Excitons in Electrostatic Lattices

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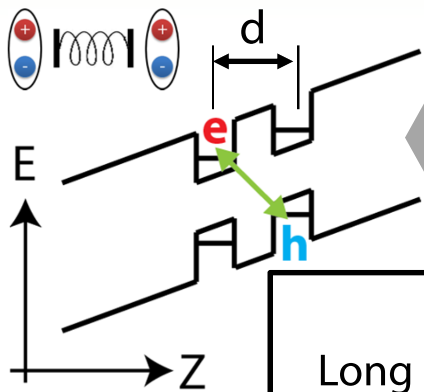
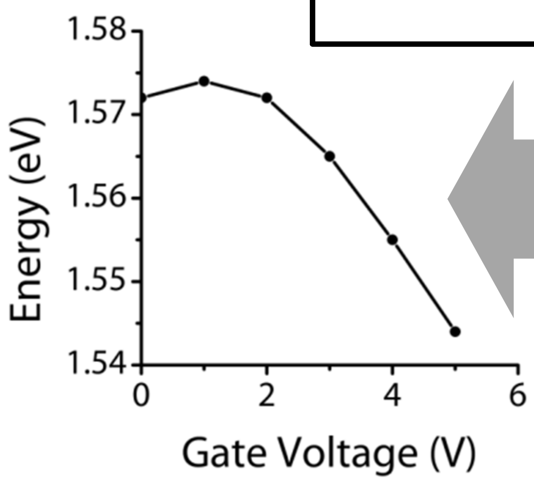
CLEO:QELS 2012

Indirect Excitons



Bound pair of an electron and a hole confined to separate quantum wells

Long lifetime → Can cool down below temperature of quantum degeneracy



Indirect Exciton Energy is controlled by applied voltage:

$$\delta E = edF_z$$

More about indirect excitons:

Transport of Indirect Excitons in a Potential Energy Gradient

QM1G.7 Y. Kuznetsova, Monday, 9:45am, A7

Spontaneous Coherence of Indirect Excitons in a Trap

QTu3D.3 A. High, Tuesday , 5:15pm, A4.

Spontaneous coherence in a cold exciton gas

QTh4E.4 A. High, Thursday, 5:15pm, A5.

Electrostatic Lattices for Indirect Excitons

Depth controlled in-situ by voltage

- High speed control

Structure determined by electrode pattern

- Arbitrary lattice structures
- Compatible with semiconductor technology

Exciton number controlled by laser power

- Selective loading to individual lattice sites

Other controlled parameters

- Interaction strength
- Effective mass
- Exciton lifetime
- Exciton temperature

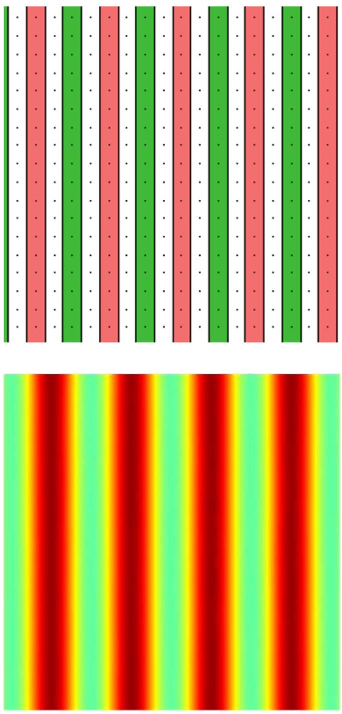
Excitons in lattices – a condensed matter system with controllable parameters

Another system with controllable parameters: cold atoms in optical lattices

- Cold particles
- Tunable lattice depth
- Used for emulation of condensed matter systems

Electrostatic Lattice Design

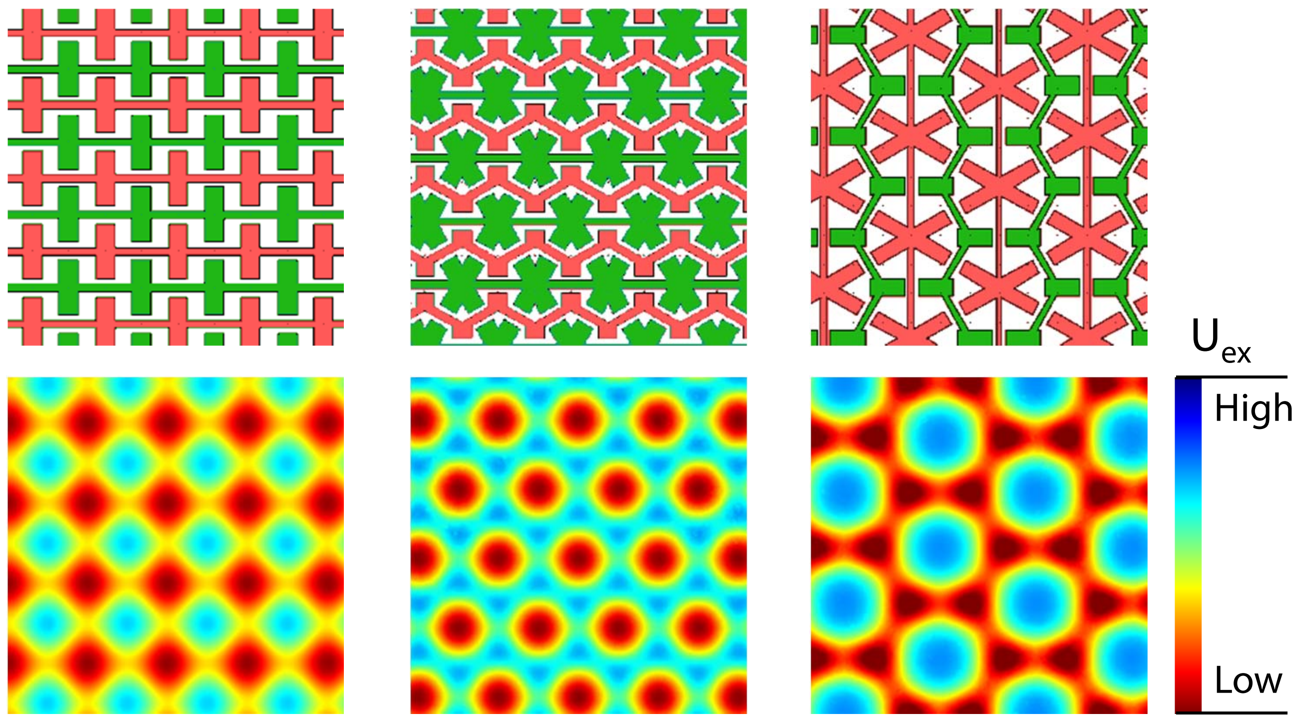
Linear Lattices



Two Dimensional Lattices

- Different lattice structures

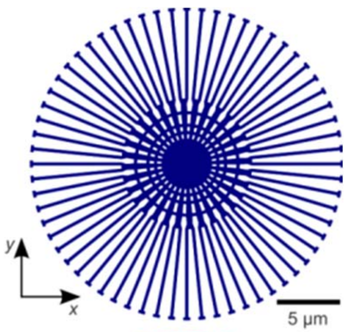
Square Triangular Honeycomb



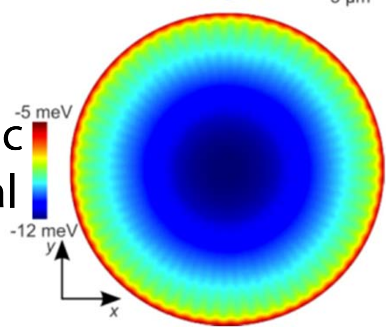
Two Dimensional Lattice Design

Method of Potential Control by Electrode Density

Snowflake trap



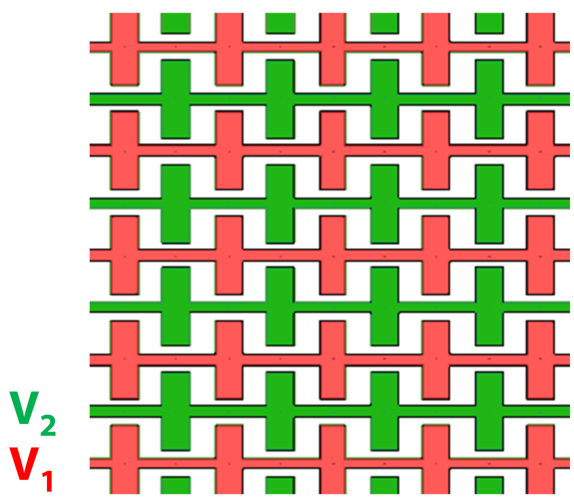
Parabolic Potential

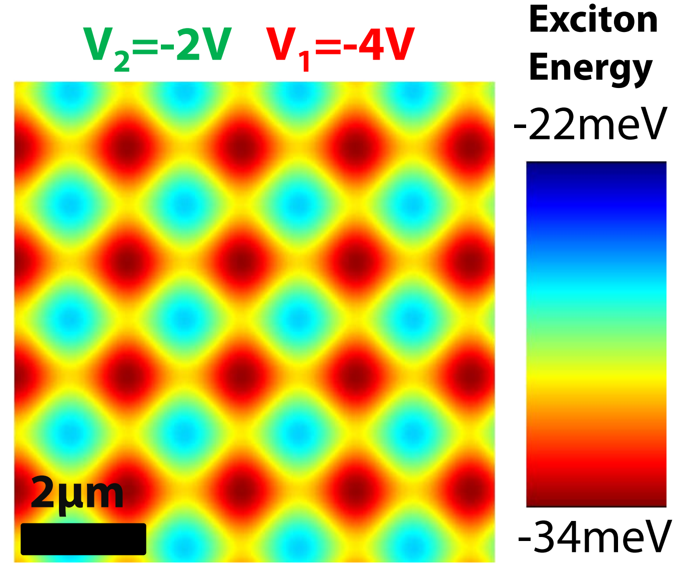


Y. Y. Kuznetsova, A. A. High, L. V. Butov, *APL* 97, 201106 (2010)

Applied to a Lattice Potential:

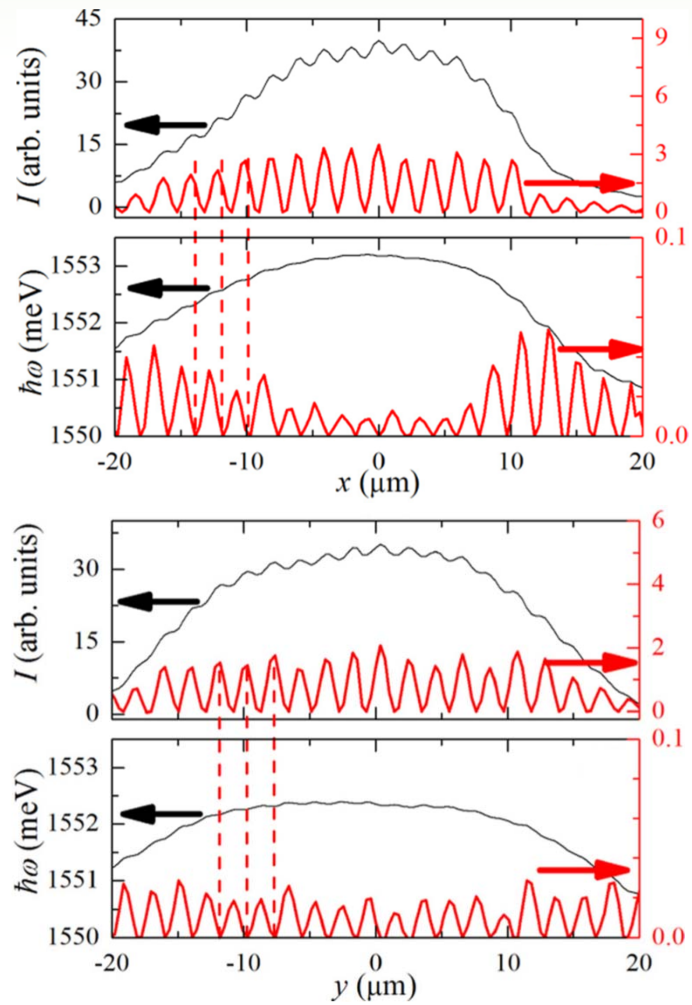
- Lattice structure determined by electrode design
- Independently controlled lattice depth and base energy
- Electrode pattern fabricated in a single lithography step

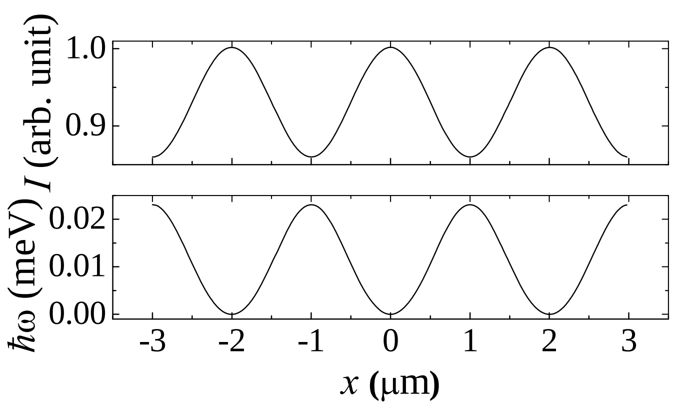




Proof of Principle for 2D Lattices for Excitons

- **Realized 2D lattice for indirect excitons**
- **Excitons collect to lattice sites**
- **Lattice potential is in agreement with simulation**



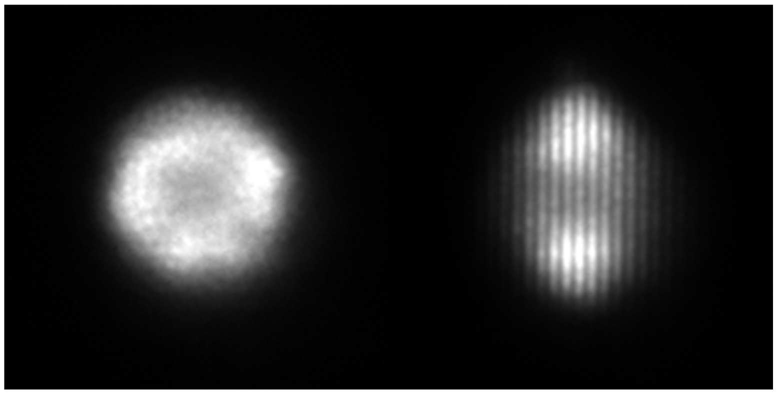


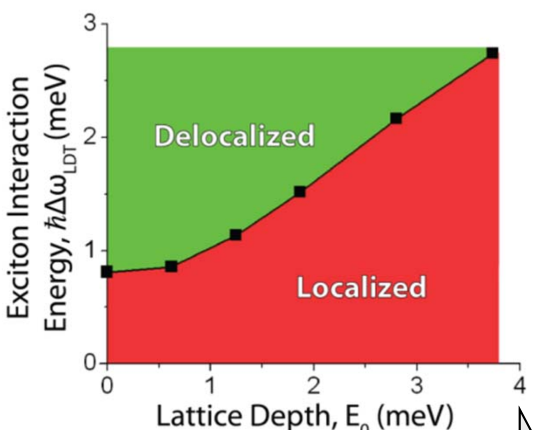
Simulation

M. Remeika, M. M. Fogler, L. V. Butov, M. Hanson, A. C. Gossard, *APL* 100,061103 (2012)

Exciton localization

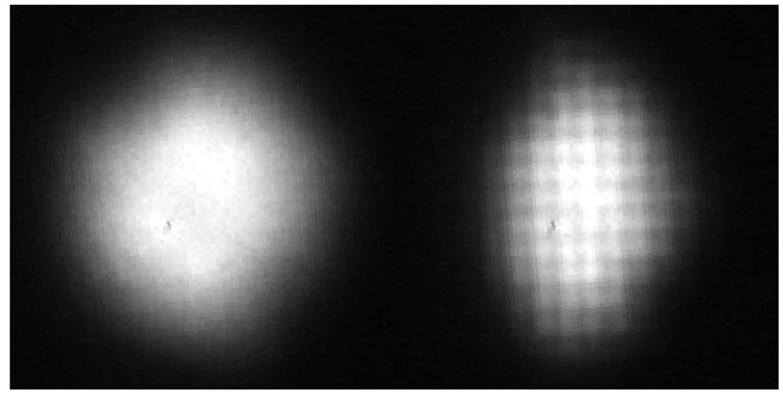
Linear

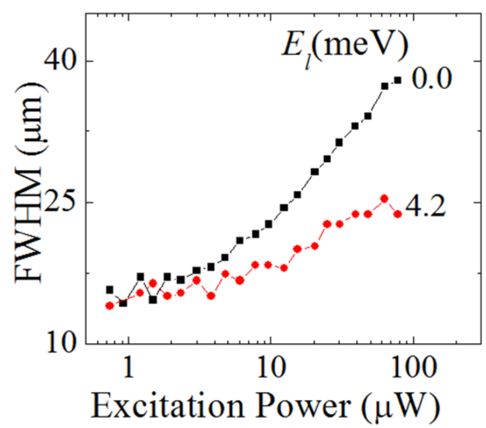




M. Remeika, J. C. Graves, A. T. Hammack, A. D. Meyertholen, M. M. Fogler, L. V. Butov, M. Hanson, A. C. Gossard, *PRL* 102,186803 (2009)

Square





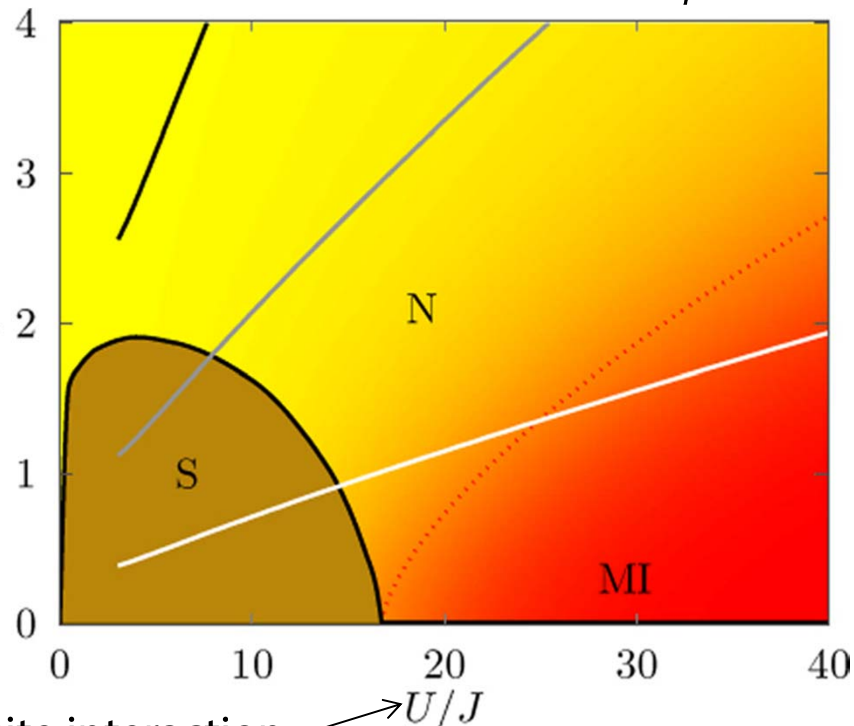
M. Remeika, M. M. Fogler, L. V. Butov, M. Hanson, A. C. Gossard, *APL* 100,061103 (2012)

at loc-deloc transition

Interaction energy ≈ **Lattice depth**

Superfluid – Mott Insulator Transition for Excitons in an Electrostatic Lattice

$T = 0.8E_r$ $T = 0.35E_r$



Inter-site hopping

On-site interaction

$$E_r = \frac{h^2}{2m_{ex}b^2}$$

Exciton mass

Lattice constant

$T = 0.12E_r$

$T = 50$ mK
$b = 200$ nm

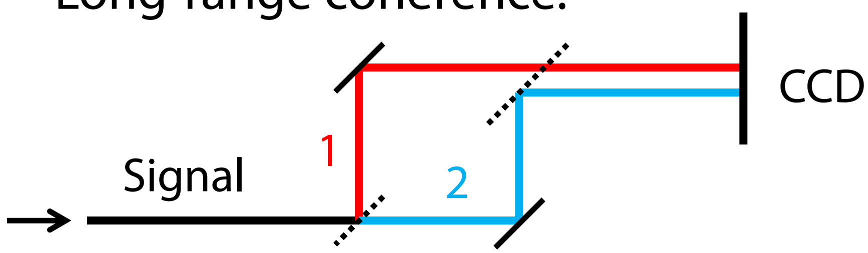
Experimentally accessible!

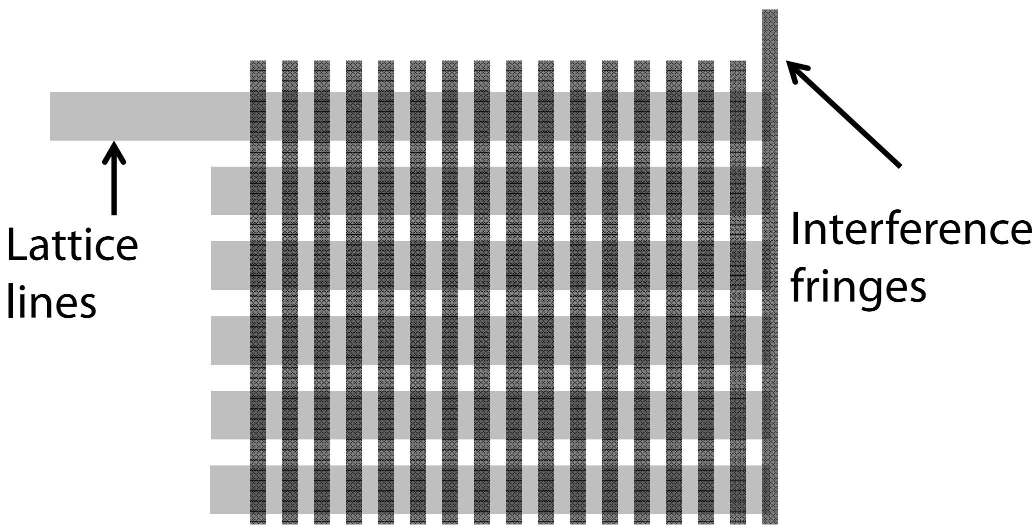
Superfluid – Mott insulator transition for atoms in an optical lattice
M. Greiner, O. Mandel, T. Esslinger, T.W. Hansch, I. Bloch, Nature 415, 39 (2002)

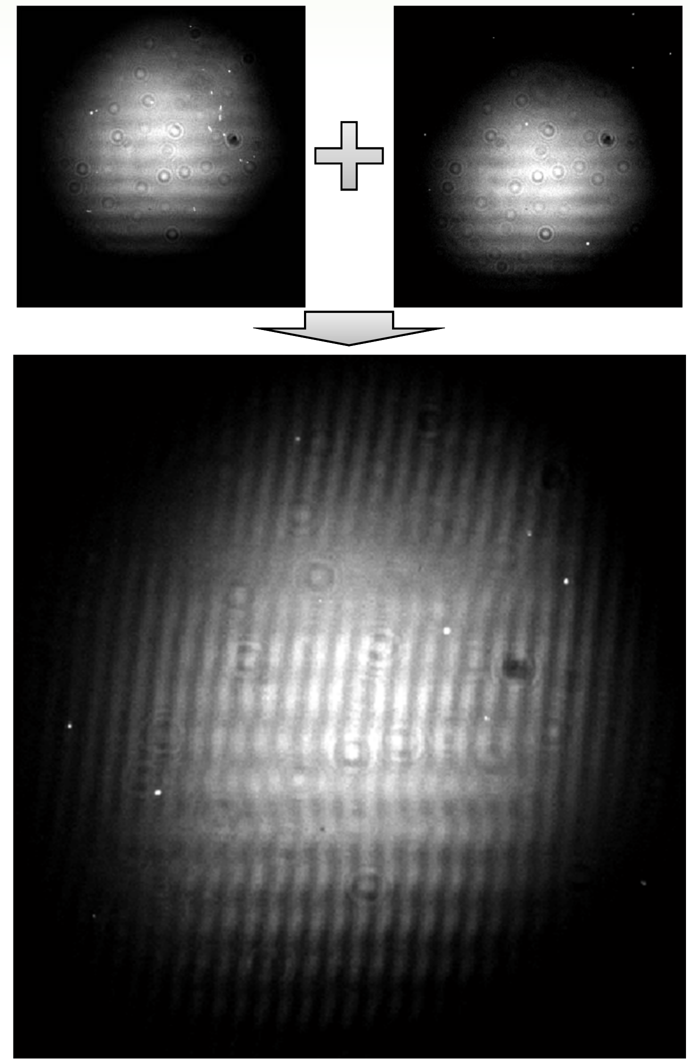
M. Remeika, M. M. Fogler, L. V. Butov, M. Hanson, A. C. Gossard, *APL* 100,061103 (2012)

Work in Progress: Exciton Coherence in a Lattice

- Spatially resolved coherence measurement using Mach–Zehnder interferometer.
- Long-range coherence.







Conclusions

- Developed a method to create 2D electrostatic lattices for excitons.
- Demonstrated 2D lattices for excitons.
- Realized coherent exciton gas in a lattice.