Resonant Tunnelling Devices

A survey on their progress

CMOS Scaling has been key to performance increase

- CMOS scaling gives us three things:
  - Higher clock
  - More components
  - Same cost
- We are currently at 90nm
- 65nm in 2006
- Everybody's favourite line: Moore's law will hit a wall (so far all false)
- Some technology will eventually replace CMOS
- What is that technology?

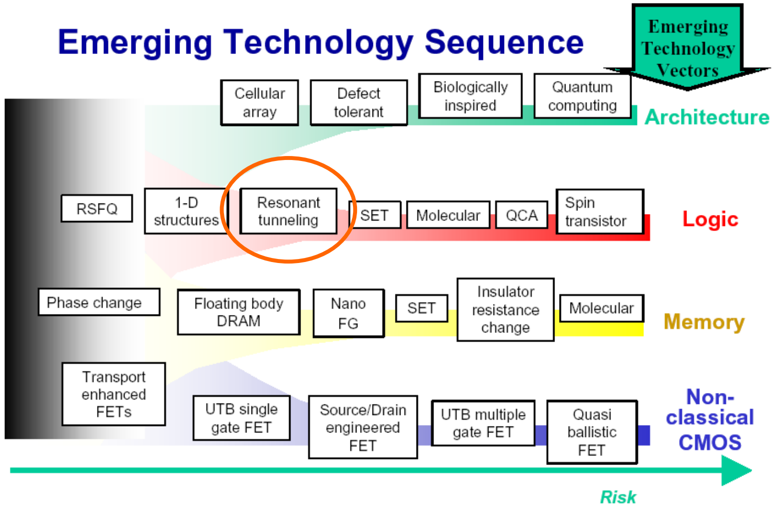
Research idea: Find the next CMOS

- So many post-CMSO proposals
  - Quantum computing
  - Molecular electronics
  - DNA computing
  - … (countless)
- Hear about "breakthroughs" everyday
- Yet we're still using silicon transistors
- So are we really?

How things fit

- Plain CMOS scaling will carry us to 10nm (and maybe more)
- That means at least another 10-15 years before we must switch to a new tech
- But it might make sense to switch ealier
- Key theme: below 100nm, two options are available:
  - Smaller CMOS
  - Quantum-effect based devices

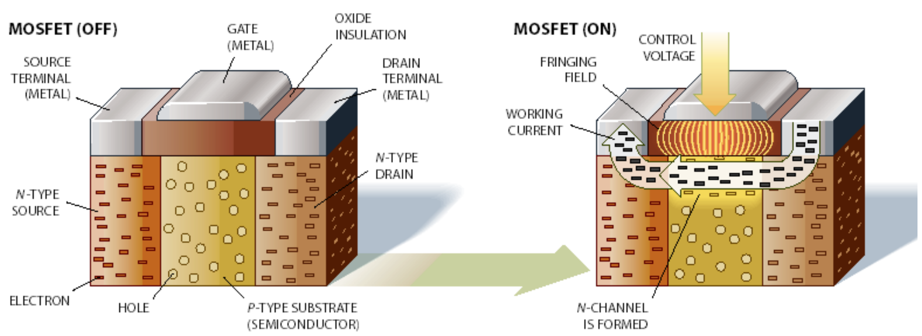
What about all the “breakthroughs”?



Why Resonant Tunnelling Devices?

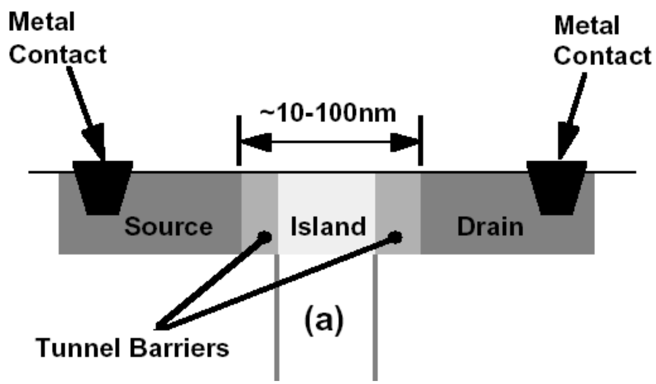
- Works at room temperature!
- Extremely high switching speed (THz)
- Low power consumption
- Well demonstrated uses
  - Logic gates, fast adders, ADC etc.
- Can be integrated on existing processes
- In one word: Feasible

What we’ve been using: The MOSFET



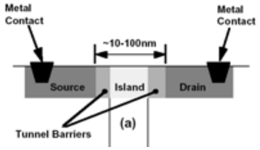
Source: Scientific American

Resonant Tunnelling Diodes

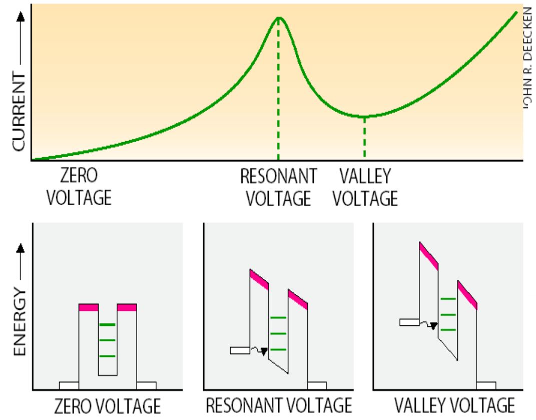


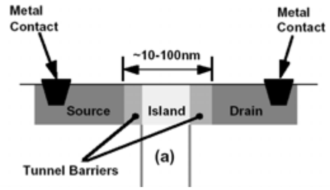
Resonant Tunnelling Diodes

- Fundamentally different operating principle
  - Quantisation
  - Quantum tunnelling
- Computation comes from Negative Differential Resistance (NDR)



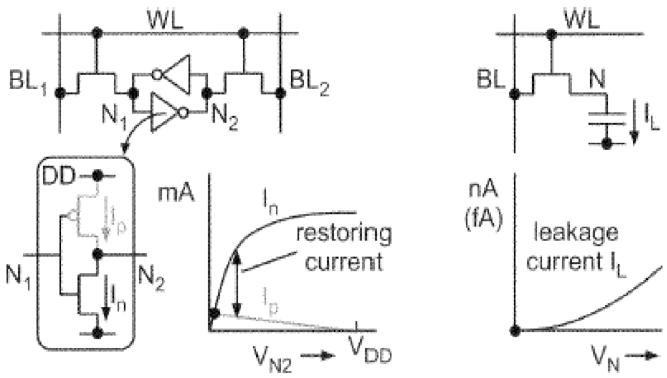
Negative Differential Resistance





Need high peak to Valley Current Ratio (PVCR)
PVCR of 2-4 desirable

Example Circuit: TSRAM



Example Circuit: Shift Register

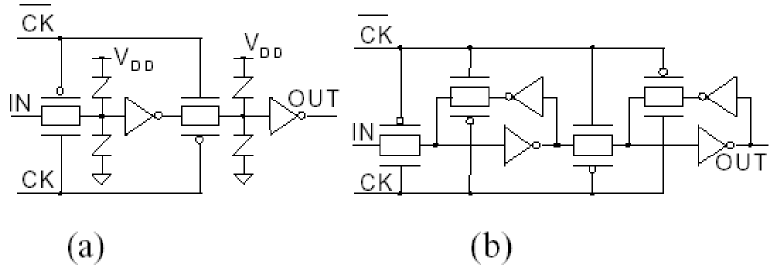


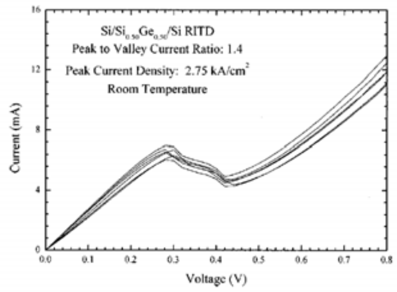
Fig.6: Static shift register comparison: (a) CMOS/TD and (b) CMOS only.

Problem

- Up until now, all usable circuits made using III-V compound semiconductors
  - Eg. GaAs, InP
  - Good PVCR and current density
  - Good for high frequency switching applications
  - CMOS incompatible
- Need a silicon solution before any chance of mass uptake

Silicon based RTDs

- Prior to 1998, Si based RTD displayed no usable NDR
- In 1998, Rommel et al produced first Si/SiGe/Si RITD with NDR at room temperature
- RITD exhibits better PVCR



Integration with CMOS

- In 2003, monolithic integration with CMOS demonstrated
- Performance comparable to discrete RITD

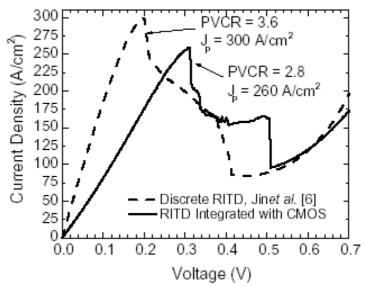


Fig. 4. *I–V* characteristics of the first integrated 25×25 μm² patterned growth RITD. The RITD is in the same die as the CMOS devices plotted in Fig. 3.

Integrated FET/RITD

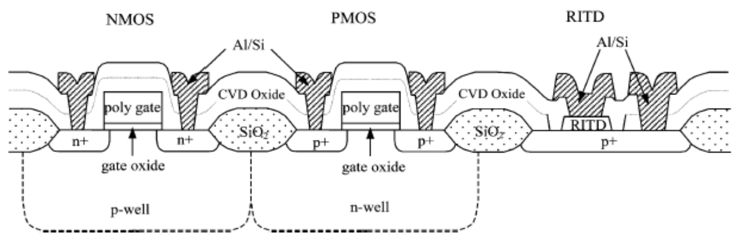
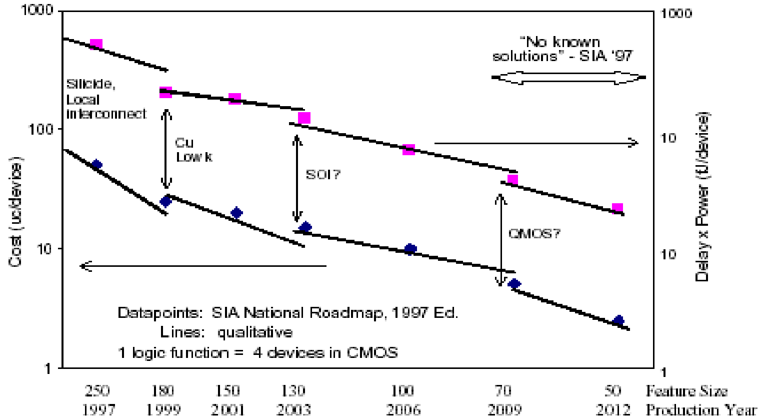


Fig. 2. Schematic diagram of the monolithically integrated CMOS and Si/SiGe RITD.

What does it mean for architecture?

- CMOS / RTD hybrid circuits
  - Factor of reduction in component complexity
  - Higher operating frequency
  - Lower power consumption
- TSRAM
  - 1 transistor SRAM with DRAM density on chip
  - Greatly reduced power consumption
  - More design options with eDRAM

A Roadmap to RTDs?



Take home message

- CMOS scaling will continue, one way or another
  - Double Gate MOSFET will get us to 10nm
  - Plenty of new options
- The transistor of the future will exploit quantum effects
  - SET, QD, Molecular, Spin transistor
- Silicon RTDs can now be integrated with CMOS
  - Excellent for extending CMOS
- Good chance they will be the first quantum effect devices to become mainstream