THE LITTLE TRANSISTOR AND THE CCAS REVOLUTION

Alexander Stefanov Athanassov

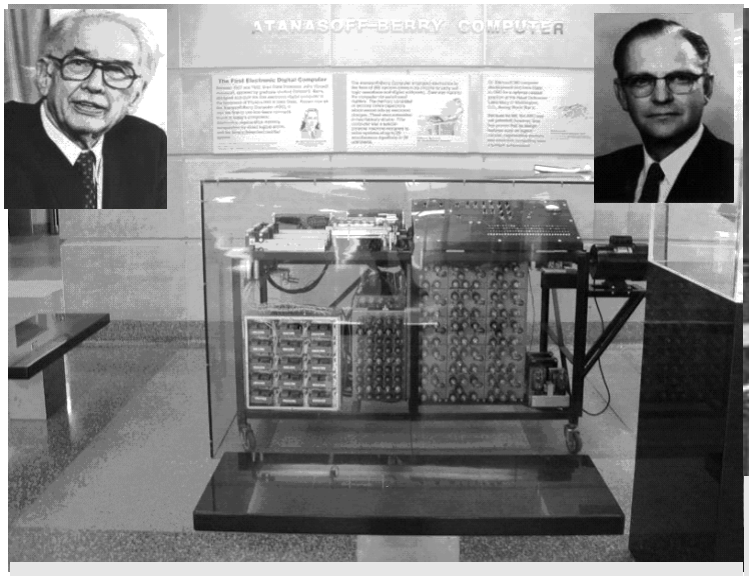
<alathanassov@abv.bg>

A scientific trip trough the years - from the birth of the first transistor to the contemporary Computers, Communications and Automation Systems (CCAS). How did the first transistor start the worldwide technology revolution – the microprocessor power, RAM, Global Net and changed the world as a whole.

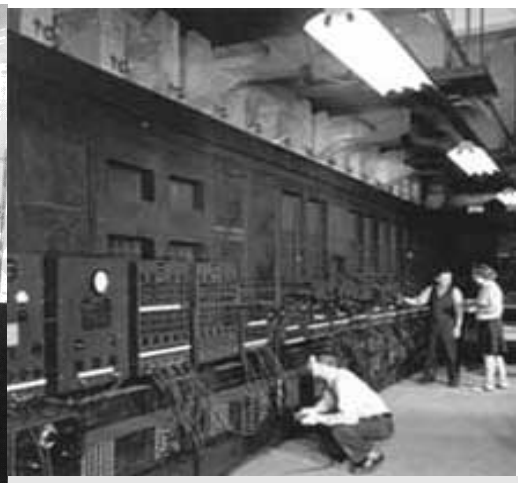
Keywords: transistor, silicon technology, computer, communication.

IN THE BEGINNING

Nearly a century ago, in 1904, the vacuum electron tube was patented. The wireless communications, first computers and military systems were developed due to vacuum tube electronics during the first half of 20 century.



The Atanasoff–Berry Computer (ABC) was the first electronic digital computing device , 1937



ENIAC - the first world working computer contained 18 000 electron tubes with consumption of 70 kW and weight 300 tons.

Before World War II the *Atanasoff–Berry Computer (ABC)* was the first electronic digital computing device. Conceived in 1937, the machine was capable of solving up to 29 simultaneous linear equations and was successfully tested. The *ABC* pioneered important elements of modern computing, including binary arithmetic and electronic switching elements.

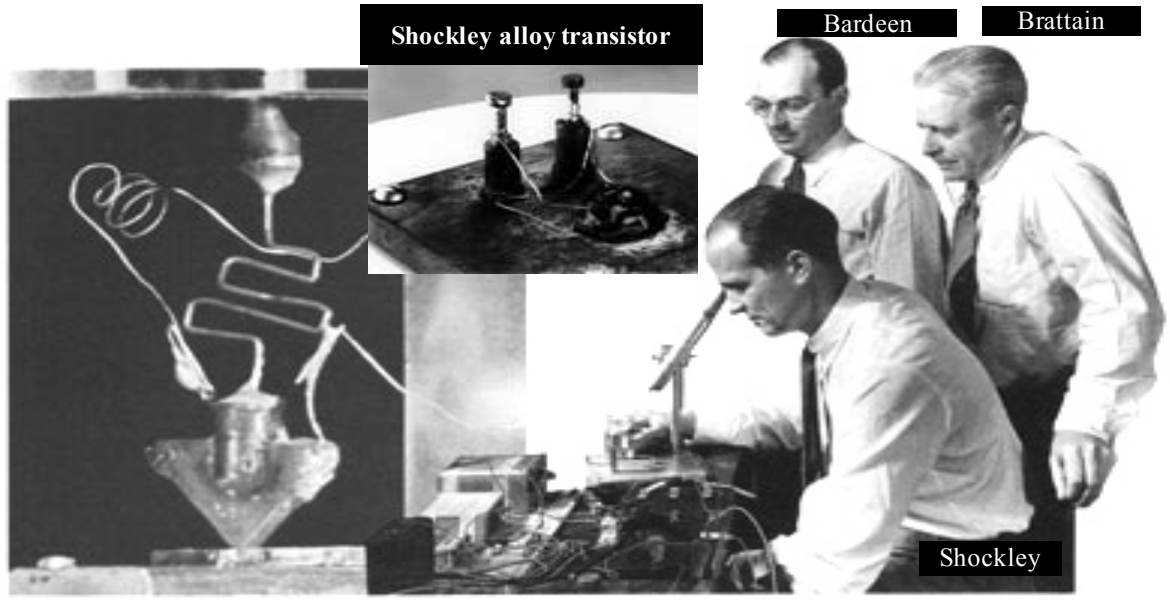
The machine was the first to implement four ideas that are still part of every modern computer:

1. Using binary digits to represent all numbers and data;

2. Performing all calculations using elctronic tubes rather than wheels, ratchets, or mechanical switches;
3. Organizing a system in which computation and memory are separated;
4. The system pioneered the use of regenerative capacitor memory, as in the DRAM still widely used today.

HAPPY BIRTHDAY TRANSISTOR!

At the end 1947, two American physicists *Walter Bratain* and *John Bardeen* displayed a new device – a much smaller than electron tube, with less consumption power and high amplifying. The first prototype of the point contact transistor has nothing in common with the modern transistors except for the idea that changed the world.



Bardeen, Brattain and Shockley and the first experimental point contact transistor .
Base is P type GE, wedge with 2 golden points are Emitter and Collector
Alloy Ge transistor (upper photo) and construction for mass production are Shockley's achievement

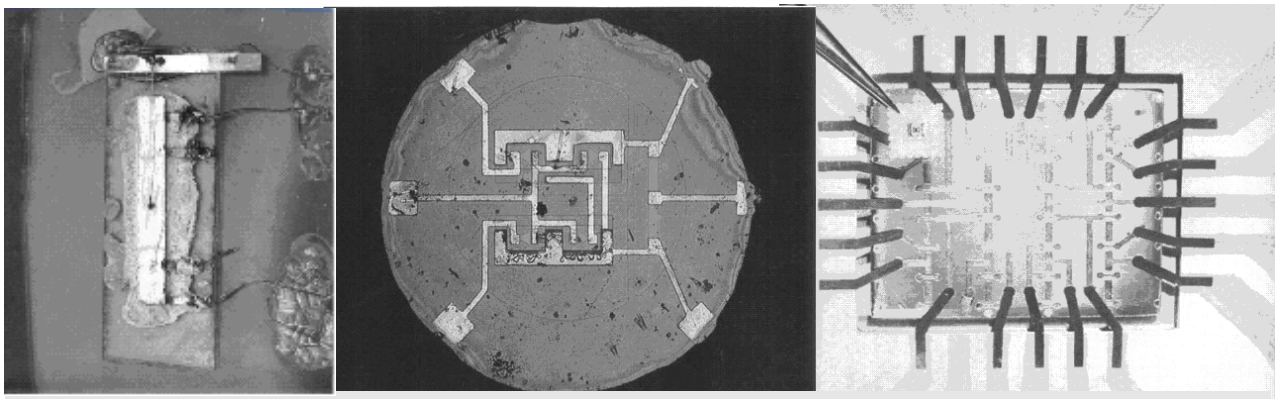
Not long after that William *Shockley* offered the a*lloy germanium transistor*, mass produced after year 1950. The first price was 6.5$, soon 2.5 $, but the price of electronic tube at the same time was as low as 1$. During year 1953 1 million transistors were produced, in 1955 - 3,5 million, and in 1957 – over 30 million.

FET birth. The German physicists *Julius Lilienfeld* in 1930 and *Heil* in 1934 patented the field effect. In 1959 American physics *Shockley* and *Pearson* extended the theory on field effect in semiconductors. In 1960 *John Atalla* showed the first working FET transistor. The next MOS FET technology is the result of the efforts of numerous researchers of USA, Europe and Japan.

During 1959-61 *Faichild* and *Texas Instruments* developed silicon planar technology, which offered cheaper mass production of quality transistors. This planar silicon technology fueled the coming electron revolution.

THE ERA OF SOLID STATE CIRCUITS

On the summer 1958 *Jack Kilby*, an young engineer of *Texas Instr* demonstrated simple electron circuits on common mini substrate, patented next year like *"Solid Circuit"*. But 7 years before that, in 1952, British researcher *Geoffrey Dummer* announced similar idea in Washington conference. It seemed like ABC John Atanassoff's – Berry computer patent and ENIAC history was repeating.



Micropictures of the first IC

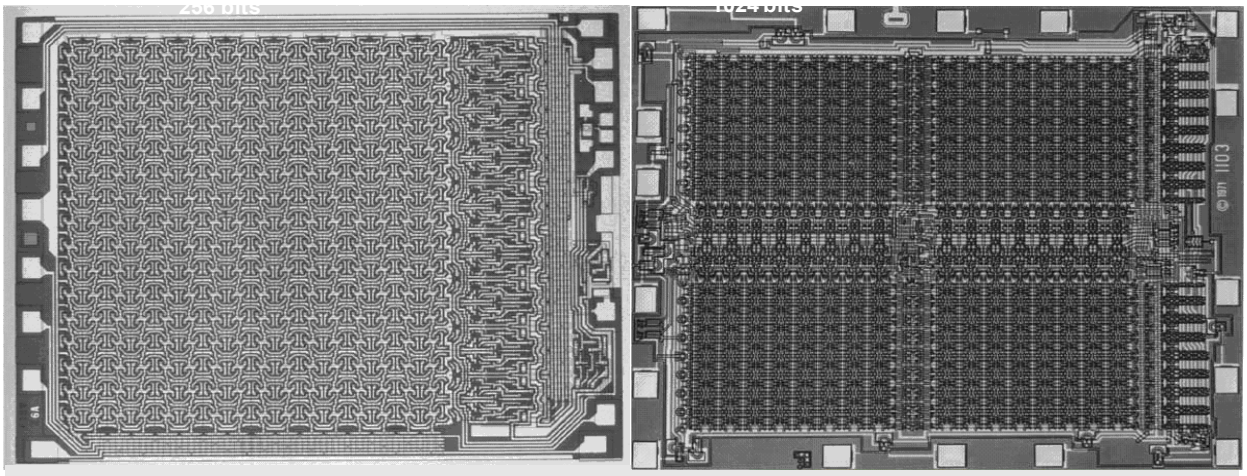
1958 - The beginning *Jack Kilby's* "Solid Cicuit"

1961 – *R. Noyce* the first bipolar silicon IC

1962 – the first PMOS IC

In 1961 *Robert Noice* from *Fairchild* patented the first planar silicon IC.

In the beginning of the sixties new MOS semiconductor devices came into competition with bipolar IC. New MOS integrated technology fueled the progress of digital integrated systems. In 1962 the first PMOS IC started.



Fairchild is the first company produced bipolar 256 bits SRAM in 1970.
Intel produced the first 1024 bits SRAM

The research intensity over the new planar bipolar and MOS technology fascinated the whole world!

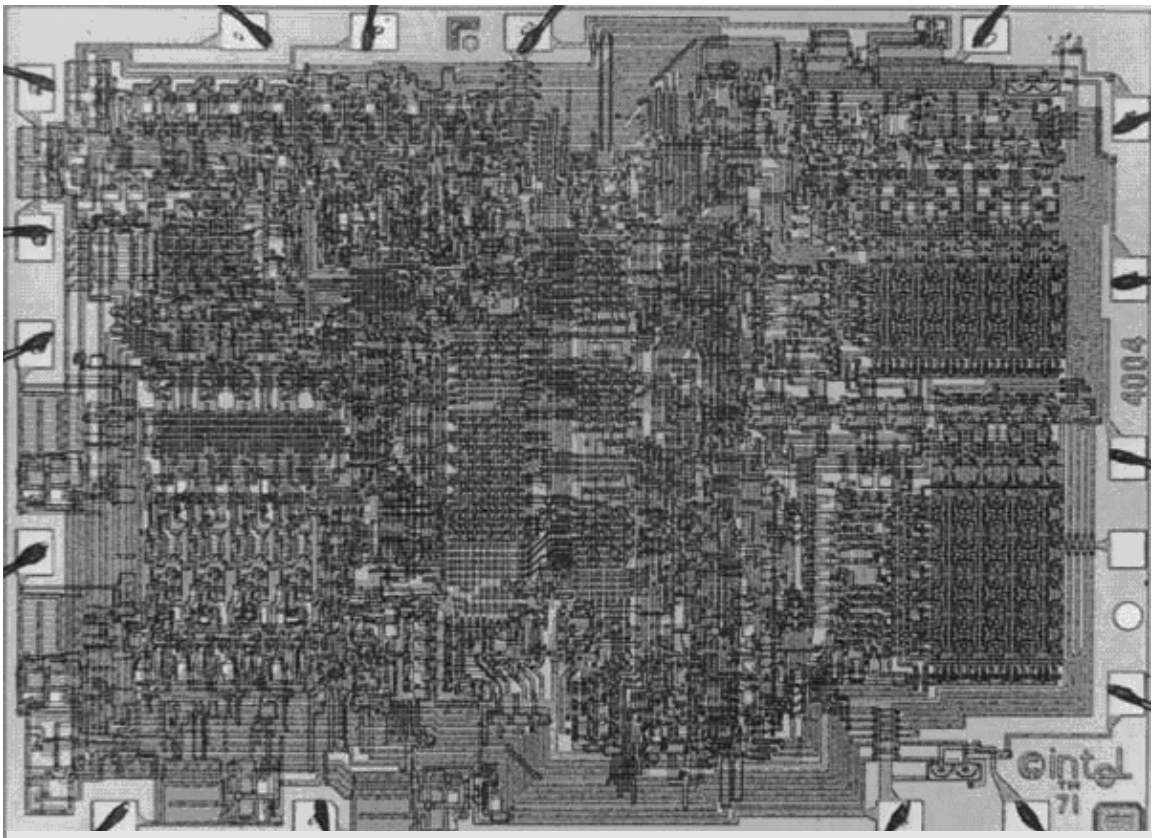
In 1964-65 *Fairchild* produced the first operation amplifiers μA702 and μA709. By bipolar RTL, DTL, TTL and ECL new generation of computers with IC came to the market. In 1970 *Fairchild* was the first company producing bipolar RAM, with enormous capacity for that time – 256 bits!

In 1968 a new player came to market. *Andy Grove, Bob Noyce and Gordon Moore* left Fairchild and established *Intel* (***Inte***grated ***el***ectronic). The first Intel's device was a 1024 bits *RAM,* which was the biggest at that moment.

In 1965 Intel's co-founder *Gordon Moore* saw the future. His prediction, now popularly known as Moore's Law, states: "The number of transistors on a chip doubles every two years" .

This rule, known as Moore's law holds more than 40 years

THE NEW MICROPROCESSOR AND CMOS PERIOD



In November 1971 Intel publicly introduced the world's first single chip microprocessor 4004, invented by engineers F . Faggin, T.Hoff and Stan Mazor . The Intel 4004 contained 2 250 MOST on chip area 12mm^2 and consumption - less 1W. Power efficiency of 60 000 ops/s is much more higher of ENIAC's

In 1971 *Intel* presented a new electronic system. The first 4 bit microprocessor invention changed the basics of the principles of IC electronic digital systems. The 4004 chip area was only 12 mm^2 and contained 2250 PMOS transistors. The clock frequency 108 kHz and power consumption of less than 1W were remarkable for this

years. The giant ENIAC with 18 000 electron tubes, weight 300 tons and power consumption 80kW had less power efficiency than this new-born pigmy.

In 1972 the first 8 bit microprocessor 8008, ant two years later – the first general purpose 8 bit microprocessor 8080 were produced by Intel.

In the beginning of the seventies the first CMOS IC are produced and in 1975-76 – the first CMOS microprocessor CDP 1801 by RCA is presented. Next year this family microprocessors COSMAC flew in many satellites like OSCAR, Voyager, Viking, Galileo. The COSMAC's that flew in space were space/radiation hardened versions using a CMOS/SOS chip.

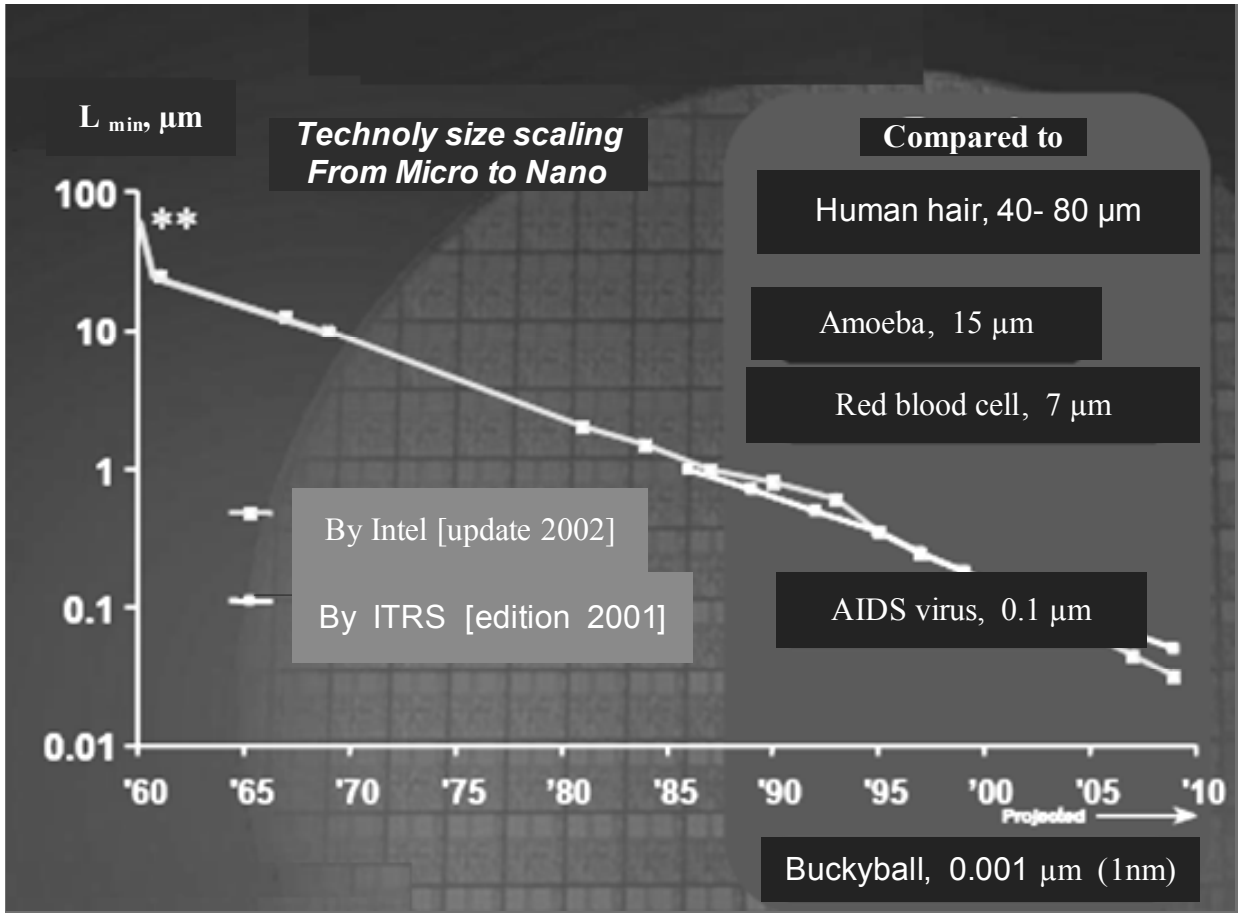
Now, more than 30 years CMOS technology is leading technology for all computer, communication and automation systems.

In 1972 a technology fight burned between leading world companies in the field of scaling. *Bob Dennard* of *IBM* discovered MOSFET scaling "If the electric field maintain constant while shrinking a MOSFET, all others parameters improve while producing a smaller device". *Actual physical gate lengths* of transistors have delivered to roughly ½ the size of the "lithography rule linewidth". Now this physical gate length is popular like *silicon technology size STS* [μm or nm].

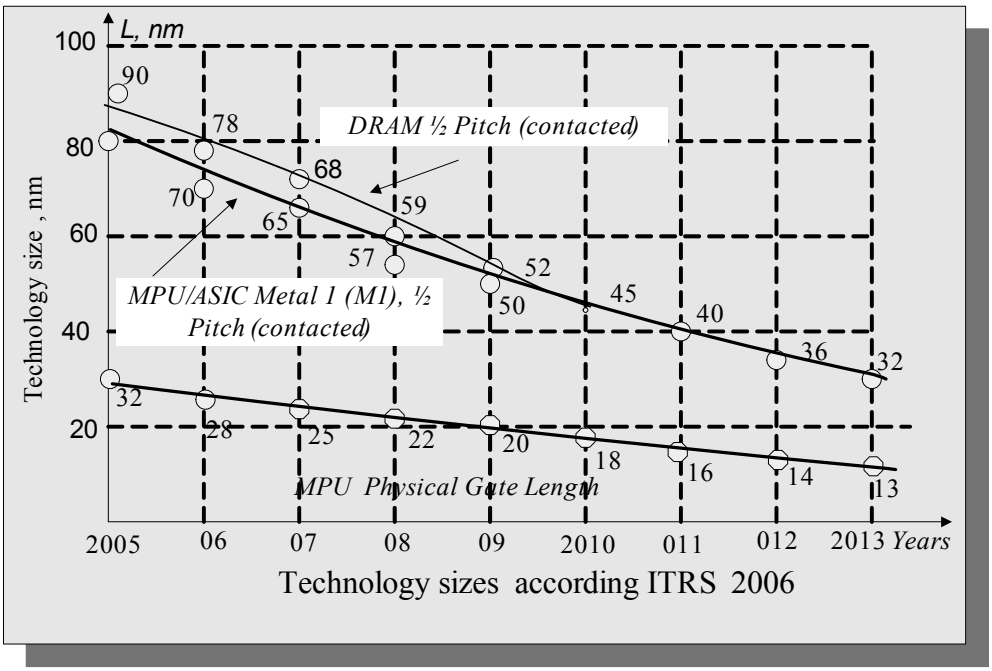
In 1972 *STS* was 10 μm, in 2007 *STS* is 65 nm.

During 80-ties the barrier of 1μm technology size was crossed.

The first decade of the 21century is a period of nanotechnology – down 0,1μm.

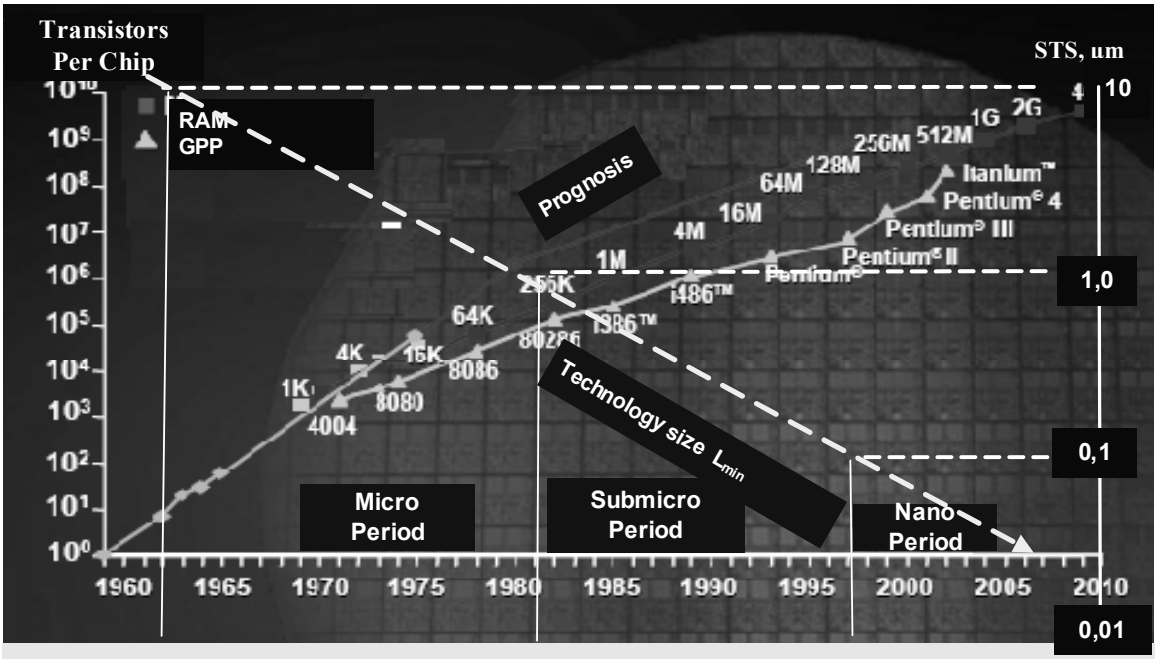


The statistic show – up to 2000, 30% reducing of happened every 3 years, and after that time – every two years. Technology size reduction 100x for 30 years from 10 μm to 0,1μm is equal to 10 000 more transistors on the same chip area.



Years 2003-04 were the time of 90nm IC technology production, but at that time leading world companies had energetic work on 45nm nanotechnology.

The number of integrated transistors on chip now is more 300 million. The expectations are that in 2016 by 11nm technology, 130 billion transistors will be integrated on chip. For the year 2018 - twice more.



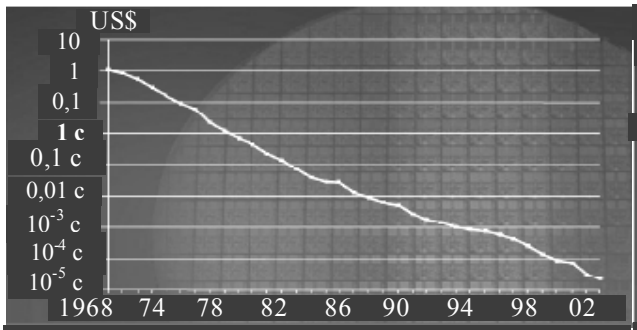
Throughout 30 Years Technology Sizes Reduced 100x, but the Integrated Transistors Increased More 60 000 x

Obviously Gordon Moore has been right in his prediction.

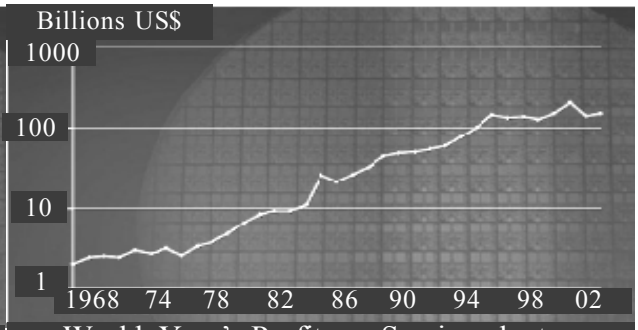
Each technology size reduction needs big investments. The statistics show that the technology equipment increase ten times every 10 years.

In spite of big investment the world leading companies make big profits from IC production - mainly from memories and microprocessors of any type.

The increasing of microprocessor power efficiency and memory capacity on other side, is accompanied by exponential decreasing of the price of each integrated transistor.



On Chip Integrated Transistors Year's Prices



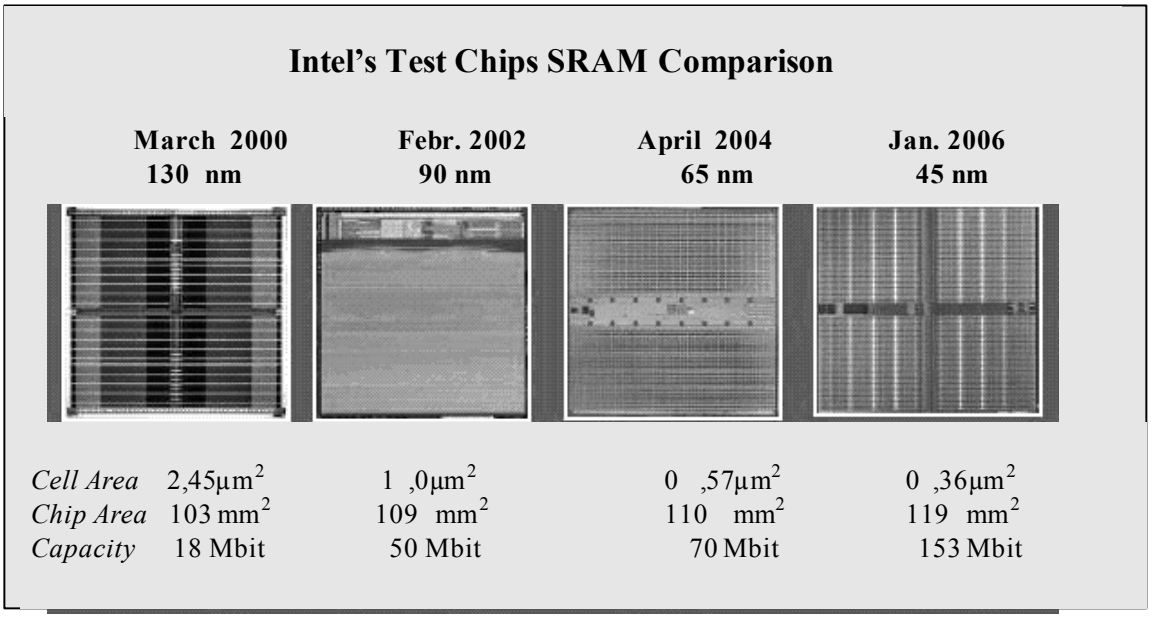
World Year's Profits on Semiconductor Devices – IC and Discreet

THE ADVANCE OF BIG DIGITAL SYSTEMS

Let's compare the power efficiency of microprocessors:

- Intel '386 had 10MIPS (as much as a contemporary microcontroller PIC with price less than 1 euro).
- The power of the first Pentium was 100 MIPS.

Intel's Test Chips SRAM Comparison



- In 2005 the efficiency surpassed 20 000 MIPS.

The number of transistors on chips exceeds 300 millions, the clock is over 3GHz, and the PC's consumption of electric power - over 50W. During the last 30 years microprocessors consist a power core with effective arithmetic blocks, a great

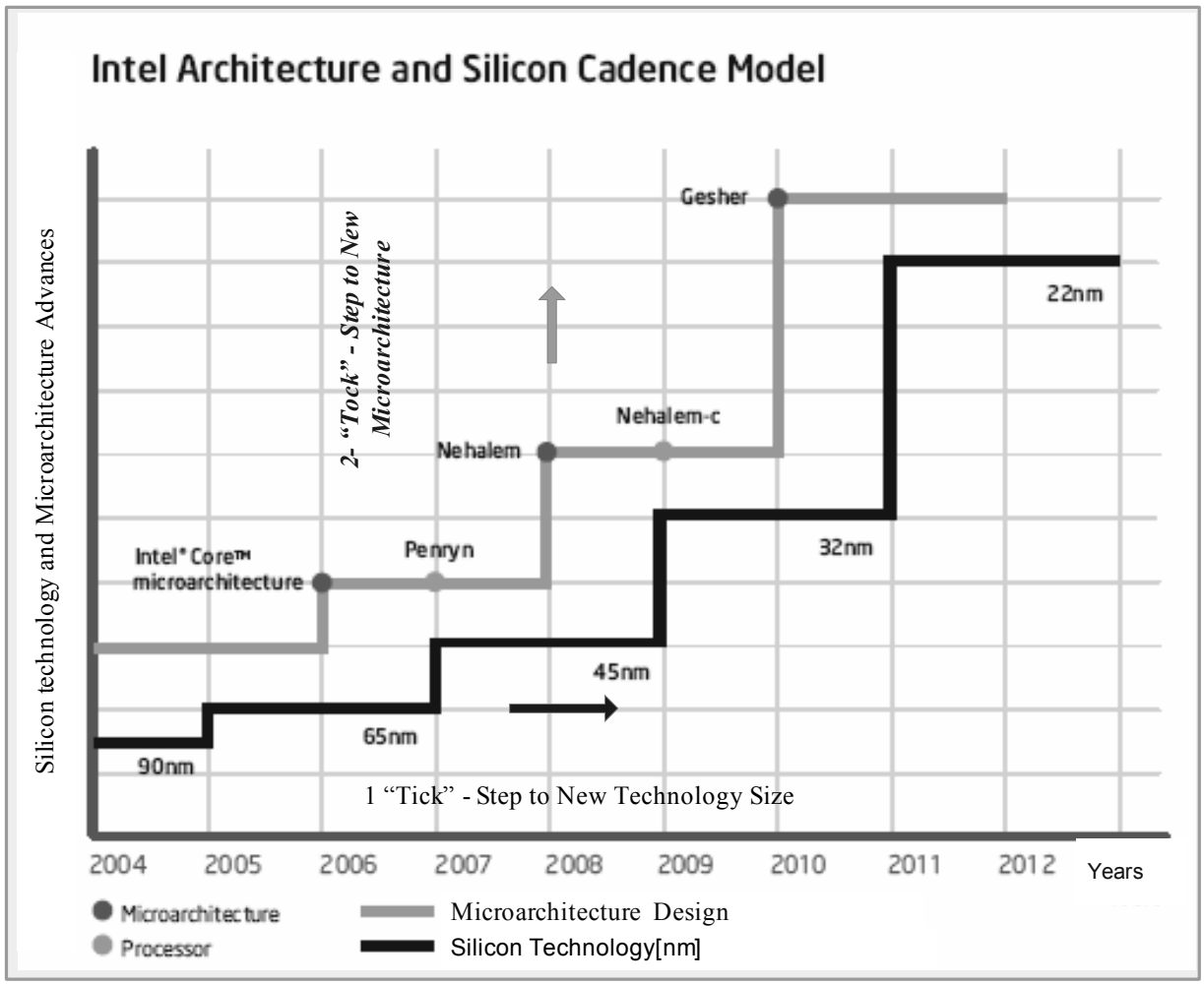
diversity of cash memories and are subject to non-stop clock increasing. As a result the microprocessors computing power has reached 100 GFlops.

AND NOW WHAT?

It's time the microprocessor researchers to apply the idea for parallel computing on one chip.

In the period 2005-07 *Intel,* followed soon by *AMD, IBM* and other companies produced two and four core microprocessors with 65 nm silicon technology. The Intel family *DUO2 Core* contain about 150 million transistors, and the 4 core *QUAD* – over 300 million. The next 45 nm Duo and Quad will be with 410 и 820 million transistors, Cash L2 – 6MB and 12 MB, and electric power 65W/130W for PC and 35W/80W for laptops.

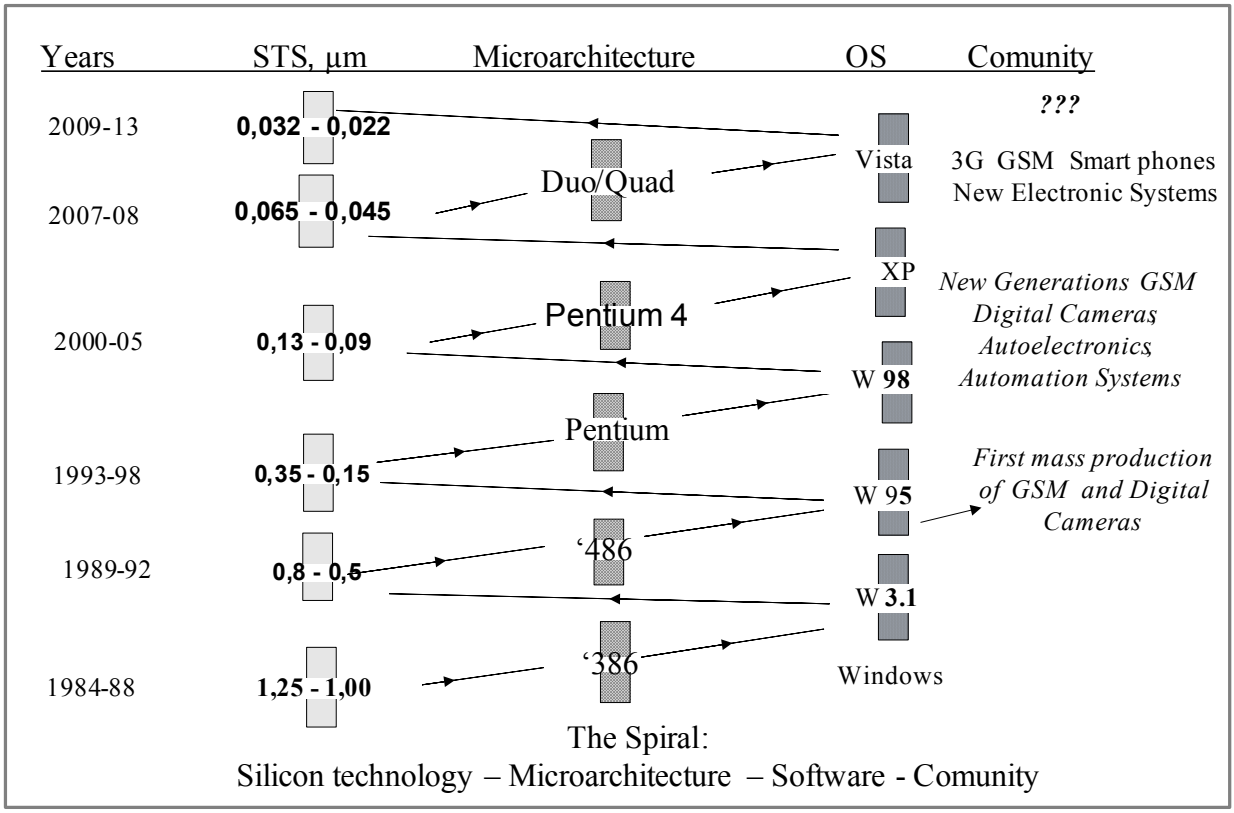
A microprocessor with terra speed is necessary for high speed real time computing, artificial intelligence systems, image recognition, direct real time speech translation, fast multimedia and so on.



Intel® multi-core architecture strategy – each reducing of the technology size will lead to an improving of processor microarchitecture. New microarchitecture is introduced only after silicon technology is approved. To adopt new silicon size and

microarchitecture at the same time is risky. The first two core microprocessors are produced in two different sizes (90 and 65 nm) in the course of two years.

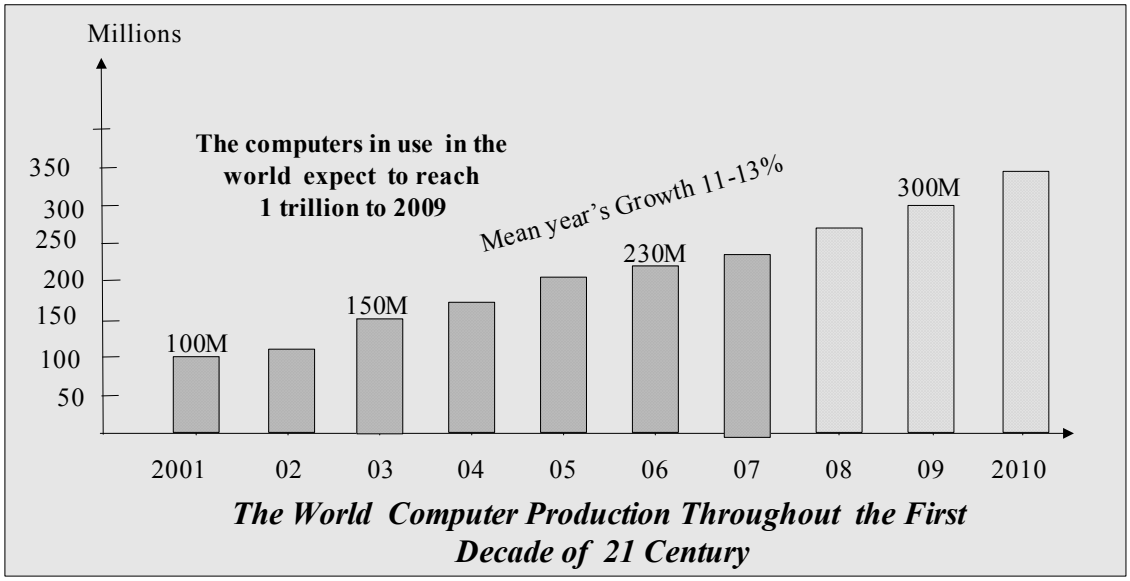
Intel displays experimental multicore chip with 80 cores. The chip size is 17x16mm, clock- 3.16GHz and total power consumption P_{tot} = 62 W, which is less



than the power of "normal" PC. This chip has the remarkable power efficiency E_{ff}= 1.01 TeraFlops.

Comparing the relative efficiency to the power consumption E_{ff}/P_{tot} we get the remarkable ratio: $E_{ff}/P_{tot} = 1{,}01.10^{12}/62 = 16{,}3$ Gflops/Watt!

The birth of the first transistor was followed by many generation IC and computer



architectures, in order to reach such high levels, that nobody imagined 60 years ago.

The last pictures show the headway of computers, communications and all new electronic systems. Many of us remember the first personal computers XT, AT, '286 with floppy disc DOS, and the old ½ kilo weighting mobiphones!

Now 30 years after they look antediluvian dinosaurs.

But the basis made by these dinosaurs lead to today's and future's successes.

CONCLUSION

60 years have passed after the first, little, primitive transistor has fueled the worldwide CCAS semiconductor technology revolution and changed irrecognizably all the information technologies.

This simple device changed the life of billion of people all over the world.

Who can imagine now the world without GSM, Global net and computers?

What could be expected after 40 years –

- 100 years from the transistor birth?

REFERENCES

[1] European Commission, IST Programme Future and Engineering Technology, Roadmap for Nanoelectronic.

[2] John R. Caruthers. Computing with Nanoelectronoic Devices, Portland State University

[3] State fo the Art, National Museum of American History

[4] A Photogfraphic History of the Integrated Circuits, by Stan Augarten

[5] The Bell Systems Memorial on Transistors

[6] www.Intel.com

[7] www. antiqutech.com/chips

[8] www. wikipedia.org

[9] U.S. Patent 1,745,175 - Julius E. Lilienfeld, 1930

[10] U.S. Patent 2,524,035 - J. Bardeen and other

[11] U.S. Patent 2,561,347 - W. Shockley