14EC230-SEMICONDUCTOR DEVICES INNOVATIVE METHOD

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1928

- The first patents for the transistor principle were registered in Germany by **Julius Edgar Lilienfeld.**
- He proposed the basic principle behind the **MOS field-effect transistor.**

1934

- German Physicist **Dr. Oskar Heil** patented the Field Effect Transistor

1936

- **Mervin Kelly** Bell Lab's director of research. He felt that to provide the best phone service it will need a better amplifier; the answer might lie in semiconductors. And he formed a department dedicated to solid state science.

1945

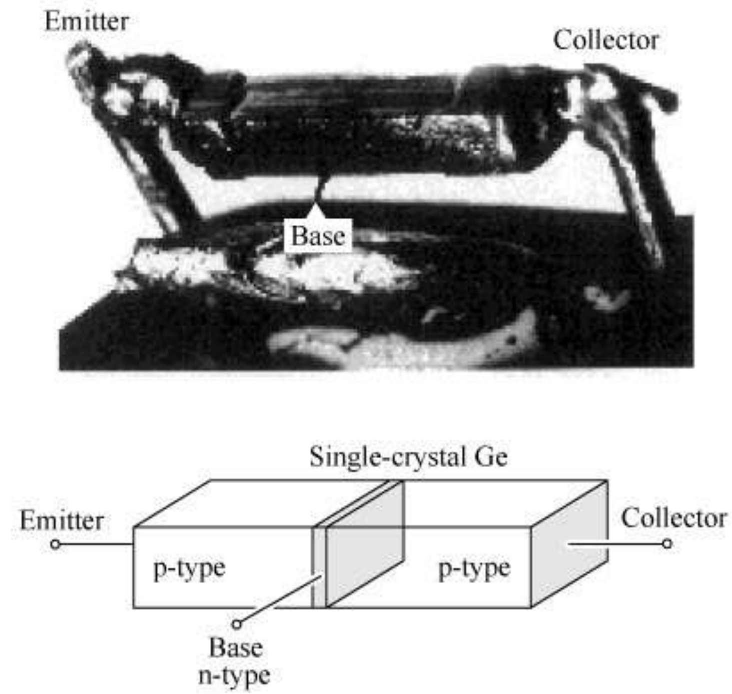
- **Bill Shockley** the team leader of the solid state department (Hell's Bell Lab) hired Walter Brattain and John Bardeen.
- He designed the first semiconductor amplifier, relying on the field effect.
- His device was a small cylinder coated thinly with silicon, mounted close to a small, metal plate.
- The device didn't work, and Shockley assigned Bardeen and Brattain to find out why.

1949 cont.

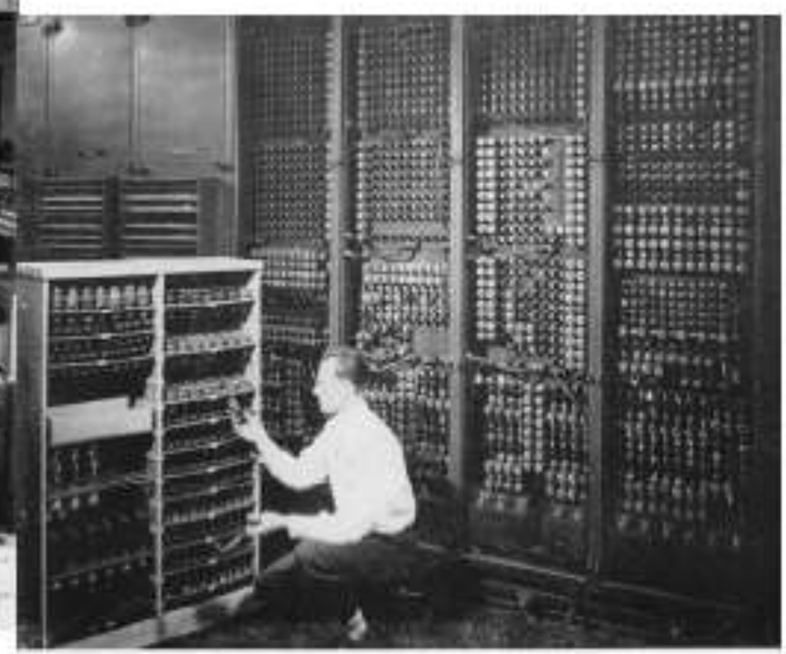
- **Shockley** make the Junction transistor (sandwich).
- This transistor was more practical and easier to fabricate.
- The Junction Transistor became the central device of the electronic age

The First Junction Transistor

First transistor with diffused pn junctions by *William Shockley*
Bell Laboratories, Murray Hill, New Jersey (1949)



ENIAC – First electronic computer (1946)



- **Built by John W. Mauchly** (Computer Architecture) and **J. Presper Eckert** (Circuit Engineering) , Moore School of Electrical Engineering, University of Pennsylvania. Formed Eckert & Marchly Computer Co. and built the 2nd computer, “UNIVAC”. Went bankrupt in 1950 and sold to Remington Rand (now defunct). IBM built “401” in 1952 (1st commercial computer) and John von Neumann invented controversial concept of interchangeable data and programs.

Vacuum Tubes in First Computer

1947

- **Bardeen and Brattain** built the point contact transistor.
- They made it from strips of gold foil on a plastic triangle, pushed down into contact with slab of germanium.

1948

- Bells Lab unveil the transistor.
- They decided to name it transistor instead of Point-contact solid state amplifier.
- **John Pierce** invented the name, combining transresistance with the ending common to devices, like varistor and thermistor.

1957

- The traitorous **eight** abandoned Shockley founding Fairchild Semiconductor.

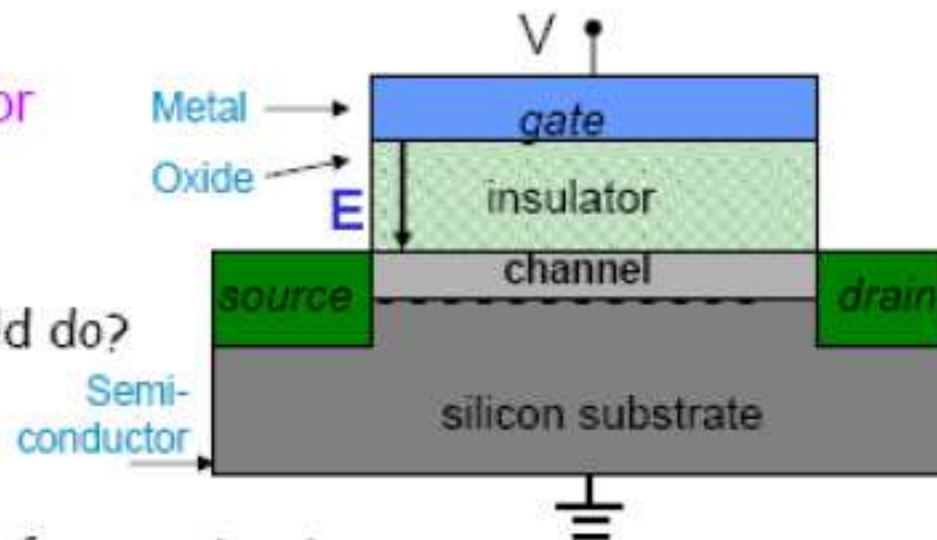
What is a MOSFET?

Digital integrated circuits rely on transistor switches

- most common device for digital and mixed signal: MOSFET

Definitions

- MOS = Metal Oxide Semiconductor
  - physical layers of the device
- FET = Field Effect Transistor
  - What field? What does the field do?
  - Are other fields important?
- CMOS = Complementary MOS
  - use of both nMOS and pMOS to form a circuit



Primary Features

- gate
- gate oxide (insulator)
- source and drain
- bulk/substrate
- channel

NOTE: "metal" is replaced by polysilicon in modern MOSFETs

MOST Regions of Operation

- **Cut-off, or non-conducting: $V_{GS} < V_T$**

  $I_D = 0$

- **Conducting: $V_{GS} >= V_T$**
  - **Saturation: $V_{DS} > V_{GS} - V_T$**

$$i_D = \frac{\mu C_{ox} W}{2L}(v_{GS} - V_T)^2$$

  - **Triode or linear or ohmic or non-saturation: $V_{DS} <= V_{GS} - V_T$**

$$i_D = \frac{\mu C_{ox} W}{L}((v_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2})$$

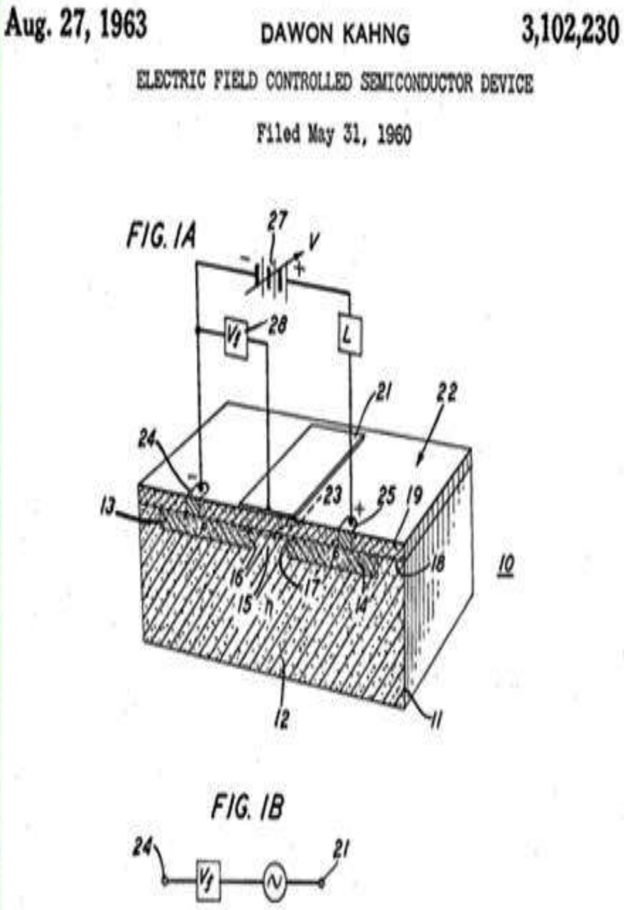
Martin John Atalla
(1924-2009)

- He was an engineer and entrepreneur in the field of semiconductor technology and computer data security. After his studies, Atalla was employed at Bell Laboratories. He researched among other things, the use of silica as a protective layer of silicon semiconductor devices.
- Atalla assigned the task to Dawon Kahng a scientist in his group. Atalla and Kahng announced their successful MOSFET at a 1960 conference.
- Their research led to the development of the first metal oxide semiconductor field effect transistor (MOSFET)
- The MOSFET has evolved since the central component of today's integrated circuits such as microprocessors and semiconductor memory.

Dawon Kahng
(1931-1992)

- Dr. Kahng, in collaboration with M. Atalla, fabricated a MOSFET using a gate insulator formed from high quality SiO_2 grown in situ by a new high-pressure steam oxidation process at Bell Labs (1960)
- First successful demonstration of MOSFET and a major milestone in semiconductor technology
- Invented in 1967 a field effect memory, the first nonvolatile silicon memory (floating gate memory)
- Became Founding President of NEC, Princeton, NJ in 1988

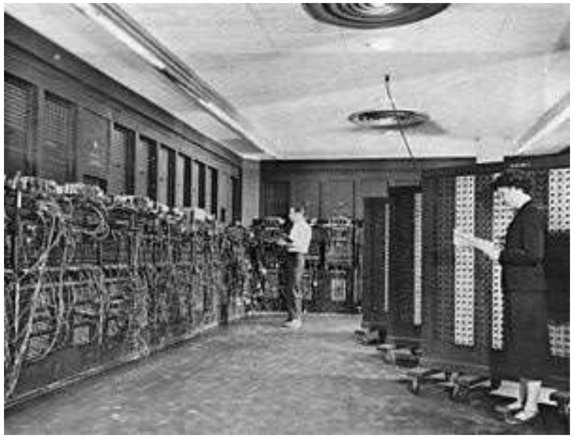
(SNU (BS), Ohio State Univ. (Ph.D. 1959)



1968

- Bob Noyce and Gordon Moore, two of the traitorous eight together with Andy Grove, form Intel Corporation
- Focused on Random Access Memory (RAM) Chips
  Ted Hoff designs the **Intel 4004**, the first microprocessor in **1969**

Device Modeling Enable System Transformations

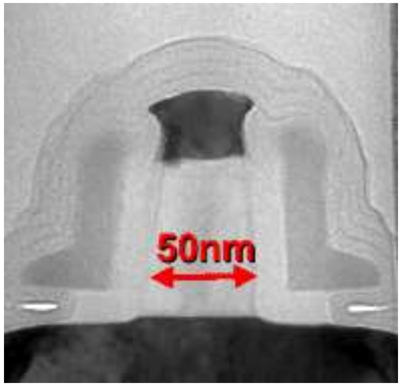


Miniaturisation: why?

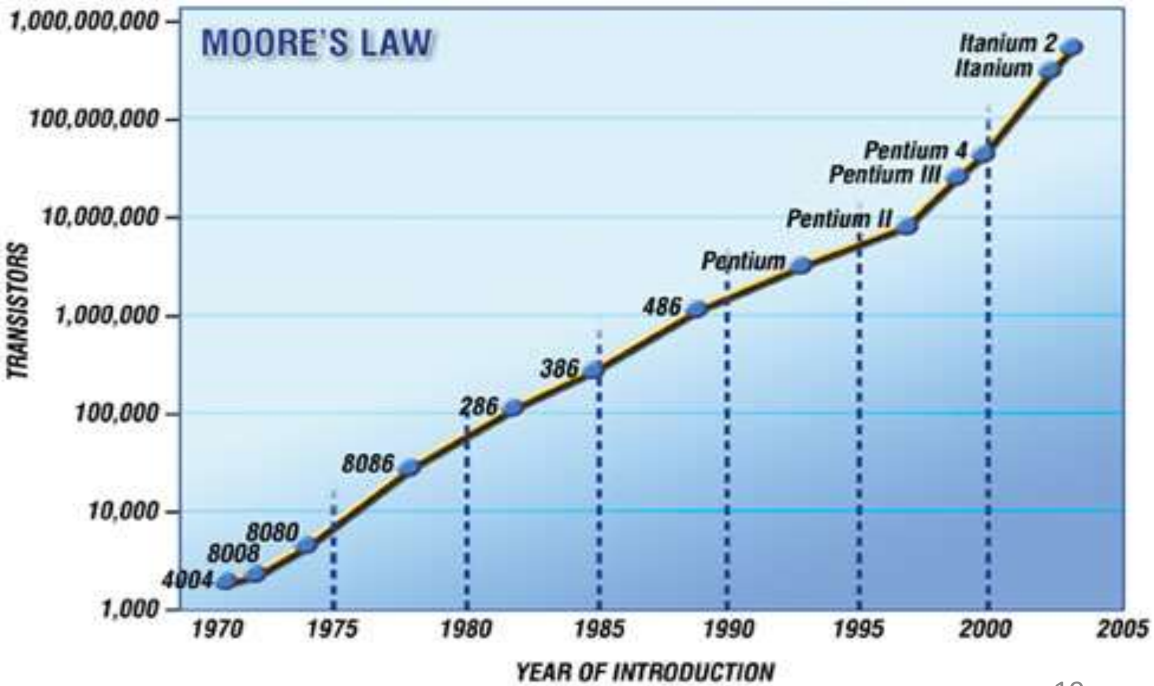
- Smaller
- Faster
- Cheaper

Device down-scaling:

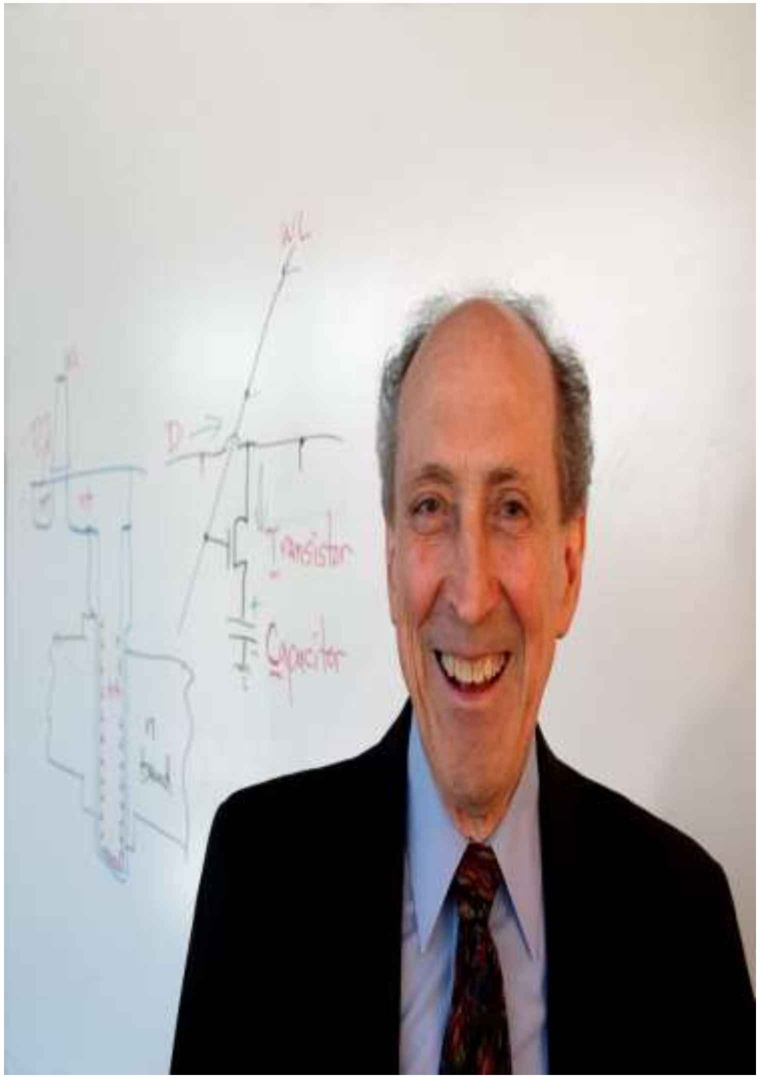
Transistor size ↓, device per chip ↑



Gordon Moore noticed in 1965: number of devices on a chip doubled every 18-24 months & predicted this trend would continue



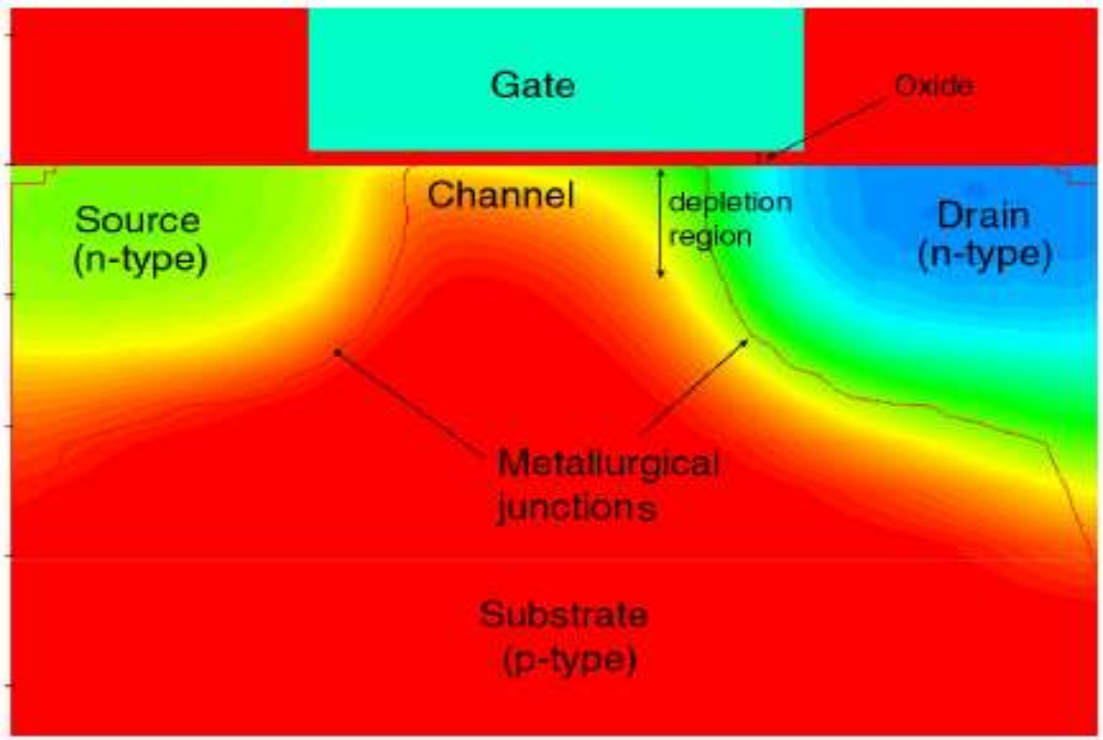
Robert Dennard's Scaling Theory



- Dennard scaling , also known as MOSFET scaling, is a scaling law based on a 1974 paper co-authored by Robert H. Dennard, after whom it is named.
- Originally formulated for MOSFETs it states, roughly, that as transistors get smaller their power density stays constant, so that the power use stays in proportion with area: both voltage and current scale (downward) with length.

Scaling

- Shrink dimensions maintaining aspect-ratio
- Must shrink electrostatic features as well (depletion regions→ doping level and profiles)



1980 → 1985 → 1988 → 1991 → 1994 → 1999 → 2011 …

L_{GATE} = 10 µm 5 µm 2.5 µm 1.3 µm 0.63 µm 0.25 µm 22 nm ….

Scaling…

Smaller MOSFETs are desirable for 3 Reasons

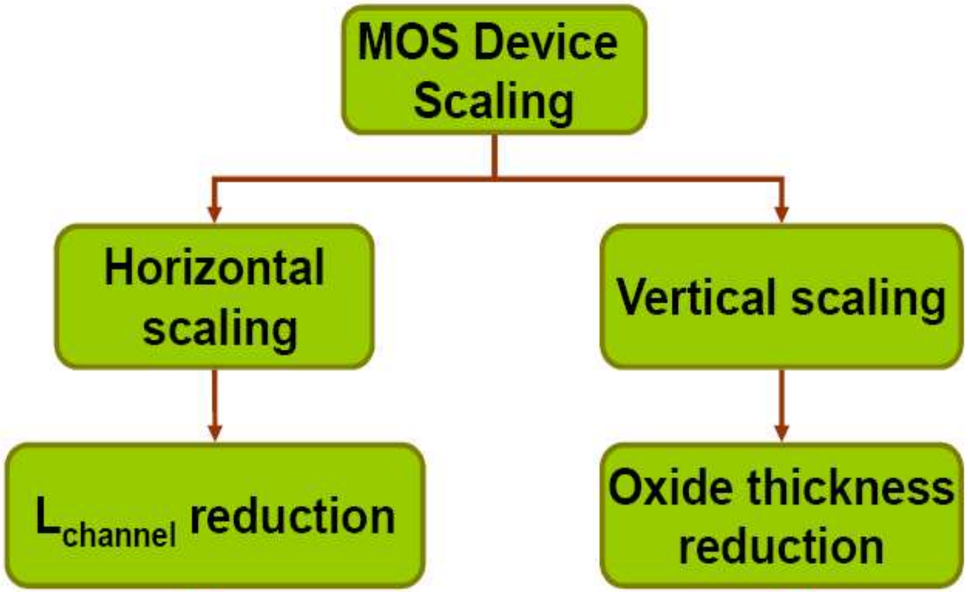
1. allow more current to pass
2. smaller gate capacitance

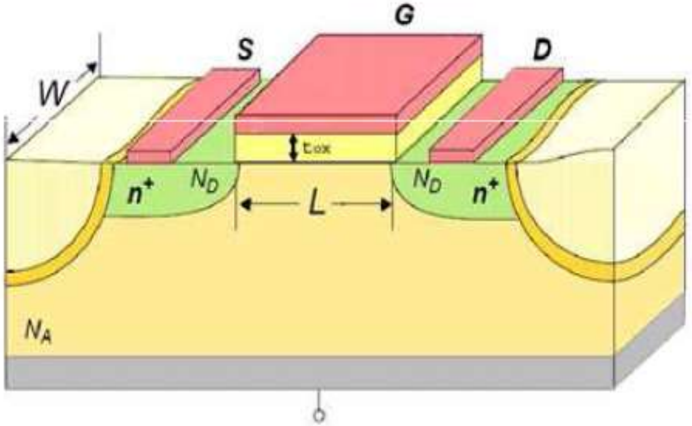
These two factors contribute lower switching times and thus higher processing speeds.

3. reduced cost.

Smaller ICs allow more chips per wafer, reducing the price per chip

MOSFET SCALING

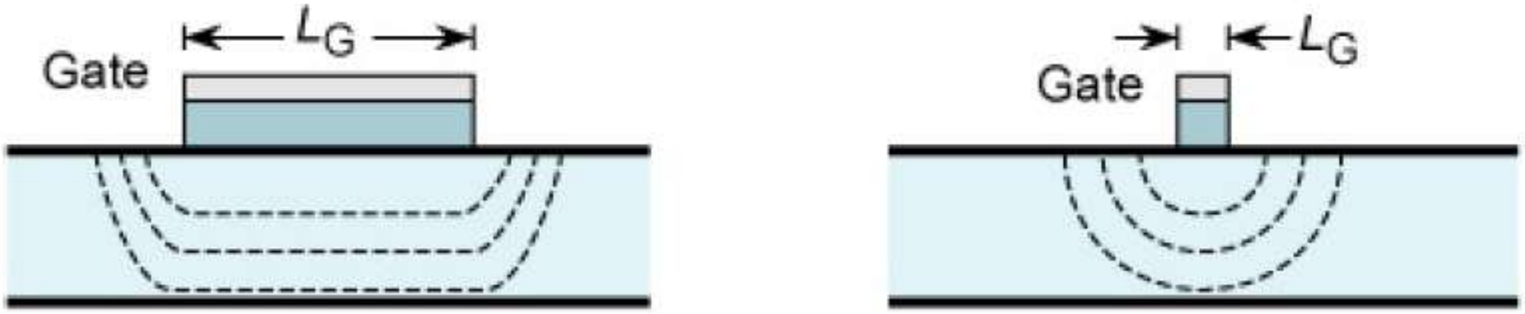




Short Channel Effect

As the gate length is reduced, the characteristics of a MOSFET change due to Short-channel effects, i.e., effects that arise at very short gate (and channel) lengths.

- Gate length modulation
- Drain induced barrier lowering
- Threshold voltage shift
- Increased leakage current
- Clear pinch-off of channel
- Increased output conductance



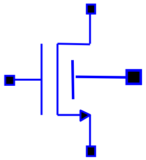
WHAT IS MODELING?

DEVICE → EQUATIONS → MODEL

$$V_{th} = V_{Tideal} + K_1\left(\sqrt{\Phi_s - V_{bs}} - \sqrt{\Phi_s}\right) - K_2 V_{bs}$$

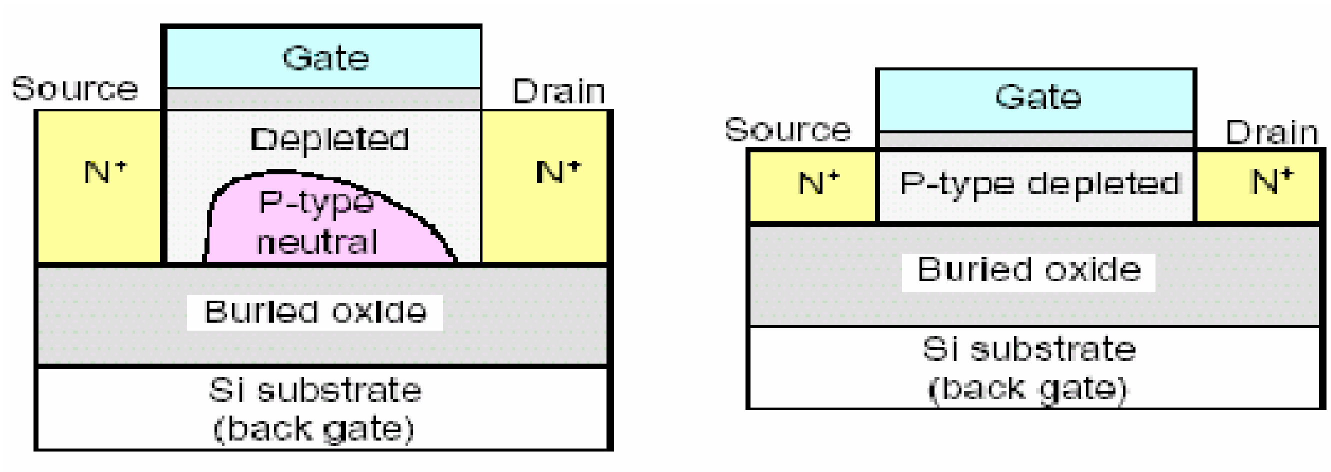
.....

```
enm (d g s b) enm_model w=10 l=0.8
model    enm_model   bsim3v3   type=n
+ vth0 = 0.582
+ u0 = 290
+ rdsw = 749.6872
+ tox = 7.10e-9
+ vsat = 5.55e4
+ k1   = 0.55
+ dvt0 = 10.7
+ cj = 1.02e-3
+ cjsw  = 3.11e-10
+ cjswg = enm_cjswg
+ js = 3.5e-7
+ jsw = 5e-13
…….
```



- **DEVICE MODEL -** set of mathematical relations between node voltages and terminal currents
- **GOAL -** accurately represent electrical behavior in circuit simulators
- **DEPENDEND ON DIFFERENT KIND OF PARAMETERS:**
  - technology parameters
  - geometry (layout) parameters
  - empirical (fitting) parameters

Single gate MOSFETs



a) PD SOI

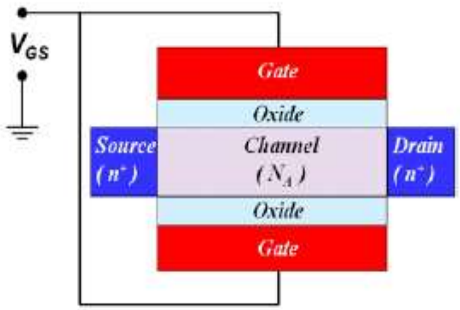
b) FD SOI

Advantages

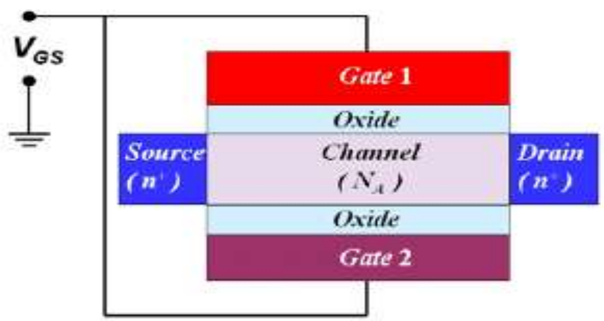
- Free from Kink effect
- Enhanced Subthreshold swing
- Reduced Power requirement
- Highest gains in circuit Speed

When Depletion region extends through entire thickness of the silicon film

Multiple gate MOSFETs



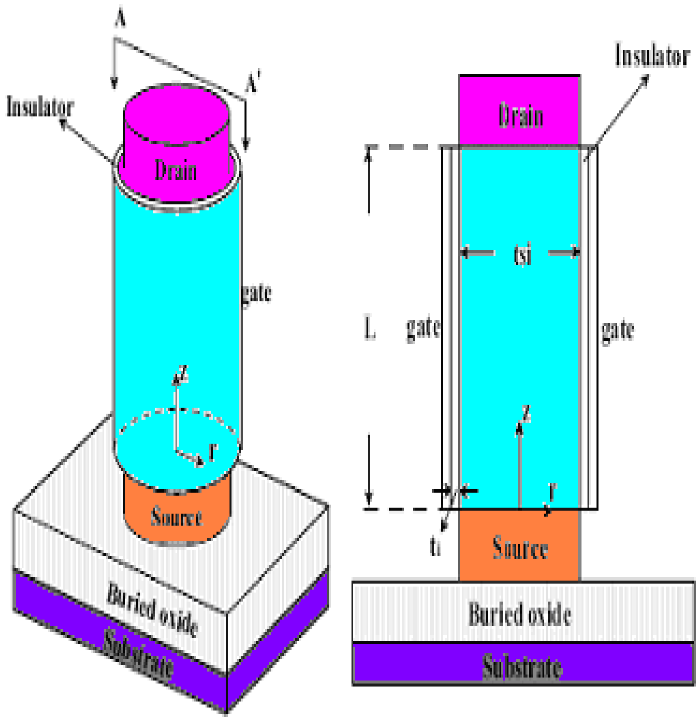
(a) DG MOSFET (Symmetric)



(b) DG MOSFET(Asymmetric)

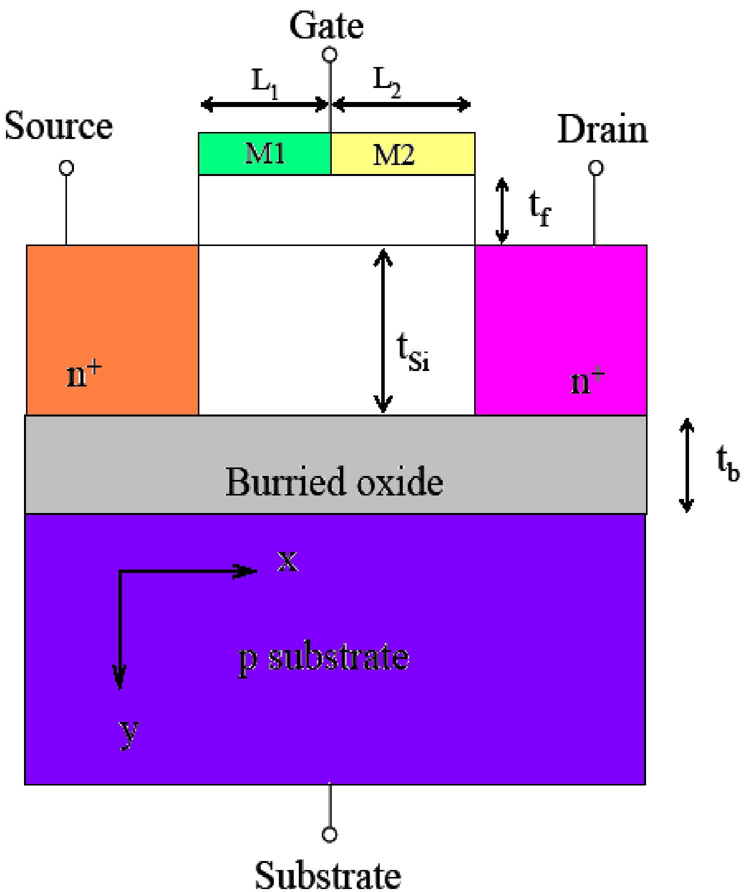
Advantages	Disadvantages
•Sharper subthreshold slope	• Hardly dependent on the doping concentration
•Improved carrier transport	•Strongly affected by the t_{si}.

Surrounding Gate MOSFET



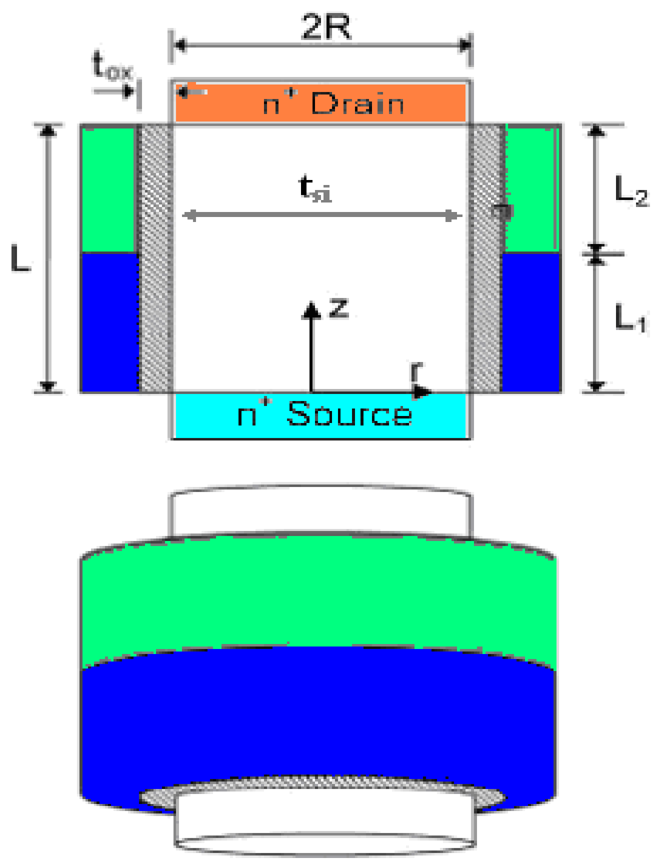
Advantages	Disadvantage
• Improved sub threshold slope	SCEs can not be neglected from channel lengths below 100nm
• Higher packing density	
•Controlling short channel effect	

Dual Material Gate MOSFET



Advantages	Disadvantage
•Suppression of SCE	• Trans conductance is not good
•Enhancement of average carrier velocity in the channel	
•Alleviation of reduced Vt	

DMSG Structure



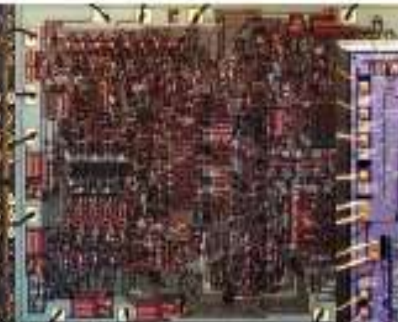
ADVANTAGES

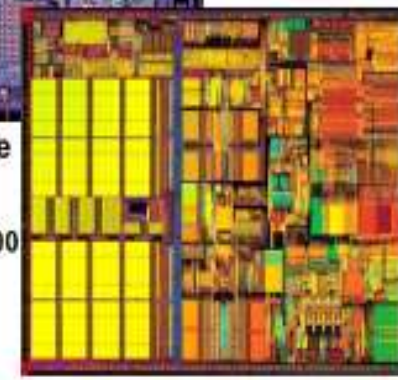
- Simultaneous suppression of SCE
- Improved subthreshold slope
- Higher Drive Current
- Enhancement of average carrier

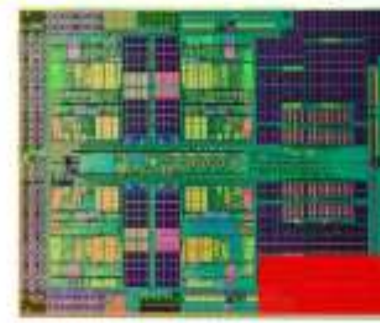
  velocity in the channel

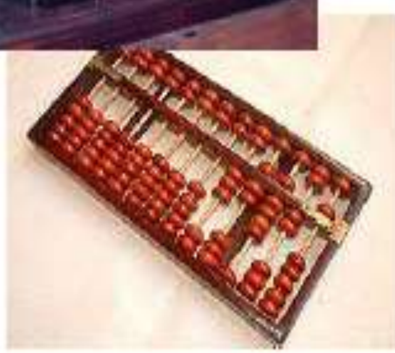
- MJ Kumar - overlooked the SCEs of DMSG devices.
- Chiang - Lot of mathematical complexity and makes its understanding and application difficult

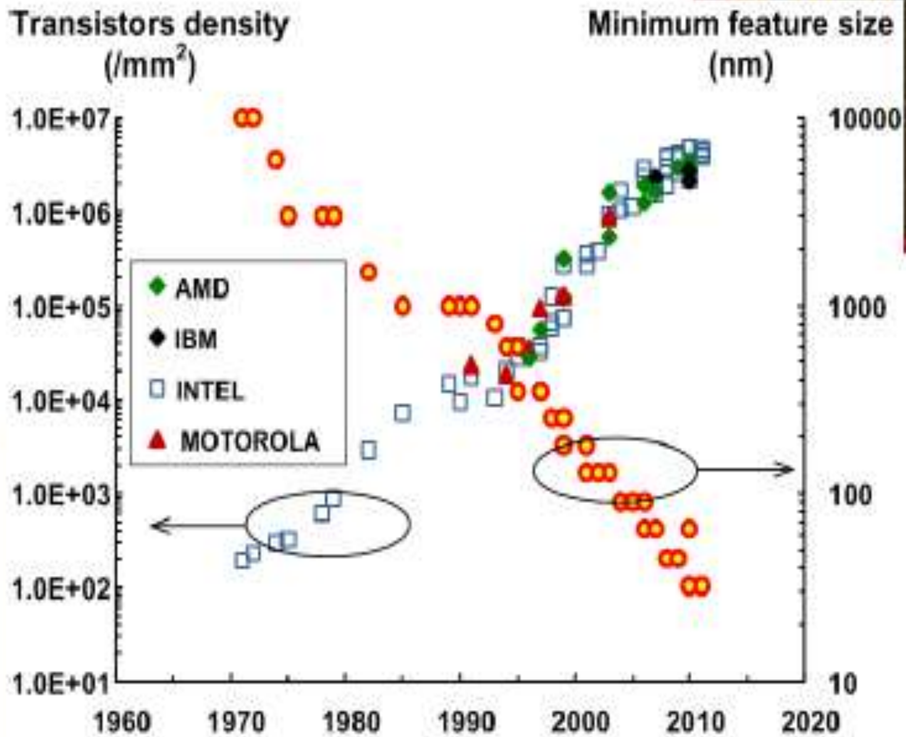
DSIR ACE PILOT MODEL 1950 NPL











Transistors density
(/mm²)
Minimum feature size
(nm)
1.0E+07
1.0E+06
1.0E+05
1.0E+04
1.0E+03
1.0E+02
1.0E+01
10000
1000
100
10
1960
1970
1980
1990
2000
2010
2020
AMD
IBM
INTEL
MOTOROLA

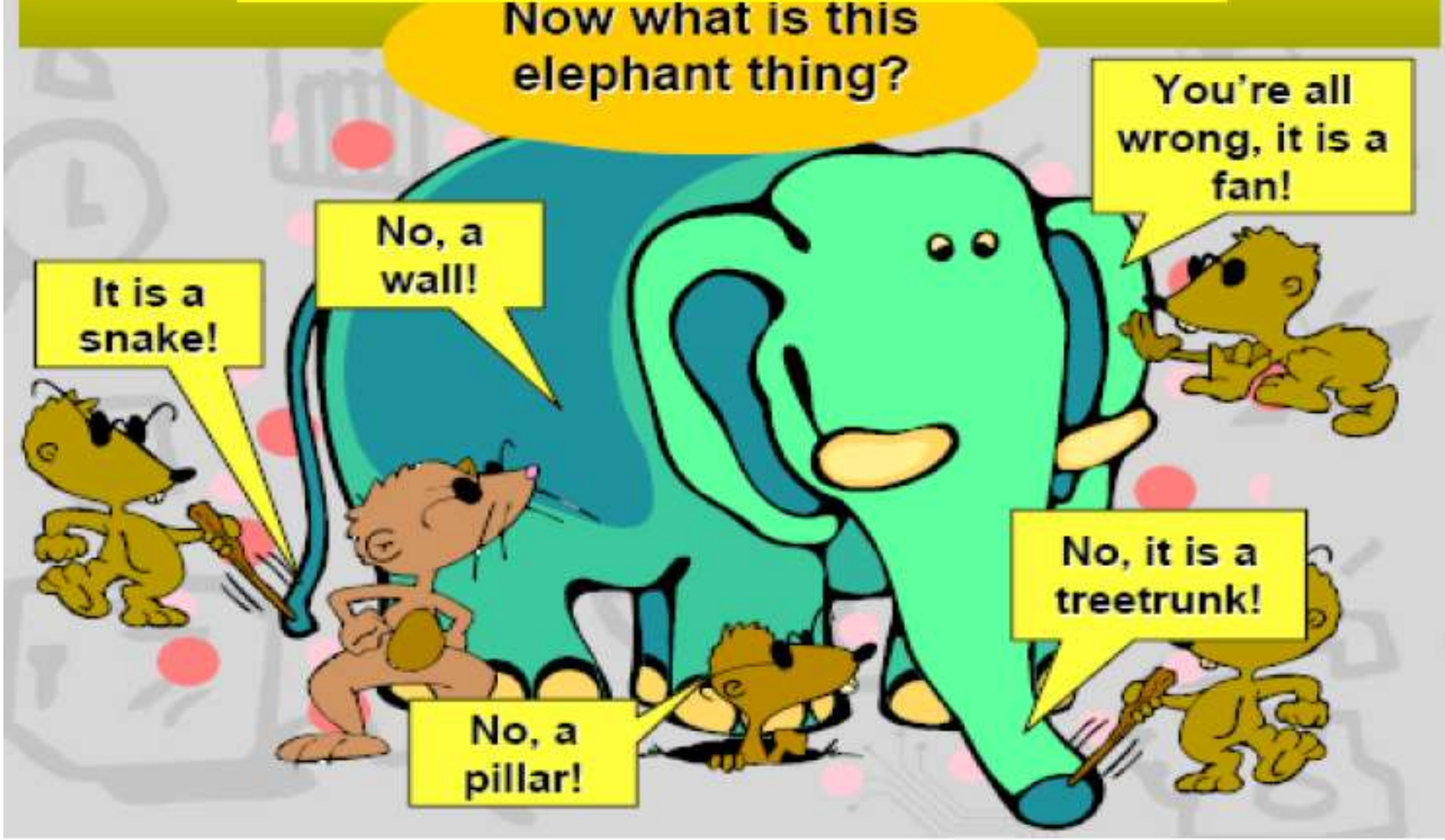
VLSI

- Is it VHDL?
- Is it Verilog HDL?
- Is it ASIC?
- Is it FPGA?
- Is it SOC?

VLSI

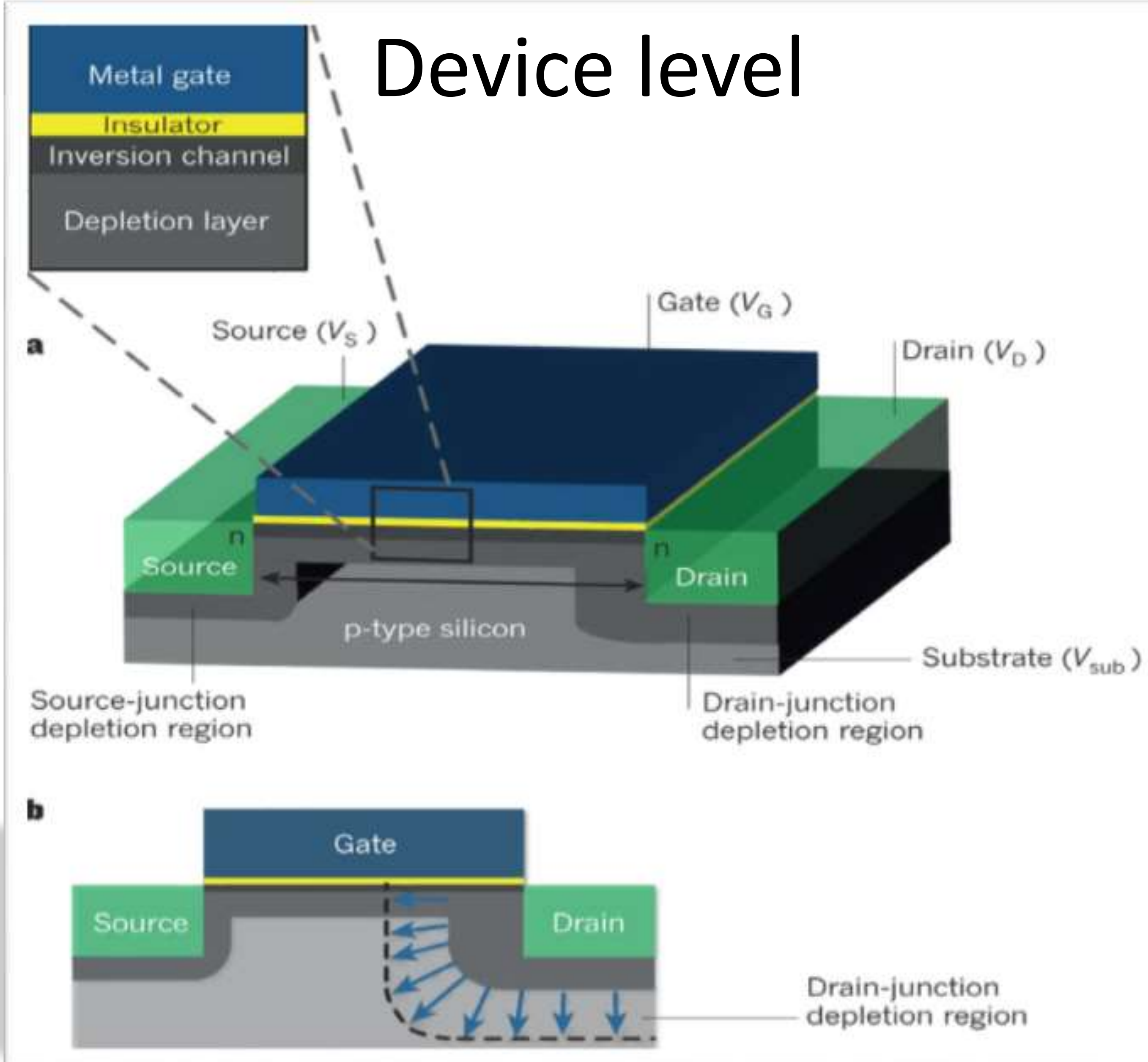
- Is it SPICE model file?
- Is it Layout editor?
- Is it extracting parasitic capacitances?
- Is it creating gds file?

VLSI

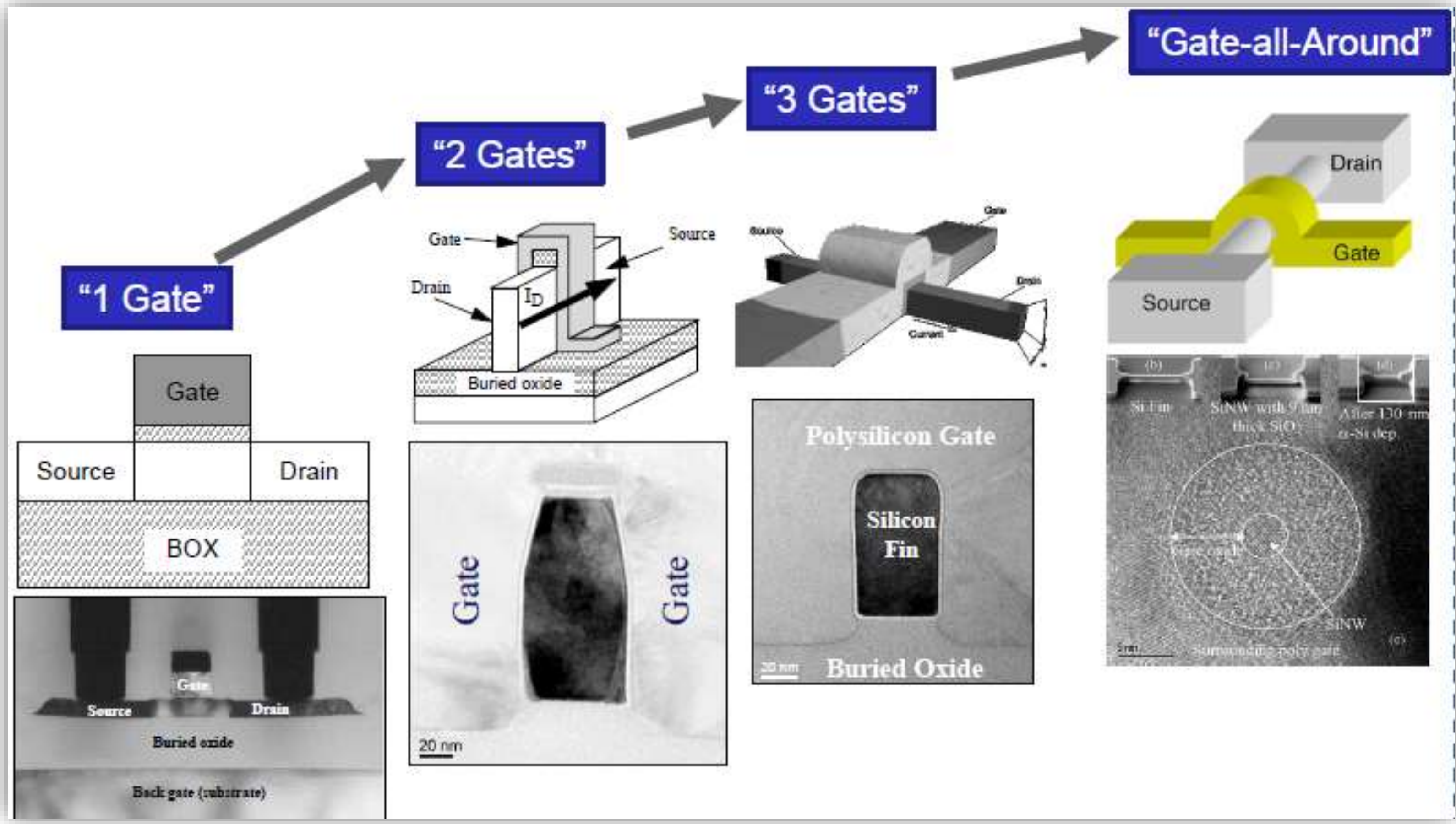

Now what is this elephant thing?
It is a snake!
No, a wall!
No, a pillar!
No, it is a treetrunk!
You're all wrong, it is a fan!

Hard Choices?

Device level



Different Gate Structures



Ref: www.tyndall.ie