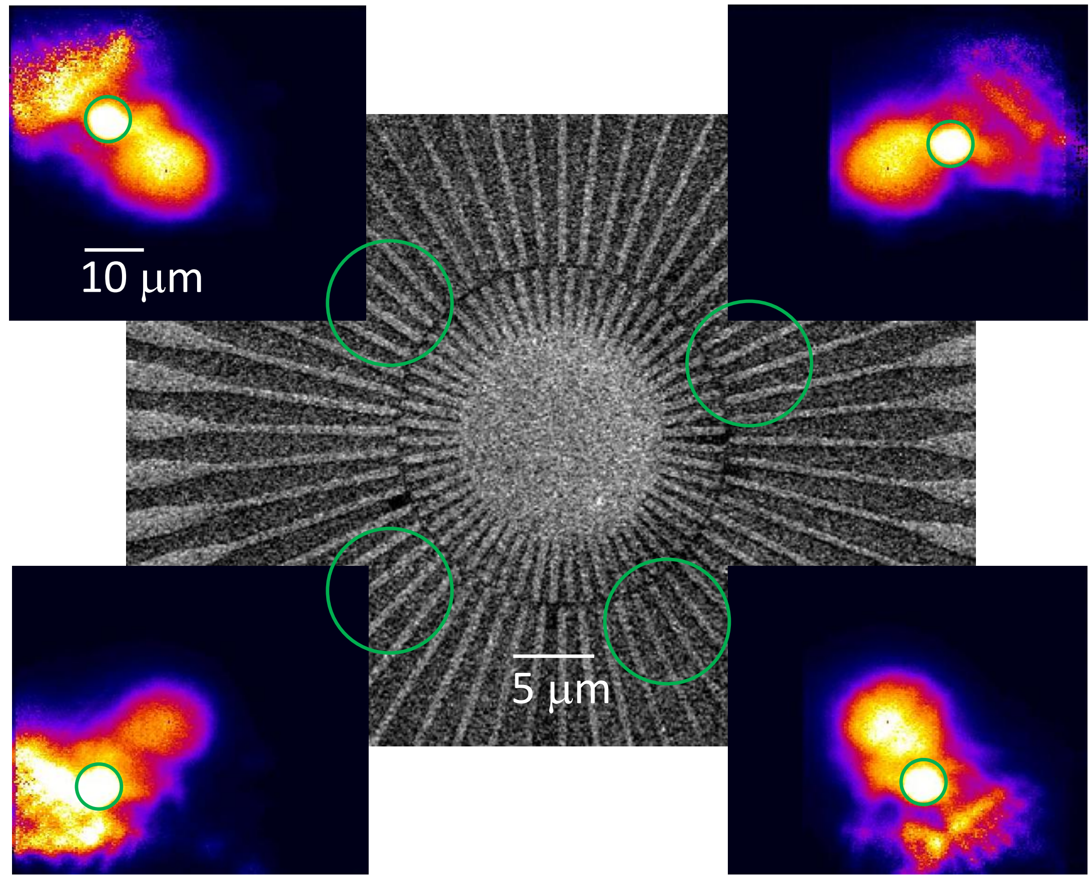


- Confining potential in large area

-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



Green circles mark excitation spots

Overview

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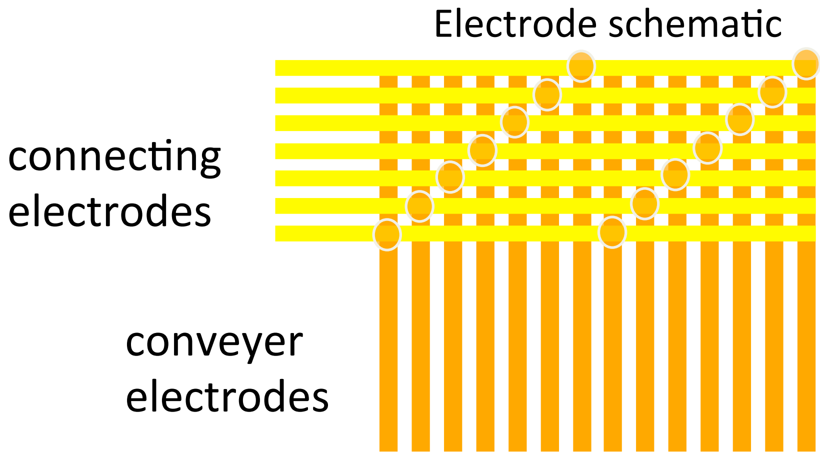
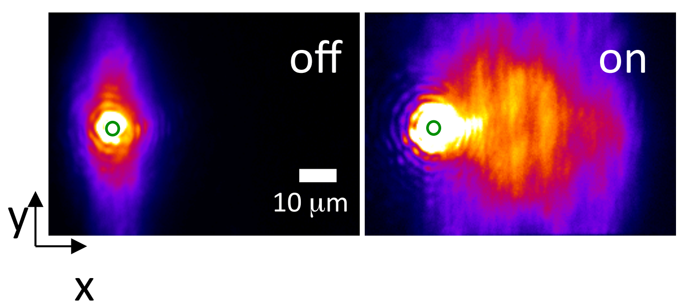
Moving Lattice: Conveyer

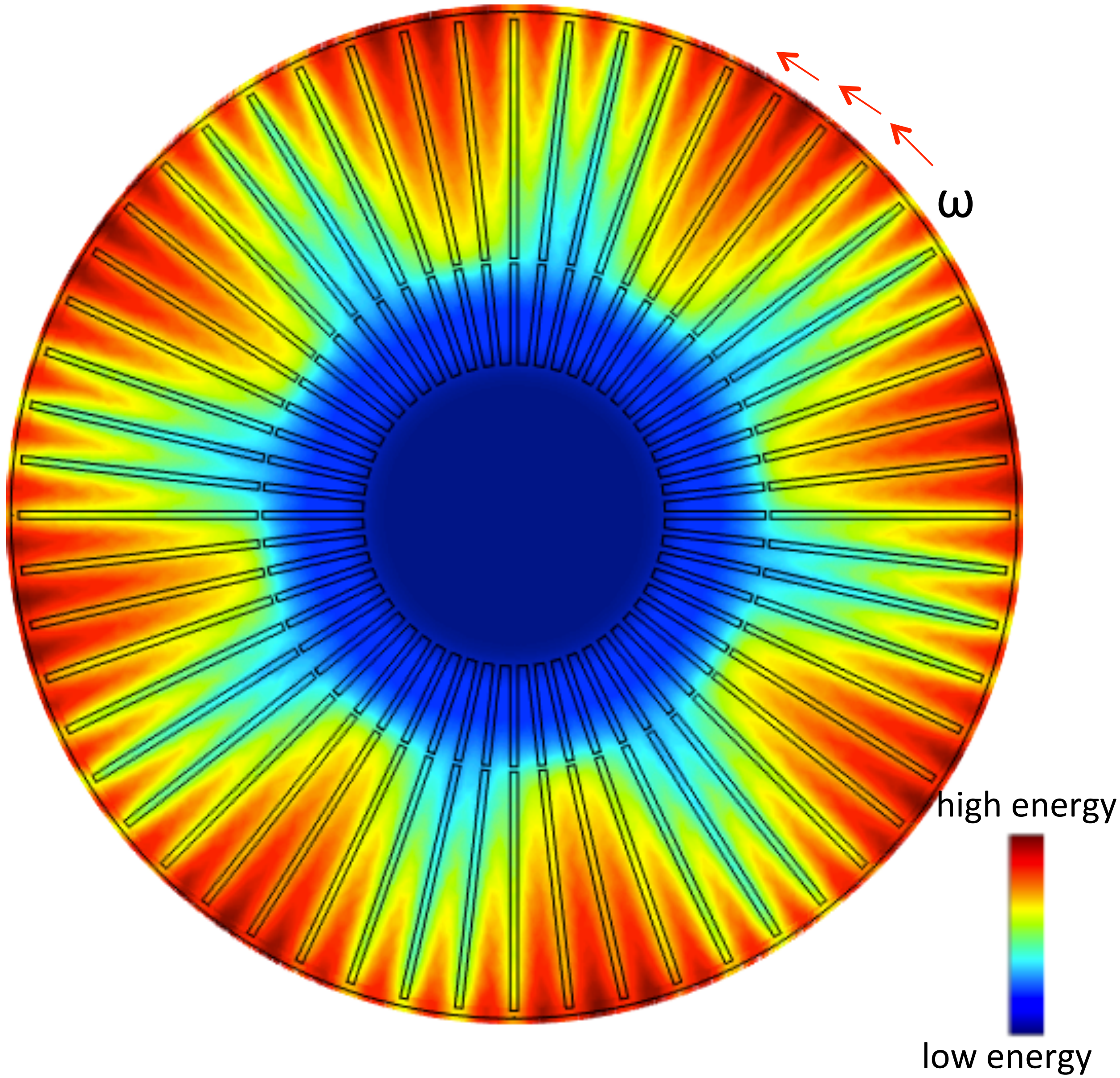


Works as exciton CCD



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.

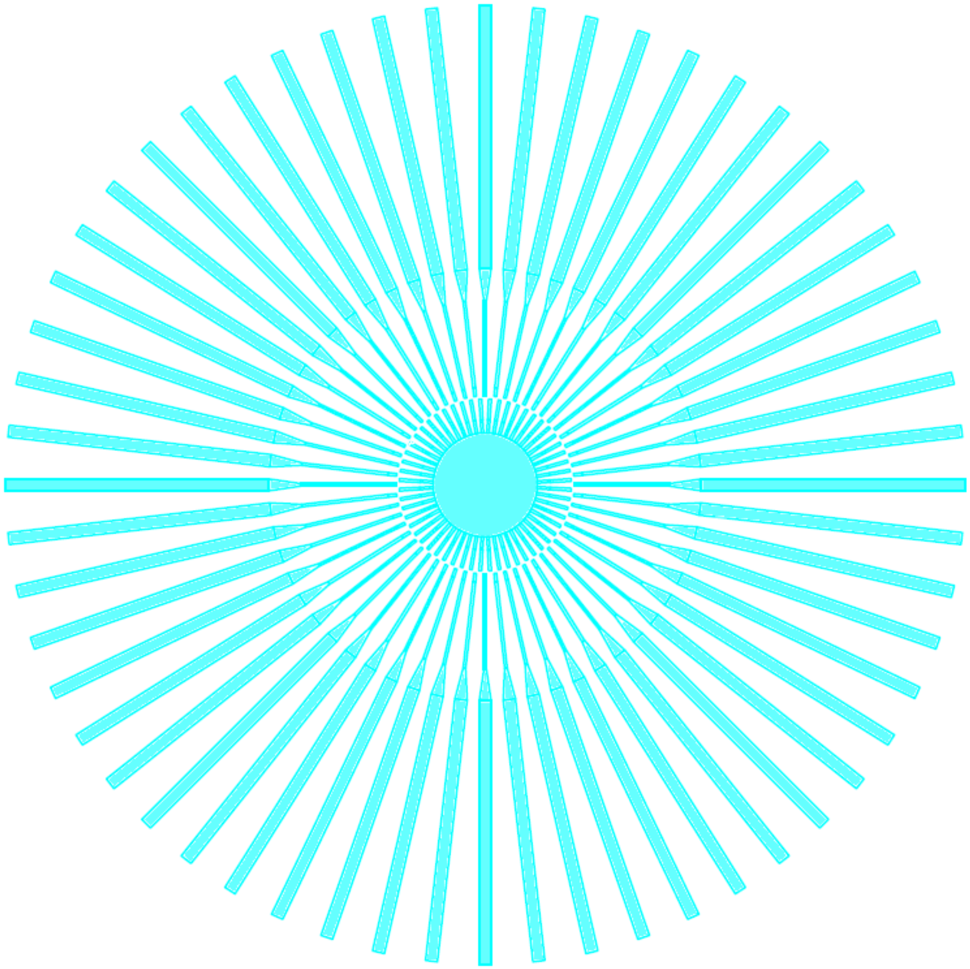
Control of Stirring Potential:

•Angular velocity is controlled by AC frequency

•Wavelength is determined by electrode periodicity

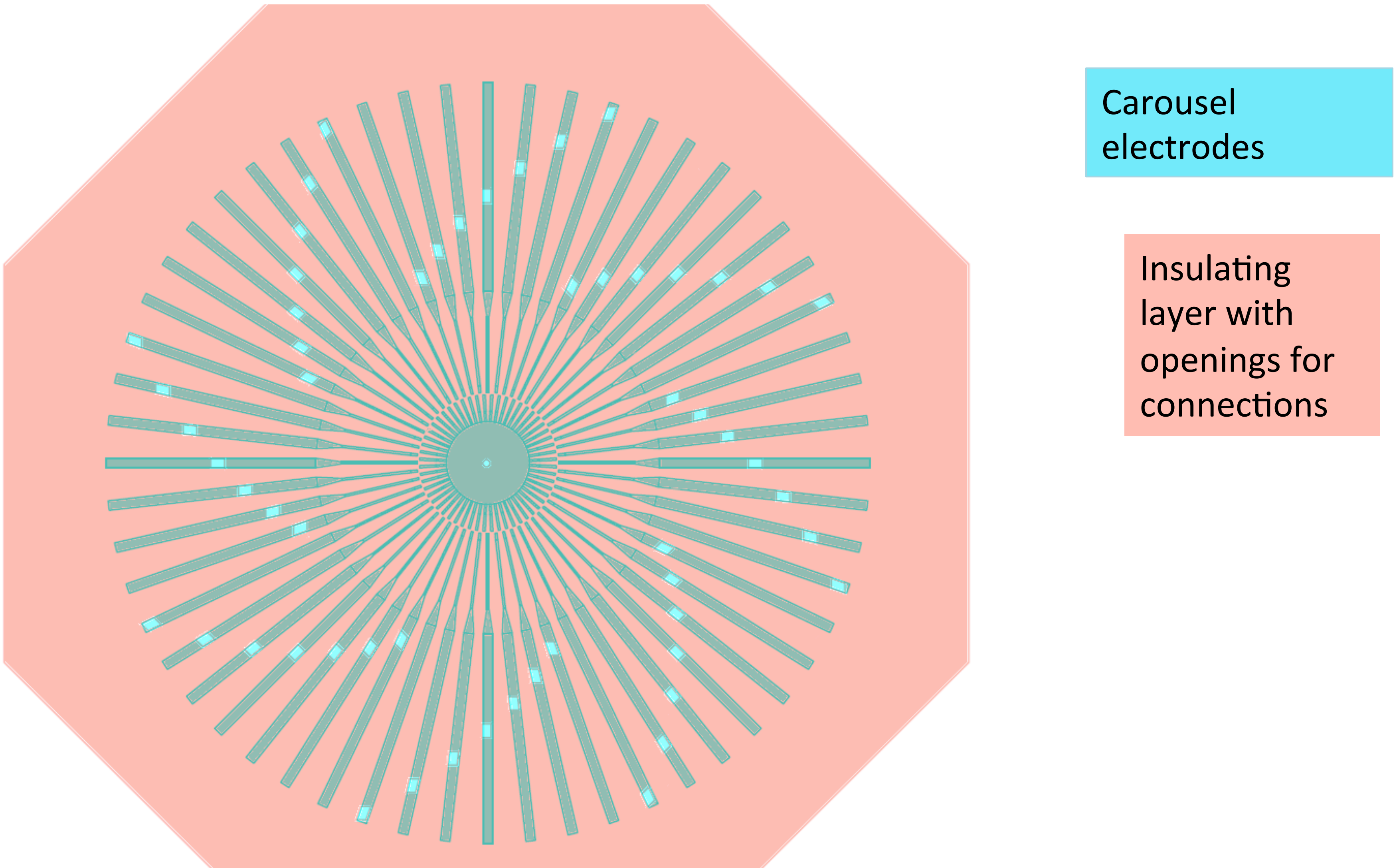
•Potential amplitude is controlled by AC amplitude

Design of Stirring Potential for Excitons (Carousel)

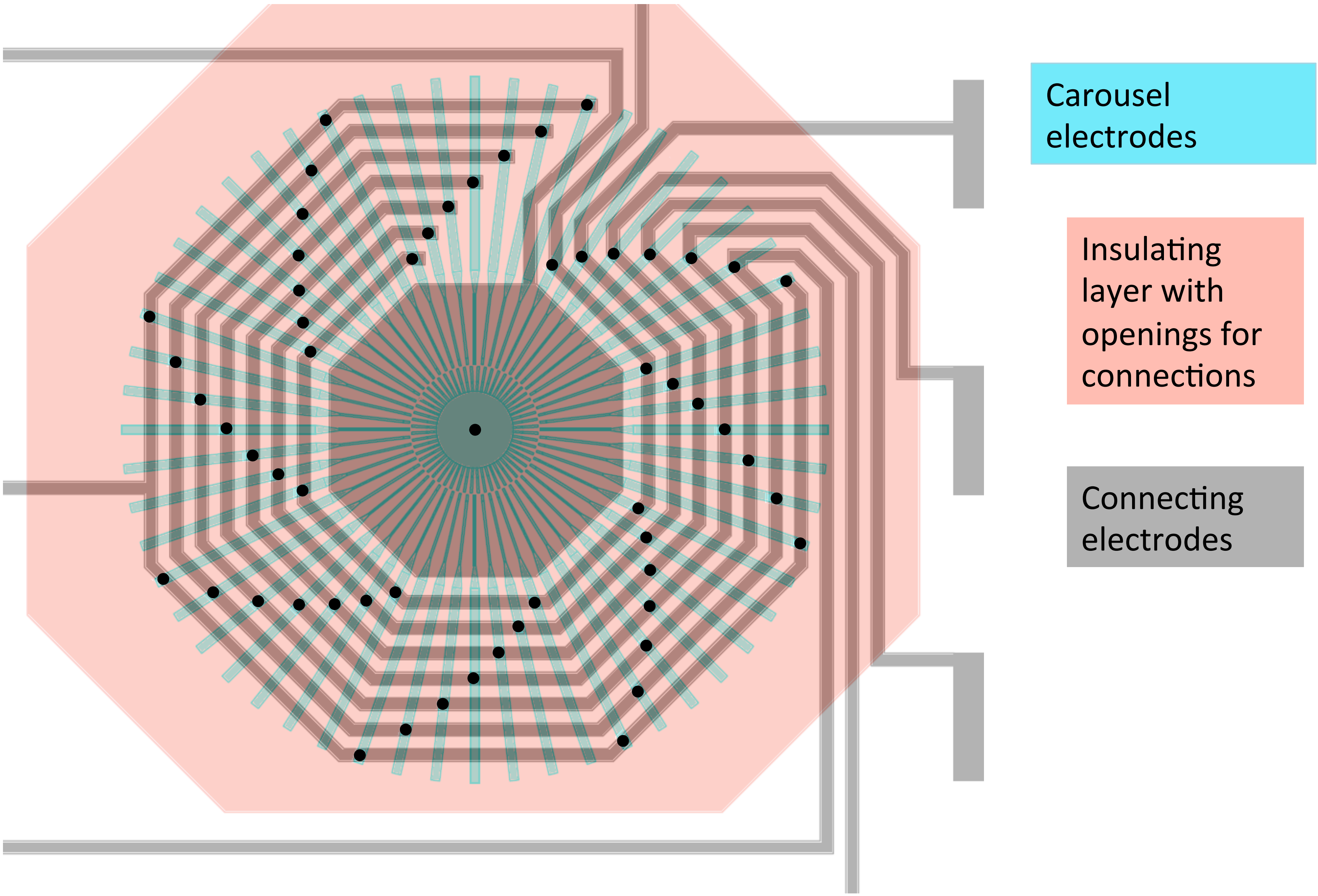


Carousel electrodes

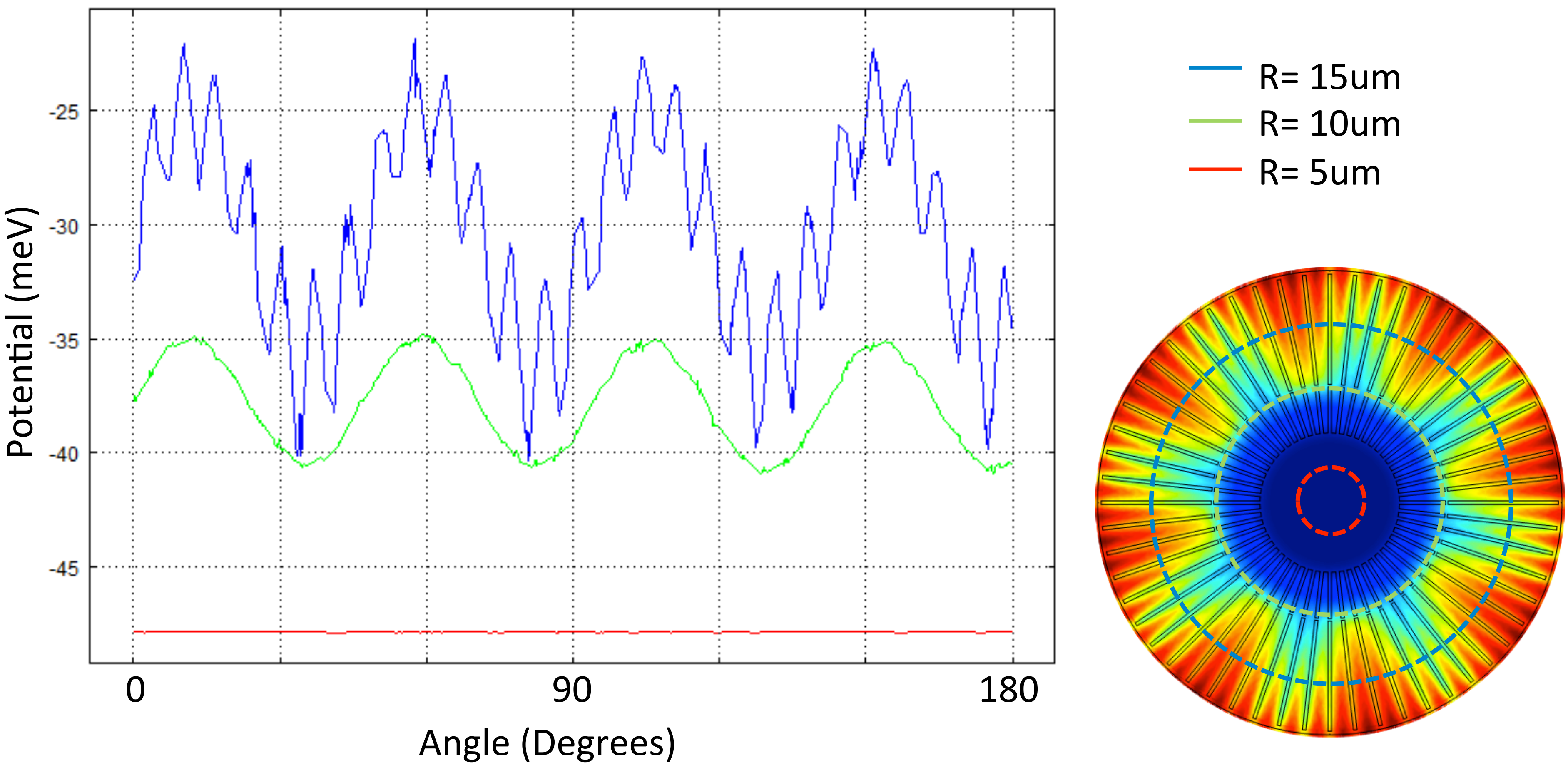
Design of Stirring Potential for Excitons (Carousel)



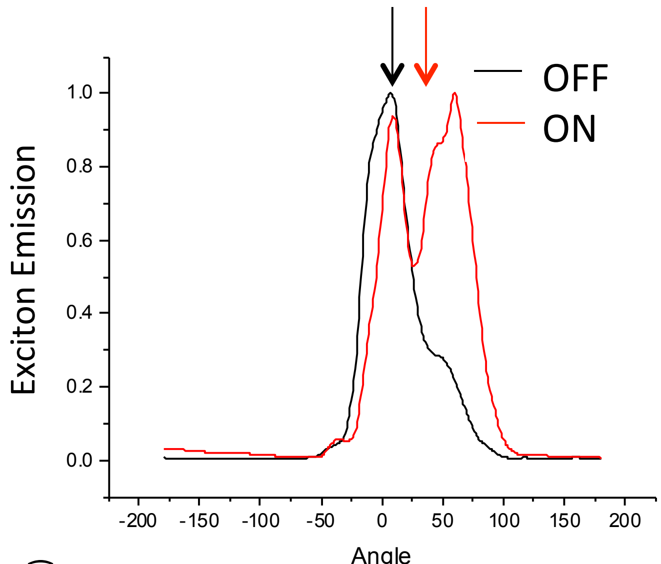
Design of Stirring Potential for Excitons (Carousel)

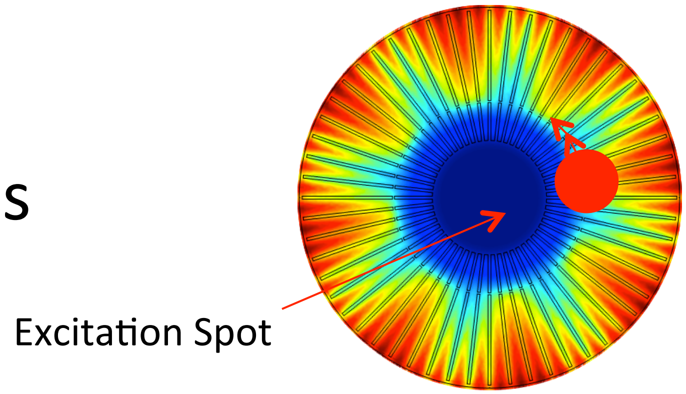


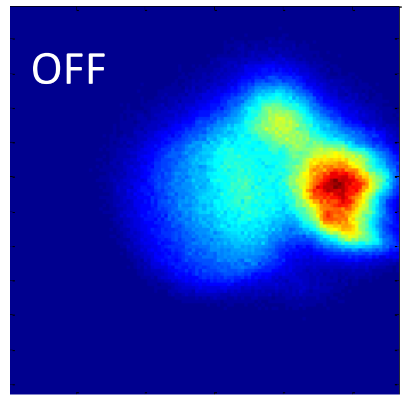
Stirring Potential for Excitons at Different Radii

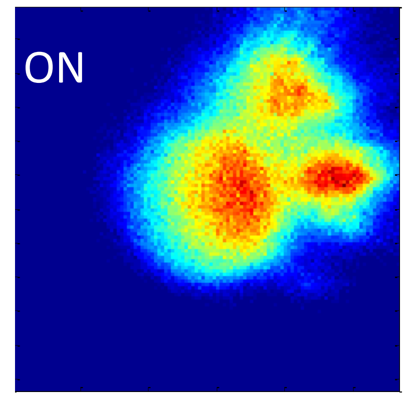


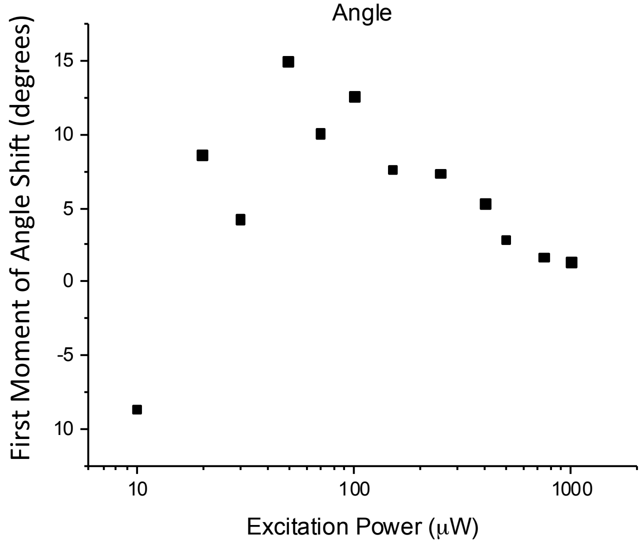
Carousel Results

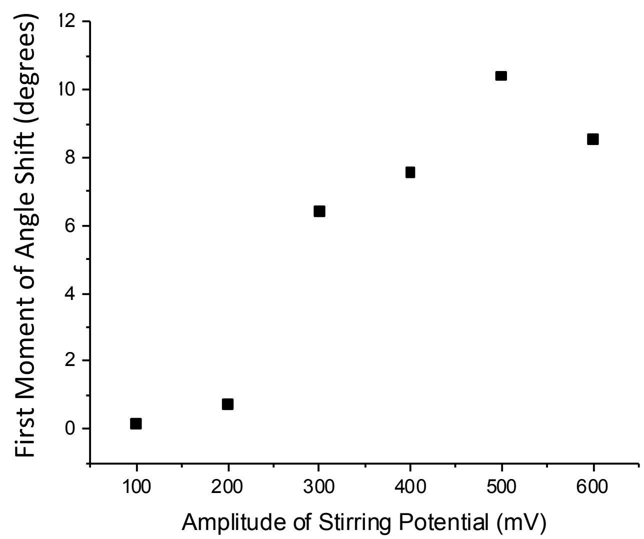




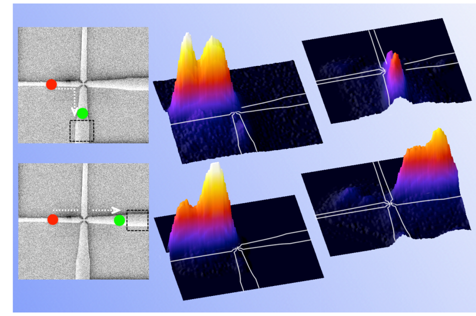




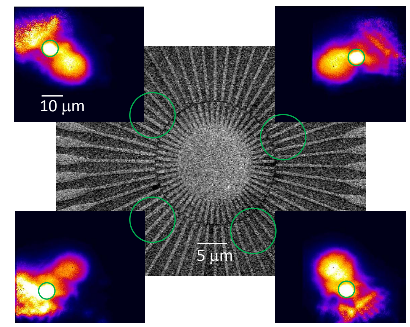




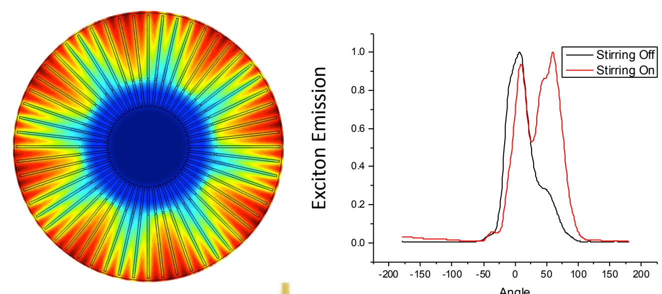
Conclusions



- Demonstrated an all-optical excitonic transistor and router



- Demonstrated a 2D snowflake trap for excitons



- Demonstrated a stirring potential for excitons