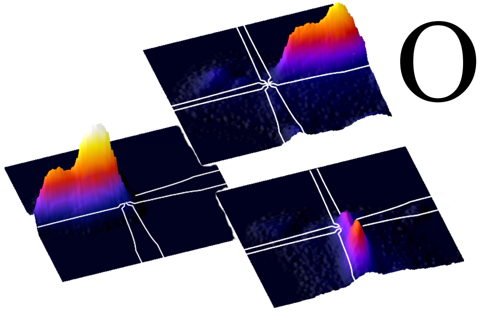

Optically Controlled Excitonic Transistor and Router

P. Andreakou[1,2], S. V. Poltavtsev[1,3], J. R. Leonard[1], E. V. Calman[1], M. Remeika[1],
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[3]: Spin Optics Laboratory, St. Petersburg State University, Russia
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[5]: Materials Department, University of California at Santa Barbara, USA
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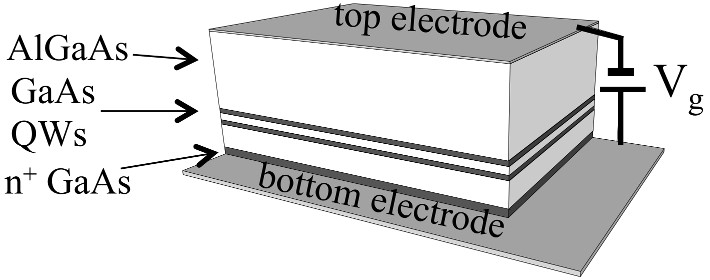
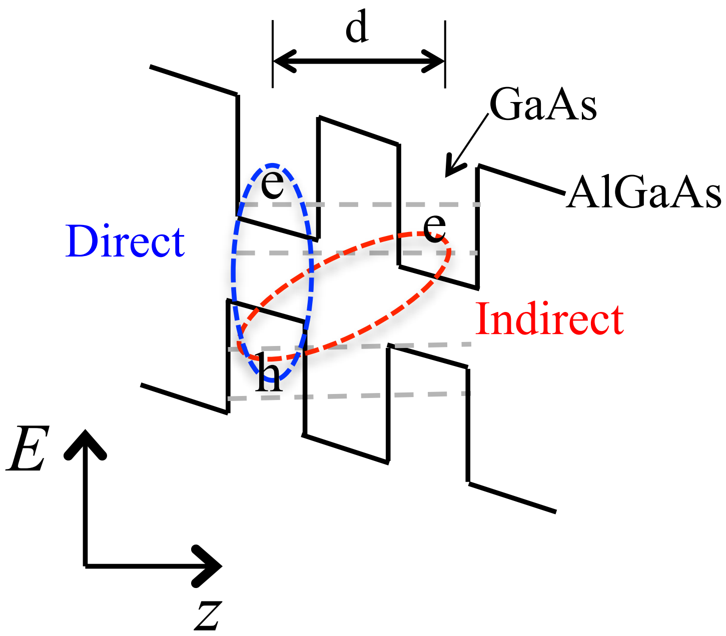
Introduction to indirect excitons



Exciton: bound electron – hole pair

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

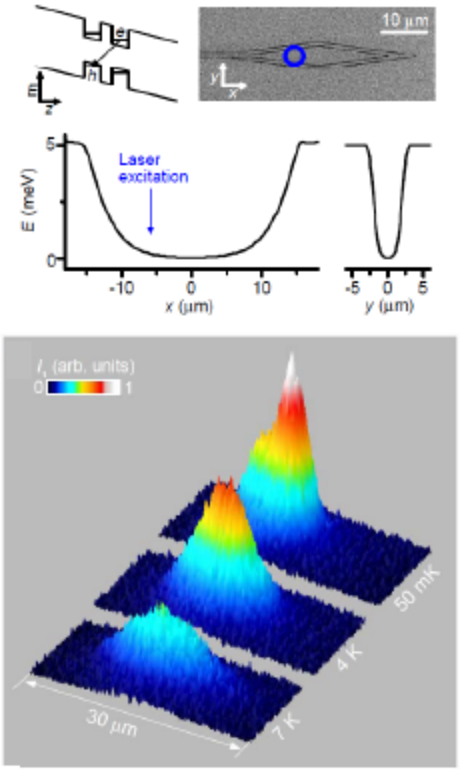


Properties of indirect excitons

✓ Increased lifetime
  - ➢ increased transport distances

✓ are oriented dipoles:
  - ➢ repulsive interaction screens disorder in the sample
  - ➢ exciton energy is controlable by applied voltage $E=edFz$

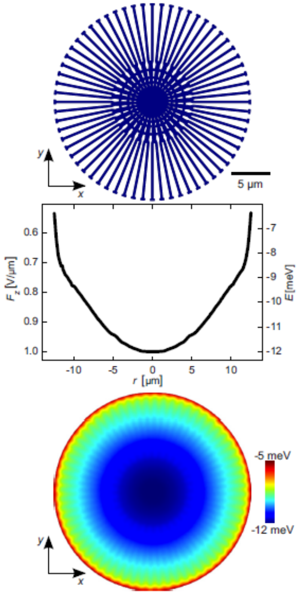
Excitonic Devices



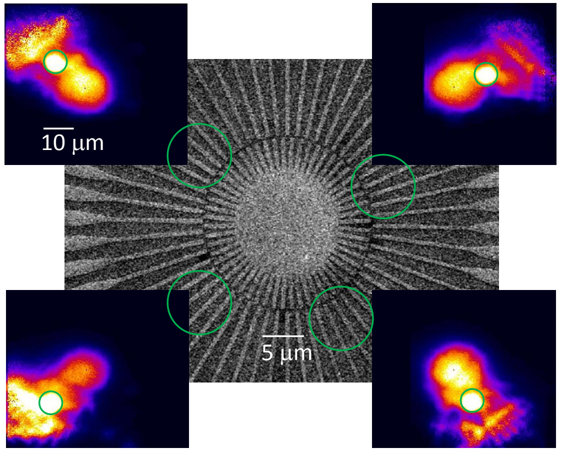
- Electrostatic traps for excitons

A.A. High et al, PRL (2009)

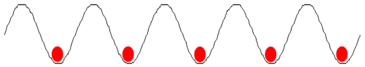
A.A. High et al, Nano Lett. (2012)



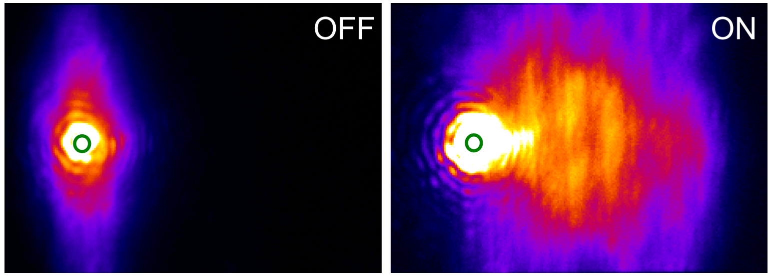
- 2D large electrostatic traps for excitons



Moving Lattices:



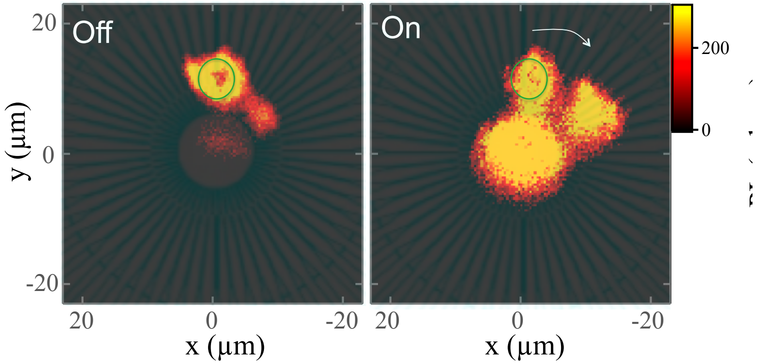
- Excitonic conveyer



A.G. Winbow et al, PRL (2011)

J.R. Leonard et al, APL (2012)

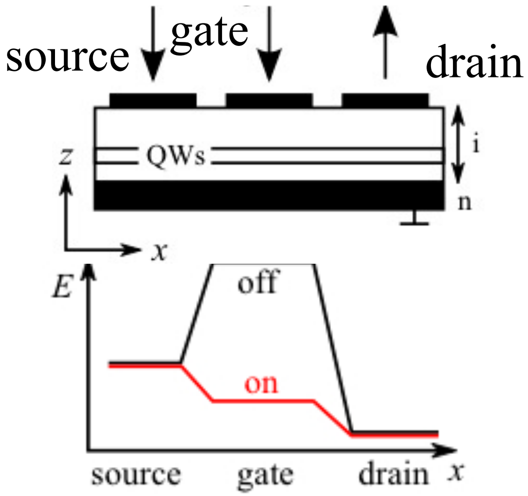
- Stirring potentials -Carousel



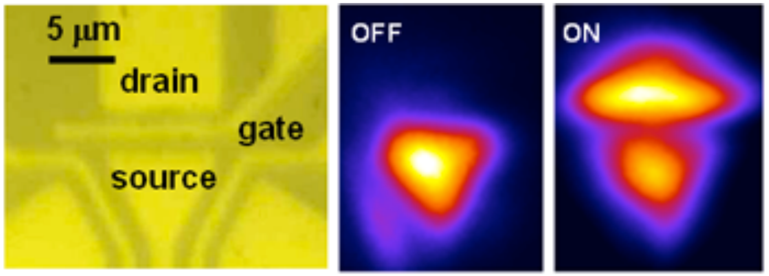
Excitonic transistors

- Compact
- High speed

Time delay between signal processing and optical communication is effectively eliminated



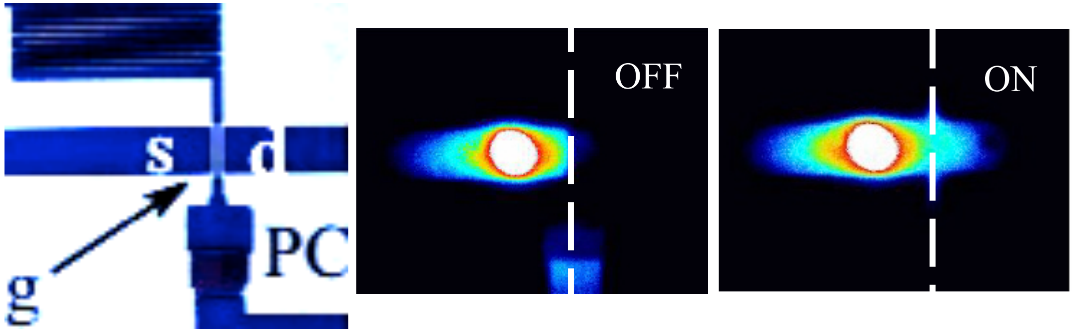
Exciton optoelectronic transistor



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*. **32**, 2466 (2007)

All-optical excitonic transistor



Light controls light by using excitons as an intermediate medium.
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*. **35**, 1587 (2010)

Excitonic transistors

- Compact
- High speed

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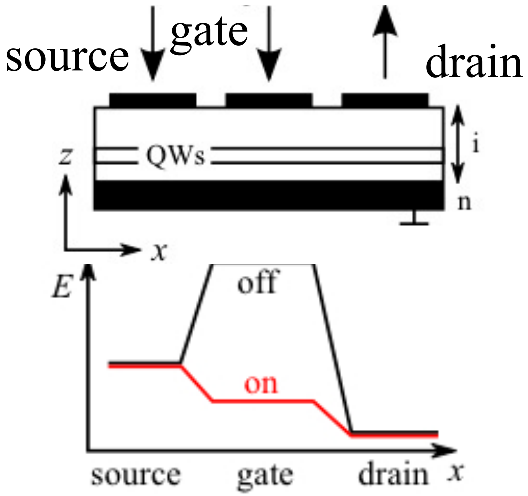
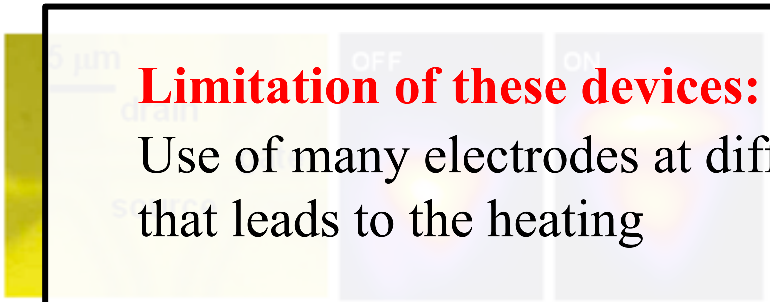


Exciton optoelectronic transistor



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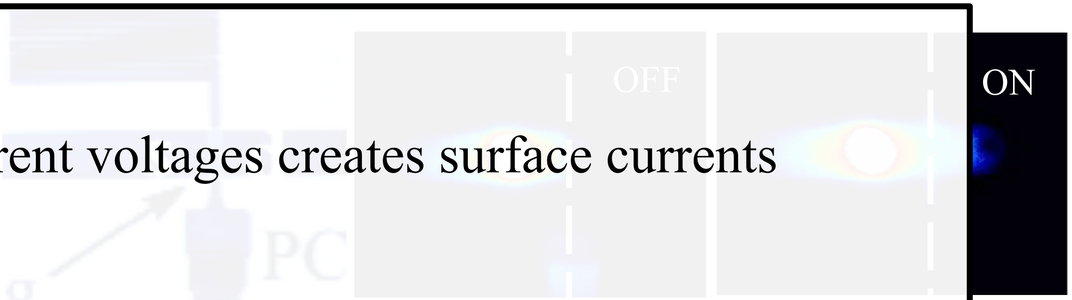


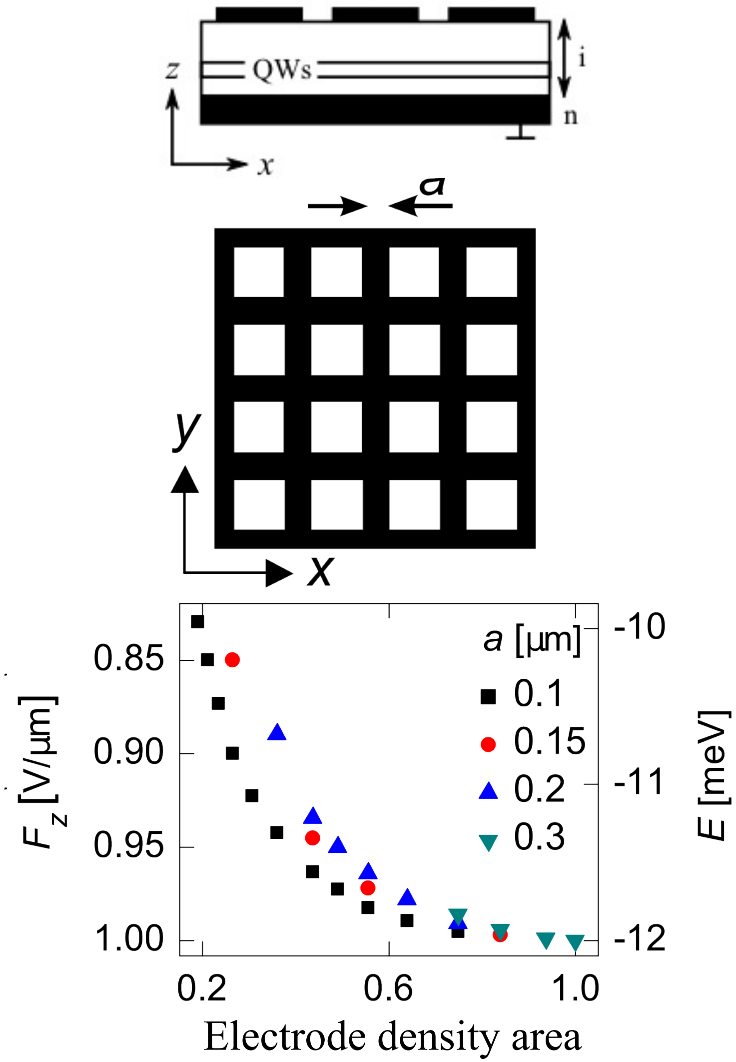
Light controls light by using excitons as an intermediate medium.
Source and drain are photonic.
Light changes voltage at gate electrode..

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

Limitation of these devices:
Use of many electrodes at different voltages creates surface currents that leads to the heating

✓ **Solution:** Development of a **single electrode device** at constant voltage – Easy to connect and control

Control of indirect excitons energy landscape



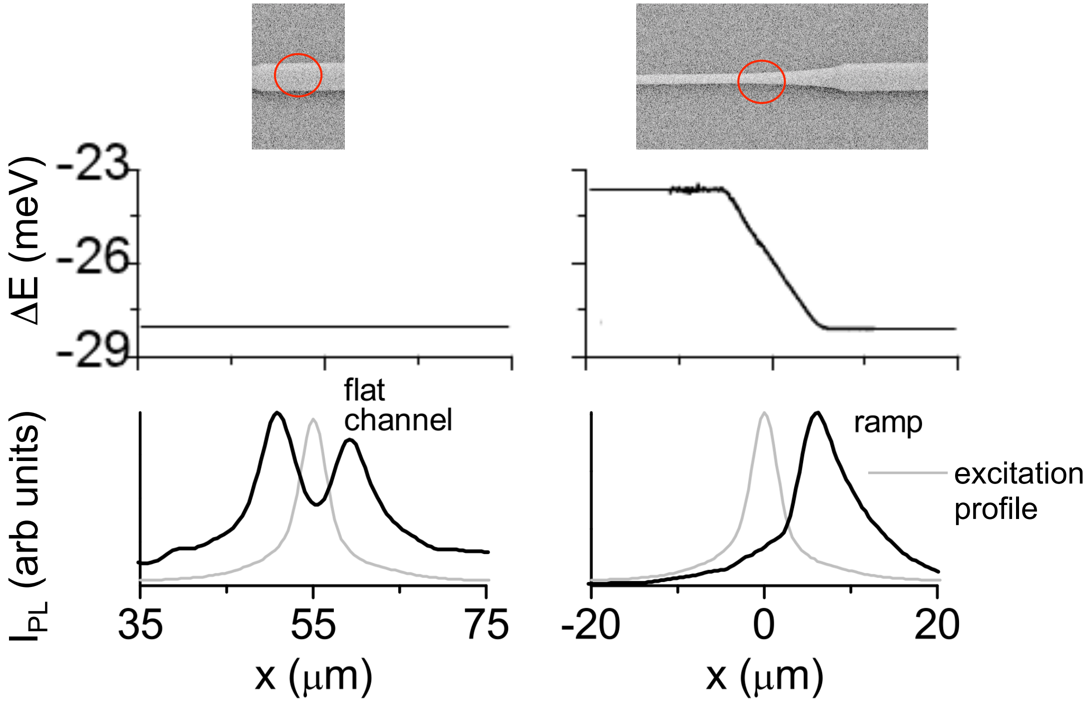
$$\Delta E = edF_z = edV/d_s$$

- Exciton energy landscape is controlled using a single shaped electrode at constant voltage
- Gaps in the top electrode reduce F_z due to the divergence of electric field

Appl. Phys. Lett. 97, 201106, (2010)

Excitonic Ramp- Diode

Single electrode device at constant voltage



Flat channel: exciton transport symmetric about the excitation spot

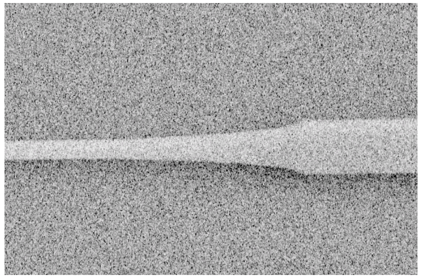
Ramp: exciton transport in the direction of lower potential energy
→ realizes directed transport of excitons as a diode
realizes directed transport of electrons

Appl. Phys. Lett. 100, 231106, (2010)

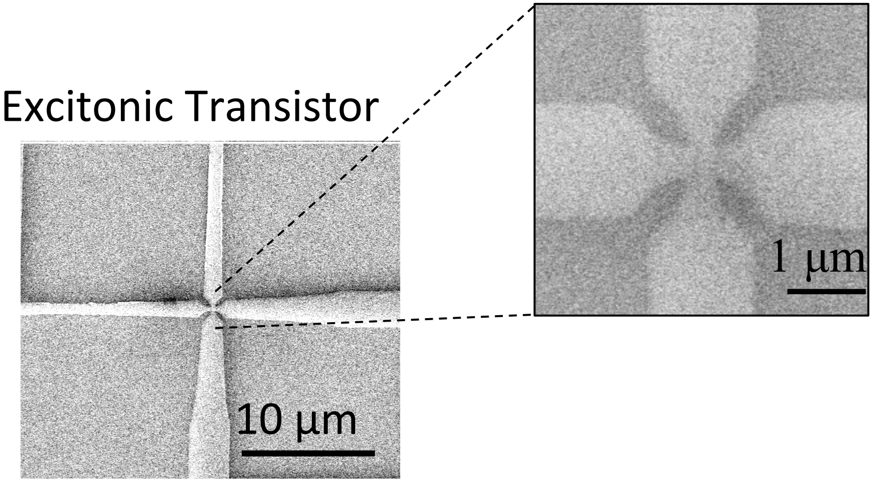
Optically controlled excitonic transistor

Single electrode devices

Excitonic Ramp



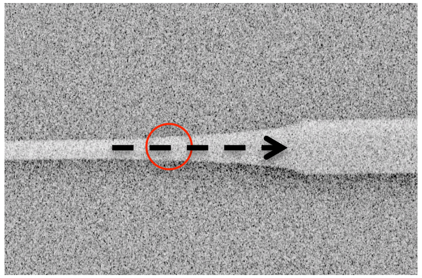
Excitonic Transistor



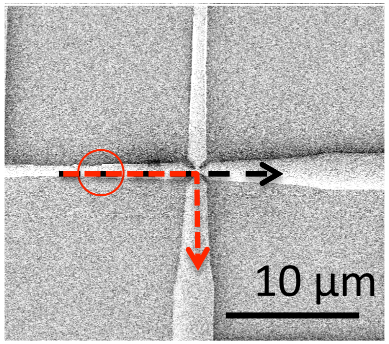
Optically controlled excitonic transistor

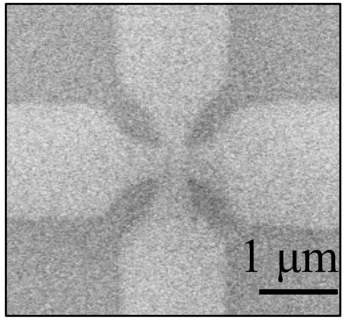
Single electrode devices

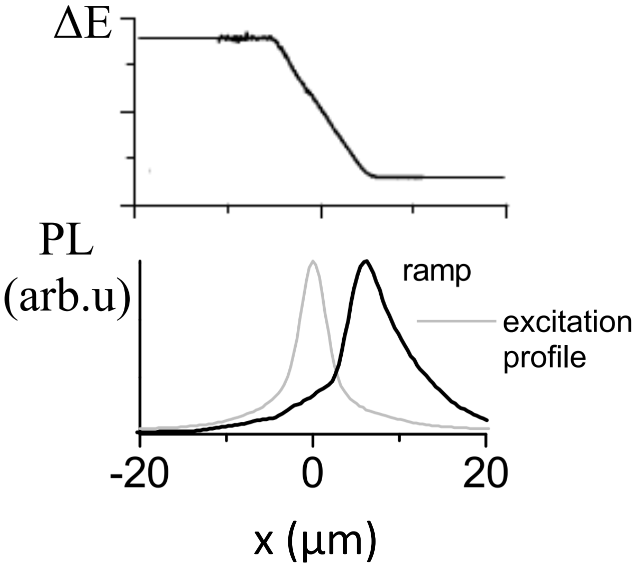
Excitonic Ramp

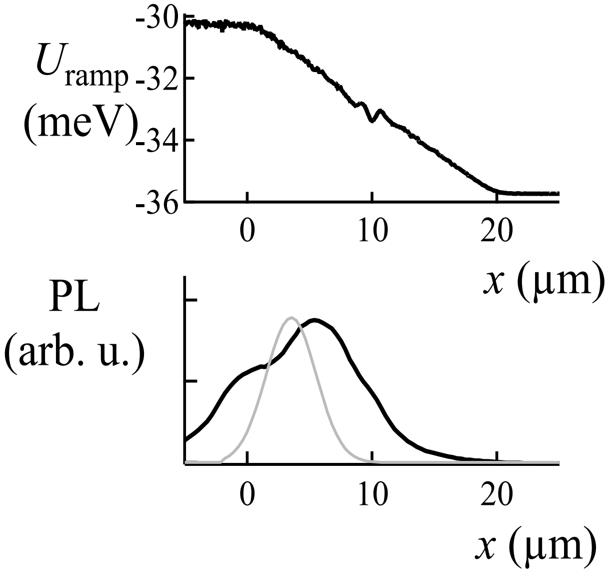


Excitonic Transistor



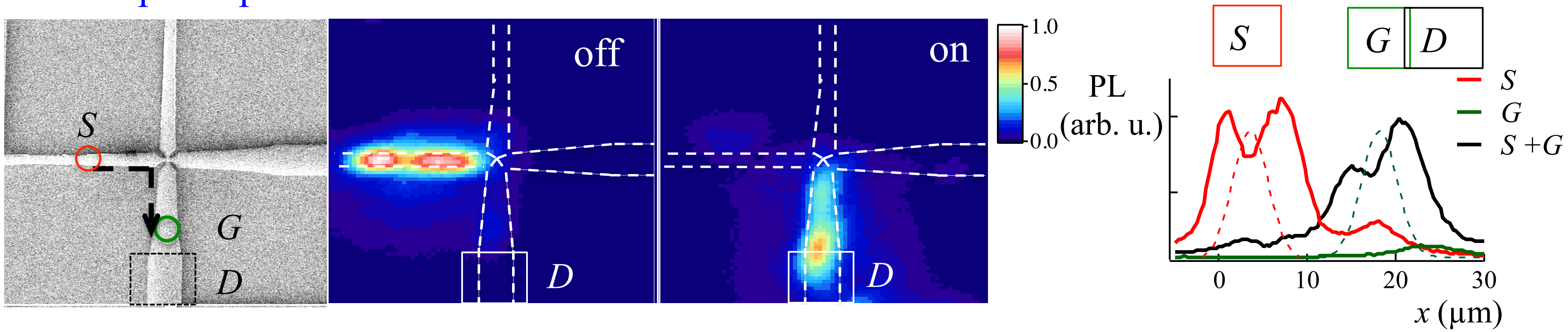




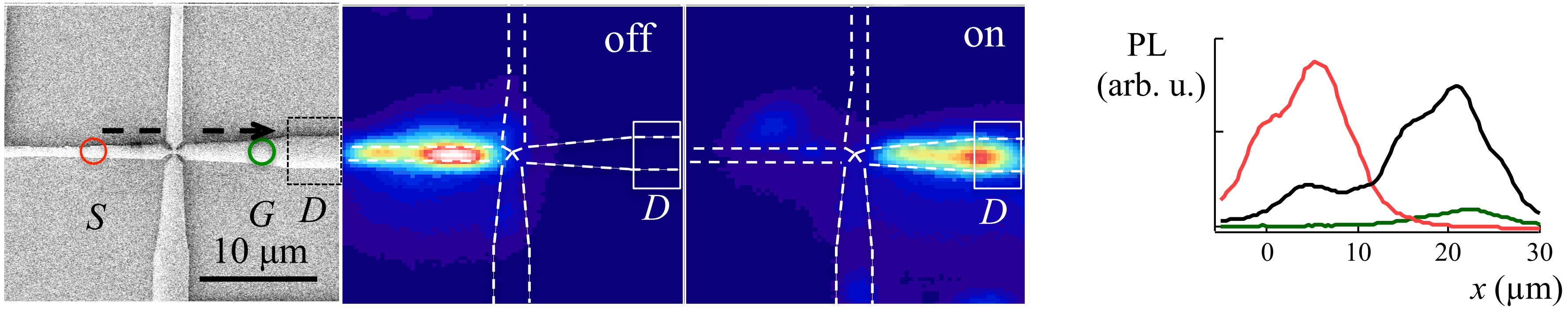


Operation of the excitonic transistor-router

Turned path operation

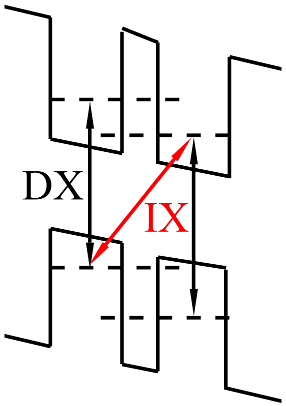


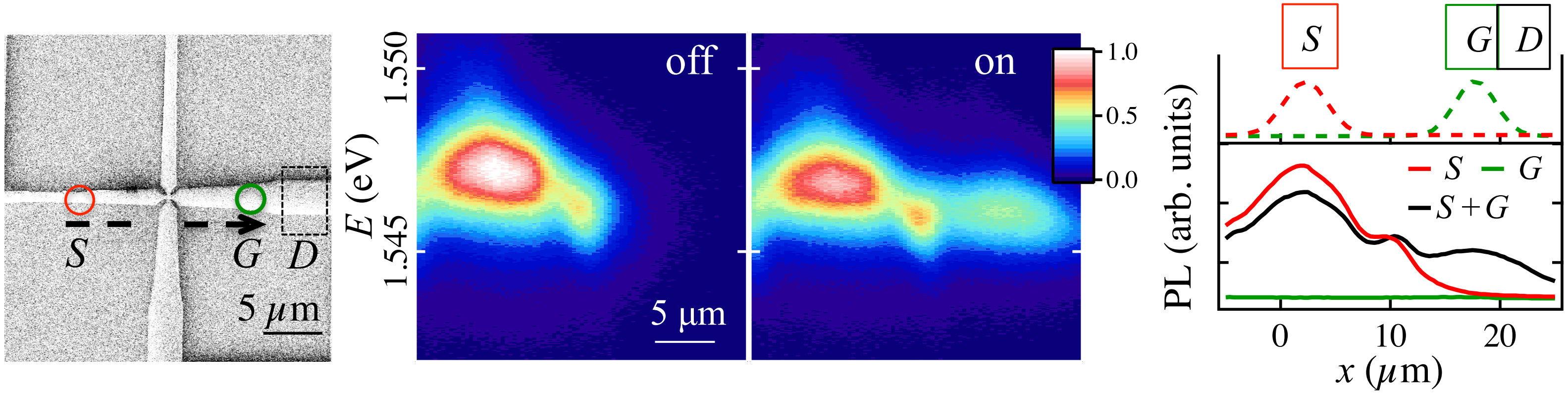
Straight path operation



P_S=0.5 µW - P_G=0.2 µW

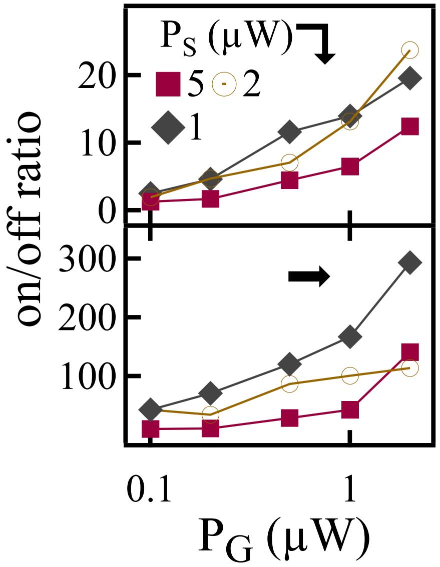
Transistor effect at DX resonance excitation

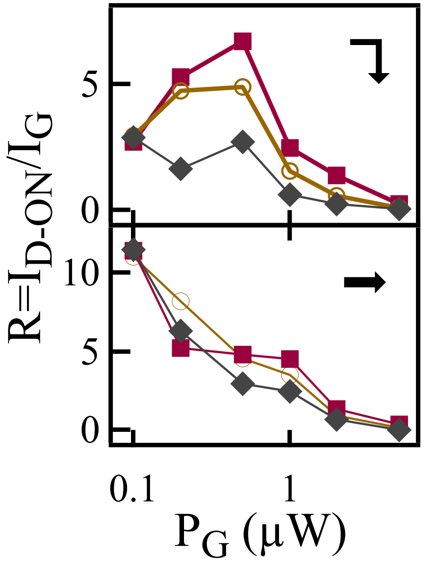


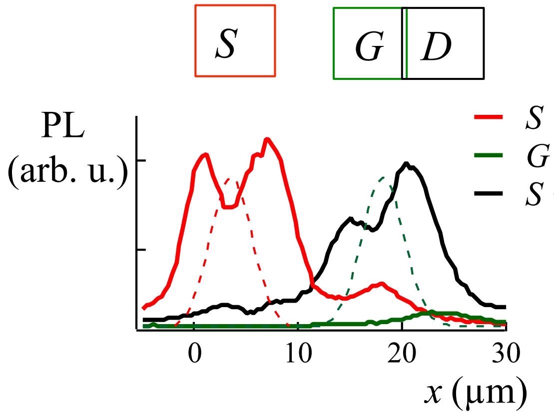


P_S=2 μW – P_G=1 μW

Transistor effect efficiency







$$\textit{on/off ratio} = \frac{\text{Excitonic signal at drain: S, G on}}{\text{Excitonic signal at drain: S on G off}}$$

$$R = \frac{\text{Excitonic signal at drain: S, G on}}{\text{Excitonic signal: S off- G on}}$$

Drift diffusion modeling

Non-linear transport equation:

$$\nabla\left[\underbrace{D\nabla n}_{\text{Diffusion}} + \underbrace{\mu n\nabla\left(u_0 n + U_{ramp}\right)}_{\text{Drift}}\right] - \frac{n}{\tau_{PL}} + \Lambda_S + \Lambda_G = 0$$

n: distribution of IX
D: diffusion coefficient
μ: mobility
Do: diffusion coefficient in absent of disorder

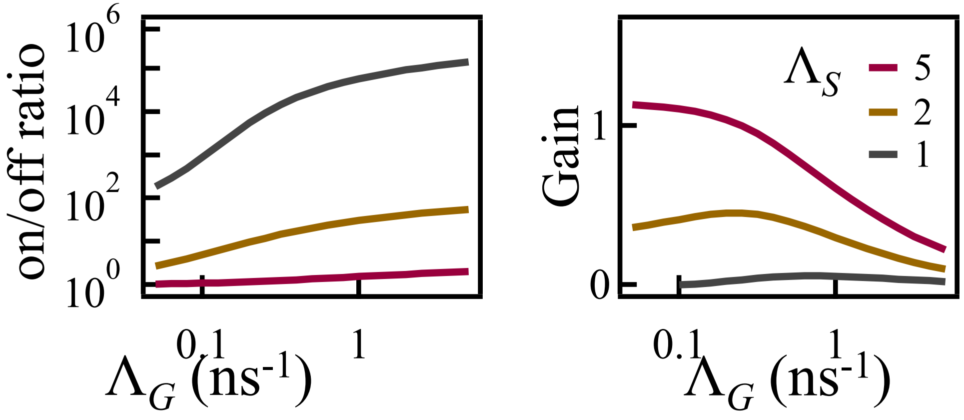
$$\mu = D/(k_B T)$$

$$D = D_o \exp[-U_o/(u_o n + k_B T)]$$

Disorder Amplitude: $U_o/2 = 0.5meV$

Calculation of spatially varying temperature through the thermalization equation

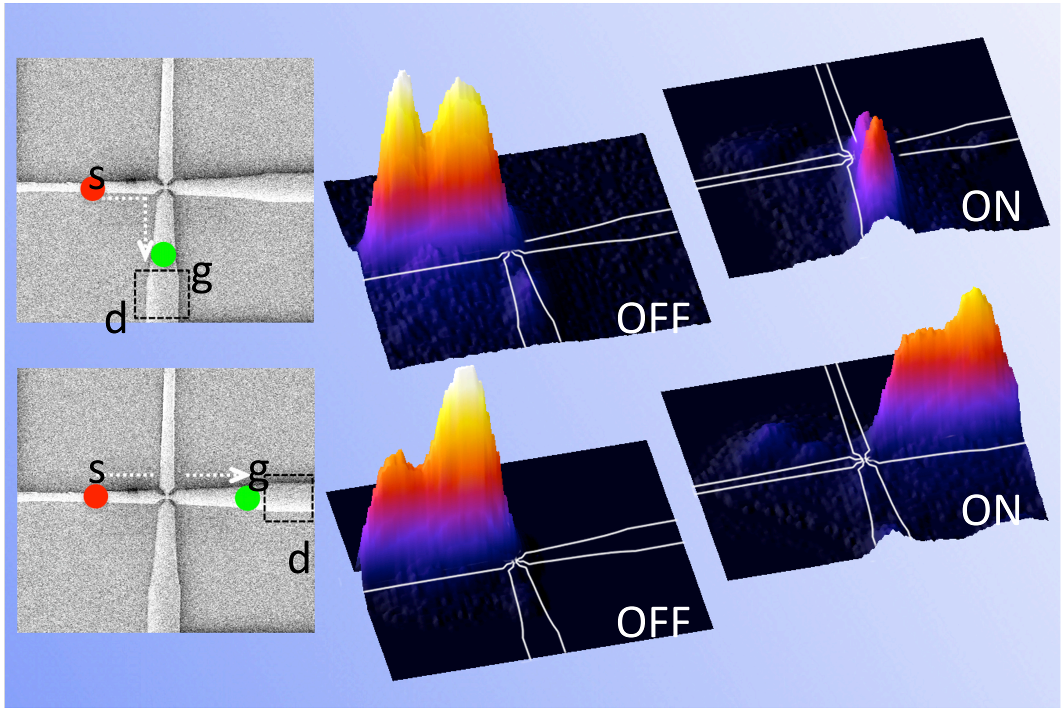
$$S_{phonon}(T_o, T) = S_{pump}(T_o, T, \Lambda_S + \Lambda_G, E_{inc})$$

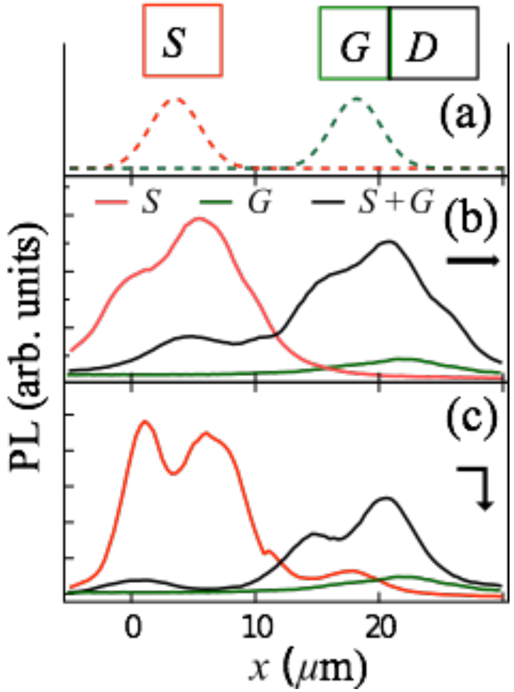


PRB **80**, 155331 (2009)

Conclusions

New optical excitonic transistor/router





- Single-electrode design prevents heating by in-plane currents
- ON-OFF ratio reaches 300
- Low-intensity gate beam creates 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)

Thank you for your attention!