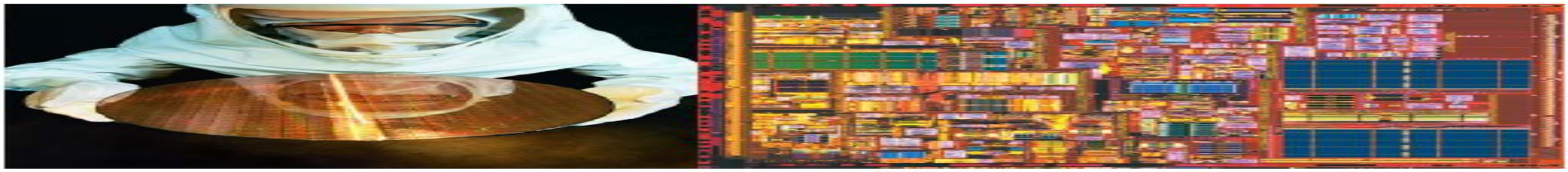


Figure 13. 300mm wafer and Pentium 4™ IC. Photos courtesy of Intel.

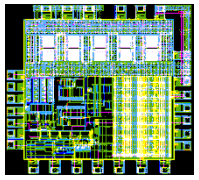
CÔNG NGHỆ CHẾ TẠO VI MẠCH ĐIỆN TỬ

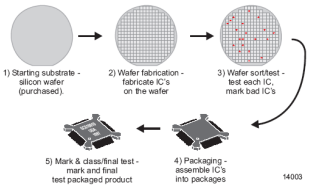
(MICROELECTRONICS & TECHNOLOGY PROCESSES)

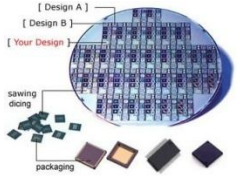
Dr. DANG TRONG-TRINH

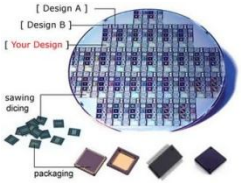
Email: trinhqtu@yahoo.com

Tel: 09 84 70 90 15









Plan

Chương 1. Tổng quan về công nghệ chế tạo vi điện tử & nền công nghiệp bán dẫn

1.1. Công nghệ vi điện tử (microelectronic technology)

1.2. Công nghệ bán dẫn (Semiconductor technology)

1.3. Các công đoạn công nghệ chính (Technology processes)

1.4. Tiềm năng và xu hướng (Strategies & trends)

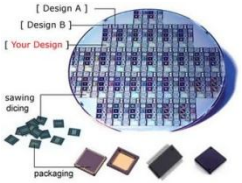
Chương 2. Vật liệu bán dẫn (Semiconductor materials)

2.1. Giản đồ năng lượng (energy diagram)

2.2. Tinh thể học và cấu trúc tinh thể (crystal structure)

2.3. Khuyết tật tinh thể & pha tạp (dopage)

2.4. Các loại chất bán dẫn



Plan

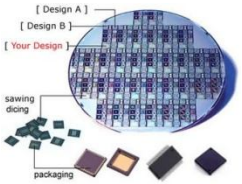
Chương 1. Tổng quan về công nghệ chế tạo vi điện tử & nền công nghiệp bán dẫn:

1.1. Công nghệ vi điện tử (microelectronic technology)

1.2. Công nghệ bán dẫn (Semiconductor technology)

1.3. Các công đoạn công nghệ chính (Technology processes)

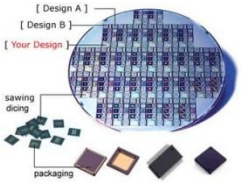
1.4. Tiềm năng và xu hướng (Strategies & trends)



Semiconductor Industry

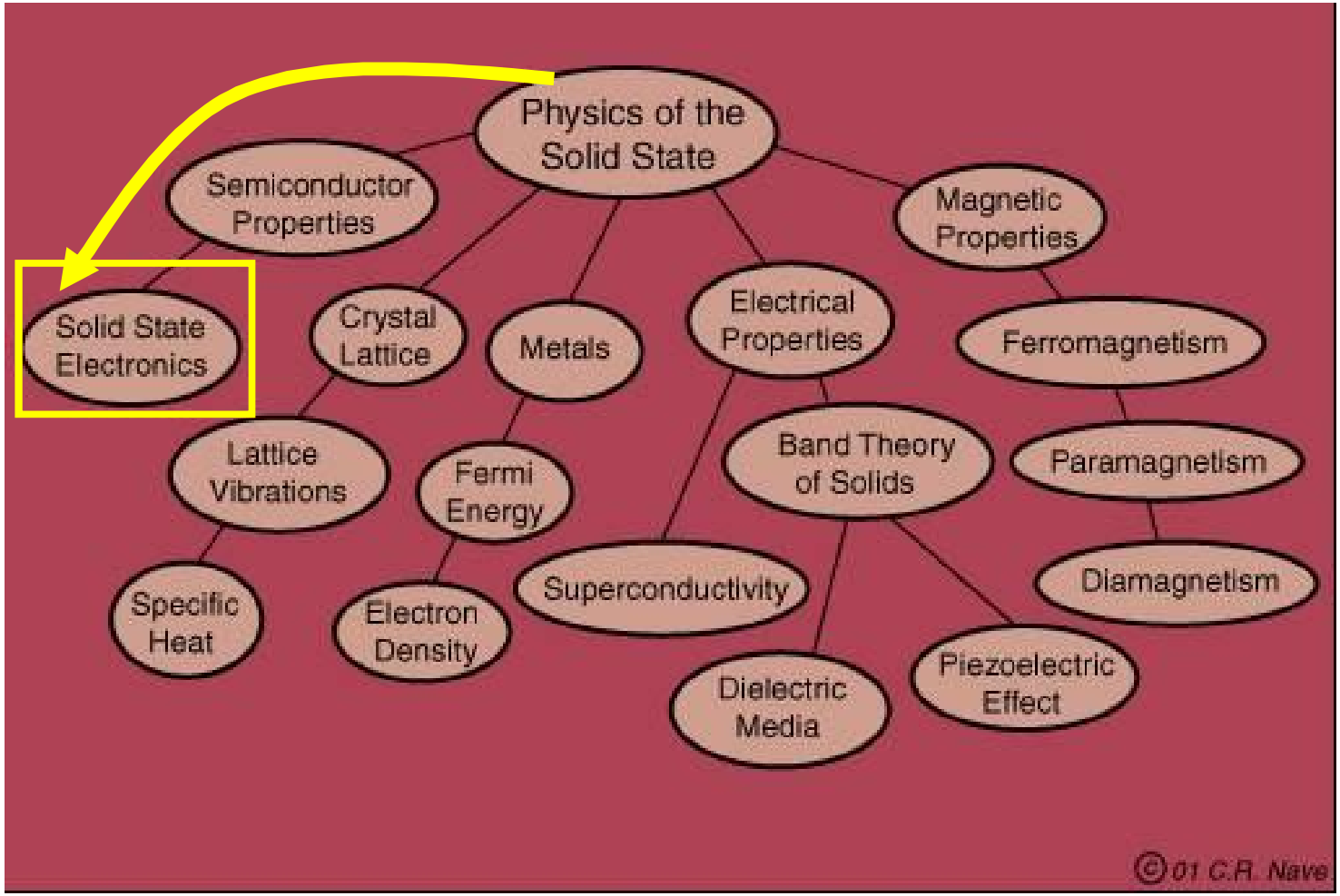
Content:

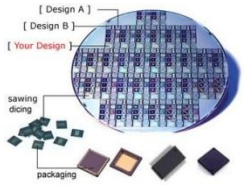
1. **Semiconductor History**
2. **Semiconductor Industry**
   - ✓ **Semiconductor companies all over the world**
   - ✓ **Semiconductor Industry in Vietnam**
3. **Semiconductor Technology**



Semiconductor Industry

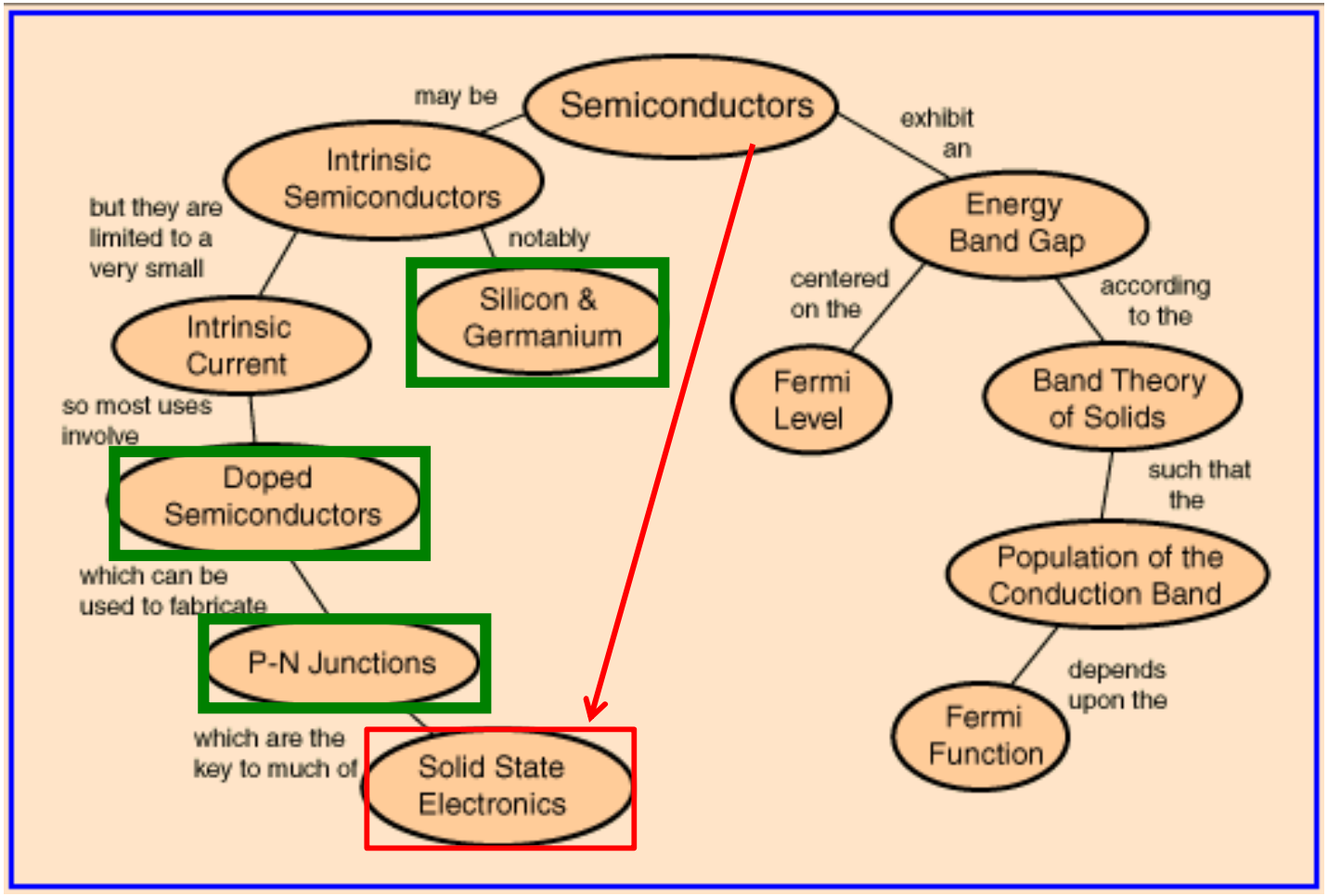
History: Physics of the Solid state

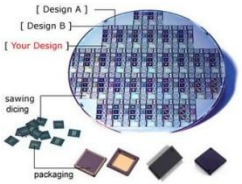




Semiconductor Industry

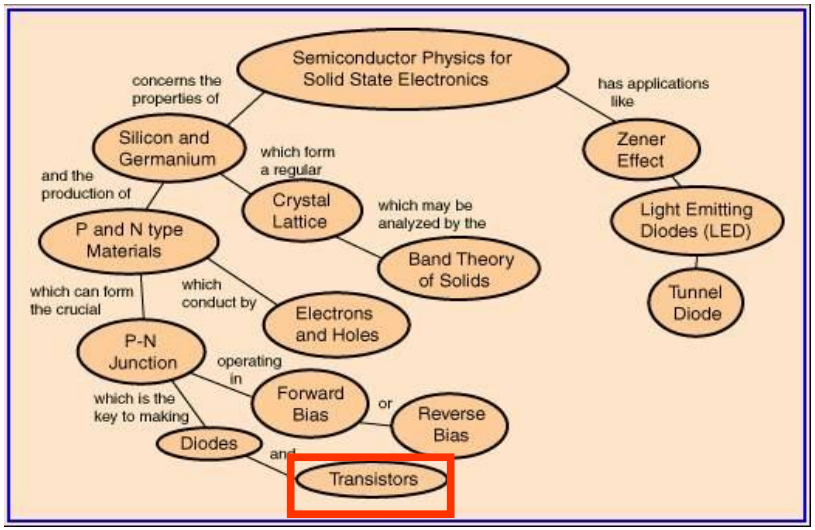
History: Physics of the Solid state





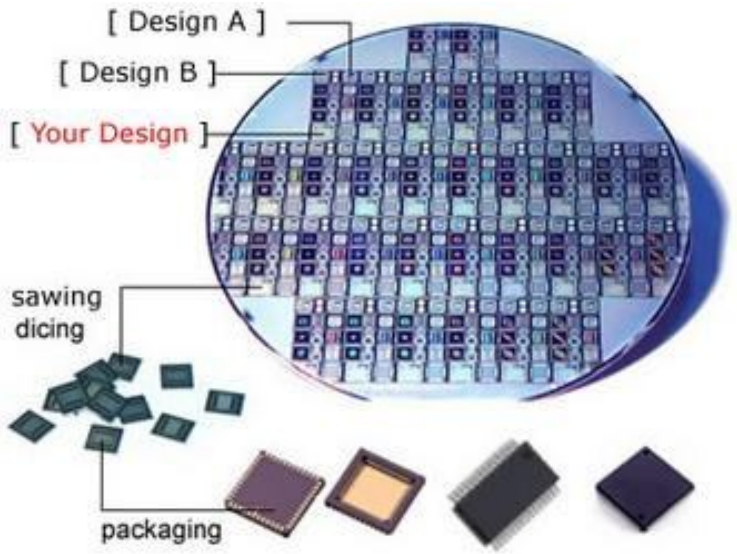
Semiconductor Industry

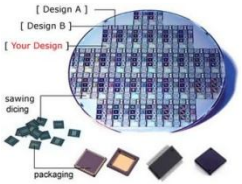
History: Element active component - transistors



1947

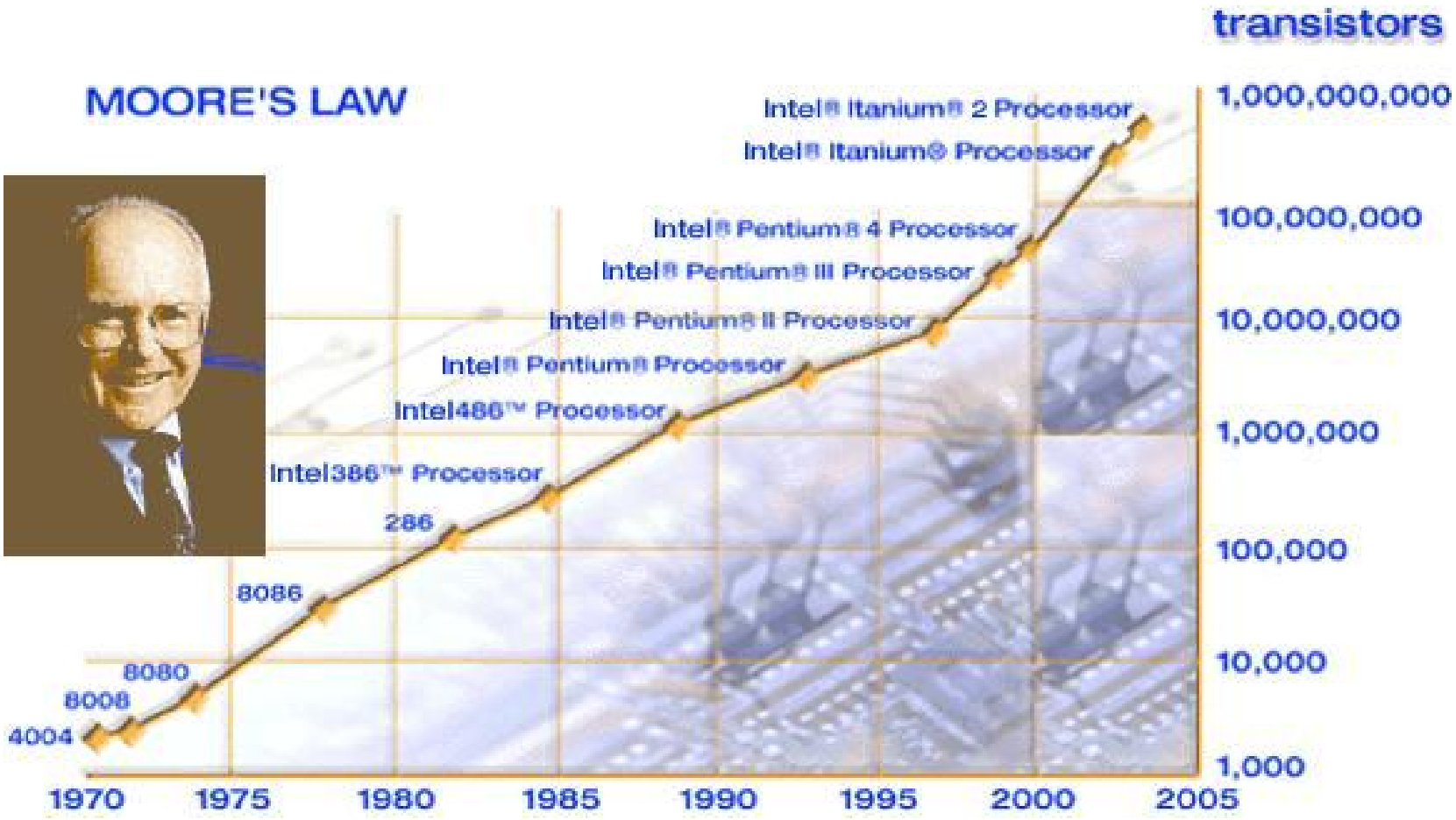
Now

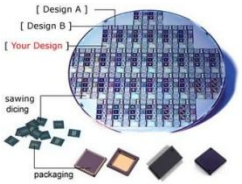




Semiconductor Industry

History: Moore law





Semiconductor Industry

History: clock frequency evolution

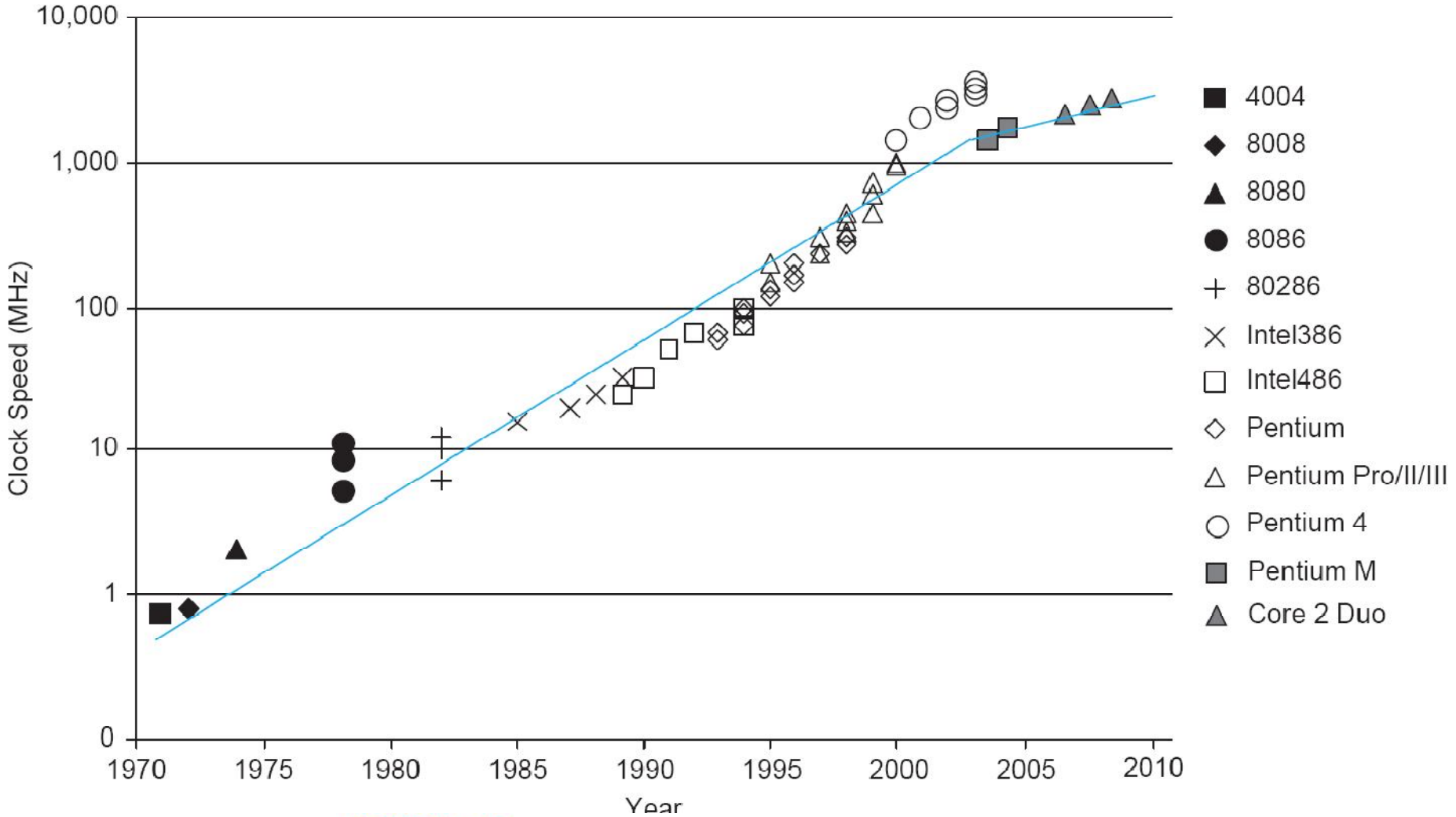
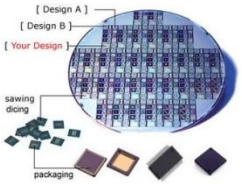


FIGURE 1.5 Clock frequencies of Intel microprocessors

Semiconductor Industry

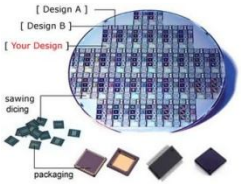


Semiconductor Industry

Semiconductor Industry: Categories

Companies designing and/or manufacturing "semiconductor products"

1. **Silicon wafer producers**
2. **Foundry semiconductor companies (fab)**
3. **Assembly and Test semiconductor companies**
4. **Fabless semiconductor companies (fabless)**
5. **Equipment semiconductor companies**

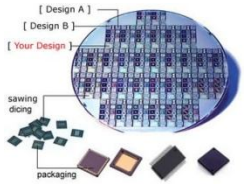


Semiconductor Industry

Semiconductor Industry: Silicon wafer producers

A list of major producers of wafers (made of high purity Silicon, mono- or polycrystalline):

1. Shin-Etsu Handotai Chemical Company (Shin-Etsu Chemical)
2. Sumco (Mitsubishi/Sumitomo Sumco Silicon) (Sumitomo Metal Industries)
3. Siltronic AG
4. MEMC Electronic Materials
5. Zhejiang DC Chemical
6. LDK Solar
7. Renewable Energy Corporation
8. Renesola
9. M. Setek
10. Covalent
11. Tokuyama
12. Topsil
13. SOItech



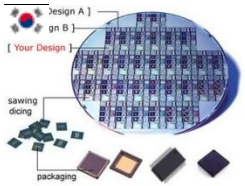
Semiconductor Industry

Semiconductor Industry: Foundry (fab)

The foundry: a semiconductor fabrication plant (commonly called a **fab**) is a factory where devices such as integrated circuits are manufactured.

Foundries are typically located in countries with lower cost of labor.

1. **Pure-play semiconductor foundry:** not offer a significant amount of IC products of its own design, but instead operates semiconductor fabrication plants focused on producing ICs for other companies (TSMC, UMC)
2. **IDM (Integrated device manufacturer) semiconductor foundry:** provide foundry services & fabricate their own design (Texas Instruments, IBM, and Samsung)

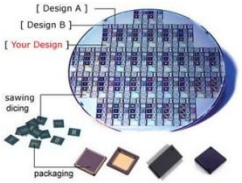


Semiconductor Industry

Semiconductor Industry: Foundry sales

Rank	Company	Foundry Type	Country of origin	Revenue (million $USD)		
2009				2009	2008	2007
1	TSMC	Pure-play	Taiwan	8,989	10,556	9,813
2	UMC	Pure-play	Taiwan	2,815	3,070	3,430
3	Chartered (1)	Pure-play	Singapore	1,540	1,743	1,458
4	GlobalFoundries	Pure-play	USA	1,101	0	0
5	SMIC	Pure-play	China	1,075	1,353	1,550
6	Dongbu	Pure-play	South Korea	395	490	510
7	Vanguard	Pure-play	Taiwan	382	511	486
8	IBM	IDM	USA	335	400	570
9	Samsung	IDM	South Korea	325	370	355
10	Grace	Pure-play	China	310	335	310
11	He Jian	Pure-play	China	305	345	330
12	Tower Semiconductors	Pure-play	Israel	292	252	231
13	HHNEC	Pure-play	China	290	350	335
14	SSMC	Pure-play	Singapore	280	340	359
15	Texas Instruments	IDM	USA	250	315	450
16	X-Fab	Pure-play	Germany	223	368	410
17	MagnaChip	IDM	South Korea	220	290	322

(1) Now acquired by GlobalFoundries



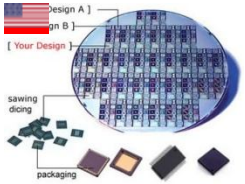
Semiconductor Industry

Semiconductor Industry: Fabless semiconductor company

• A fabless semiconductor company specializes in the design and sale of hardware devices and semiconductor chips while outsourcing the fabrication.

• The first fabless semiconductor company, the Western Design Center, was founded in 1978.

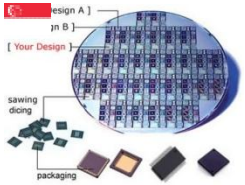
• Only since the early 1990s, the fabless business model has grown exponentially both in terms of net output and global presence.



Semiconductor Industry

Semiconductor Industry: Fabless sales

Rank 2009	Company	Country of origin	Revenue (million $ USD)
1	Qualcomm	USA	6,585
2	AMD	USA	5,252
3	Broadcom	USA	4,190
4	MediaTek	Taiwan	3,500
5	Nvidia	USA	3,135

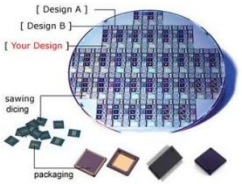


Semiconductor Industry

Semiconductor Industry: Semiconductor equipment companies

An IC equipment suppliers provide systems used to manufacture semiconductors, thin-film heads, MEMs, integrated circuits, as well as service, support

Rank		Company	Country of origin	Revenue
2009	2008			(million $USD)
1	1	Applied Materials	USA	3,597
2	3	Tokyo Electron	Japan	2,324
3	2	ASML	Netherlands	2,268
4	6	Nikon	Japan	1,547
5	4	KLA Tencor	USA	1,321
6	5	Lam Research	USA	1,198
7	9	Dainippon Screen	Japan	805
8	11	ASM International	Netherlands	690
9	10	Novellus Systems	USA	582
10	12	Teradyne	USA	552
11	8	Hitachi High-Tech	Japan	474
12	13	Advantest	Japan	416
13	18	Aixtron	Germany	412
14	14	Varian Semiconductor	USA	396
15	15	Verigy	Singapore	333



Semiconductor Industry

Semiconductor Industry: Assembly and Test semiconductor companies

Customer Inputs

- Simulation Output
- Specification

Amkor Test Services

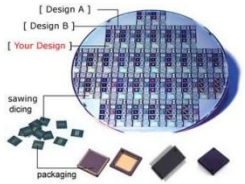
Complete Test Solution

- Develop Load Board(s)
- Develop Probe Card(s)
- Develop ESD Test Fixtures
- Develop Qualification Fixtures
- Provide Eng. Support from this Time Zone
- Develop Test Program
- Develop Q.A. Program
- Develop Characterization Program
- Install Probe and Final Test in Asia
- Test Engineering Samples
- Run Complete Qualification & Write Report
- Run all ESD/Latch-up Tests & Write Report
- Characterize Parts & Write Reports
- Test Initial Production or Quick Turn Parts

Customer Outputs

- Installed Wafer Probe & Final Test Programs
- Tested Engineering Samples
- Characterized Devices
- Finished Qualification Report
- Finished ESD & Latch-up Test Report
- Load Board(s) & Qualification Tooling
- Initial Production Parts
- Speed Sorted Parts
- Characterization Data

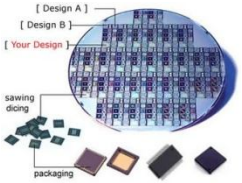
Amkor Technology, Inc



Semiconductor Industry

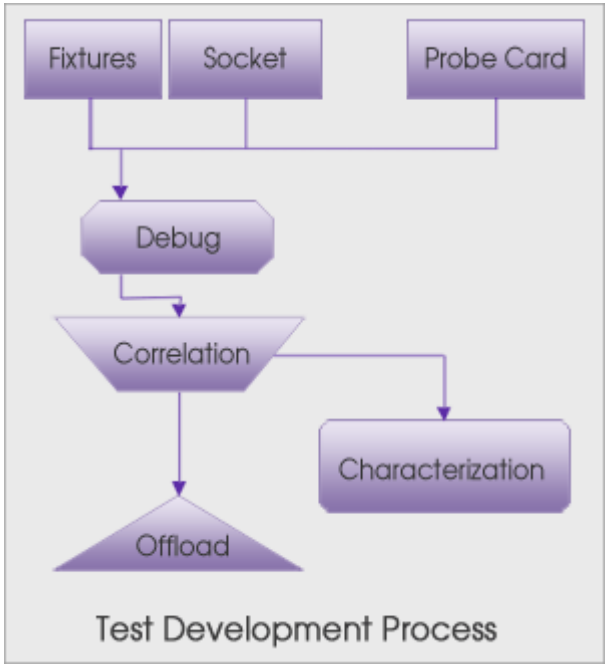
Semiconductor Industry: Assembly and Test semiconductor companies

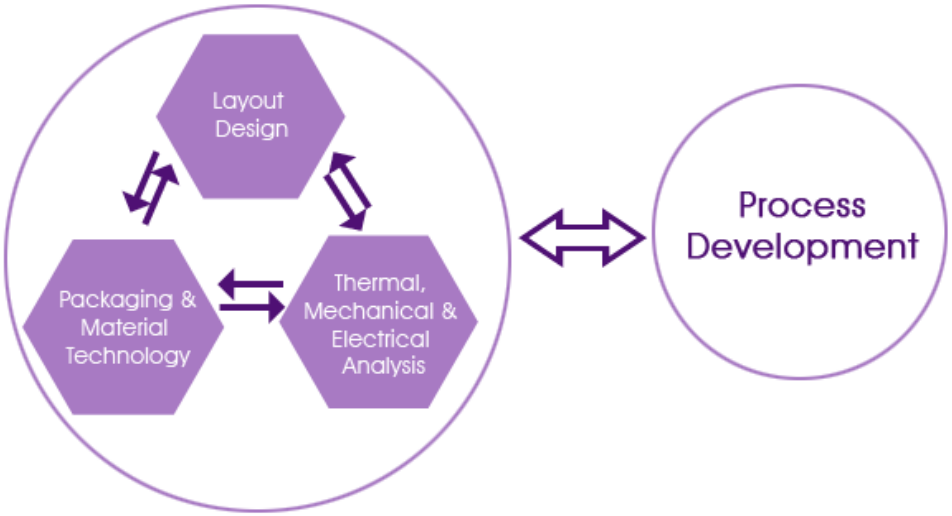
Signetics company



Semiconductor Industry

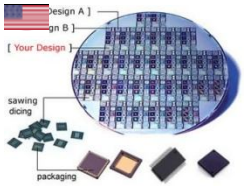
Semiconductor Industry: Assembly and Test semiconductor companies





Packaging & Assembly

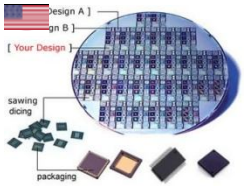
UTAC company



Semiconductor Industry

Semiconductor Industry: Semiconductor Sales

Rank 2009	Rank 2008	Company	Country of origin	Revenue (million $ USD)	2009/2008 changes	Market share
1	1	Intel Corporation	USA	32 410	-4.0%	14.1%
2	2	Samsung Electronics	South Korea	17 496	+3.5%	7.6%
3	3	Toshiba Semiconductors	Japan	10 319	-6.9%	4.5%
4	4	Texas Instruments	USA	9 617	-12.6%	4.2%
5	5	STMicroelectronics	France Italy	8 510	-17.6%	3.7%
6	8	Qualcomm	USA	6 409	-1.1%	2.8%
7	9	Hynix	South Korea	6 246	+3.7%	2.7%
8	12	AMD	USA	5 207	-4.6%	2.3%
9	6	Renesas Technology	Japan	5 153	-26.6%	2.2%
10	7	Sony	Japan	4 468	-35.7%	1.9%



Semiconductor Industry

Semiconductor Industry: Semiconductor Sales

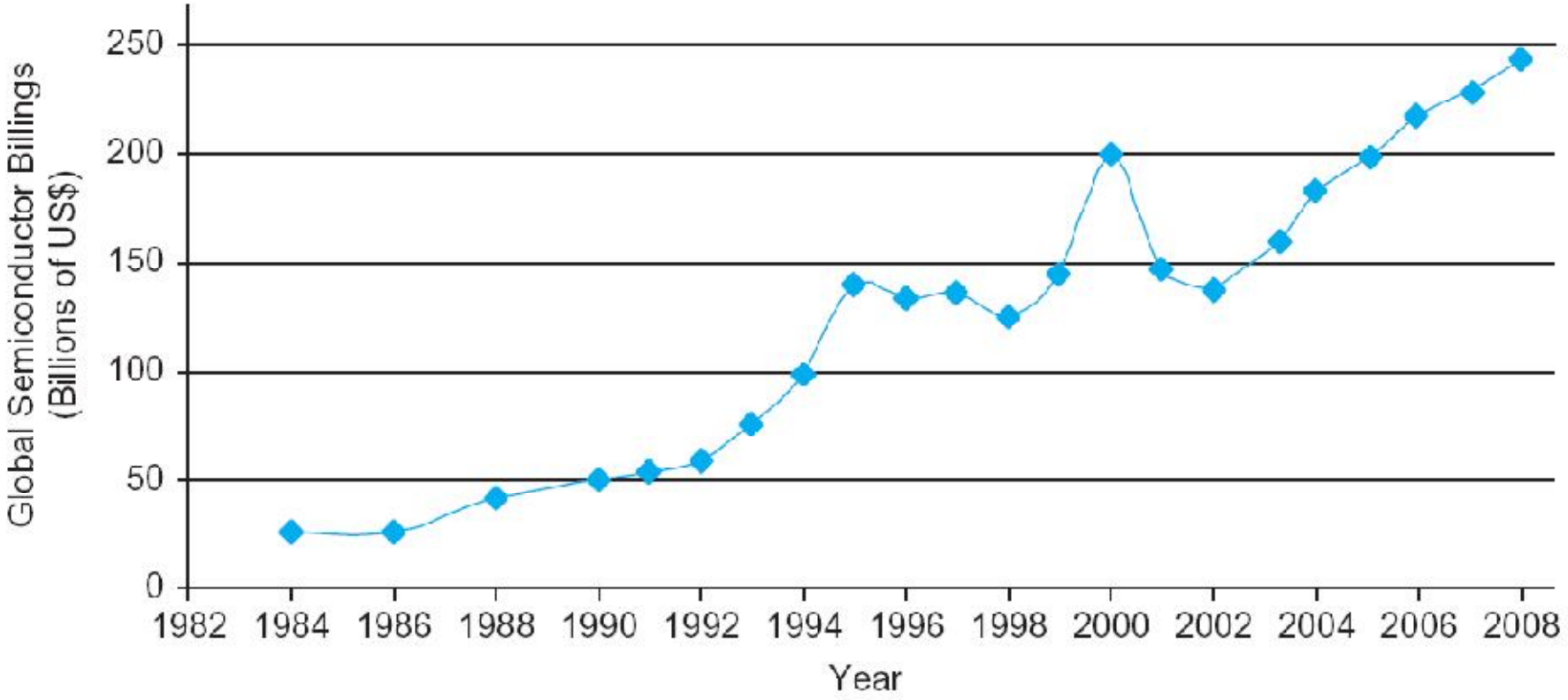
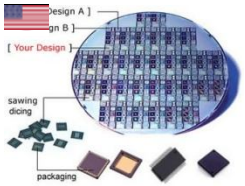


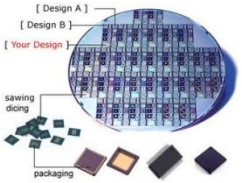
FIGURE 1.1 Size of worldwide semiconductor market (Courtesy of Semiconductor Industry Association.)



Semiconductor Industry

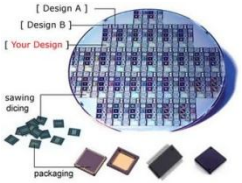
Semiconductor Industry: Semiconductor sales

Rank 2009	Rank 2008	Company	Country of origin	Revenue (million $ USD)	2009/2008 changes	Market share
11	10	Infineon Technologies	Germany	4 456	-25.2%	1.9%
12	11	NEC Semiconductors	Japan	4 384	-24.8%	1.9%
13	16	Micron Technology	USA	4 293	-3.2%	1.9%
14	14	Broadcom	USA	4 278	-7.9%	1.9%
15	19	Elpida Memory	Japan	3 948	+9.7%	1.7%
16	24	MediaTek	Taiwan	3 551	+22.6%	1.5%
17	13	Freescale Semiconductor	USA	3 402	-31.5%	1.5%
18	15	Panasonic Corporation	Japan	3 243	-27.5%	1.4%
19	17	NXP	Netherlands	3 240	-20.1%	1.4%
20	18	Sharp Electronics	Japan	2 977	-17.5%	1.3%
21	20	NVIDIA	USA	2 826	-12.8%	1.2%
22	25	Rohm	Japan	2 586	-22.8%	1.1%
23	23	Fujitsu Microelectronics	Japan	2 574	-13.6%	1.1%
24	22	Marvell Technology Group	USA	2 572	-15.9%	1.1%
25	26	IBM Microelectronics	USA	2 253	-8.9%	1.0%
Top 25				**156 472**	**-10.39%**	**68.1%**
All Other companies				**73 445**	**-14.2%**	**31.9%**
TOTAL				**229 917**	**-11.7%**	**100.0%**



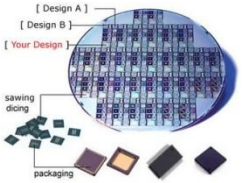
Semiconductor Industry

Tình hình chung về ngành bán dẫn và vi điện tử tại Việt Nam



Semiconductor Industry

Phối cảnh nhà máy Intel tại Khu Công nghệ cao, Q.9, TP.HCM



Semiconductor Industry

Khối công nghiệp liên quan đến lĩnh vực vi điện tử

1/. Intel (http://www.intel.com/jobs/Vietnam/):

- Chuyên về đóng gói vi mạch và test sản phẩm sau đóng gói.

2/. Acrosemi (http://www.acrosemi.com)

- Chuyên về cung cấp thiết bị + công cụ design.
- Cung cấp giải pháp thiết kế, chủ yếu ở mức coding (VHDL hoặc Verilog HDL).

3/. Signet Design Solutions Vietnam

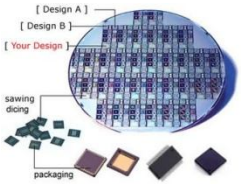
- Tập trung vào khâu Physical Design (Place & Route) - Làm Layout cho chip.
- Thiết kế layout cho những chip phức tạp, có hàng triệu cổng.
- Cộng nghệ từ 130nm đến 65nm.
- Liên hệ: P. 3.7, E-Town 2, 364 Cộng Hòa, Q.Tân Bình, TP. HCM. Tel.: (84.8) 812 5616 – Email: info@signetdesign.vn

4/. VSMC - Công ty bán dẫn Việt Nam (http://www.vsmc.com.vn/)

- Chuyên nghiên cứu và sản xuất các sản phẩm vi mạch số liên quan đến vấn đề kiểm soát năng lượng. Tên sản phẩm : Chíp Quản Lý Năng Lượng Kỹ Thuật Số Phổ Thông - VS8801L

5/. SDS - Silicon Design Solution (http://www.sds.com.vn)

- Chuyên cung cấp các dịch vụ thiết kế liên quan đến ASIC design như: Tổng hợp thiết kế các mức (synthesis), làm layout, back-end,...
- Chuyển đổi thiết kế từ FPGA sang ASIC
- Verification,...



Semiconductor Industry

6/. Renesas Technology Corporation VIETNAM (Renesas)

- **Coding HDL (VHDL, VERILOG) (RTL level).**

7/. Panasonic R&D Center Vietnam

- **LSI team hướng phát triển sẽ chuyên về mảng chip design.**

8/. *Công ty* Arrivetechnologies (http://arrivetechnologies.com)

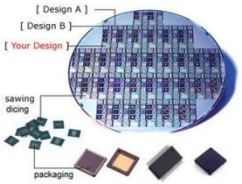
- **Năm 2006 đã tung ra thị trường AT4848 multiservice ADM system-on-a-chip & Europa dùng trong lĩnh vực truyền tải cáp quang.**
- **Địa chỉ: P.13, Lầu 10, 364 Cộng Hòa, Q. Tân Bình , TP.HCM**

9./ Active-Semi Việt Nam Ltd. (http://www.active-semi.com)

- **ActivePMUTM Power Management Units**
- **High Power DC/DC Converters**
- **ActivePSRTM AC/DC Converters**
- **Battery Charger ICs (*chip IC analog quản lý nguồn điện dùng trong các thiết bị điện tử như ĐTDĐ, laptop*)**

10./ WiCHIP Technologies Inc. (http://www.wichiptech.com)

- **FPGA và xử lí tín hiệu Video RF ID?**



Semiconductor Industry

11/. AMCC (http://investor.amcc.com/releasedetail.cfm?releaseid=302047) ➔

AppliedMicro company: new name

- IC design , software development

- Q7, TP HCM

12/. Công ty Viet Vmicro (http://www.vietvmicro.com)

-Đầu tư vào Khu Công nghệ Cao TPHCM và xây dựng nhà máy sản xuất chip đầu tiên tại VN.

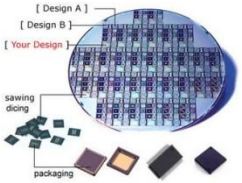
-Sản phẩm chính sẽ là các analog IC dùng trong thiết bị cầm tay, IC design, solar cells.

13. SplendID (http://www.splendidtechnology.com.vn/)

-RFID solution

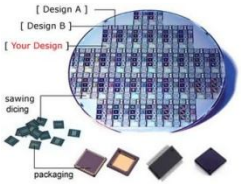
-Consulting Service

- Located in Ho Chi Minh city.



Semiconductor Industry

STMicroelectronics có thể đầu tư vào Việt nam?



Semiconductor Industry

Trung tâm nghiên cứu và hoạt động liên quan đến lĩnh vực vi điện tử

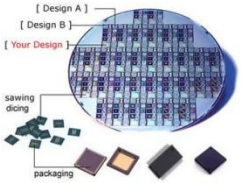
1/. Trung tâm SIS (Smart Integrated System), Trường ĐH Công nghệ, ĐHQGHN (http://www.coltech.vnu.vn/sis/)

2/. Trung tâm ICDREC, ĐHQG TPHCM (http://www.icdrec.edu.vn/)

3/. Phòng thí nghiệm Nano (Laboratory of Nanotechnology) (http://www.hcmlnt.edu.vn/index.php?Module=Content&Action=view&id=39&Itemid=298)

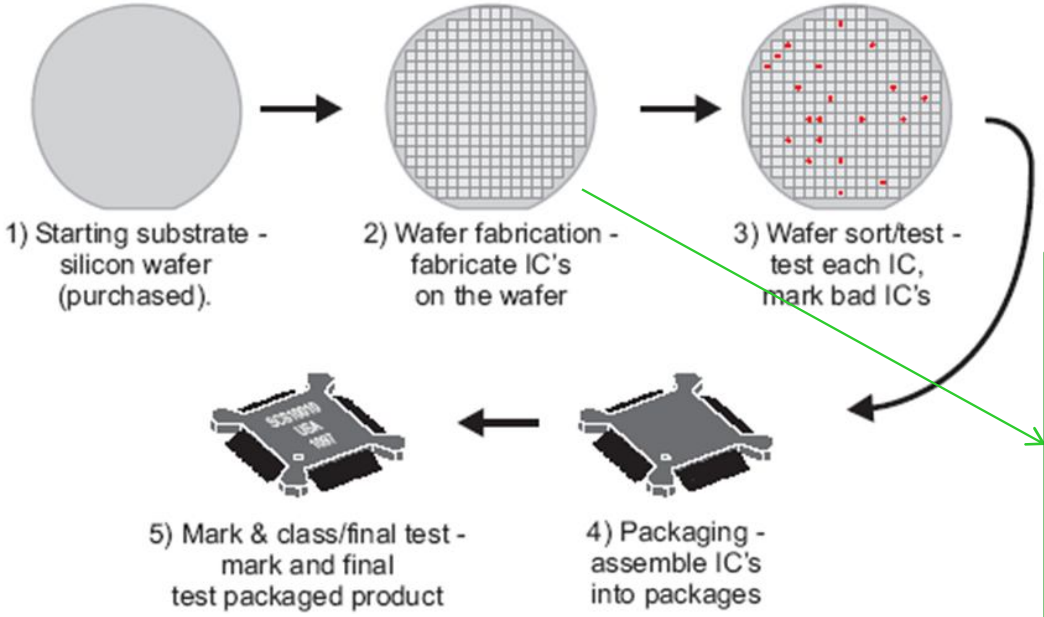
4/. R&D cleanroom of SHTP (Saigon Hitech Park)

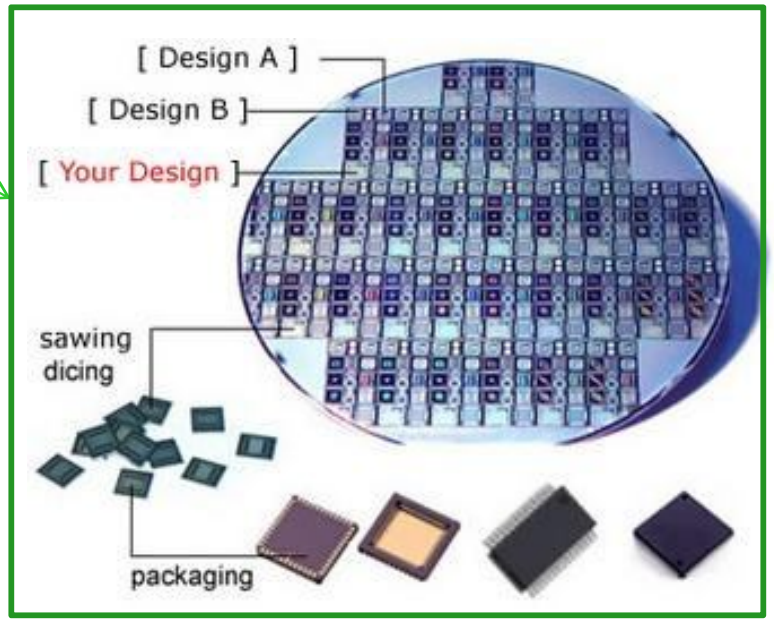
Semiconductor Technology

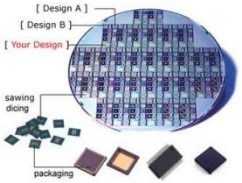


Semiconductor Industry

Semiconductor Technology: IC fabrication







IC manufacturing process

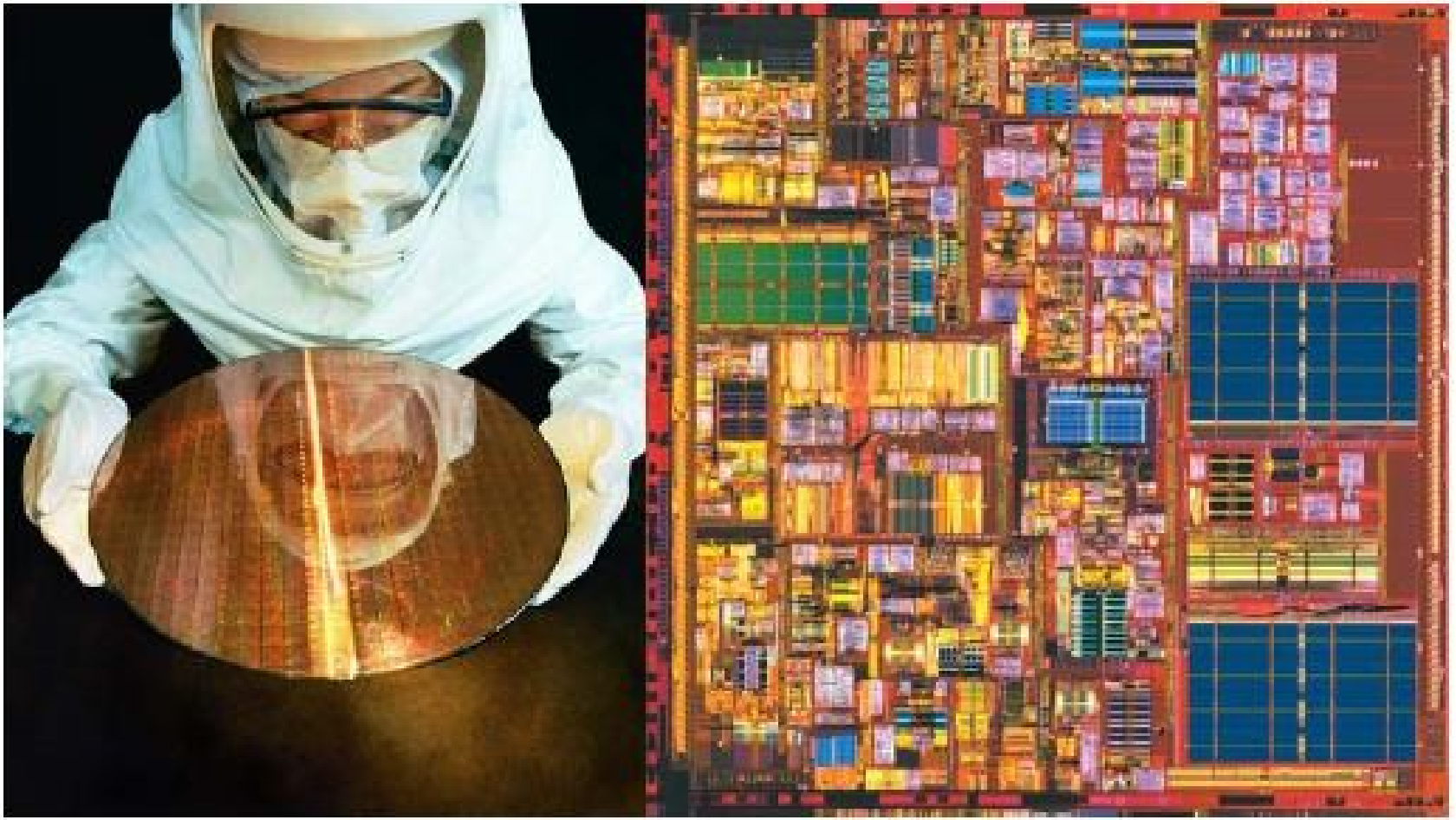
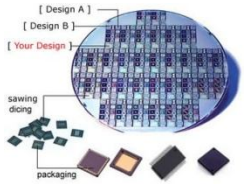


Figure 13. 300mm wafer and Pentium 4™ IC. Photos courtesy of Intel.

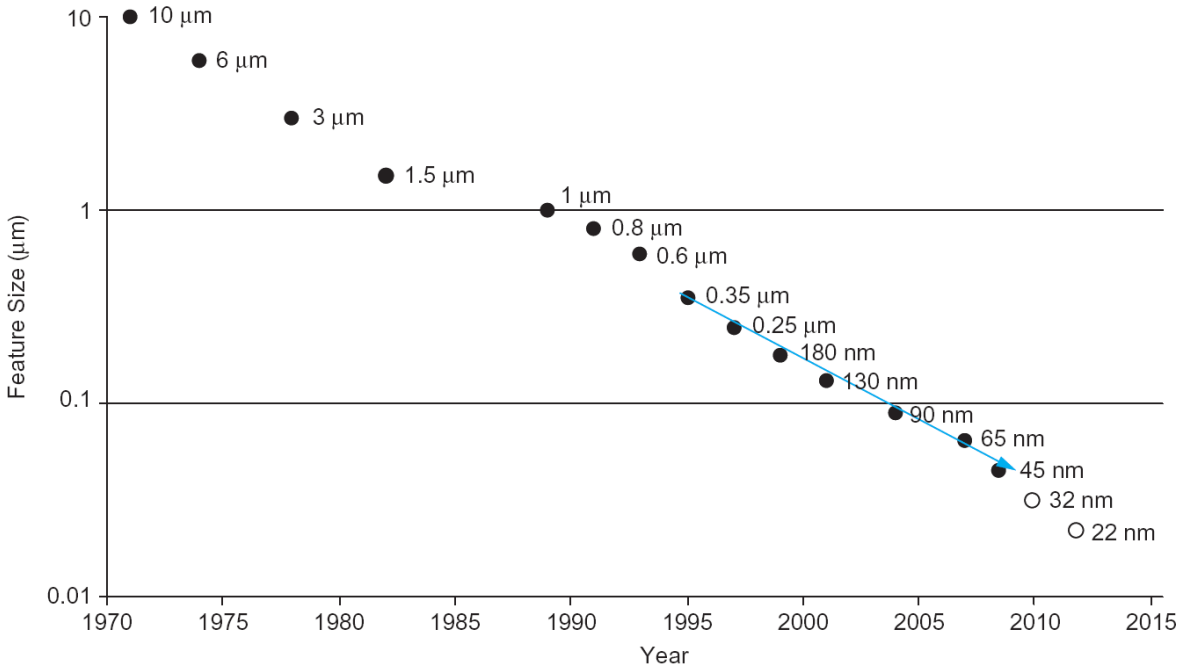


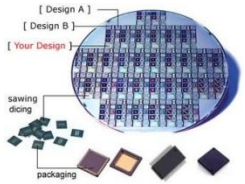
Semiconductor Industry

Semiconductor Technology: Manufacturing process

Semiconductor manufacturing processes

- 10 µm — 1971
- 6 µm — 1974
- 3 µm — 1975
- 2 µm — 1979
- 1.5 µm — 1982
- 1 µm — 1985
- 800 nm (0.80 µm) — 1989
- 600 nm (0.60 µm) — 1994
- 350 nm (0.35 µm) — 1995
- 250 nm (0.25 µm) — 1998
- 180 nm (0.18 µm) — 1999
- 130 nm (0.13 µm) — 2000
- 90 nm — 2002
- 65 nm — 2006
- 45 nm — 2008
- 32 nm — 2010
- 22 nm — approx. 2011
- 16 nm — approx. 2013
- 11 nm — approx. 2015



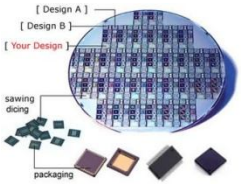


Semiconductor Industry

Semiconductor Technology: ITRS (Intl. Technology Roadmap for Semiconductors)

Table 4.17 Predictions from the 2002 ITRS

Year	2001	2004	2007	2010	2013	2016
Feature size (nm)	130	90	65	45	32	22
V_{DD} (V)	1.1–1.2	1–1.2	0.7–1.1	0.6–1.0	0.5–0.9	0.4–0.9
Millions of transistors/die	193	385	773	1564	3092	6184
Wiring levels	8–10	9–13	10–14	10–14	11–15	11–15
Intermediate wire pitch (nm)	450	275	195	135	95	65
Interconnect dielectric constant	3–3.6	2.6–3.1	2.3–2.7	2.1	1.9	1.8
I/O signals	1024	1024	1024	1280	1408	1472
Clock rate (MHz)	1684	3990	6739	11511	19348	28751
FO4 delays/cycle	13.7	8.4	6.8	5.8	4.8	4.7
Maximum power (W)	130	160	190	218	251	288
DRAM capacity (Gbits)	0.5	1	4	8	32	64



Semiconductor Industry

Semiconductor Technology: ITRS (Intl. Technology Roadmap for Semiconductors)

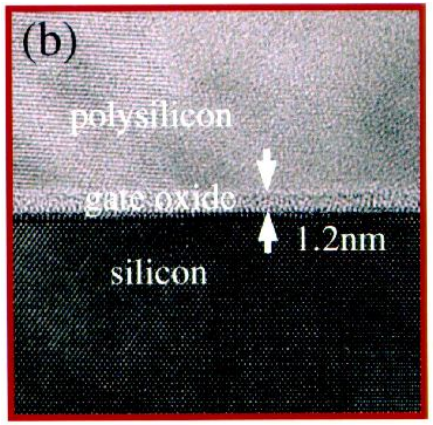
Technology Node	0.25 µm	0.18 µm	0.13 µm	90 nm	65 nm	45 nm	32 nm	22 nm	16 nm
V_{dd}	2.5 V	1.8 V	1.3 V	1.2 V	1.1 V	1.0 V	0.9 V	0.8 V	0.7 V

Why V_{dd} scaling slowed?

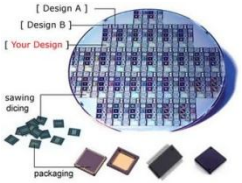
- We used to control power by scaling V_{dd} and maintain good speed by reducing T_{ox}.

$$\text{Speed} \sim \text{transistor current} \sim \mu^*(V_{dd} - V_{th})/T_{ox}$$

- But, T_{ox} can not be reduced much more, not even with high-k dielectrics.
- But new materials will raise the mobility (µ): Ge film on Si substrate, InGaAs, InAs, and graphene MOSFET

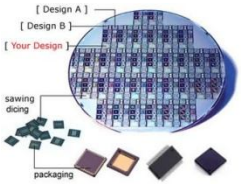


	Ge	Si
µn (cm^2/V-sec)	3,900	1,500
µp (cm^2/V-sec)	1,900	450
Eg (eV)	0.66	1.12



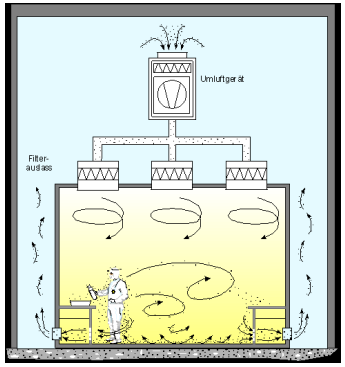
Semiconductor Industry

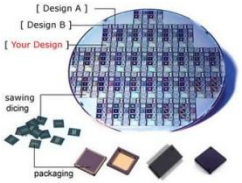
Semiconductor Technology: cleanroom



US FED STD 209E cleanroom standards

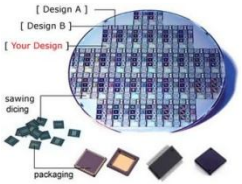
Class	maximum particles / ft³					ISO equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥5 µm	
1	35	7	3	1		ISO 3
10	350	75	30	10		ISO 4
100		750	300	100		ISO 5
1,000				1,000	7	ISO 6
10,000				10,000	70	ISO 7
100,000				100,000	700	ISO 8





BS 5295 cleanroom standards

	maximum particles / m³				
Class	≥0.5 µm	≥1 µm	≥5 µm	≥10 µm	≥25 µm
Class 1	3,000				
Class 2	300,000		2,000	30	
Class 3		1,000,000	20,000	4,000	300
Class 4			200,000	40,000	4,000



Plan

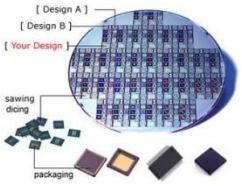
Chương 2. Vật liệu bán dẫn (Semiconductor materials)

2.1. Tinh thể học và cấu trúc tinh thể (crystal structure)

2.2. Giản đồ năng lượng (energy diagram)

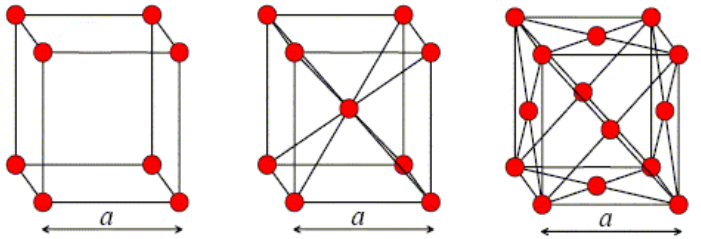
2.3. Khuyết tật tinh thể & pha tạp (doping)

2.4. Các loại chất bán dẫn: n-type & p-type

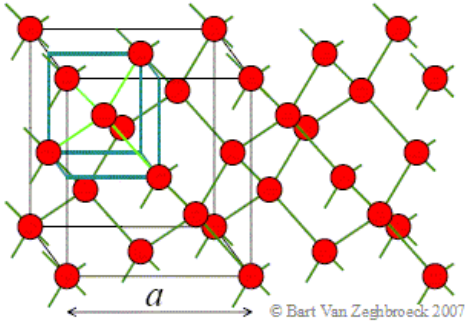


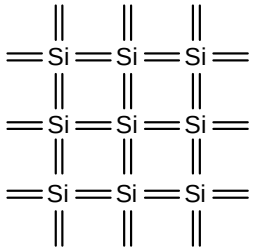
Semiconductor material

Silicon Lattice: crystal structure



The simple cubic (a), the body-centered cubic (b) and the face centered cubic (c) lattice.





The diamond lattice of Si & Ge

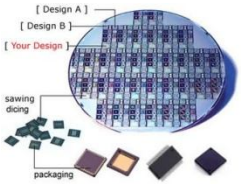
- Transistors are fabricated on the silicon substrate
- Silicon is the IV-group material
- Silicon crystal structure is crystal lattice: 4 Silicon atoms nearby

5×10^{22} atoms per cm^3

		Germanium	Silicon	GaAs
Smallest energy bandgap at 300 K	E_g (eV)	0.66	1.12	1.424
Electron effective mass for density of states calculations	$\frac{m^*_{e,dos}}{m_0}$	0.55	1.08	0.067
Hole effective mass for density of states calculations	$\frac{m^*_{h,dos}}{m_0}$	0.37	0.811	0.45
Electron effective mass for conductivity calculations	$\frac{m^*_{e,cond}}{m_0}$	0.12	0.26	0.067
Hole effective mass for conductivity calculations	$\frac{m^*_{h,cond}}{m_0}$	0.21	0.386	0.34

Effective mass of carriers in germanium, silicon and gallium arsenide (GaAs)

Effective mass of carriers in Ge, Si, & GaAs



Semiconductor material

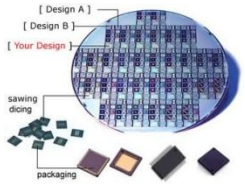
Semiconductor materials

Group #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo
* Lanthanides (Lanthanoids)			57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
** Actinides (Actinoids)			89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Grayish white
Germanium (Ge)

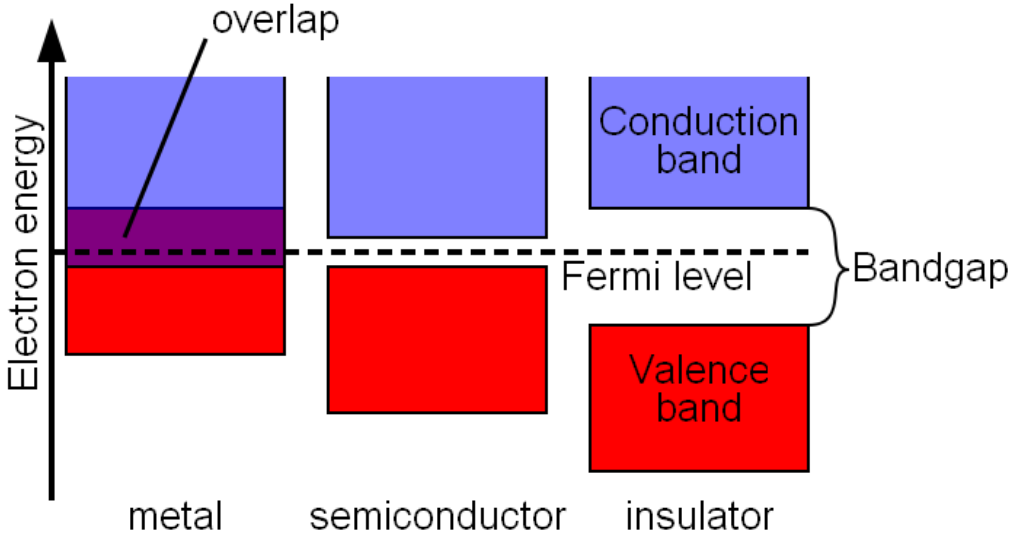
Property	Silicon	Germanium
atomic mass	28.08	72.59
density (g/cm^3)	2.33	5.35
Lattice spacing (nm)	0.54	0.56
melting point (°C)	1.400	947
color	gray	gray

Silicon (Si)



Semiconductor material

Semiconductor material: energy band



	Germanium	Silicon	GaAs
$E_g(0)$ (eV)	0.7437	1.166	1.519
α (meV/K)	0.477	0.473	0.541
β (K)	235	636	204

Energy band diagram

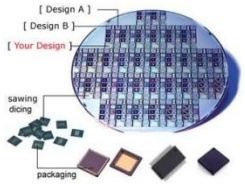
Group IV materials
-Diamond (C)
-Silicon (Si)
-Germanium (Ge)

Group IV compounds
-Silicon carbide (SiC)
-Silicon germanide (SiGe)

Organic semiconductors
-Carbon nanotube

III-V compounds
-Gallium arsenide (GaAs)
-Gallium nitride (GaN)
-Gallium phosphide (GaP)

http://ecee.colorado.edu/~bart/book/book/contents.htm

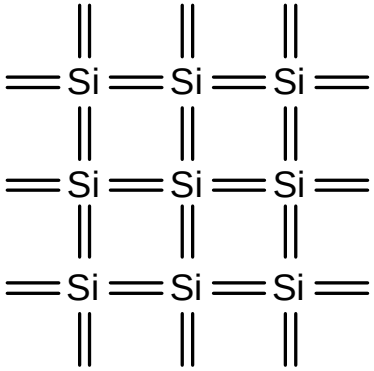


Semiconductor material

Impurities & doping Silicon

- **Pure/Intrinsic semiconductor (Si, Ge):** low carrier (electrons, holes) concentration.
- **Doped/Extrinsic semiconductor :** higher carrier concentration at thermal equilibrium.
- **Doping agents:** **Acceptor** (**group III**) – Boron, Aluminum, & **Donor** (**group V**): Arsenic, Phosphorus

Intrinsic semiconductor

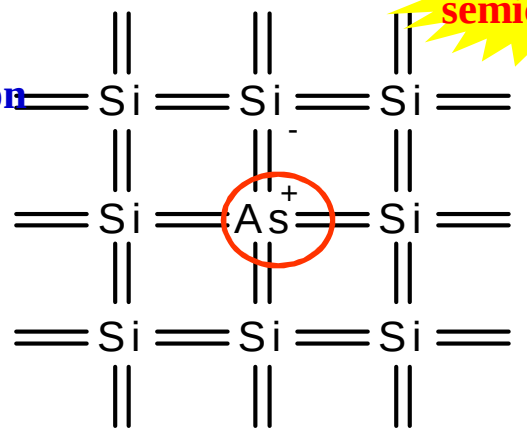


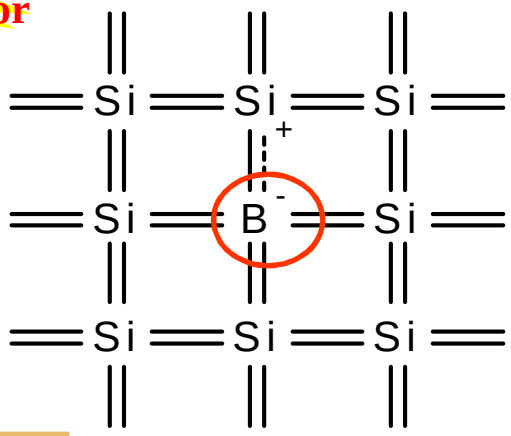
- ❑ **Ion implantation**
- ❑ **Diffusion**

Doping

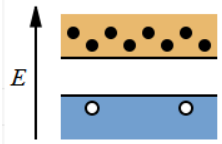
Extrinsic semiconductor

10^{14} -> 10^{16} (cm^3)



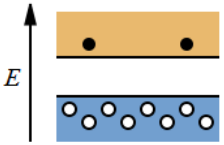


	Germanium	Silicon	Gallium Arsenide
300 K	2.02×10^{13}	8.72×10^{9}	2.03×10^{6}
400 K	1.38×10^{15}	4.52×10^{12}	5.98×10^{9}
500 K	1.91×10^{16}	2.16×10^{14}	7.98×10^{11}
600 K	1.18×10^{17}	3.07×10^{15}	2.22×10^{13}



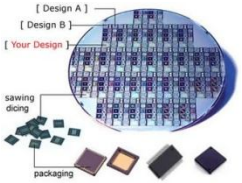
Donor (V)

N-type: Larger electron concentration than hole
➔majority carriers: **electrons**



Acceptor (III)

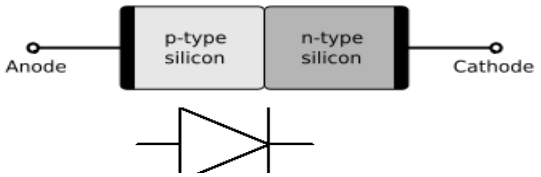
P-type: Larger hole concentration than electron.
➔ majority carriers: **holes**

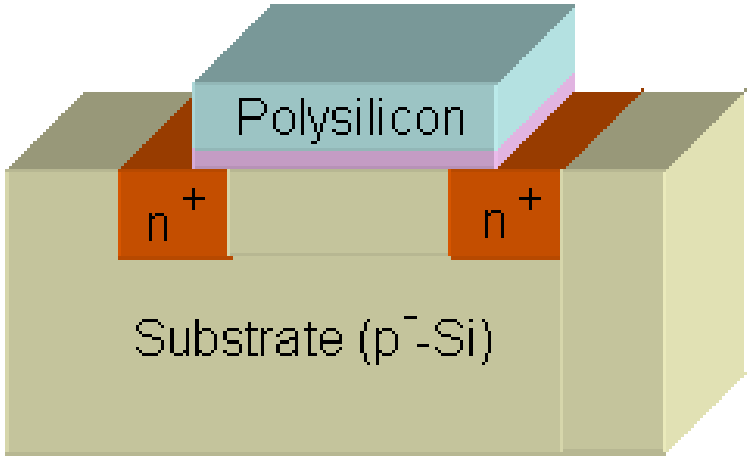


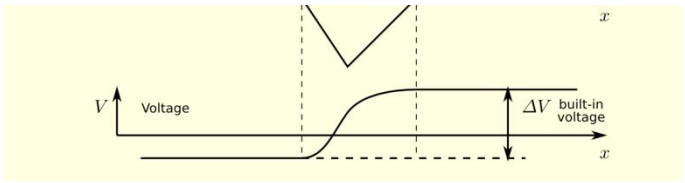
Semiconductor material

P-n junction

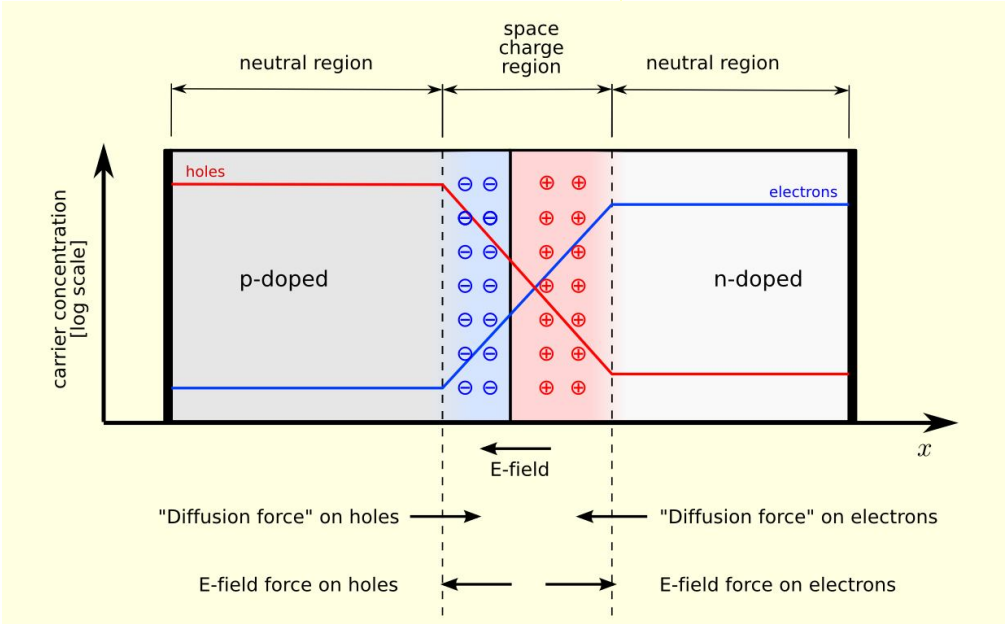
_Ion implantation
_Diffusion



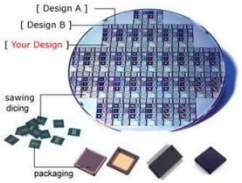




A p–n junction in thermal equilibrium with zero bias voltage applied. Under the junction, plots for the charge density, the electric field and the voltage are reported.



A p–n junction in thermal equilibrium with zero bias voltage applied. Electrons and holes concentration are reported respectively with blue and red lines. Gray regions are charge neutral. Light red zone is positively charged. Light blue zone is negatively charged. The electric field is shown on the bottom, the electrostatic force on electrons and holes and the direction in which the diffusion tends to move electrons and holes.



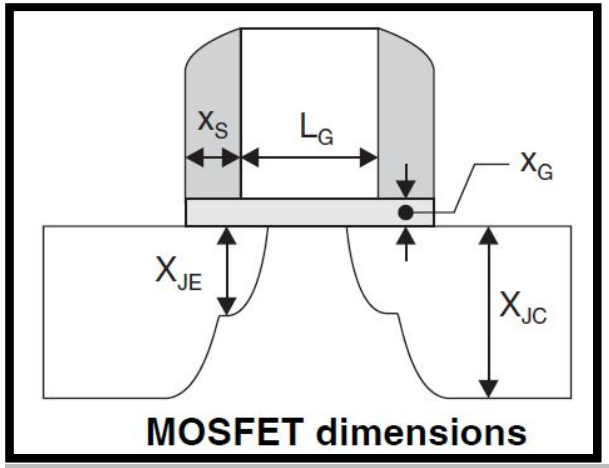
Plan

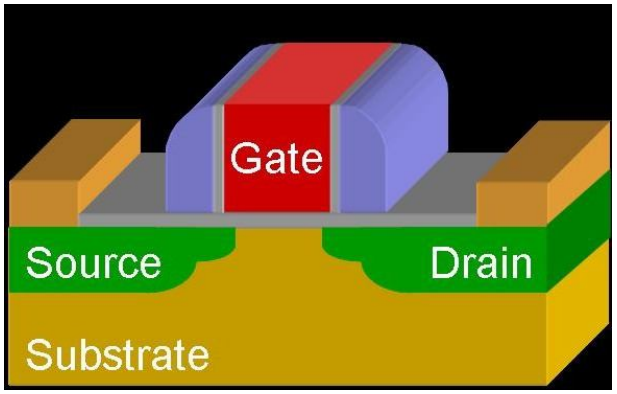
3. Semiconductor devices

3.1. MOSFET: structure

3.2. MOSFET: operation

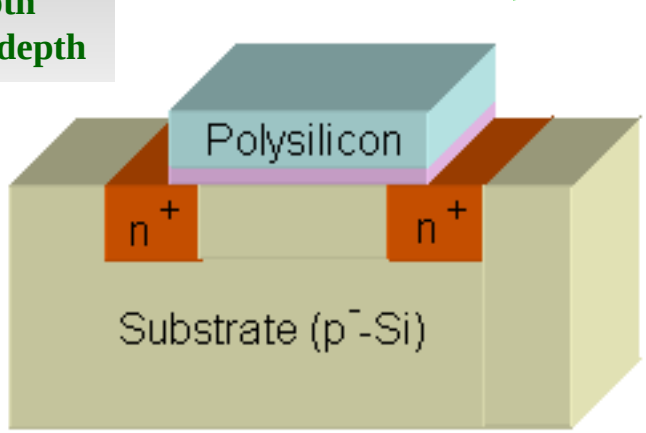
MOSFET: structure



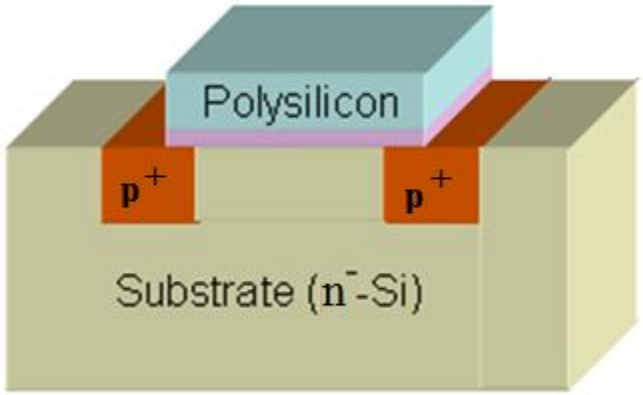


Lg: Gate length
Xs: Spacer thickness
Xg: Gate oxide thickness
Xje: Drain extension junction depth
Xjc: Source-drain contact region depth

-How many layers?
-How many electrodes?
- Materials?
- Difference: p+/p/p-??

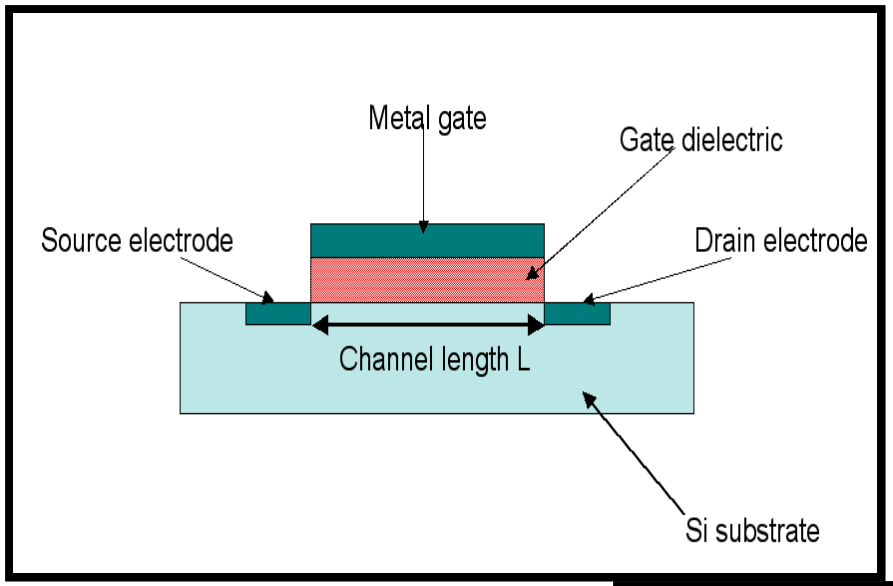


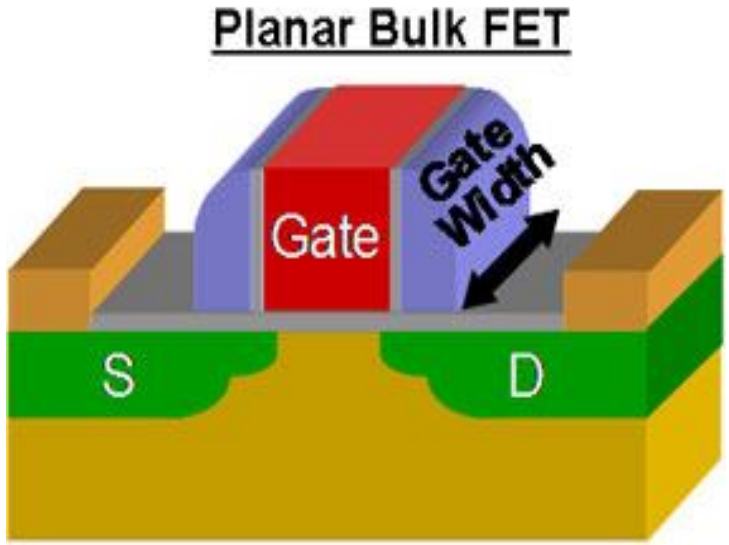
Bulk N-type MOSFET



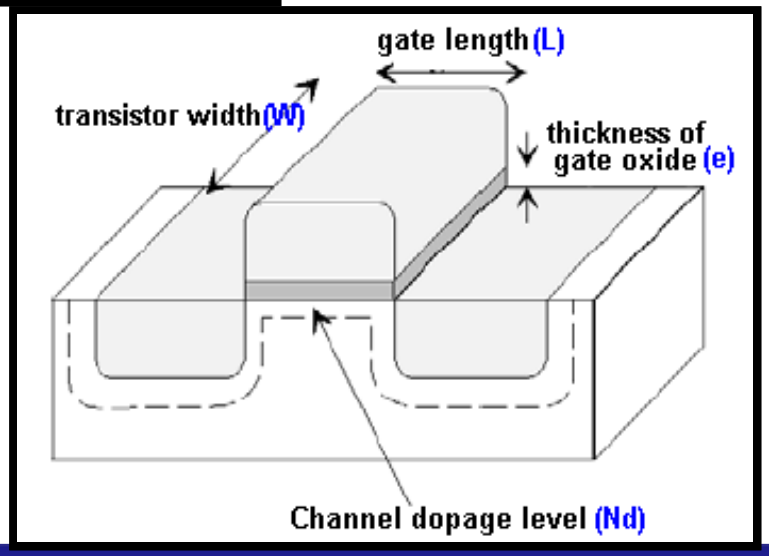
Bulk P-type MOSFET

MOSFET: structure

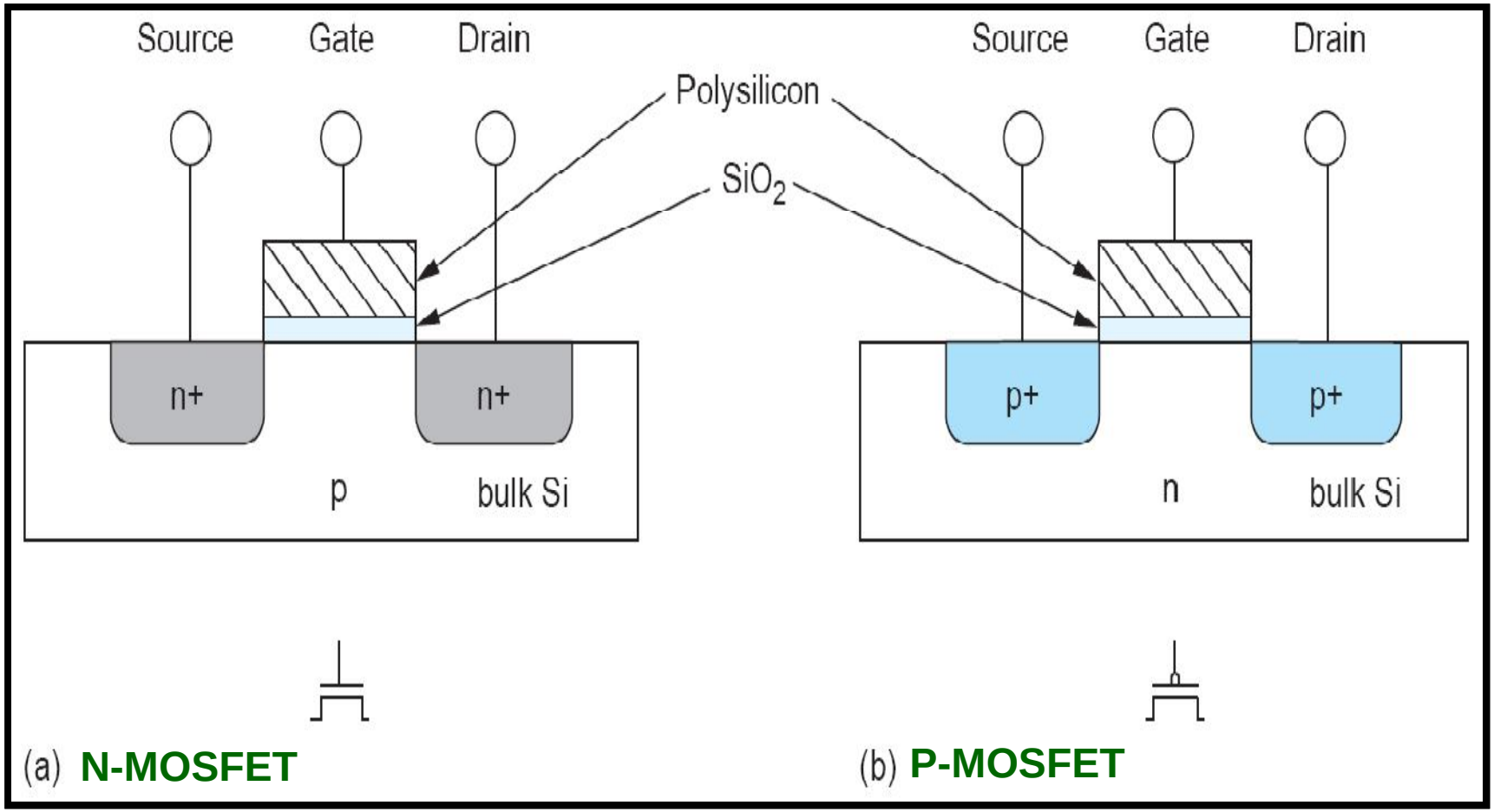




Bulk MOSFET

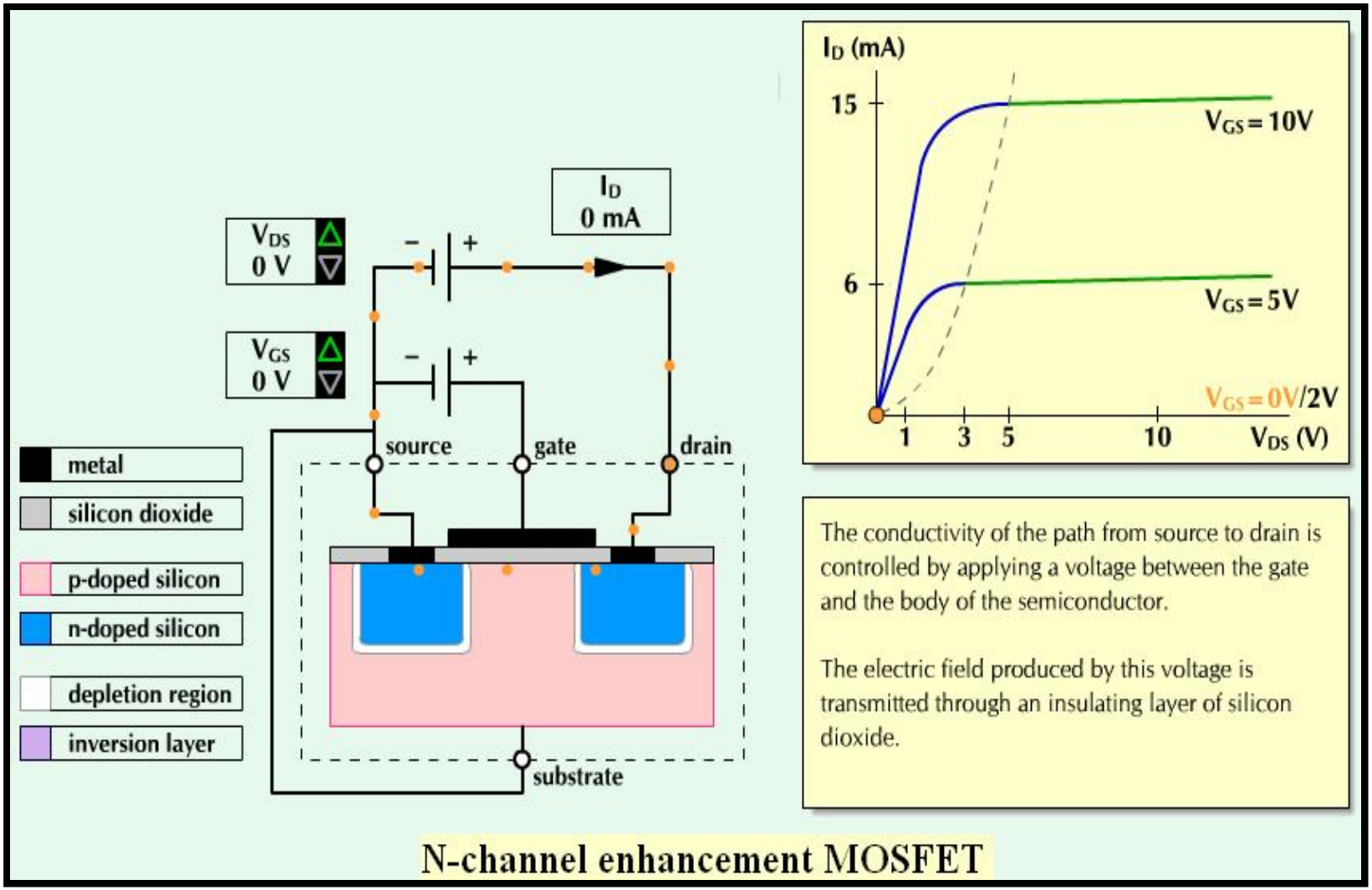


MOSFET: operation

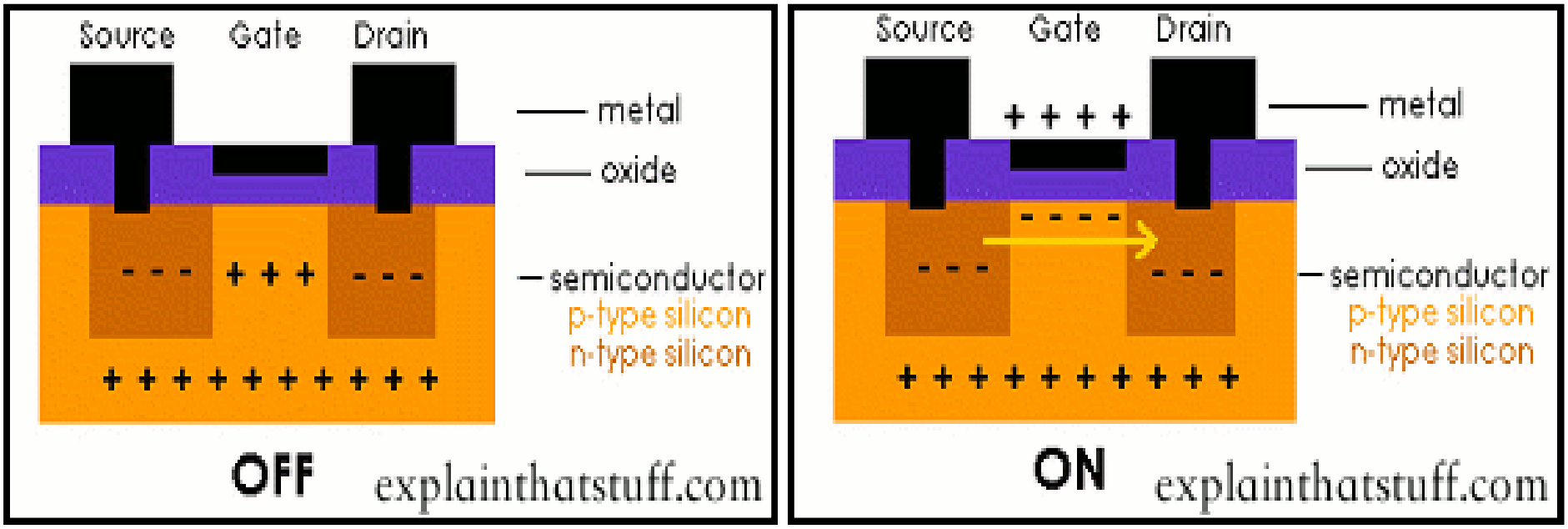


Symbolize two types of MOSFET

MOSFET: operation

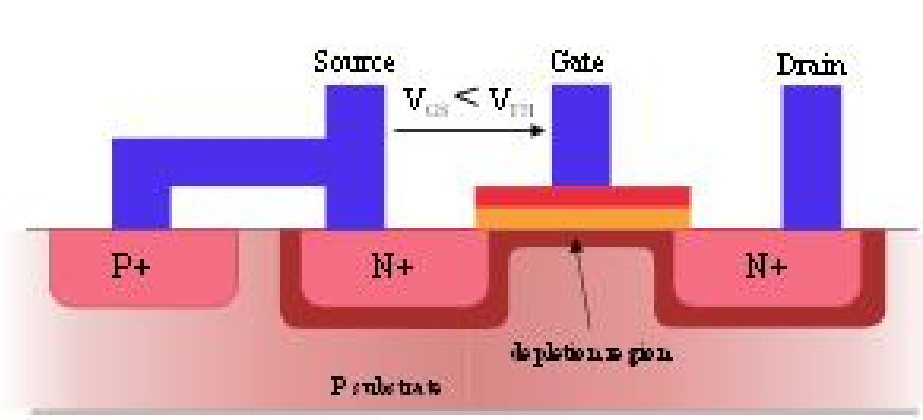


MOSFET: operation



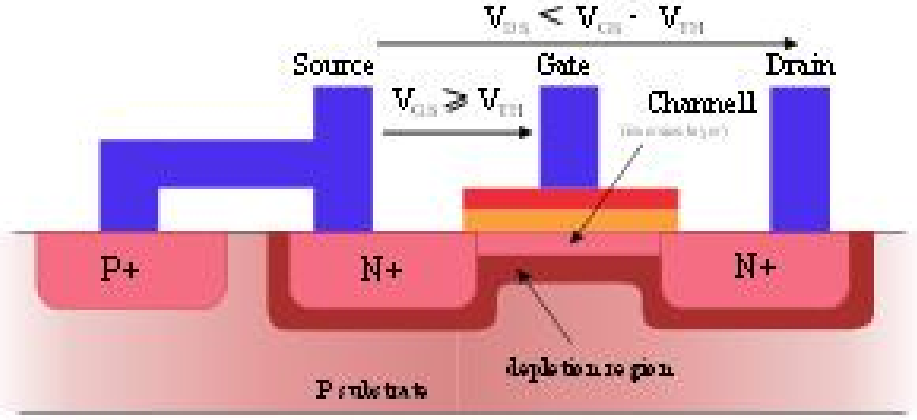
Bulk N-type MOSFET

MOSFET: Body effect



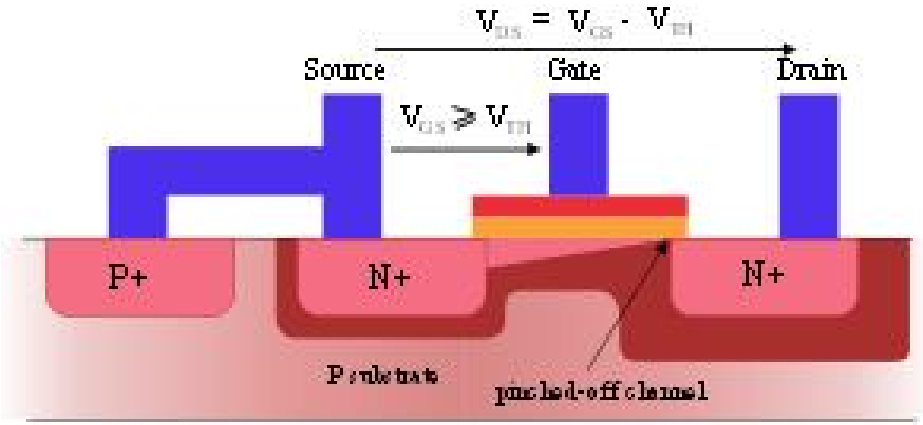
Cutoff, subthreshold, or weak-inversion mode

When $V_{GS} < V_{th}$



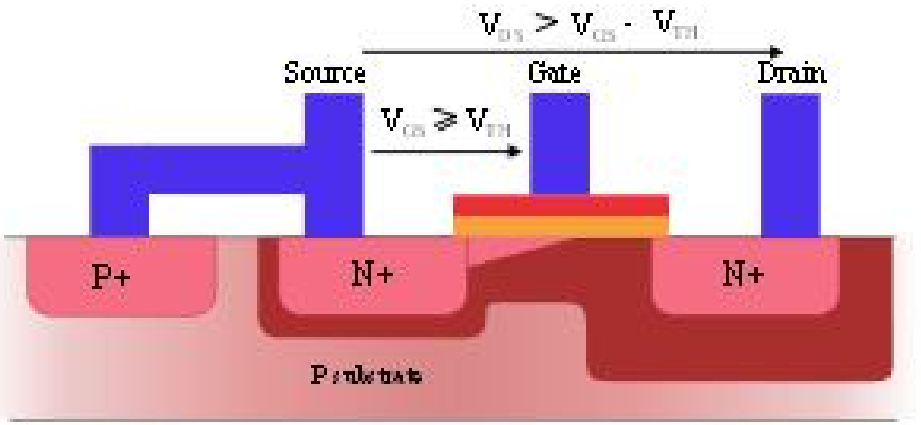
Linear operating region (ohmic mode)

When $V_{GS} > V_{th}$ and $V_{DS} < (V_{GS} - V_{th})$



Saturation mode at point of pinch-off

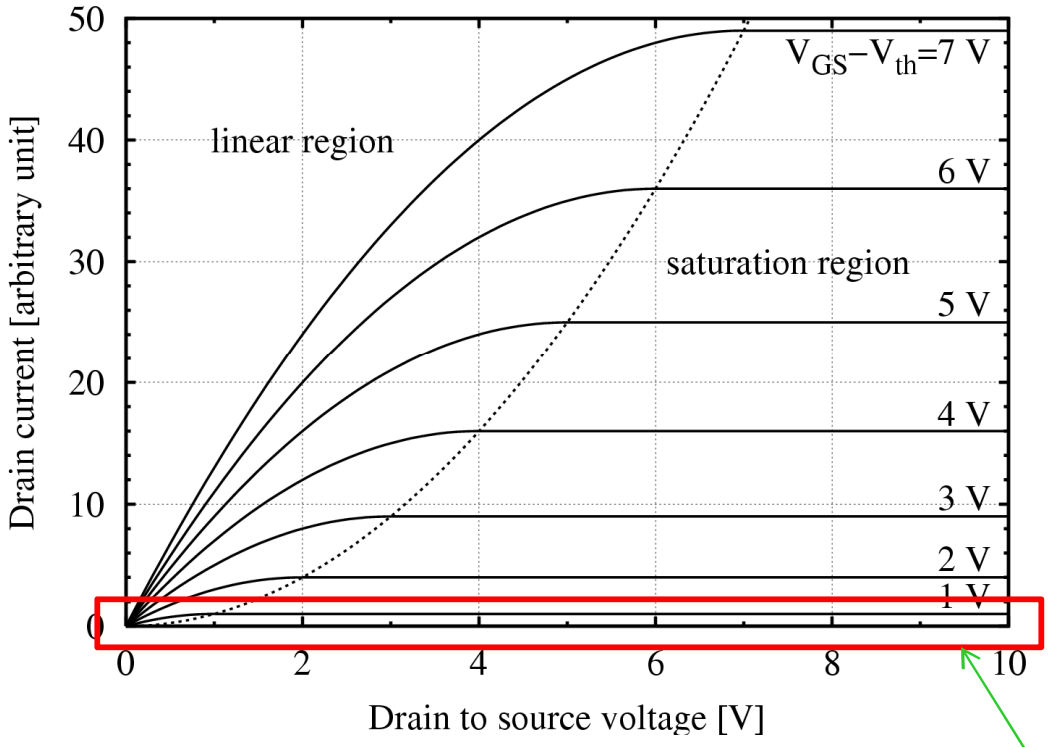
When $V_{GS} > V_{th}$ and $V_{DS} > (V_{GS} - V_{th})$

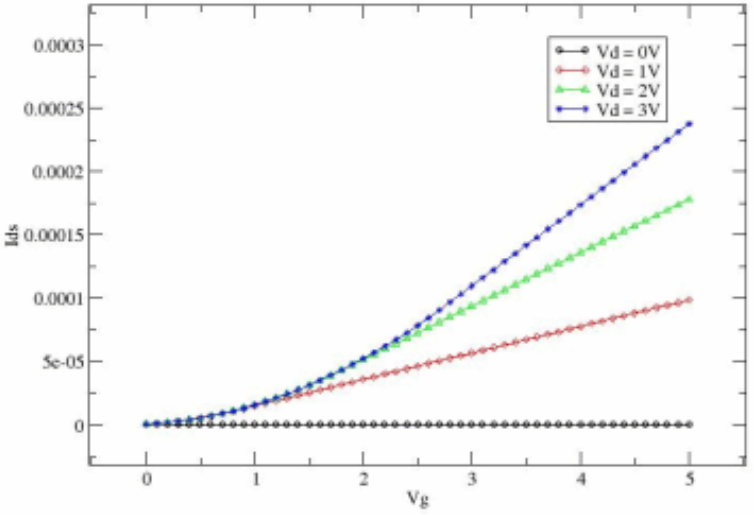


Saturation mode

When $V_{GS} > V_{th}$ and $V_{DS} > (V_{GS} - V_{th})$

MOSFET: 03 modes of operation



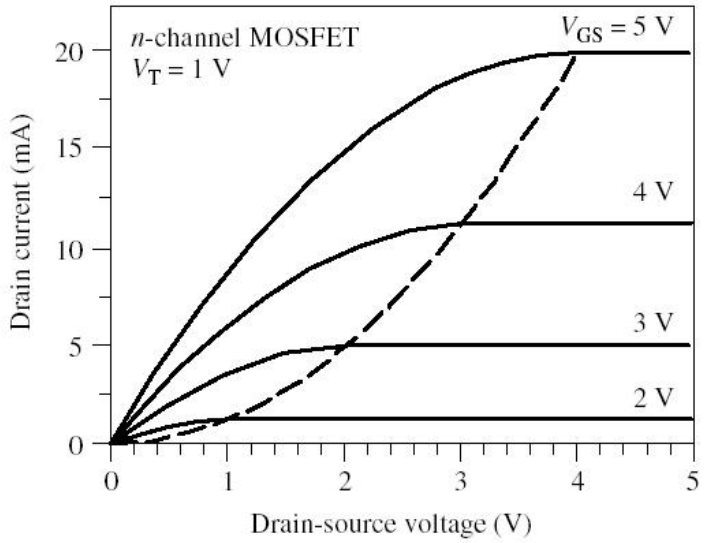


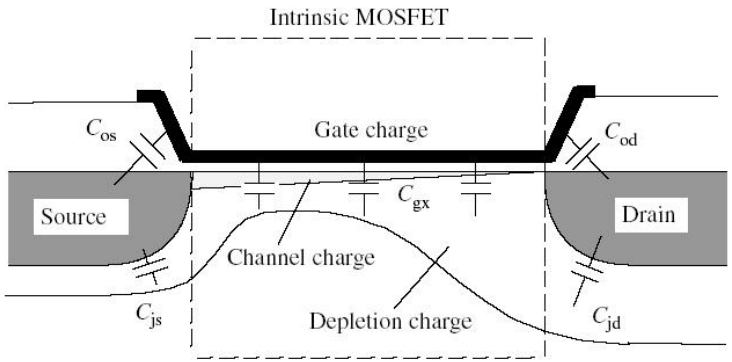
Cutoff /Subthreshold /Weak-inversion region

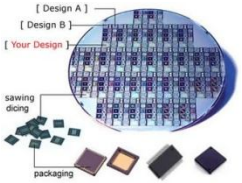
MOSFET: operation

MOSFET operation

- The MOSFET can be categorized into three separate modes when in operation.
- The first is the **sub-threshold or cut-off mode**: VGS < Vt, where Vt is the threshold voltage. In the example shown Vt = 1V. In this mode the device is essentially off, and in the ideal case there is no current flowing through the device.
- The second mode of operation is **the linear region** when VGS > Vt and VDS < VGS − Vt. Essentially, the MOSFET operates similar to a resistor in this mode with a linear relation between voltage and current.
- Lastly, **saturation mode** occurs when VGS > Vt and VDS > VGS − Vt. In this mode the switch is on and conducting, however since drain voltage is higher than the gate voltage, part of the channel is turned off. This mode corresponds to the region to the right of the dotted line, which is called the pinch-off voltage.
- **Pinch-off** occurs when the MOSFET stops operating in the linear region and saturation occurs.
- **In digital circuits MOSFETS are only operated in the linear mode, while the saturation region is reserved for analogue circuits.**







Semiconductor Industry

End Part 1