Intel Nanotechnology Virtual Open House

New nano logic devices for the 2020 time frame

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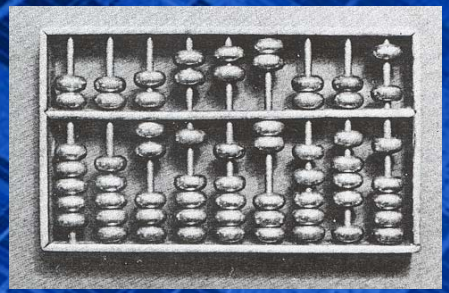
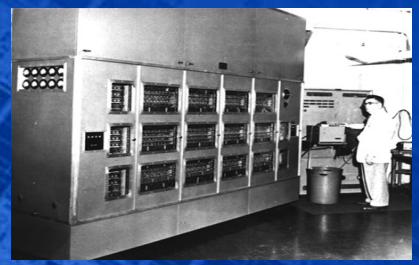
A brief history of computing



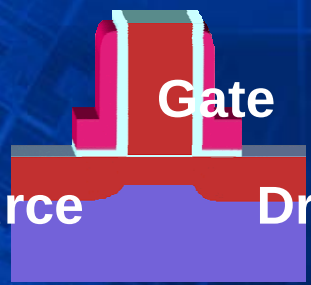
Abbacus 1500 BC



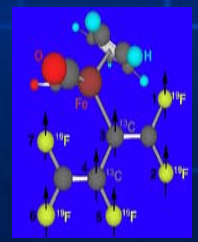
Illiac IV 1954

Moore's Law

Moore's Law



CMOS



Beyond CMOS 2020

Common elements

continue

Intel Nanotechnology
Virtual Open House

Outline

- A brief history of computing
- Understanding the basics of computing
- Building on the basics
- Some options for nano computing and extending Moore's law

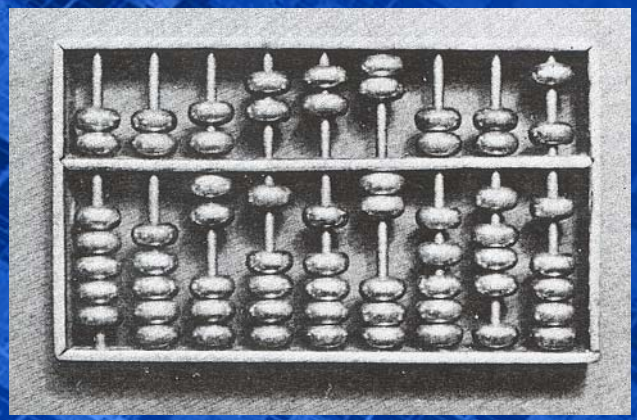
What are the elements common to all computers?

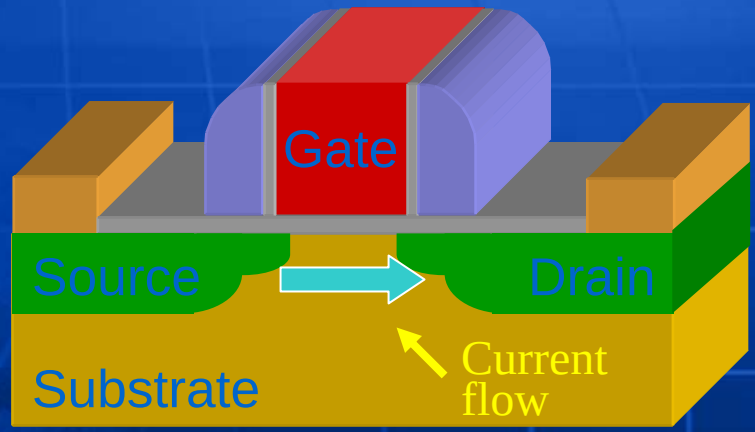
- We need to be able to write a bit .
  - ***Can we make red particles and yellow particles?***
- We need to be able to read a bit
  - . ***Is it red or is it yellow?***
- *We need to be able to change bits*
  - ***Can we change red to Yellow?***

BUT

All information is physical – Information must be represented by a physical system

The notion of "computational state" and material systems



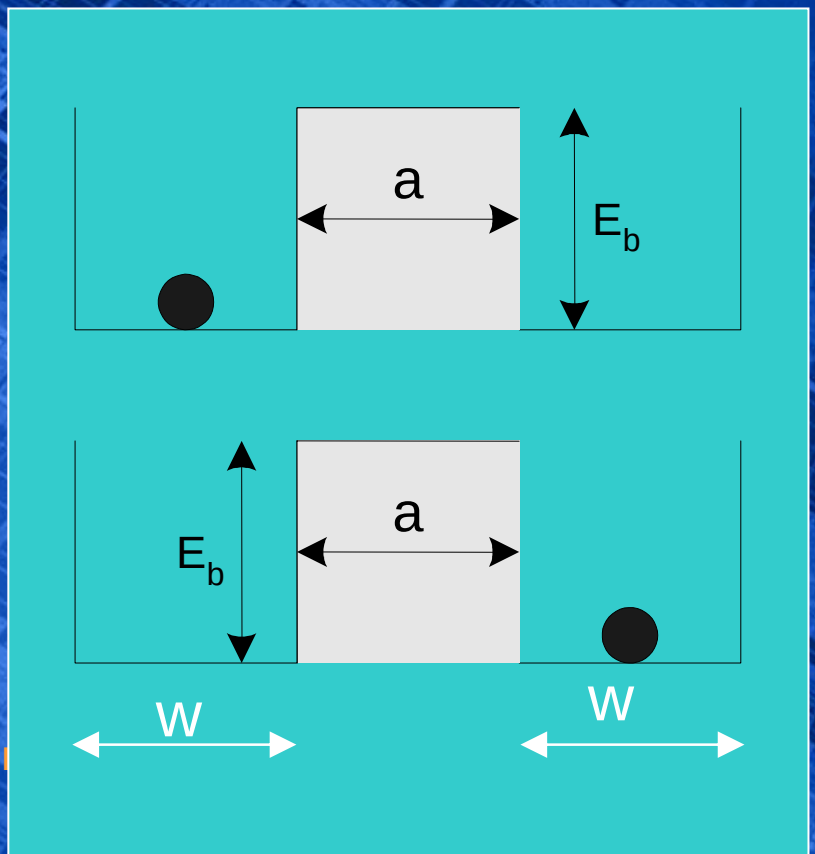


- The computational state is the position of the beads
- The material system is a set of stings in a frame

The computational state is electron current flow
The material system is a semi-conductor MOSFET

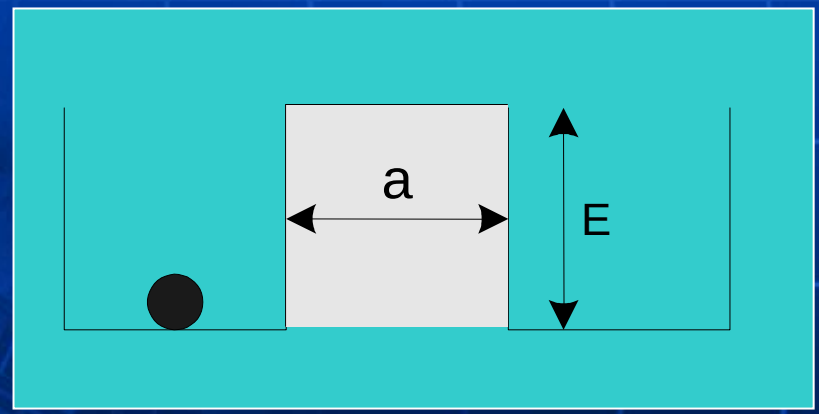
NEW MATERIAL SYSTEMS ⟺ NEW COMPUTATIONAL STATE VARIABLES

For binary logic, we need two computational states



***Sufficient* energy barrier is needed to prevent spontaneous transitions**

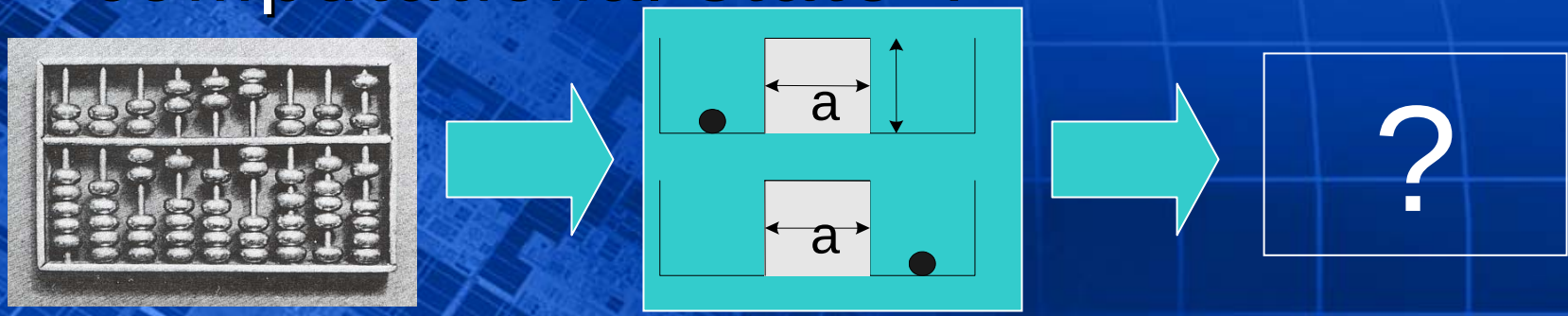
BUT



This is the fundamental energy loss mechanism In computing

Building on the basics

- Can we find other ways of storing "computational state"?



- Will it require less energy to switch?
- Do the material structures exist?
- Can it be manufactured?

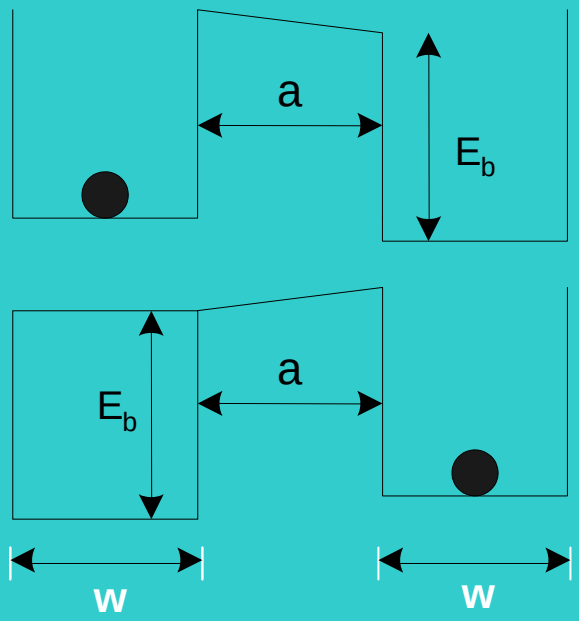
What are some of the logic alternatives?

- Spintronics
- Phase change logic devices
- Interference devices
- Optical switches

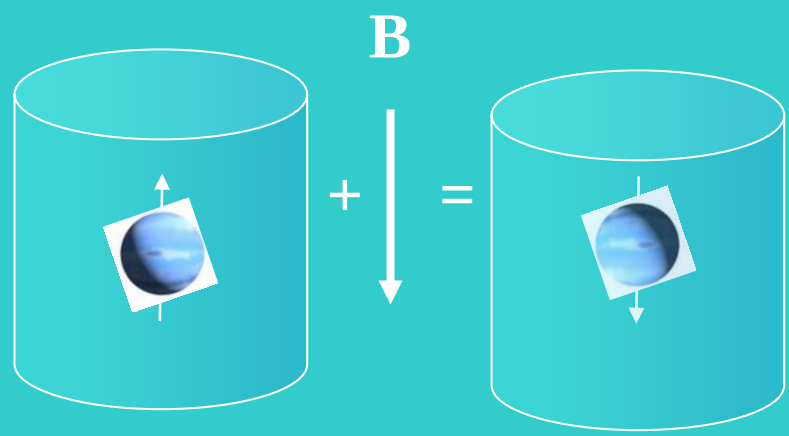
Build on existing memory and communication technologies

What about Spintronics?

Charge

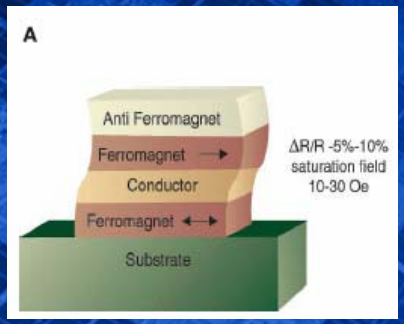


Spin

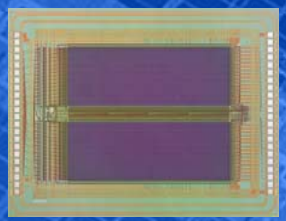


$\Delta E_b(e\text{-}) \sim 1.7X10^{-2}eV \quad >> \quad \Delta E(spin) \sim 8.6X10^{-8}eV$

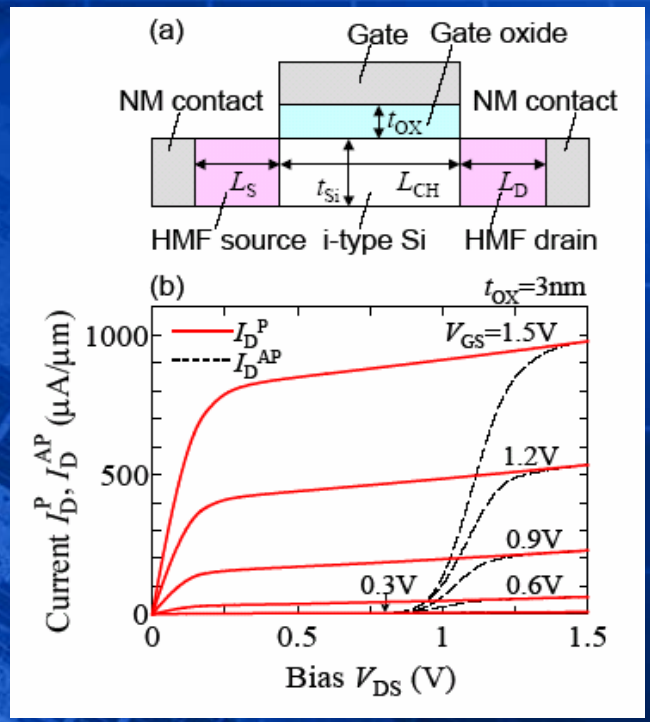
Magnetic devices>spin transistors



Magnetic Read heads



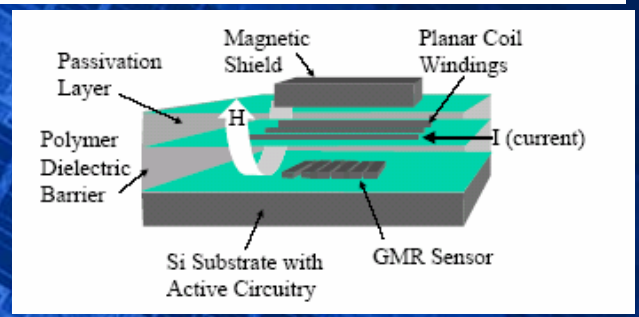
Magnetic memories



MOS SpinFET*

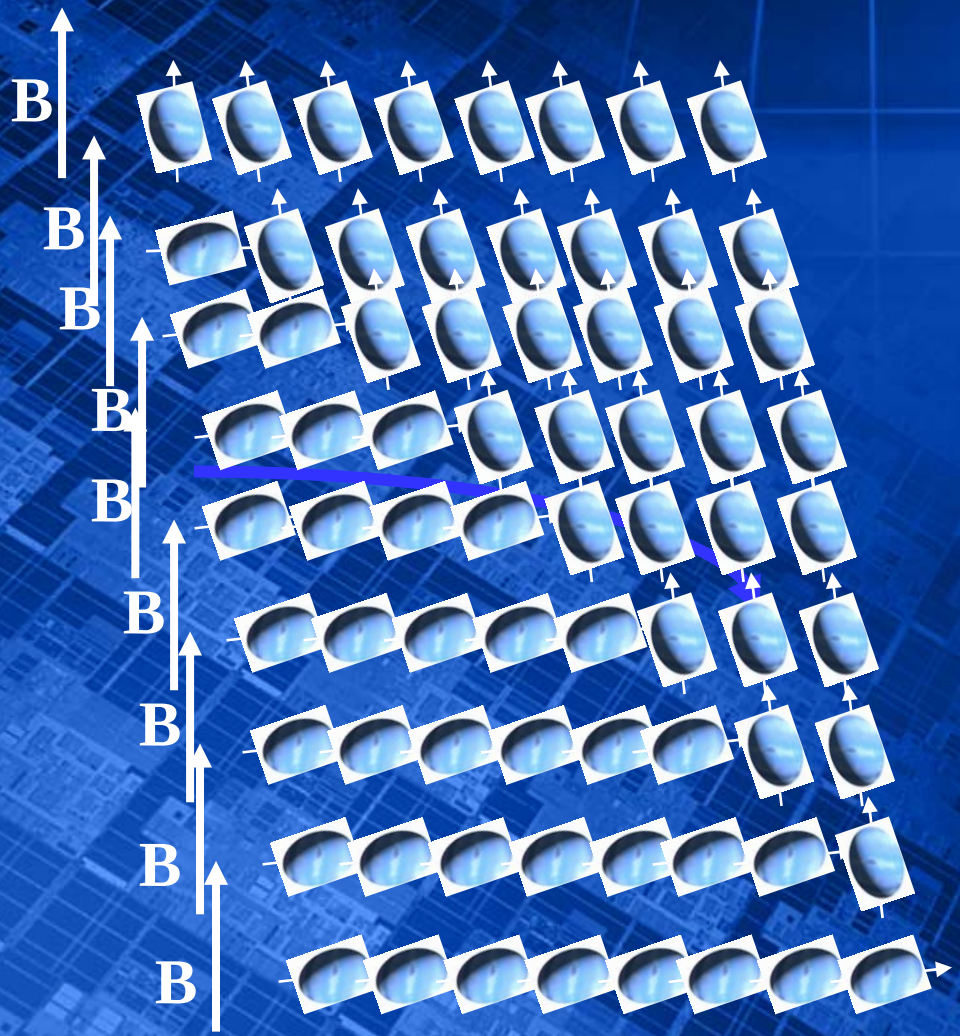
- Use spin to Control current
- Intel funding research at UCSB

*Sugahara and Tanaka, Vol 84, No 13 Mar 2004

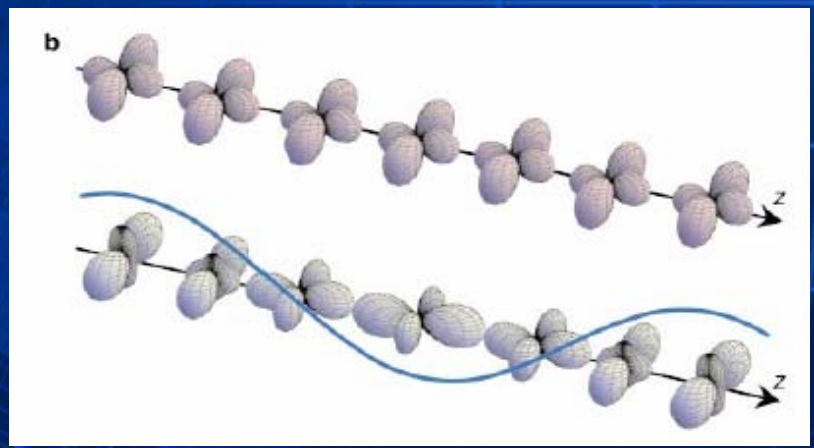


GMR isolators

Spin interactions enable coherent waves



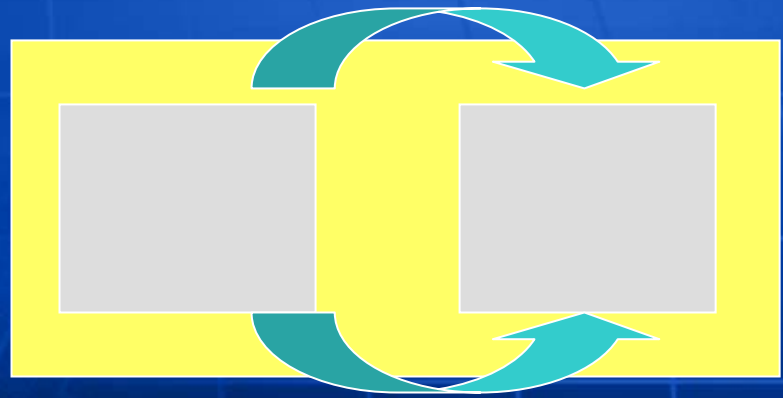
Orbitron waves -
Electrical properties
related to
Magnetic properties

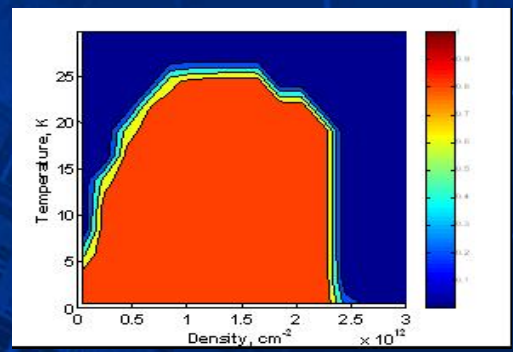


Low energy, high speed
interactions

Phase change logic devices

- Ice to water
- Crystalline to polymorphous
- Metals to insulators
- Non-magnetic to magnetic
- Correlated magnetic and electrical states

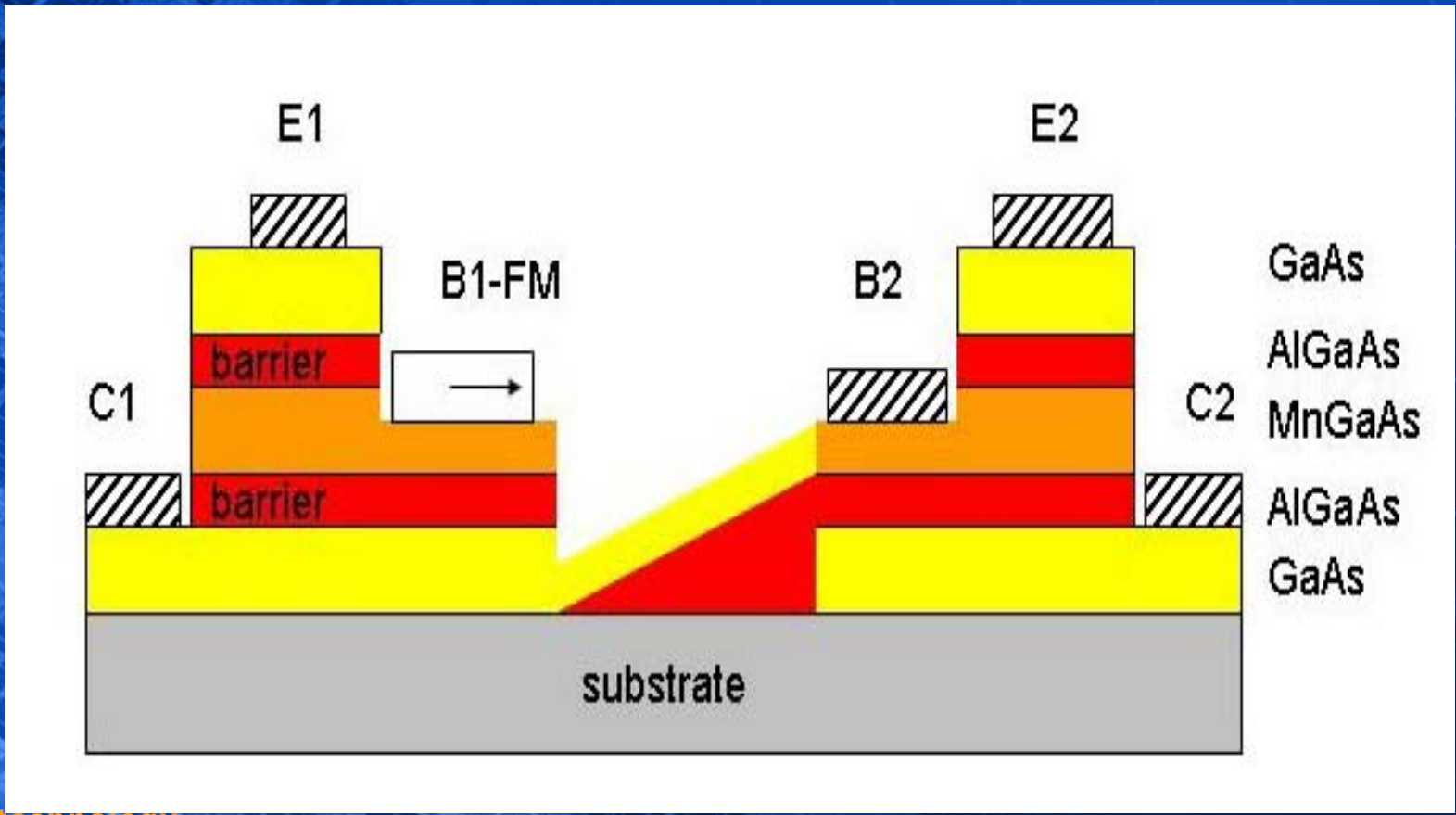




Spontaneous ferromagnetic Phase transition

Spin gain transistor*

based on spontaneous ferromagnetic phase transition



*Patent pending

Ferroelectric transistor

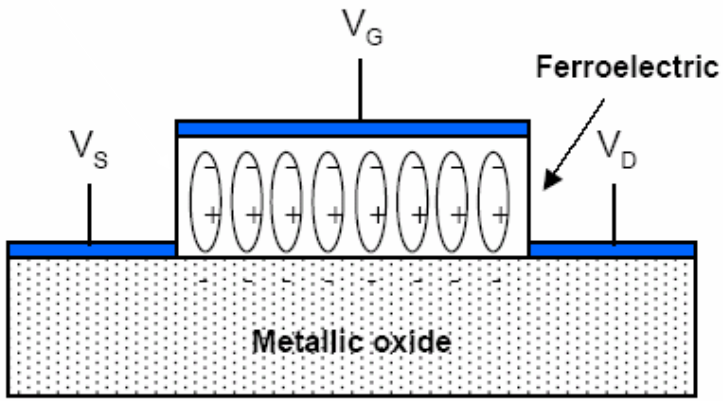
- Nonvolatile field effect

  Programmable logic considerations

- Device works at metallic densities -> ~1 nm depletion width

  Post CMOS scaling considerations

- Oxide epitaxial devices

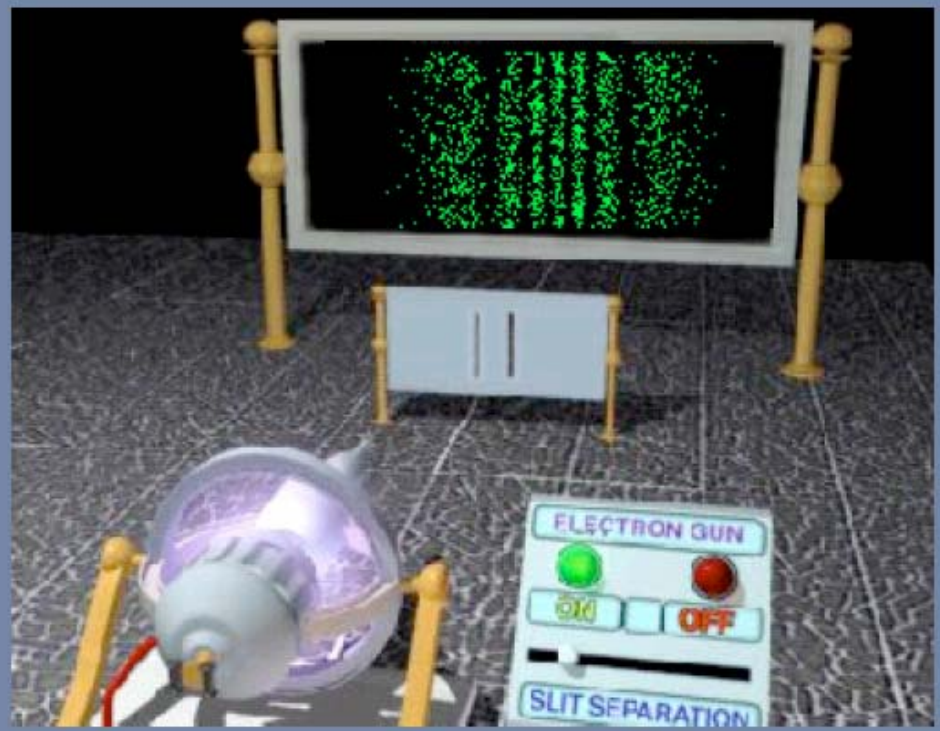


C.H. Ahn et al., Science 284, 1152 (1999)

*Research sponsored at Yale University

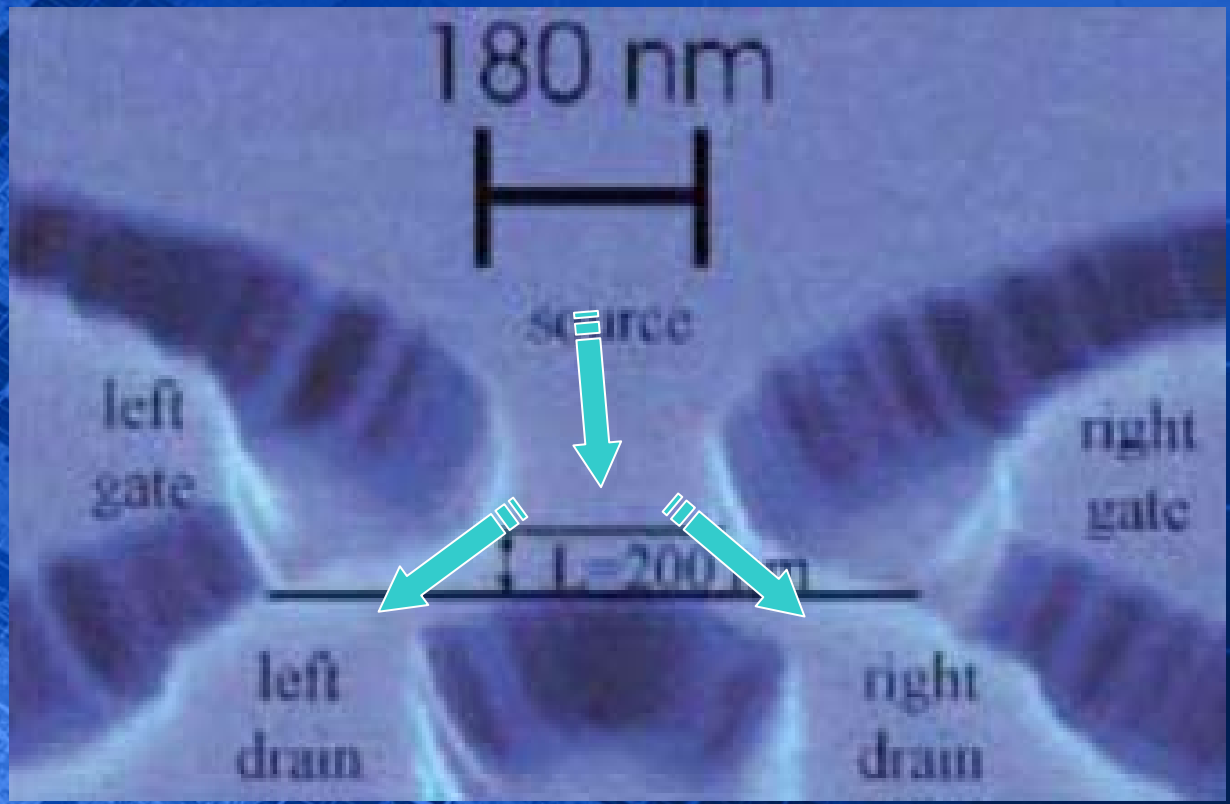
Interference based devices

- Electrons have wave properties
- Waves can interfere



http://www.colorado.edu/physics/2000/schroedinger/two-slit3.html

Interference based switching devices have been built*

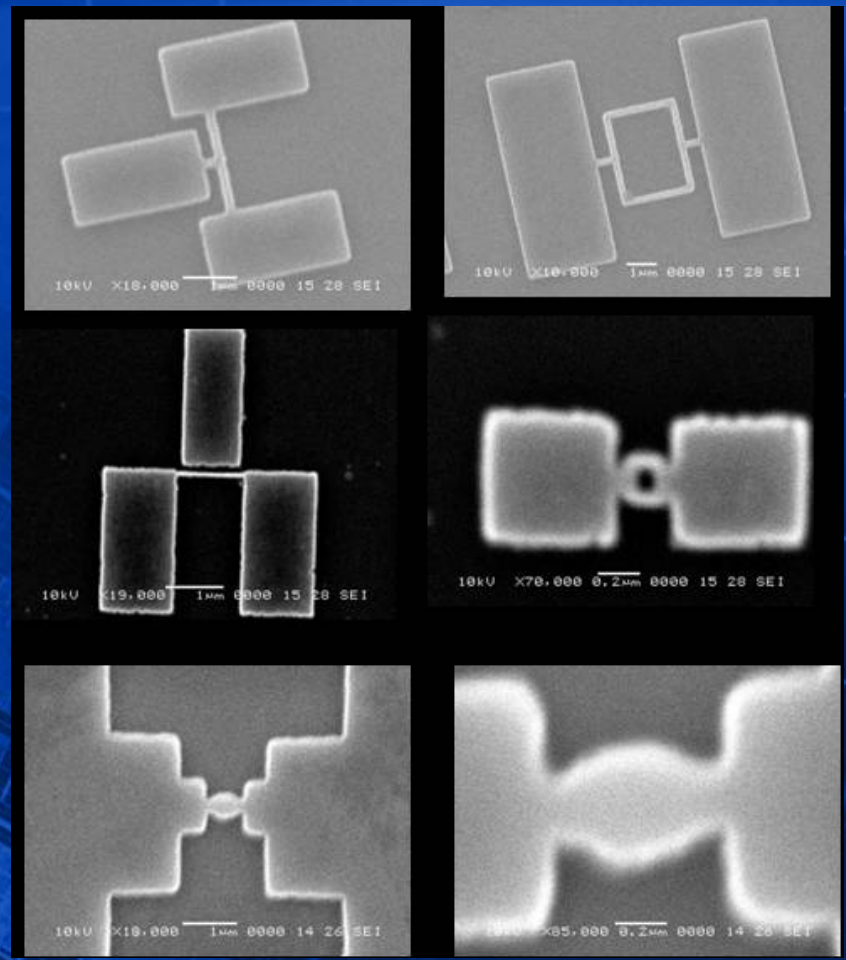


GaAs/AlGaAs system

*Worschech et. al., Appl. Phys. Ltrs, vol 78, no 21, 2001

Epitaxial graphene films for interference devices

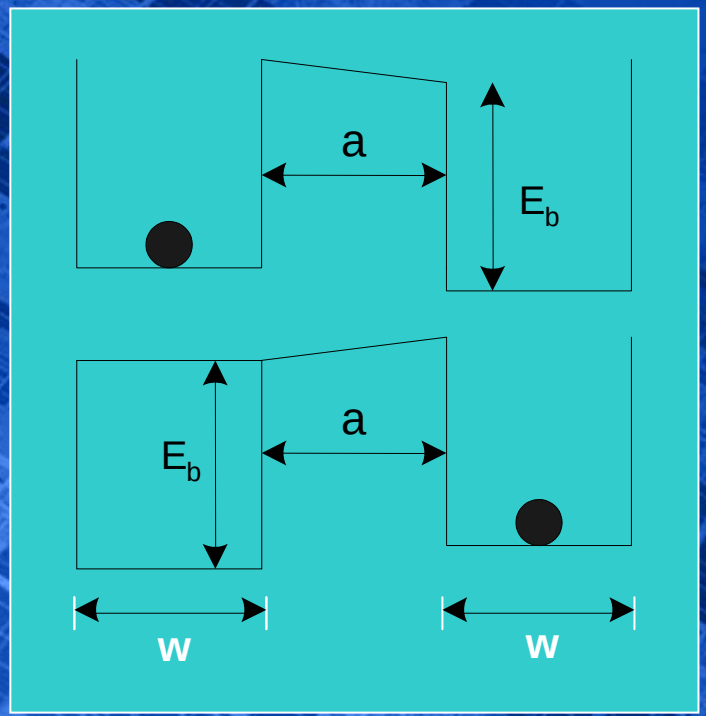
- Graphene is same material as CNTs
- Coherent transport has been observer in films
- Films may be patterned to manufacture interference based devices
- Sponsored research project at Georgia Tech

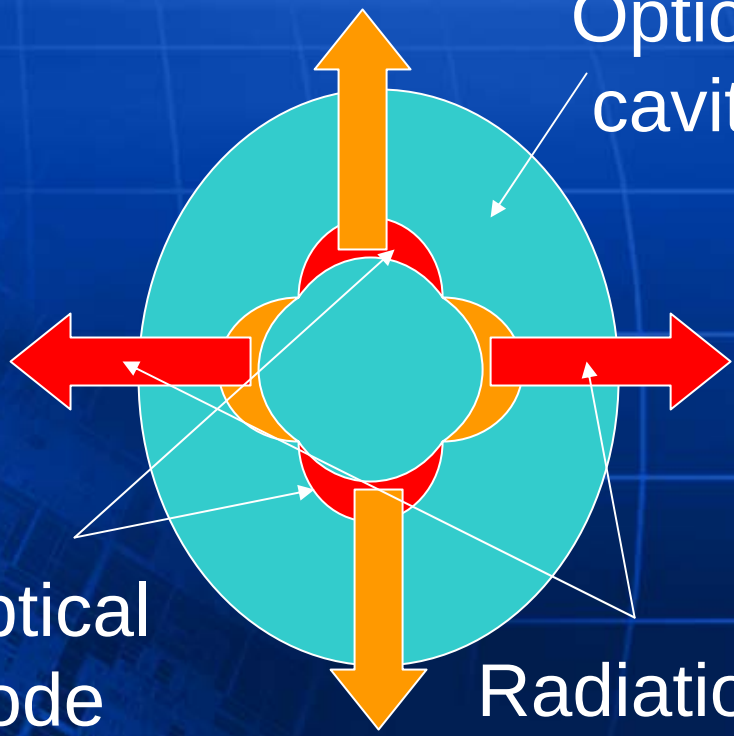


Used by Permission, W. de Heer

What about optical switching?

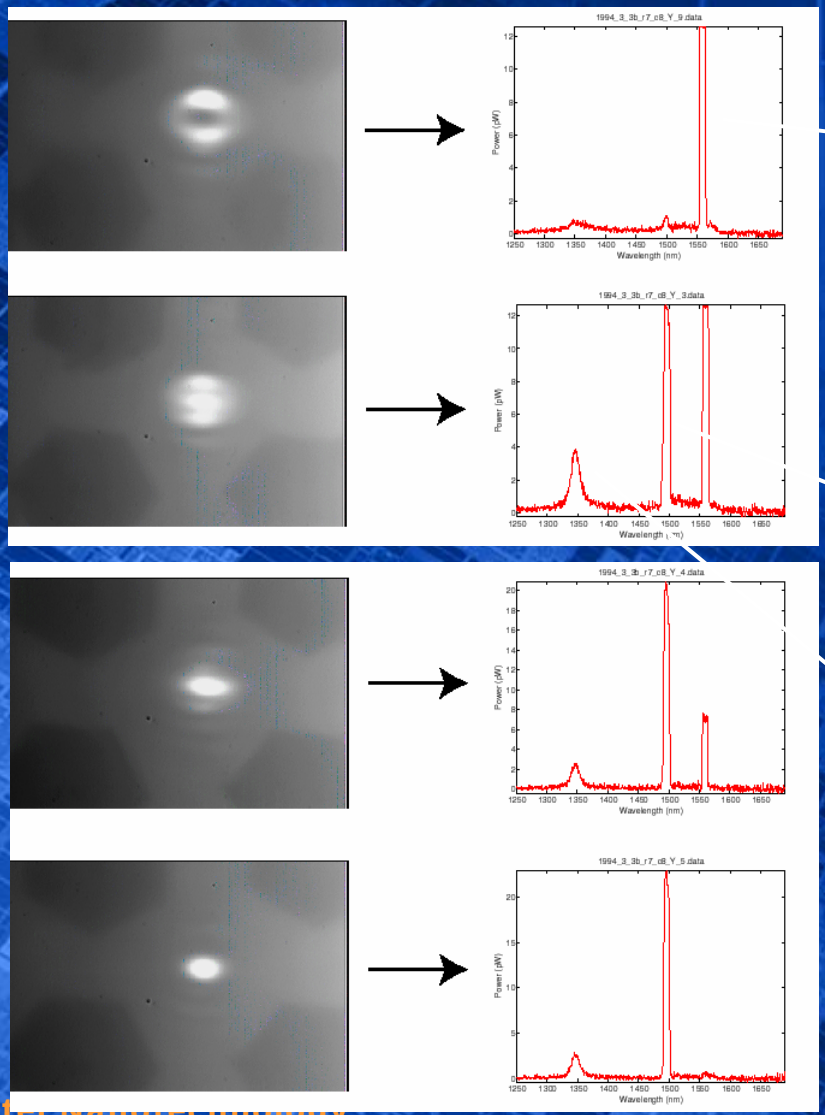
Charge





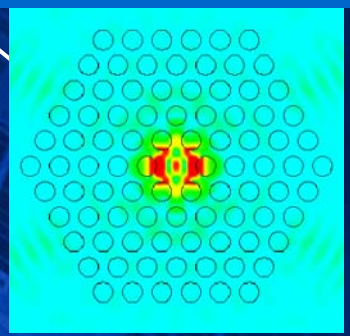
Switching energy and switching times being investigated at Caltech – see poster

Optical modes in a cavity to store computational state



The photonic crystal laser cavity can support two perpendicular high-Q dipole modes.

The lasing direction can be modulated by changing the relative Q of one of the dipole modes with a switching beam



Used by permission Axel Scherer, Ca. Inst. Of Tech.

The size of the pump beam determines the spectrum of the laser

Conclusion

- New logic devices will be needed in the 2020 time frame
- Novel concepts related to existing technologies exist but need to be investigated
- Intel is engaged with key university research programs to monitor and guide the research