Design and Implementation of VLSI Systems lecture01

Lecturer: Dr. Nguyễn Vũ Thắng
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Lecture 01: the big picture

- Introduction
- History
- Tour of VLSI Design and Implementation
- IC market
- Design flow

Objectives of the class

- Learn fundamental knowledge on IC design: design flow, fabrication
- How to use commercial design software
- How to code Verilog
- Learn how to design a simple VLSI systems that implement required functionalities.

- Syllabus

Course information

- **Instructor:** Nguyễn Vũ Thắng nvuthang74@yahoo.com
- **FPT:** Mr. Nguyễn Thanh Yên – Head of FPT LSI

- **Books:** CMOS VLSI design, Weste and Harris
- **Grade:**

  -Homeworks: 10%

  -Midterm exam: 30%

  -Practical works and Project: 60%

Introduction

- A VLSI (Very Large Scale Integration) system integrates millions of “electronic components” in a small area (few $mm^2 \rightarrow$ few cm^2).

- What are the design metrics?
  - Circuit Speed / Performance
  - Power consumption
  - Design Area
  - Yield

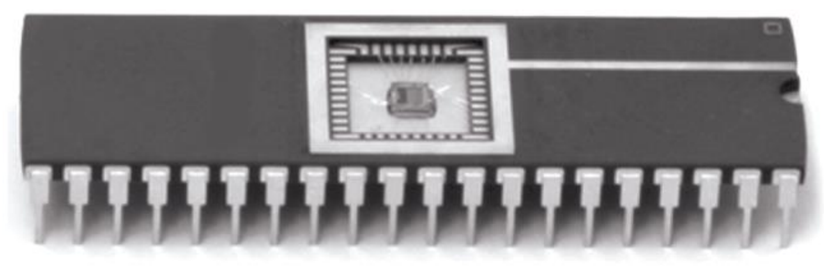
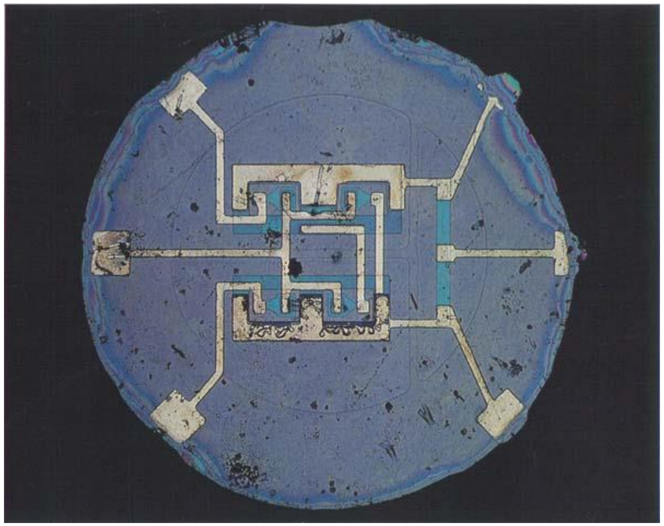


FIG 1.71 Chip in a 40-pin dual-inline package

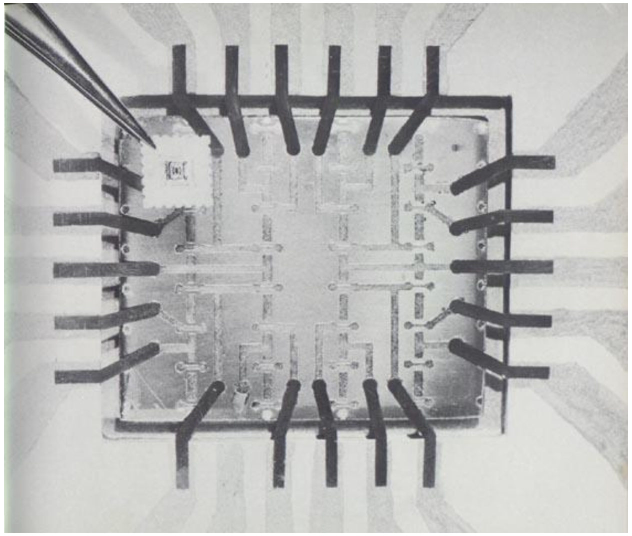
Integrated Circuits

- 1958: Jack Kilby makes the first IC
- 1961: TI and Fairchild introduce the first logic ICs ($50 in quantity)
- 1962: RCA develops the first MOS transistor
- 1965: the Moores Law

Fairchild bipolar RTL Flip-Flop

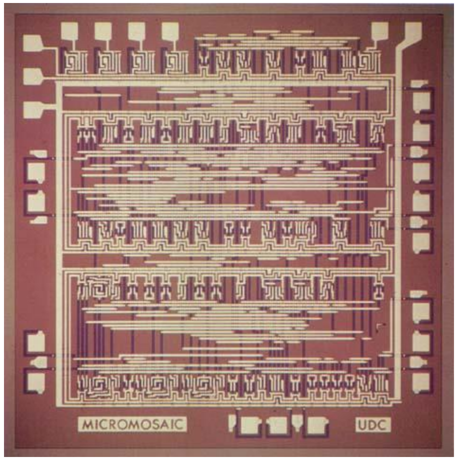


RCA 16-transistor MOSFET IC



Computer-Aided Design

- 1967: Fairchild develops the “Micromosaic” IC using CAD
  – Final Al layer of interconnect could be customized for different applications

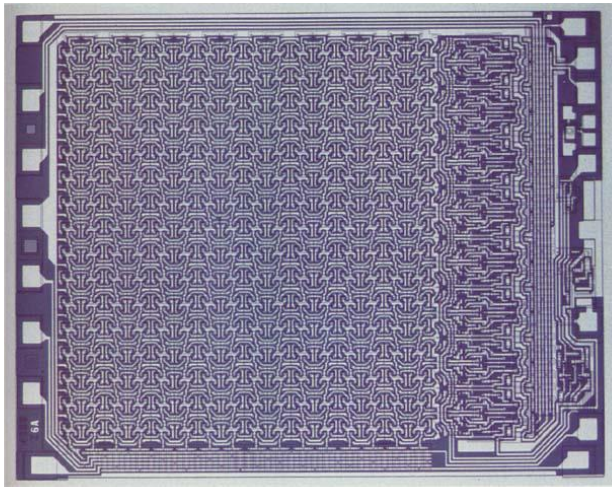


- 1968: Noyce, Moore leave Fairchild, start Intel

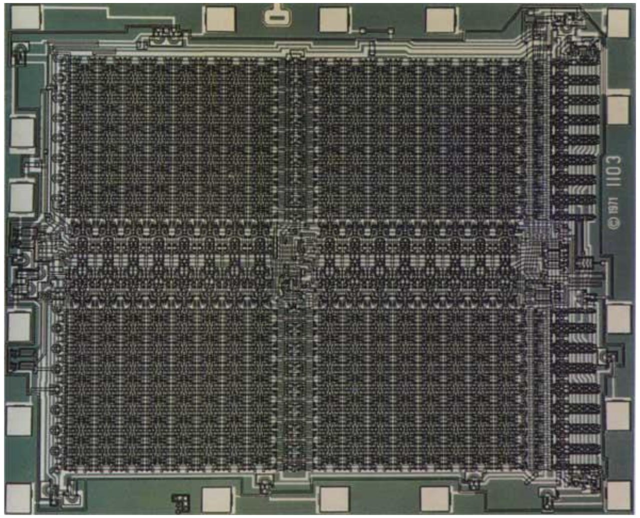
RAMs

- 1970: Fairchild introduces 256-bit Static RAMs
- 1970: Intel starts selling1K-bit Dynamic RAMs

Fairchild 4100 256-bit SRAM

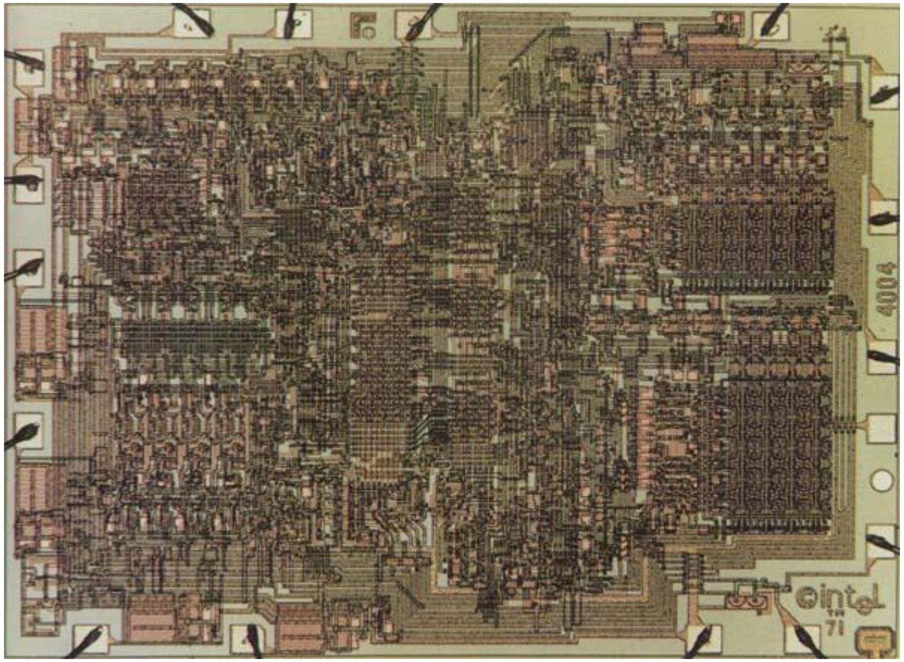


Intel 1103 1K-bit DRAM



The Microprocessor

- 1971: Intel introduces the first Microprocessor: 4004
  - General purpose programmable computer instead of custom chip for Japanese calculator company

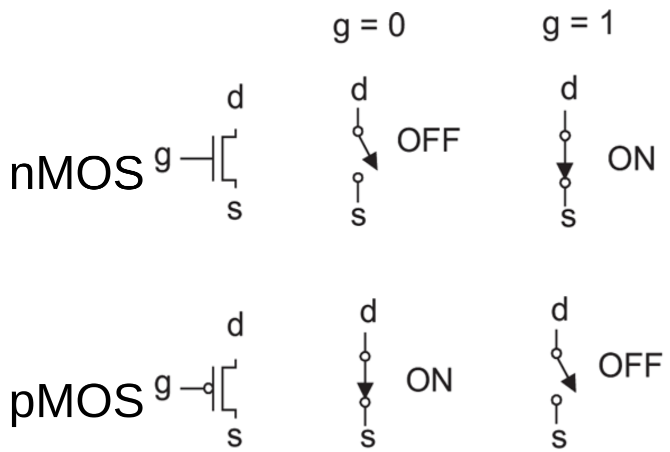


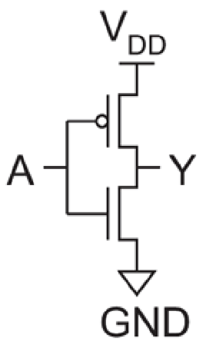
The Microprocessor

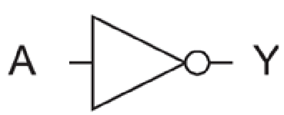
- 1975: the first Personal computer and the birth of Microsoft
- 1976: the birth of Apple

What are VLSI systems composed of?

1.Transistors



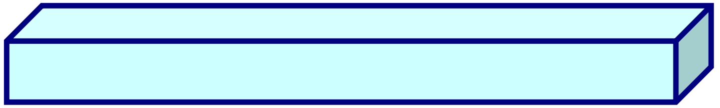




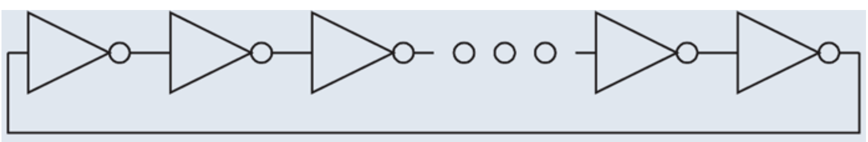
CMOS logic gates

+

2. Wires

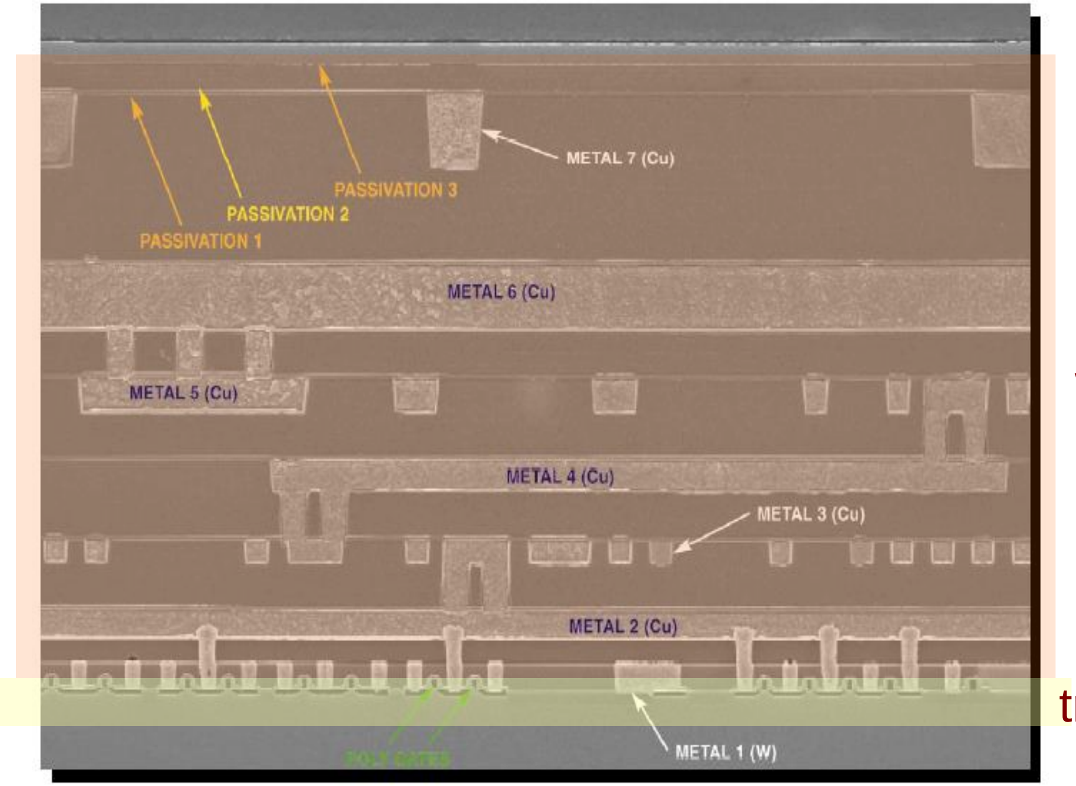


|| design

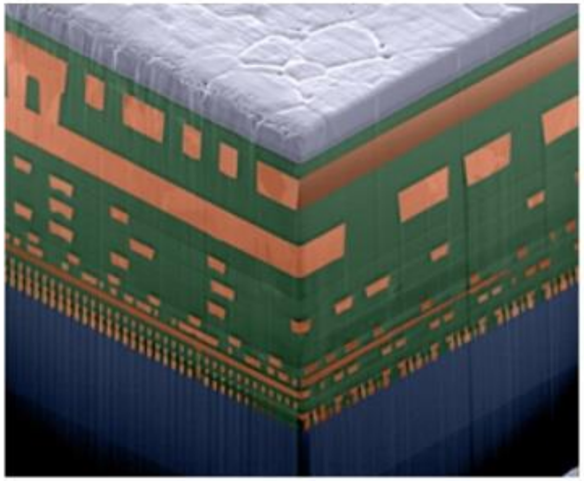


Circuits

How does an IC look like from the inside?



wires



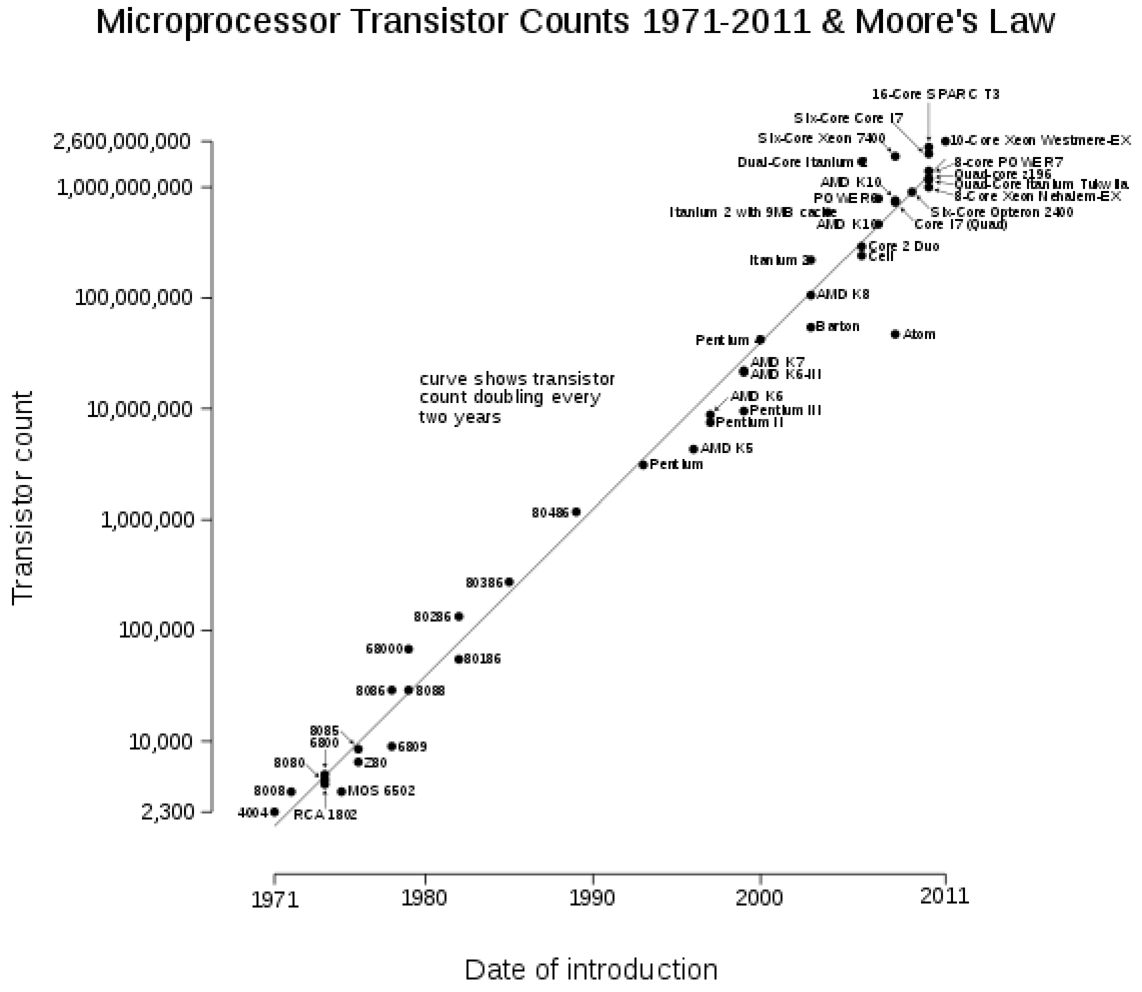
transistors

R. Noyce

J. Kilby

Technology scaling

Moore's Law. The number of transistors in an integrated circuit doubles every 2 years.



Technology scaling

1971: Intel 4004 – 2300 transistors – 10um tech

1979: Motorola 68000 – 68000 trans – 3.5um tech

1982: Intel 80286 – 134k trans – 1.5um tech

1989: Intel 80486 – 1180k trans – 1um tech

1999: AMD K7 – 22M trans – 250nm tech

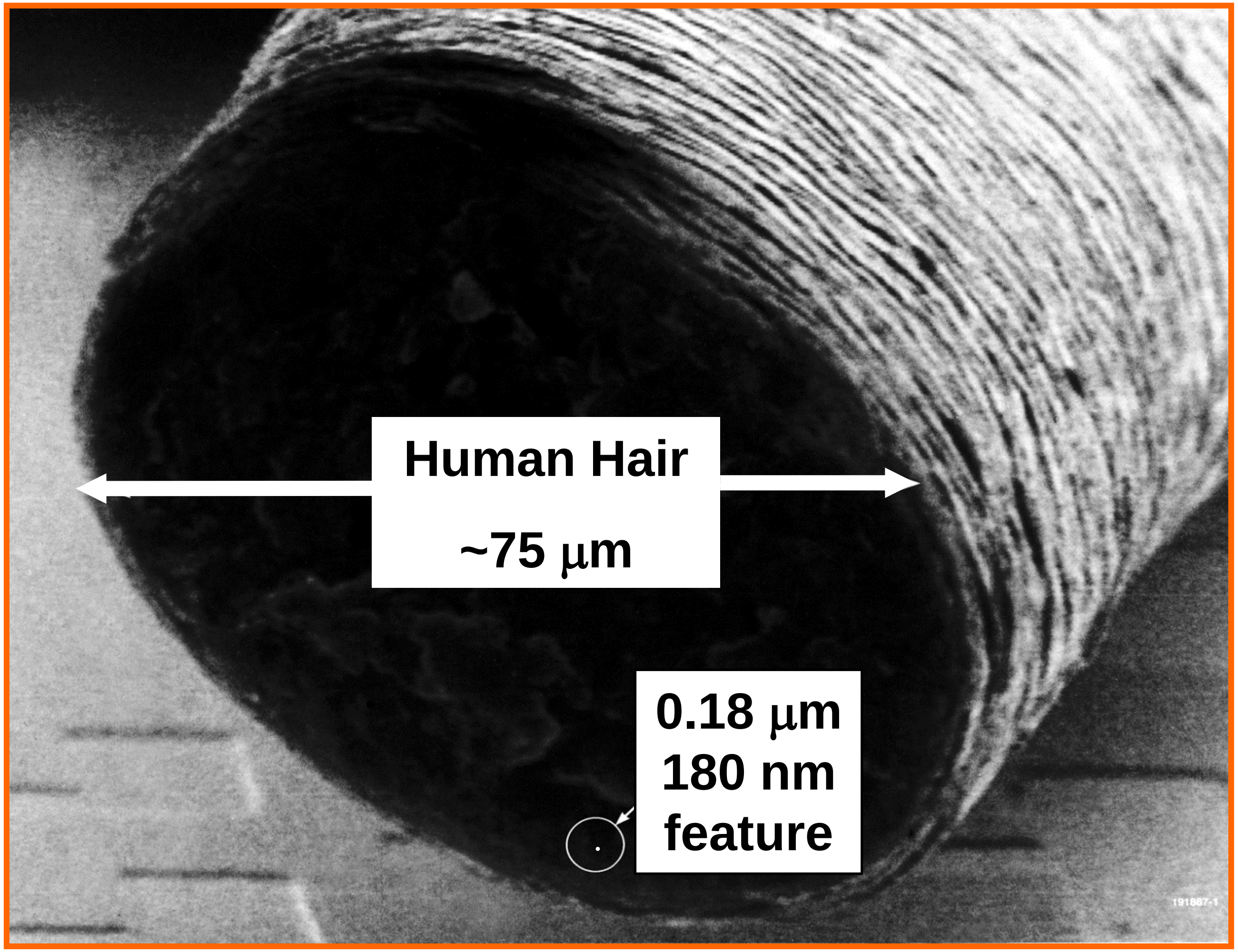
2002: Intel – Itanium – 220M trans – 180nm tech

2010: Sun/Oracle – 16 core Sparc T3 – 1B trans – 40nm tech

2015: Oracle - 32-core Sparc M7 – 10B trans – 20nm tech

2017: AMD - 32-core AMD Epyc – 19.2B trans – 14nm tech

Feature sizes



~40,000 (65-nm node) transistors could fit on cross-section

[C. Keast]

IC market

Top 10 Worldwide Semiconductor Sales Leaders (Excluding Foundries)

	1993			2000			2006			2016			2017F		
Rank	Company	Sales ($B)	Share	Company	Sales ($B)	Share	Company	Sales ($B)	Share	Company	Sales ($B)	Share	Company	Sales ($B)	Share
1	Intel	$7.6	9.2%	Intel	$29.7	13.6%	Intel	$31.6	11.8%	Intel	$57.0	15.6%	Samsung	$65.6	15.0%
2	NEC	$7.1	8.6%	Toshiba	$11.0	5.0%	Samsung	$19.7	7.3%	Samsung	$44.3	12.1%	Intel	$61.0	13.9%
3	Toshiba	$6.3	7.6%	NEC	$10.9	5.0%	TI	$13.7	5.1%	Qualcomm (1)	$15.4	4.2%	SK Hynix	$26.2	6.0%
4	Motorola	$5.8	7.0%	Samsung	$10.6	4.8%	Toshiba	$10.0	3.7%	Broadcom (1)	$15.2	4.2%	Micron	$23.4	5.3%
5	Hitachi	$5.2	6.3%	TI	$9.6	4.4%	ST	$9.9	3.7%	SK Hynix	$14.9	4.1%	Broadcom (1)	$17.6	4.0%
6	TI	$4.0	4.8%	Motorola	$7.9	3.6%	Renesas	$8.2	3.1%	Micron	$13.5	3.7%	Qualcomm (1)	$17.1	3.9%
7	Samsung	$3.1	3.8%	ST	$7.9	3.6%	Hynix	$7.4	2.8%	TI	$12.5	3.4%	TI	$13.9	3.2%
8	Mitsubishi	$3.0	3.6%	Hitachi	$7.4	3.4%	Freescale	$6.1	2.3%	Toshiba	$10.9	3.0%	Toshiba	$13.5	3.1%
9	Fujitsu	$2.9	3.5%	Infineon	$6.8	3.1%	NXP	$5.9	2.2%	NXP	$9.5	2.6%	Nvidia (1)	$9.2	2.1%
10	Matsushita	$2.3	2.8%	Philips	$6.3	2.9%	NEC	$5.7	2.1%	MediaTek (1)	$8.8	2.4%	NXP	$9.2	2.1%
Top 10 Total ($B)		$47.2	57.2%	—	$108.1	49.4%	—	$118.2	44.1%	—	$202.1	55.3%	—	$256.7	58.5%
Semi Market ($B)		$82.6	100.0%	—	$219.0	100.0%	—	$268.2	100.0%	—	$365.6	100.0%	—	$438.5	100.0%

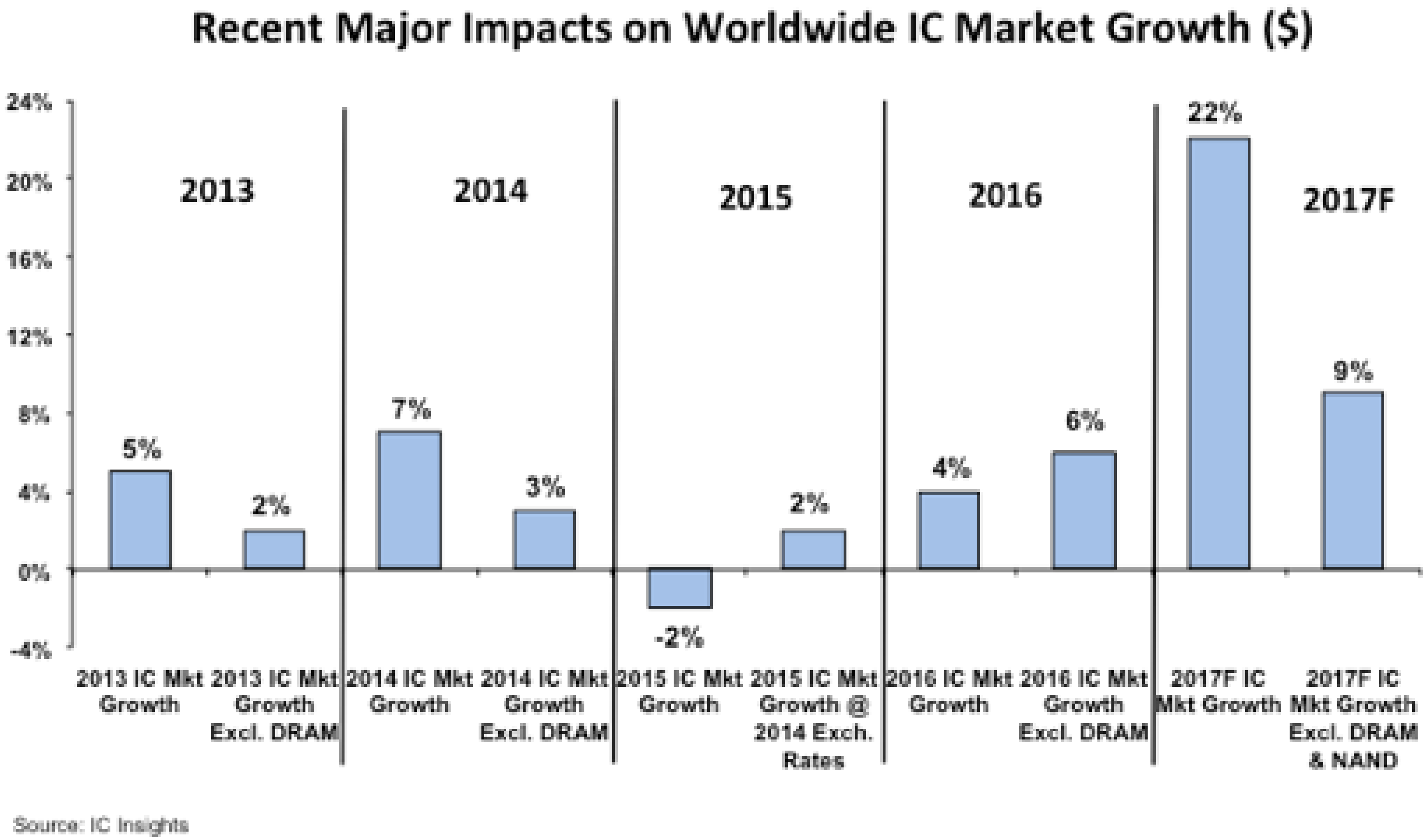
Source: IC Insights (1) Fabless

IC market

2017 Rank	2016 Rank	Vendor	2017 Revenue	2017 Market Share (%)	2016 Revenue	2016-2017 Growth (%)
1	2	Samsung Electronics	61,215	14.6	40,104	52.6
2	1	Intel	57,712	13.8	54,091	6.7
3	4	SK Hynix	26,309	6.3	14,700	79.0
4	6	Micron Technology	23,062	5.5	12,950	78.1
5	3	Qualcomm	17,063	4.1	15,415	10.7
6	5	Broadcom	15,490	3.7	13,223	17.1
7	7	Texas Instruments	13,806	3.3	11,901	16.0
8	8	Toshiba	12,813	3.1	9,918	29.2
9	17	Western Digital	9,181	2.2	4,170	120.2
10	9	NXP	8,651	2.1	9,306	-7.0
		Others	174,418	41.6	157,736	10.6
		Total Market	419,720	100.0	343,514	22.2

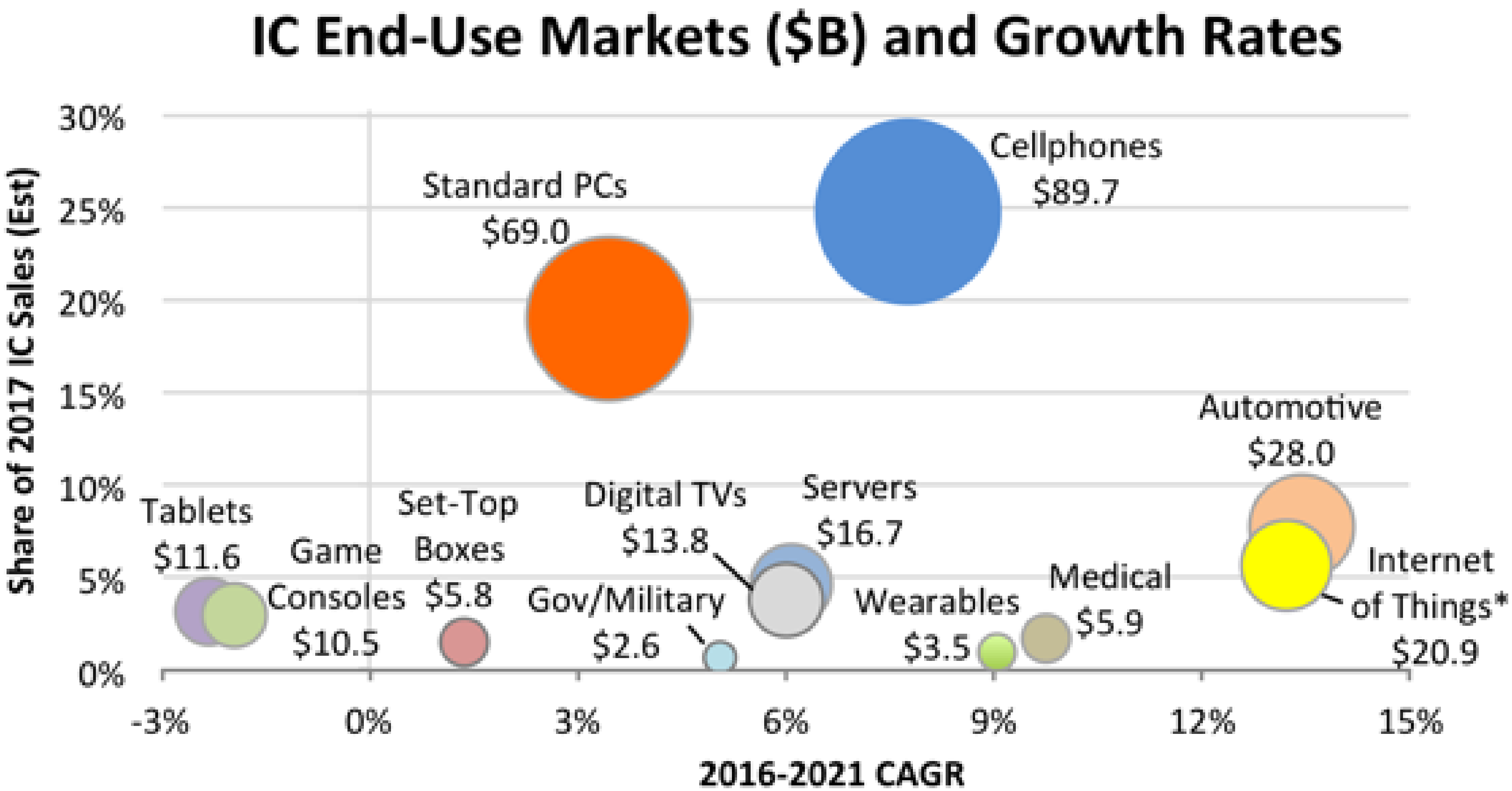
Source: Gartner (January 2018)

IC market



Recent Major Impacts on Worldwide IC Market Growth ($)
24%
20%
16%
12%
8%
4%
0%
-4%
2013
2014
2015
2016
2017F
5%
2%
7%
3%
-2%
2%
4%
6%
22%
9%
2013 IC Mkt Growth
2013 IC Mkt Growth Excl. DRAM
2014 IC Mkt Growth
2014 IC Mkt Growth Excl. DRAM
2015 IC Mkt Growth
2015 IC Mkt Growth @ 2014 Exch. Rates
2016 IC Mkt Growth
2016 IC Mkt Growth Excl. DRAM
2017F IC Mkt Growth
2017F IC Mkt Growth Excl. DRAM & NAND
Source: IC Insights

IC market

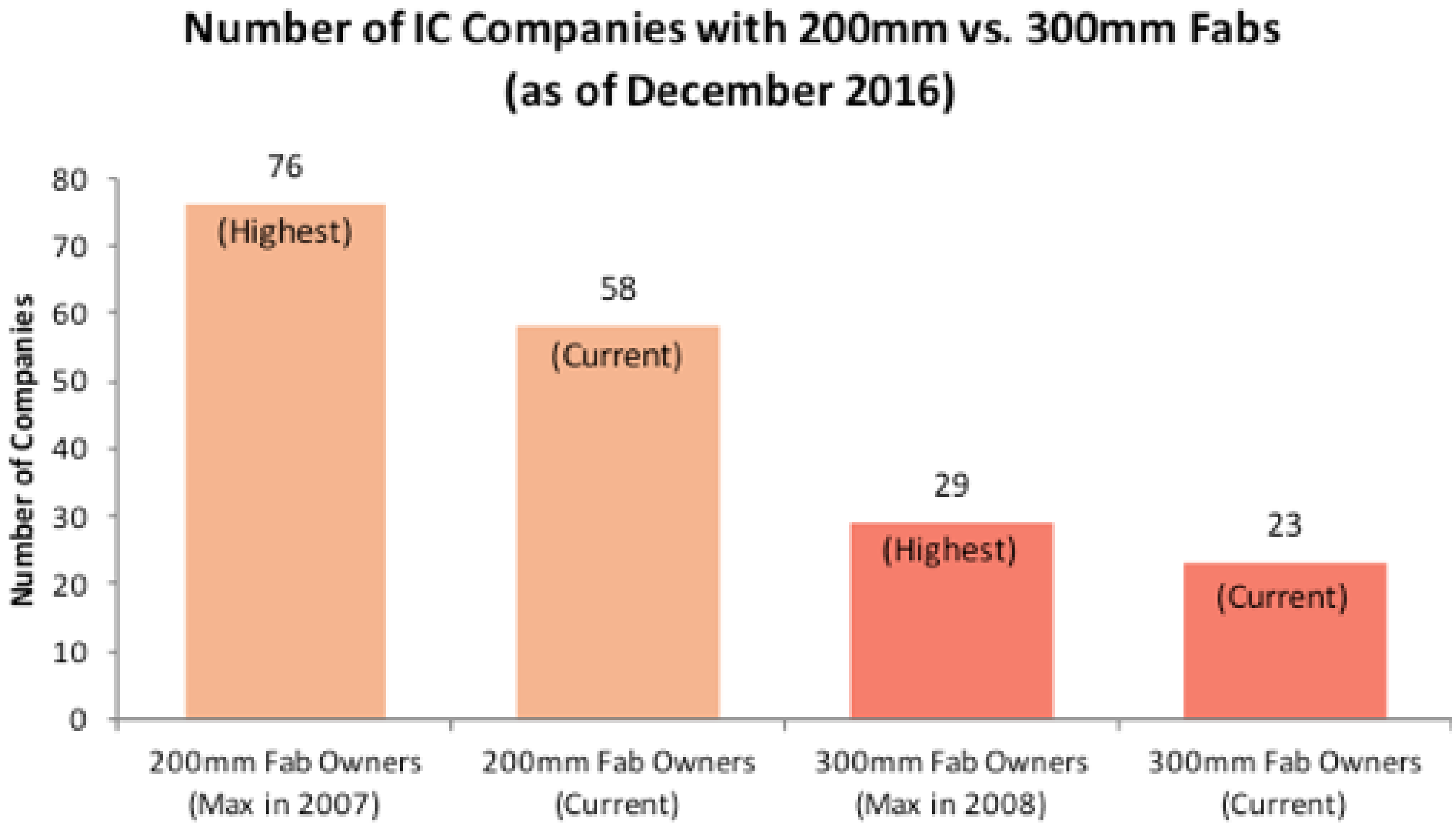


*Covers only the Internet connection portion of systems.

Source: IC Insights

Silicon wafer size

Silicon wafer size



Includes pilot- and volume-production-class, but not R&D, fab facilities (IC fabs only).
Each member of joint-venture companies counted separately

Source: IC Insights' *Strategic Reviews* database

Silicon wafer size

Installed Capacity Leaders at Dec-2016 – by Wafer Size

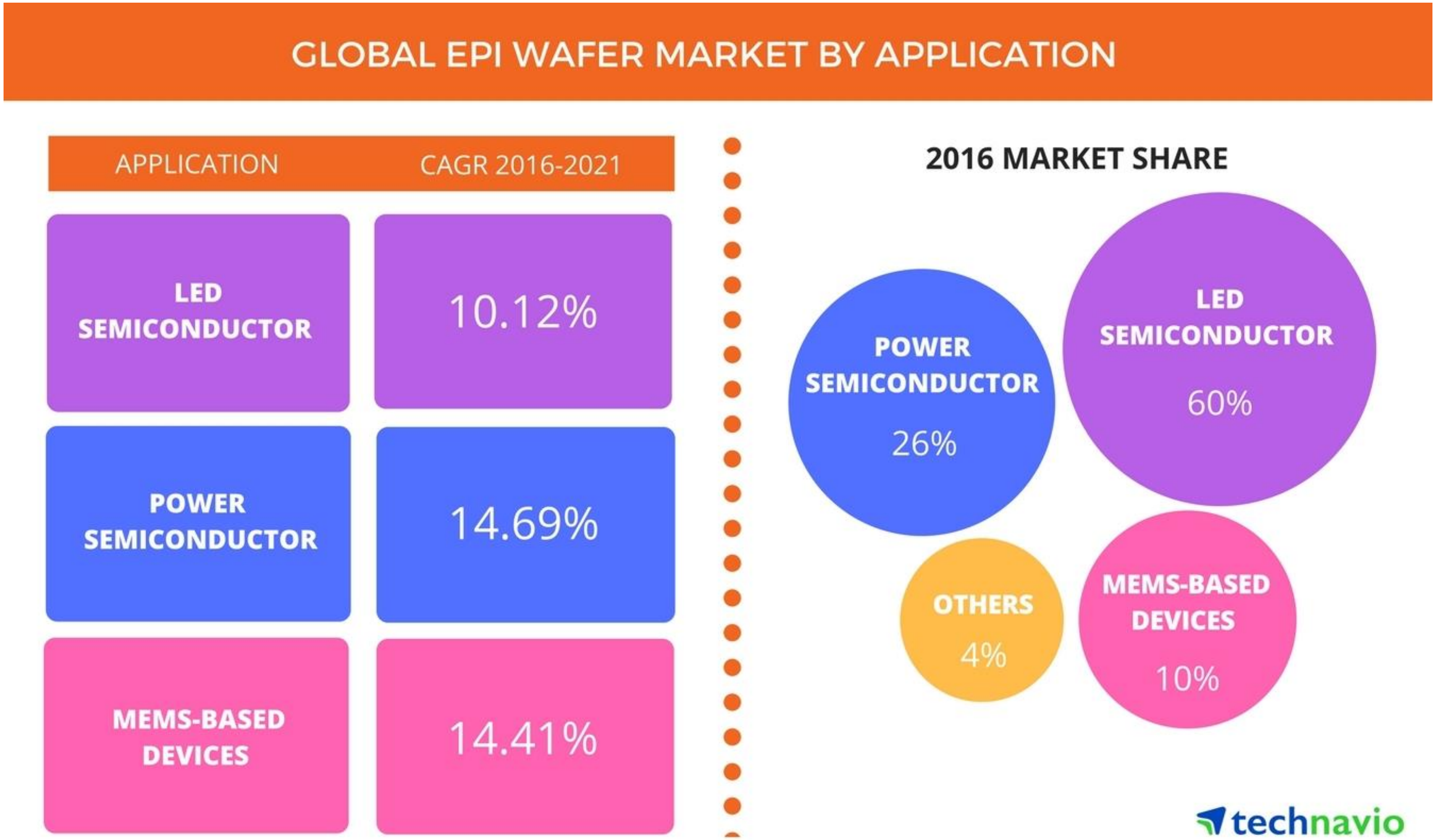
(Ranked by Share of Total WW Monthly Installed Capacity)

300mm Wafers			200mm Wafers			≤150mm Wafers		
WW Share	**Top 10 Relative**	**Top 10 in Capacity**	**WW Share**	**Top 10 Relative**	**Top 10 in Capacity**	**WW Share**	**Top 10 Relative**	**Top 10 in Capacity**
22%		Samsung	11%		TSMC*	12%		STMicro
14%		Micron*	7%		TI	11%		ON Semi
13%		SK Hynix	6%		STMicro	7%		Panasonic
13%		TSMC	6%		UMC	6%		CR Micro
11%		Toshiba/WD	5%		Infineon	5%		Silan
7%		Intel*	4%		NXP	4%		Renesas
6%		GlobalFoundries	4%		Toshiba	3%		TI
3%		UMC	4%		SMIC	3%		TSMC
2%		Powerchip	4%		Samsung	3%		Rohm/Lapis
2%		SMIC	3%		HHGrace	3%		Toshiba

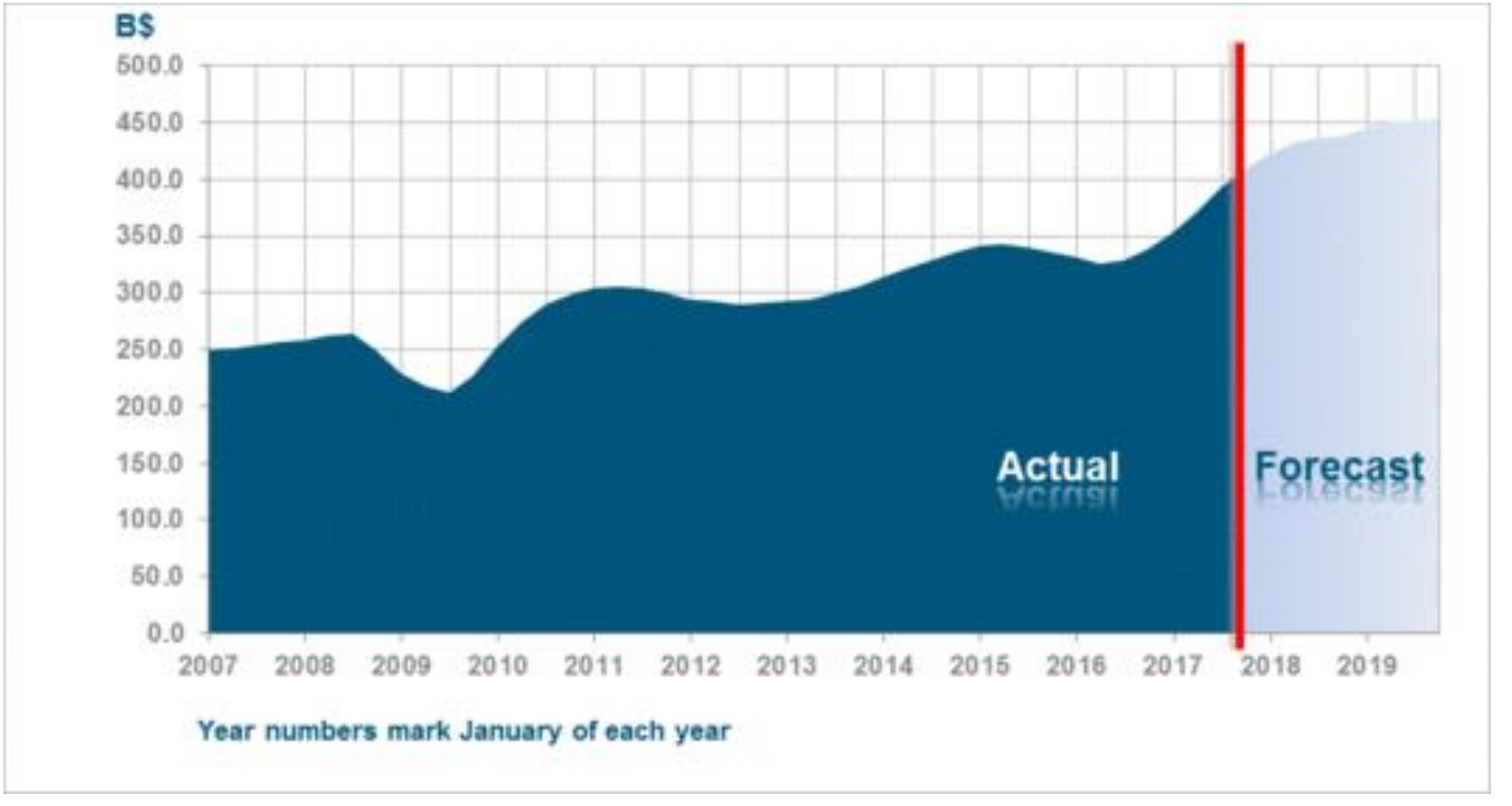
WW Share is each company's share of total industry capacity for that wafer size.
Blue bars indicate the relative amount of capacity held by each company among the top 10 leaders.
*Includes shares of capacity from joint ventures.

Source: IC Insights

Silicon wafer size



IC industry Revenue



IC revenue vs Market by region

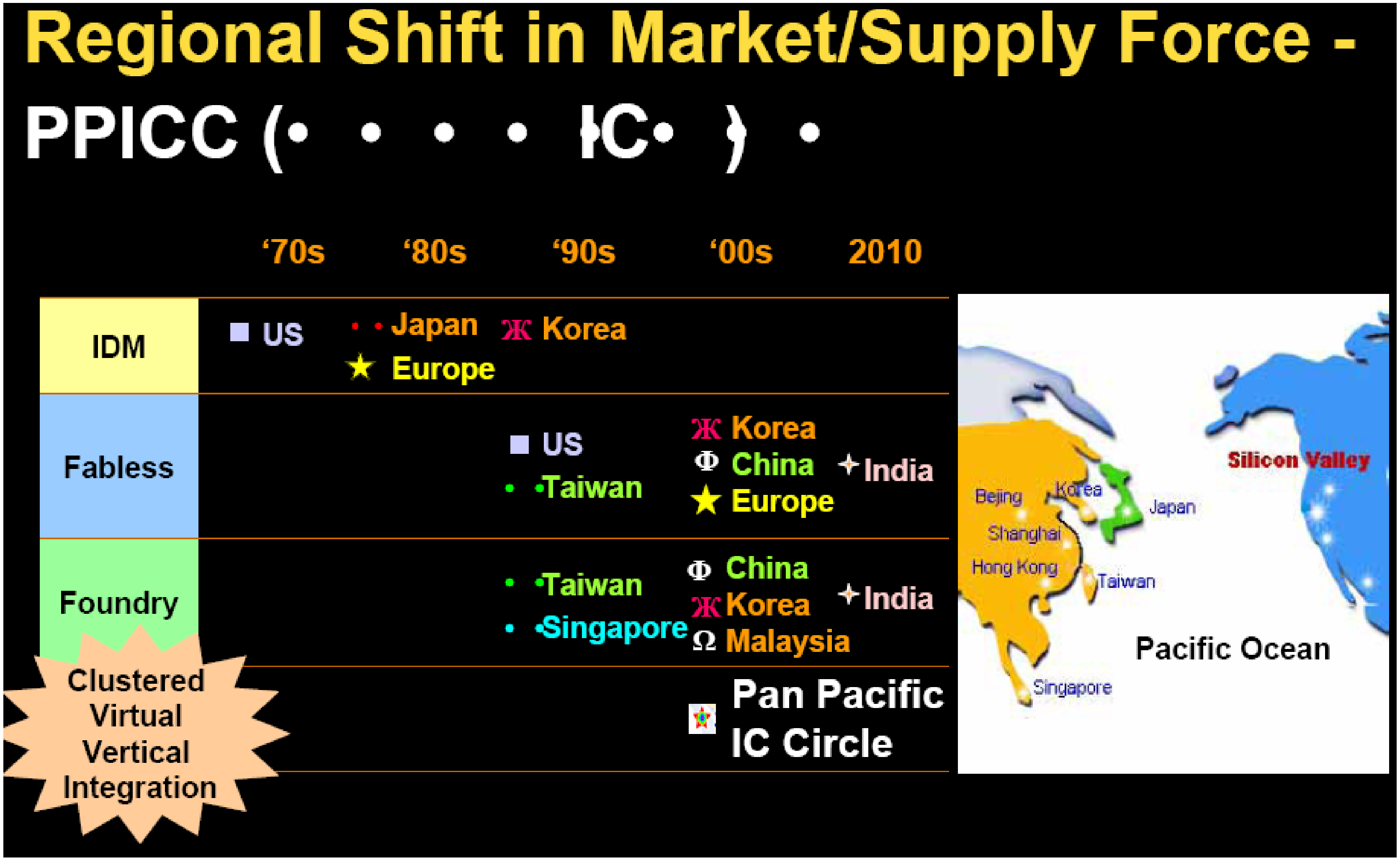
WSTS Forecast Summary

From the autumn 2017 Forecast Meeting, held November 14 to 16, 2017:

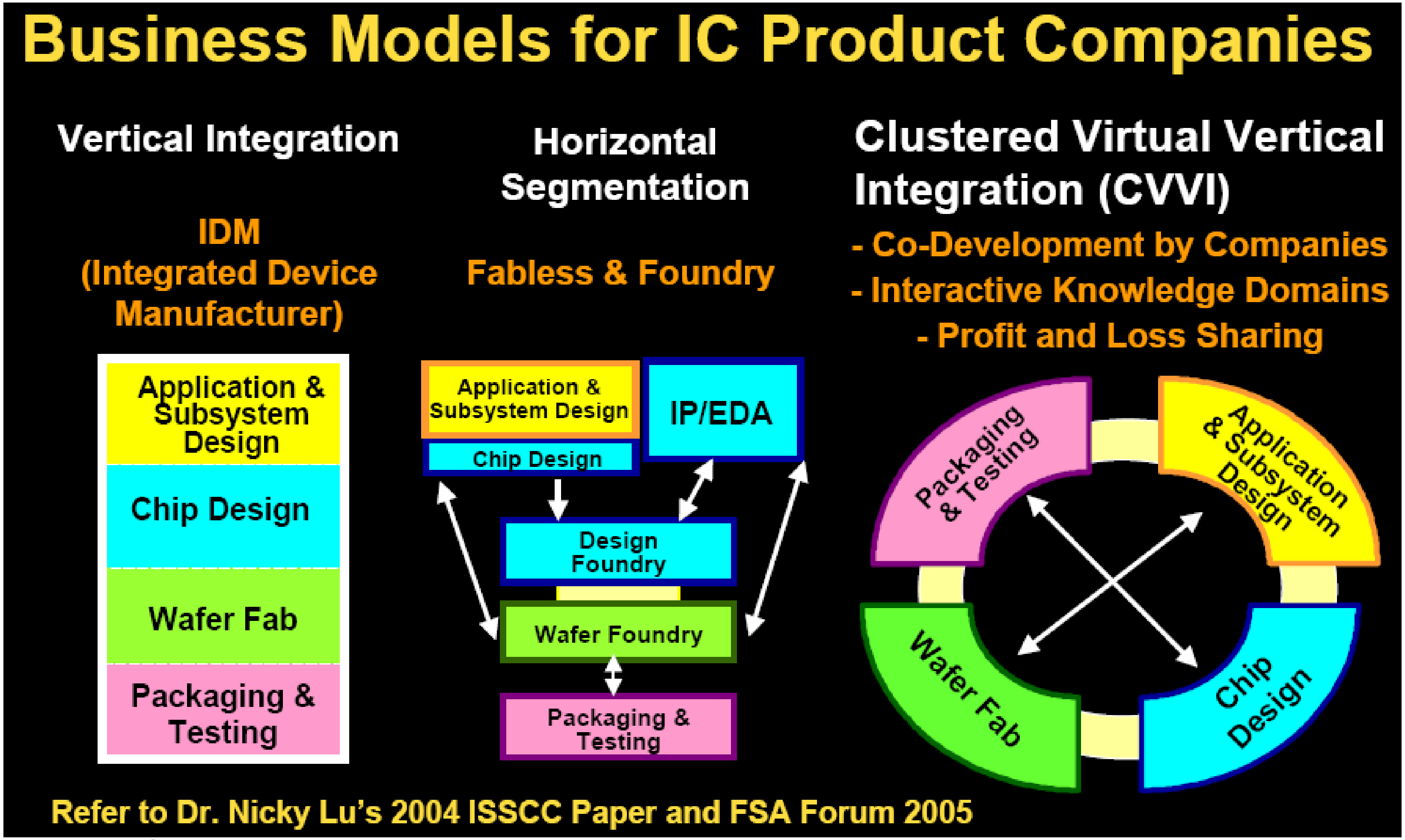
Autumn 2017	Amounts in US$M			Year on Year Growth in %		
	2016	2017	2018	2016	2017	2018
Americas	65,537	**86,458**	**95,380**	-4.7	31.9	10.3
Europe	32,707	**38,048**	**39,799**	-4.5	16.3	4.6
Japan	32,292	**36,350**	**37,990**	3.8	12.6	4.5
Asia Pacific	208,395	**247,834**	**264,097**	3.6	18.9	6.6
Total World - $M	338,931	**408,691**	**437,265**	1.1	20.6	7.0
Discrete Semiconductors	19,418	**21,498**	**22,490**	4.3	10.7	4.6
Optoelectronics	31,994	**34,467**	**37,302**	-3.8	7.7	8.2
Sensors	10,821	**12,537**	**13,439**	22.7	15.9	7.2
Integrated Circuits	276,698	**340,189**	**364,034**	0.8	22.9	7.0
Analog	47,848	52,711	55,909	5.8	10.2	6.1
Micro	60,585	63,147	65,331	-1.2	4.2	3.5
Logic	91,498	101,413	108,467	0.8	10.8	7.0
Memory	76,767	122,918	134,327	-0.6	60.1	9.3
Total Products - $M	338,931	**408,691**	**437,265**	1.1	20.6	7.0

Note: Numbers in the table are rounded to whole millions of dollars, which may cause totals by region and totals by product group to differ slightly.

Regional shift in Market force



Business models for IC companies



IC development

- World:
  - Fabrication to Asia
  - Outsource to Asia, especially to South East of Asia

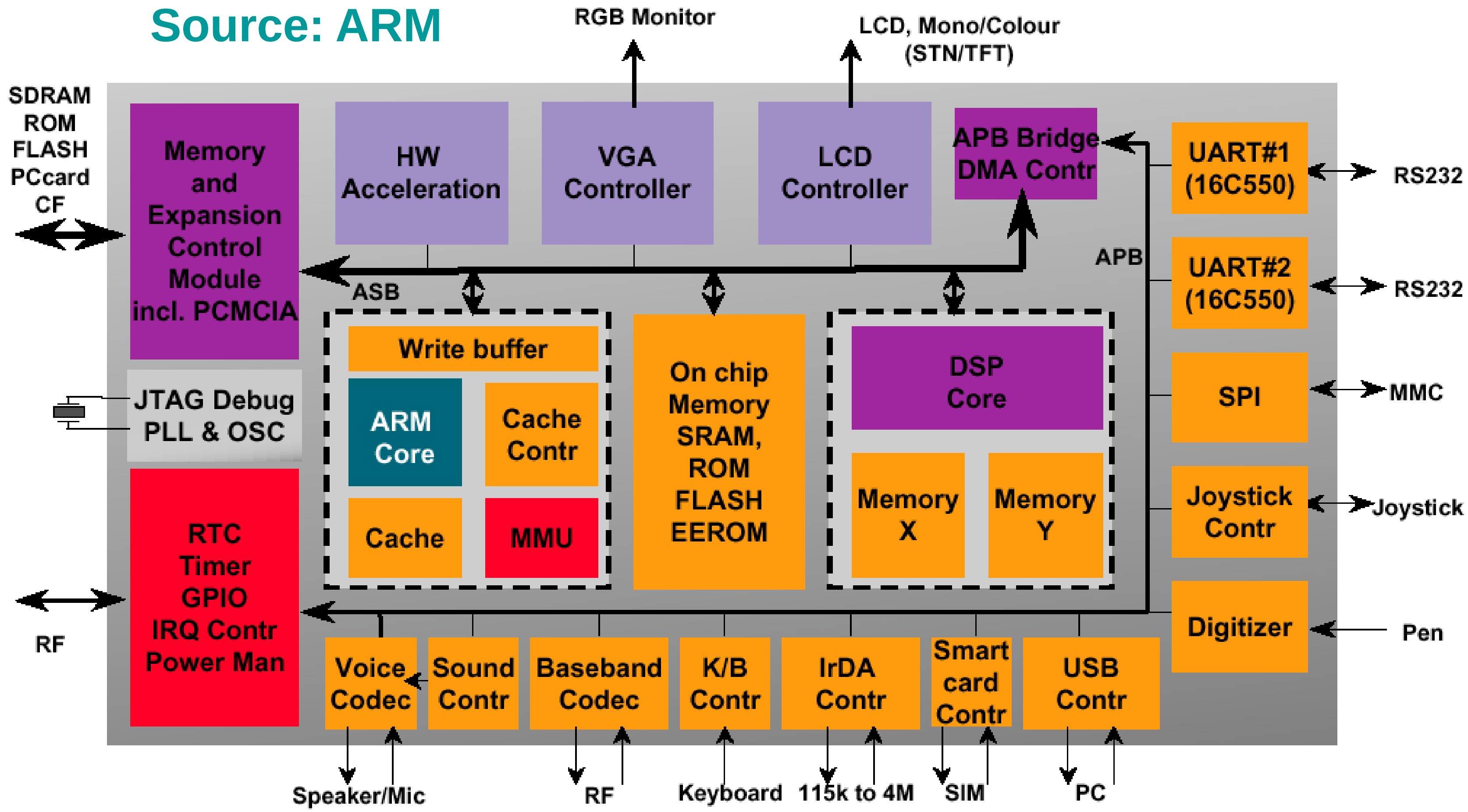
    => Vietnam

IC design in Vietnam

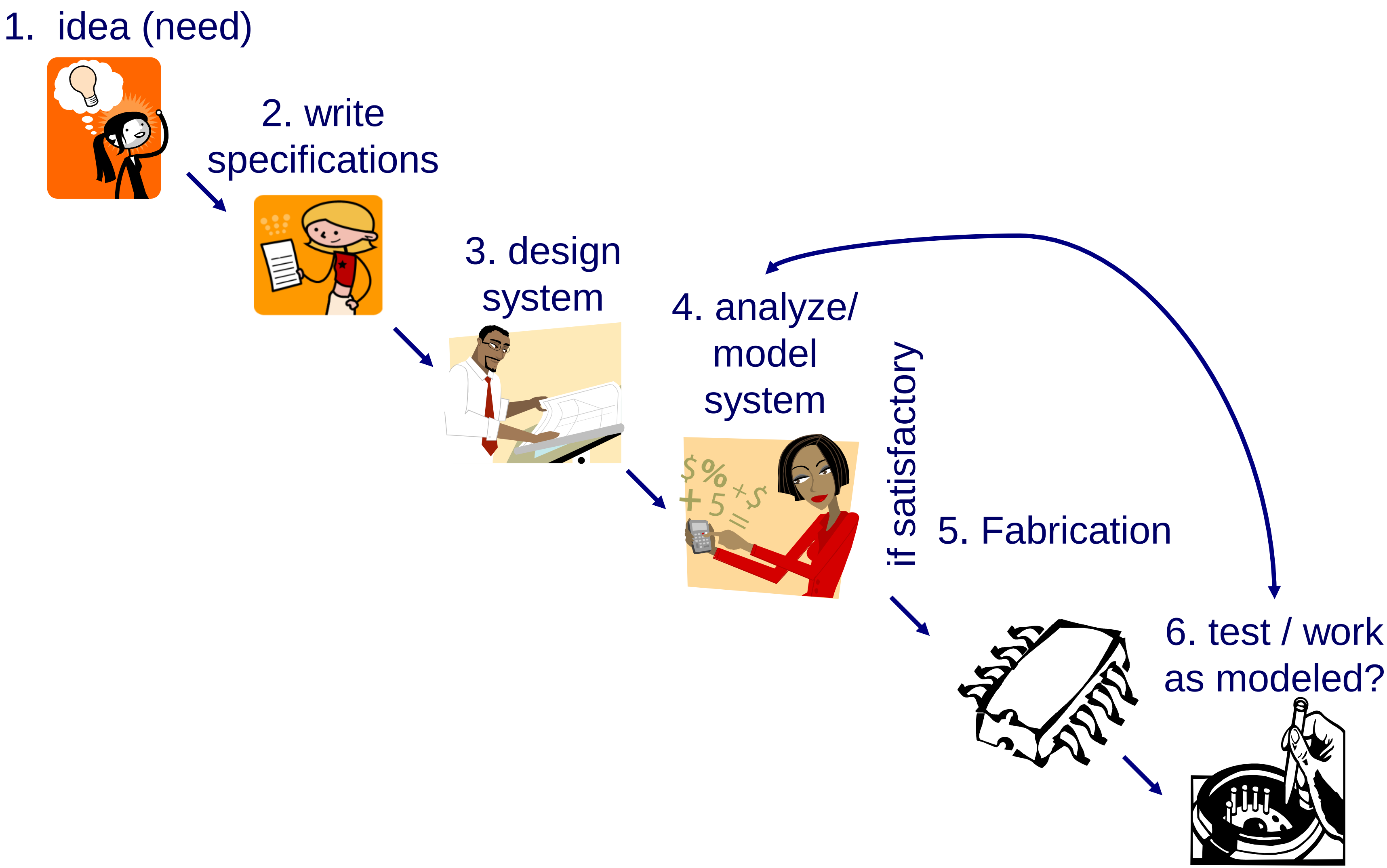
- Hanoi:
  - Analog IC : Active Semiconductor, ETA, Viettel
  - Layout and verification: Dolphin
  - Service: FPT LSI, Toshiba
  - Related: Panasonic R&D, Toshiba, Samsung, Viettel, VNPT Tech, VP9
- HCM city:
  - Renesas, ACMM
  - Arrive Technologies, ESilicon …
  - ICDREC

System on a Chip

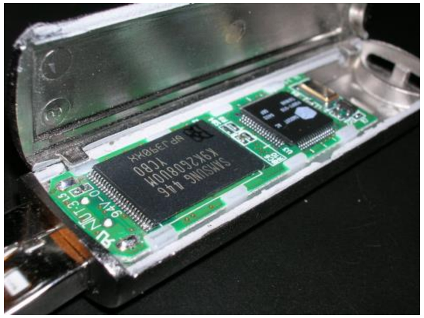
Source: ARM



What does it take to design VLSI systems? Same engineering principles you learned so far



1. Applications / Ideas



2. Specifications

- Instruction set
- Interface (I/O pins)
- Organization of the system
- Functionality of each unit in the and how it to communicate to other unit

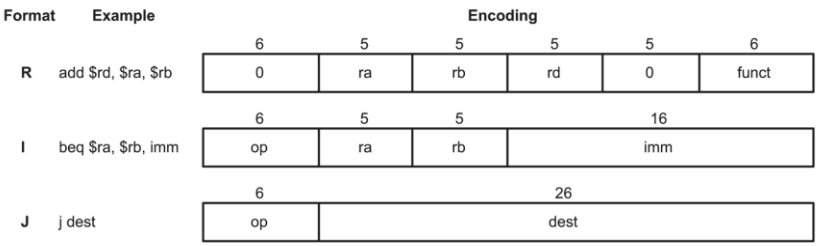
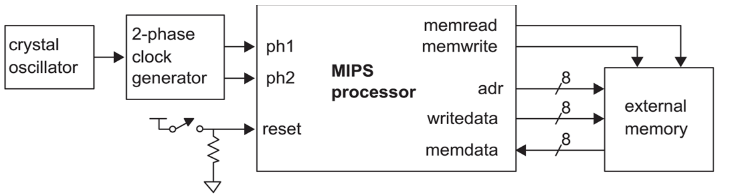


FIG 1.49 Instruction encoding formats



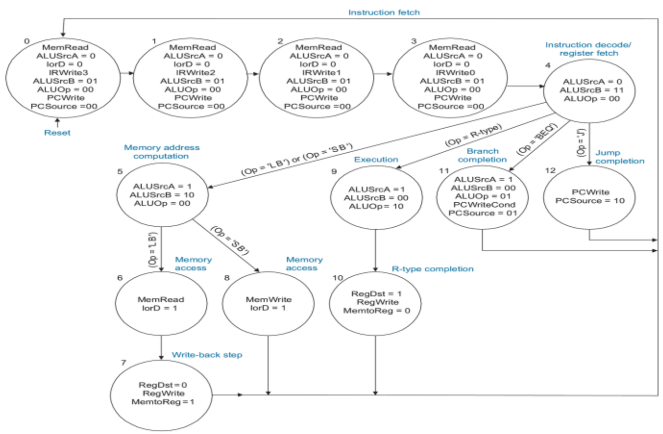


FIG 1.54 Multicycle MIPS control FSM. Reprinted from [Patterson04] with permission from Elsevier.

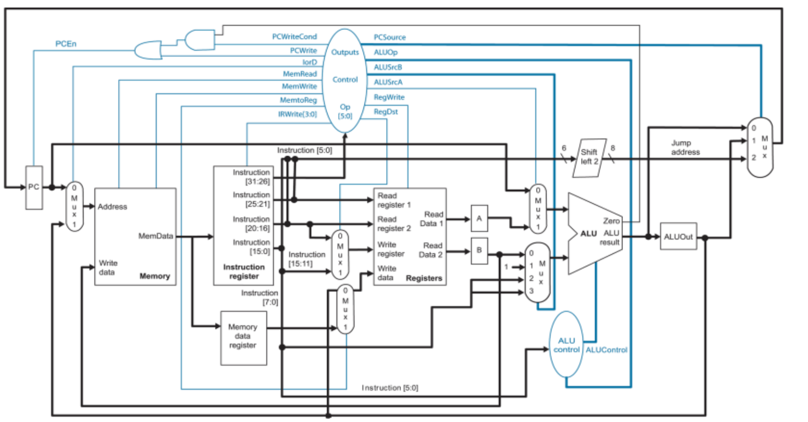
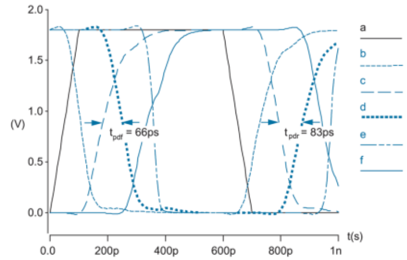
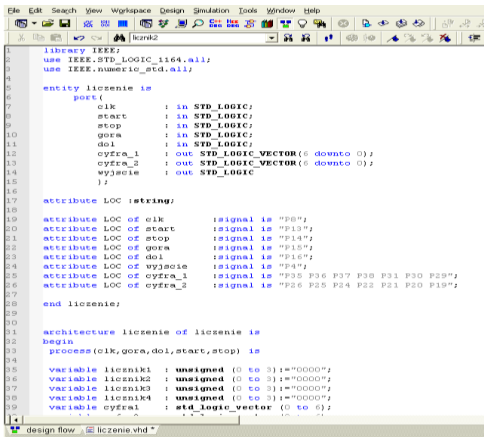


FIG 1.53 Multicycle MIPS microarchitecture. Reprinted from [Patterson04] with permission from Elsevier.

3/4. Design and Analysis



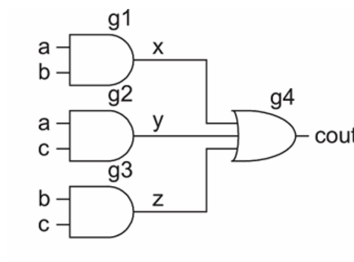
VHDL / Verilog / SystemC

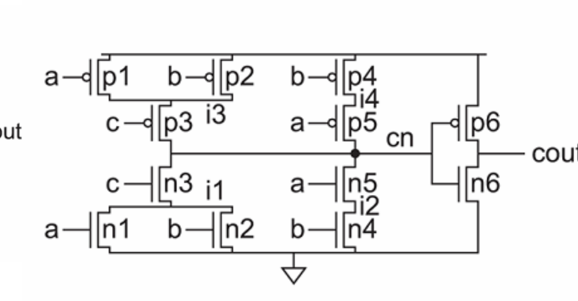



```
library IEEE;
use IEEE.STD_LOGIC_1164.all;
use IEEE.numeric_std.all;

entity liczenie is
     port(
          clk        : in STD_LOGIC;
          start      : in STD_LOGIC;
          stop       : in STD_LOGIC;
          gora       : in STD_LOGIC;
          dol        : in STD_LOGIC;
          cyfra_1    : out STD_LOGIC_VECTOR(6 downto 0);
          cyfra_2    : out STD_LOGIC_VECTOR(6 downto 0);
          wyjscie    : out STD_LOGIC
          );

attribute LOC :string;

attribute LOC of clk        :signal is "P8";
attribute LOC of start      :signal is "P13";
attribute LOC of stop       :signal is "P14";
attribute LOC of gora       :signal is "P15";
attribute LOC of dol        :signal is "P16";
attribute LOC of wyjscie    :signal is "P4";
attribute LOC of cyfra_1    :signal is "P35 P36 P37 P38 P31 P30 P29";
attribute LOC of cyfra_2    :signal is "P26 P25 P24 P22 P21 P20 P19";

end liczenie;


architecture liczenie of liczenie is
begin
 process(clk,gora,dol,start,stop) is

 variable licznik1  : unsigned (0 to 3):="0000";
 variable licznik2  : unsigned (0 to 3):="0000";
 variable licznik3  : unsigned (0 to 3):="0000";
 variable licznik4  : unsigned (0 to 3):="0000";
 variable cyfra1    : std_logic_vector (0 to 6);
```

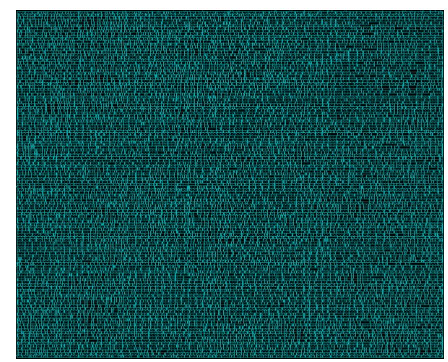
design schematics

compilation/
synthesis

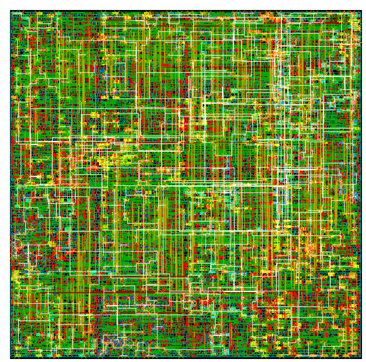




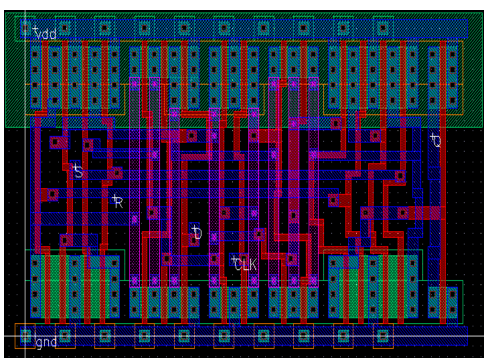
device layout



find wire routes

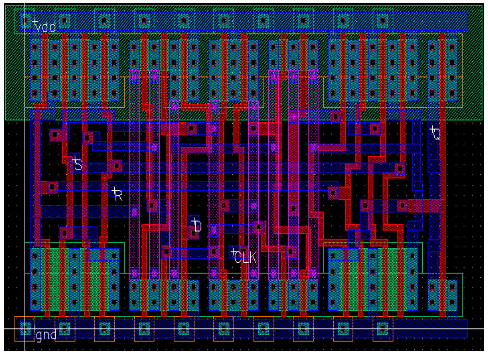


mask layout patterns



- Design development is facilitated using Computer-Aided Design (CAD) tools

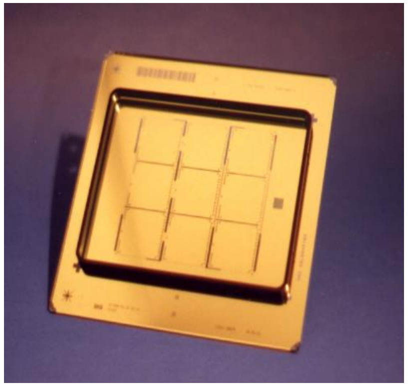
5. Fabrication



mask layout patterns

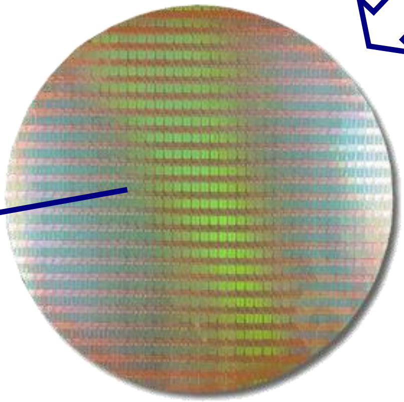
tapeout

mask writer

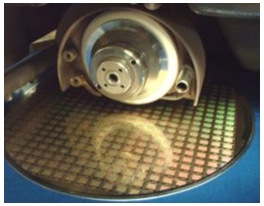


masks

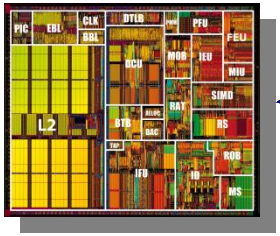
printing



wafer



dice

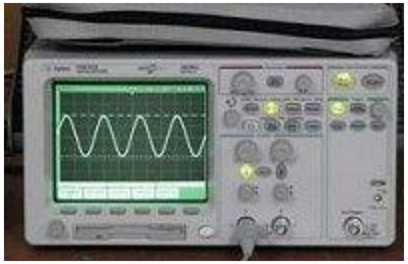


die

test and packaging

chip

6. Evaluate design and compare to model.



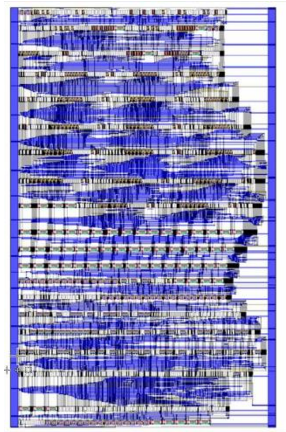
- Check signal integrity
- Power consumption
- Input/output behavior

board

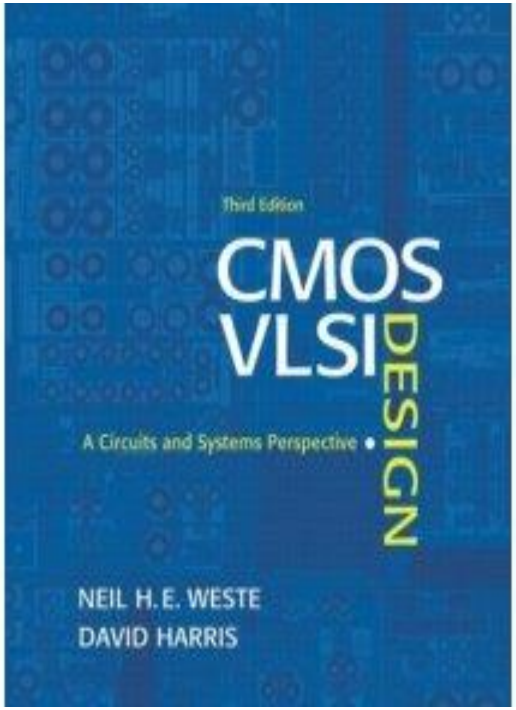
- Does the chip function as it is supposed to be?
- Does it work at desired clock frequency? (can we overclock?)

What are we going to cover in this class?

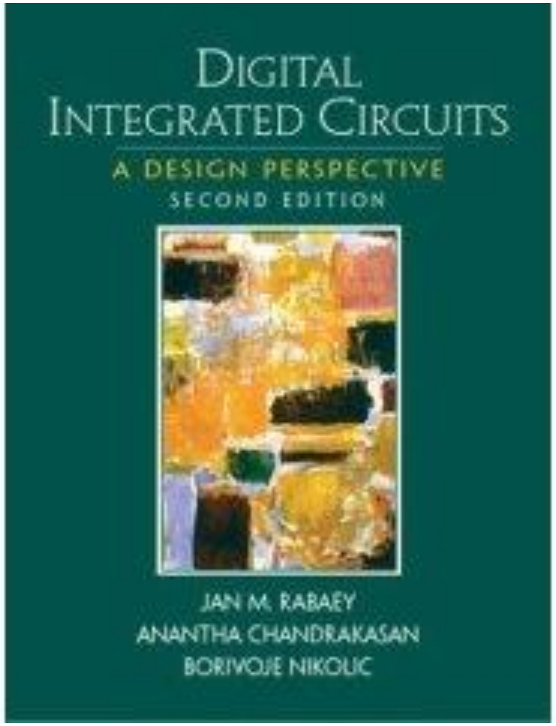
- Overview of VLSI CMOS fabrication
- MOS transistor theory
- VLSI Layout design
- Circuit analysis and performance estimation
- Computer-aided design and analysis tools
- Design project



Textbooks



Recommended



Additional