ECE 6450

Quantum Dots

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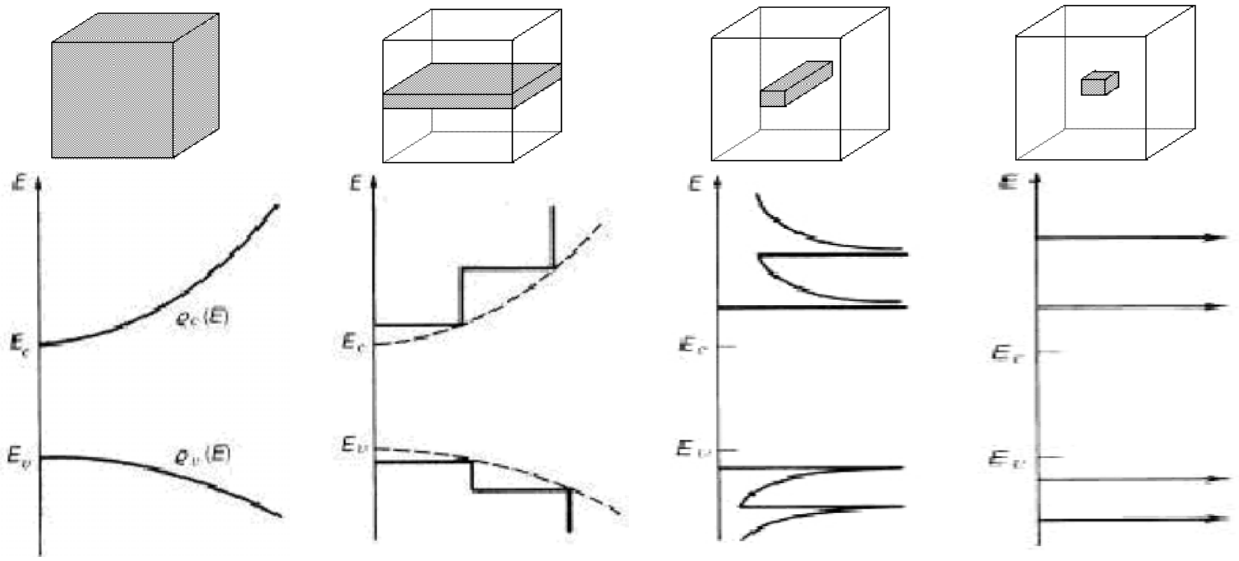
Outline

- Introduction
- Structure and Properties
- Quantum Cellular Automata
- Fabrication Techniques
- Other Applications

Introduction

- **Quantum Dot : A zero-dimensional electron gas realized by 3-D spatial confinement of electrons in the nanometric regime**
- **Discrete Quantum (energy) levels : atom-like behavior**



Bulk Material (3-D)

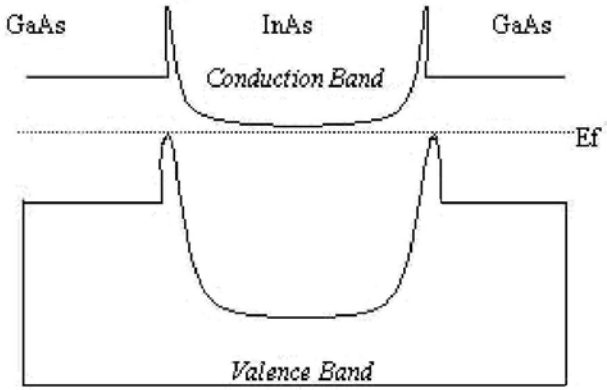
Quantum Well (2-D)

Quantum Wire (1-D)

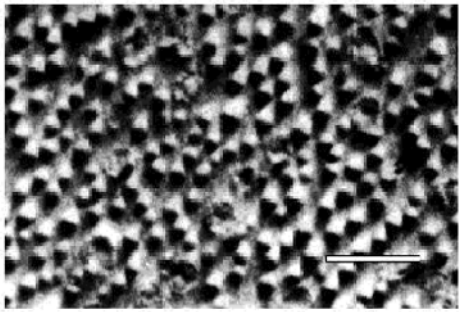
Quantum Dot (0-D)

Structure

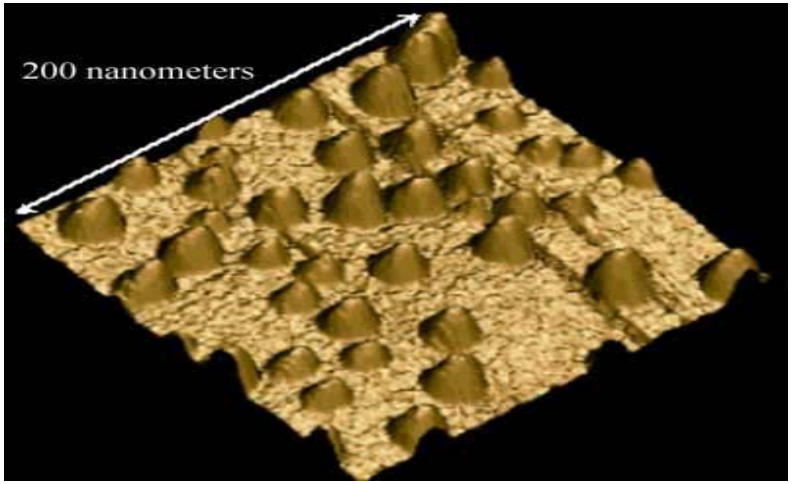
- Low Band Gap Material forms Dots
- High Band Gap Material provides confinement
- Typical Materials Used : GaAs/AlGaAs, GaAs/InGaAs, Al/SiO_2
- Small number of electrons per dot
- 0-D degrees of freedom for carriers inside dot



Typical Energy Band Diagram

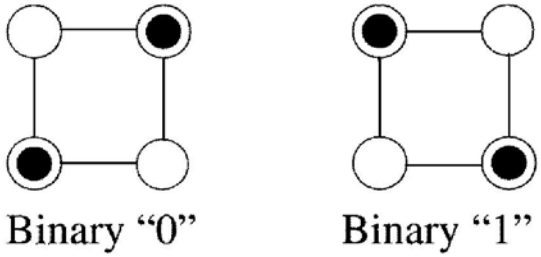


InAs Quantum Dots on GaAs substrate (1.2 nm InAs layer)

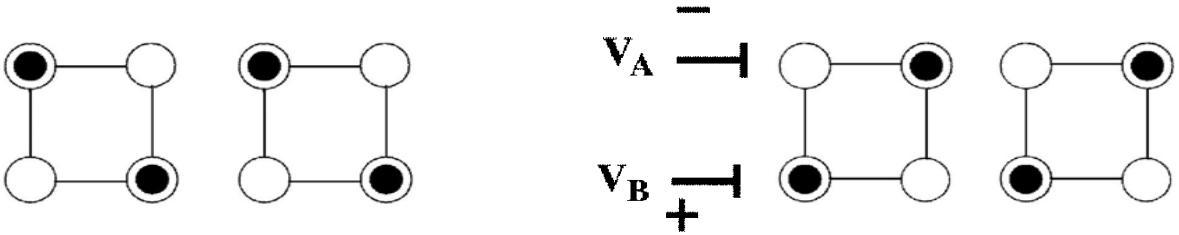


Quantum Cellular Automata

- New Computing Paradigm
- Boolean Logic using Coupled Quantum Dots
- Life beyond FET scaling limits
- Basic QCA cell : 4/5 coupled dots,
  2 stable states (‘1’,’0’)
- States can be switched using external voltage
- Coupled Pair switches next



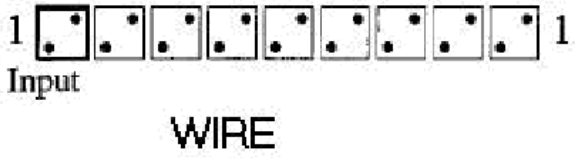
Basic QCA Cell



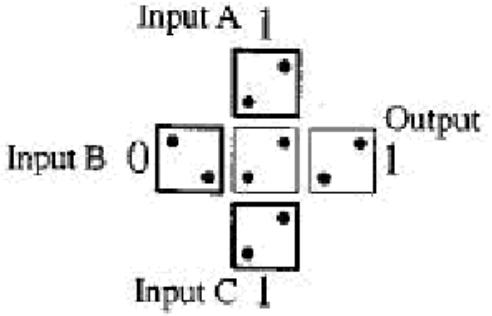
Data Propagation in subsequent QCA cells

QCA Logic Blocks

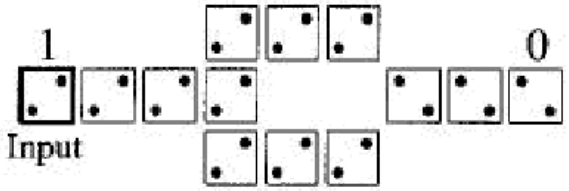
- **Majority Gate can function as 2 input AND/OR**



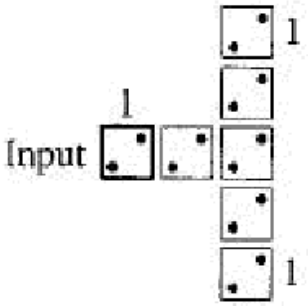
WIRE



MAJORITY GATE



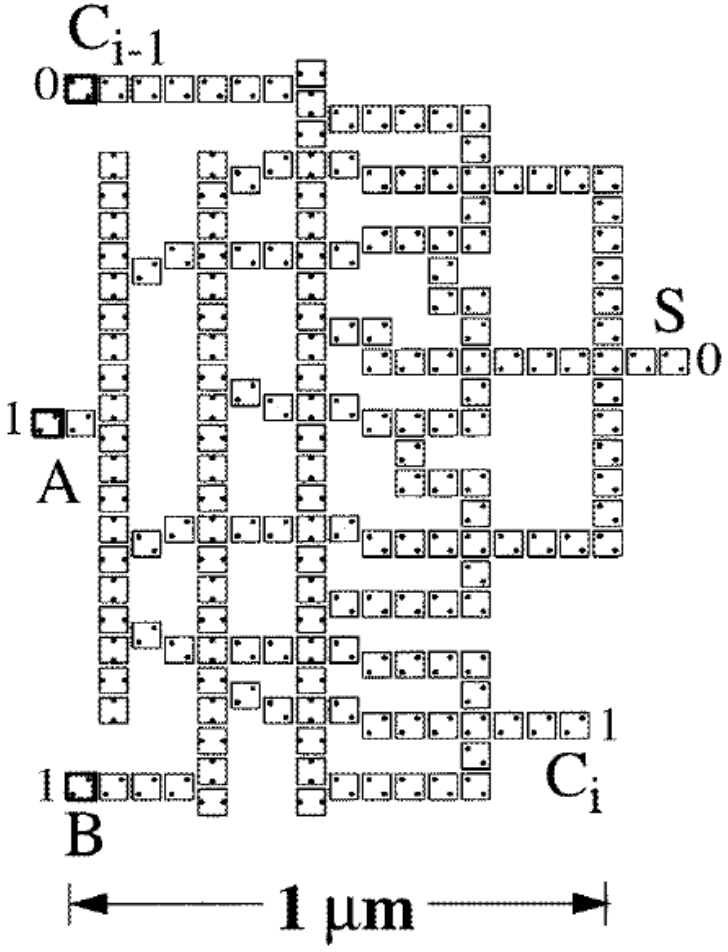
INVERTER



FANOUT

QCA Circuits

- 1-Bit Full Adder (Lent, et al, 1994)
- For a dot size of 10 nm, area required is less than 1.5 µm2 and replaces about 30 transistors
- Very Low Power
- No power is directly supplied to the interior of the array
- Theoretical Switching Frequency : in THz range !!



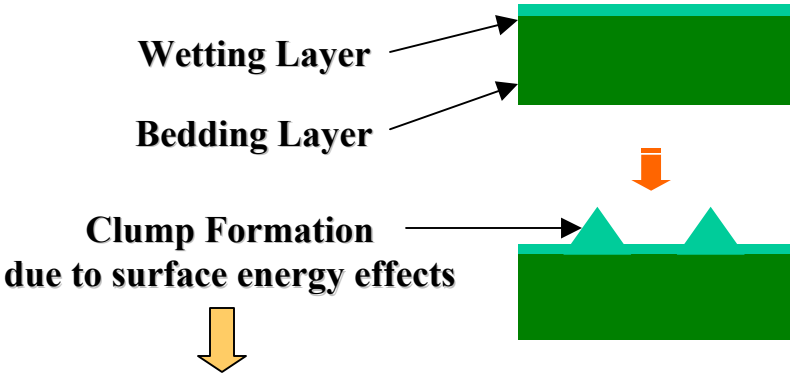
A QCA 1-Bit Full Adder

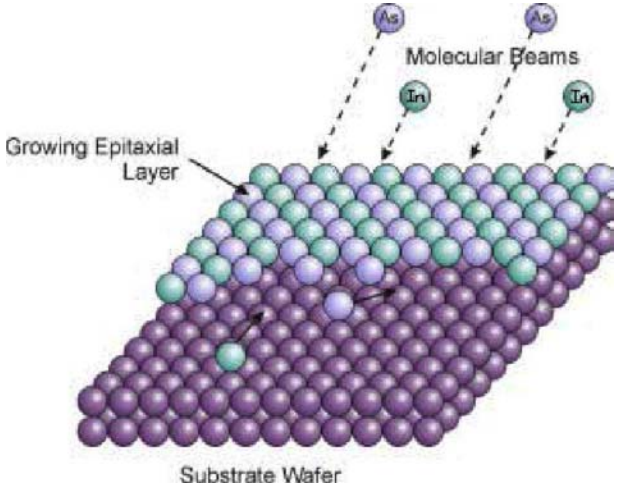
Fabrication Techniques

- **Heteroepitaxial Growth :**
  - * Molecular Beam Epitaxy (MBE)
  - * Metal-Organic Chemical Vapour Deposition (MOCVD)
  - * Chemical Beam Epitaxy
- **Lithographic Techniques :**
  - * Electron Beam Lithography (EBL)
  - * Nano-Imprint Lithography

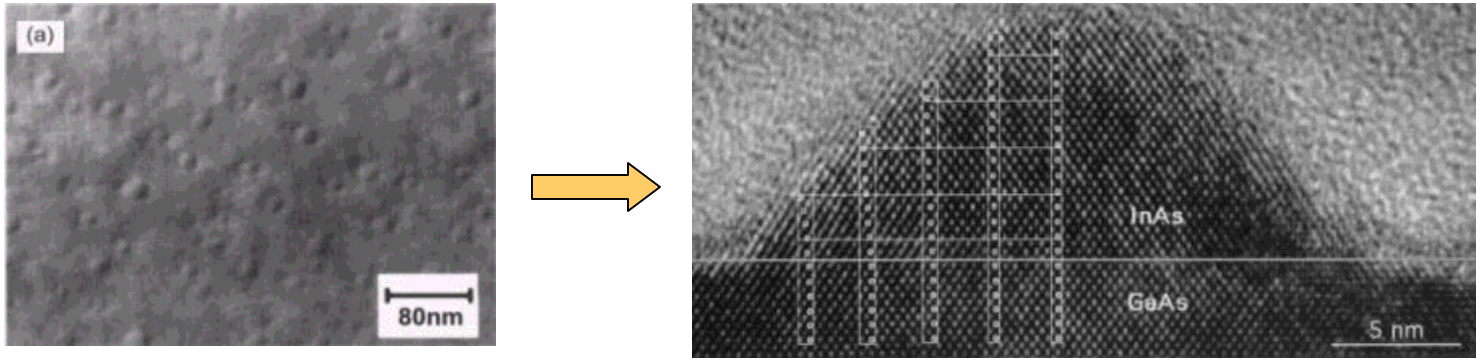
Self-Assembly during MBE

- **Self-Assembling Technique during MBE (Stranski-Krastanov Growth Mode)**





MBE Growth Mechanism



A cross-sectional high-resolution TEM image of an InAs island grown on GaAs

Other Applications

- QD Lasers
- QD Flash Memories
- QD Solar Cells
- QD VCSELs
- QD IR Photo-Detectors
- DNA matching using QDs….

…. The future is limited only by our imagination

Questions ??

Thank You