The Development, Present Status, and Conceivable Evolutions of Nanoelectronics in Nanotechnology.

Kirk Lau
(9713279)

Abstract: This report is focused on nanoelectronics as a particular type of nanotechnologies. The developments and the present status are based on the research, proposals and funding in the nanoelectronics industry. A substantial amount of journals have been published and are being reviewed on the techniques one might use in fabricating a nano-scale device, and its difficulties. It was found that nano-electronics still has several technical, as well as social complications. However, the basis of such techniques is expected to become solid in the coming decade.

Submitted in partial fulfillment of Eng. Phys. 4C03 (Prof. A.A. Harms), Department of Engineering Physics, McMaster University, Hamilton, Ontario, Canada

November 10, 2001

I. Introduction

The dependency on high-speed computers is increasing daily in the modern technological world. In 1965, Gordon Moore made a forecast that "the number of transistors per integrated circuit would double every 18 months" (Silicon). For example, the newest home-use Pentium 4 CPU [Central Processor Unit] consists of almost 100 million transistors (Silicon). In order to maintain reasonable sizes and speeds for the devices, the size of transistors, resistors, and other components on the IC [Integrated Circuits] must be inversely proportional to the number of transistors. In other words, the size must decrease while the number of components increases.

Transistors are made out of a combination of P-N junctions, to produce PNP or NPN transistors. Its speed is determined by how fast the carrier can go from one side to the other. Therefore, in order to increase the speed of processing, size is the essential factor. As the technological revolution continues, electronics is making its pathway down to nano-meter scales. The remaining portion of this report will be focused on the development, present status, and the evolution of Nanoelectronics.

II. Developments

In the early 1970s, a group of scientists in Bell Laboratories and IBM first realized the existence of Quantum Wells (Reed and Kirk, 3). From then on, a "new dimension with the ability to microfabricate matter on an unprecedented scale" (Reed and Kirk, 3) had opened up. This led to the development of small size electronics.

In 1989, 160 scientists gathered in College Station, Texas, for a meeting called *International Symposium on Nanostructure Physics and Fabrication*. This meeting turned out to be a trigger for a numbers of today's nanostructure topics, such as quantum point contacts, quantum dot, etc. (Reed and Kirk, 3-4)

Two years after the meeting, while the tools to fabricate nano systems became better controlled, another follow up meeting was set up in New Mexico in order to discuss the change in the nanotechnology field (Reed and Kirk, 4).

At this time, Scientists and Engineers recognized the possibility of nanofabrication, the knowledge and control one can gain from fabrication of micro-scale devices. Such techniques could lead to a new era in nanostructure engineering (Reed and Kirk, 4)

III. Present Status

In 1996, the European Commission launched a four year research project called "Microelectronics Advanced Research Initiative (MELARI)" directed to IC operating at a nanoscale. A budget of 16.7 Million dollars was assigned for the project. After this, a follow up research called "Nanotechnology Information Devices (NID)" started with a 20 million dollar budget fund. (Compano, 85)

Currently, NID research is focused on devices such as logic cells, memory and elementary processors. However, problems in terms of scalability, operating temperature, and the interface to the macroscopic world remain unsolved (Compano, 85). In addition, architecture is also a main issue in terms of operational efficiency. "These architectures are far more demanding than the traditional CMOS ones and fault-tolerant concepts, as well as self-testing approaches, may have to be included. (Compano, 85)"

Presently, about 55% of the research is performed at universities, 30% by research institutes, and the rest (15%) is done by industry (Compano, 85). Combining these numbers with the figure of funding, one can predict that enormous evolution will occur in the near future.

IV. The Conceivable Evolution

As the size of the integrated circuits becomes smaller and smaller, the evolution of microelectronics to nanoelectronics may become more demanding. Presently, semiconductor devices are down to sub-micron (<0.2μm) scales (Fig 1), if Gordon E. Moore is correct in "Moore's Law", sizes of semiconductor devices will decrease to about 30nm within a decade as illustrated in figure 2.

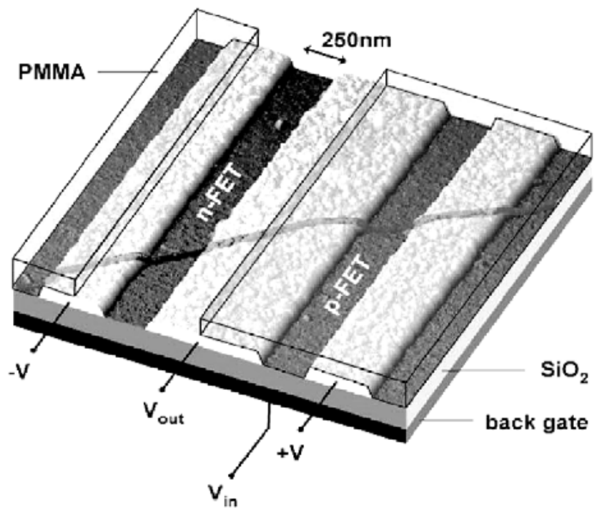

Figure 1: The world's first single-molecule computer circuit, a Not-gate (IBM)

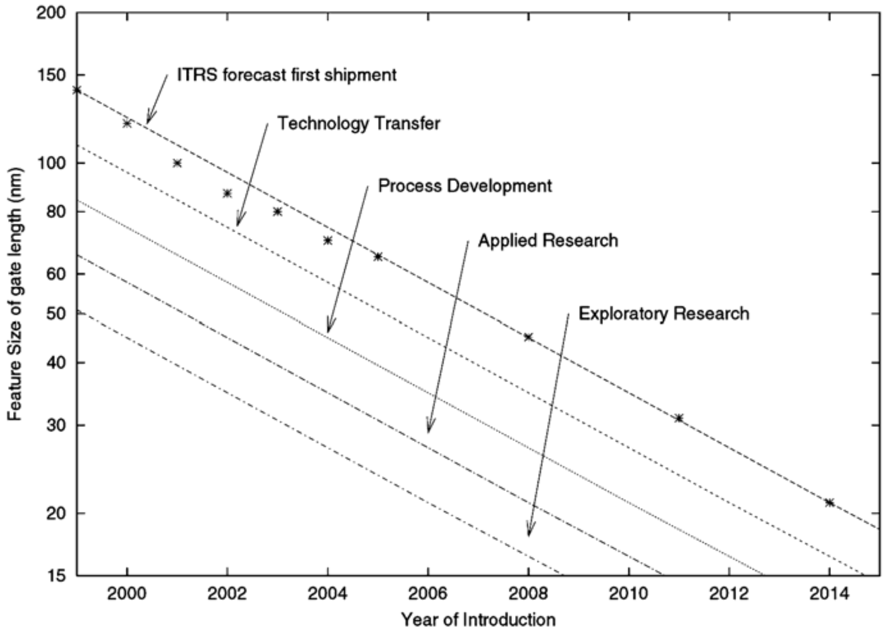

Figure 2: Minimum size vs. year of introduction. (Compano, 86)

Many alternative devices to CMOS are under development, with their own advantages and disadvantages. The basic 5 alternative device concepts that are undergoing the evolution are Single-Electrons Tunnelling (SET), Magnetic Memories (MRAM), Resonant Tunnelling diodes (RTDs), Rapid Single-Flux-Quantum logic (RSFQ), and Molecular Electronics (ME) (Compano, 86). In Table 1 is the comparison of the five.

Device Concepts	Advantage	Disadvantage
SET	High Density, Low power	RC Constant high, Low Speed
MRAM	Long retention time without power, Large Memory Density	Currently operate at low speed
RTDs	High Speed (GHz Range), ultra low power	Low tolerances in film technology, difficult to fabricate
RSFQ	High Speed, superconductive	Close to micrometer scale, high temperature
ME	Possibilities of chemical Synthesis and Self assembly	Still in research state, huge obstacles in developments

Table 1: Comparison between the five alternative concepts of CMOS (Compano, 86-87)

From the above table, one can see how these alternative devices for CMOS have distinct characteristics. Each can have their own conceivable evolution in terms of replacing CMOS.

Earlier this year, a paper published by Aassime, Delsing and Claeson announced that they had fabricated an aluminium SET transistor to operate at a maximum of 8MHz based on the quantum tunnelling effect (Aassime, Delsing and Claeson, 96). As is apparent, such a frequency is much slower than the current solid-state semiconductor can handle. Therefore, experiments must be performed in the future in order to achieve both size and speed advancement. On the other hand, one can expect such a device to be available in the very near future for slower applications.

For MRAMs, a device prototype had already been produced, but the speed is still slow compared to DRAM that is currently widely used. It is expected that "Spin devices in form of tunnel junction MRAMs may penetrate the market in the near future" (Compano, 87). In addition, considering the size and memory density MRAM can provide (~2nm each), one can expect MRAM to completely takeover the current DRAM, or SDRAM once the desired speed is achieved. This should be done within a decade with the rate it is evolving.

RTDs on the other hand, have already achieved very high speed (10-100GHz). This concept has been studied widely, and a large amount of experimentation has been conducted. For example, in late 2000, a paper was published by a group of scientists announcing a population inversion observed with Resonant Tunnelling (Mityagin, Murzin, Kazakov, Chuenkov, Karuzskii, Perestoronin, Pishchulin and Shchurova). With the observation of population inversion, one can predict that a RTDs Laser will become possible in the foreseeable future. The characteristic advantage of having high speed and low power consumption will provide significant benefits for optical communication in providing high bandwidth and frequent high-speed regeneration.

The disadvantage of RSFQ is that it requires low temperature cooling; this is mainly due to the system being based on super-conducting material (Compano, 87). A study concluded that in order to reduce the thermal noise of RSFQ an operational temperature of 20K° is required (Ortlepp, Toepfer and Uhlmann). However, its extreme high speed (again in 10-100 GHz range) will be ideal for replacing traditional CMOS logics. With such high speed one can foresee that, with proper cooling, RSFQ could takeover the current TTL and CMOS logics in PCs and microprocessors in order to provide high-speed computations, detect and conversion, and perform logical calculation, in addition to forming a perfect combination with RTDs

The ideas of Molecular Electronics are geared more towards the biological discipline. As suggested by Compano, "there are huge obstacles that must be overcome" (Compano, 87). Considering it has the possibilities of chemical synthesis and self-assembly (Compano, 87), the "obstacles" are not only on the technical side and on how to fabricate such a device, but on the social and ethical point of view as well. Since it has the ability of synthesis and self-assembly, it can reproduce itself without the control of humans. In other words, a living being could be created. Questions like "how will it evolve itself?" and "how will it reproduce in order to maintain its life cycle?" will arise in the very near future. The answer must be proven by experiment, probabilistic analysis, and simulation.

As one can see, there are still enormous amounts of research, testing and experimentation to be done before Nanoelectronics can become reality. However, such evolution is proceeding very rapidly. Integrated circuits that are densely packed with Nanoelectronics should become available within a decade.

V. Conclusions:

As the demand for size reduction in electronic devices increased in the past two decades, the evolution of transforming microelectronics to nanoelectronics began. Currently, the evolution has gone half way. Sub-micron scale devices have fully developed in industries.

Concepts have been very well developed. However, technical difficulties such as low operating speed, high operating temperature, stability, mechanical vibration tolerances, and technique in fabrication have to be resolved in order to make nanoelectronics became a reality.

As the problems are continuously resolved, electronic devices in nano-meter scales are expected to become available within the next decade. By that time, both cost and size are expected to decrease while speed and densities rise at the other end of the spectrum.

VI. Work Cited

Aassime A, Delsing P, Claeson T. A sensitive and fast radio frequency single-electron transistor. Nanotechnology. pp 96-99. Vol. 12, 2001

Compano, Ramon. Trends in nanoelectronics. Nanotechnology. pp. 85-88. Vol. 12, 2001

IBM Scientists Build World's First Single-Molecule Computer Circuit. http://www.research.ibm.com/resources/press/logiccircuit/ . (Nov. 13, 2001)

Mityagin Yu A, Murzin V N, Kazakov I P, Chuenkov V A, Karuzskii A L, Perestoronin A V, Pishchulin A A and Shchurova L Yu. Intersubband population inversion under resonance tunnelling in wide quantum well structures. http://www.iop.org . (Nov. 13, 2001)

Reed M. A. and Kirk W. P. Nanostructures and Mesoscopic systems. Academic Press, INC. San Diego, CA. 1991

Silicon Showcase. Moore's Law. http://www.intel.com/research/silicon/mooreslaw.htm . (Nov. 13, 01)