Excitons in Electrostatic Lattices

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Indirect Excitons

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

Can cool down below temperature of quantum degeneracy

Indirect Exciton Energy is controlled by applied voltage:

\[ \delta E = e dF_z \]

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 \textit{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

Two Dimensional Lattices

- Different lattice structures

Square

Triangular

Honeycomb

Linear Lattices

$U_{ex}$

High

Low
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

$V_2 = -2V$, $V_1 = -4V$

Exciton Energy
-22meV

-34meV

Excitons in Electrostatic Lattices
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

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

Linear

Square


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

Interaction energy $\approx$ Lattice depth

at loc-deloc transition
Superfluid – Mott Insulator Transition for Excitons in an Electrostatic Lattice

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

Exciton mass

Lattice constant

\[ T = 50 \text{ mK} \]
\[ b = 200 \text{ nm} \]

Experimentally accessible!

Superfluid – Mott insulator transition for atoms in an optical lattice


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.

Diagram:
- Lattice lines
- Signal path
- Interference fringes
- CCD
Conclusions

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