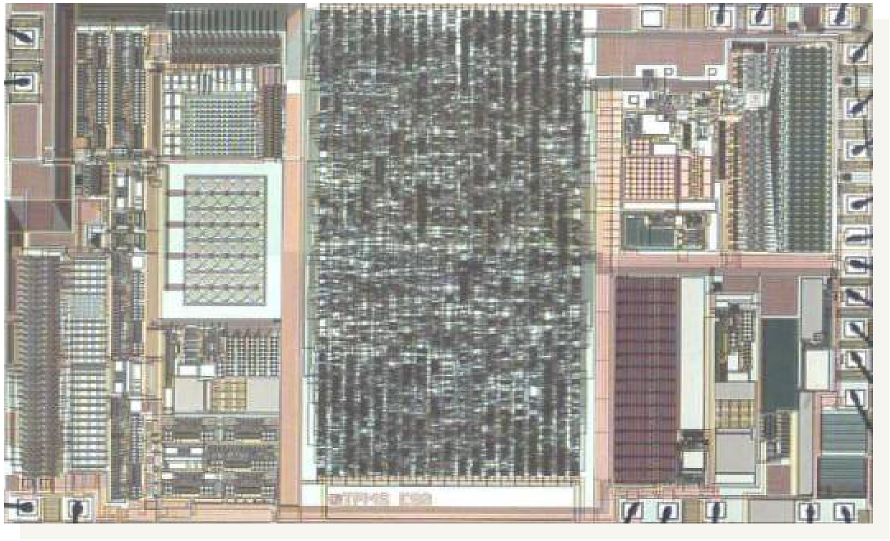
Microelectronics

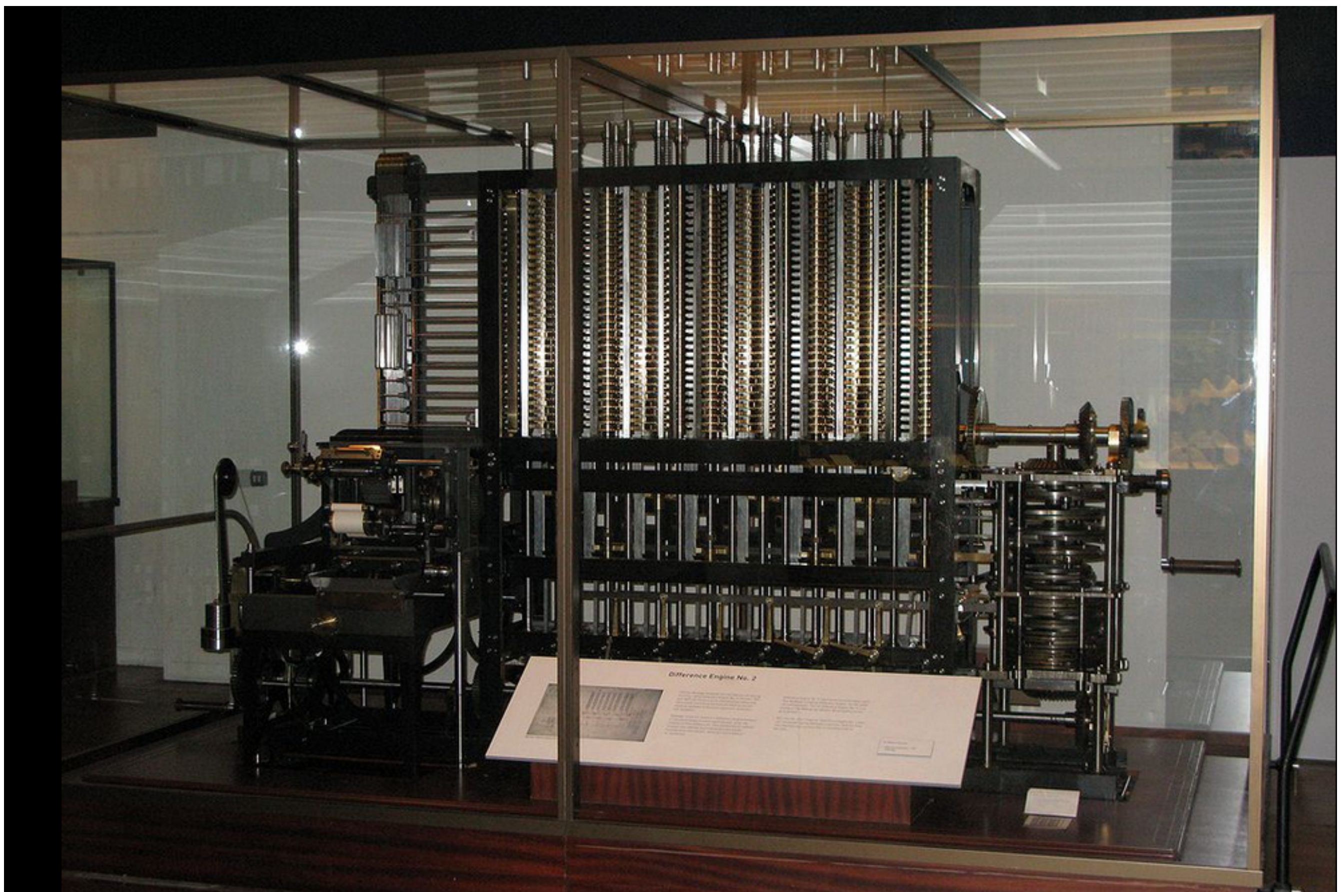
Prof. Dr. Michael Kraft



Lecture 1:
Introduction, History and Market

History of Computing

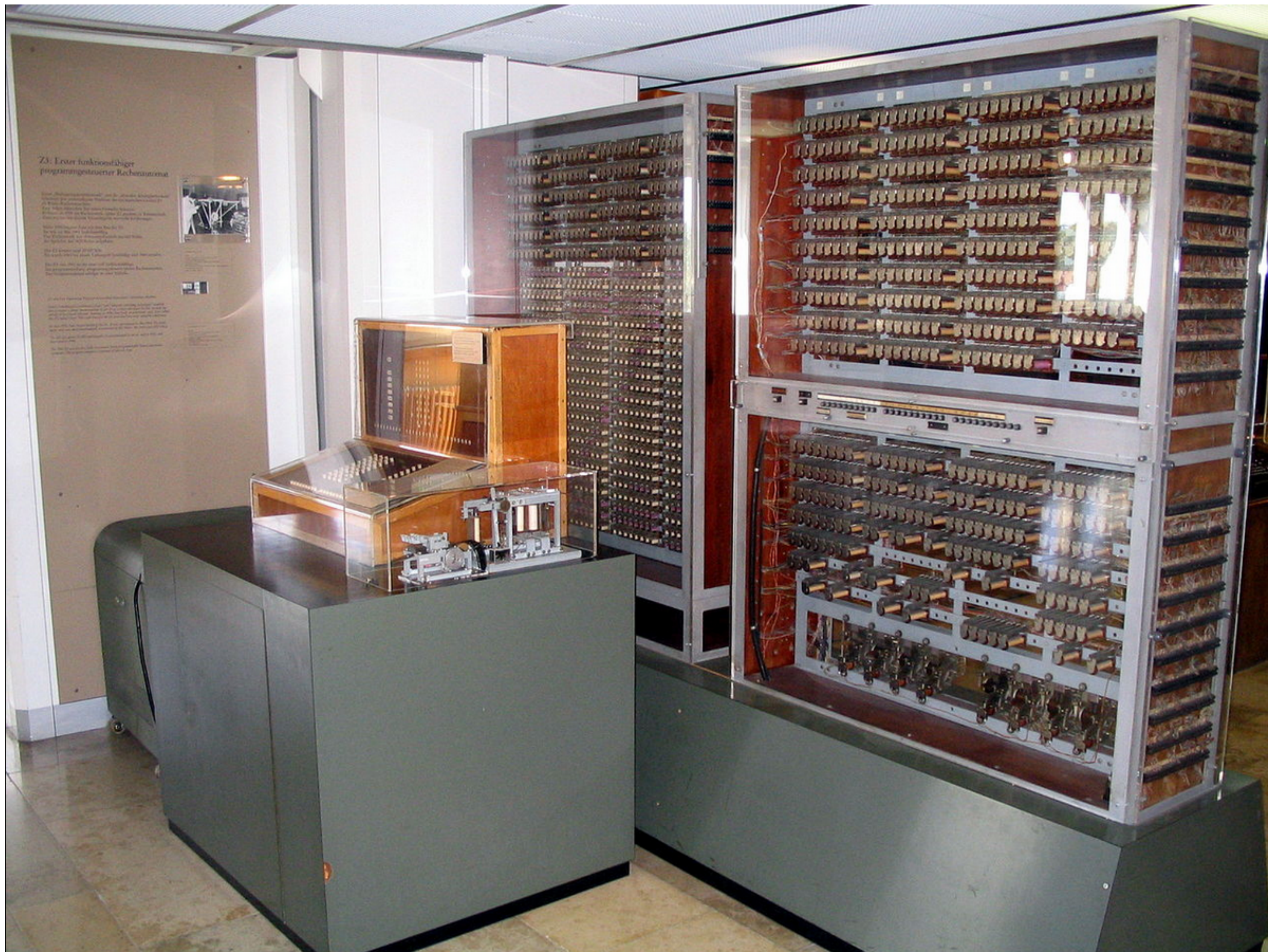
- Babbage Difference Machine (1832)
  - Mechanical computer
  - 25000 parts, cost £17470



London Science Museum

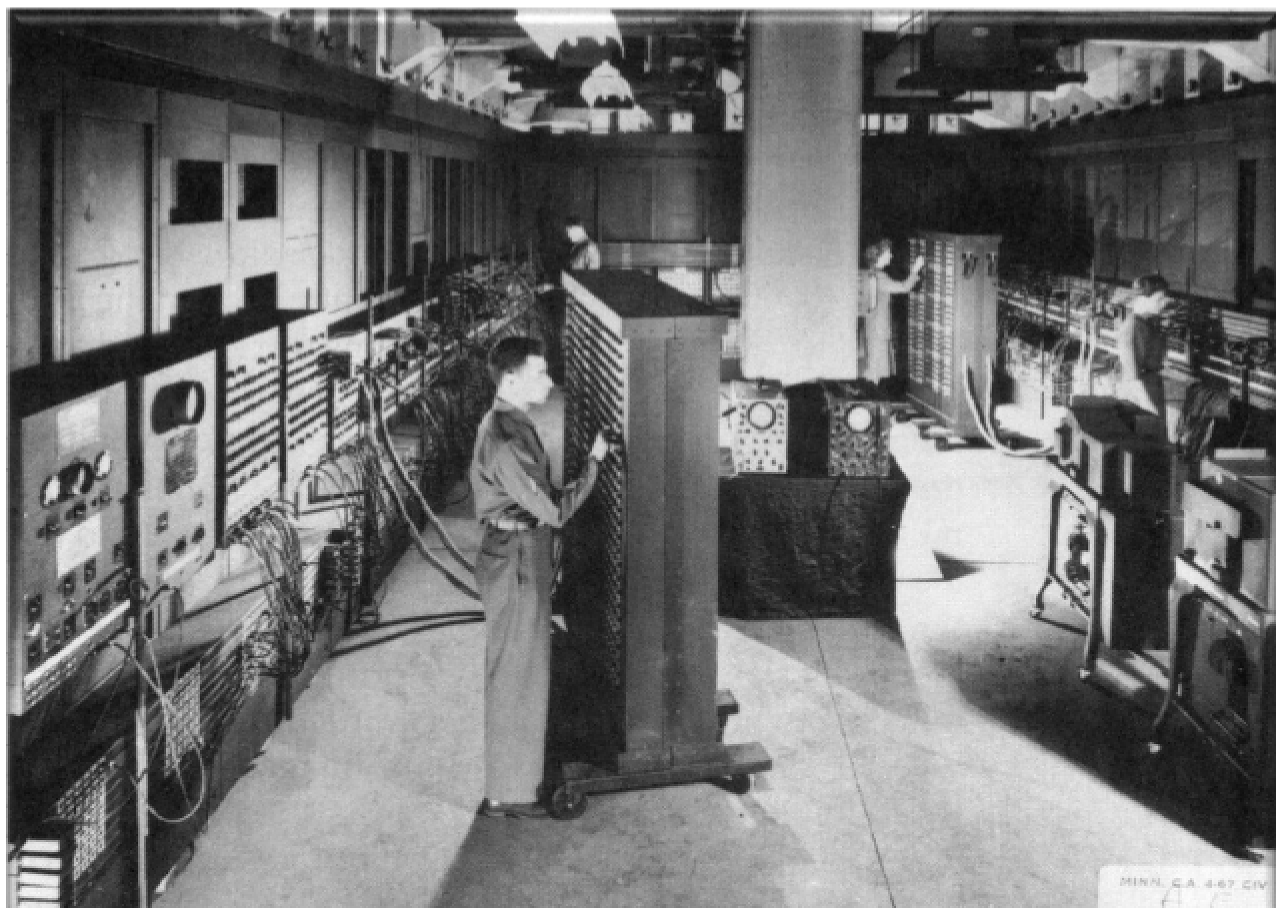
Z3 by Konrad Zuse

- Electro-mechanical computer, 1941
- World's first working programmable, fully automatic digital computer
  - Z3 was built with 2000 relays, implementing a 22-bit word length that operated at a clock frequency of about 5–10 Hz
  - Program code and data were stored on punched film

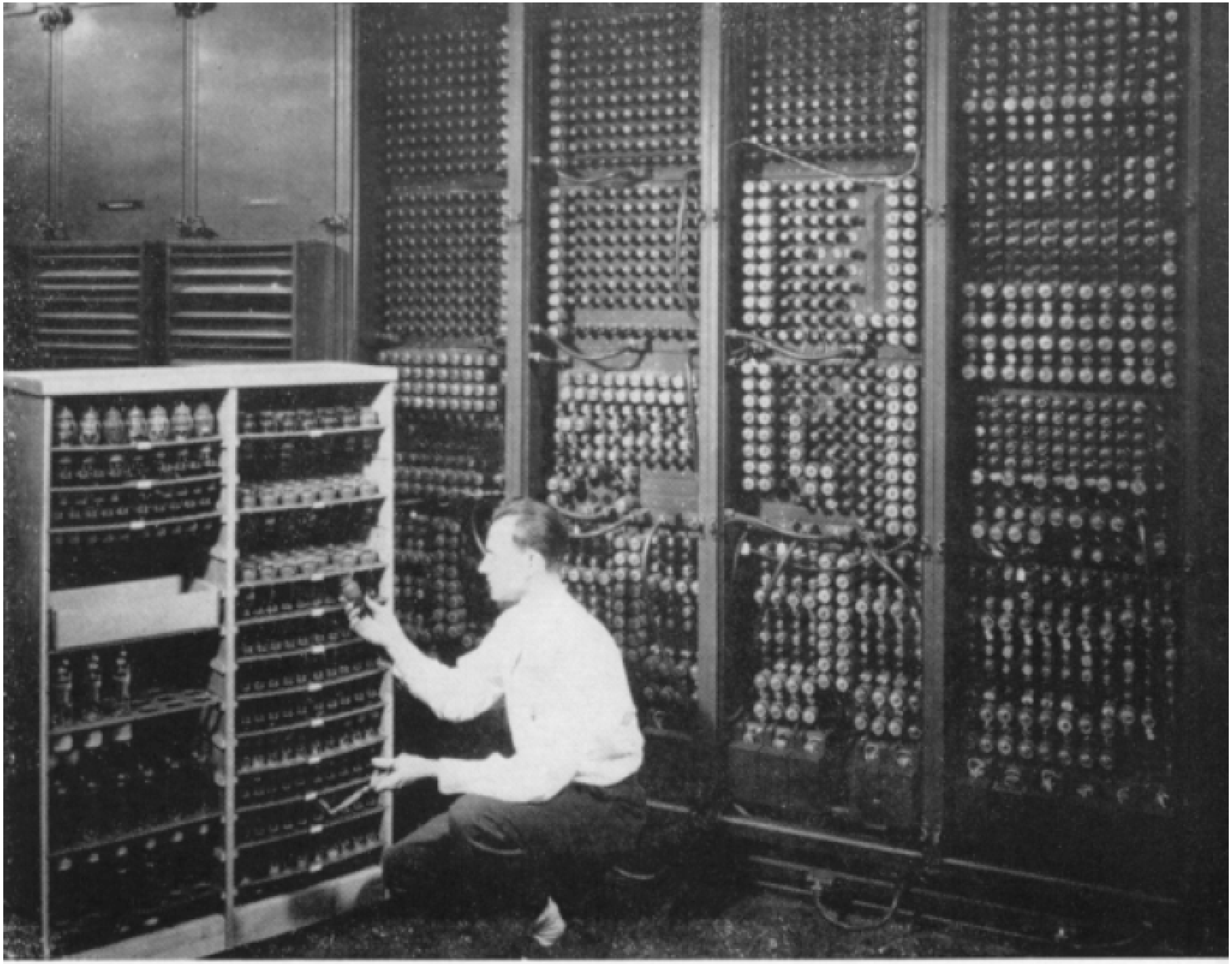


ENIAC First Electronic Computer

- ENIAC contained 17,468 vacuum tubes, 7,200 crystal diodes, 1,500 relays, 70,000 resistors, 10,000 capacitors and around 5 million hand-soldered joints.
- First "general purpose computer"
  - digital, and capable of being reprogrammed to solve "a large class of numerical problems"
  - Used for to calculate artillery firing tables for the United States Army's Ballistic Research
- John Mauchly and J. Presper Eckert, 1946



ENIAC Vacuum Tubes

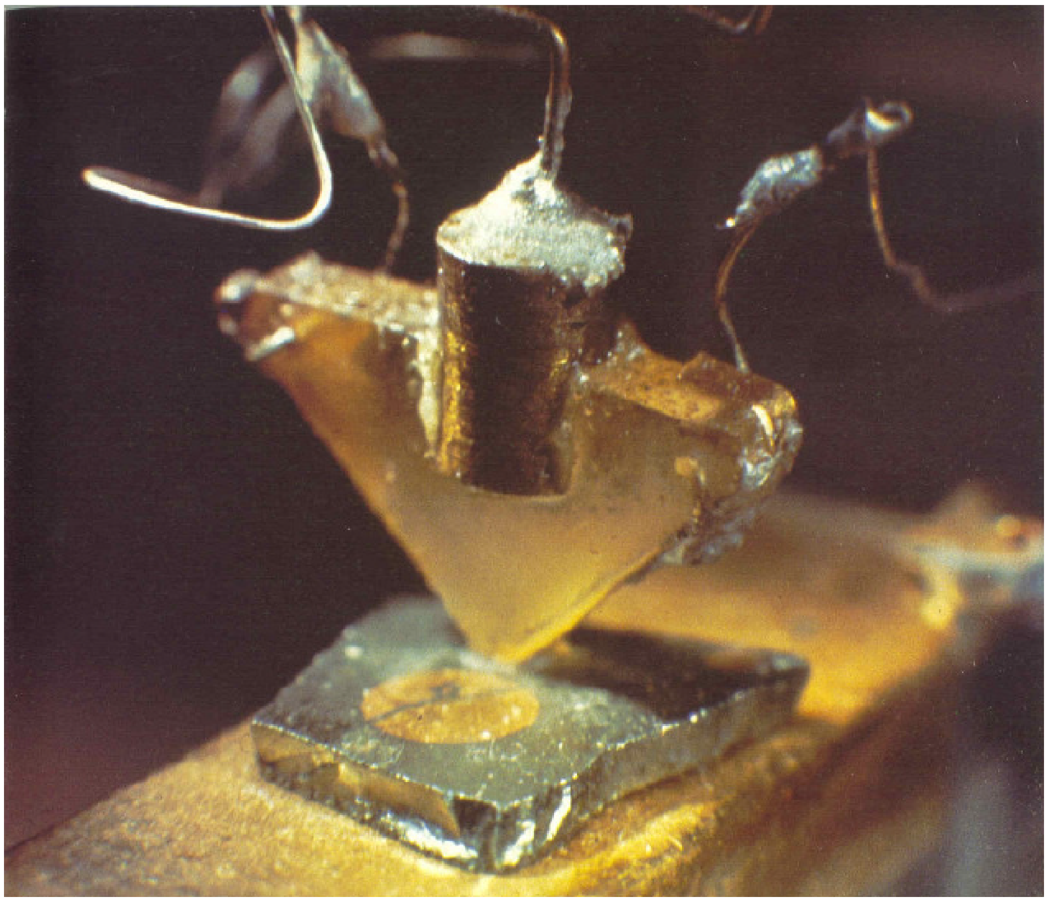


Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

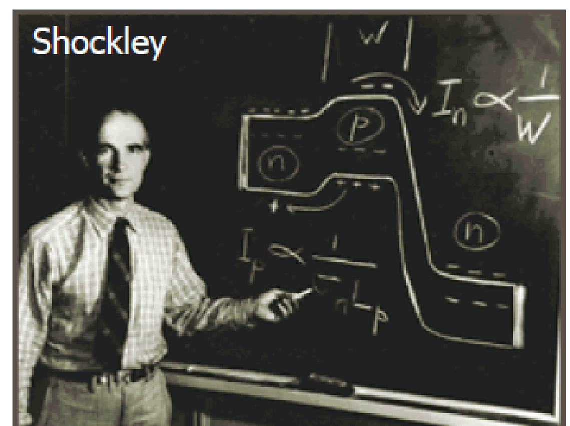
ENIAC 'Boards' and Operators

First Transistor - 1947

- 'Point Contact Transistor' made from Germanium
  - T-R-A-N-S-I-S-T-O-R: Resistor which can amplify electrical signals as they are transferred
- AT&T Bell Laboratories: William Shockley, Walter Brattain and John Bardeen
- 1956: Nobelpreis in physics




'famous picture'


Shockley

Transistor Patent

Patented Oct. 3, 1950 — 2,524,035

UNITED STATES PATENT OFFICE

2,524,035

THREE-ELECTRODE CIRCUIT ELEMENT UTILIZING SEMICONDUCTIVE MATERIALS

John Bardeen, Summit, and Walter H. Brattain, Morristown, N. J., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application June 17, 1948, Serial No. 33,466

40 Claims. (Cl. 179—171)

1

This application is a continuation-in-part of application Serial No. 11,165, filed February 26, 1948, and thereafter abandoned.

This invention relates to a novel method of and means for translating electrical variations for such purposes as amplification, wave generation, and the like.

The principal object of the invention is to amplify or otherwise translate electric signals or variations by use of compact, simple, and rugged apparatus of novel type.

Another object is to provide a circuit element for use as an amplifier or the like which does not require a heated thermionic cathode for its operation, and which therefore is immediately operative when turned on. A related object is to provide such a circuit element which requires no evacuated or gas-filled envelope.

Attempts have been made in the past to convert solid rectifiers utilizing selenium, copper sulfide, or other semi-conductive materials into amplifiers by the direct expedient of embedding a grid-like electrode in a dielectric layer disposed between the cathode and the anode of the rectifier. The grid is supposed, by exerting an electric force at the surface of the cathode, to modify its emission and so alter the cathode-anode current. As a practical matter it is impossible to embed a grid in a layer which is so thick as to insulate the grid from the other electrodes and yet so thin as to permit current to flow between them. It has also been proposed to pass a current from end to end of a strip of homogeneous isotropic semiconductive material and, by the application of a strong transverse electrostatic field, to control the resistance of the strip, and hence the current through it.

So far as is known, all of such past devices are beyond human skill to fabricate with the fineness necessary to produce amplification. In any event they do not appear to have been commercially successful.

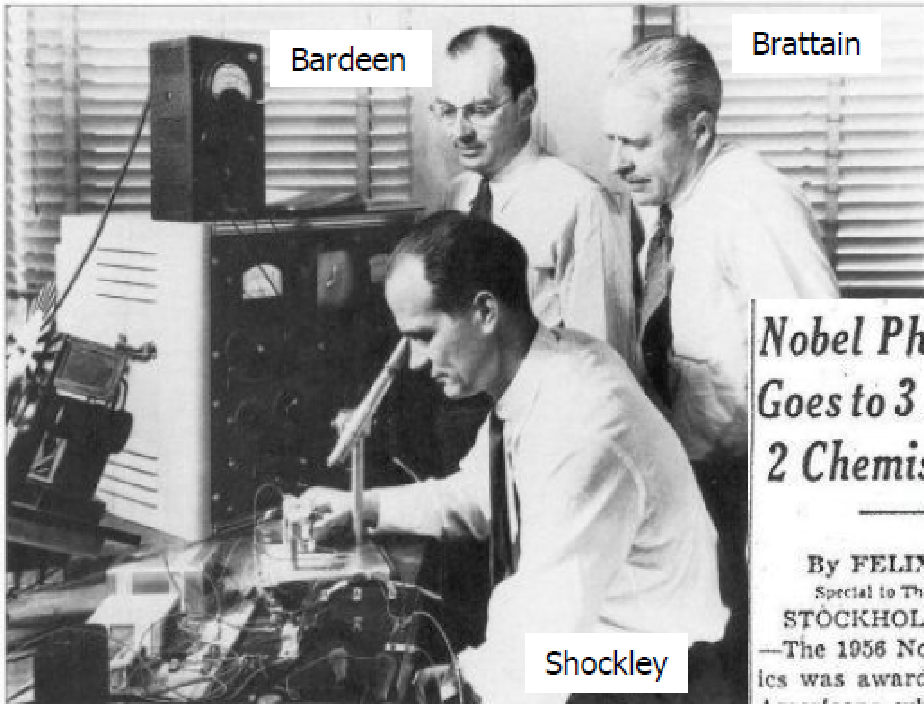
It is well known that in semiconductors there are two types of carriers of electricity which differ in the signs of the effective mobile charges. The negative carriers are excess electrons which are free to move, and are denoted by the term conduction electrons or simply electrons. The positive carriers are missing or defect "electrons," and are denoted by the term "holes." The conductivity of a semiconductor is called excess or defect, or N or P type, depending on whether the mobile charges normally present in excess in the material under equilibrium conditions are electrons (Negative carriers) or holes (Positive carriers).

2

When a metal electrode is placed in contact with a semiconductor and a potential difference is applied across the junction, the magnitude of the current which flows often depends on the sign as well as on the magnitude of the potential. A junction of this sort is called a rectifying contact. If the contact is made to an N-type semiconductor, the direction of easy current flow is that in which the semiconductor is negative with respect to the electrode. With a P-type semiconductor, the direction of easy flow is that in which the semiconductor is positive. A similar rectifying contact exists at the boundary between two semiconductors of opposite conductivity types.

This boundary may separate two semiconductor materials of different constitutions, or it may separate zones or regions, within a body of semiconductor material which is chemically and stoichiometrically uniform, which exhibit different conductivity characteristics.

The present invention in one form utilizes a block of semiconductor material on which three electrodes are placed. One of these, termed the collector, makes rectifier contact with the body of the block. The other, termed the emitter, preferably makes rectifier contact with the body of the block also. The third electrode, which may be designated the base electrode, preferably makes a low resistance contact with the body of the block. When operated as an amplifier, the emitter is normally biased in the direction of easy current flow with respect to the body of the semiconductor block. The nature of the emitter electrode and of that portion of the semiconductor which is in the immediate neighborhood of the electrode contact is such that a substantial fraction of the current from this electrode is carried by charges whose signs are opposite to the signs of the mobile charges normally in excess in the body of the semiconductor. The collector is biased in the reverse, or high resistance direction relative to the body of the semiconductor. In the absence of the emitter, the current to the collector flows exclusively from the base electrode and is impeded by the high resistance of this collector contact. The sign of the collector bias potential is such as to attract the carriers of opposite sign which come from the emitter. The collector is so disposed in relation to the emitter that a large fraction of the emitter current enters the collector. The fraction depends in part on the geometrical disposition of the electrodes and in part on the bias potentials applied. As the emitter is biased in the direction of easy flow, the emitter current



Nobel Physics Prize Goes to 3 Americans; 2 Chemists Honored

By FELIX BELAIR Jr.

Special to The New York Times.

STOCKHOLM, Sweden, Nov. 1—The 1956 Nobel Prize in Physics was awarded today to three Americans who had worked as a team in developing the transistor. This is a tiny and highly efficient substitute for the vacuum tube in electronics.

The prize winners are Dr. William Shockley, the team captain; Dr. Walter H. Brattain and Dr. John Bardeen. The three, who did their work as research scientists of the Bell Laboratories of Murray Hill, N. J., will share the award of about $38,700 made under the terms of the will of Alfred Nobel, the Swedish inventor of dynamite.

First "Pocket Radio" - 1954

- Texas Instruments:
  - "To sell a pocket radio at that point, it was our opinion that it would have to list at $50,“ Jonsson recalled. But four transistors times $16 wouldn't do it, so we had to design a manufacturing process so much better than any other at the time we could sell them for $2.50 each. We figured if we could get $10 for four transistors, the manufacturer could put the rest of the parts together for $17 or $18, sell a $50 radio, and still have a little left over for himself after paying a dealer. Well, we came up with the technique, and Regency bought the idea, and that radio went on the market at $49.95."

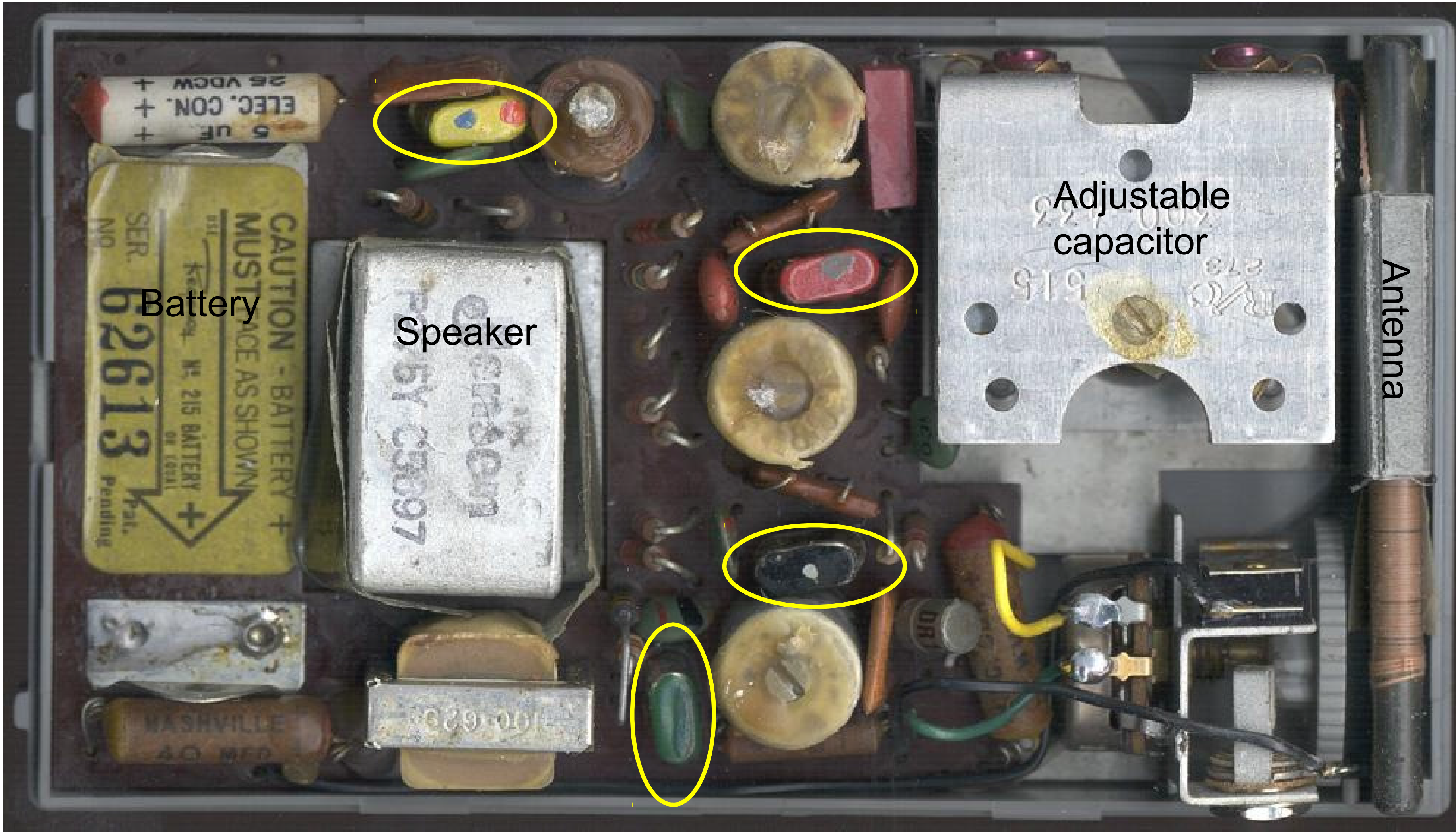
'Regency'

1957: Competition from Sony: sells much better

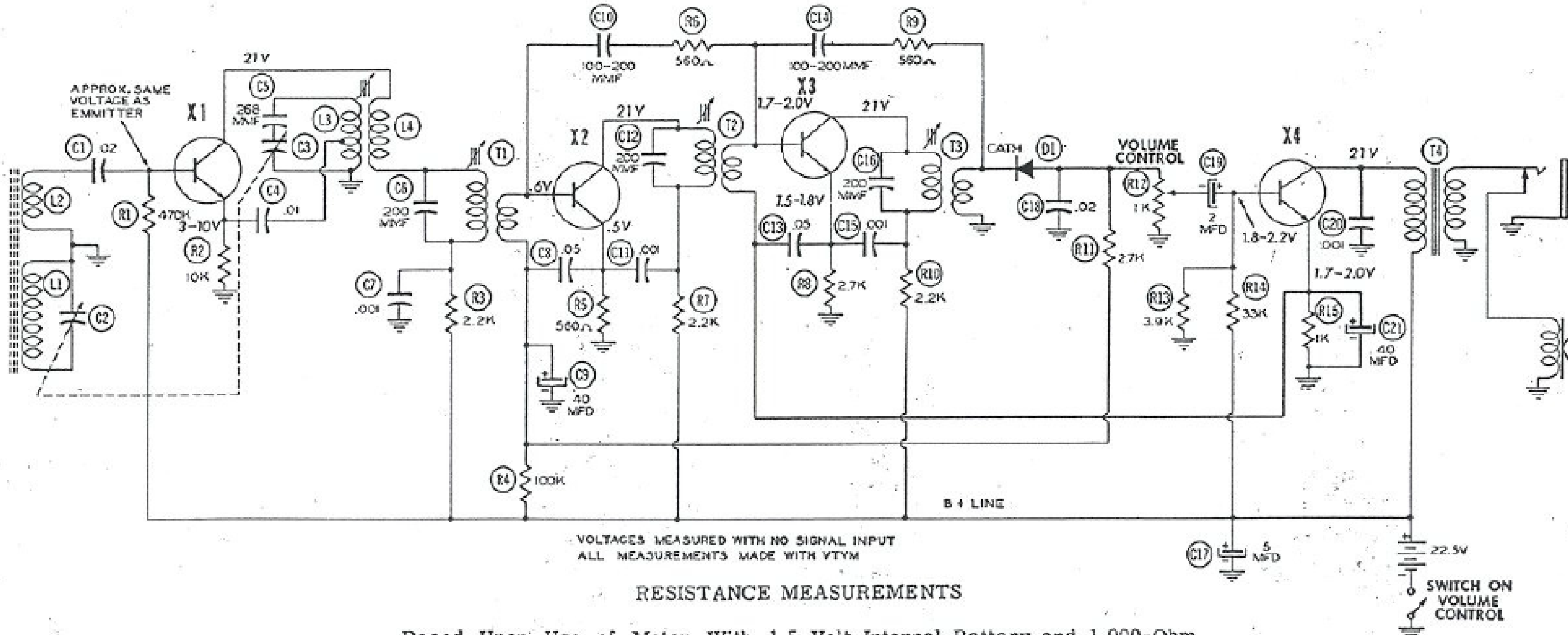
WORLD'S FIRST POCKET RADIO

Regency

Design ‘Regency’



‘Regency’ Circuit Diagram



RESISTANCE MEASUREMENTS

Based Upon Use of Meter With 1.5-Volt Internal Battery and 1,000-Ohm Center Range; All Measurements Taken With Positive Probe (Not Necessarily the Red Probe) Connected to Terminal Being Measured.

TRANSISTOR	BASE	BASE (WITH METER LEADS REVERSED)	EMITTER	COLLECTOR (MEASURED FROM B+ LINE)
X1	7KΩ		10KΩ	2. 2KΩ
X2	600Ω	3. 0KΩ	550Ω	2. 2KΩ
X3	750Ω	725Ω	2. 7KΩ	2. 2KΩ
X4	850Ω	3. 5KΩ	750Ω	850Ω

First Silicon Transistor - 1954

Teal Gordon: 10 May 1954 at the Institute of Radio Engineers (IRE) National Conference on Airborne Electronics, in Dayton, Ohio:

"Some New and Recent Developments in Silicon and Germanium," an inauspicious title. The germanium transistor was no longer news. Industry-wide research had been conducted for some time on the use of silicon for transistors, because of its ability to withstand higher temperatures. However, as far as anyone knew, no one had been able grow silicon crystals with the characteristics needed for a workable transistor.

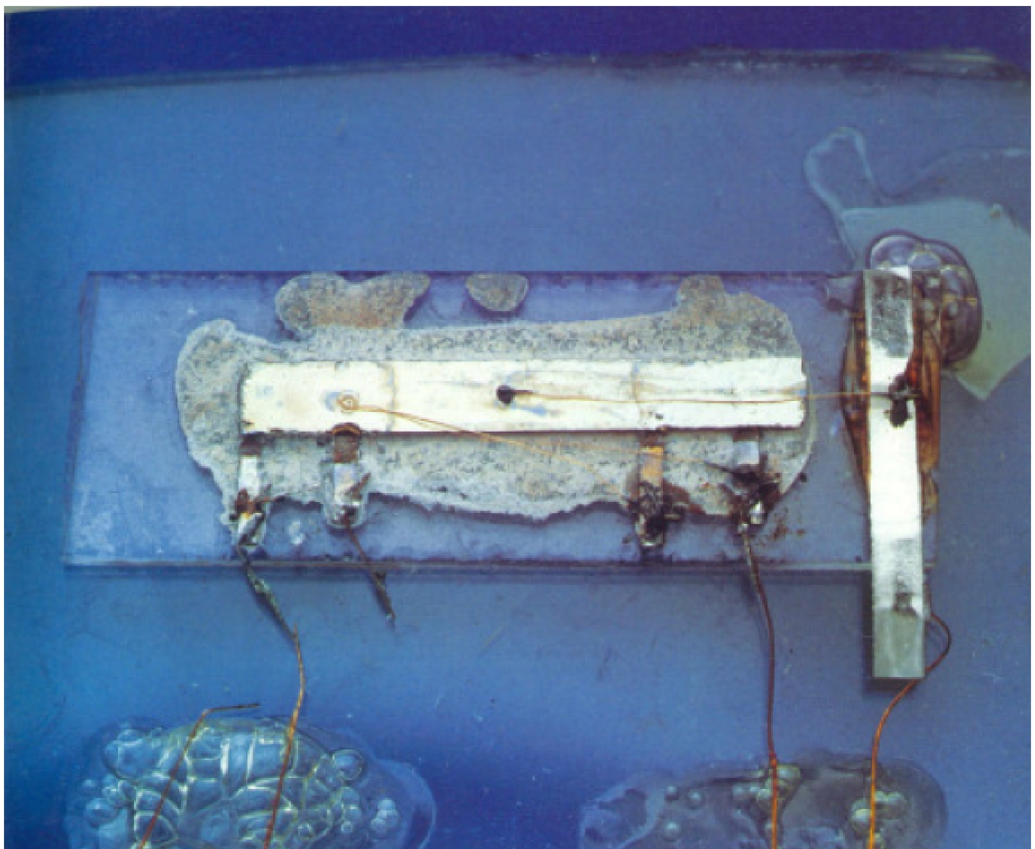
Speaker after speaker at the conference denied the near-term feasibility of the silicon transistor. Teal, next to last on the agenda, took his turn. TI cofounder Erik Jonsson recalled that Teal, "a quiet man," put everyone to sleep until, at the end of his speech, he calmly remarked, "Contrary to what my colleagues have told you about the prospects for silicon transistors, I happen to have a few here in my pocket". Teal's announcement that someone from TI was standing in the back of the auditorium with literature on the new device caused a stampede. "The poor last speaker was in trouble," Jonsson remembered. "He had no audience left."

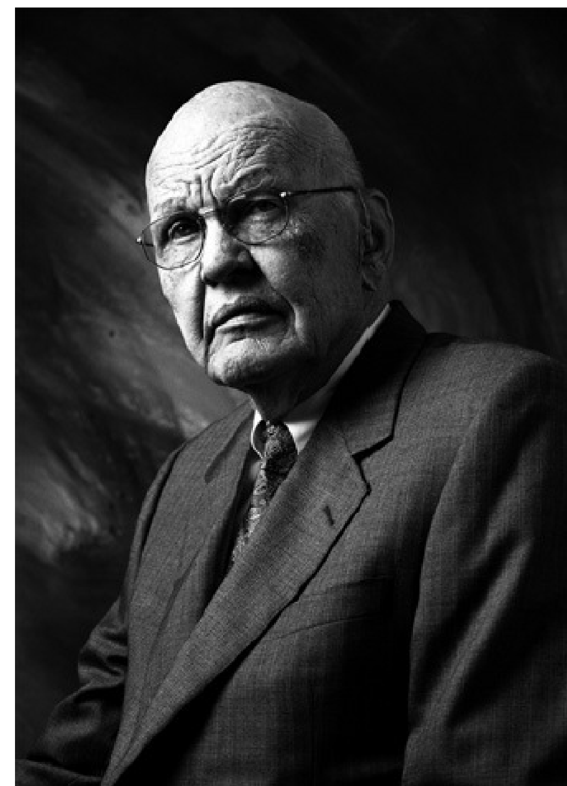
Advantages of Si:

- Operating temp up to 150°C
- Higher output power

First Integrated Circuit- 1954

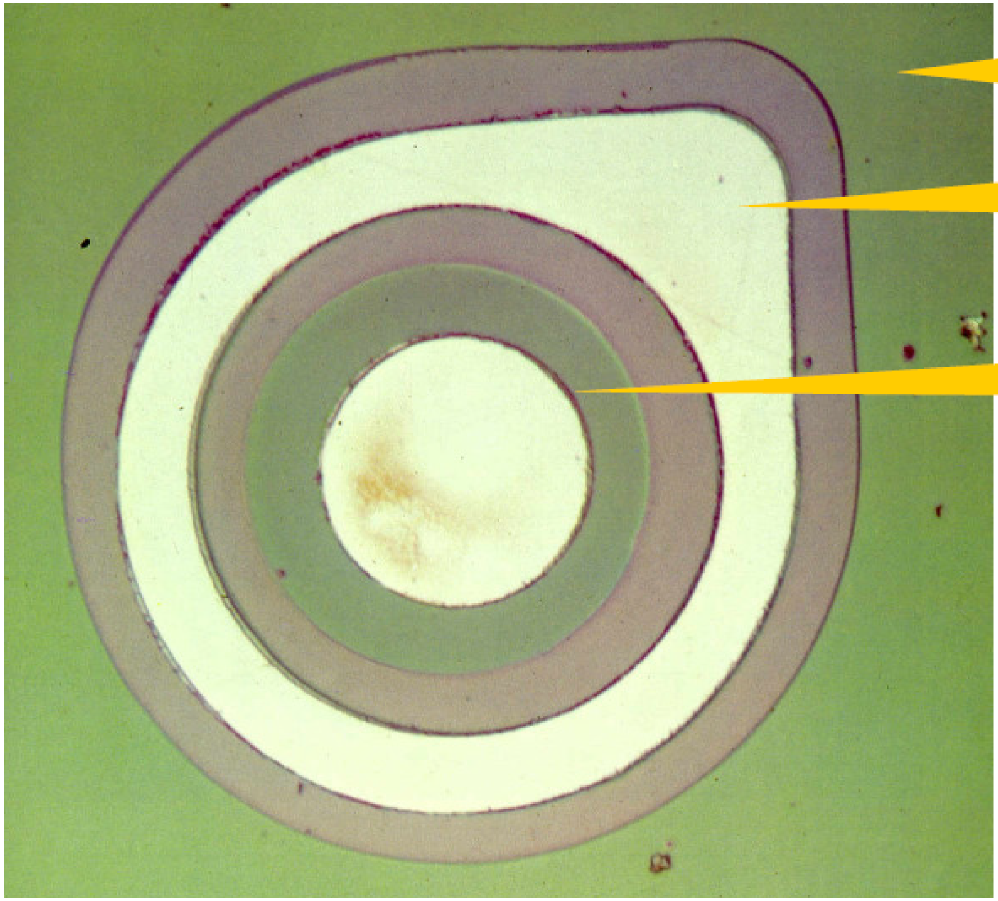
- Jack Kilby, Texas Instruments
  - http://www.ti.com/corp/docs/company/history/tihistory.htm
- 1 Transistor, 1 capacitor, 3 resistors on one Germanium chip
- Nobel prize 2000

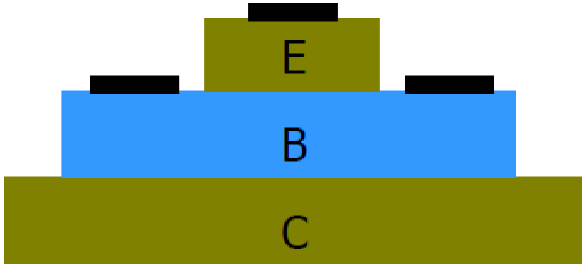




Planar Technology - 1959

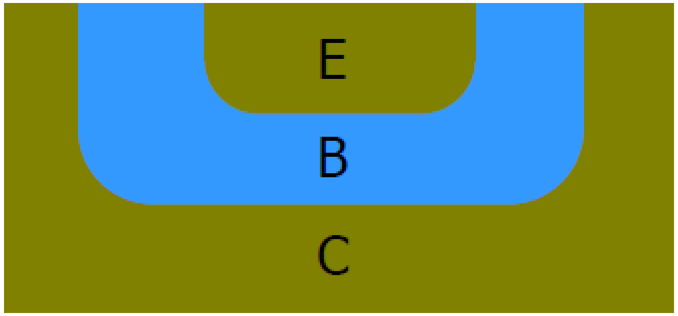
- Much more effective fabrication
  - MESA – process suitable for volume production
- PNP Bipolar Transistor made from Silicon

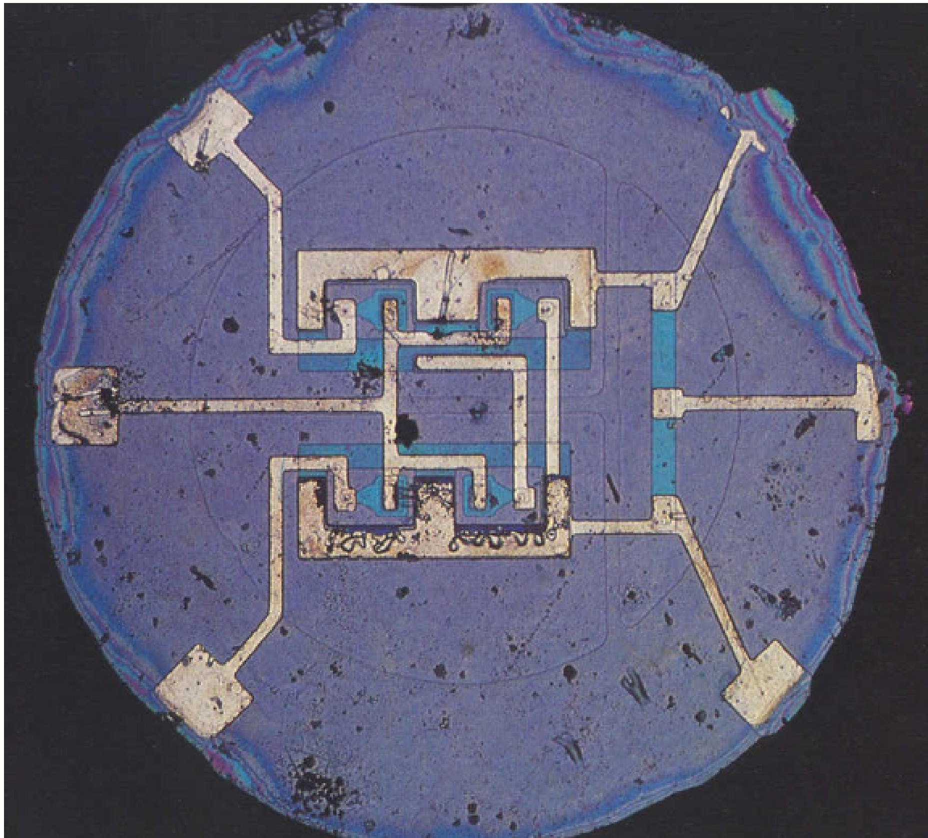




First Commercial Planar Integrated Circuit - 1959

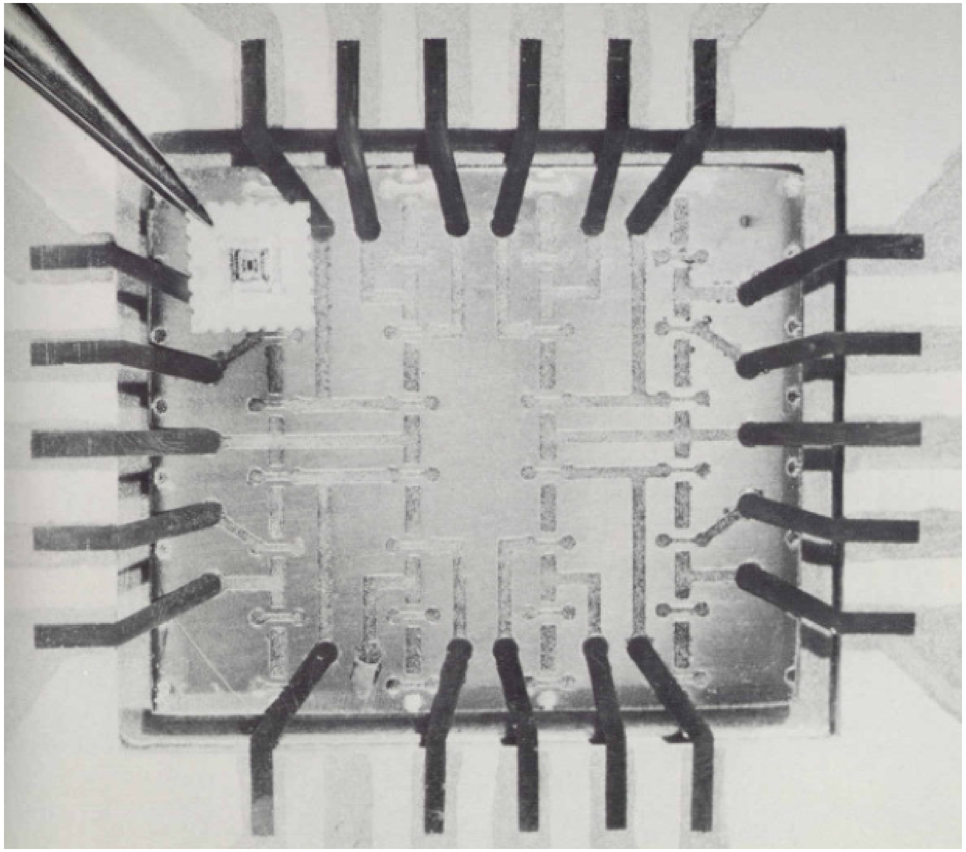
- Fairchild Electronics - Jean Hoerni und Robert Noyce: Planar Technology
- Fairchild – One Bit digital memory (flipflop) in resistor-transistor-logic (RTL)
  - 4 transistors, 5 resistors – Integration of more elements relatively simple
  - Advent of „Small Scale Integration“ : SSI
- Planar technology: doping by diffusion of other layers/elements





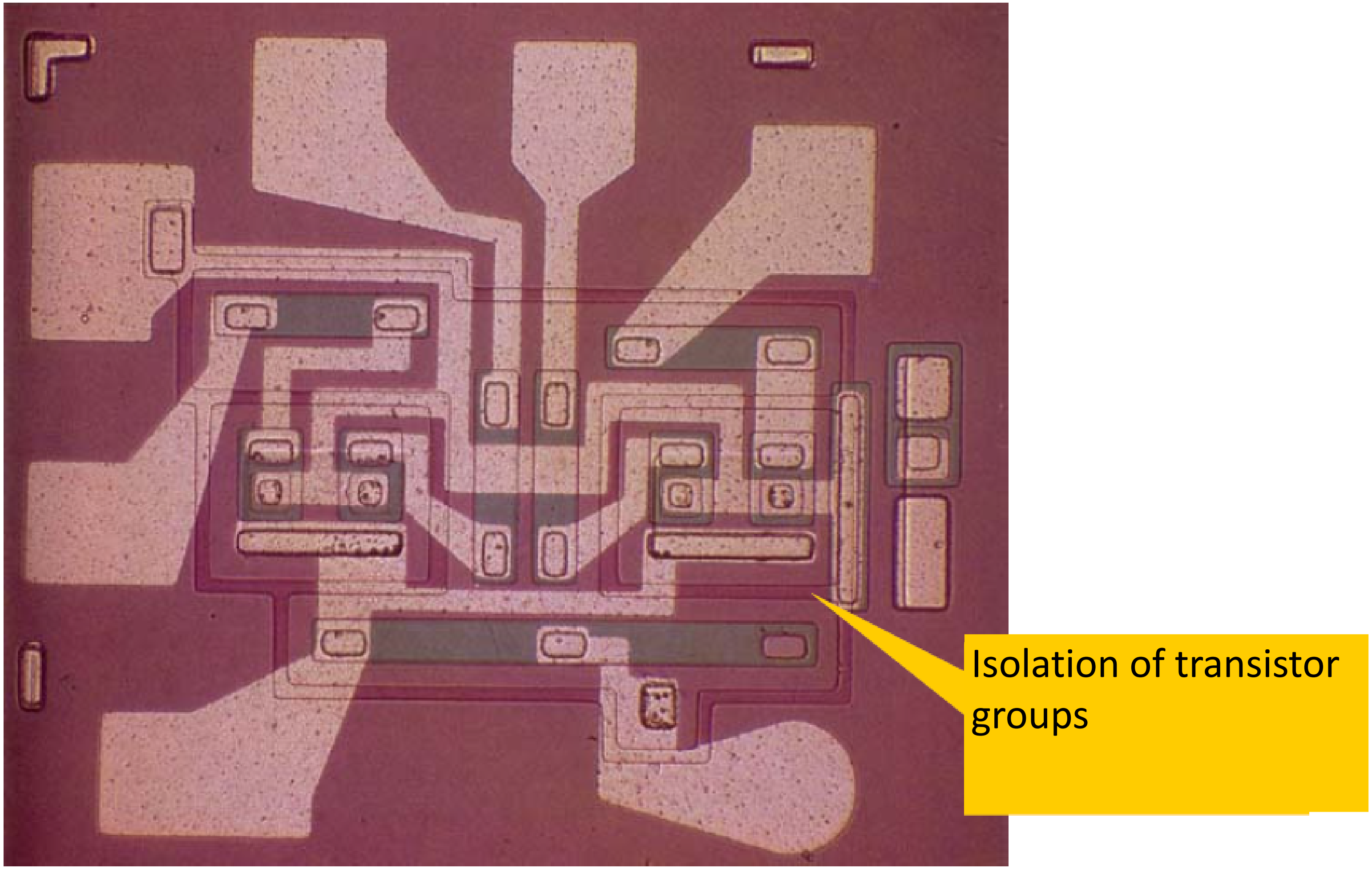
First MOSFET - 1962

- Metal-Oxide Semiconductor Field-Effect Transistor
- Radio Corporation of America (RCA)
- 'General Purpose Chip' with 16 transistors



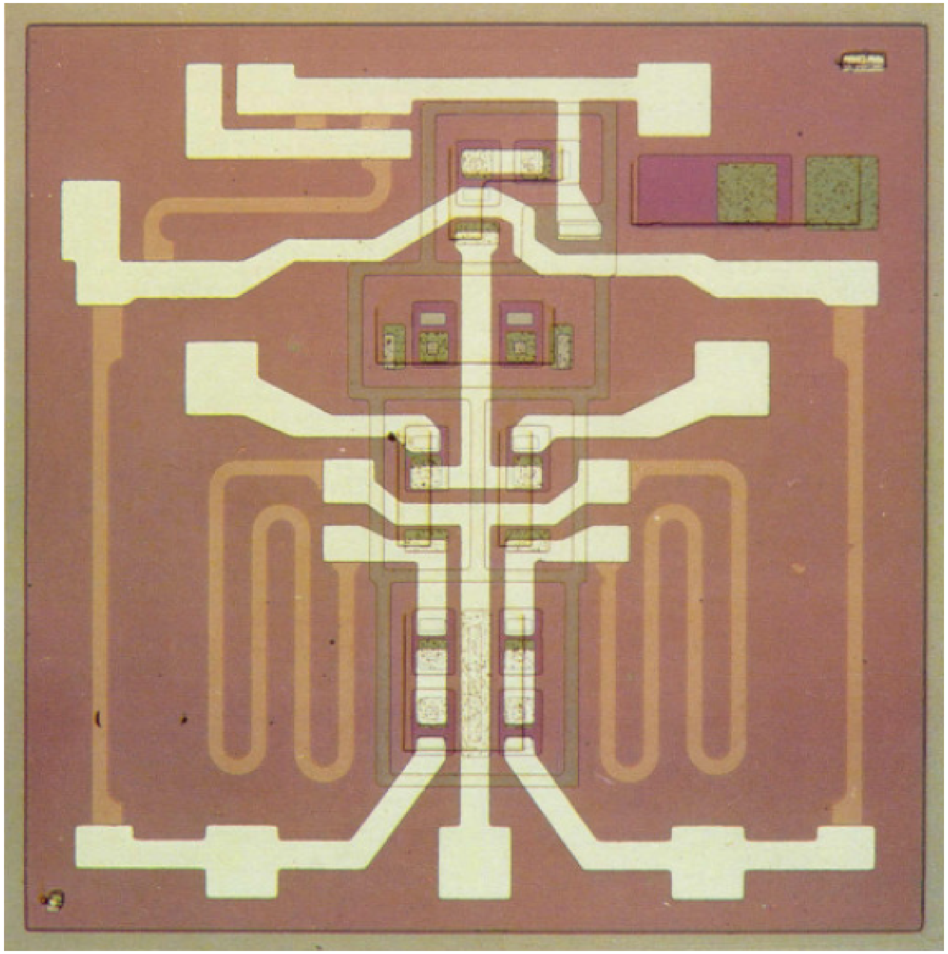
RTL Logic - 1963

- Fairchild '907': RTL Logic: 4 Transistors, 5 resistors
- 'Buried Layer' under collector reduces resistance ⇒higher speed



First Analogue IC- 1963

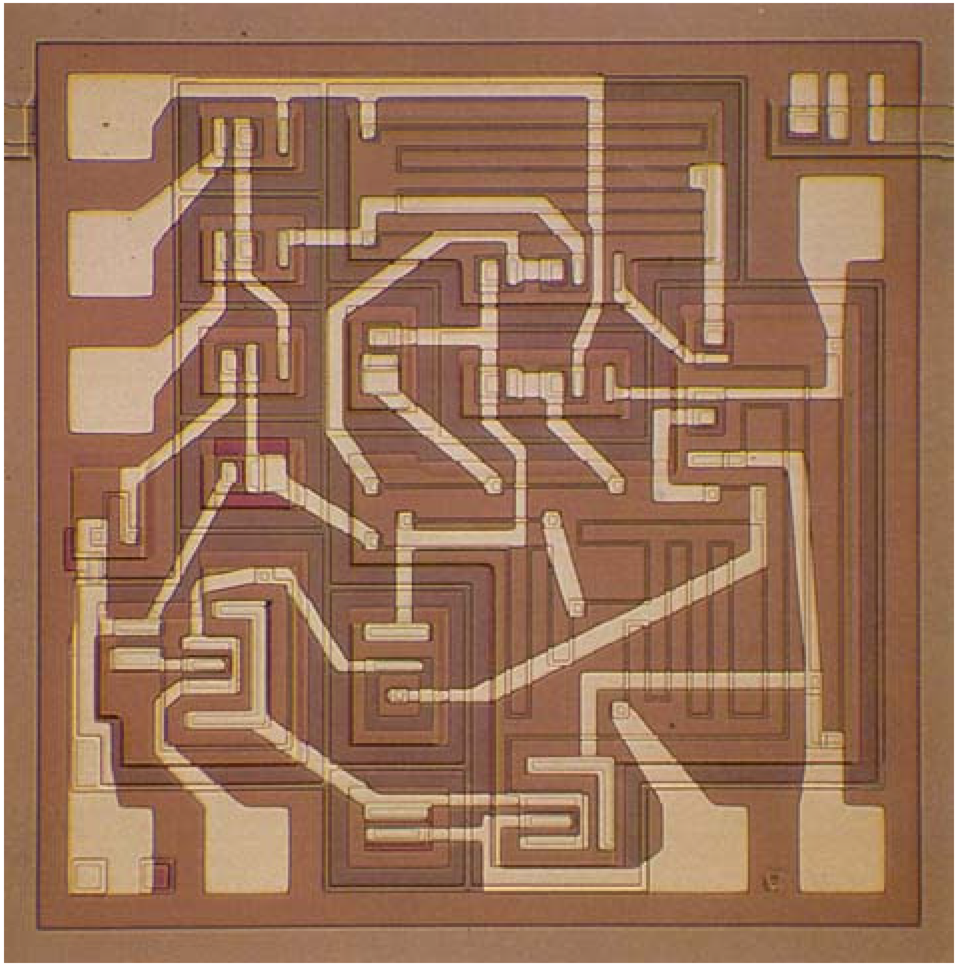
- Fairchild: Operational Amplifier (OpAmp) µA 702
- First integrated difference amplifier



1.5 cm (!)

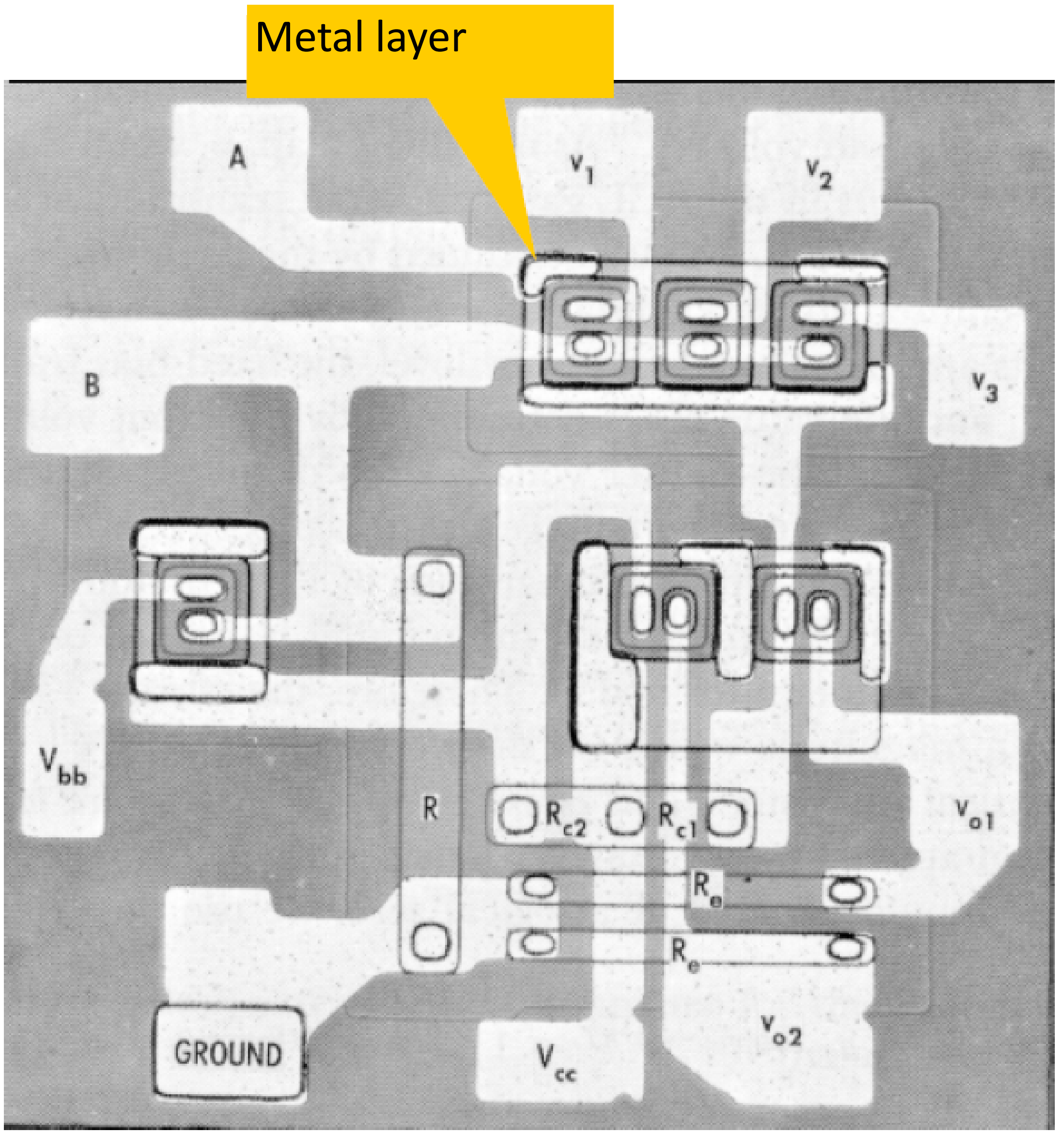
OpAmp Bestseller - 1965

- Fairchild: OpAmp μA 709 – Designed by Robert ('Bob') Widlar
  - 14 transistors, 15 resistors
  - Still being fabricated
  - Gain ~70000
  - Price: $100 1968, today 0.5$
- Competition only in 1968
  μA 741 from Texas Instruments



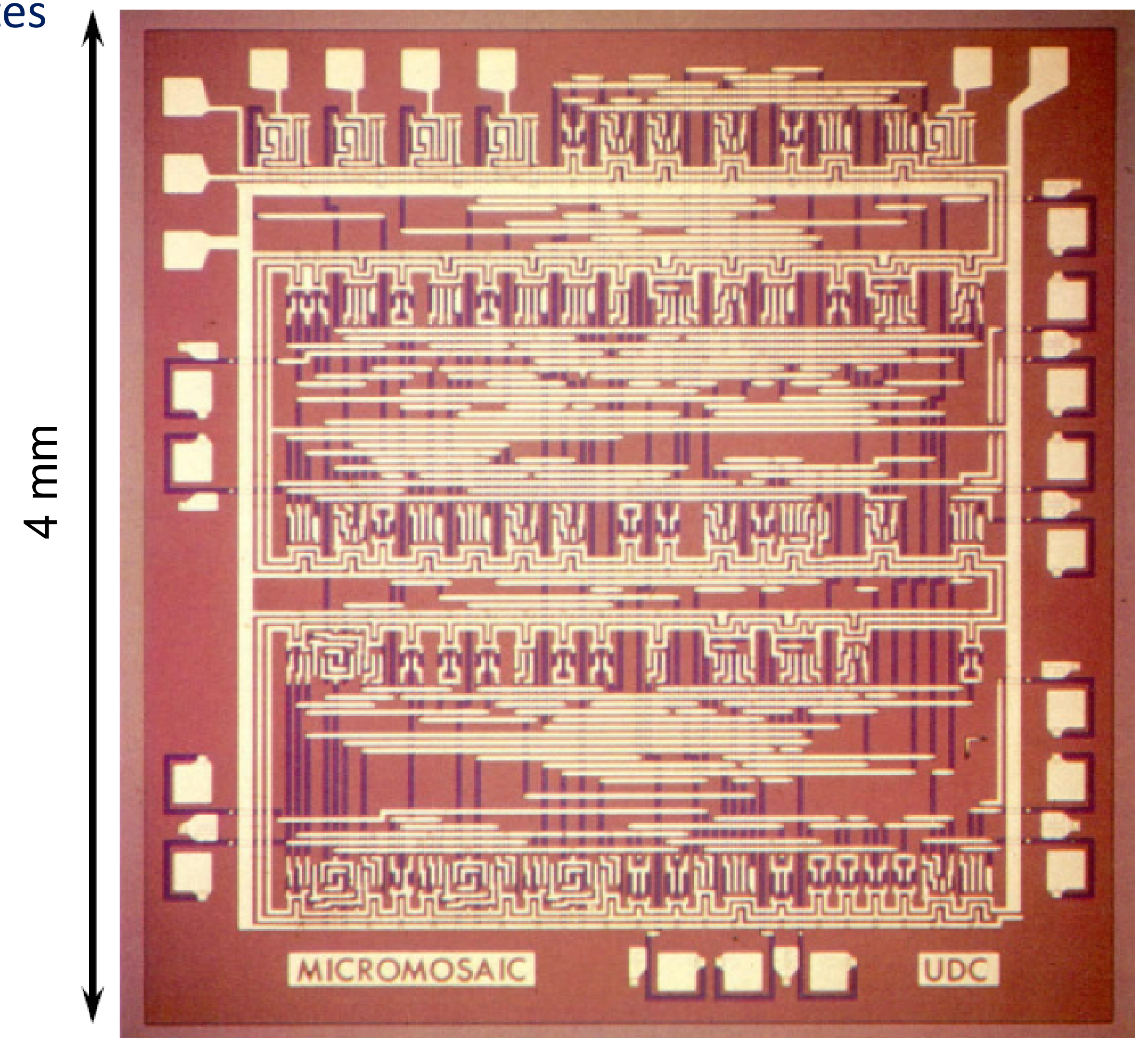
Emitter Coupled Logic - 1966

- Motorola ECL Technology
  - Gate with 3 inputs
  - Bipolar transistors and resistors
- One metal layer



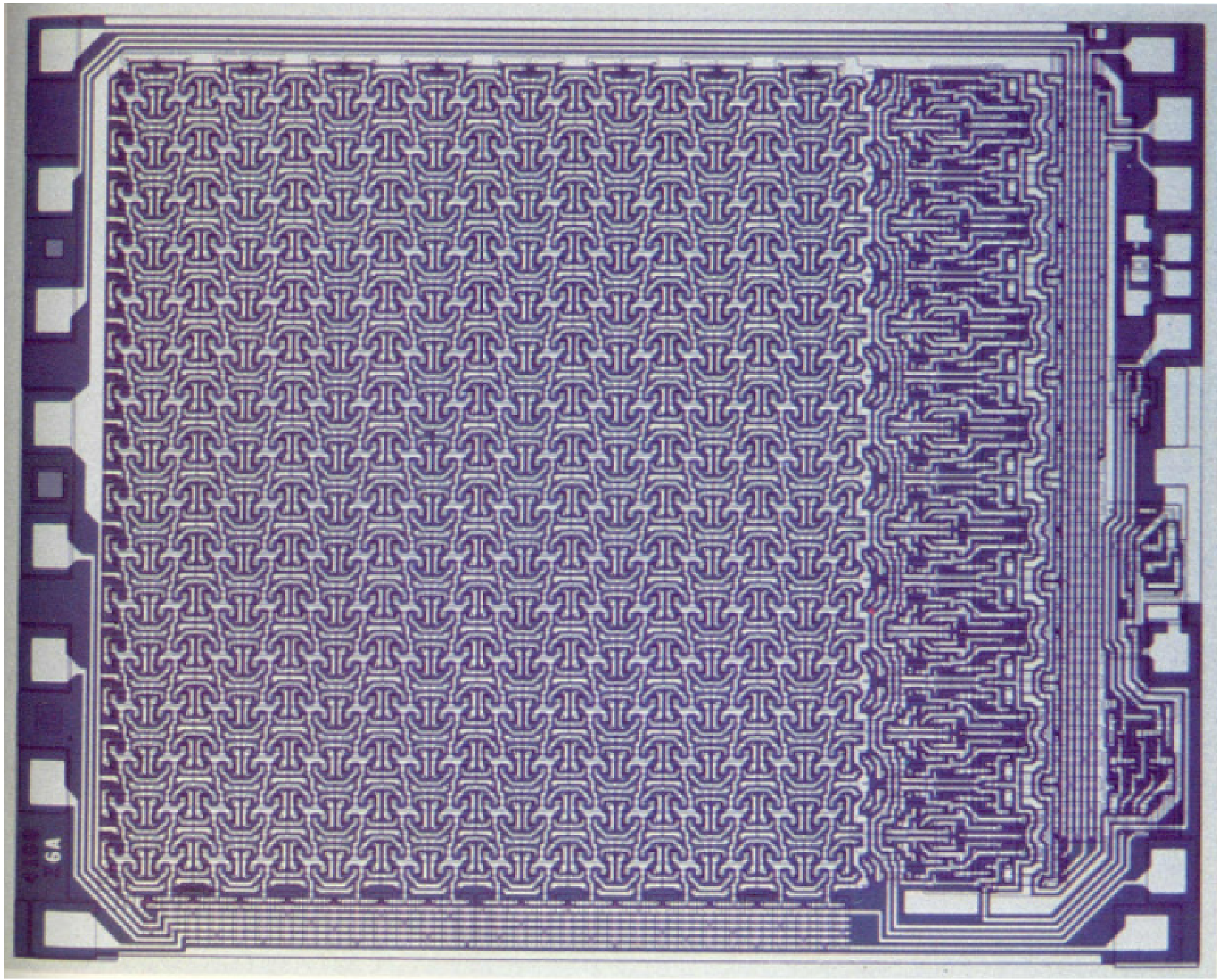
1st IC designed with CAD - 1967

- Fairchild: MICROMOSAIC
  - ca. 150 AND, OR, NOT gates
  - Generated from a pool of transistors by ‘application specific‘ metallization
  - 'Mask programmable transistor array'



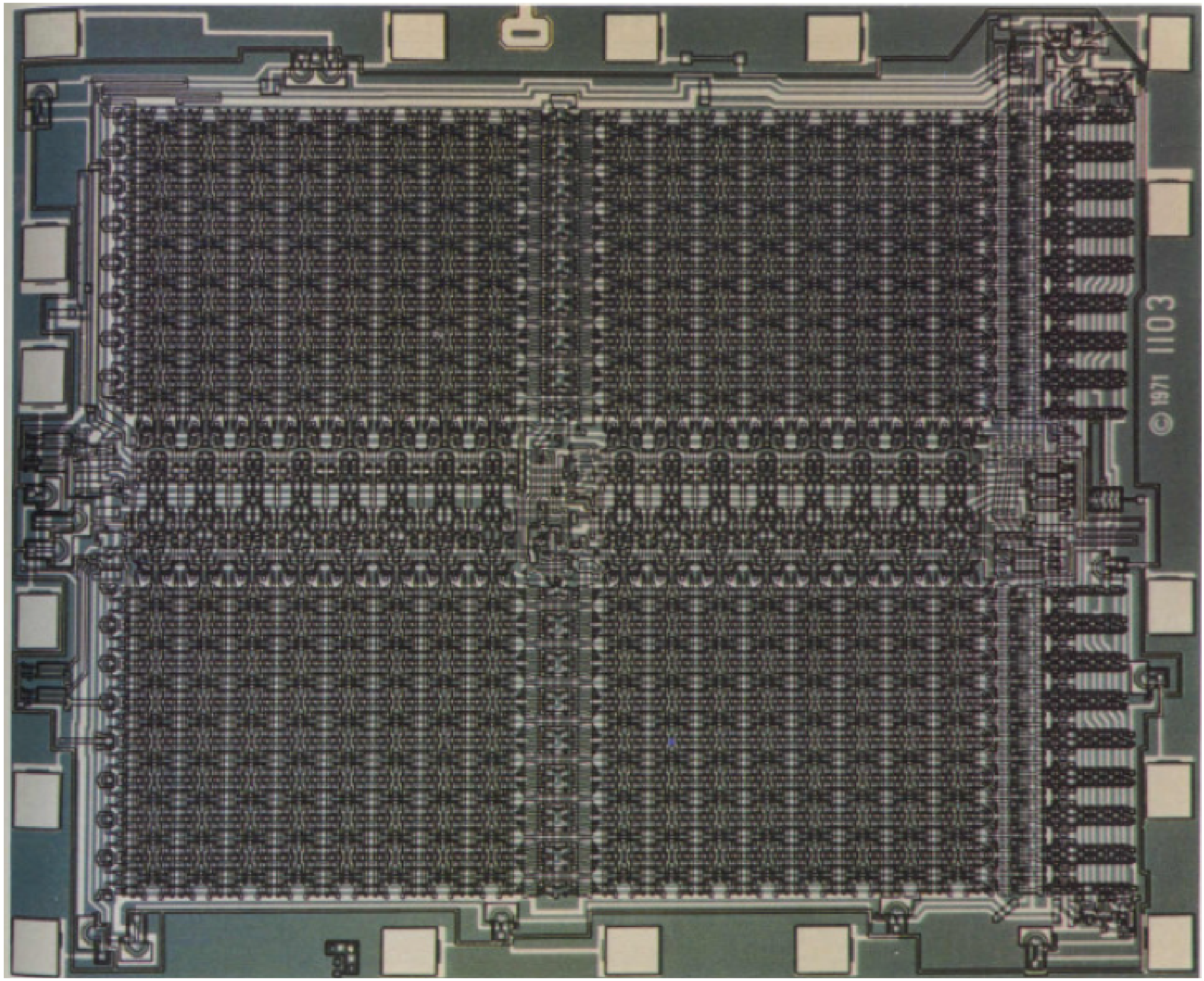
256 Bit Static RAM - 1970

- Fairchild: 4100
  - With decoder
  - 2.5mm x 3mm
  - Used in ILLIAC IV computer (NASA)



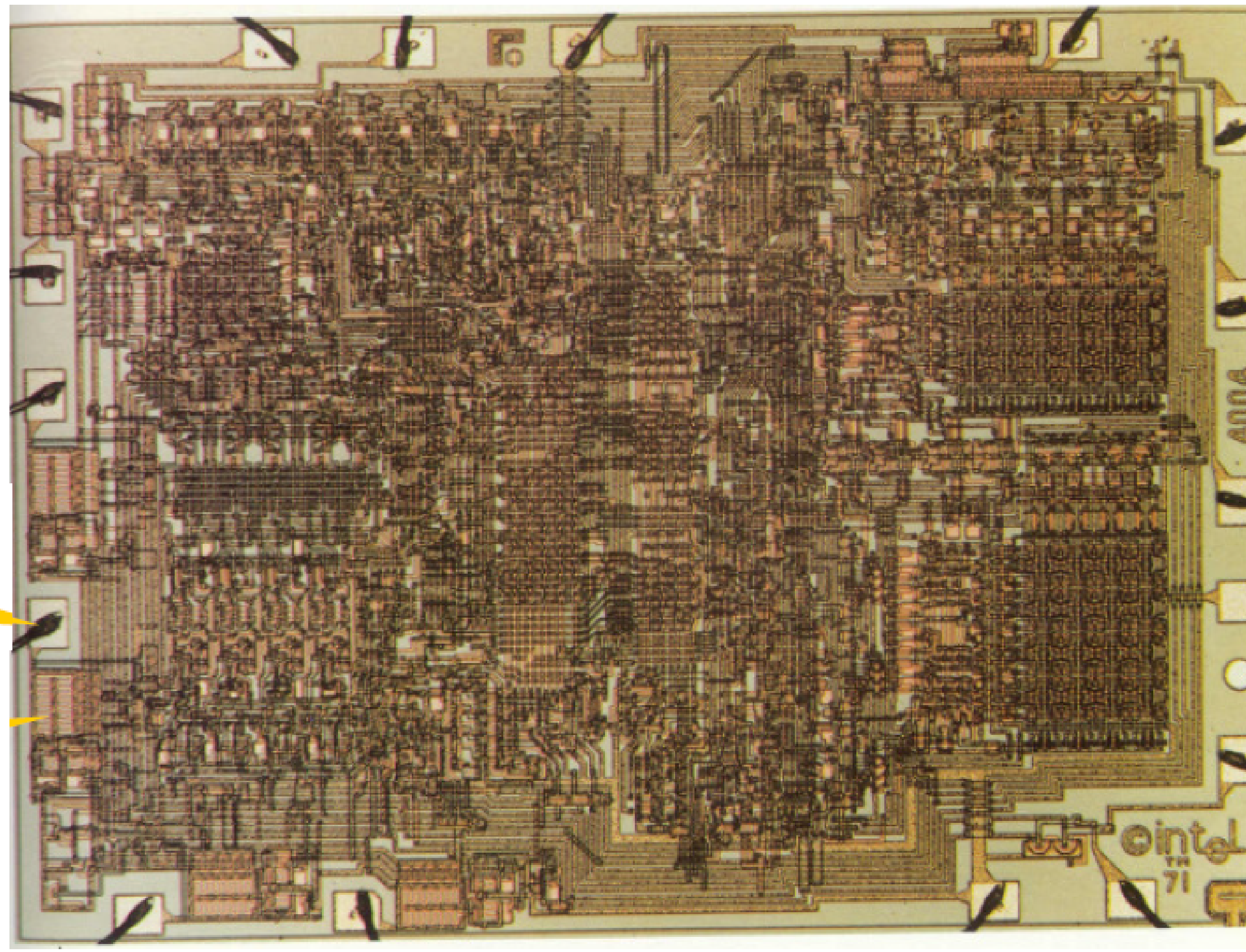
1024 Bit Dynamic RAM - 1970

- Intel Corporation
  - Founded 1968 by ex-Fairchild employees (Bob Noyce, Gordon Moore)
  - 4 x more bits on the same area as static RAMs



First Micro-Processor - 1974

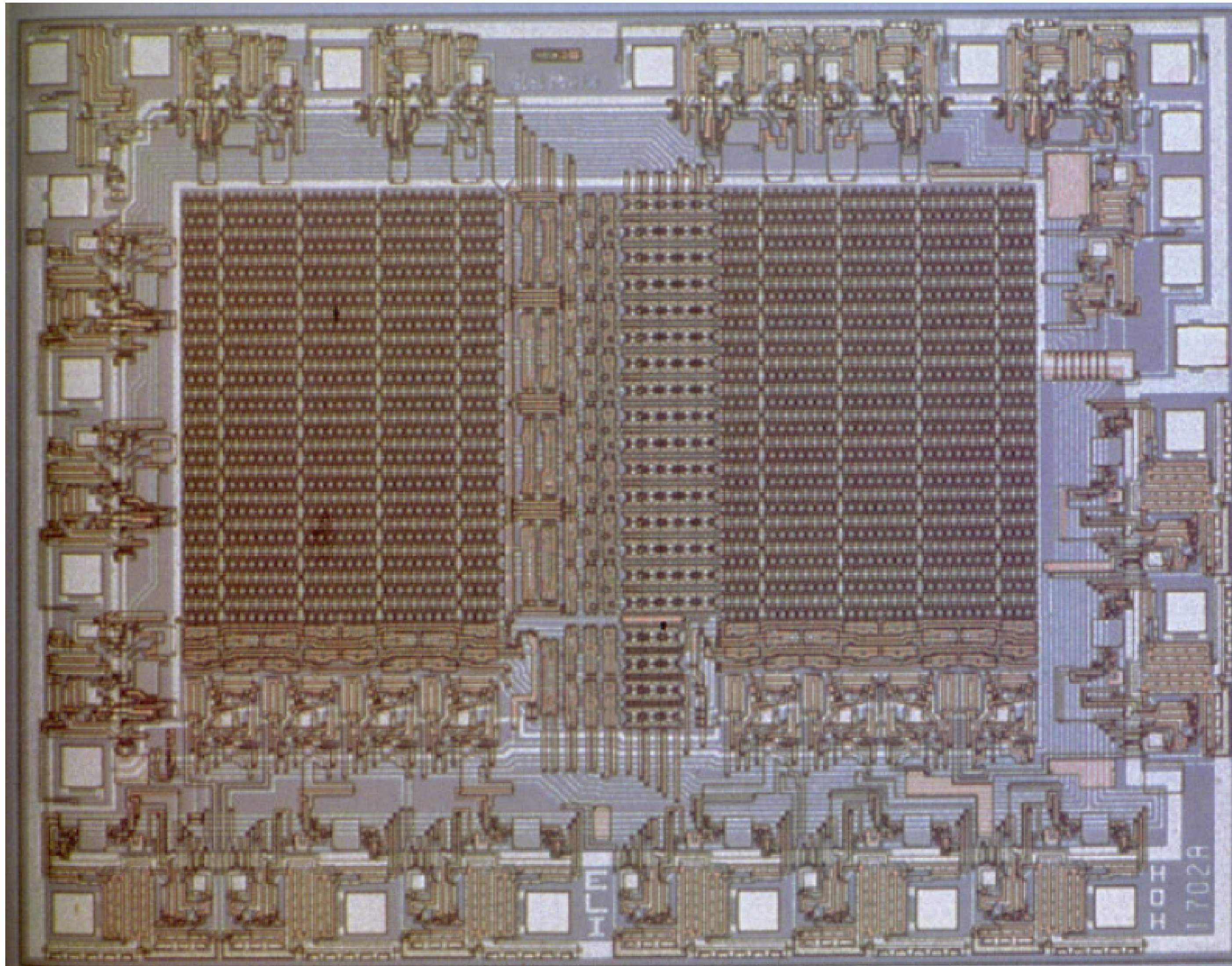
- Intel 4004 (Marcian E. Hoff)
  - First ‘computer” on a chip
  - Advent of ‘large scale integration‘ – LSI
  - 2300 MOSFETs
  - 4 bit
  - 108 kHz clock freq.



Aluminium-Wire-Bonds

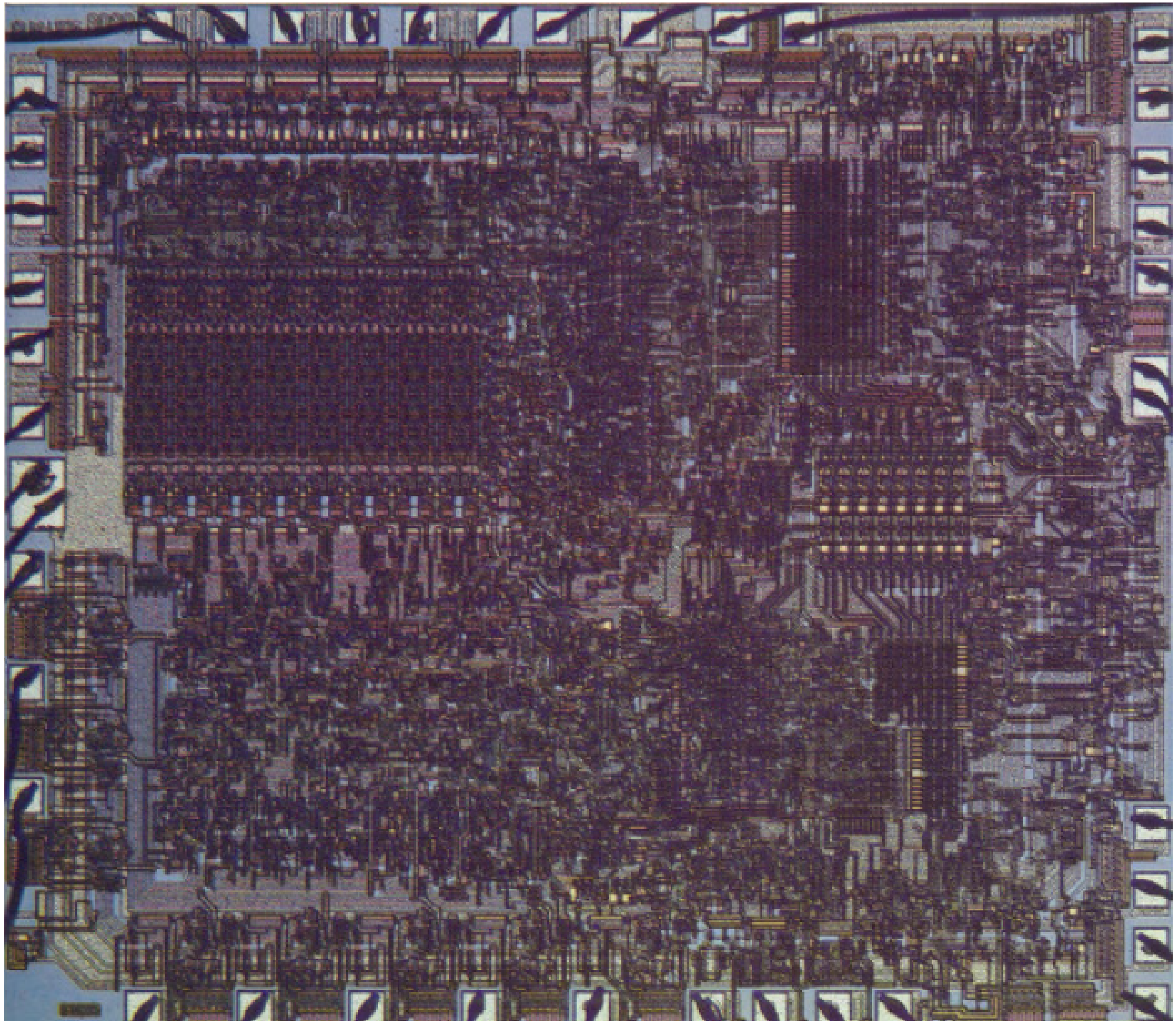
First EPROM - 1971

- Intel 1702
  - 2 kbit (256 x 8)
  - UV erasable
  - 3.7 mm x 4.1 mm
  - Costumers could programme µC



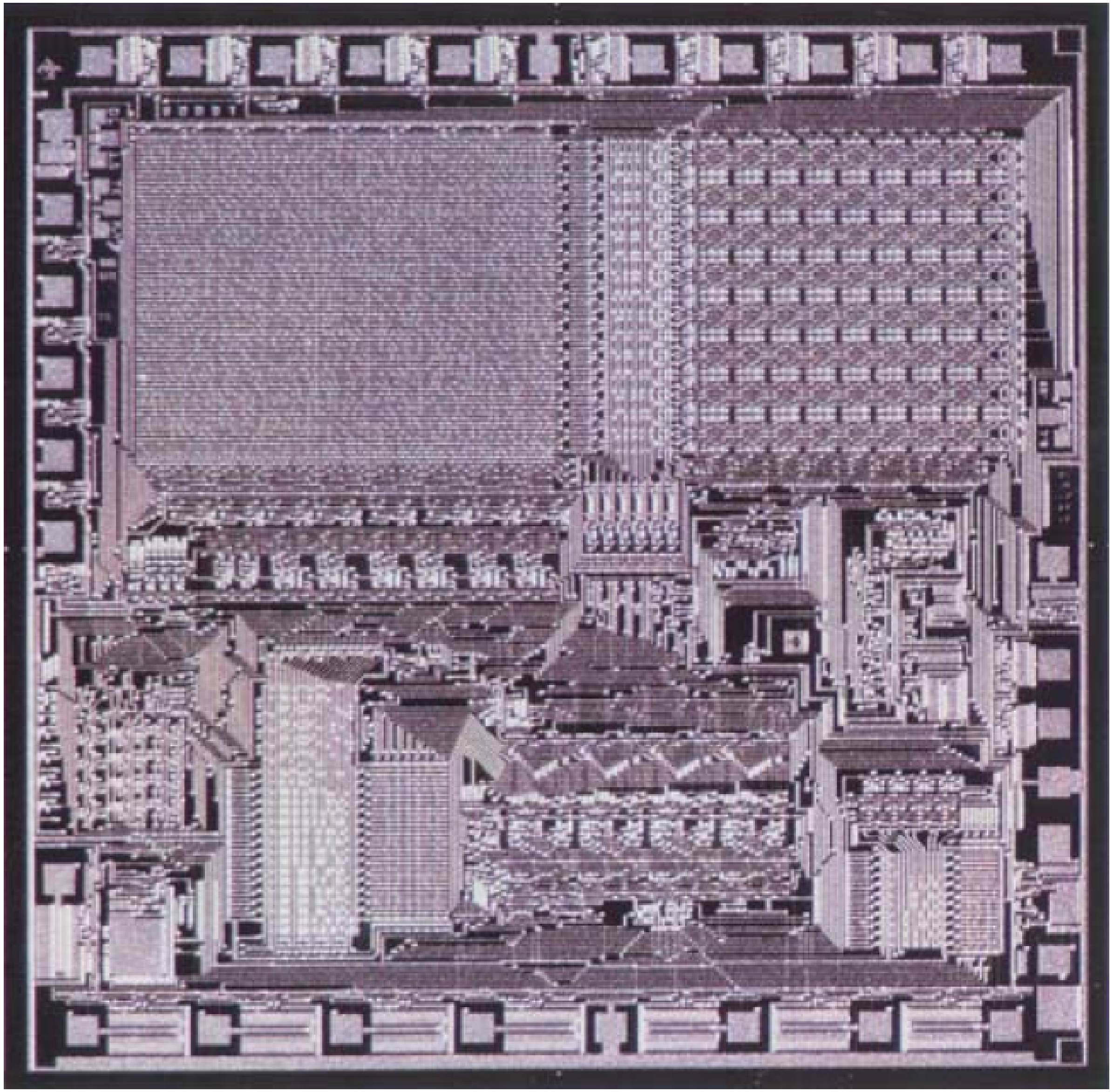
8080 Universal Processor - 1974

- Intel 8080
  - 5000 Transistors
  - 6 μm technology
  - 2 MHz clock
  - 8 bit
  - 4mm x 5 mm
  - Still produced in license by 12 companies



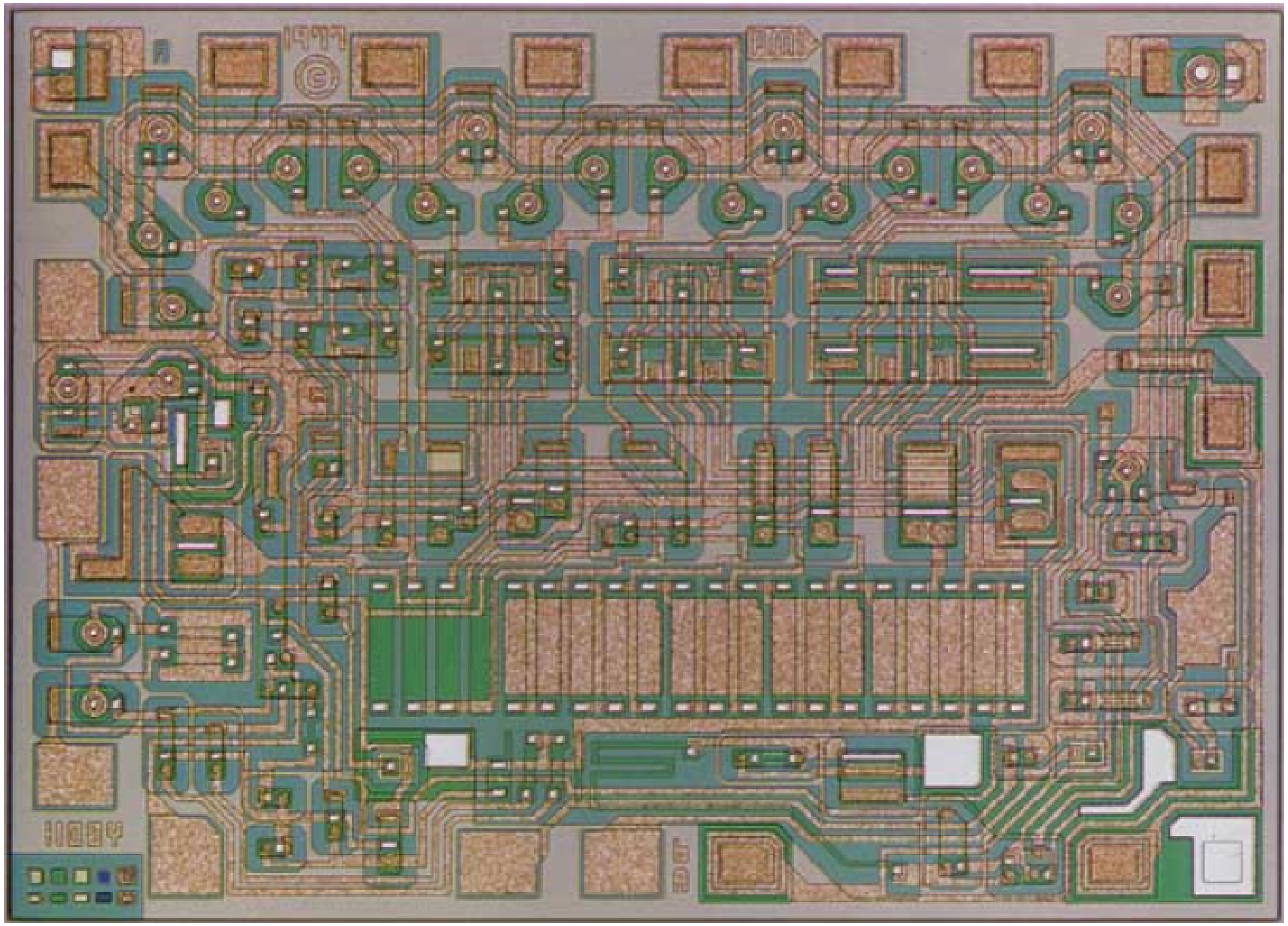
TI Competition - 1974

- TI IMS 1000 Micro Computer
  - CPU 4 bit
  - 256 RAM (right)
  - 1 kbit ROM (left)
- Used in pocket calculators and other consumer goods



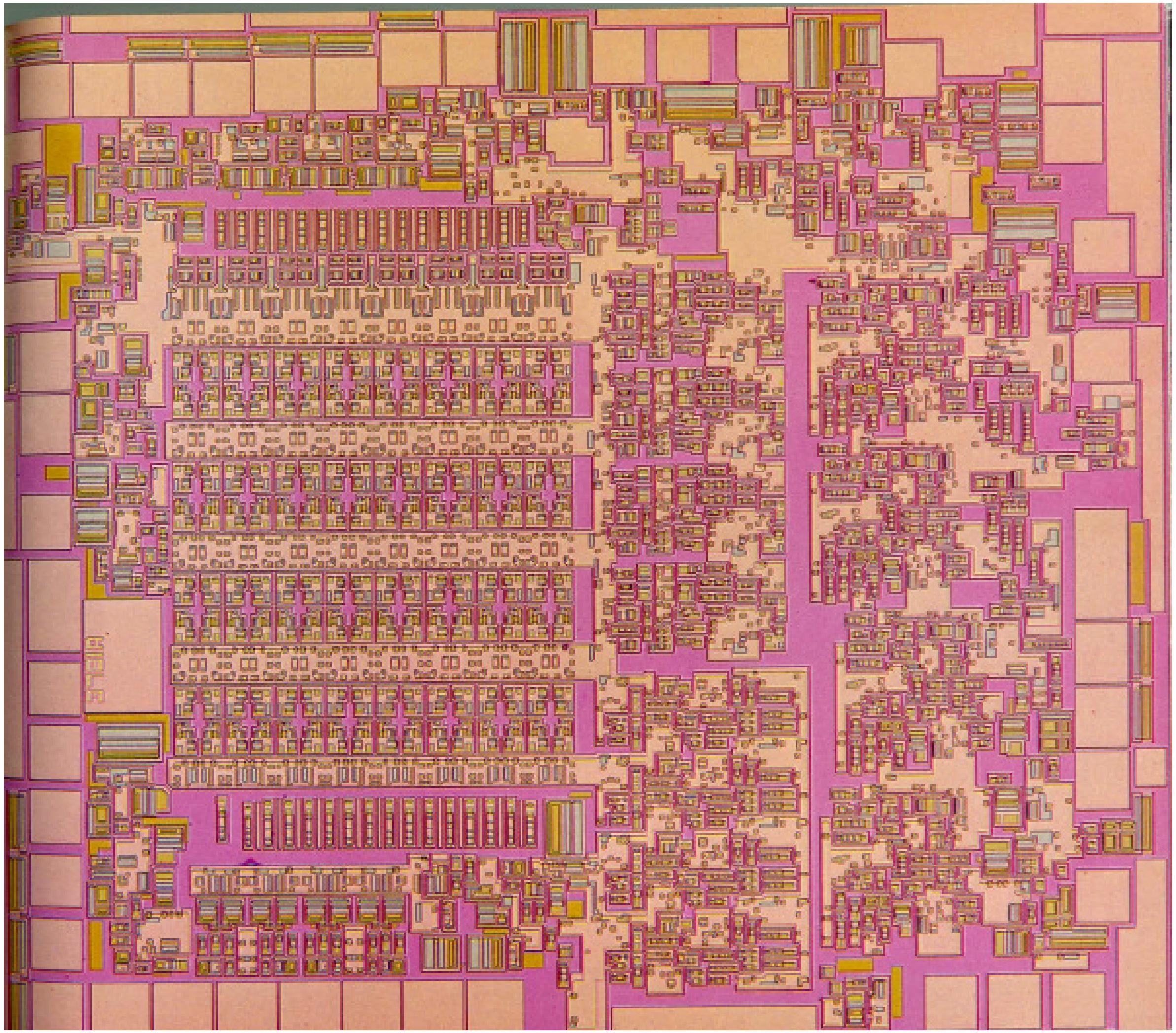
8 bit DAC - 1974

- Precision Monolithic DAC08CPU 4bit
  - First hybrid IC
  - 140 ns settling time
  - Bipolar technology
  - Still being produced
  - 1.6 mm x 2.2 mm



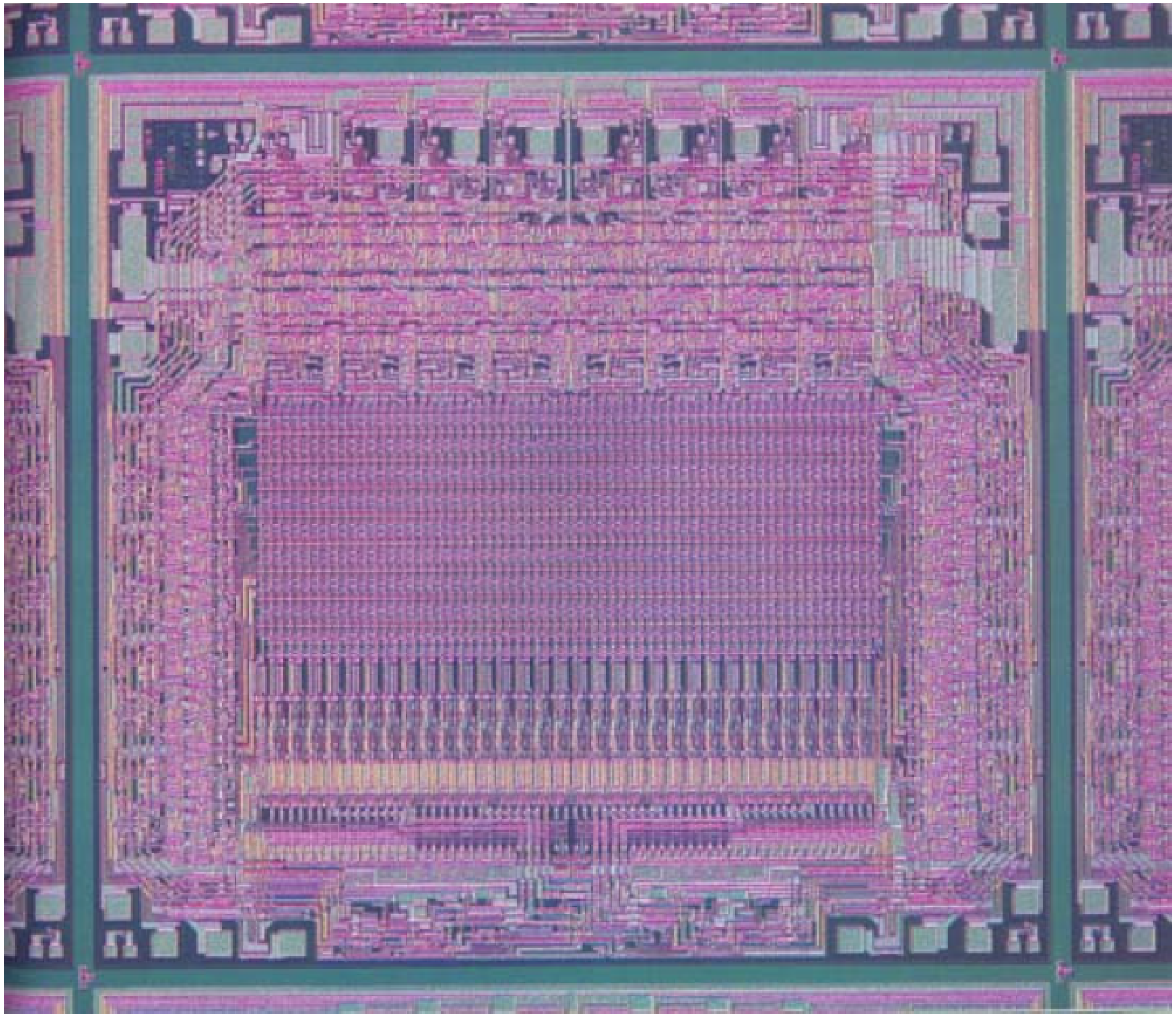
AMD Fast µP - 1974

- AMD Advanced Micro Devices
- Bit slice processor: several processors work on wider data word
- Bipolar transistors:
  – High power consumption
  – But much faster than CMOS (at this time)
  – 10 MHz clock



Programmable Array Logic (PAL) - 1977

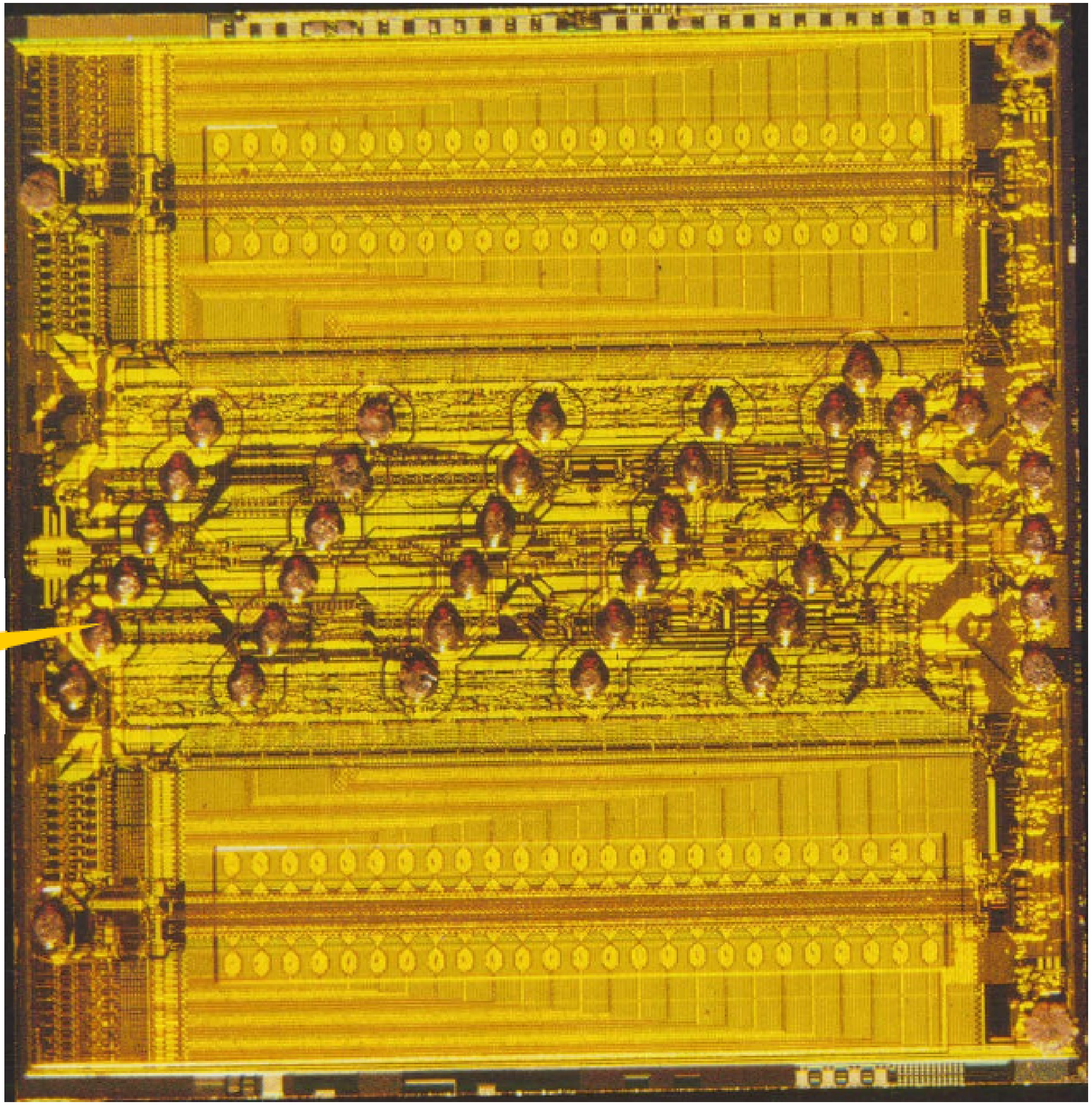
- MMI (Monolithic Memories Inc
- Programmable logic with fuses
- PAL16L8



65536 Bit Dynamic RAM - 1977

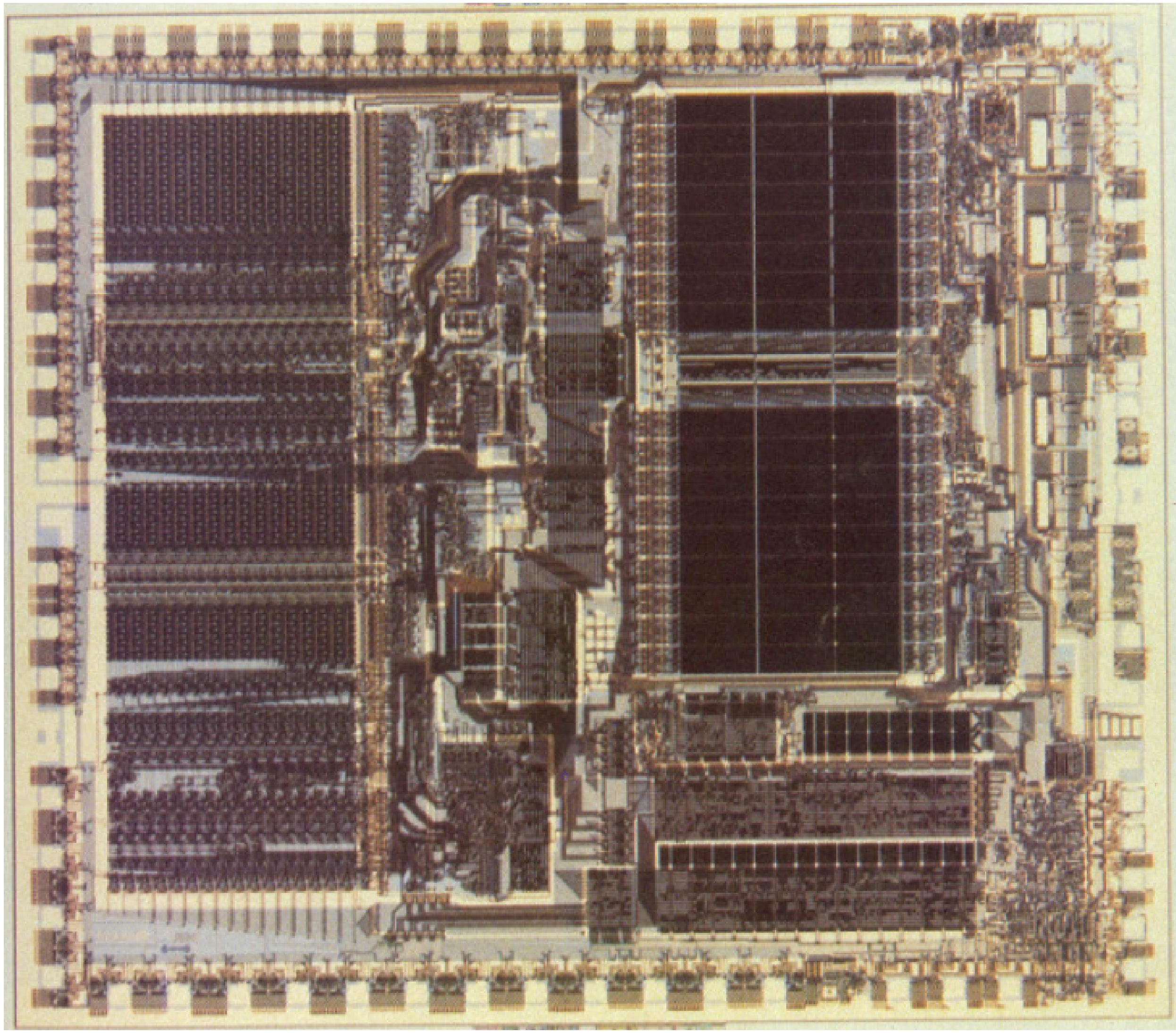
- IBM starts chip business relatively late
- Innovation:
  - Memory chip with redundancy
  - Bump bonds

Bump bonds



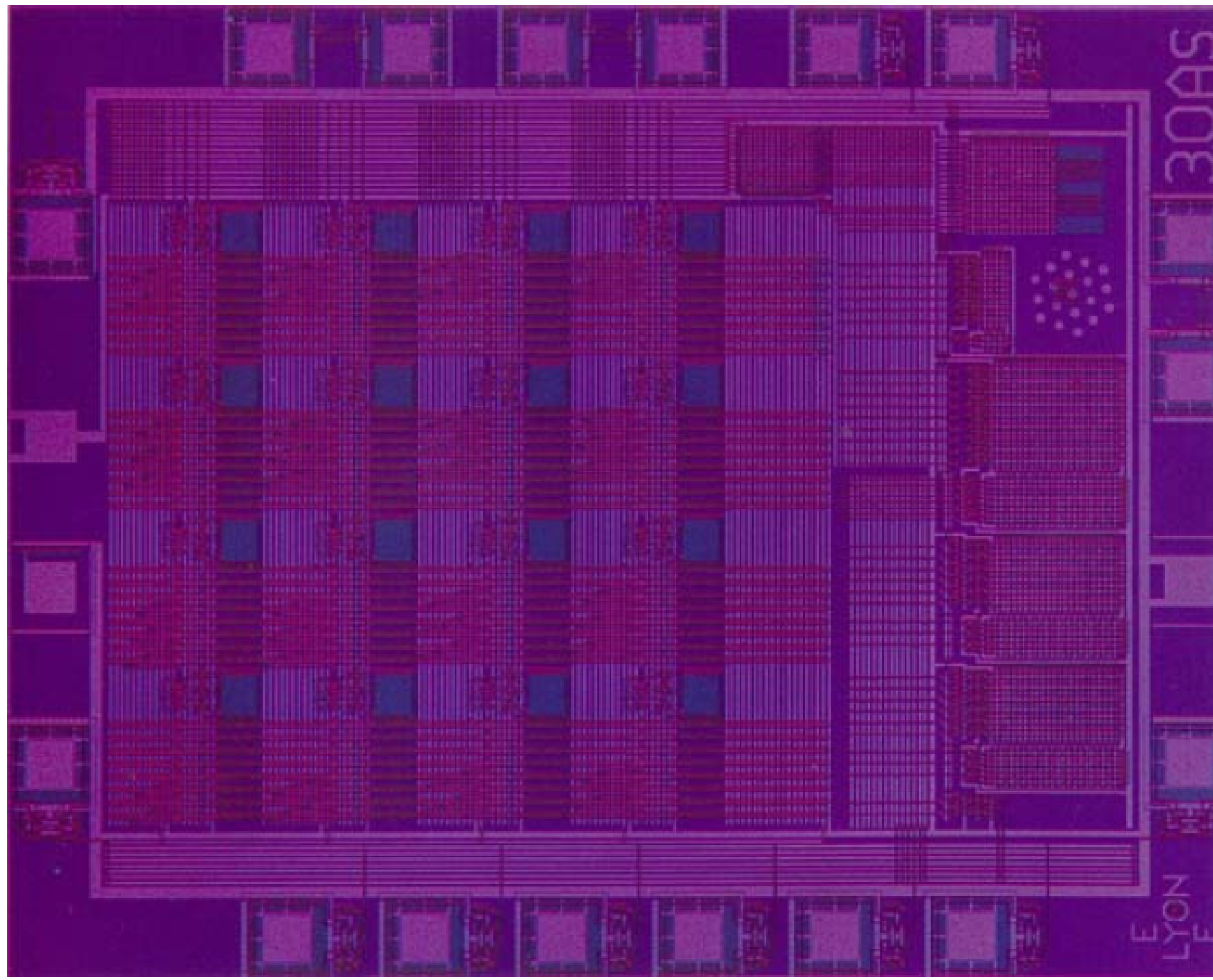
Motorola 16 Bits - 1979

- Motorola 68000
- NMOS transistors
- 16 bits but emulate 32 bits
- 50x faster than 8080
  - Multiplier on chip



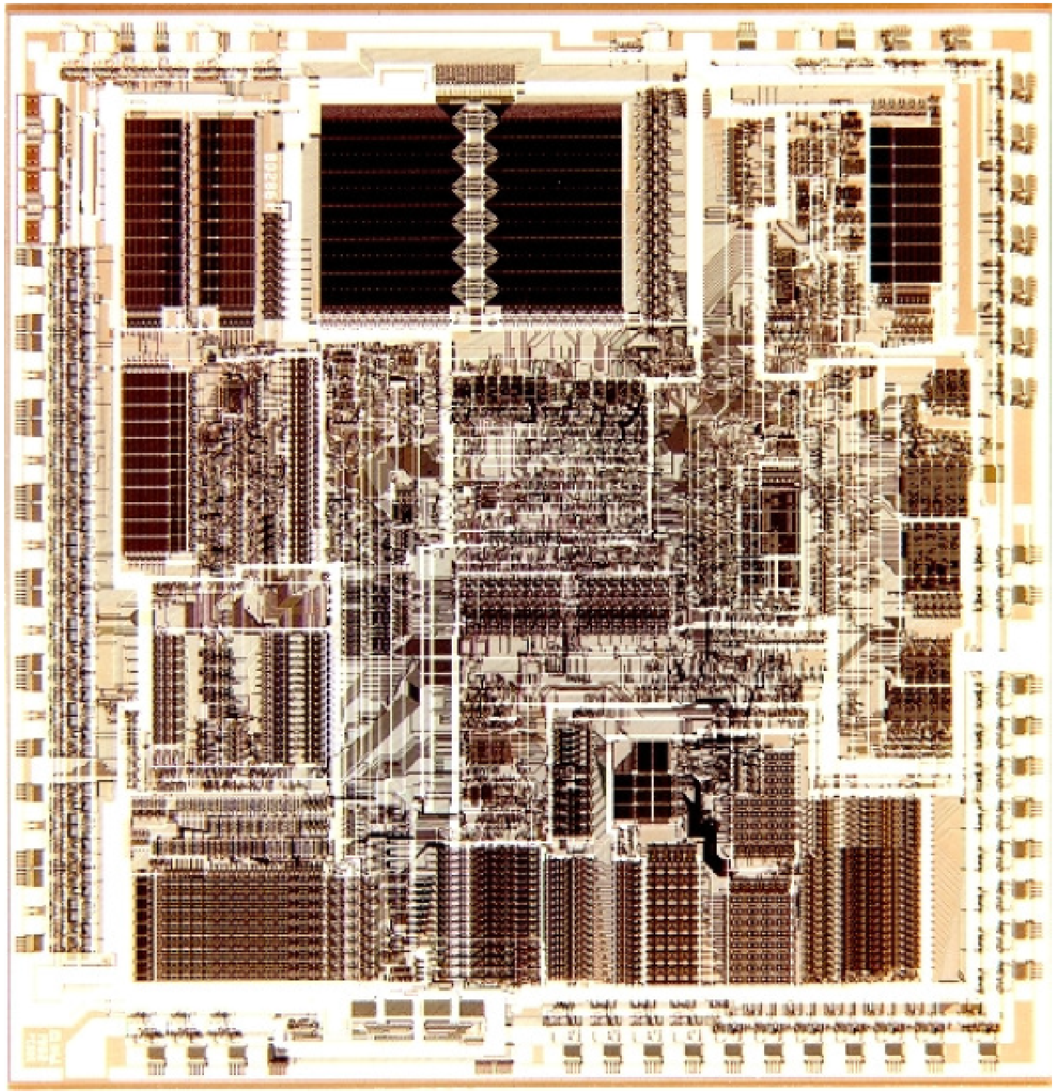
Optical Mouse- 1980

- Xerox
- 16 optical detectors recognize the movement of illuminated background surface



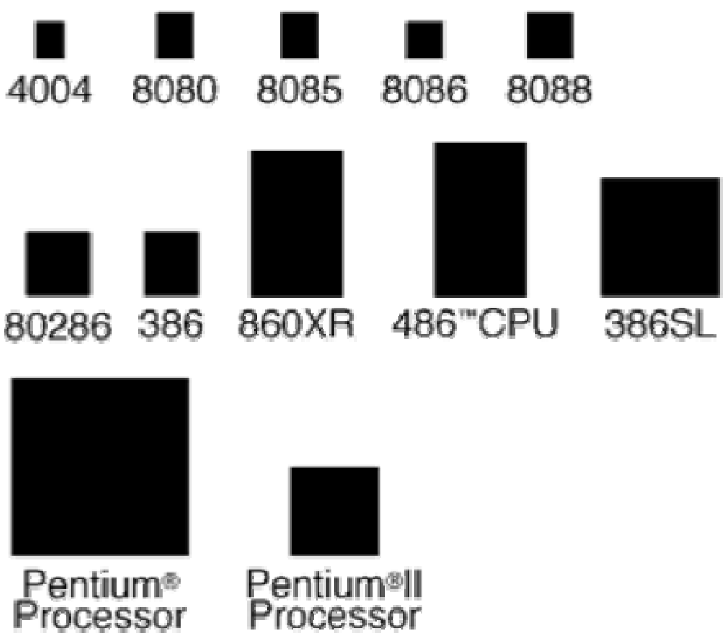
Intel 80286 - 1982

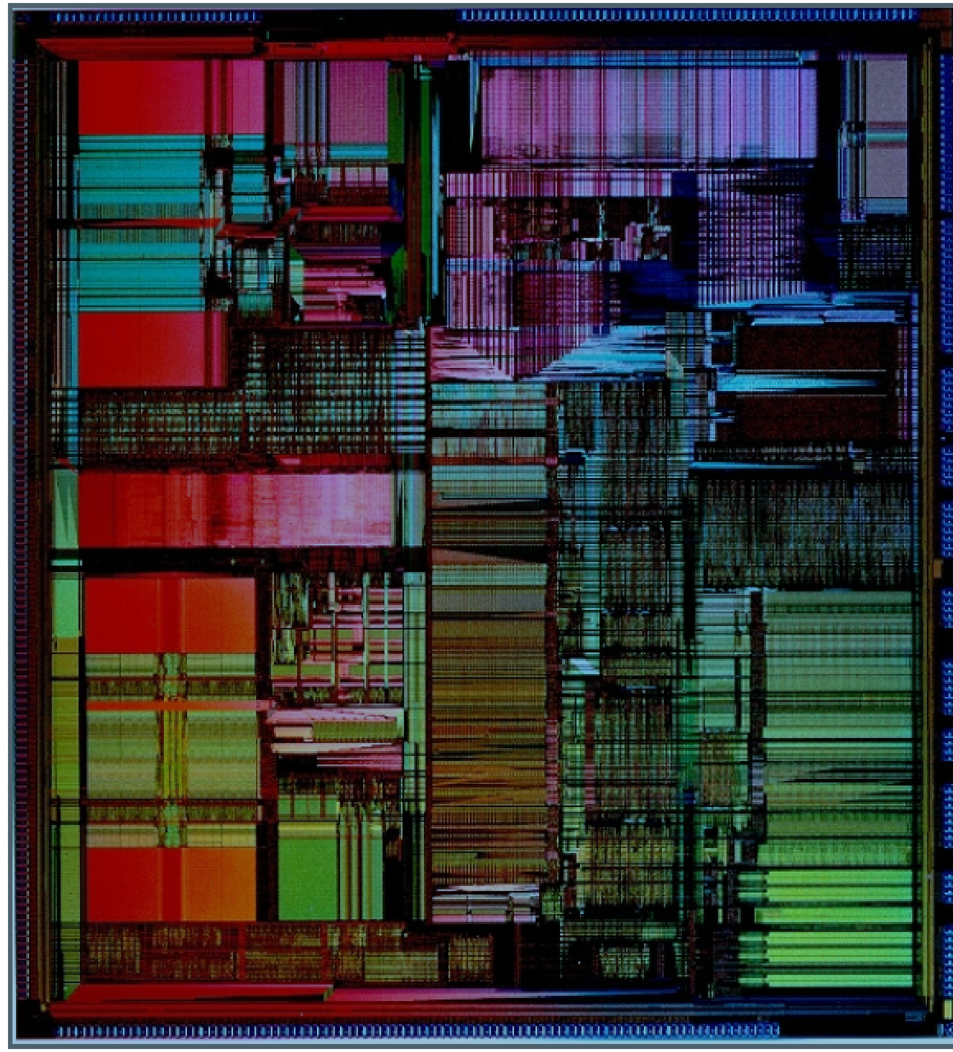
- 6 -12 MHz
- 16 bits
- 120000 transistors
- 1.5 μm technology



Intel Pentium - 1993

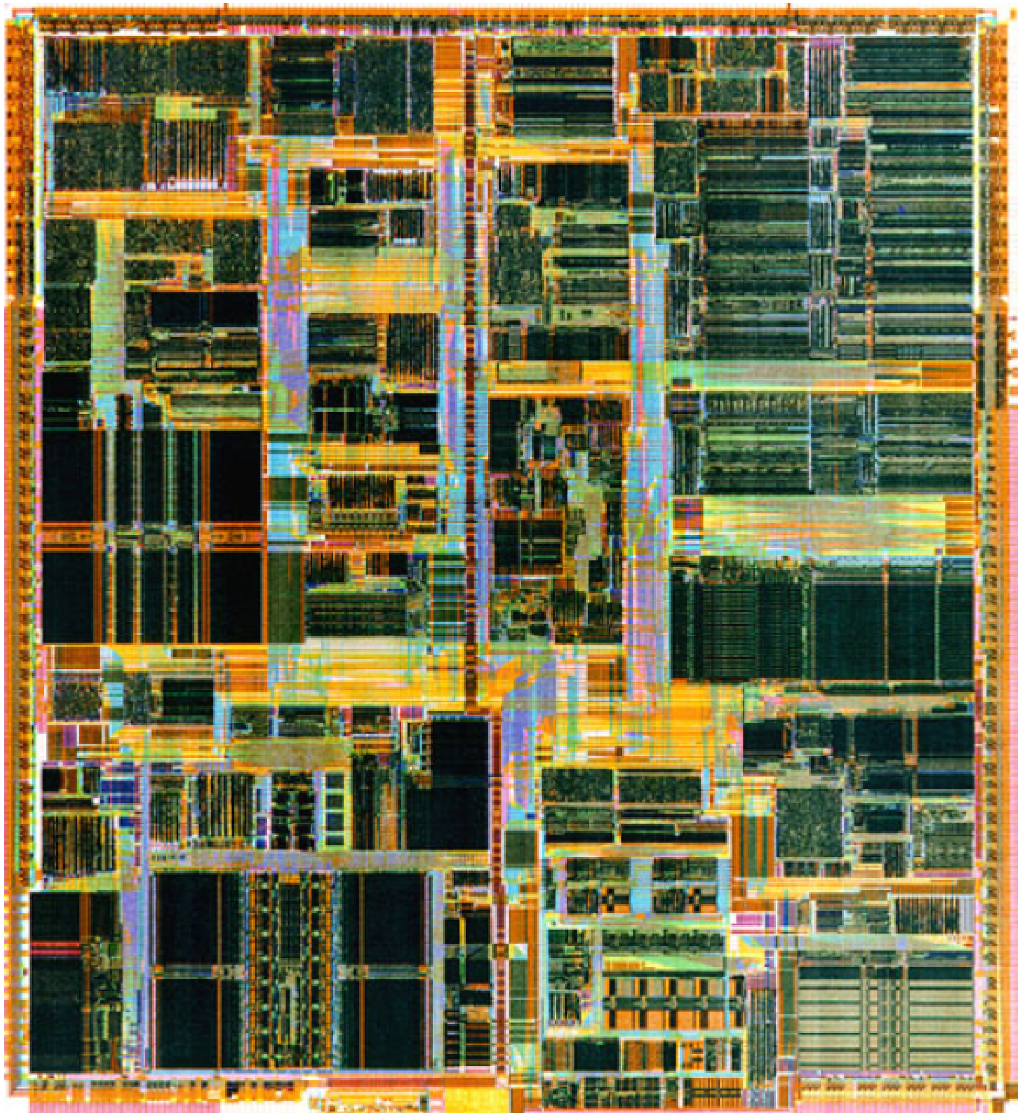
- 60 MHz
- 32 bits
- 3.1 mio transistors
- 0.8 μm technology





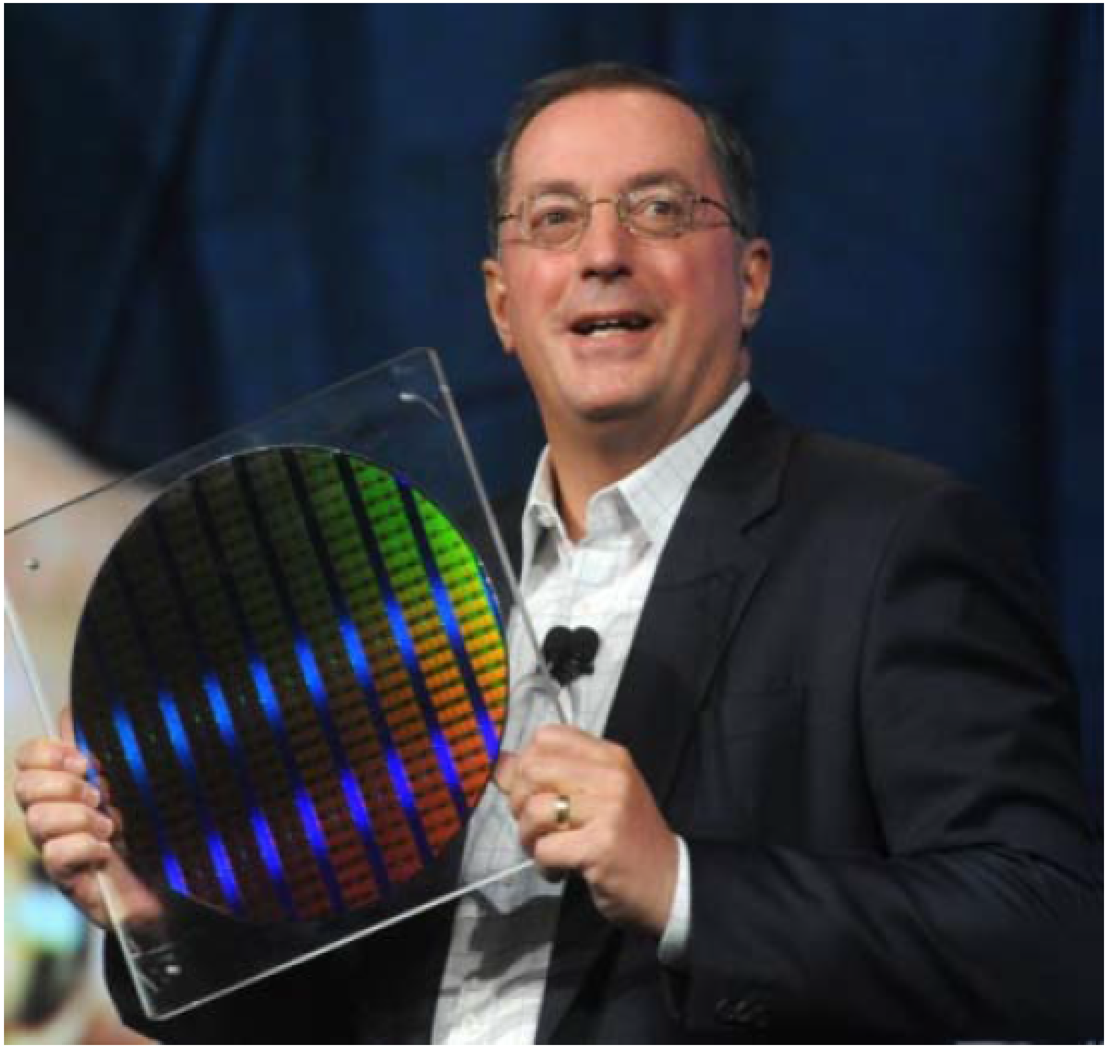
Intel Pentium IV - 2000

- 1.5 GHz
- 42 mio transistors
- 0.18 μm technology



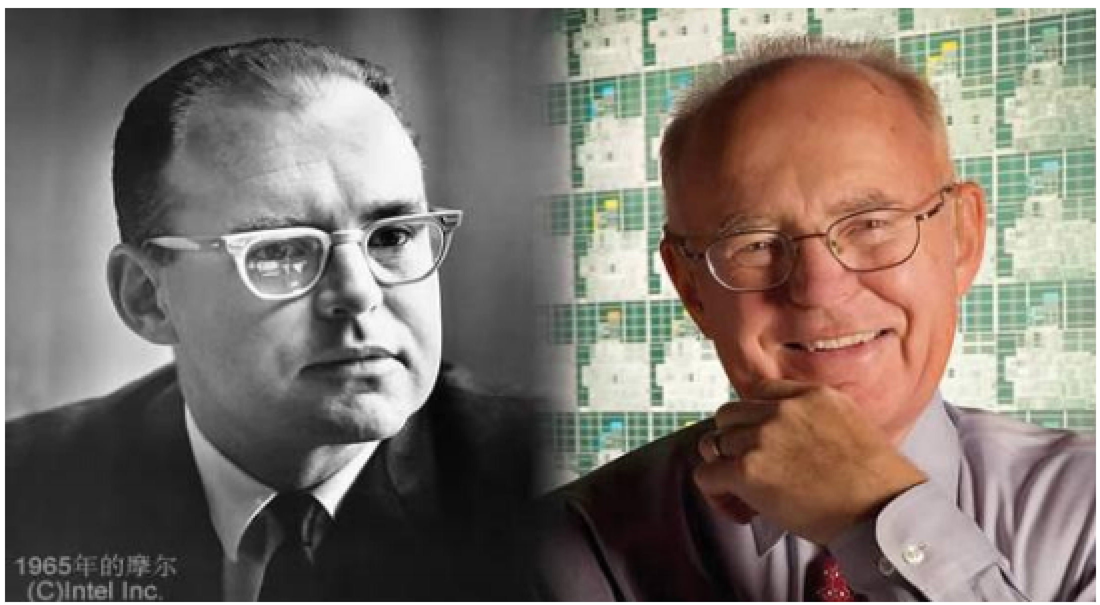
Intel Pentium - 2009

- 1.5 GHz
- 2.9 billion transistors
- 0.022 μm technology

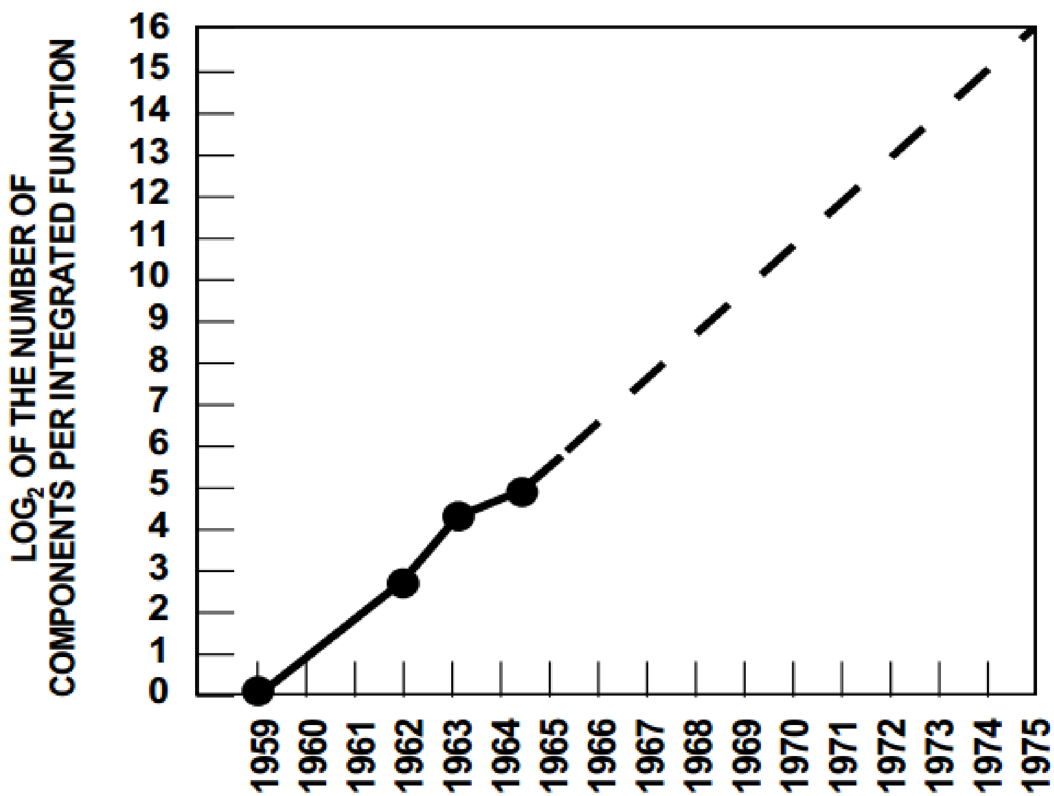


Moore's Law

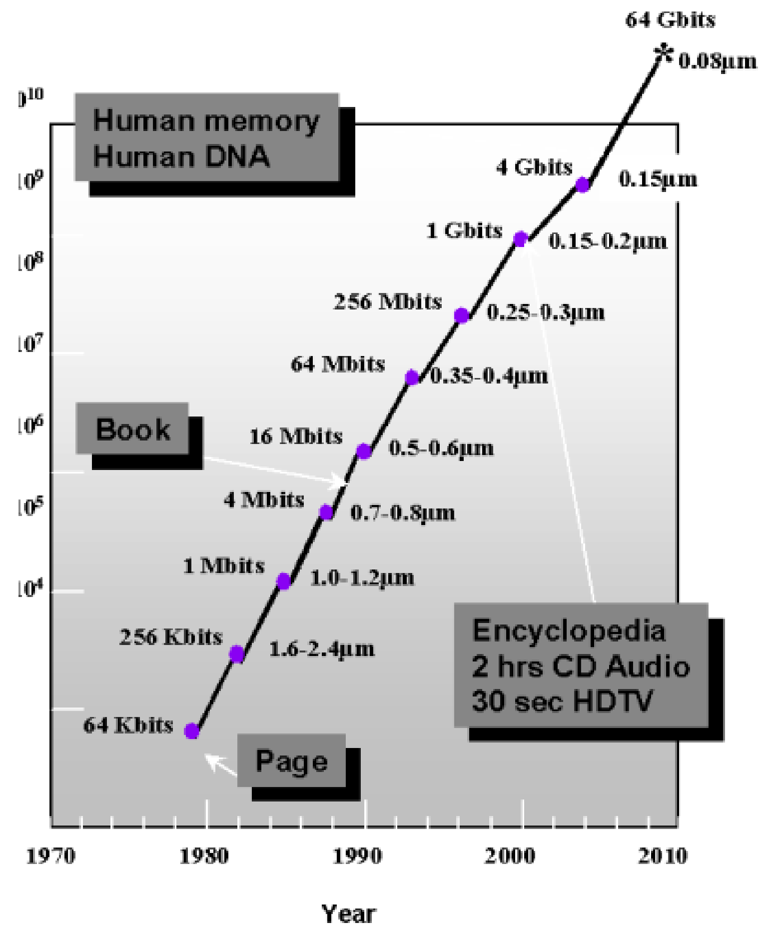
- In 1965, Gordon Moore noted that the number of transistors on a chip doubled every 18 to 24 months
- He made a prediction that semiconductor technology will double its ***effectiveness*** every 18 months



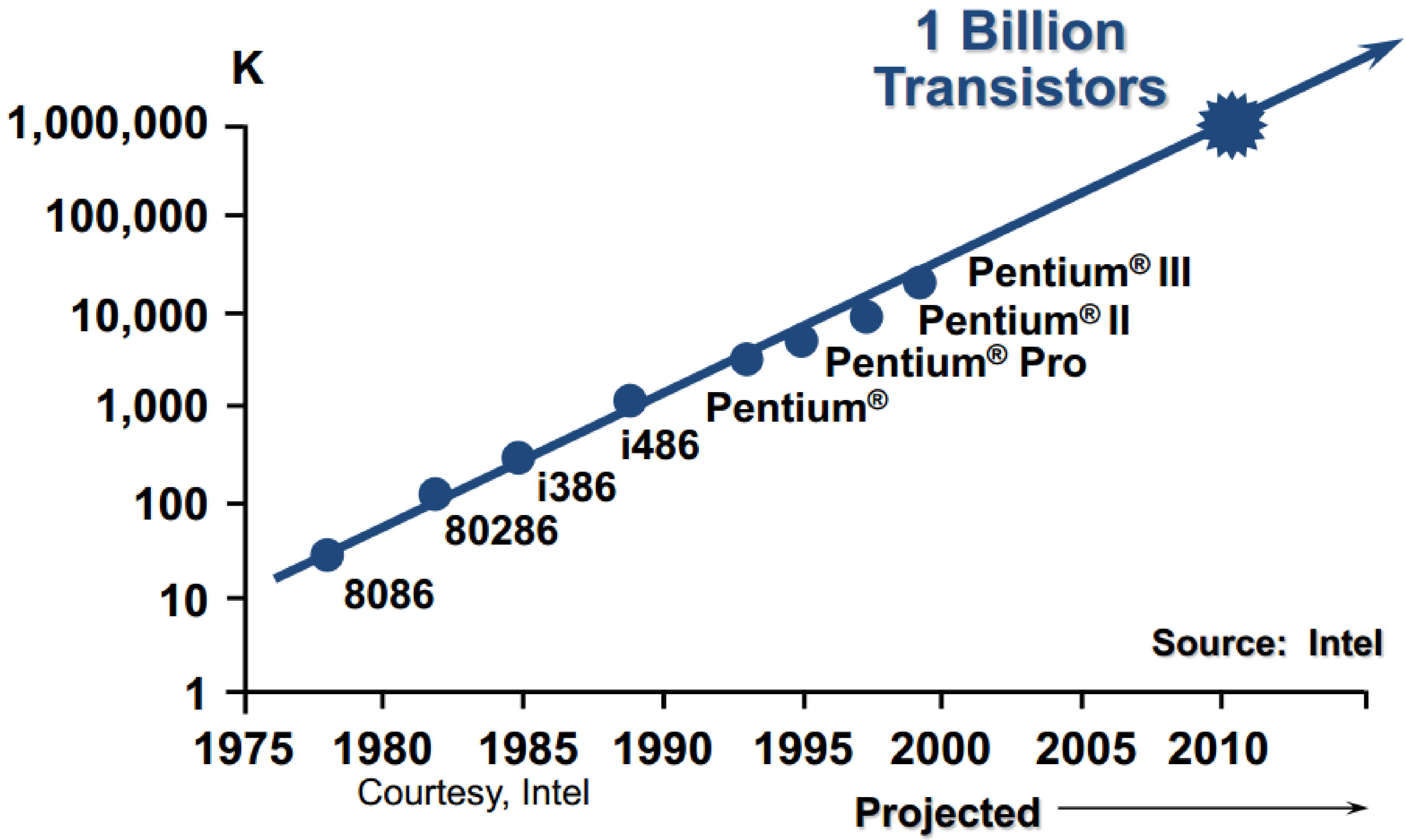
Moore's Law



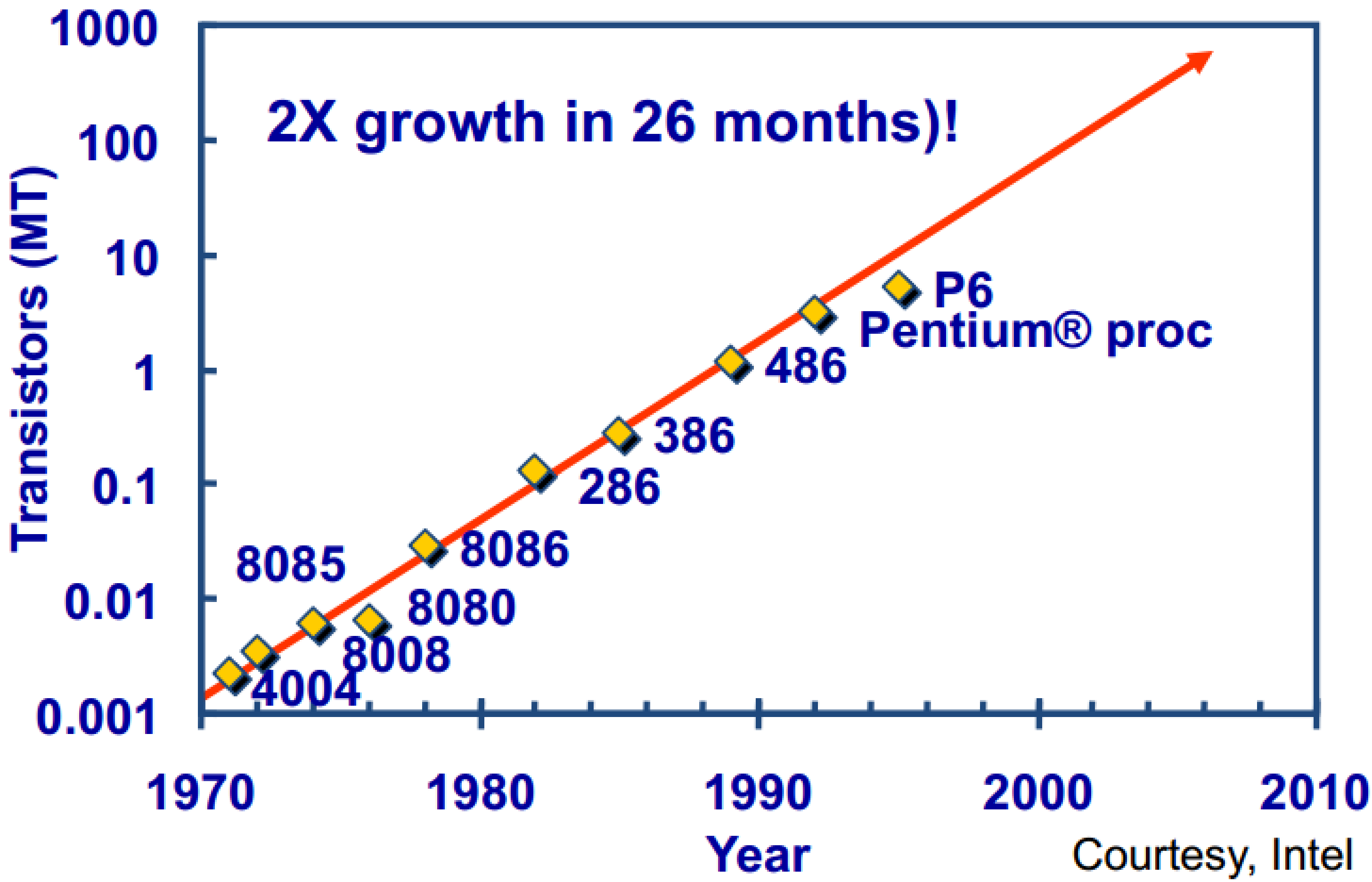
Electronics, April 19, 1965.



Transistor Number

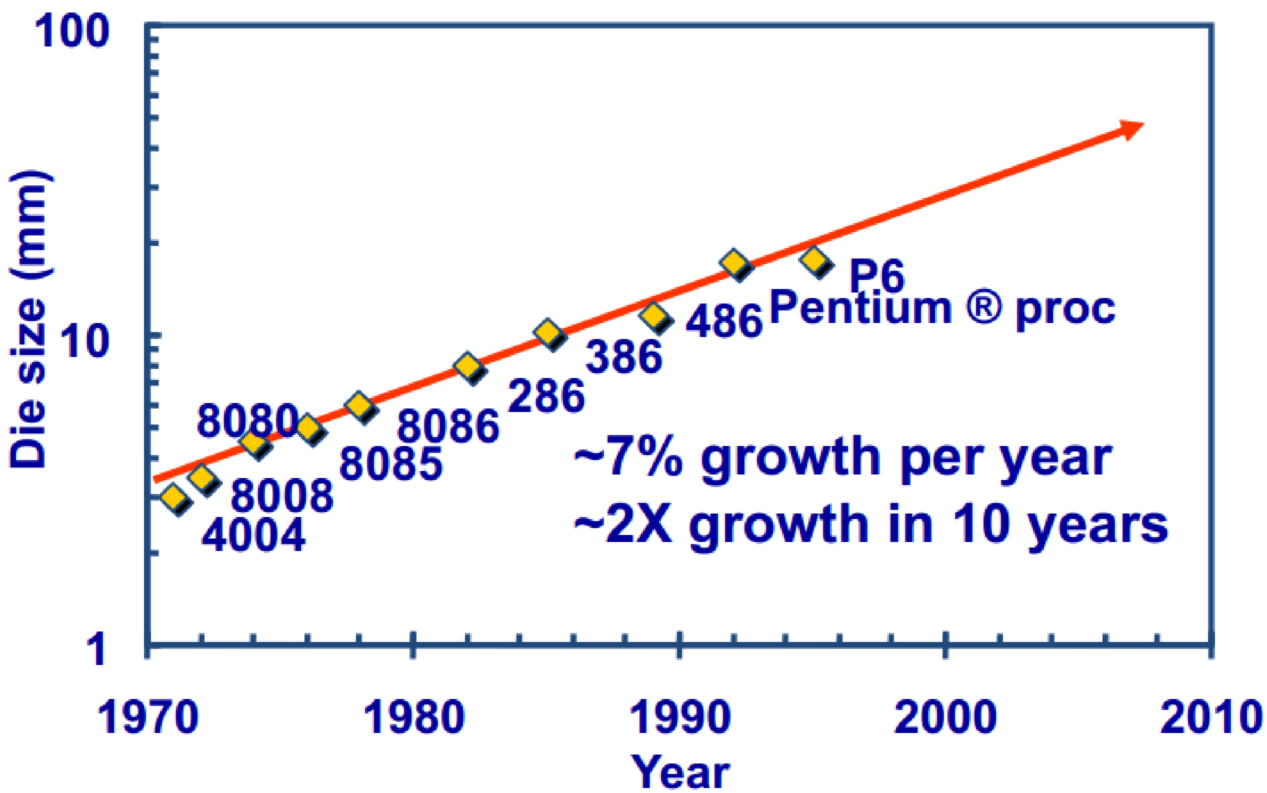


Microprocessors



Transistors on Lead Microprocessors double every 2 years

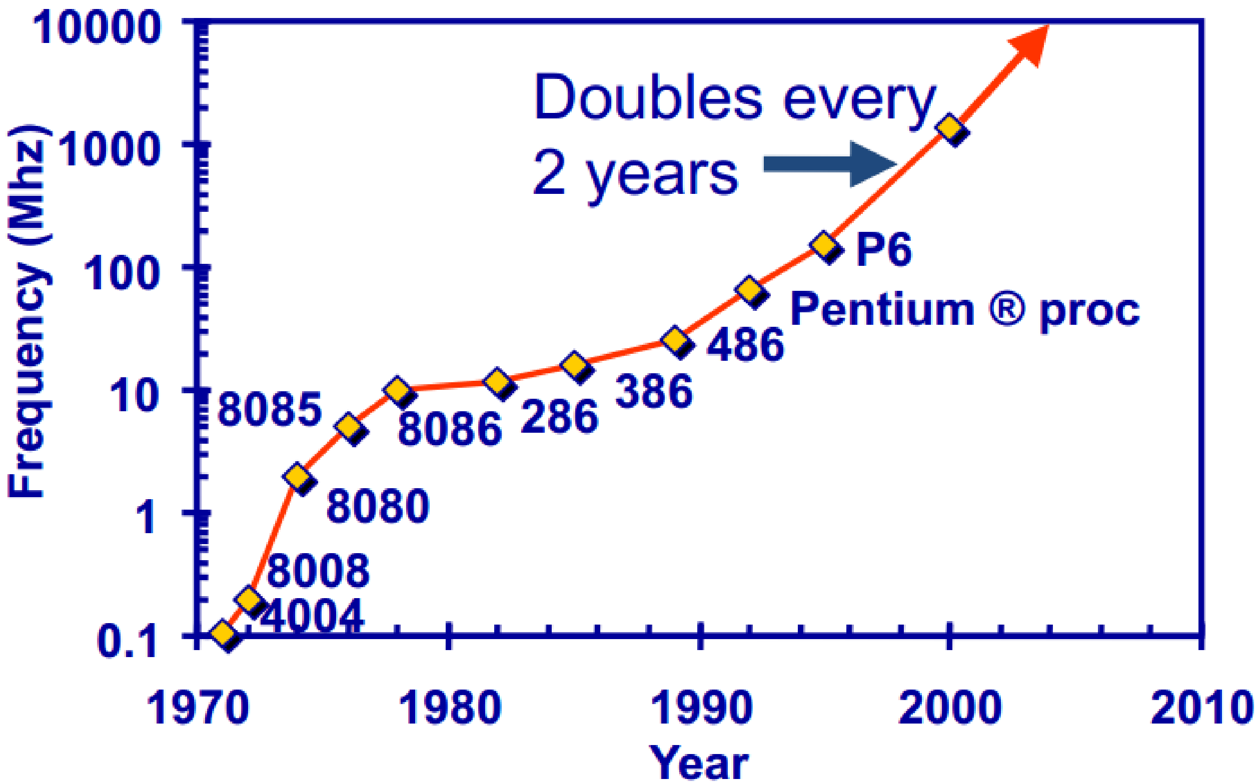
Die Size



Courtesy, Intel

Die size grows by 14% to satisfy Moore's Law

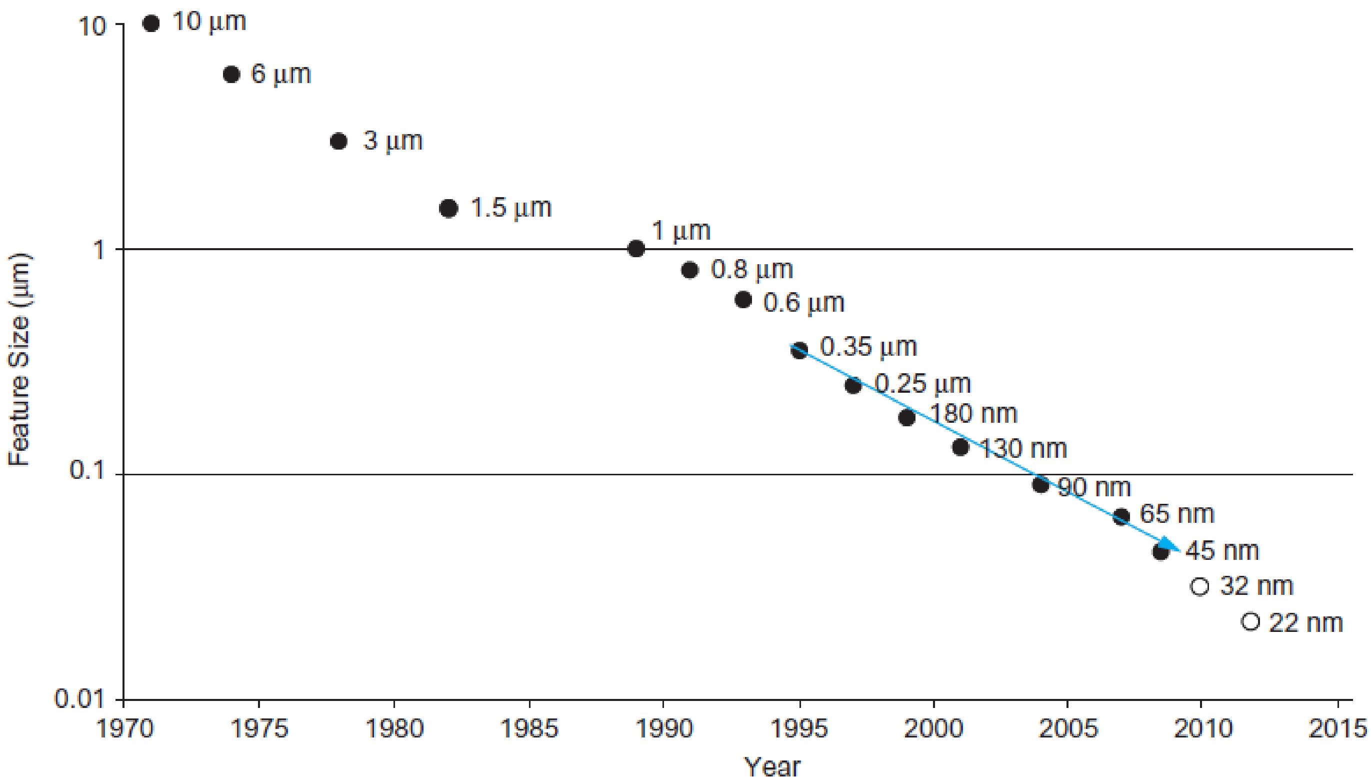
Clock Frequency



Courtesy, Intel

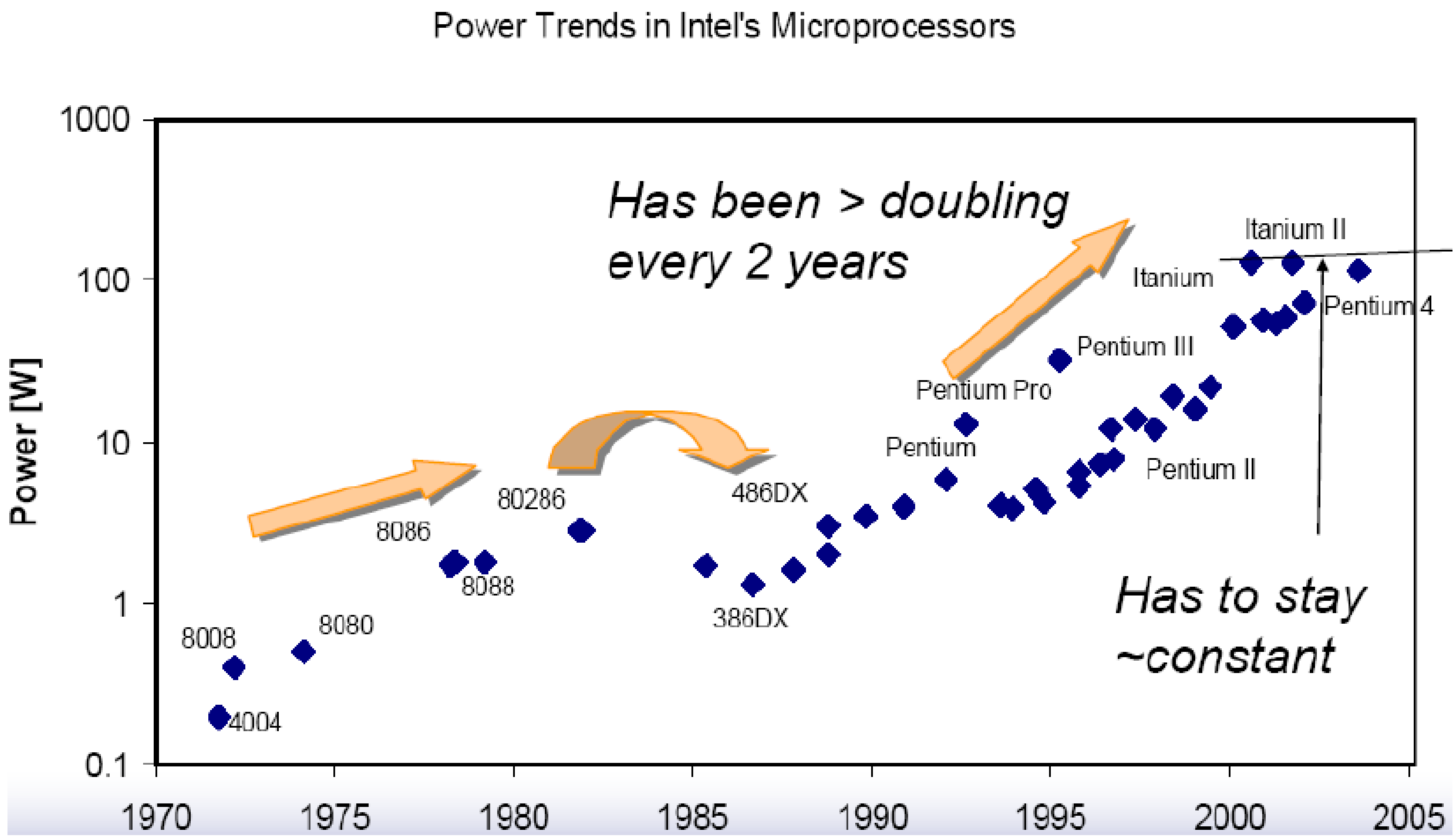
Lead Microprocessors frequency doubles every 2 years

Technology Nodes

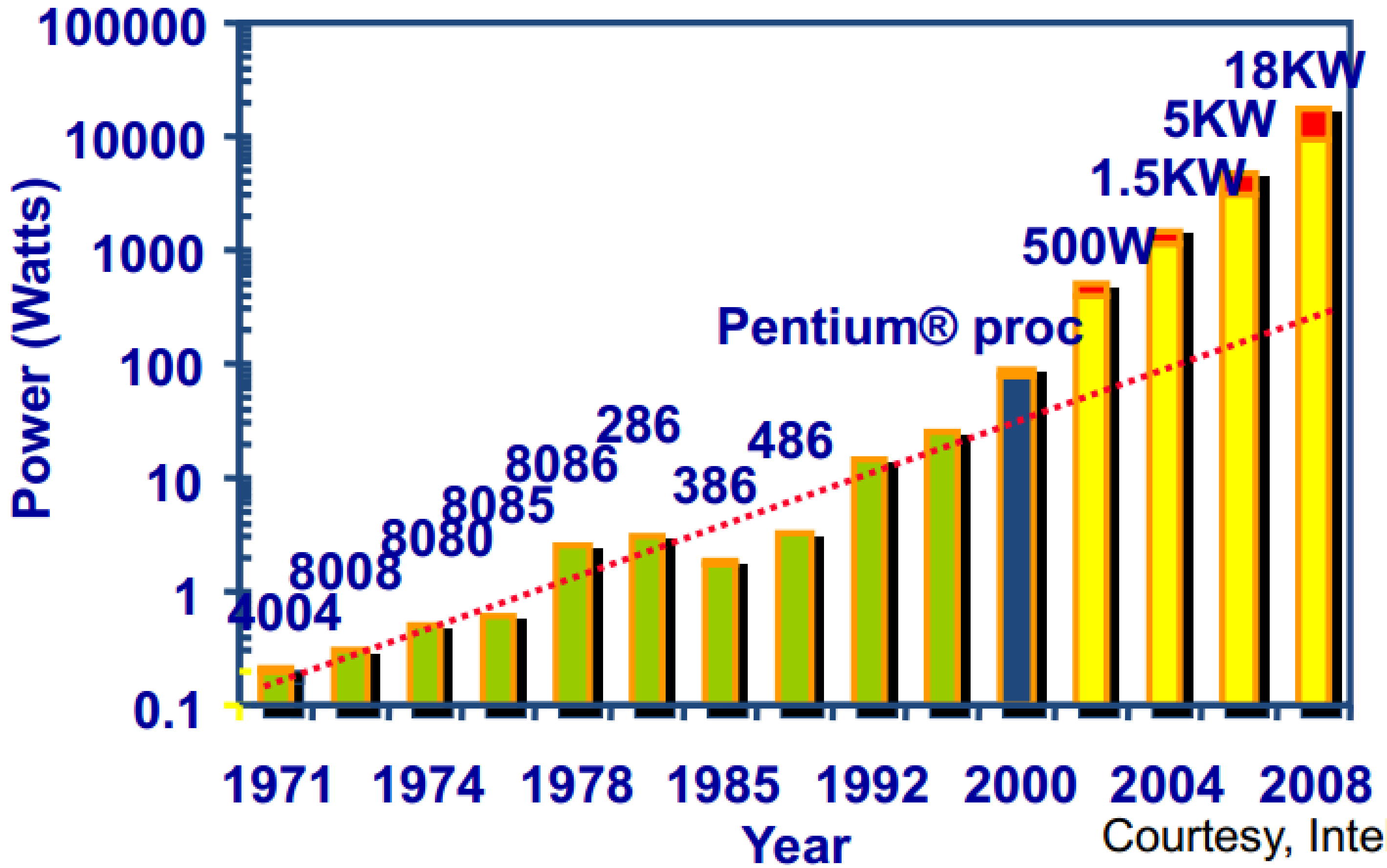


- Moore’s Law will come to an end (at least by simple scaling)

Power Dissipation



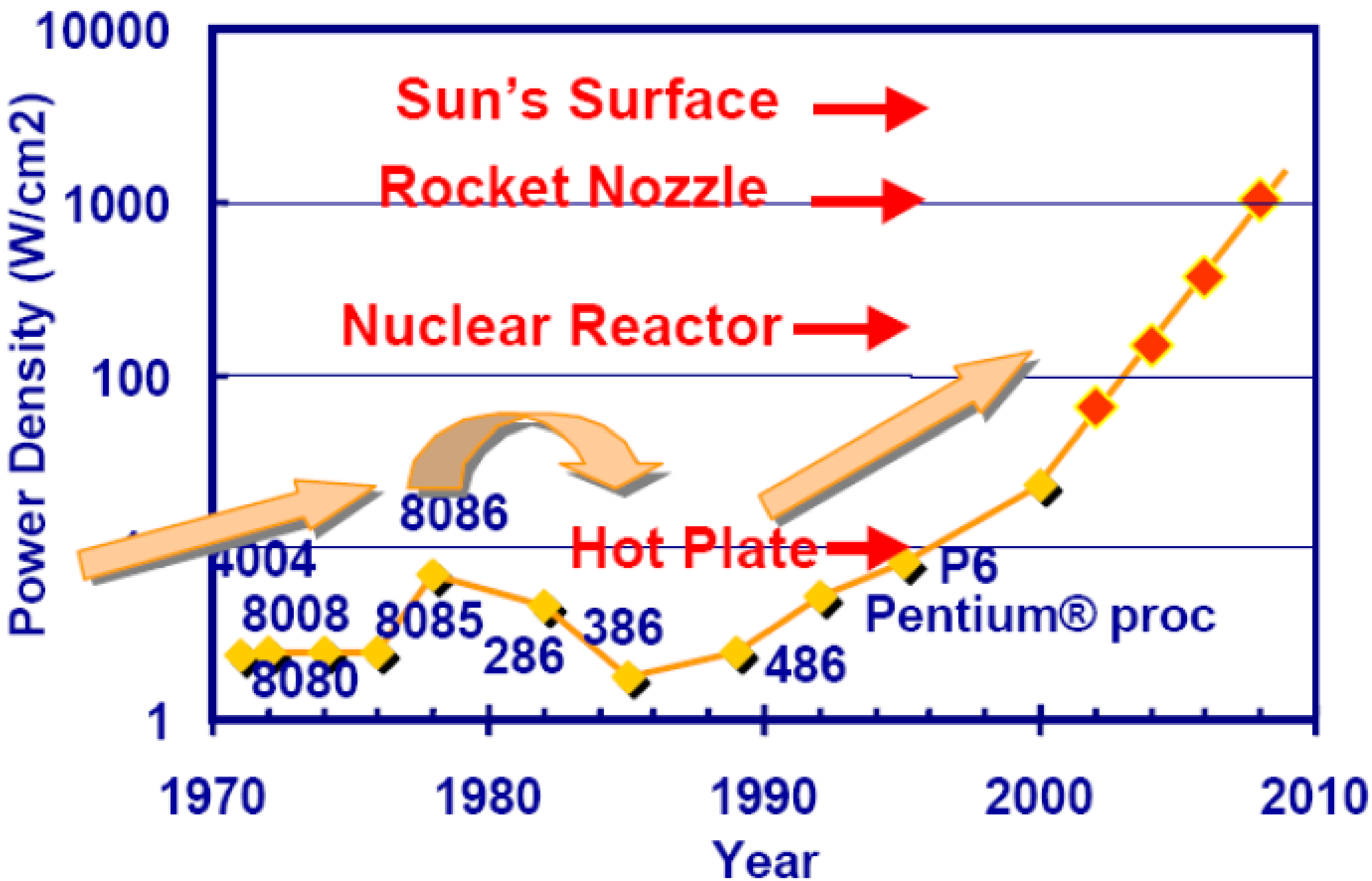
Power/Heat: Major Problem



S. Borkar, IEEE Micro 1999

P. Gelsinger: μProcessor for the New Millenium, ISSCC 2001

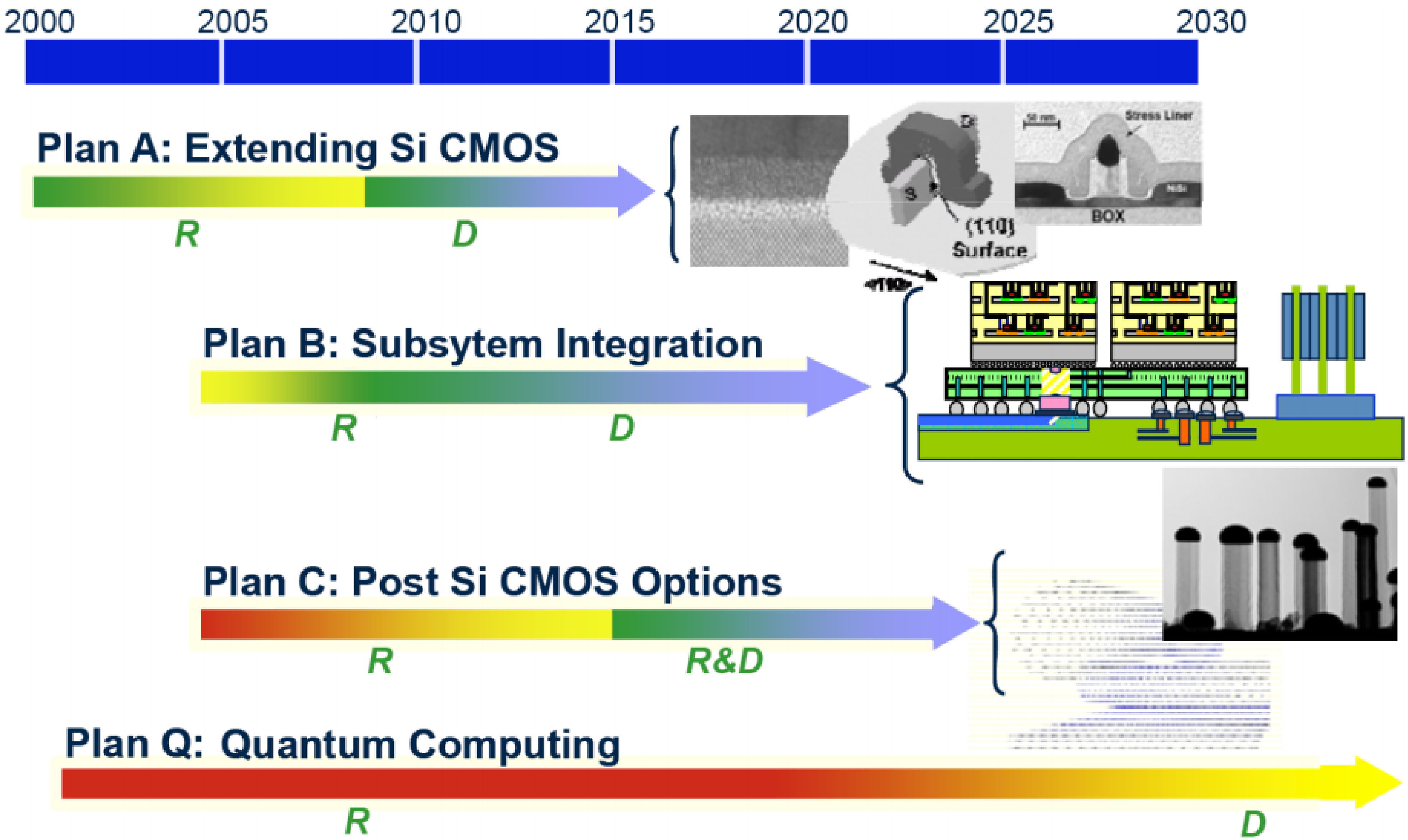
Power Density



S. Borkar

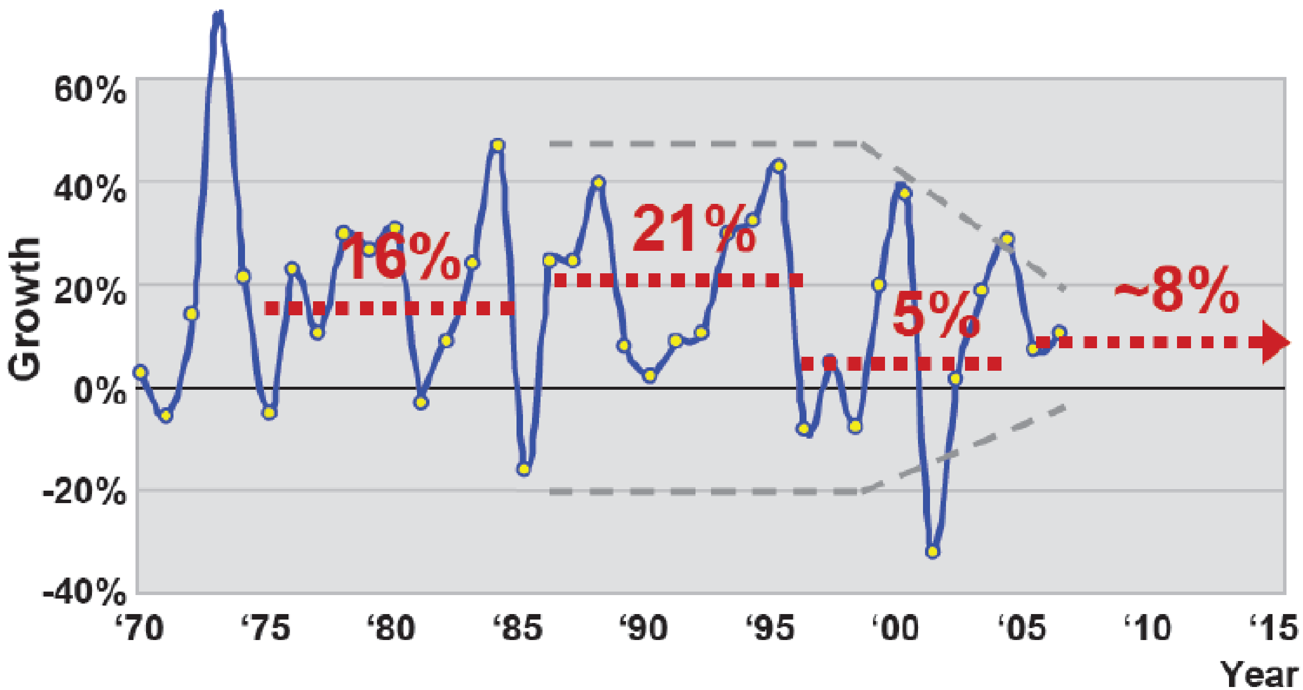
Power density too high to keep junctions at low temp

Technology Roadmap



T.C. Chen, Where Si-CMOS is going: Trendy Hype vs. Real Technology, ISSCC'06

Semiconductor Market

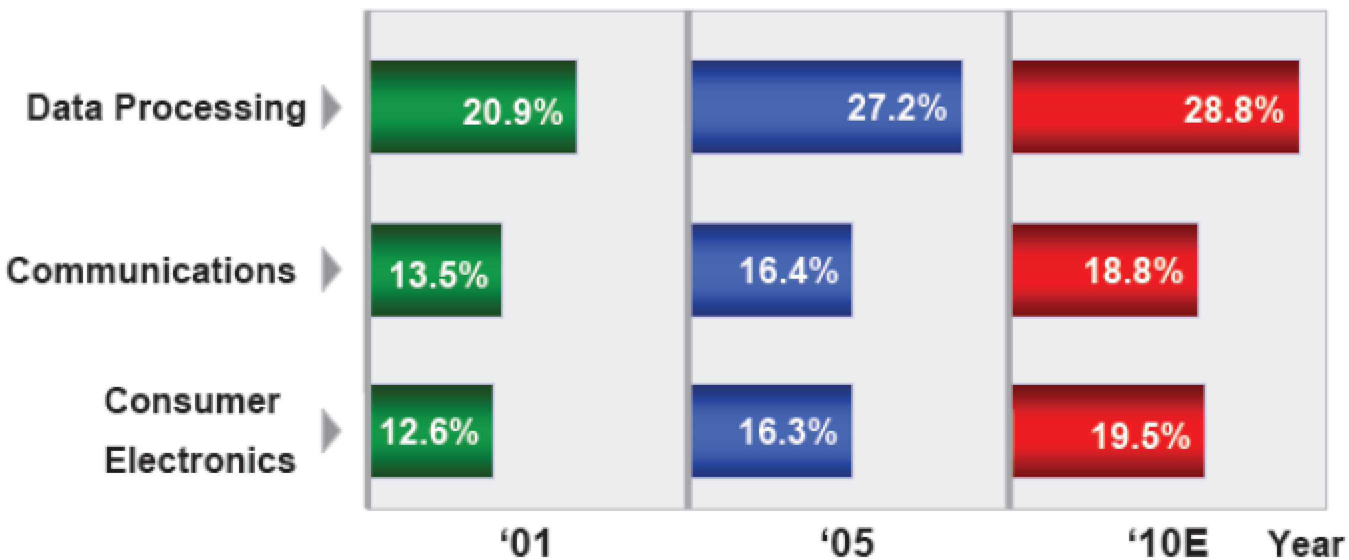


Year	Growth
'02	+1%
'03	+18%
'04	+28%
'05	+7%
'06	+9%
'07	+4%
'08E	+7~9%

Source: SIA – TSMC

- The semiconductor market will continue to grow

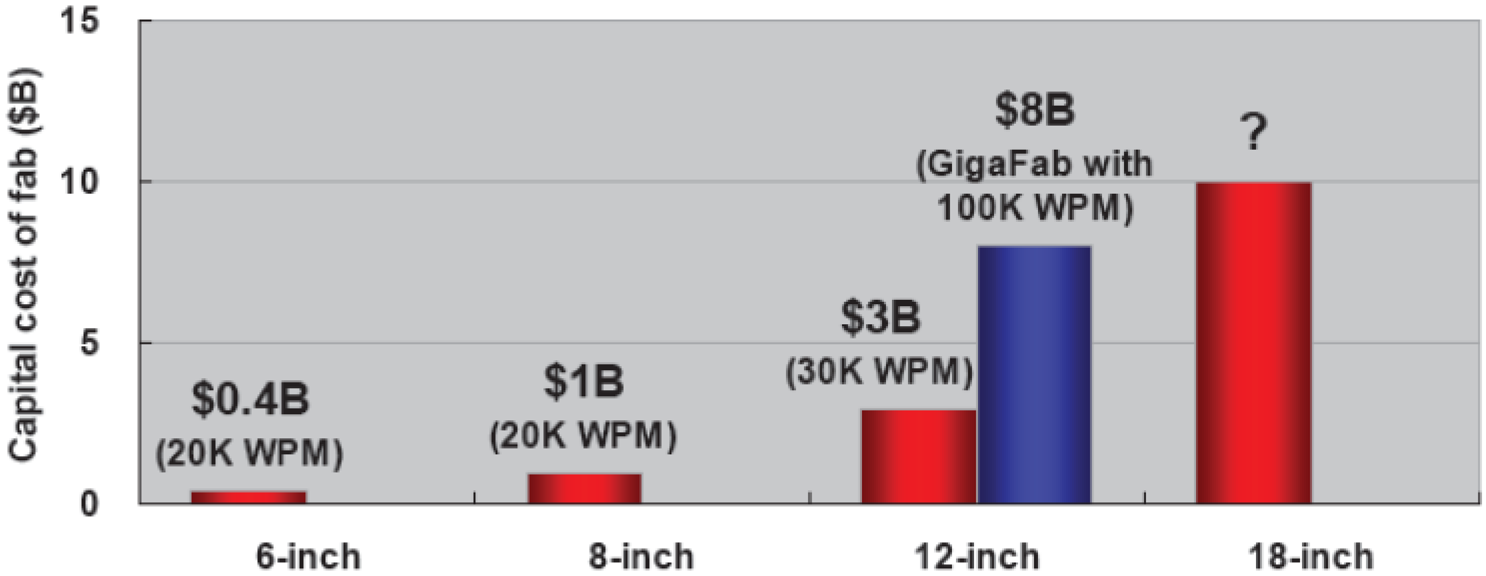
Semiconductor Market Expansion



Source: WSTS, IC Insights, TSMC

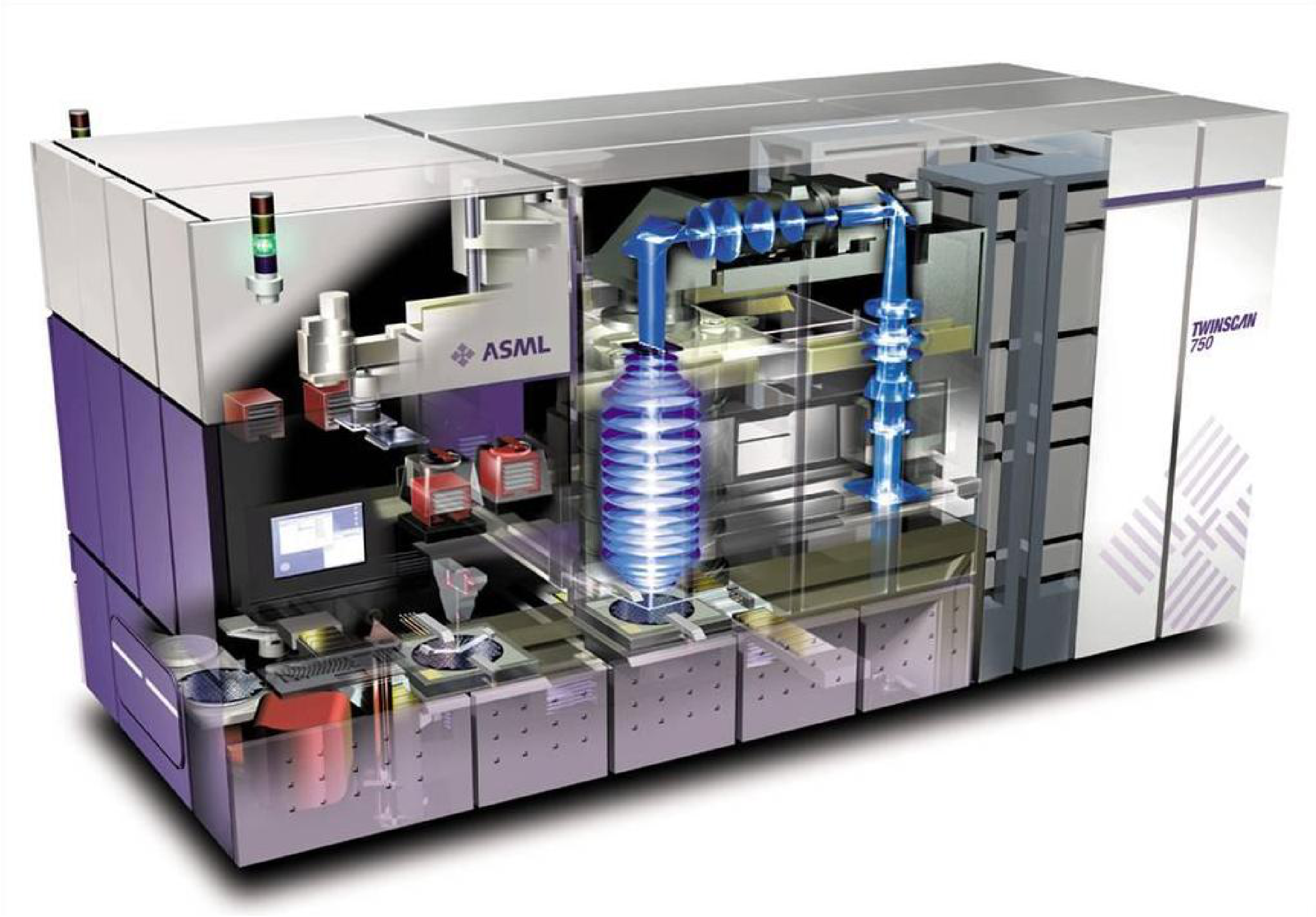
- Increasing semiconductor penetration in electronics

Future Challenge: Technology Cost



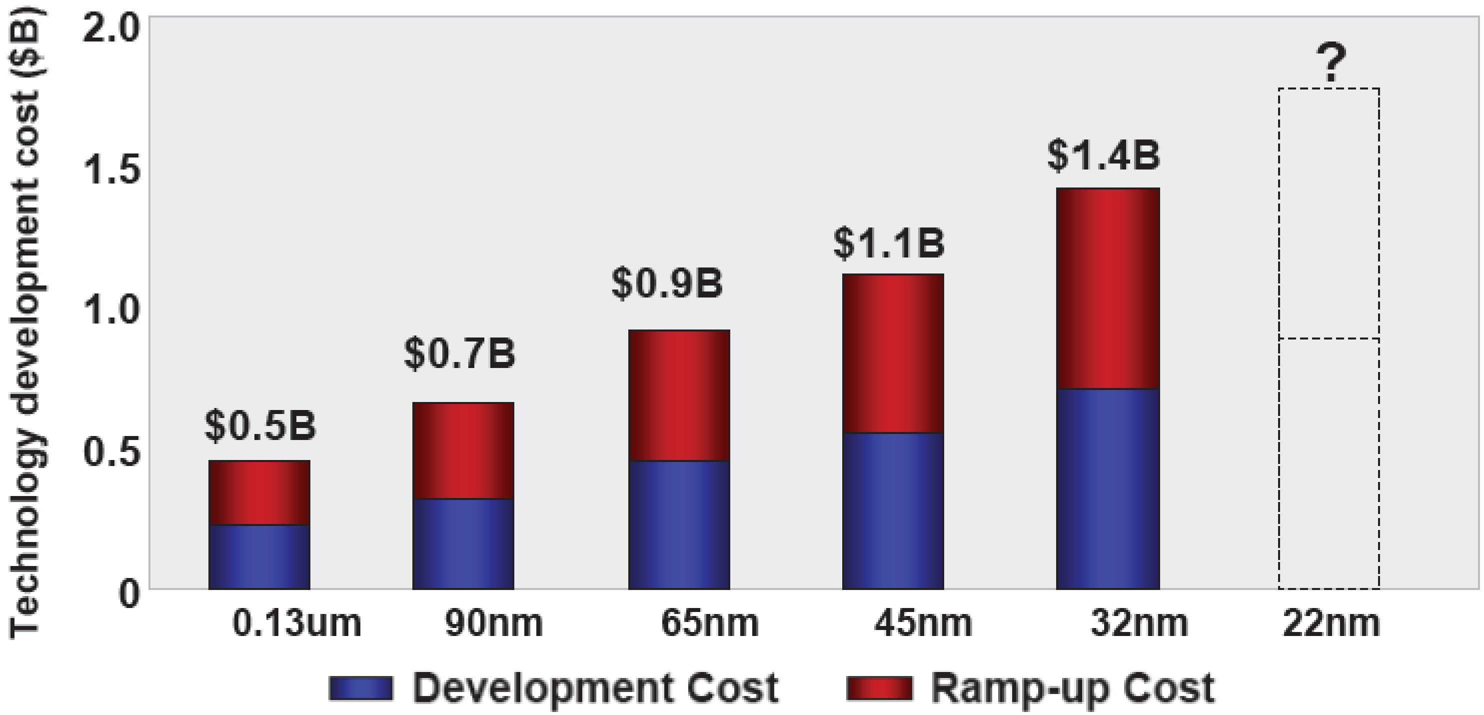
- Capital expenditure for constructing a new fab is increasing
- Major factor for financing and future profit

Example Stepper ASML



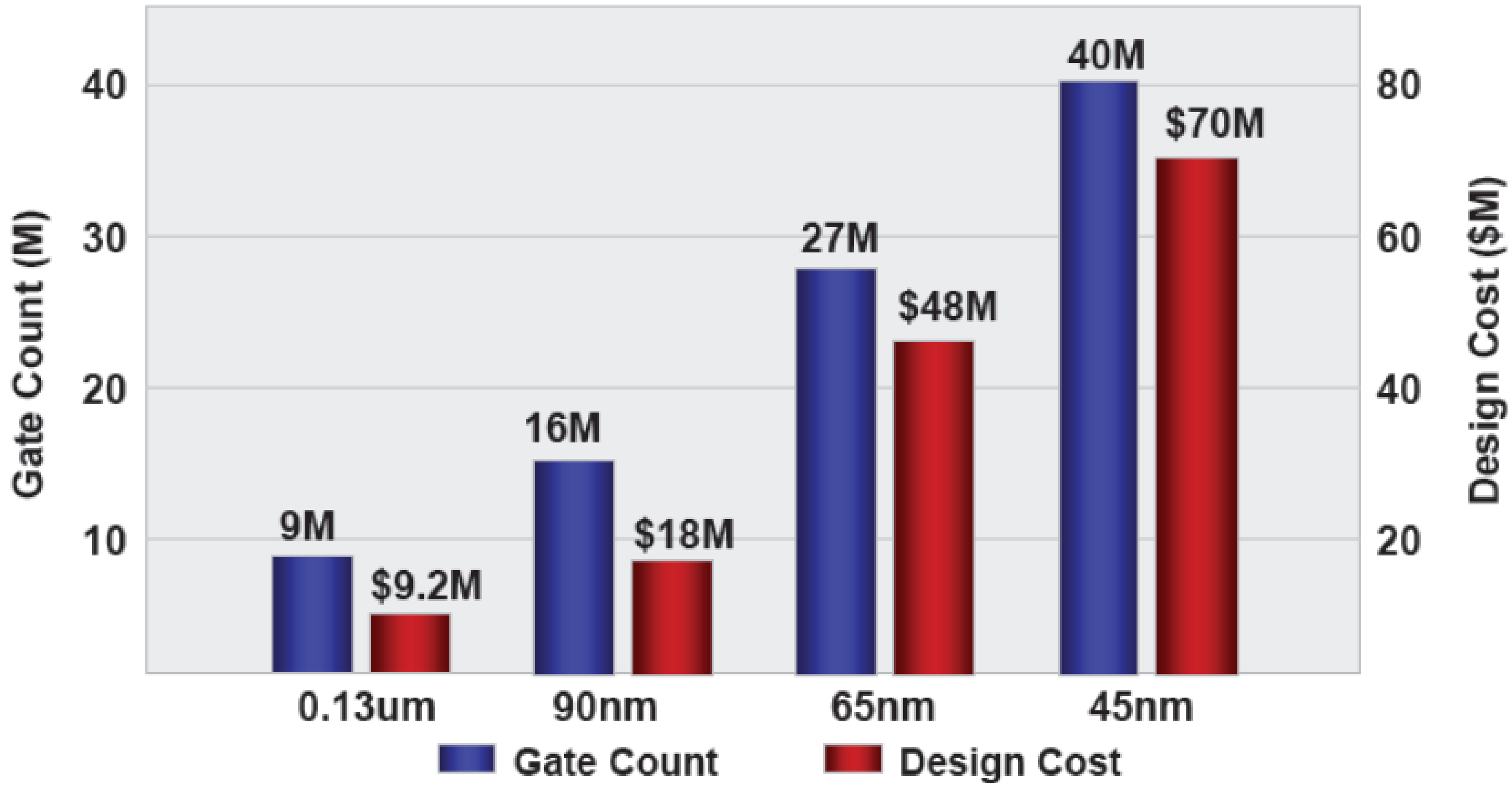
- Price Tag: 100 Mio EUR!!

Future Challenge: ROI Risk Process



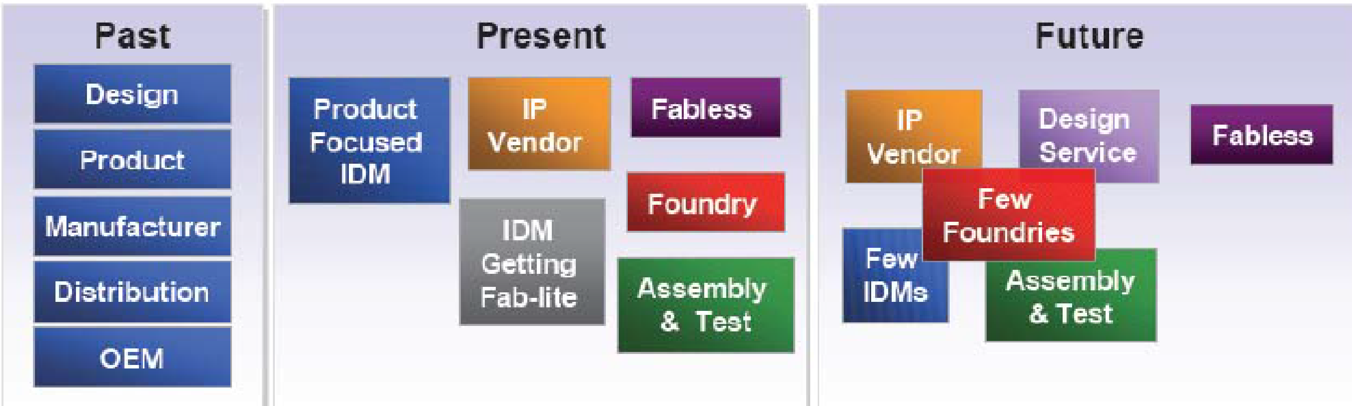
- Process technology developing costs are continuously increasing

Future Challenge: ROI Risk Product



- Design complexity and cost increase rapidly
- Short time to market

Ways To Overcome The Challenges



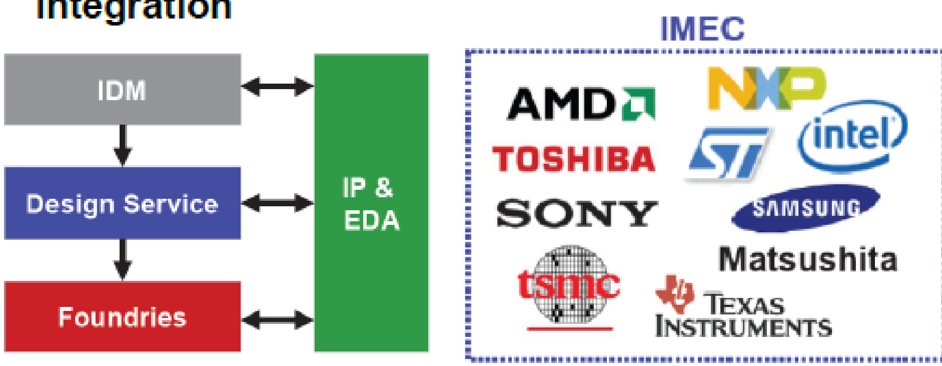
Vertical integration

Fabless getting bigger

Few IDMs, Foundries, many fabless

Solution 1:

IDM to foundry based model with many fabless companies



Solution 2:

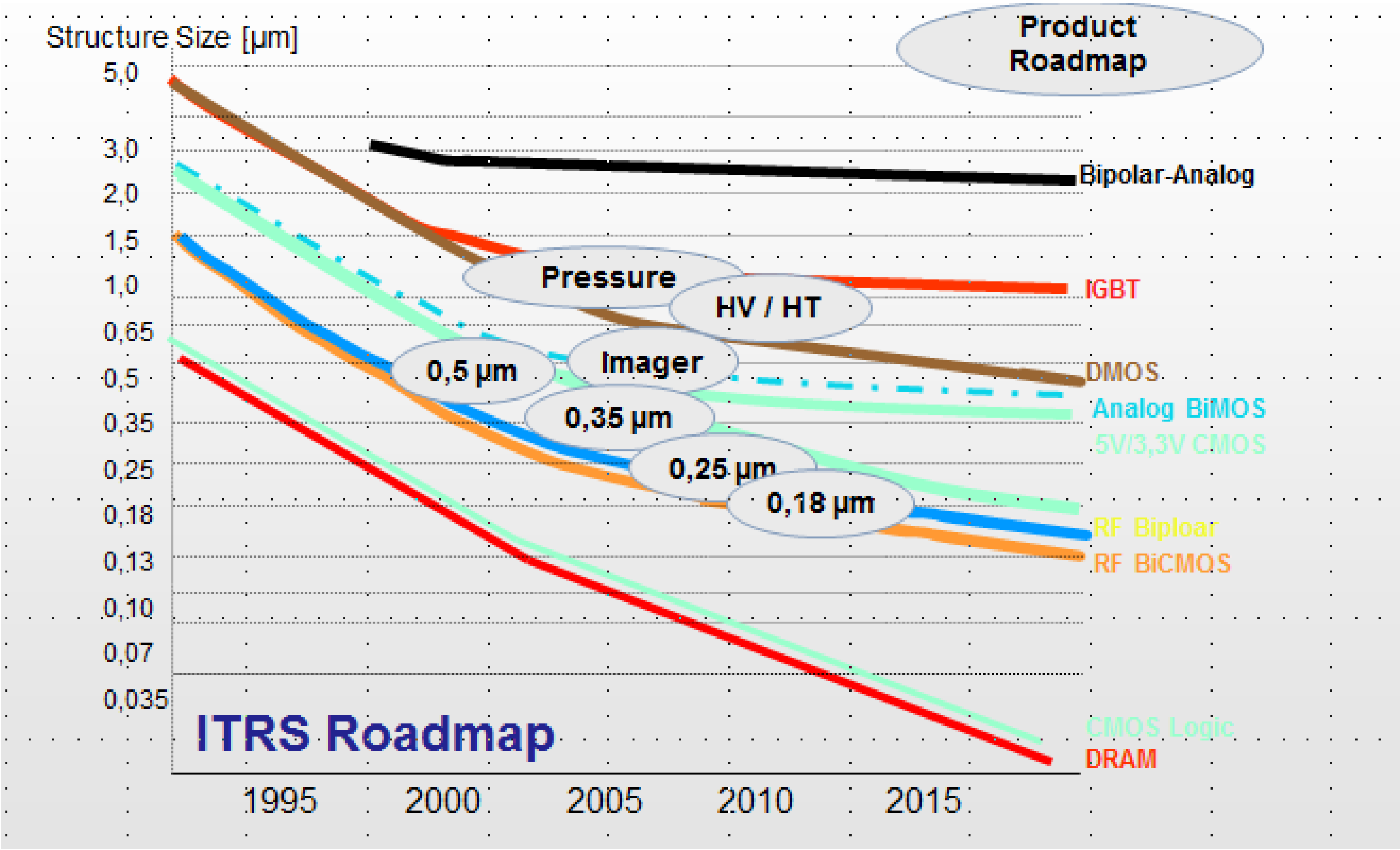
Collaboration: Overcoming technical and financial challenges. Moreover, standardization of IP and EDA tools

Solution 3:

Minimize product risk and NRE through optimal system partition, good Design Infrastructure (SPICE, PDK) and Prototyping (MLM)

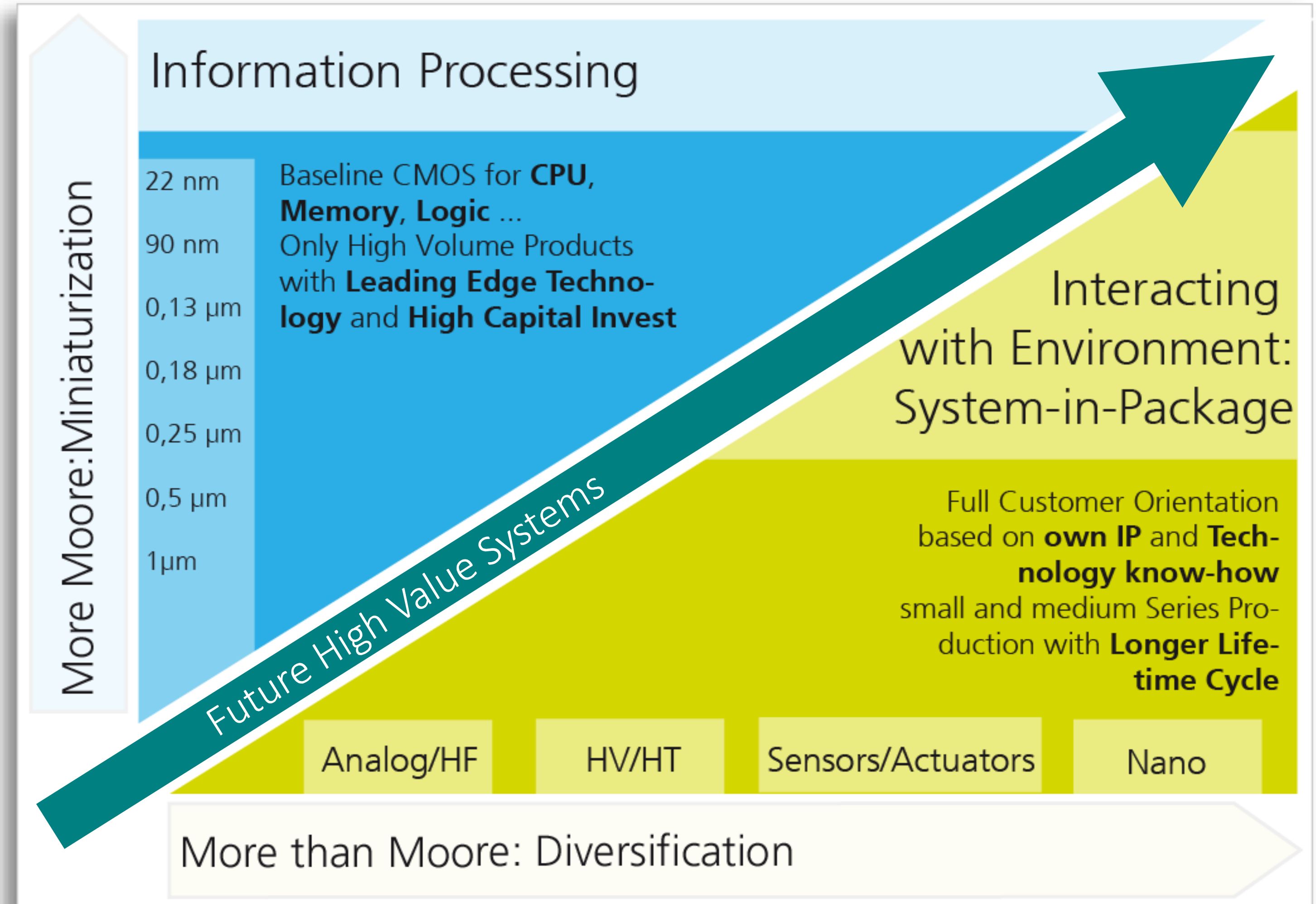
Source: TSMC

ITRS



- ITRS: International Technology roadmap for Semiconductors
  - http://www.itrs.net/

ITRS



- System aspect roadmap