VLSI Design: Introduction

The Beginning of Semiconductor Electronics

The Birth of Semiconductor Age: December 23, 1947

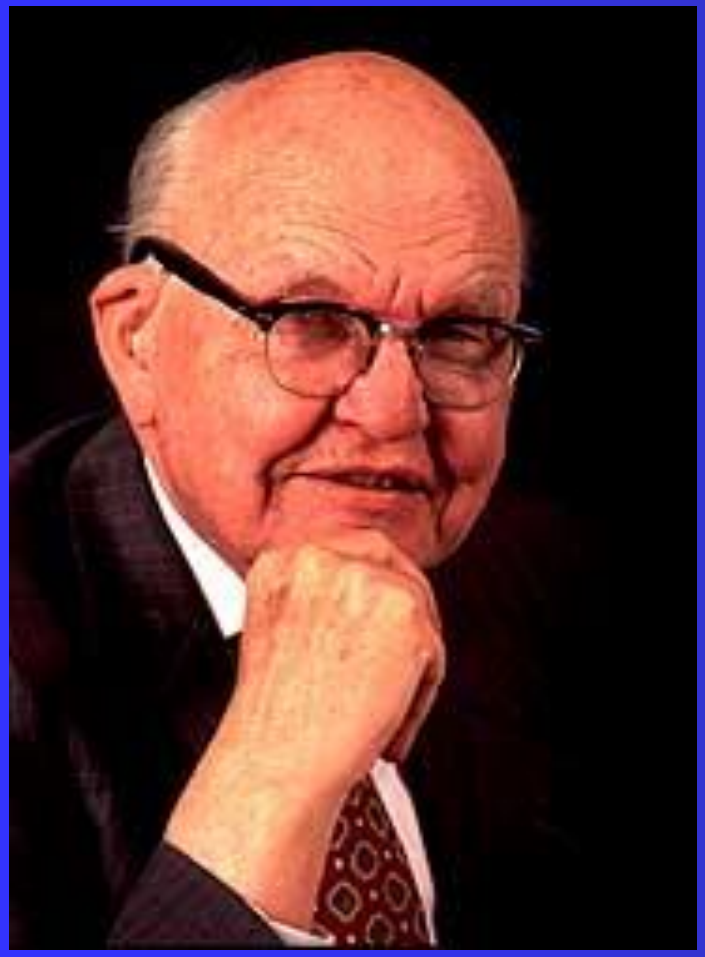
From left: Bardeen, Schokley, Brattain

Nobel Winners of Physics in 1956

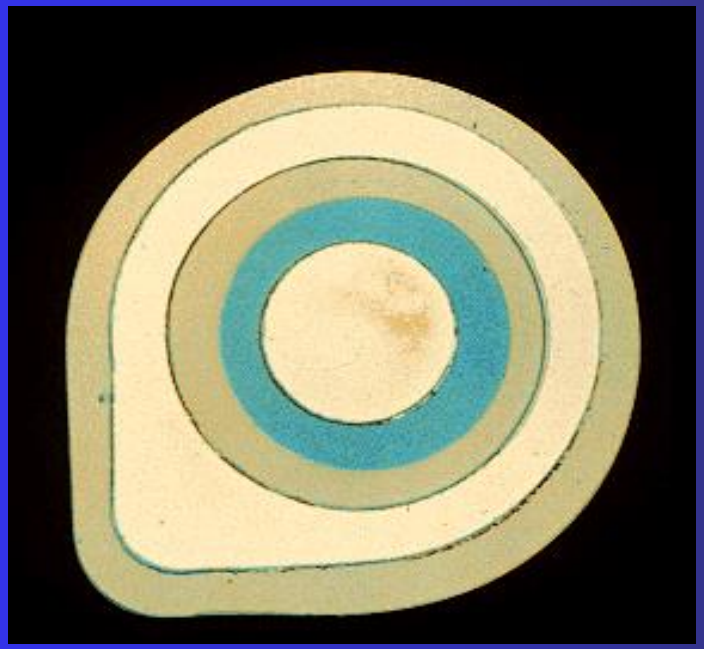
First Point Contact Transistor of Bardeen and Brattain

The Miniaturization of Electronics

Jack Kilby and his Integrated Circuit (1958)



1959 - Practical Integrated Circuits



Robert Noyce of Fairchild Camera and Instrument Corp. constructed the practical integrated circuit, which allowed conducting channels to be printed directly on the silicon surface

Its Impact in Two Decades

ENIAC vs. Microcomputer (1977)

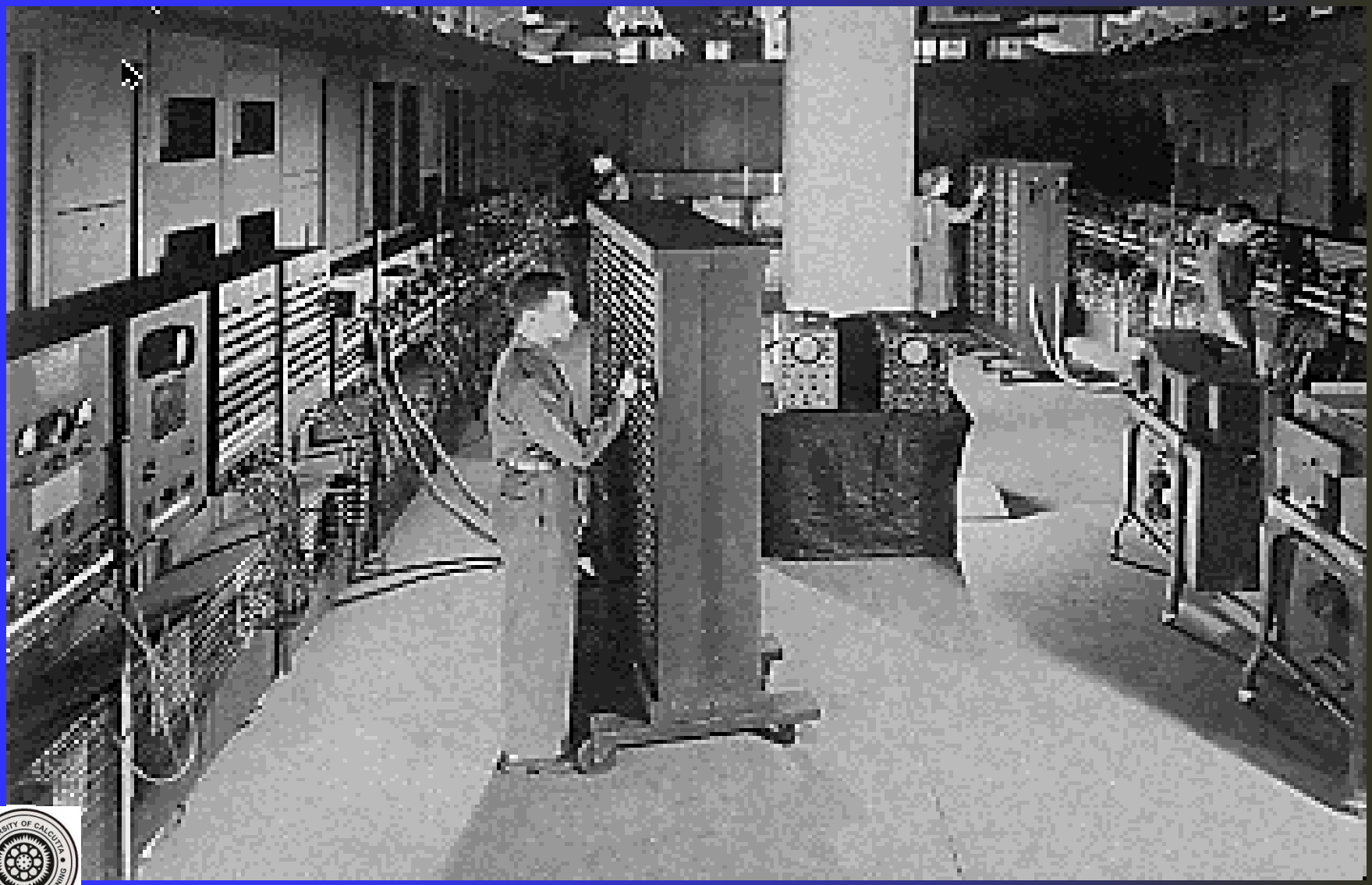
ENIAC

- **Size : 30 x 50 ft**
- **Weight : 30 tons**
- **Tubes : 18 K**
- **Resistors: 70 K**
- **Capacitors : 10 K**
- **Switches : 6 K**
- **Power : 150 kW**
- **Cost (1940) : US $ 400 K**

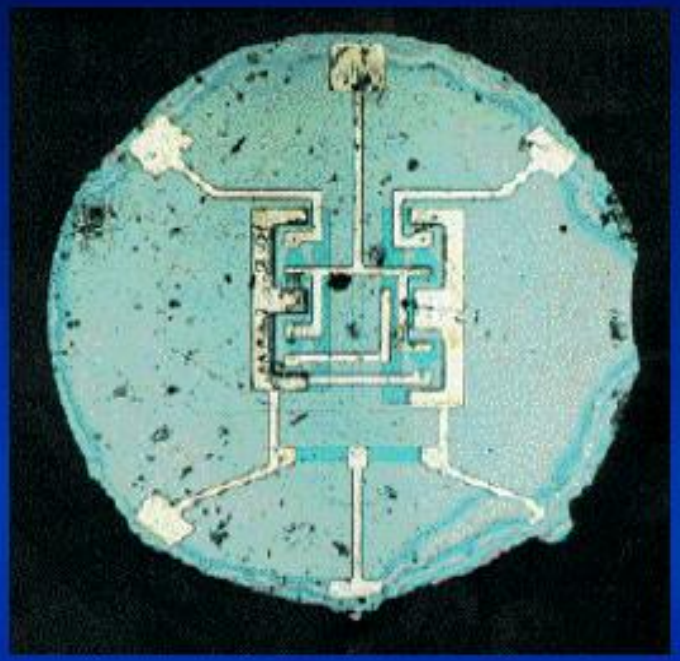
Microcomputer

- **Size : ¼ inch x ¼ inch**
- **Weight : nil**
- **Power < light bilb**
- **Speed : 20 times faster**
- **Memory : larger, more computing capacity**
- **Cost < $300 (*compare with $ 400 K + inflation over 34 years).***

First Modern Digital Computer: ENIAC (Electronic Numerical Integrator And Calculator)



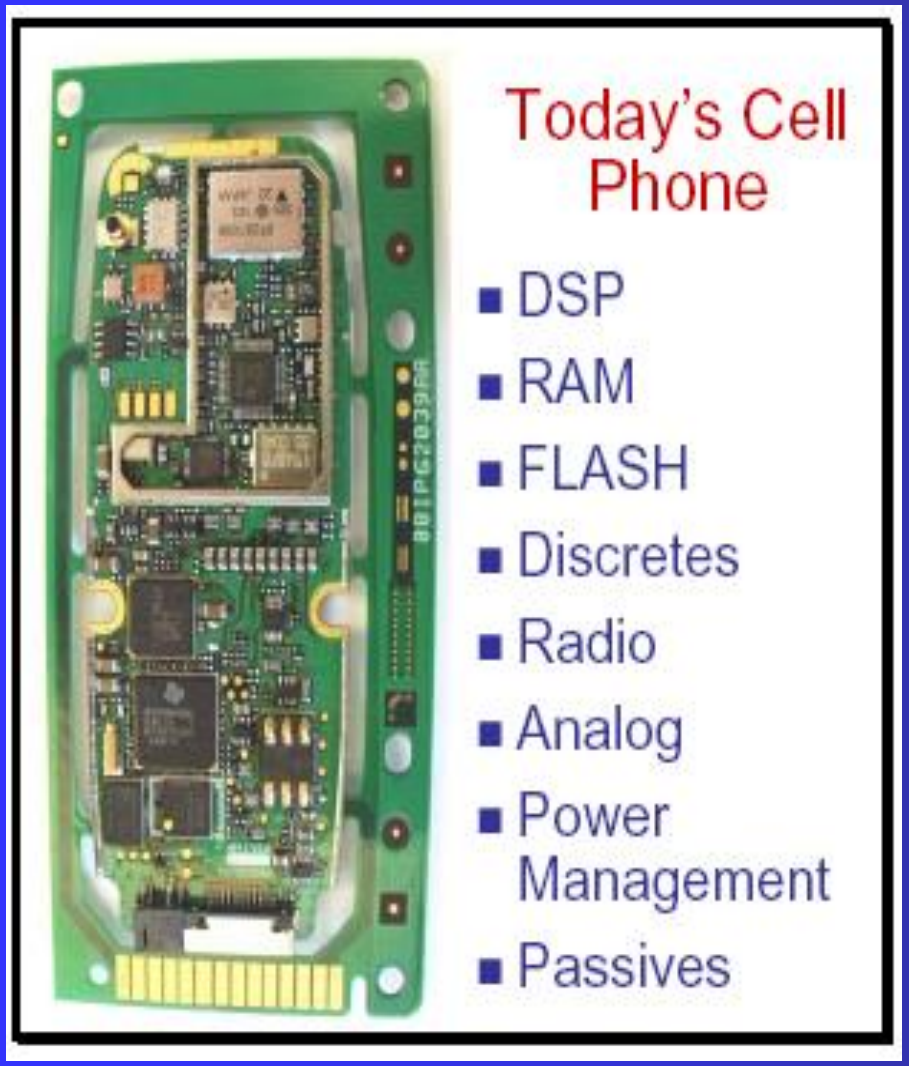
Four Decades of ICs

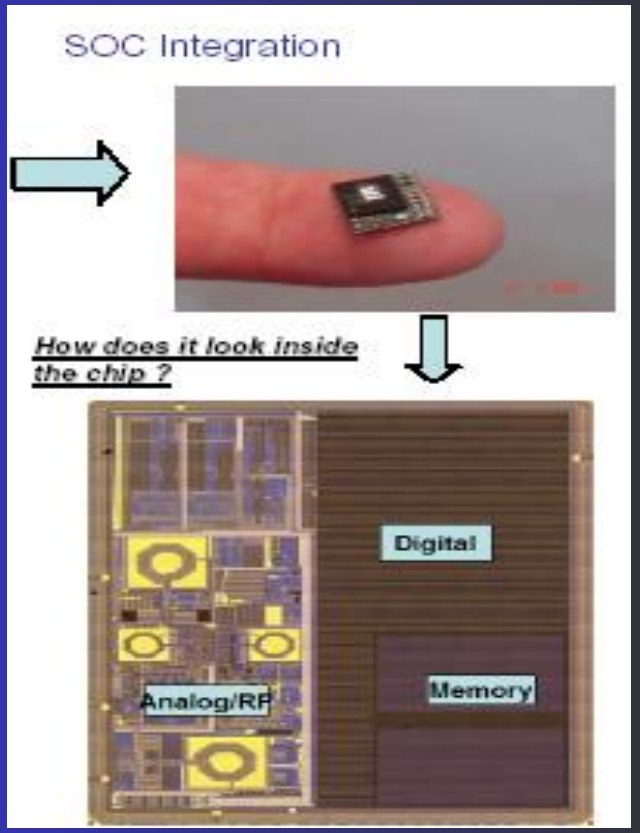


1961
First Planar Integrated Circuit
Two transistors

2001
Pentium® 4 Processor
42 million transistors

Global Semiconductor as on 2006 (Business Opportunity)





KUNGL. VETENSKAPSAKADEMIEN
THE ROYAL SWEDISH ACADEMY OF SCIENCES

Nobel Prizes 2000

The Royal Swedish Academy of Sciences has decided to award the Nobel Prize in Physics for 2000 to scientists and inventors whose work has laid the foundation of modern information technology, IT, particularly through their invention of rapid transistors, laser diodes, and integrated circuits (chips).

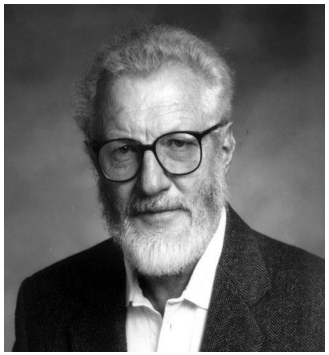
The prize is being awarded with **one half jointly to**

Zhores I. Alferov

A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia, and

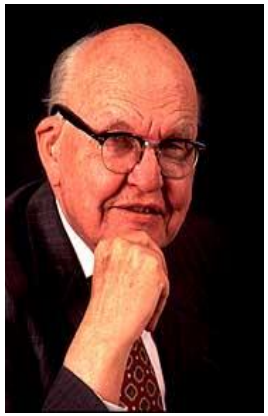
Herbert Kroemer

University of California at Santa Barbara, California, USA,



"for developing semiconductor heterostructures used in high-speed- and opto-electronics"

and one half to



Jack S. Kilby

Texas Instruments, Dallas, Texas, USA

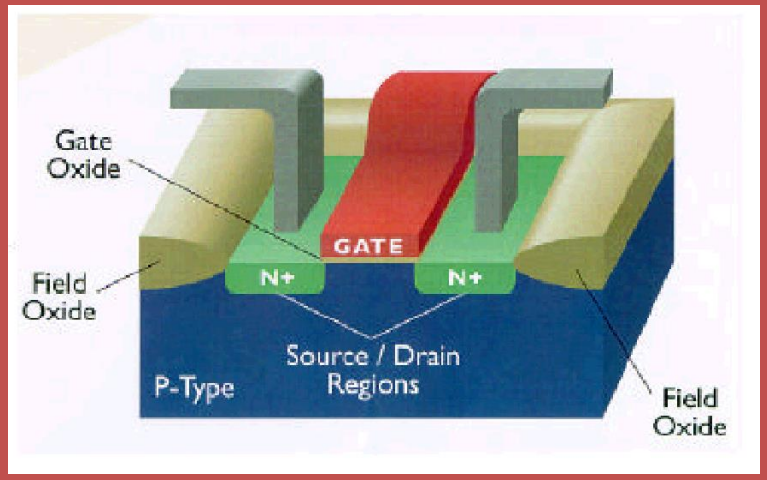
"for his part in the invention of the integrated circuit"

The Historical Journey

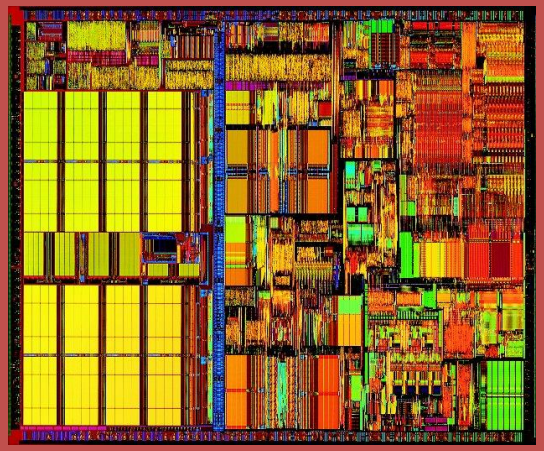
1832: Babbage Difference Engine (25000 parts)

1946: ENIAC (1500 sq. ft.)

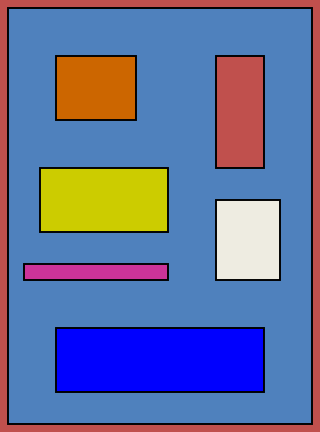
1948: First Transistor



An n-MOS transistor on Silicon



A complete processor on chip



System-on-a-chip
Network-on-a-chip

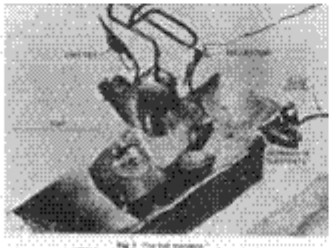
Transforming Sandpile to IC Chips

Silicon wafer
Diam = 8 to12 inches

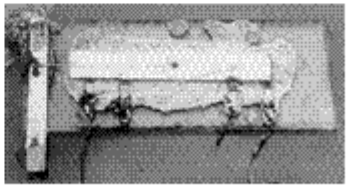
die

Milestones of IC Industry

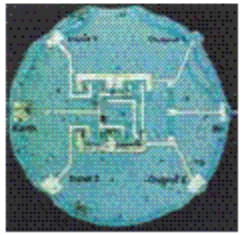
- **1947:** Bardeen, Brattain & Shockly invented the transistor, foundation of the IC industry.
- **1952:** SONY introduced the first transistor-based radio.
- **1958:** Kilby invented integrated circuits (ICs).
- **1965:** Moore's law.
- **1968:** Noyce and Moore founded Intel.
- **1970:** Intel introduced 1 K DRAM.



First transistor



First IC by Kilby

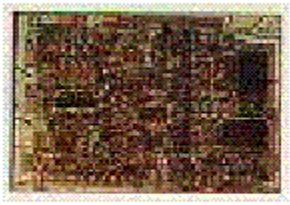


First IC by Noyce

Milestones of IC Industry (2)

- **1971:** Intel announced 4-bit 4004 microprocessors (2250 transistors).
- **1976/81:** Apple II/IBM PC.
- **1985:** Intel began focusing on microprocessor products.
- **1987:** TSMC was founded (fabless IC design).
- **1991:** ARM introduced its first embeddable RISC IP core (chipless IC design).

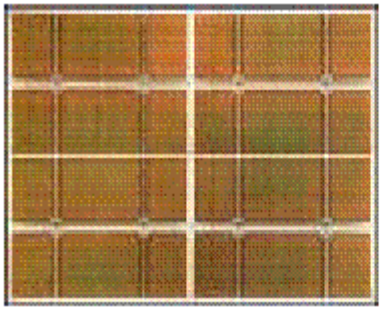

Intel founders


4004

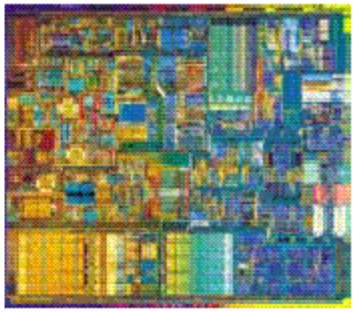

IBM PC

Milestones of IC Industry (3)

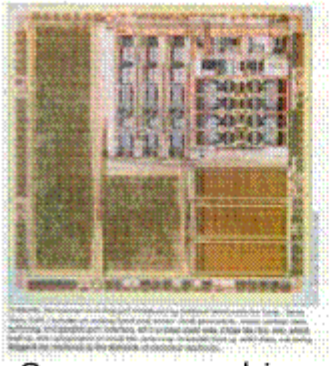
- **1996:** Samsung introduced IG DRAM.
- **1998:** IBM announces1GHz experimental microprocessor.
- **1999/earlier: System-on-Chip (SOC)** methodology applications.
- An Intel P4 processor contains 42 million transistors (1 billion by 2005)
- Today, we produce > 30 million transistors per person (1 billion/person by 2008).
- **Semiconductor/IC:** #1 key field for advancing into 2000 (*Business Week*, Jan. 1995).



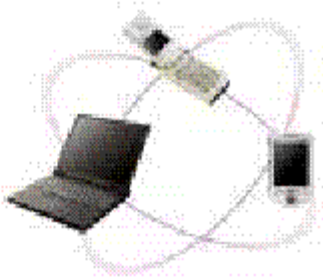
4GB DRAM (2001)



Pentium 4



Scanner-on-chip



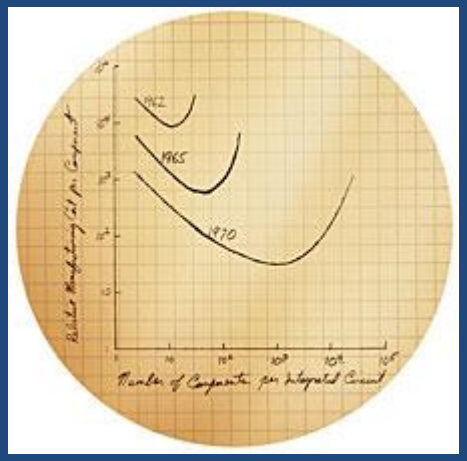
Blue tooth technology

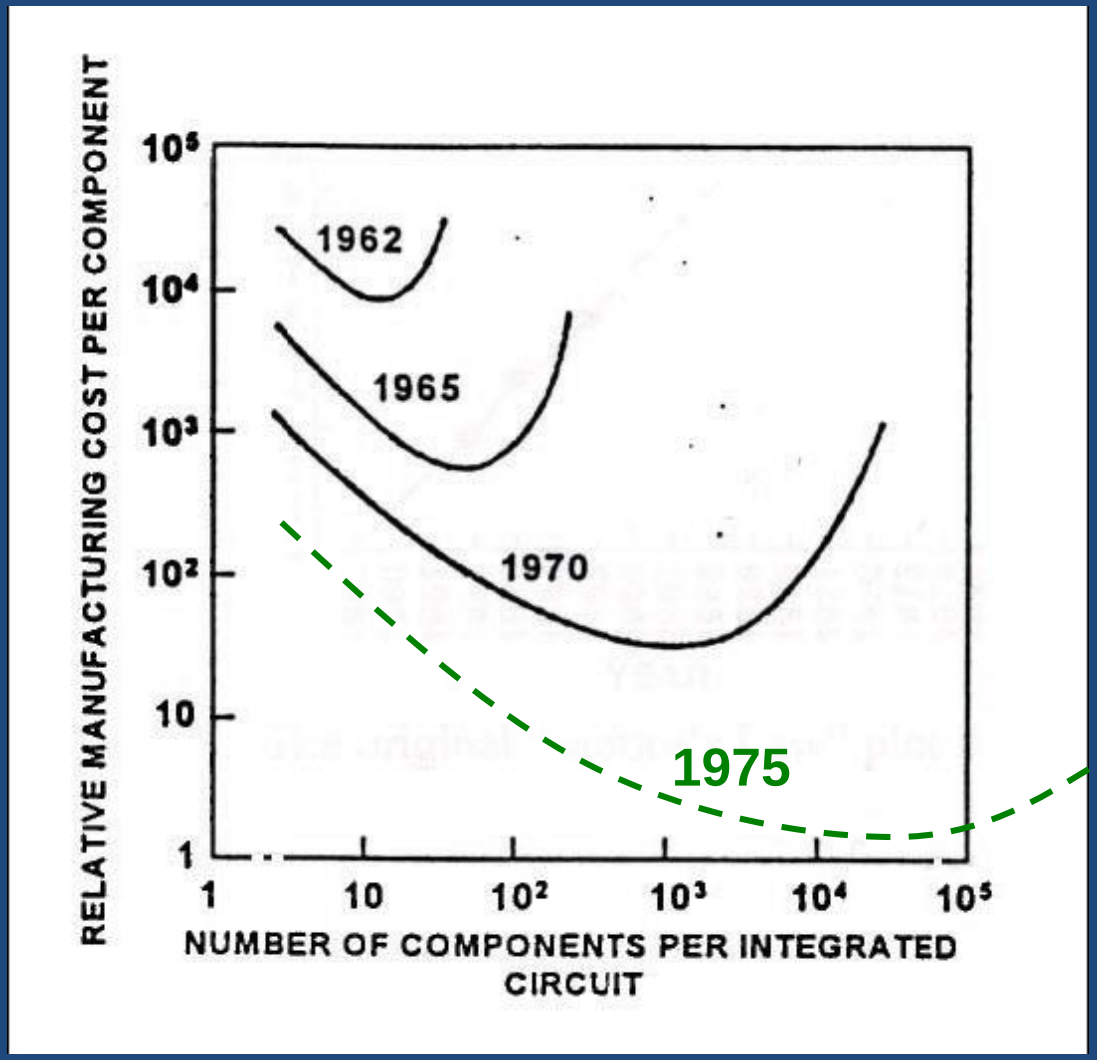
Gordon E. Moore

Gordon Moore: 1965

- Predicted that the number of transistors integrated on a die would grow exponentially (doubling every 12 to 18 months)
- Million transistors/chip barrier crossed in the 1980s
- Today:
  - 55 Million, 2 GHz clock (Intel P4)
  - 140 Million transistor (HP PA-8500)

Moore's 1965 Graph

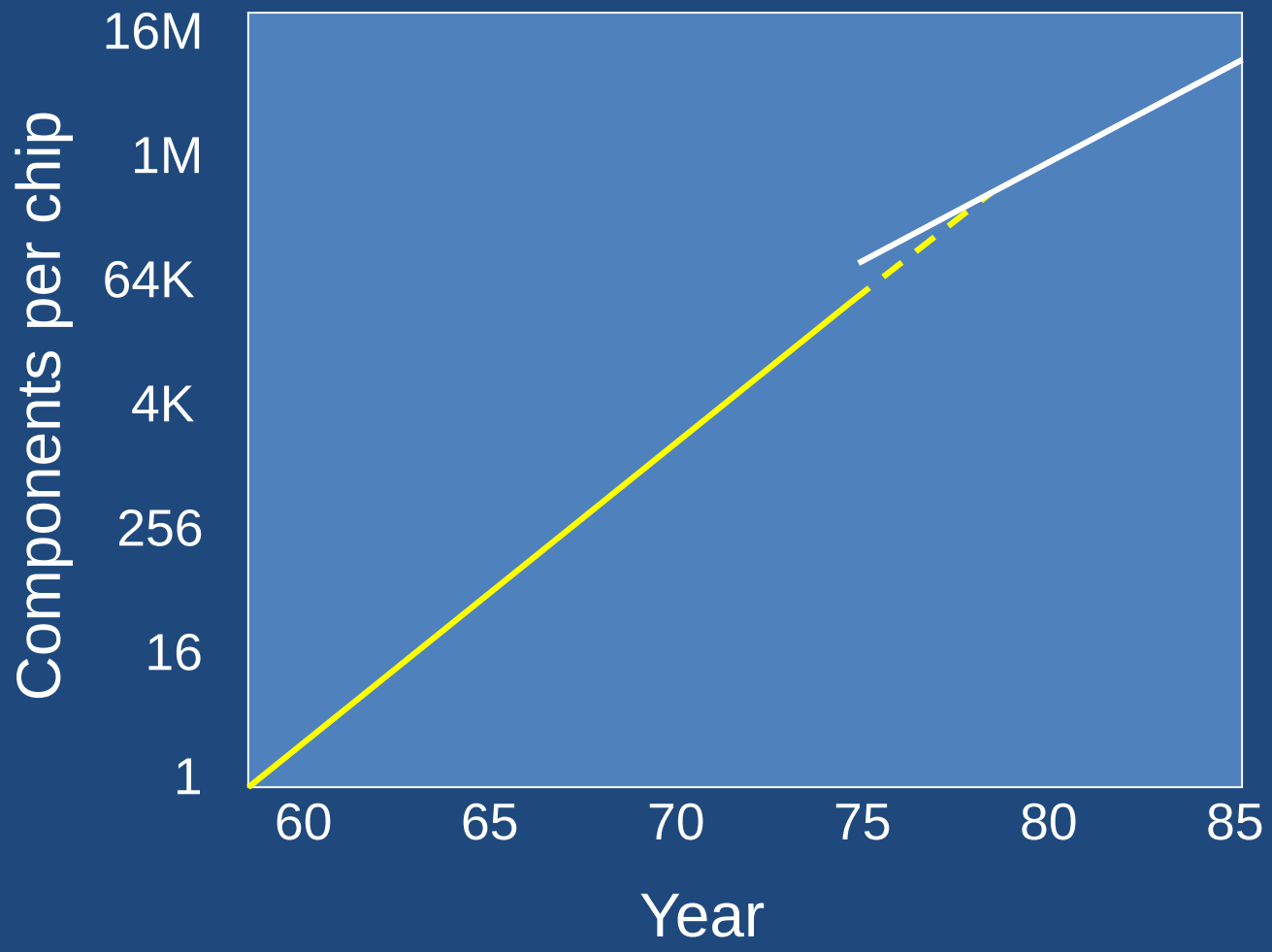




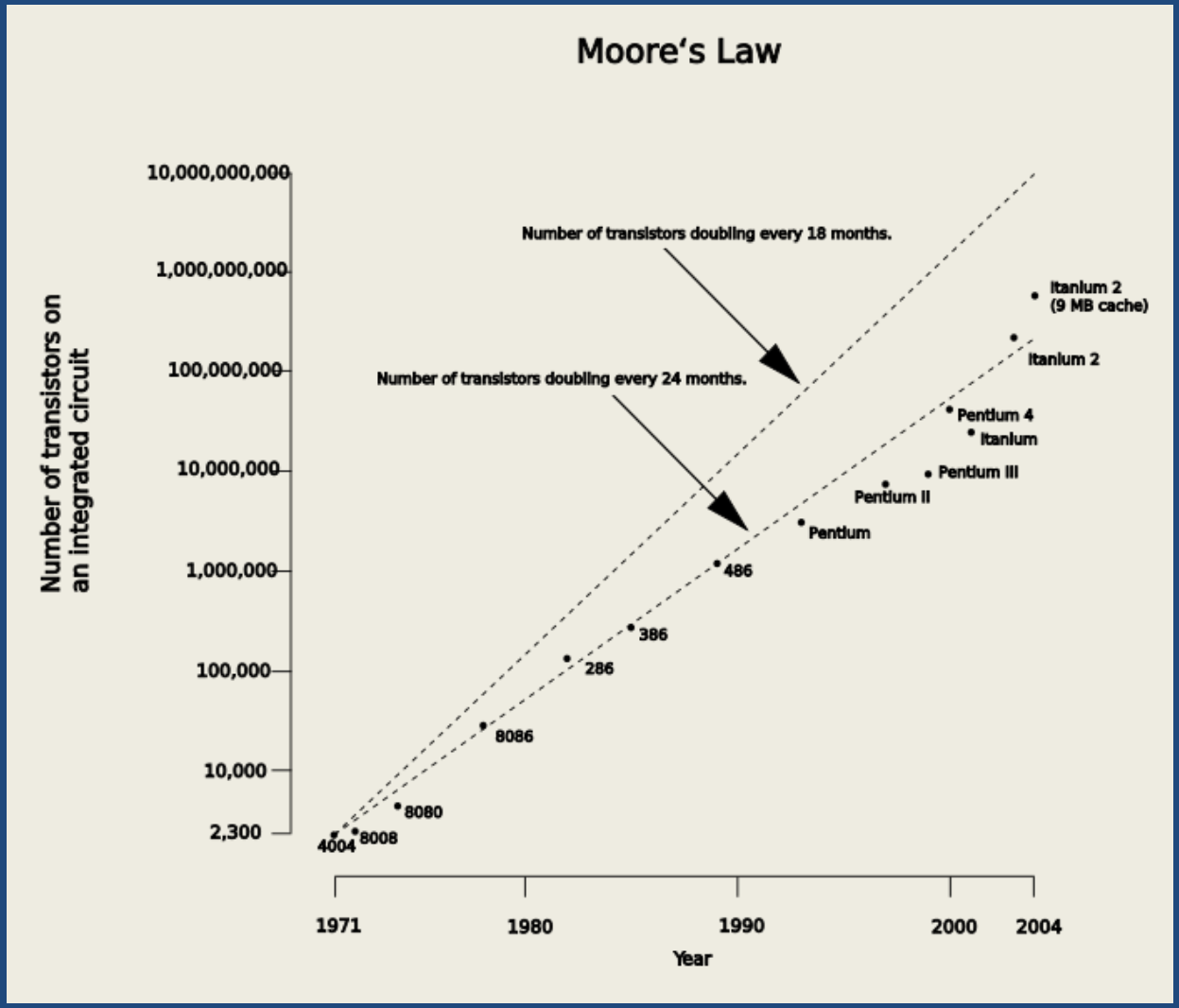
1975

- "Progress in Digital Integrated Electronics," *IEDM Tech. Digest*, 1975, pp. 11-13.
- . . . the rate of increase of complexity can be expected to change slope in the next few years as shown in Figure 5. The new slope might approximate a doubling every two years, rather than every year, by the end of the decade.

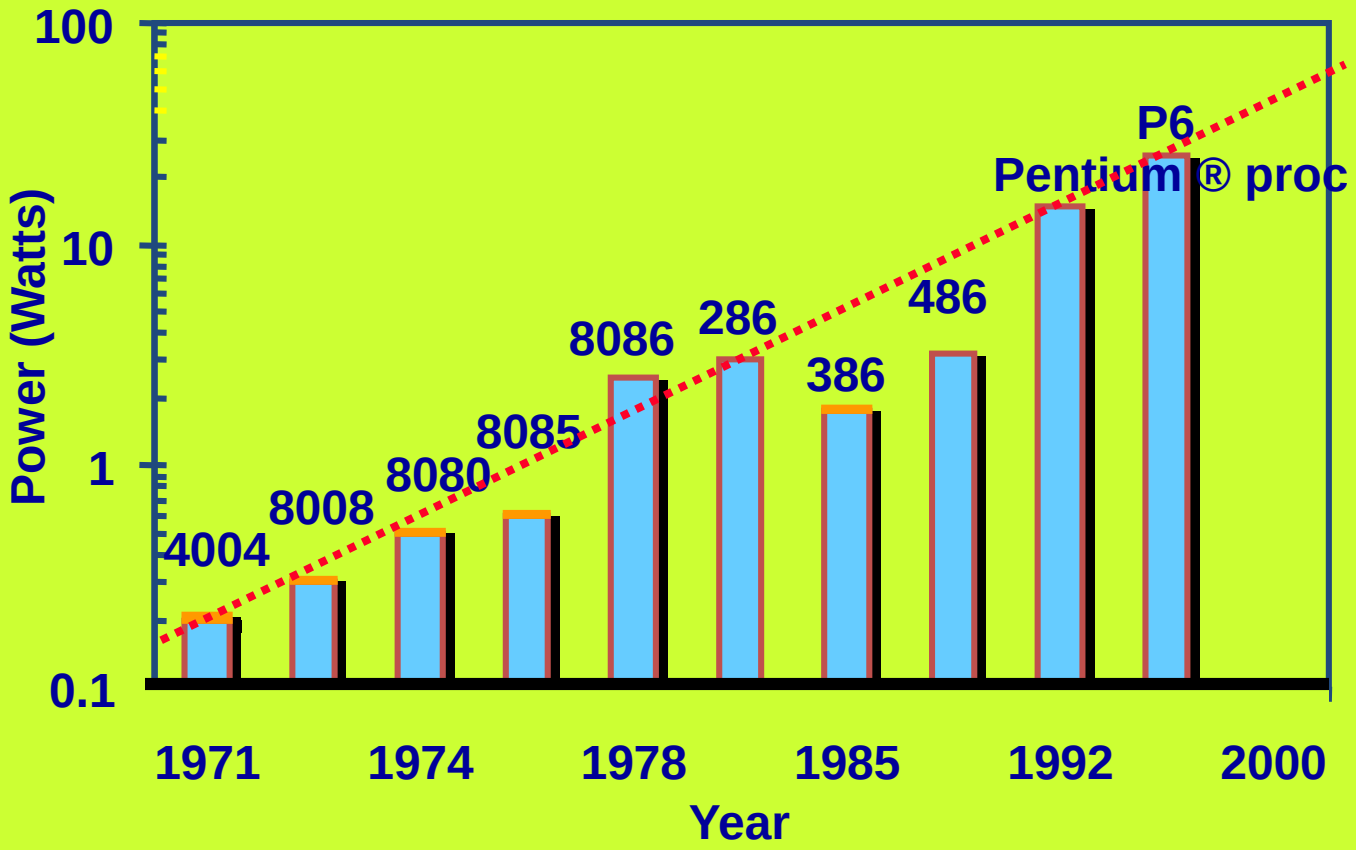
Figure 5 of Moore's 1975 Paper



Moore's Law


Moore's Law
Number of transistors on an integrated circuit
10,000,000,000
1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
2,300
Number of transistors doubling every 18 months.
Number of transistors doubling every 24 months.
Itanium 2 (9 MB cache)
Itanium 2
Pentium 4
Itanium
Pentium III
Pentium II
Pentium
486
386
286
8086
8080
8008
4004
1971
1980
1990
2000
2004
Year

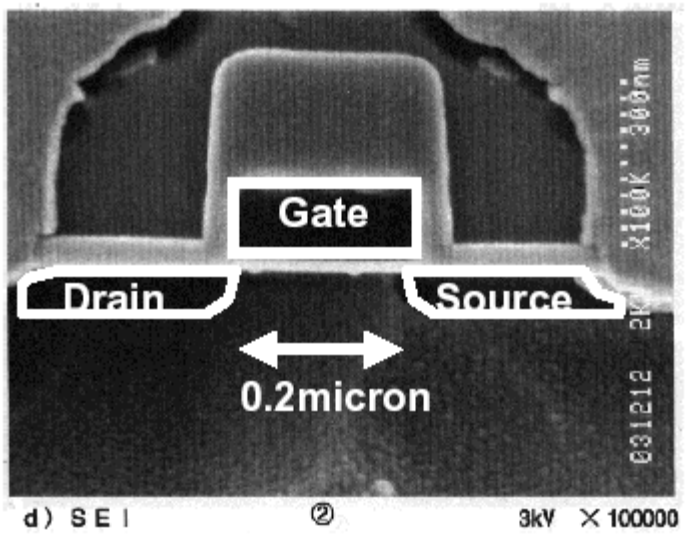
Power Dissipation



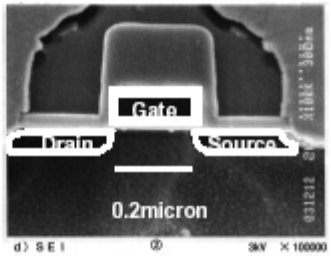
Lead Microprocessors power continues to increase

Courtesy, Intel

Scaling Law



Size 1/2



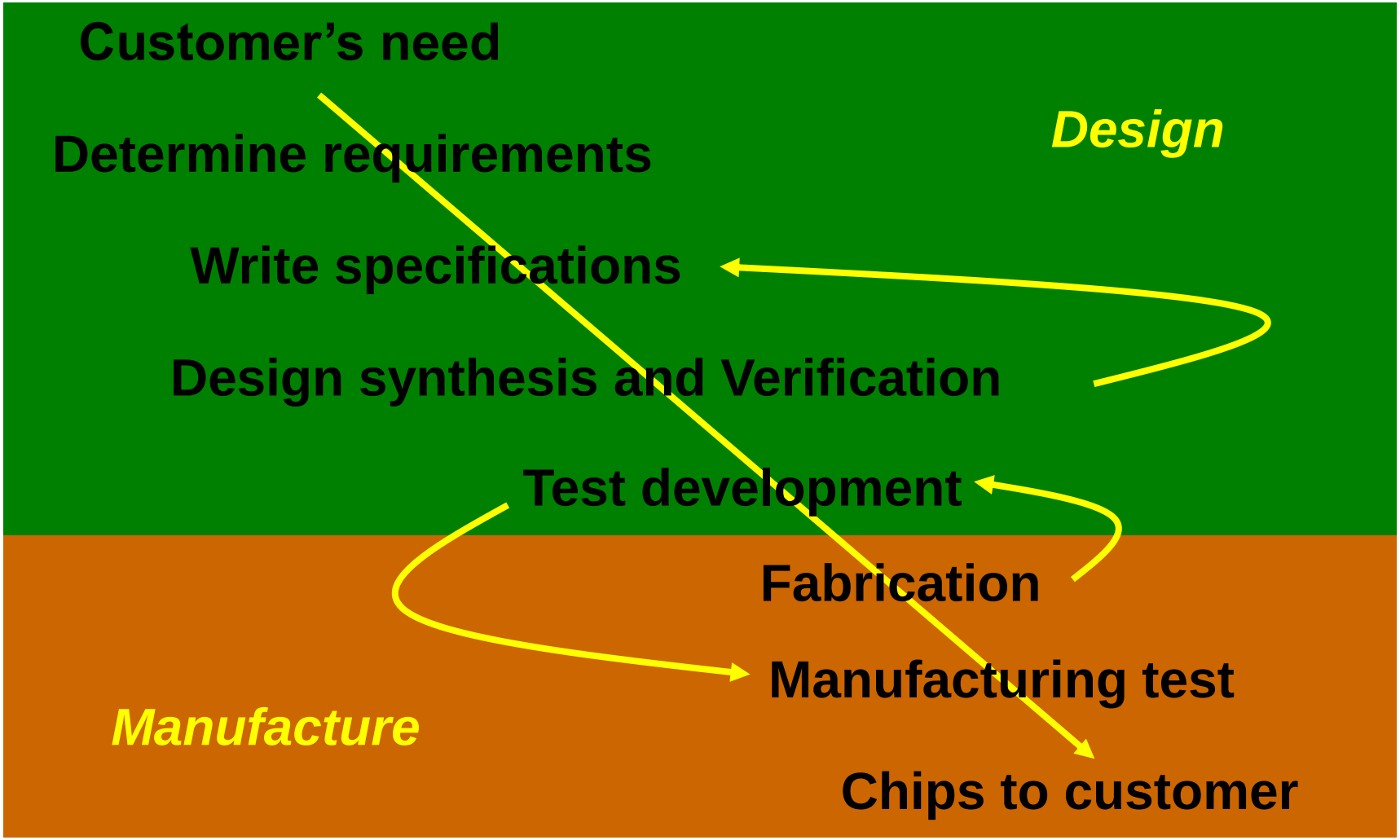
Favorable effects

Size	x1/2
Voltage	x1/2
Electric Field	x1
Speed	x3
Cost	x1/4

Unfavorable effects

Power density	x1.6
RC delay/Tr. delay	x3.2
Current density	x1.6
Voltage noise	x3.2
Design complexity	x4

VLSI Realization Process



2011

- Problems with technology:
  - High power consumption
    - Power density
    - Leakage
  - Process variation – larger as a fraction of feature size
  - Increased noise sensitivity
- Problems with design:
  - Verification of correctness – logic and timing
  - Ensuring reliable operation
  - Testing

VLSI Design Issues

Complexity Acronyms

- SSI = small scale integration (~100 components)
- MSI = medium scale integration (~1000 components)
- LSI = large scale integration (~10^5 components)
- VLSI = very large scale integration (~10^5 - 10^6 components)
- ULSI = ultra large scale integration (~10^6 - 10^9 components)
- GSI = giga-scale integration (> 10^9 components)

Design Issues and Metrics

- Cost
- Reliability
- Speed
- Power
- Energy dissipation
- Time-to-market

VLSI Chip Yield

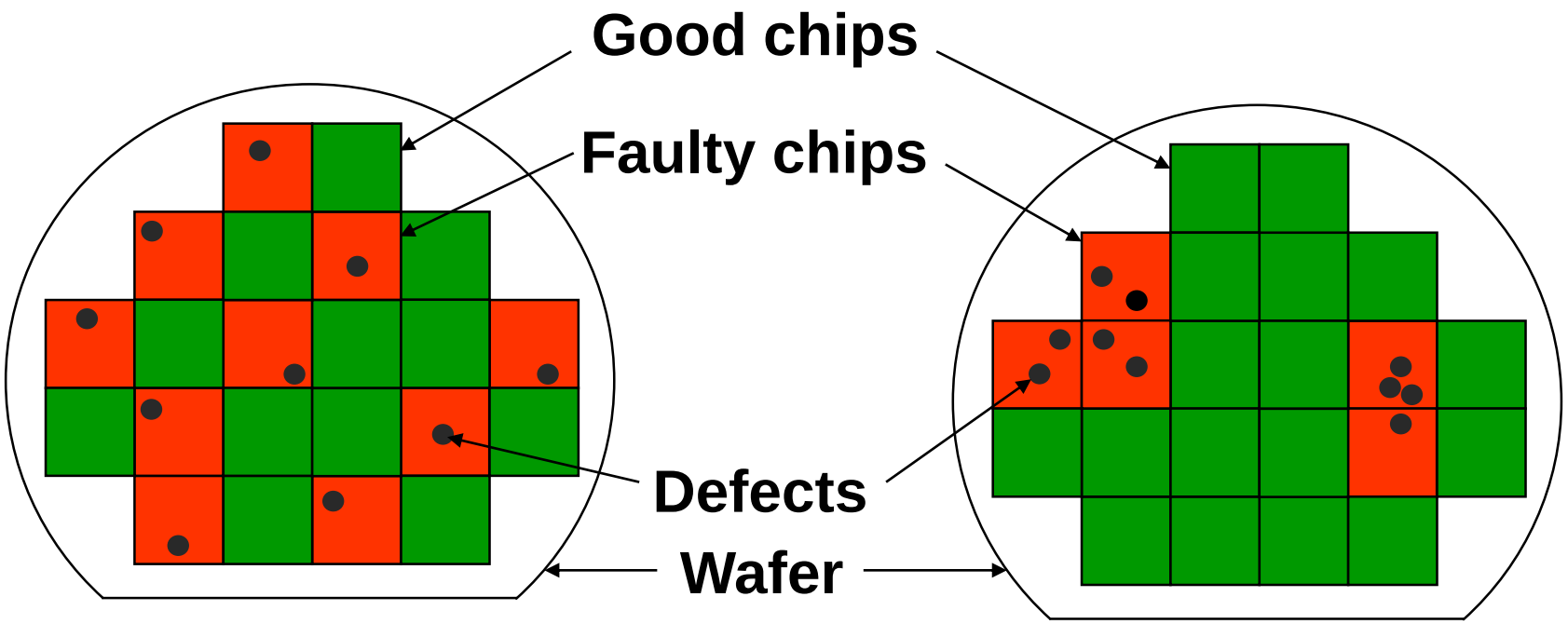
- A manufacturing defect is a finite chip area with electrically malfunctioning circuitry caused by errors in the fabrication process.
- A chip with no manufacturing defect is called a good chip.
- Fraction (or percentage) of good chips produced in a manufacturing process is called the yield. Yield is denoted by symbol *Y*.

Importance of Yield

- Cost of a chip =

$$\frac{\text{Cost of fabricating and testing a wafer}}{\text{Yield} \times \text{Number of chip sites on the wafer}}$$

Clustered VLSI Defects



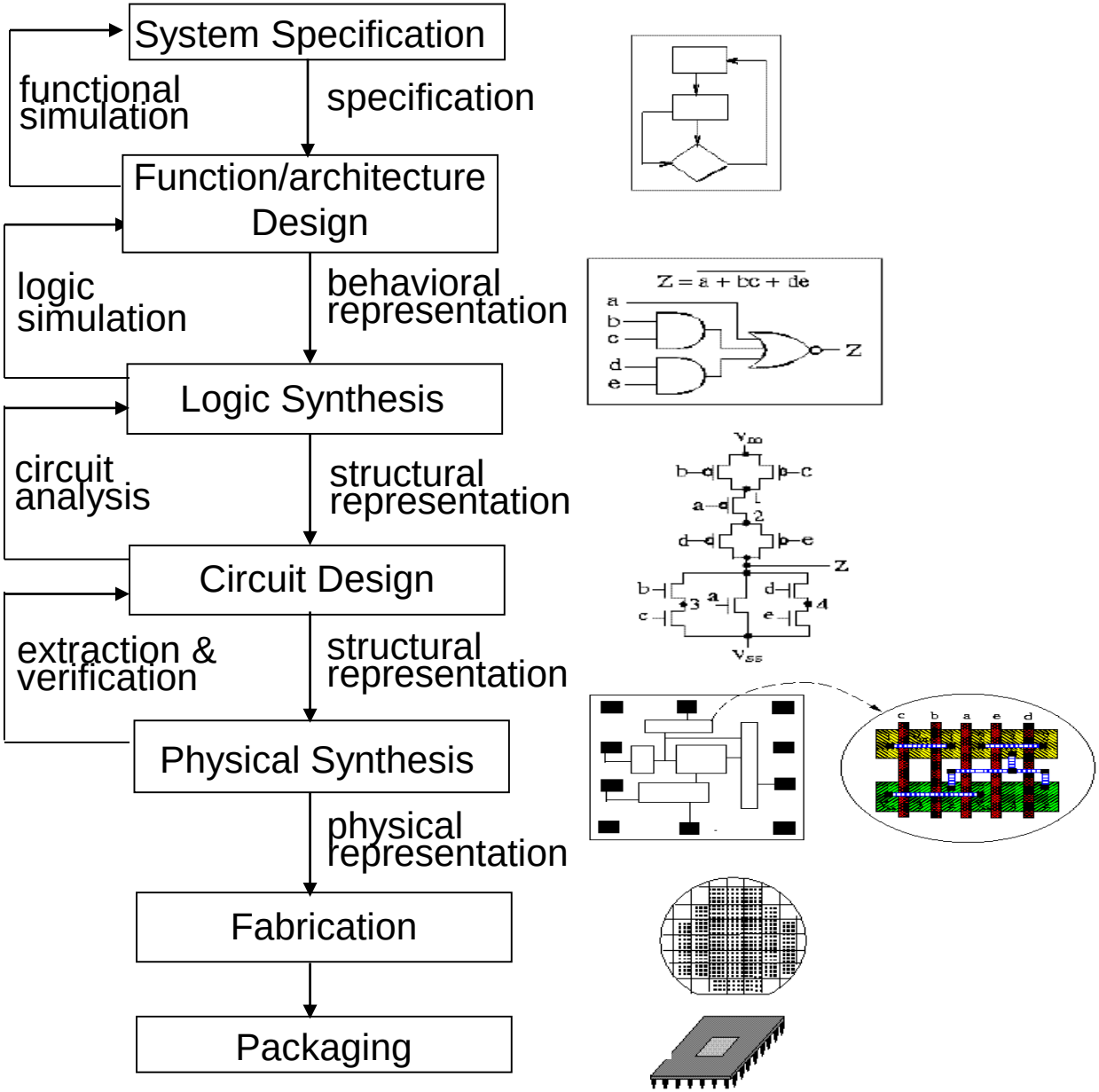
Unclustered defects
Wafer yield = 12/22 = 0.55

Clustered defects (VLSI)
Wafer yield = 17/22 = 0.77

Defining Terms

- Design synthesis: Given an I/O function, develop a procedure to manufacture a device using known materials and processes.
- Verification: Predictive analysis to ensure that the synthesized design, when manufactured, will perform the given I/O function.
- Test:
  - Characterization: A test that debugs test program by fault diagnosis.
  - Manufacturing test: A step that ensures that the physical device, manufactured from the synthesized design, has no manufacturing defect.

VLSI Design Flow



Physical Design