
Overview of Future Hardware Technologies

The chairman's notes from the plenary session appear in blue throughout this document. Subject to these notes the positions in this document can be taken as the consensus of the workshop.

Future Hardware Technologies

- ◆ Mainstream CMOS-based silicon devices.
- ◆ Nanotube memories and transistors.
- ◆ Nano-imprint crossbar devices.
- ◆ Superconducting single-flux quantum devices.
- ◆ Quantum dots and quantum cellular automata.
- ◆ Reversible computing devices (a class of technologies).
- ◆ Quantum computing.
- ◆ Chairman's Note: Everybody agrees

Conventional CMOS Silicon Devices

Chairman's Notes from
plenary session in blue

- ◆ Advantages:
 - ◆ Proven, well-understood technology.
 - ◆ Tremendous industry momentum -- 40 years of Moore's Law and billions of dollars of R&D behind it.
 - ◆ ITRS projects another ten years (correlate to ITRS) of continuing exponential growth in aggregate performance and capacity.
 - ◆ Huge infrastructure of commercial systems and software.
 - ◆ Viable option for near term (0-10 years).
- ◆ Disadvantages:
 - ◆ Significant long-term concerns of power and cooling.
 - ◆ Significant concerns of "barrier" about 10 nm (not enough atoms for features to be distinguishable – correlate 10 nm to presenters number).
 - ◆ Subject to fundamental limits of irreversible computing devices.
 - ◆ While feature size gets smaller – clock speed doesn't necessarily get faster – WS
 - ◆ As traces in copper and/or aluminum there are propagation speed limits – JG

Nanotube Transistors and Memories

◆ Advantages:

Chairman's Notes from Plenary session in blue

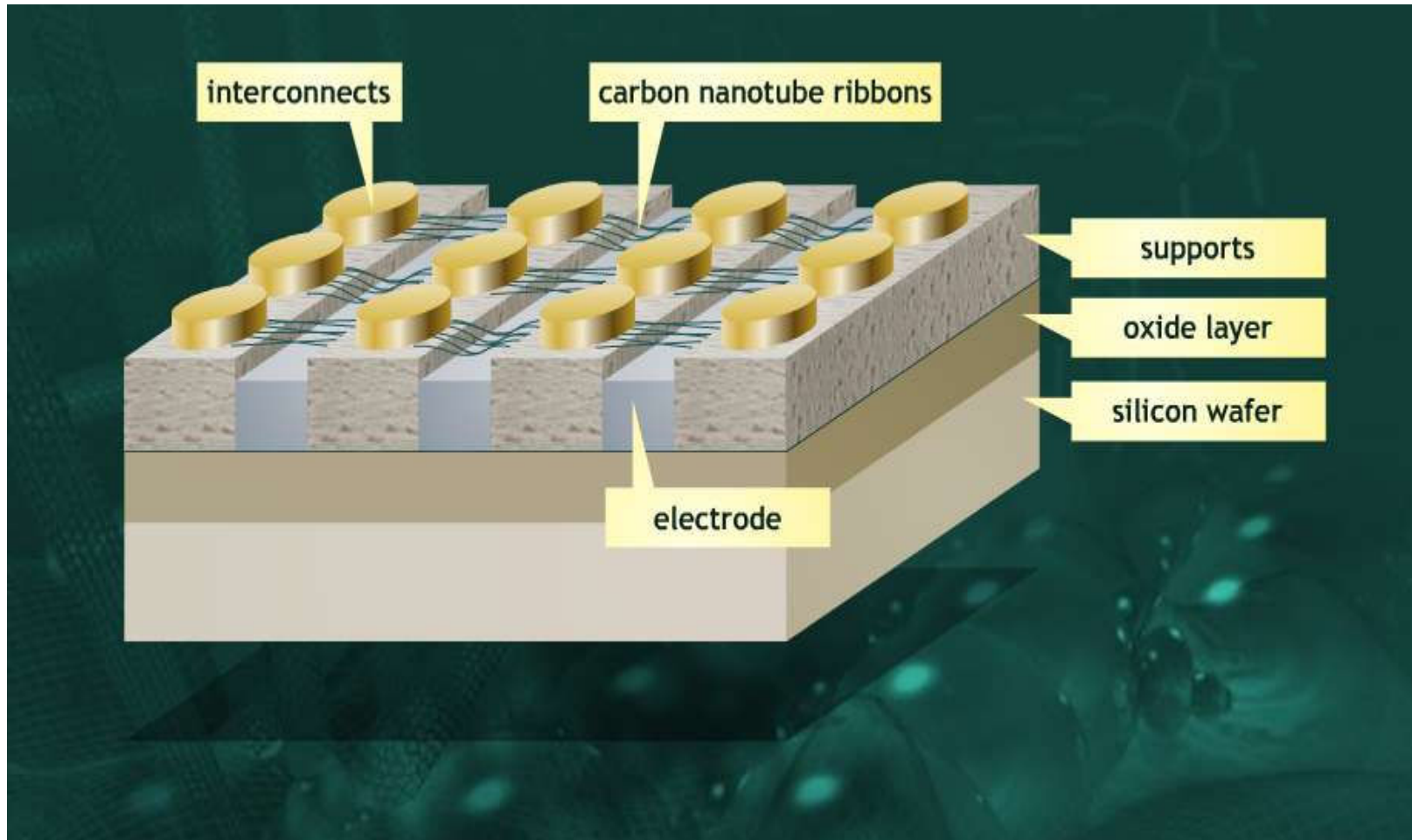
- ◆ Being pursued by IBM and venture-funded firms such as Nantero.
- ◆ Prototype devices have already been produced and tested.
- ◆ Integrates easily with conventional silicon substrates.
- ◆ Memory devices retain data when power is off.
- ◆ Possible ultra-high density memory devices could simplify and accelerate some scientific applications.
- ◆ Viable option for the mid term (5-15 years).

◆ Disadvantages:

- ◆ Will face stiff competition with conventional CMOS silicon devices for foreseeable future.
- ◆ Subject to fundamental limits of irreversible logic devices.
- ◆ Scant infrastructure of design tools, systems, software.

- ◆ ED: CNFET universally endorsed as “ultimate transistor” by ITRS and industry

Nantero NRAM™ Device



Nano-Imprint Crossbar Technology

◆ Advantages:

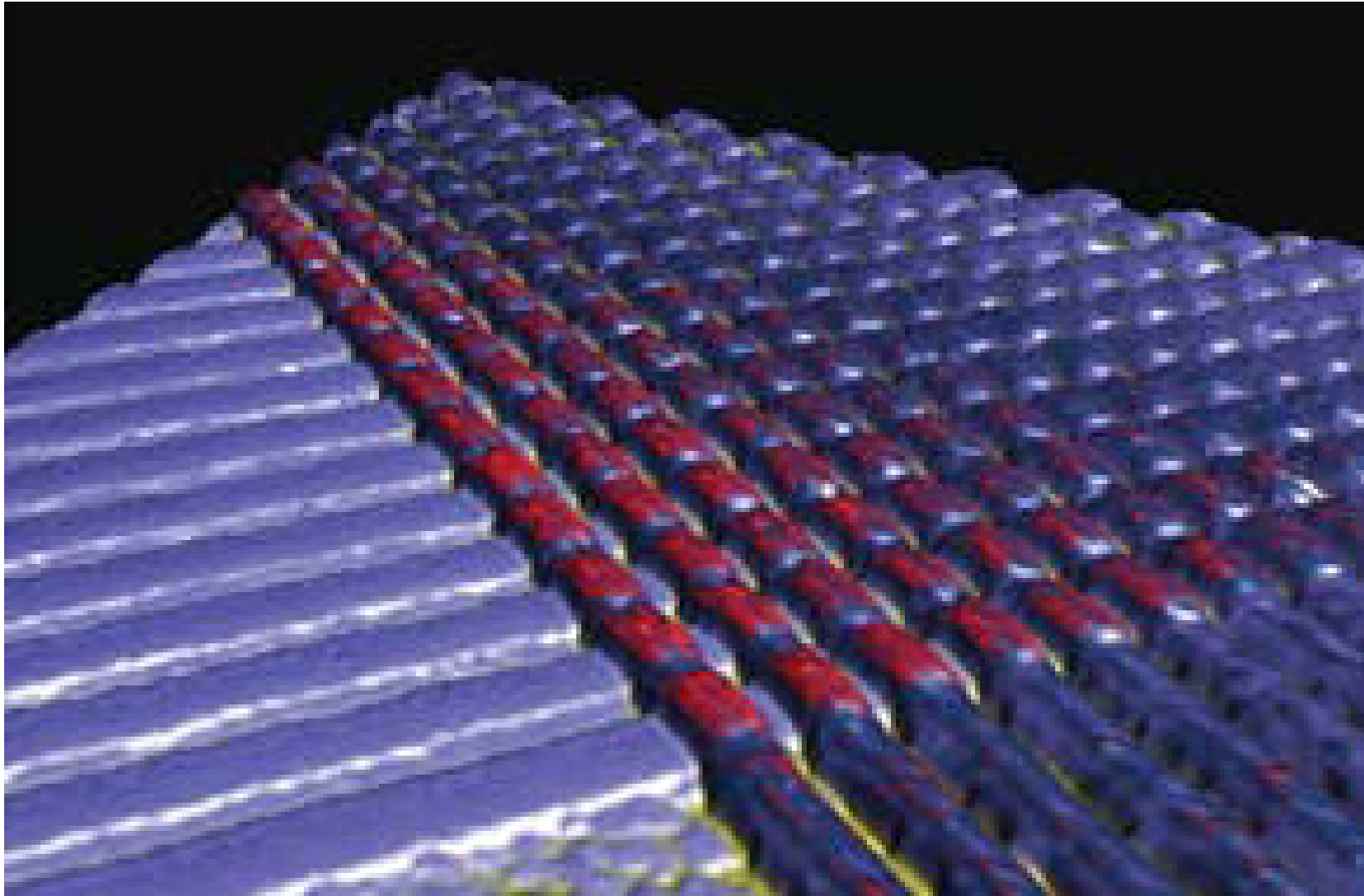
Chairman's Notes from Plenary session in blue

- ◆ Being developed by a well-funded effort at Hewlett-Packard.
- ◆ Very high density devices (17 nm features) already demonstrated; 8 nm and 4 nm features within 2 years.
- ◆ Integrates easily with conventional silicon devices.
- ◆ Can be used for both memory and logic.
- ◆ Possible ultra-high density memory devices could simplify and accelerate some scientific applications.
- ◆ Not based on current, so energy usage should be low. This statement is of questionable accuracy.
- ◆ Viable option in the mid-term (5-15 years).

◆ Disadvantages:

- ◆ Will face stiff competition from conventional CMOS silicon devices for the foreseeable future.
- ◆ Subject to fundamental limits of irreversible computing devices.
- ◆ Scant infrastructure of design tools, systems, software.

Atomic Force Microscope Image of Prototype HP Device



Superconducting Single-Flux Quantum Devices

Chairman's Notes from plenary session in blue

- ◆ Advantages:
 - ◆ Very high speed operation.
 - ◆ Very low power consumption.
 - ◆ Prototype devices have already been demonstrated with clock rates up to 20 GHz; much higher rates are possible ([near term with better fab 50 GHz 770 GHz static divider](#)).
 - ◆ Can be produced with standard silicon fabrication equipment.
 - ◆ Viable option for mid term (5-15 years).
- ◆ Disadvantages:
 - ◆ Requires cryogenic environment.
 - ◆ Will face stiff competition with more conventional devices for foreseeable future.
 - ◆ Subject to fundamental limits of irreversible logic (although reversible variants are possible).
 - ◆ Scant infrastructure of design tools, systems, software.
 - ◆ [BM: Lower density than CMOS](#)

Quantum Dots and Quantum Cellular Automata

- ◆ Advantages:
 - ◆ Based on true nanoscale quantum phenomena.
 - ◆ Very fast operation speeds are possible.
 - ◆ Very low power consumption.
 - ◆ Possibility of reversible computing designs.
 - ◆ Viable option for long-term (10-25 years). (Valid research direction that deserves continued support.)
 - ◆ Craig Lent proposed Zettaflops in 10 cm × 10 cm chip in his talk
- ◆ Disadvantages:
 - ◆ Only laboratory demonstrations – no solid large-scale devices yet.
 - ◆ Many questions on underlying physics – more study needed.
 - ◆ Devices may be subject to fundamental limits of irreversible logic.
 - ◆ Minimal infrastructure of design, systems or software.
- ◆ Question about what algorithms will work with this approach – MF

Quantum Computing

Chairman's Notes from Plenary session in blue

◆ Advantages:

- ◆ Exponential speedups possible on certain applications.
- ◆ Not subject to ordinary thermodynamic-based limits of irreversible logic.
- ◆ Viable option for long term (10-25 years). (The statement “Valid research direction that deserves continued support” was agreed to by all but one participant.)

◆ Disadvantages:

- ◆ Questions remain as to physical feasibility of large-scale applications.
 - ◆ May be limited to a small set of special applications.
- ◆ Significant amounts of research are required to better understand fundamental physics and algorithms for these systems