AUTOMOTIVE SEMICONDUCTOR FOR PURCHASING / BUYER

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SECURITY ARCHITECT - AUTOMOTIVE

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SECURE CONNECTIONS
FOR A SMARTER WORLD

AGENDA

- Introduction to Integrated Circuits (IC’s)
- IC Manufacturing Process
- Tooling, Equipment, and Investment Needs for IC Design and Manufacture
- Semiconductor Manufacturing Video

INTRODUCTION TO INTEGRATED CIRCUITS (ICS)

Semiconductor Terms and Acronyms

Microprocessor

FET

(N,P,C)MOS

Transistor

Digital

Analog

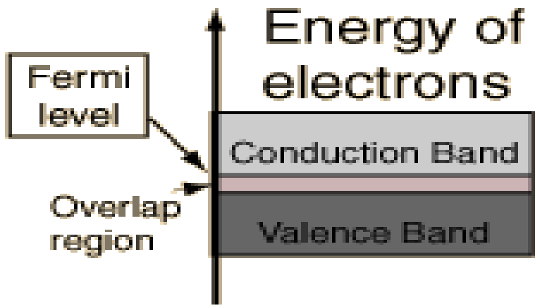
Semiconductor

Silicon

Microcontroller

What is a Semiconductor?

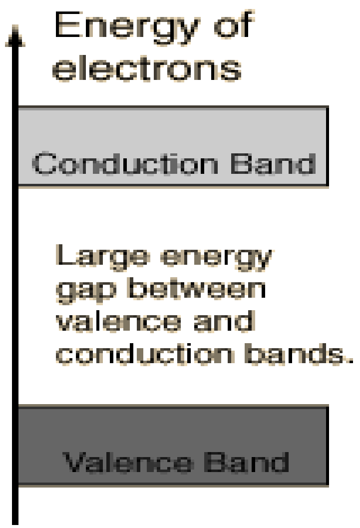
- A conductor carries electricity like a pipe carries water.



Conductor

- A semiconductor controls the flow of electricity like a faucet controls water.

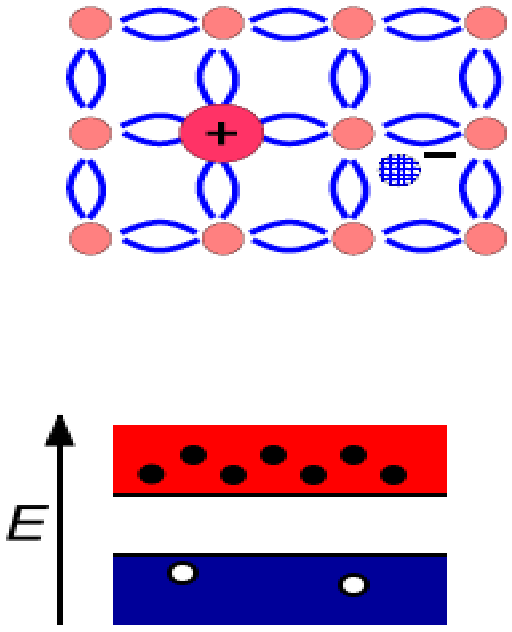
- An insulator stops the flow of electricity like a plug blocks water.



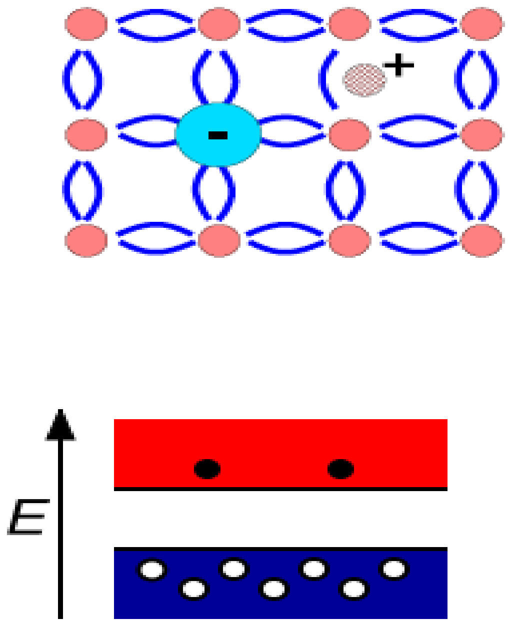
Insulator

Semiconductor Basics

- Copper, a conductor, has one electron per atom available for conduction
- A useful semiconductor requires about 10 orders of magnitude less
- This means adding as little as one doping atom in a billion
- Impurities have to be below one in 10 billion



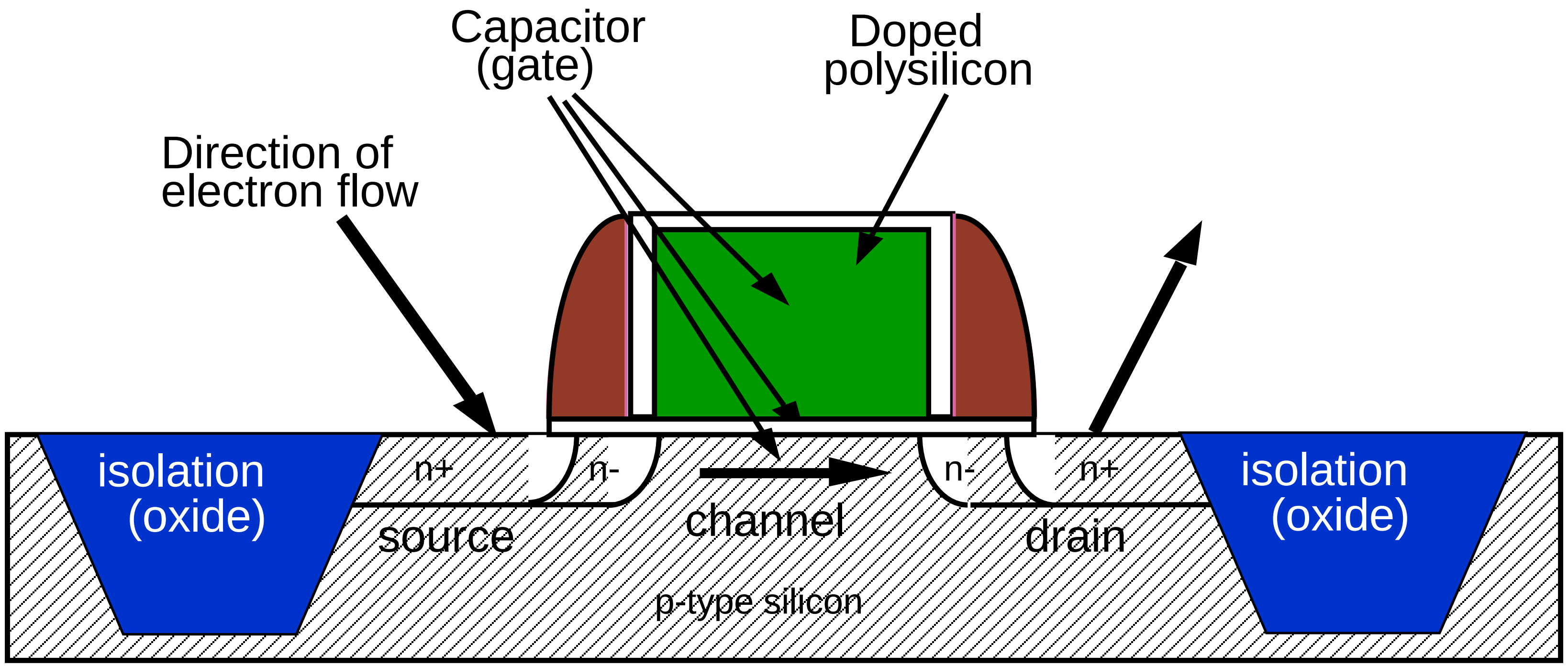
n Type doped with P or As



p Type doped with B

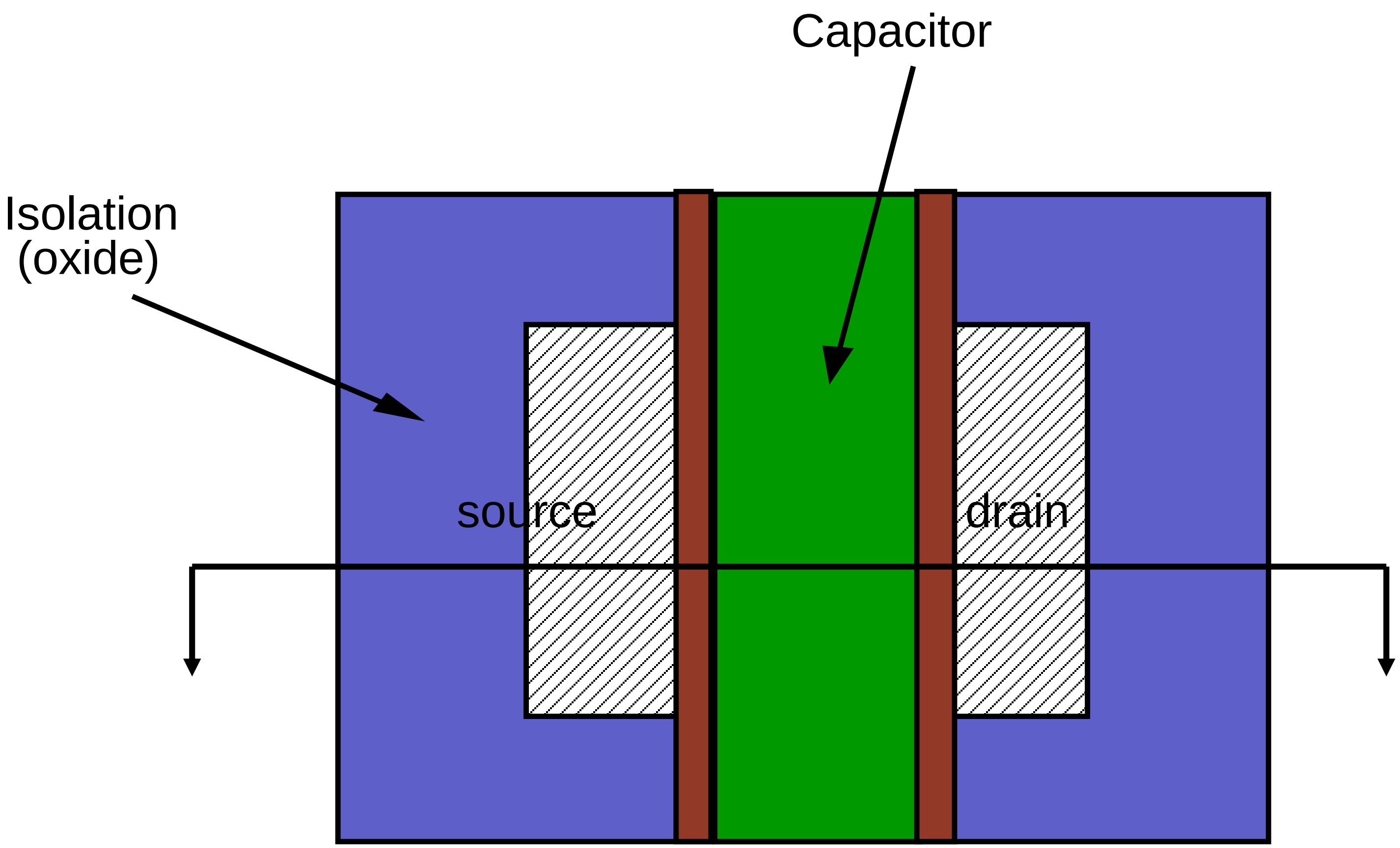
Anatomy of a MOSFET: Cross-Section

- A MOS transistor is nothing more than a voltage-controlled switch.
- A MOS transistor is really just a capacitor with two extra terminals.



Cross-Section View

Anatomy of a MOSFET: Top View



Top View

Semiconductor Device Types

- **Analog** semiconductor devices deal in precise electric properties, most commonly voltages. Transistors within the device are designed to measure and manipulate these properties. Analog devices are well suited to processing real-world signals, as electronic patterns are used to directly represent the original.
- **Digital** devices do not deal in the values of actual voltages; rather, they simply detect the presence or absence of a voltage. The presence of a voltage is represented digitally as a “1,” with the absence represented as a “0.” These 1s and 0s can be processed and manipulated digitally with great flexibility.
- **Mixed Signal** – These devices include both analog and digital circuitry. Mixed signal devices are difficult to design and build, but bring the benefits of both analog and digital processing together.

Device Types: Semiconductor Industry Association (SIA) Framework

- **Discretes, Optoelectronics, Sensors** – Includes all non-integrated circuit semiconductor devices. A discrete is a single transistor in a package. Sensors are discrete devices that measure real-world input. Optoelectronics are discrete devices that produce or measure light.
- **Analog** – Devices used to process real-world signals using electronic voltage patterns that represent the original. Includes SLICs (standard linear components) and ASSPs (application-specific analog ICs).
- **Logic** – All non-microcomponent digital logic. Includes ASICs (custom logic), ASSPs (standard specialty logic products), FPGAs (programmable logic), display drivers and general purpose logic.
- **Memory** – Memory devices are used to store data either for short periods of time or permanently. Includes volatile (DRAM, SRAM) and non-volatile (flash, ROM) memory.
- **Microcomponents** – All digital processors, including microprocessors (MPUs), microcontrollers (MCUs) and digital signal processors (DSPs).

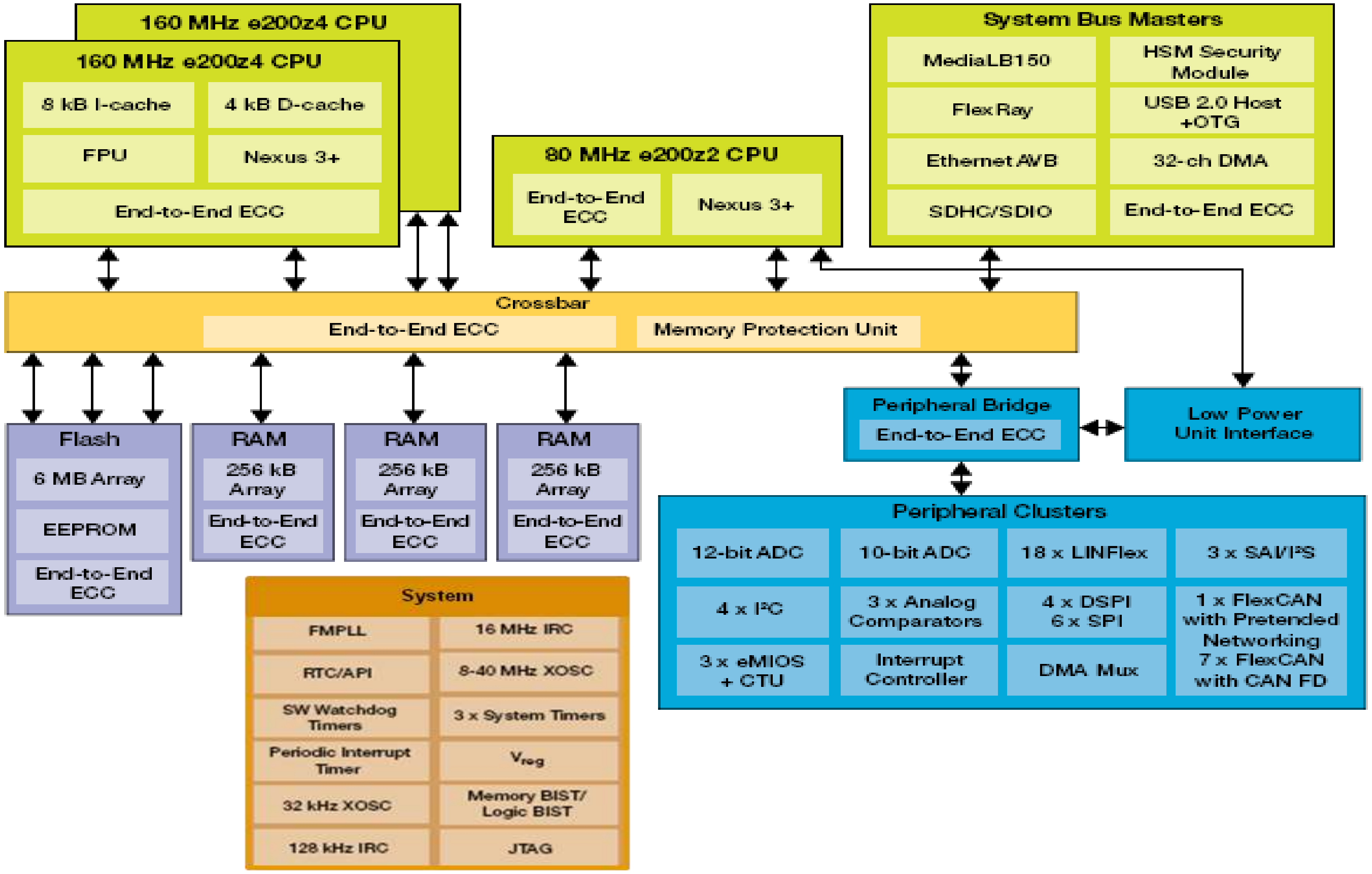
Microcomponents in Detail

Microcomponents:
Devices designed to perform intensive compute processing and system control

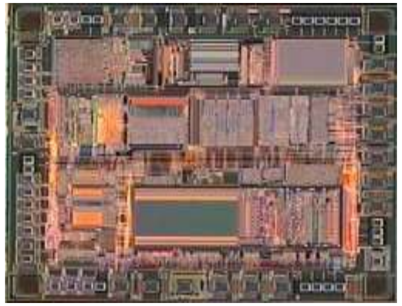
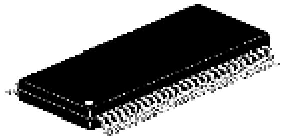
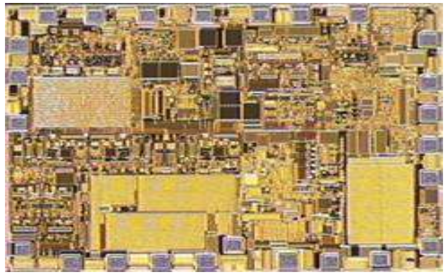
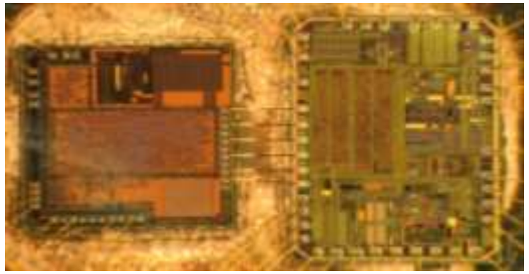
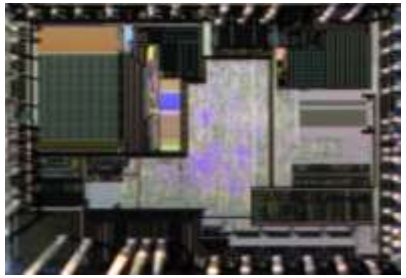
Three Key Types:

- **Microprocessors** – digital processors that execute instructions and perform system control functions. MPUs are optimized for general purpose data processing.
- **Microcontrollers** – stand-alone devices that perform embedded compute functions within an overall system. MCUs contain single or multiple processing elements as well as on-chip, RAM, ROM, and I/O logic.
- **Digital Signal Processors** – specialized high speed programmable processors designed to perform real-time processing of digital signals

Example Microcontroller – MPC5748G



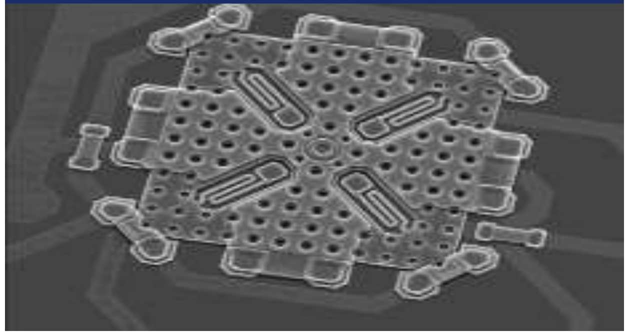
Packaging Options for Mixed-Signal Functions

Semi-Discrete Solution	Multi-die SiP	Monolithic SiP
Standard MCU	Single package	MCU and Analog on the same die
	Die-to-die bonding	
Application Specific Analog IC (ASIC)		
		

Example of Inertial Sensing Elements

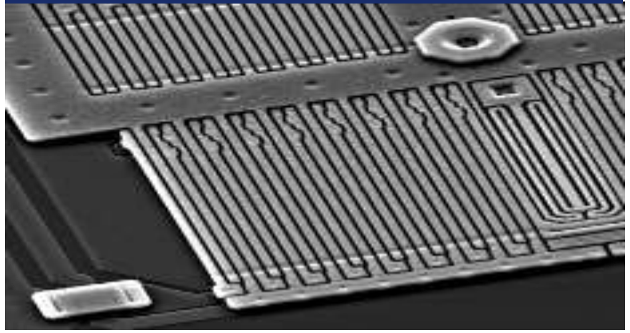
Z-Axis Elements

Poly Silicon, Folded Beam
Z-Axis Sensing

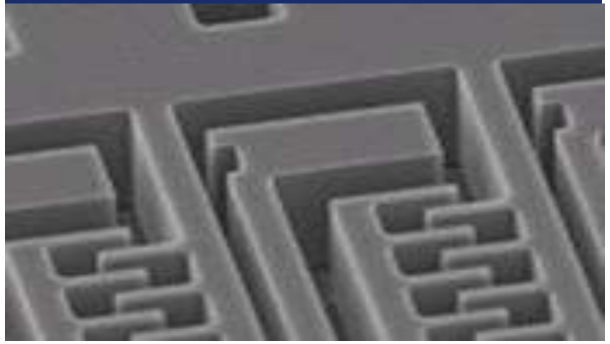


X-Axis Elements

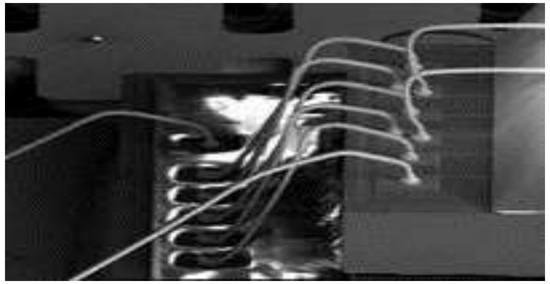
Poly Silicon, Interdigitated
X- and XY-Axis Sensing

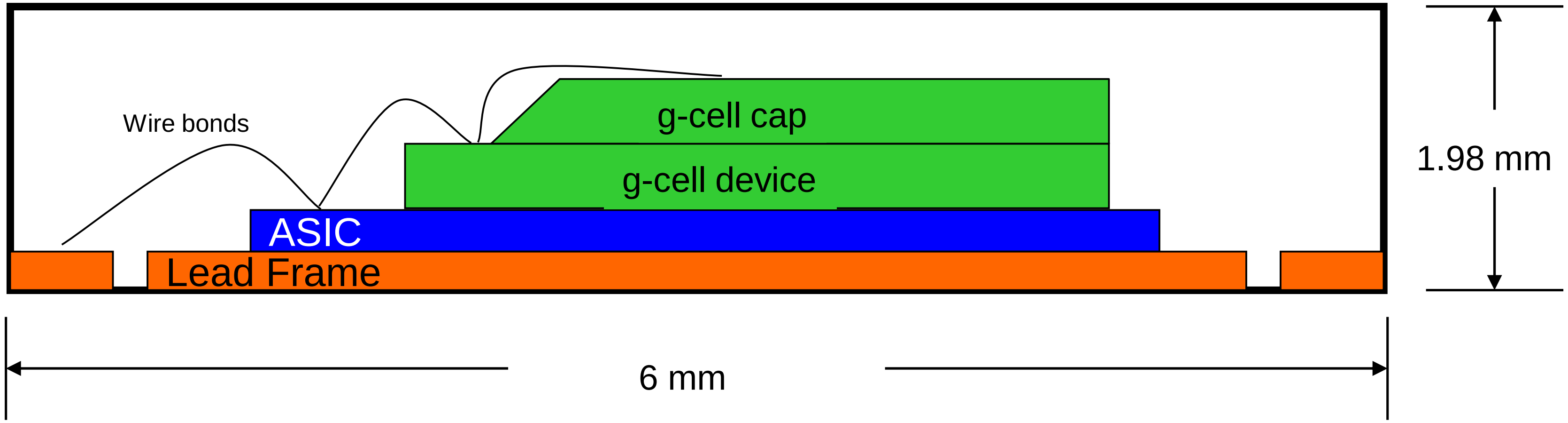


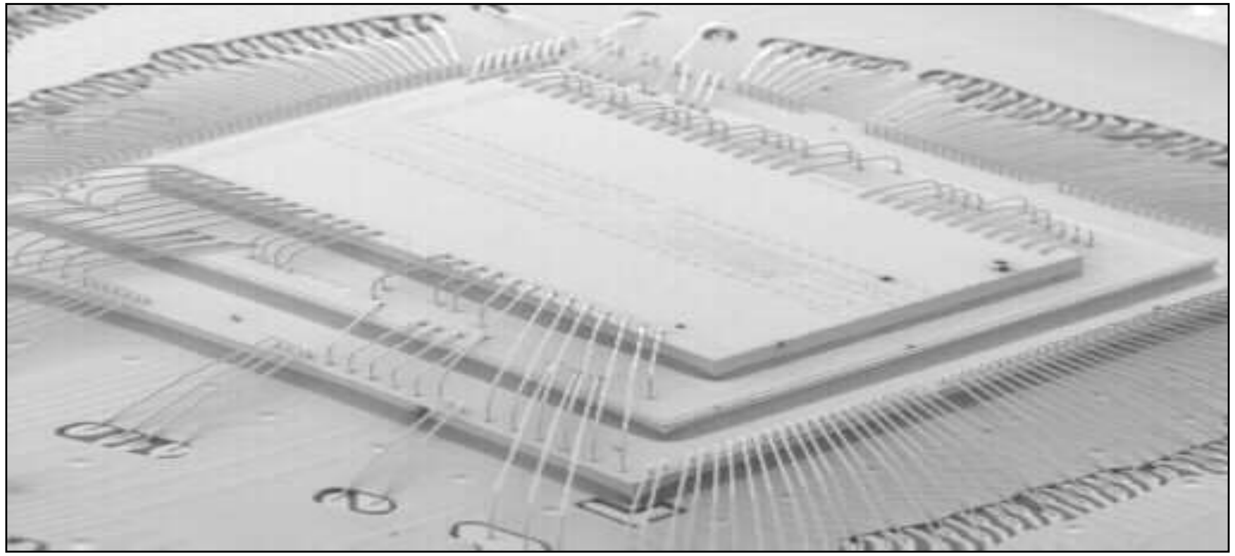
Harmems, Interdigitated
X- and XY-Axis Sensing



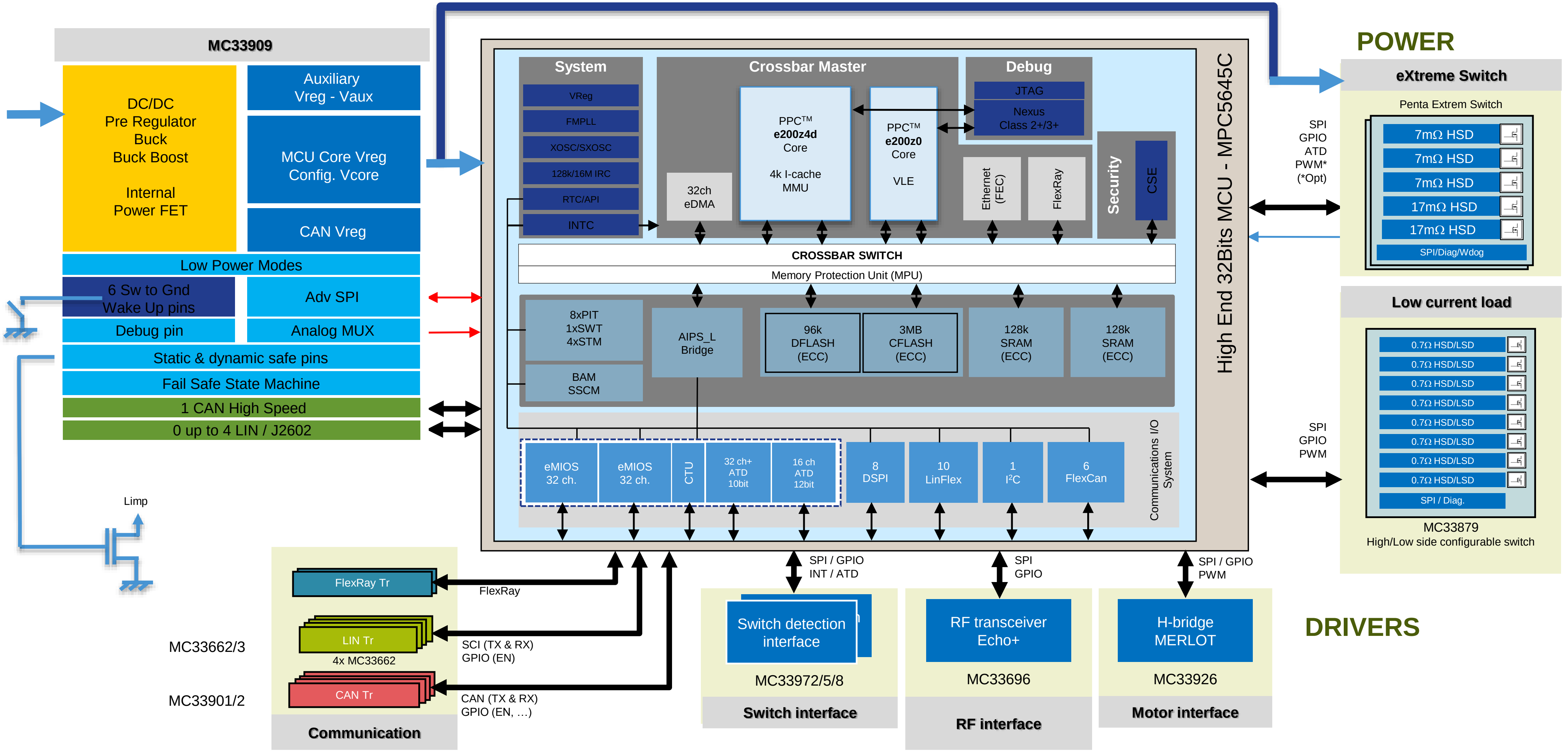
Stacked-Die Packaging for Sensors and Processors



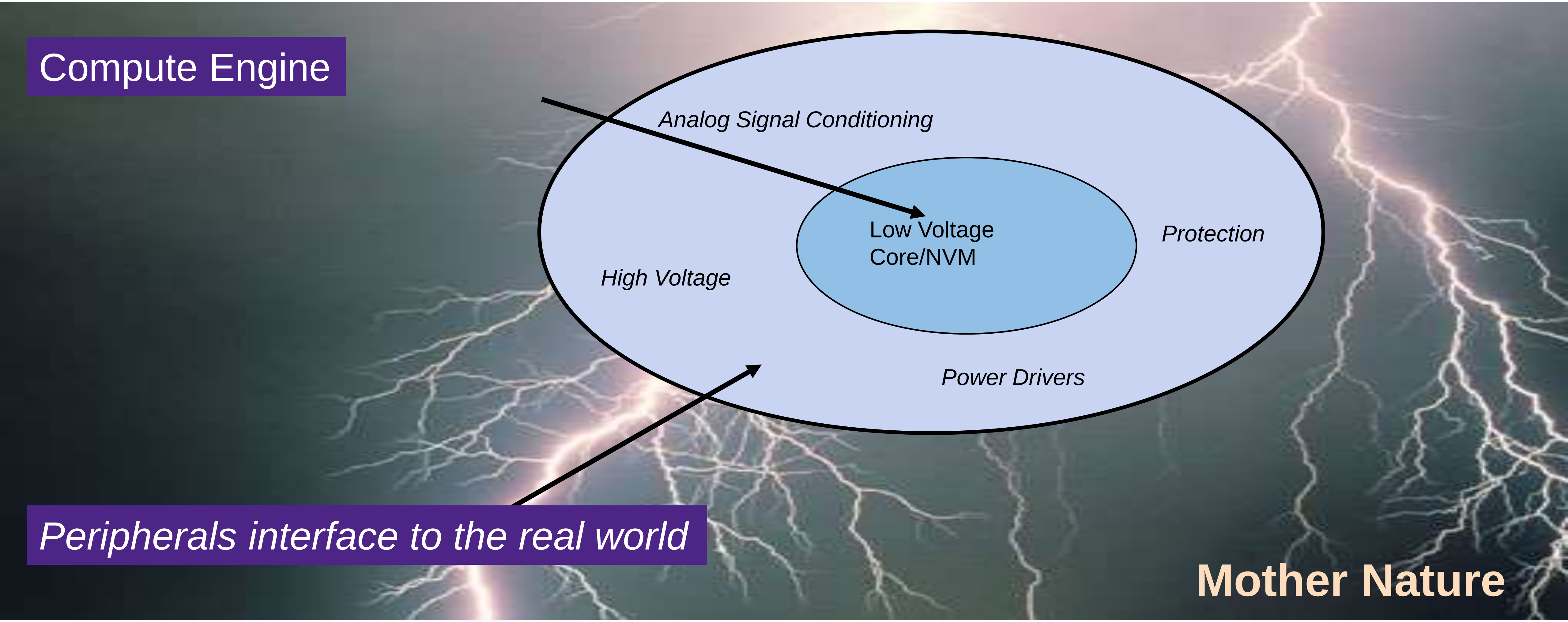




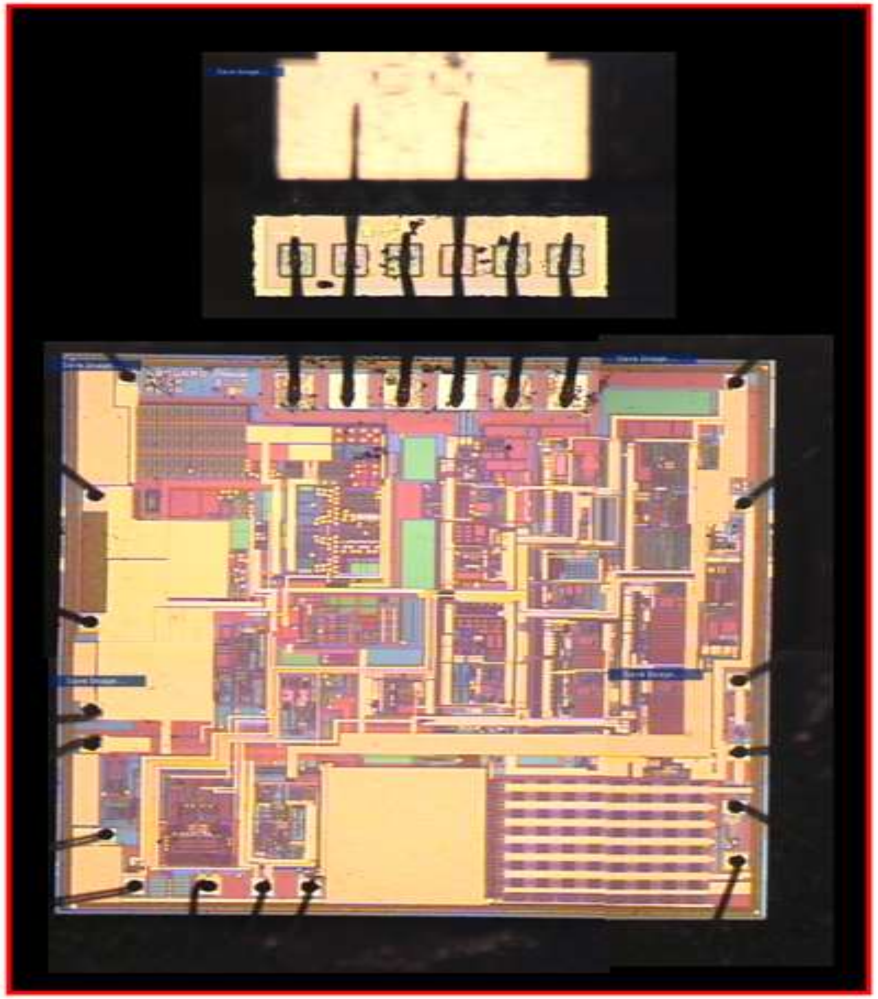
Body Controller Partitioning Example



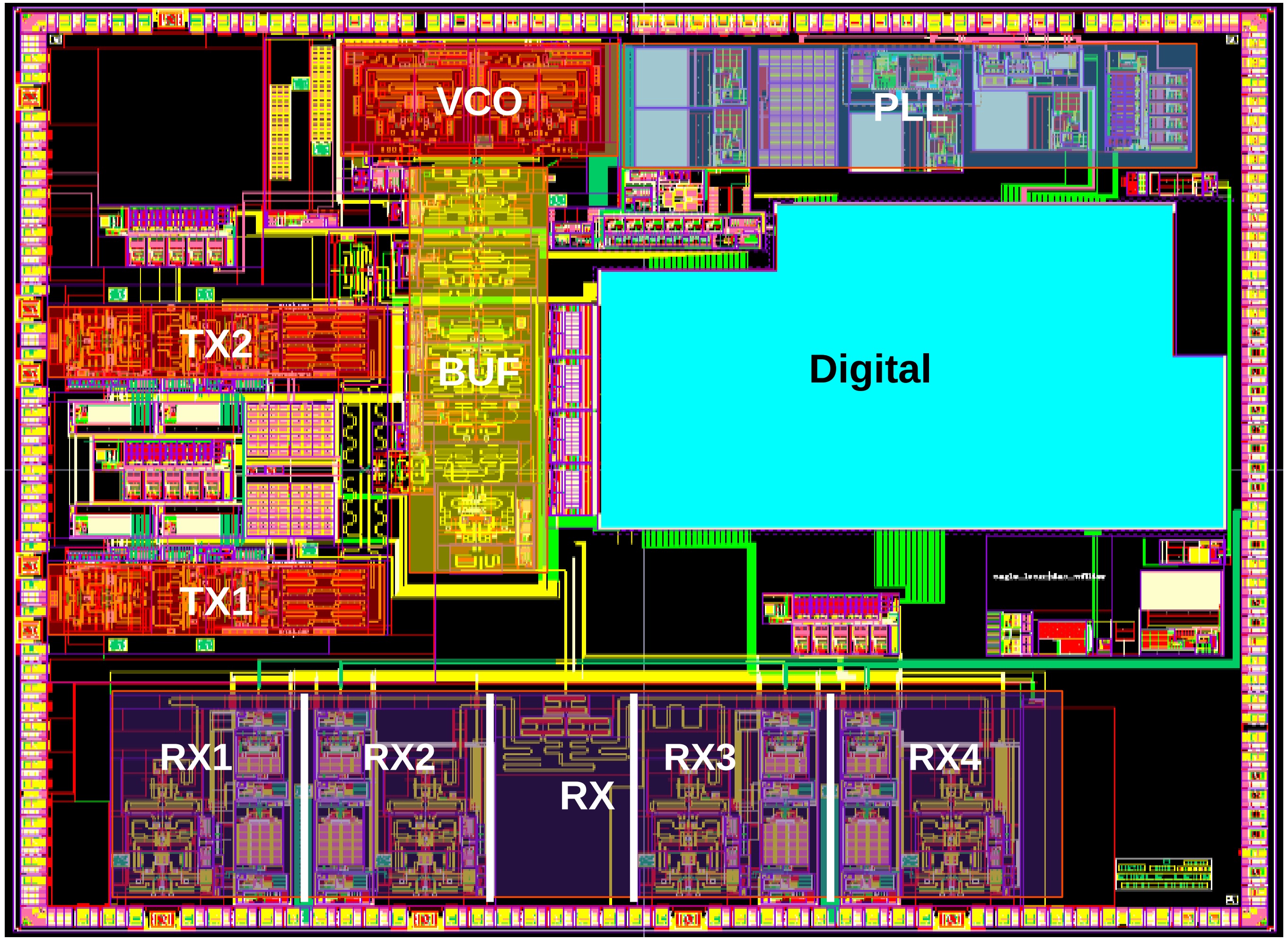
Control Modules – Functional Breakdown



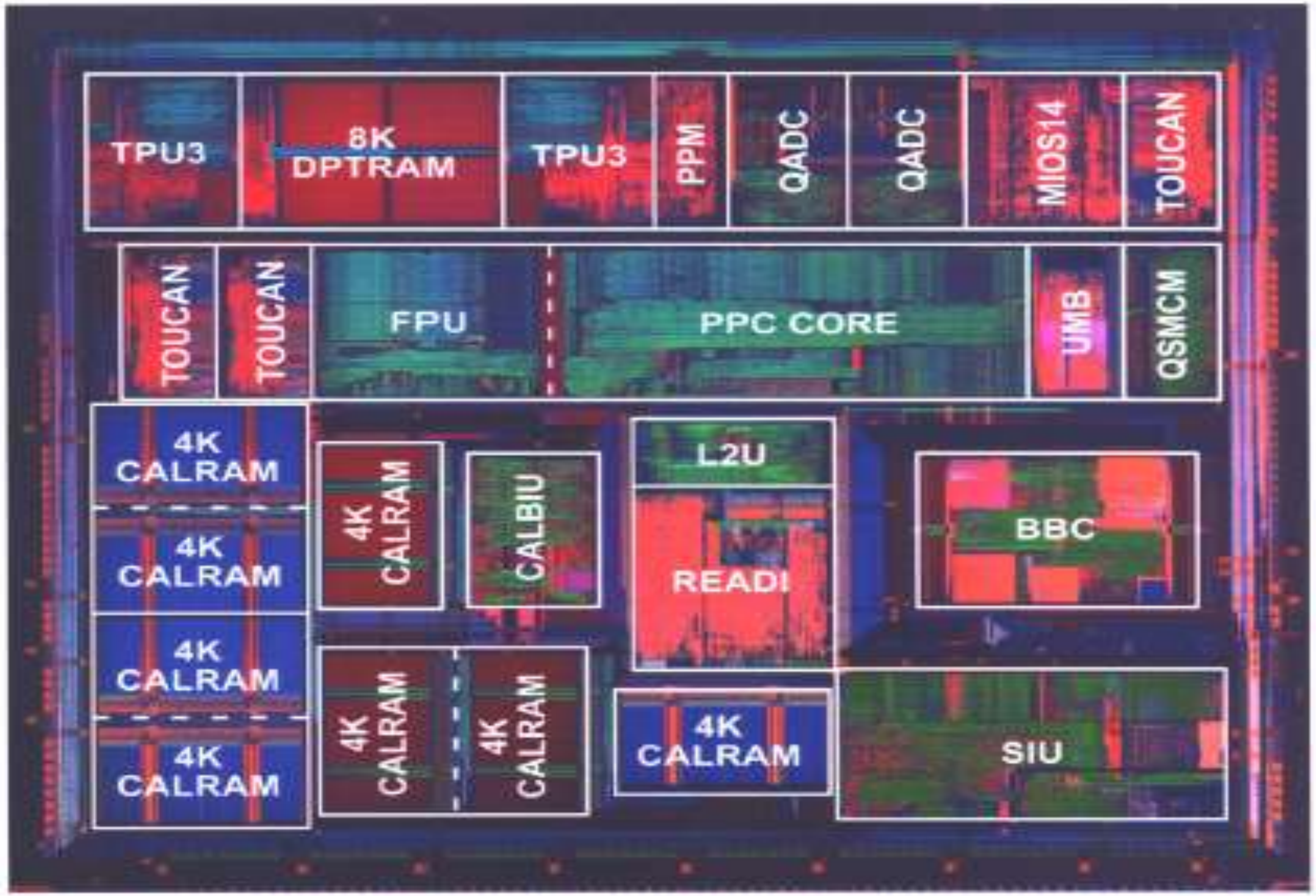
Example Die Pictures of Integrated Circuits



Radar Transceiver

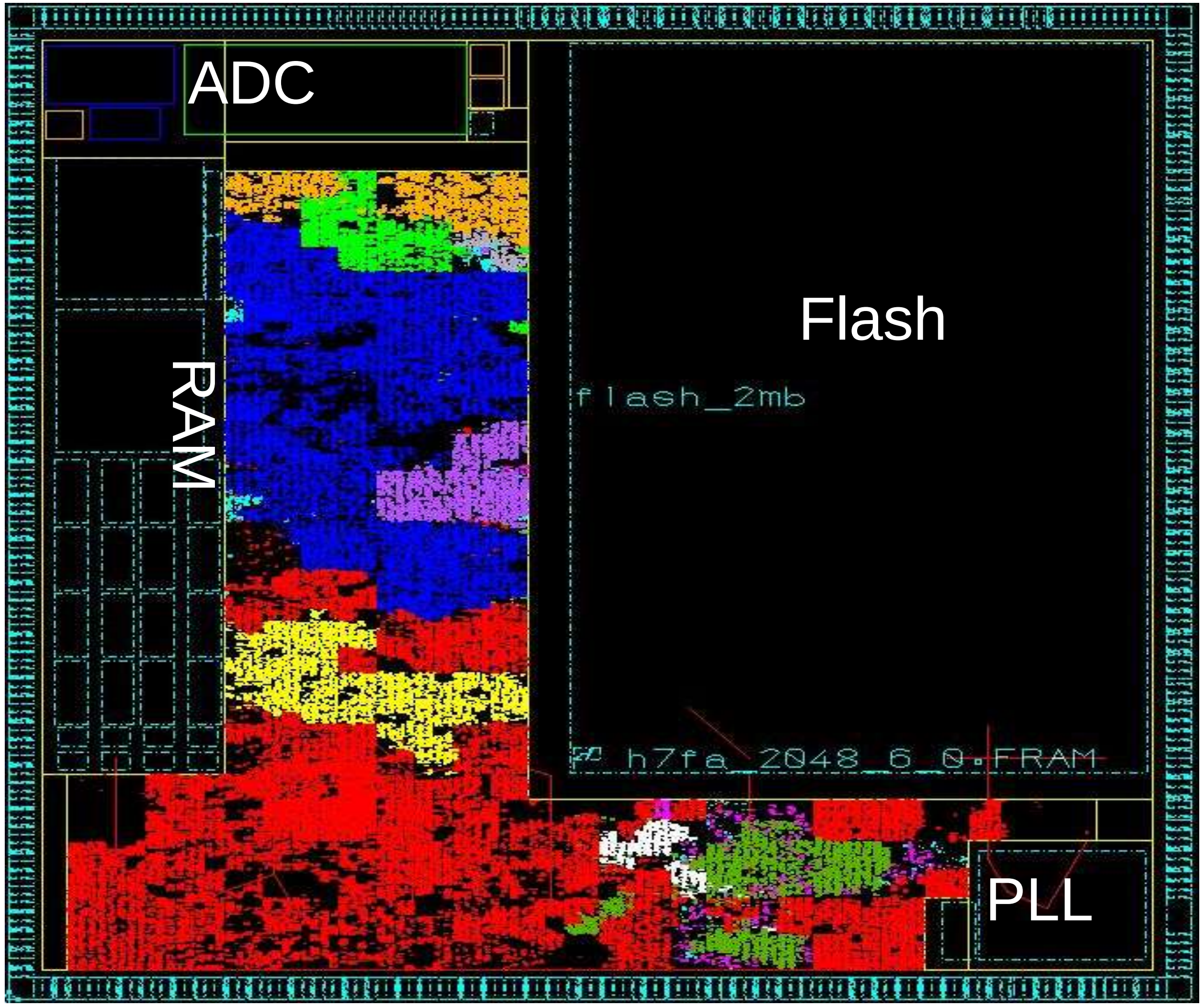


MPC561 Die Photo



- 32-bit MCU with Power Architecture® CPU core
- Die size = .55 cm2
- 5 million transistors
- 16 million vias and local interconnects
- 2 polysilicon layers
- 3 aluminum metal layers
- 0.25 µm technology

MPC5554 Floor Plan

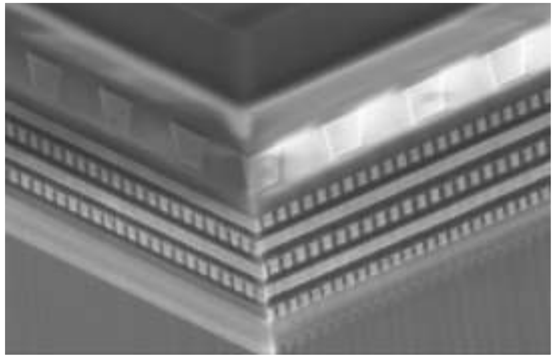


- Red – CPU
- Blue – eTPU
- Green – eQADC
- Purple – DSPI
- Yellow – eMIOS
- Orange – FlexCAN
- White – EBI
- Dark Green – SIU
- Magenta – JTAG
- Grey – SCI

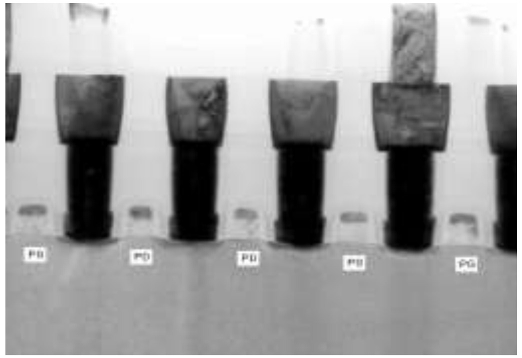
MPC5674F Technology Highlights

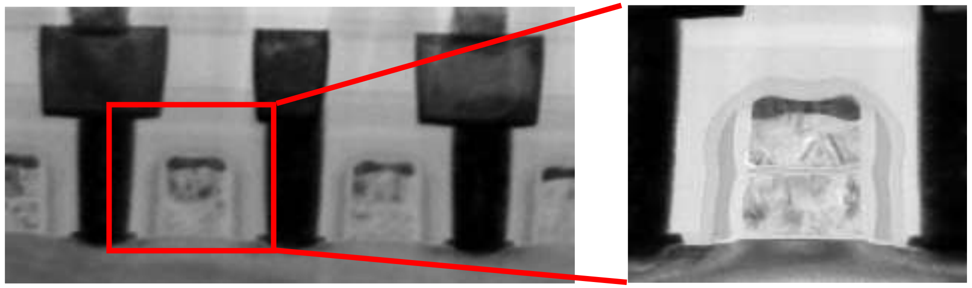
- ~350 process steps, 55 mask layers
- ~75 million transistors
- ~400 chips per 200 mm wafer
- Embedded ADC, SRAM, non-volatile memory

6 Layers of Cu Metal

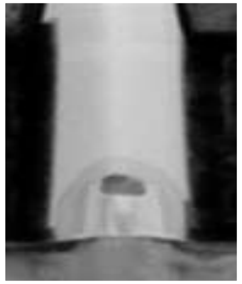


1.15 um^2 SRAM Bitcell Array

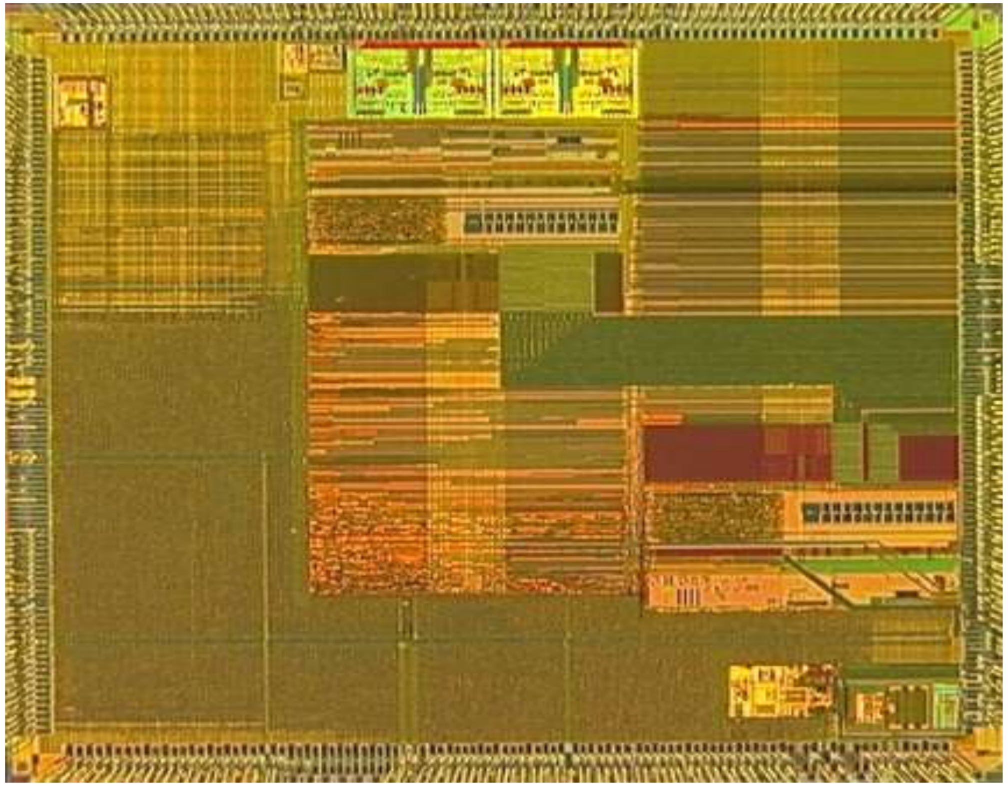




NVM Bitcell Array **NVM Bitcell**

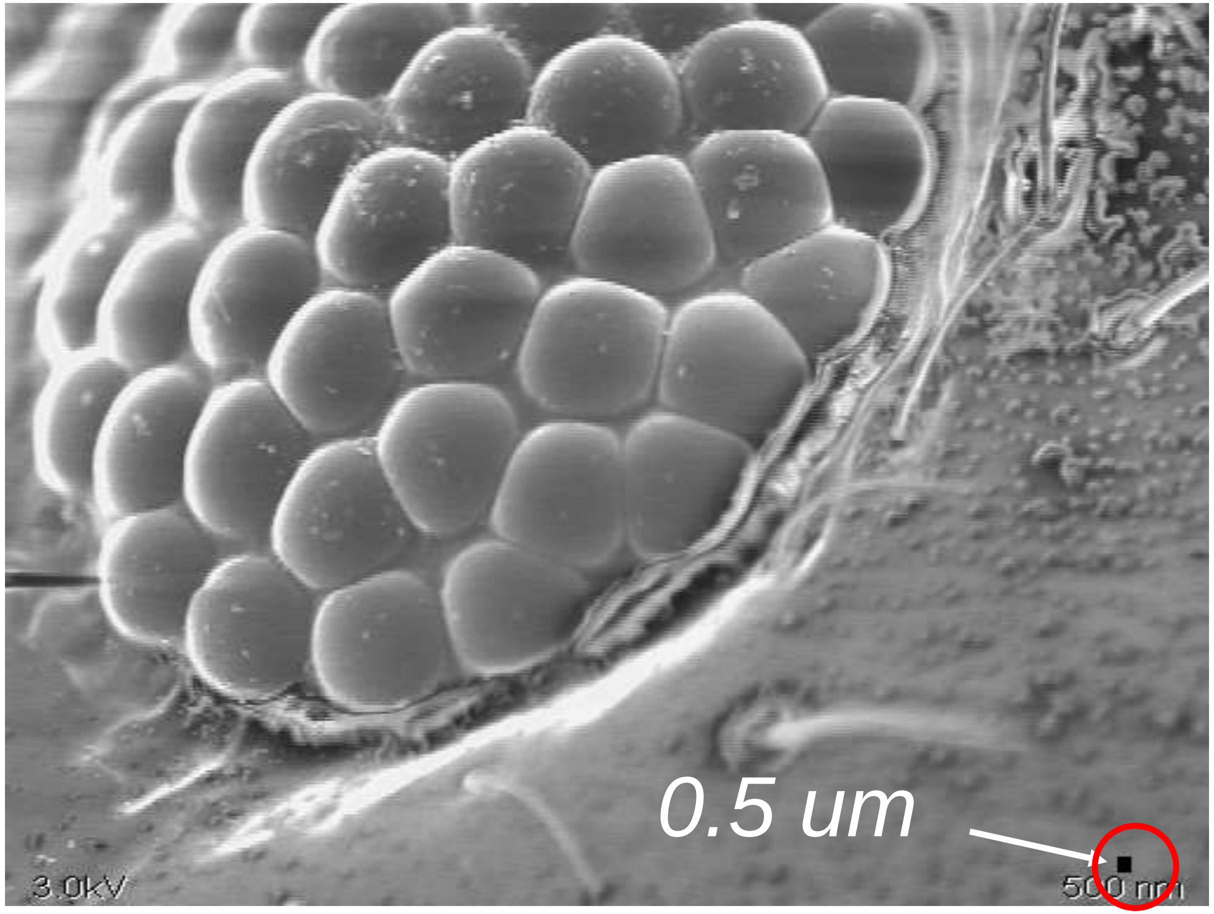


Logic



State-of-the-art Power Architecture®
32-bit MCU engine control
600+ DMIPS – MPC5674F

What is a Micron Between Friends?



Electron microscope photograph of a common Texas fire-ant eye

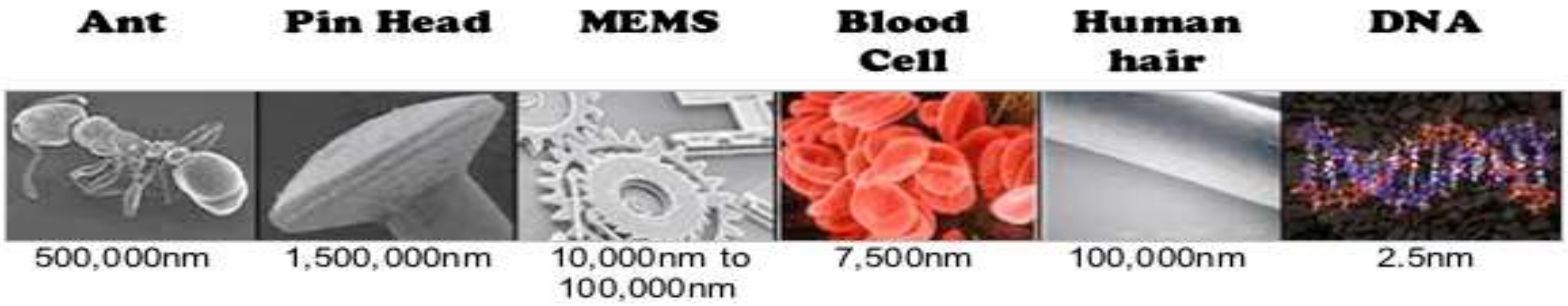
- 0.5 micron is 1/200th the width of a human hair

1997 mainstream process

- 55 nm is 1/2000th the width of a human hair

2014 mainstream process

What is a Nanometer Between Friends?



Source: nano.gov/nanotech-101/what/nano-size & http://www.nanosciencekits.org/

Semiconductor Terms and Acronyms: Review

FET

Micron

(N,P,C)MOS

Transistor

Digital

Analog

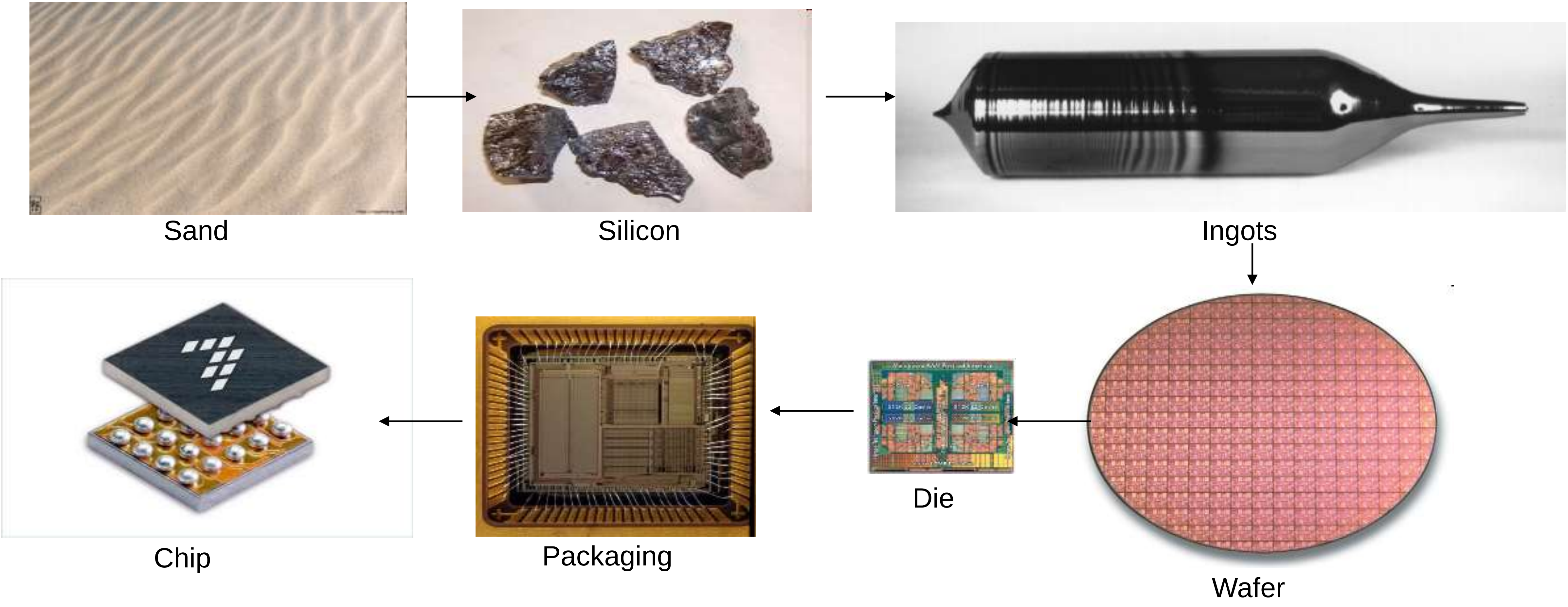
Semiconductor

Silicon

Microcontroller

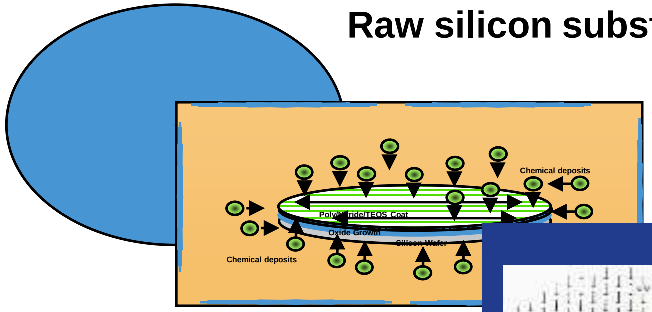
INTEGRATED CIRCUIT MANUFACTURING PROCESS

Semiconductor Manufacturing Overview



Semiconductor Overview: Fundamental Processes

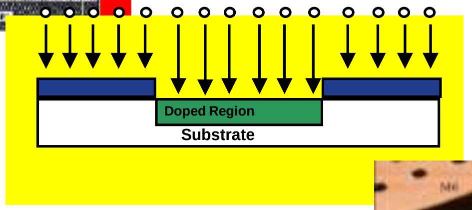
Raw silicon substrate



Diffusion grows or deposits a layer of oxide, nitride, poly or similar material.

Photo spins on photoresist, aligns reticle and exposes wafer with reticle pattern. Develop removes resist from exposed areas.

Etch removes film layer that was uncovered during develop. Strips resist.

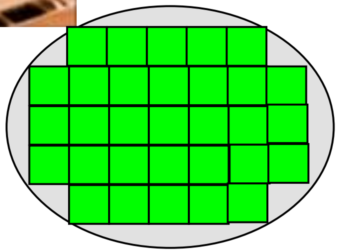


Implant dopants are implanted for electrical characteristics.

IC manufacturing uses a recursive deposition and masking process to define patterns of doped areas, isolation films and metal conductors to create solid state devices.

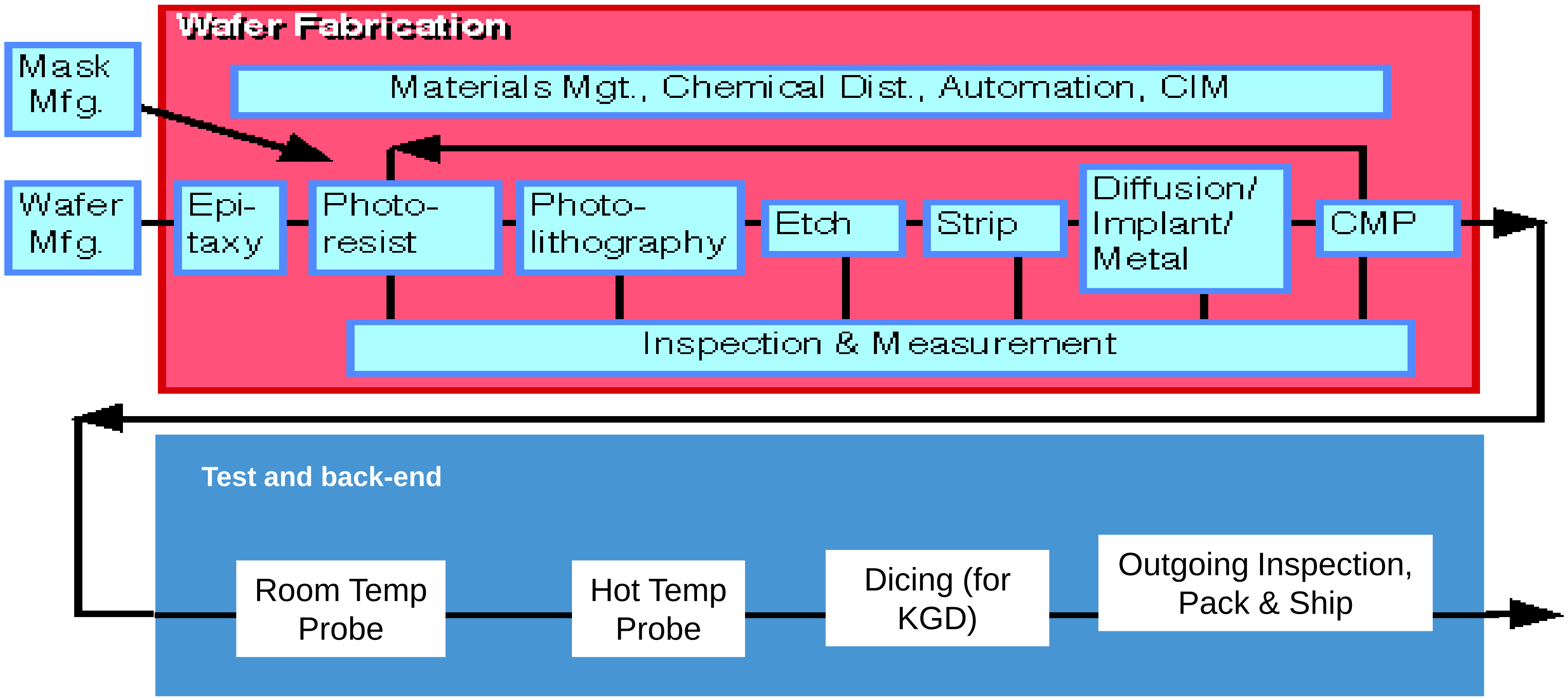
Metals/Films connects devices electrically and isolates circuit pathways.

CMP polishing technique to keep surfaces flat so more layers can be added



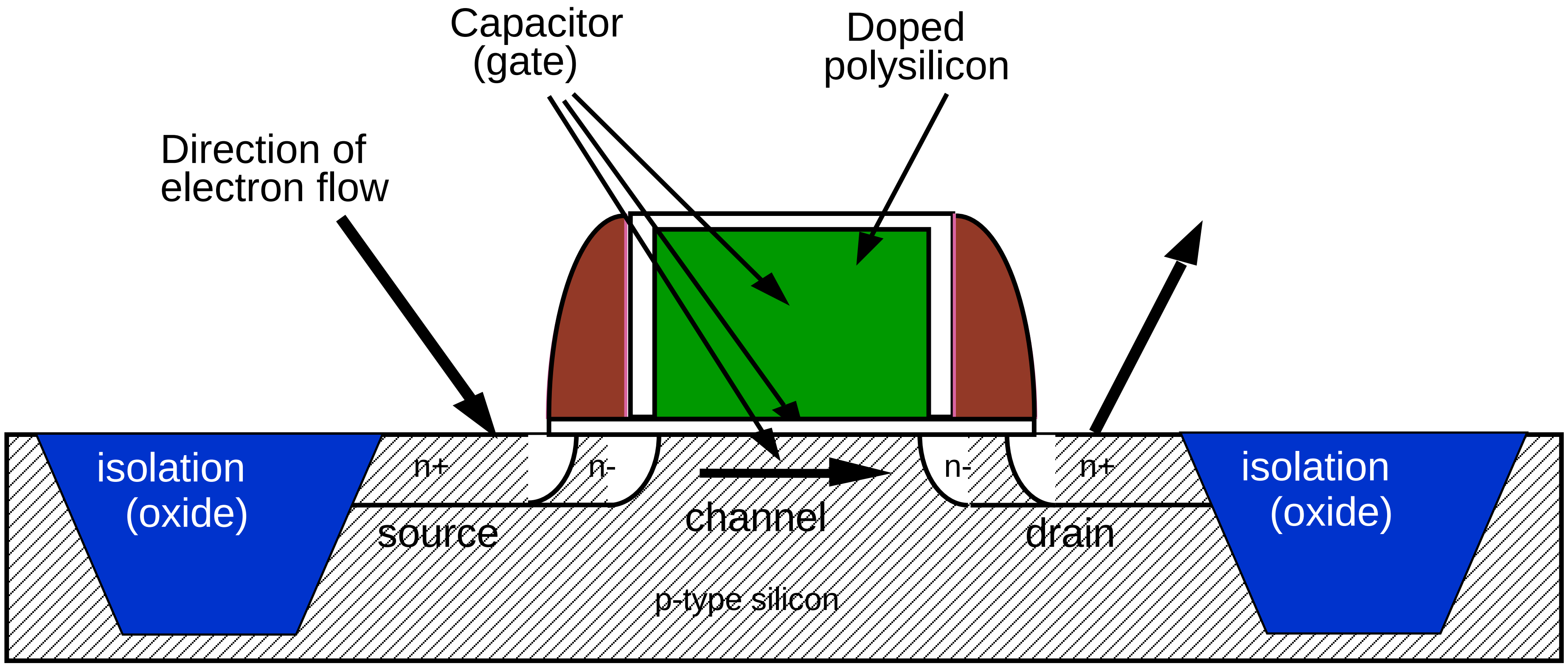
Probe/Test test device functions

Semiconductor Front-End Manufacturing Process



Anatomy of a MOSFET: Cross-Section

A MOSFET is the basis for all CMOS digital logic



Cross-Section View

Preparing Silicon for Use in Integrated Circuits

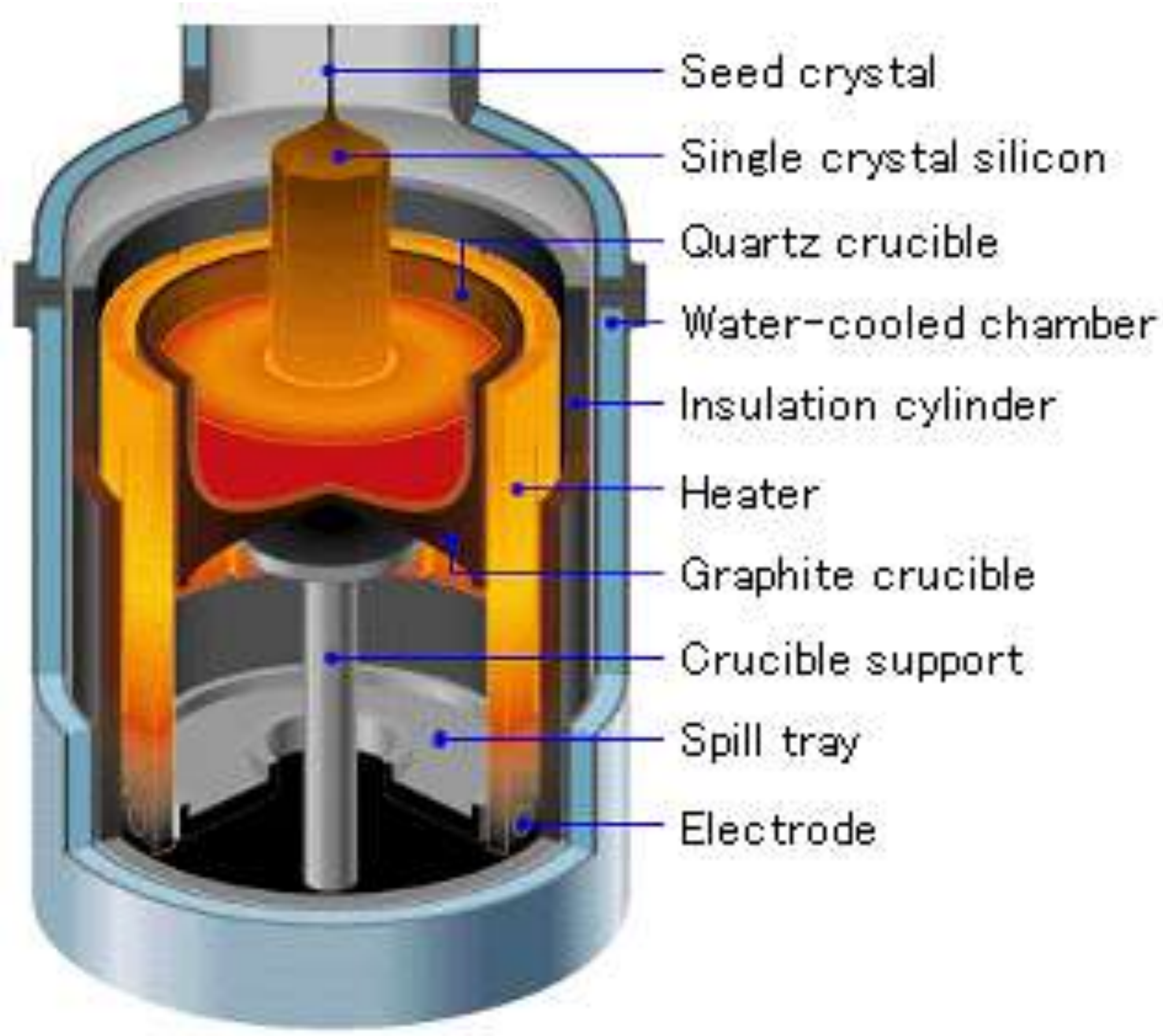
- Silicon is the second most abundant element on earth after oxygen (25% of crust)

Purification operations

Si O2 + C	→	Si + CO2	1900C Furnace gives metallurgical grade Si
Si + 3HCl	→	Si HCL3 + H2	Refining to reduce impurities
Si HCL3 + H2	→	Si + 3HCl	

The white sand of Abel Tasman's beaches in New Zealand's South Island is a typical source of silicon dioxide.

Making an Ingot



- A pure silicon seed crystal is placed into a molten sand bath.
- This crystal will be pulled out slowly as it is rotated (1 mm per hour).
- The result is a pure silicon cylinder that is called an *ingot.*

Examples of a Completed Ingot

Single crystal silicon ingot length: 110 cm

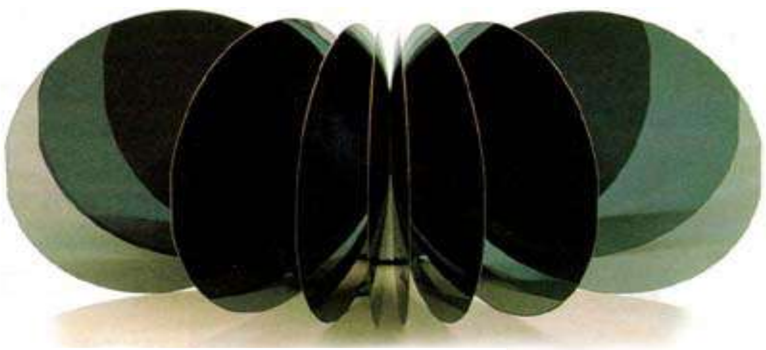
Photo courtesy of Wacker Siltronics

200mm Silicon Ingot

Preparing the Wafers

- The ingot is ground into the correct diameter for the wafers
- Then, it is sliced into very thin wafers
- This is usually done with a diamond saw

Wafer transition from 50mm to 300mm to 450mm



Slicing : 640µ thick

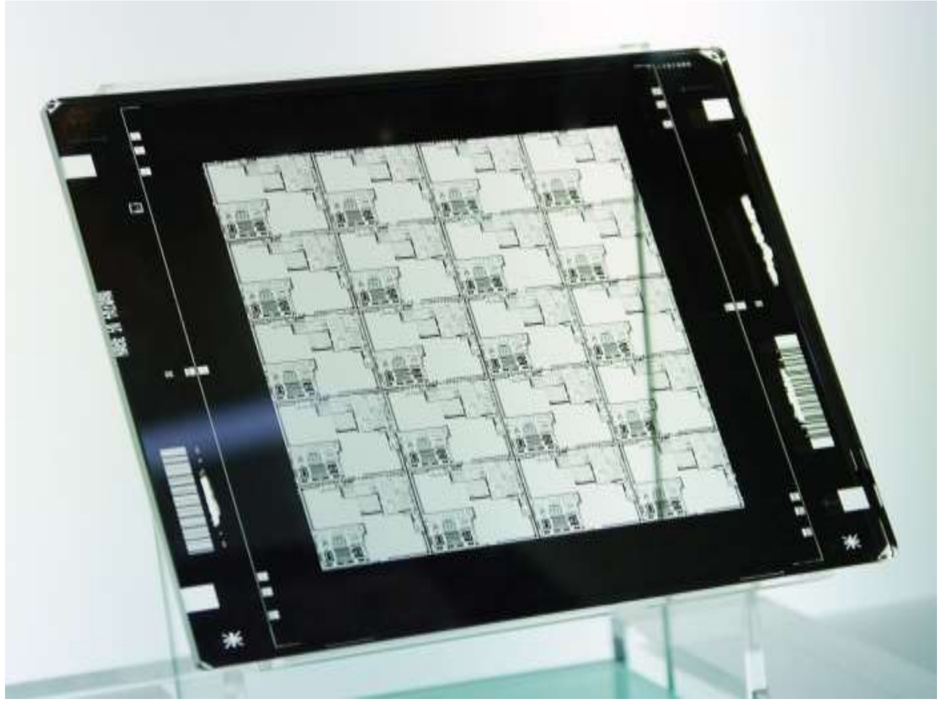
Mask-Making Process

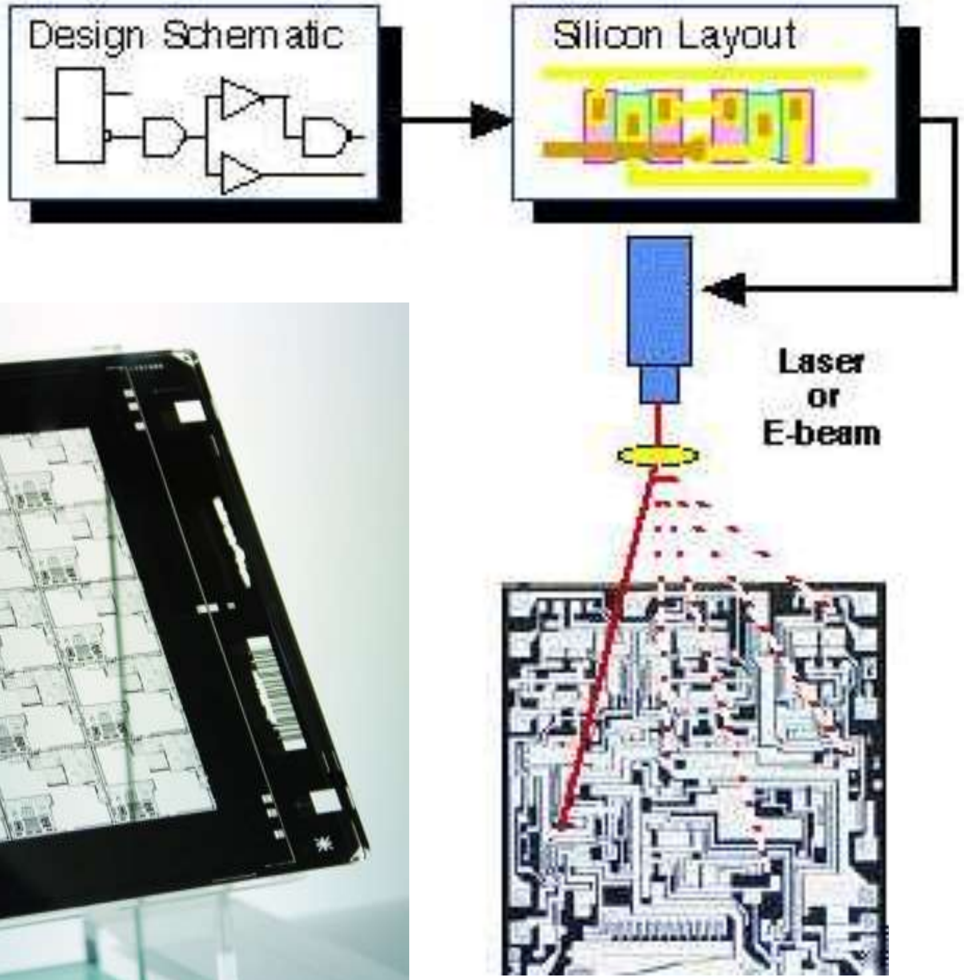
The Process

- Start with ultra-pure glass plates with a surface deposition of chromium.
- Computer generated layouts of the IC drive a laser beam or electron beam to selectively remove chromium and create the mask or reticle.

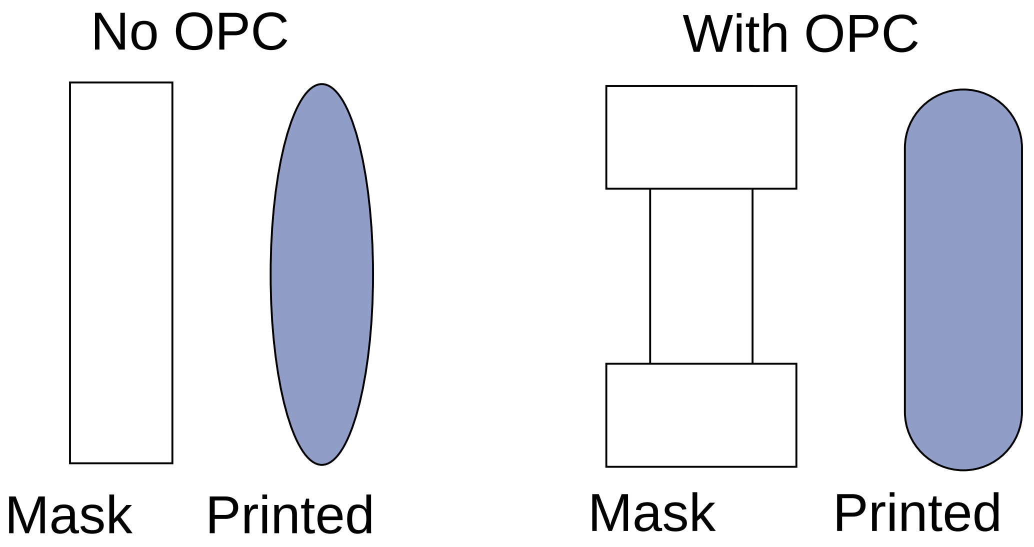
Design Driven

- Increased complexity
- Long write times



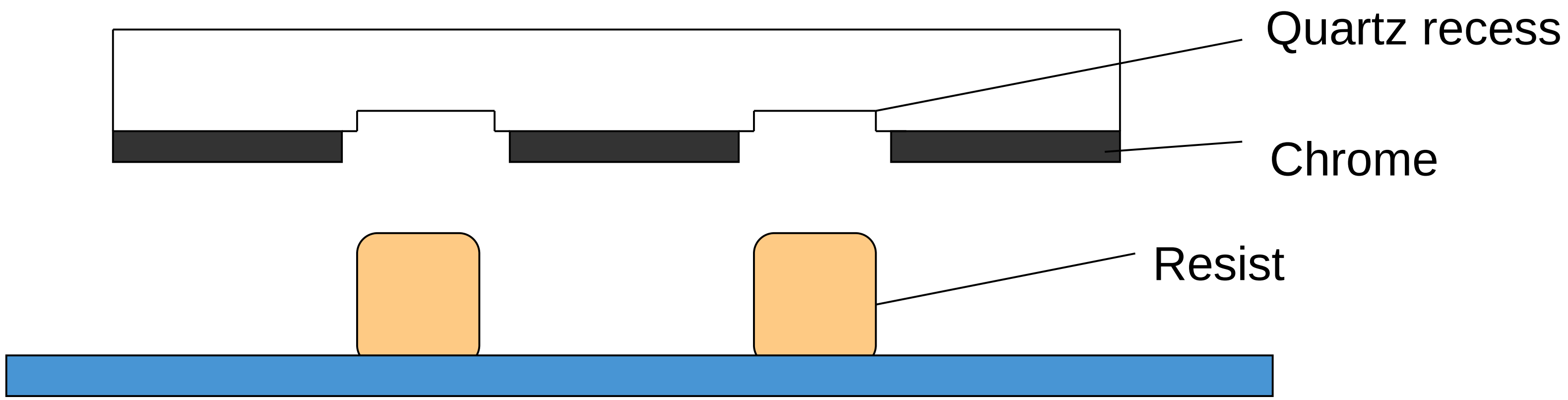


Small Geometries: Stretching the Wavelength

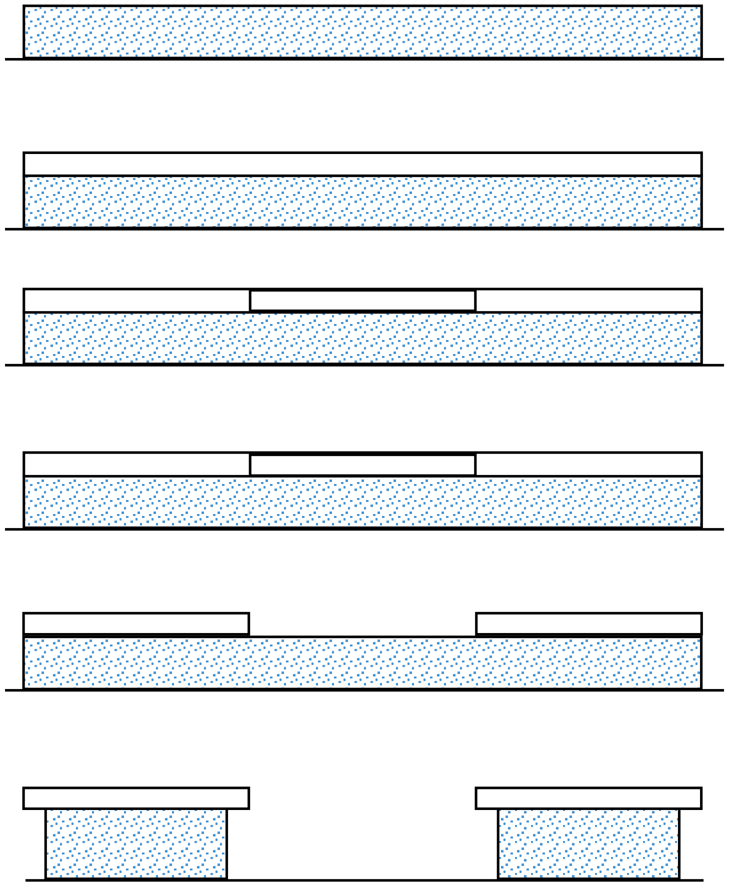


Optical Proximity Correction (OPC)

Phase Shift Mask



Lithography Process Overview



Substrate with Thin Film

Resist Coat and Post Apply Bake (PAB)

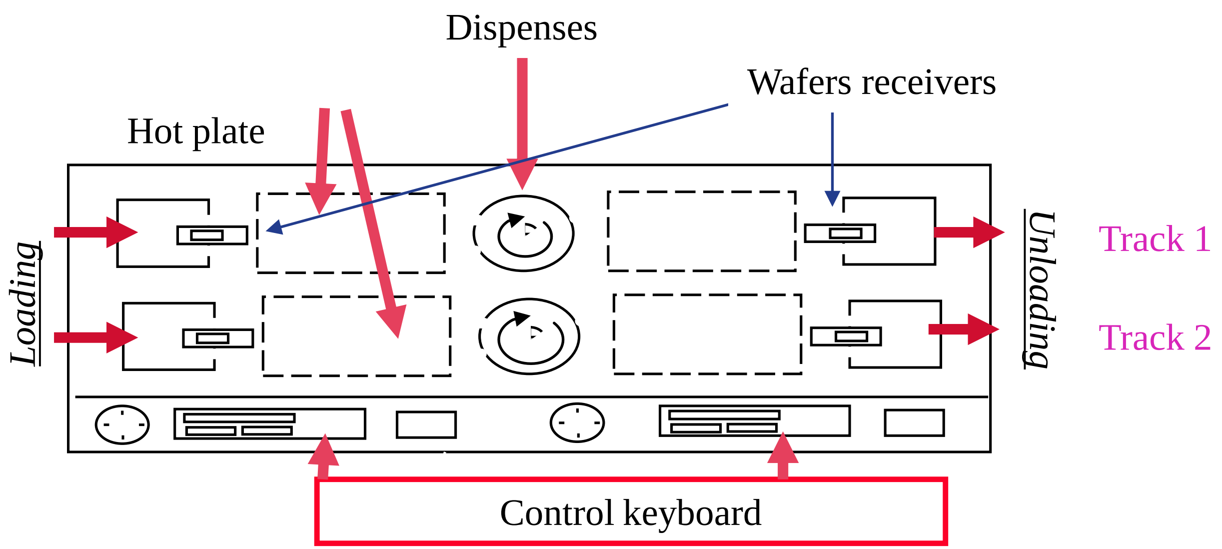
Expose Resist

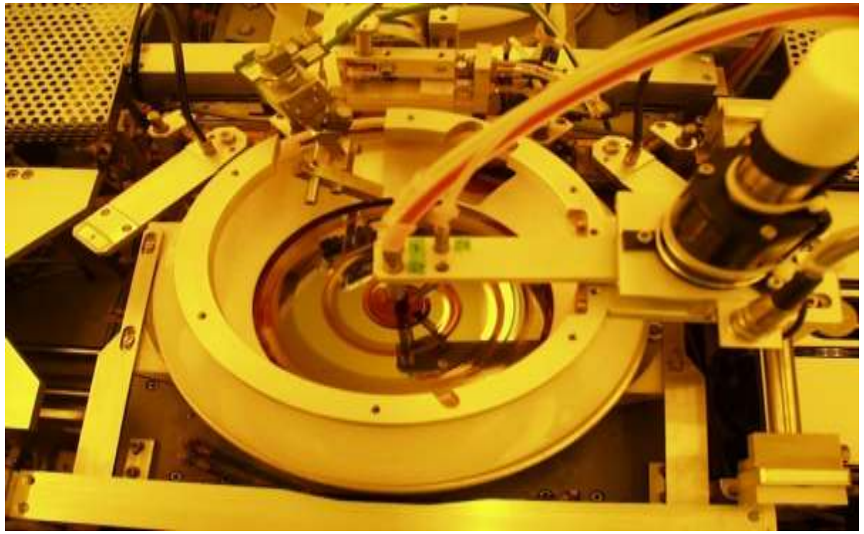
Post Exposure Bake (PEB)

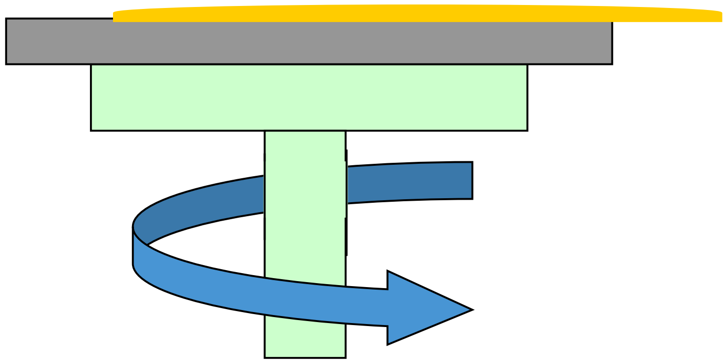
Develop Resist

Etch

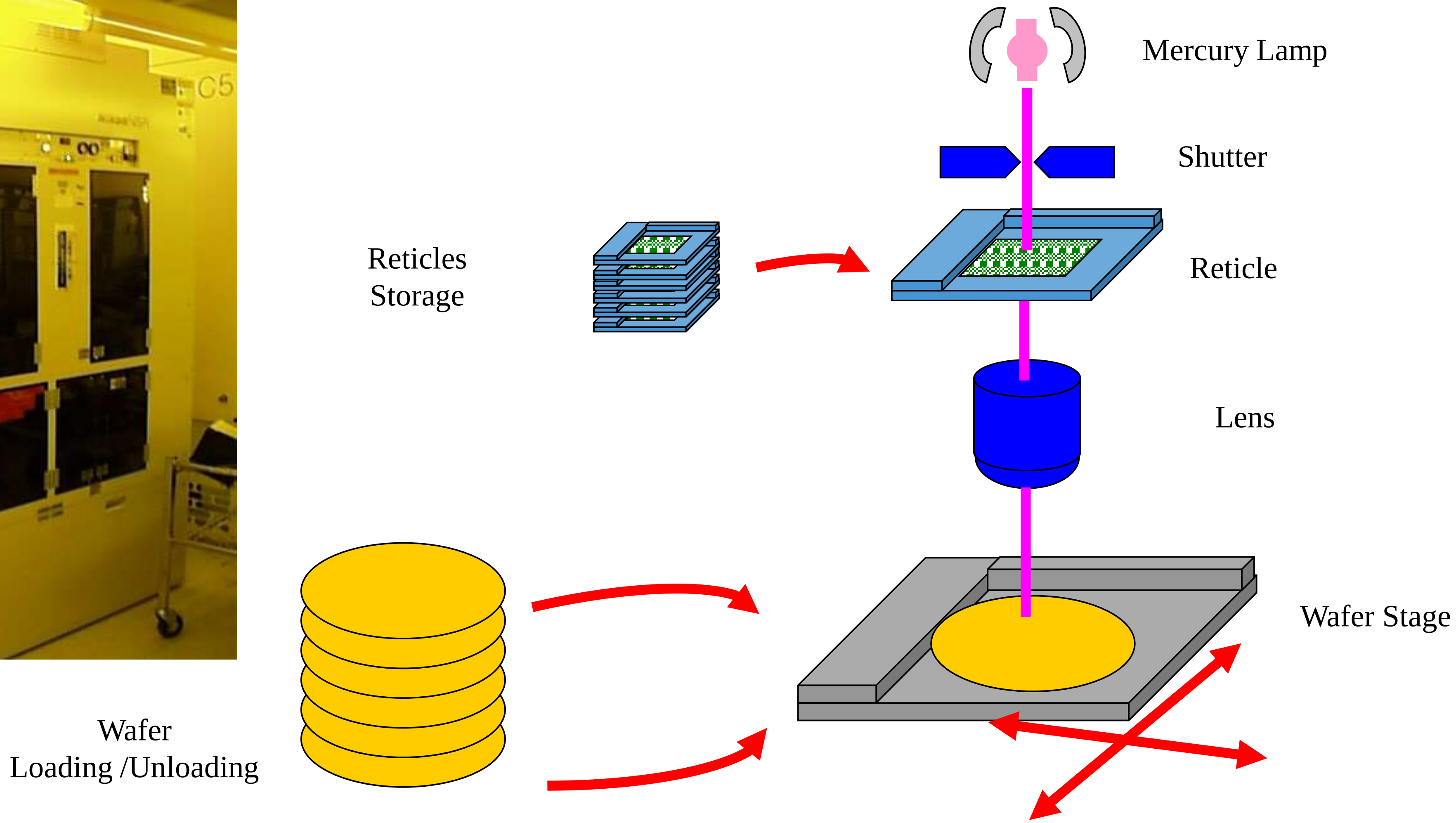
Adding Photoresist



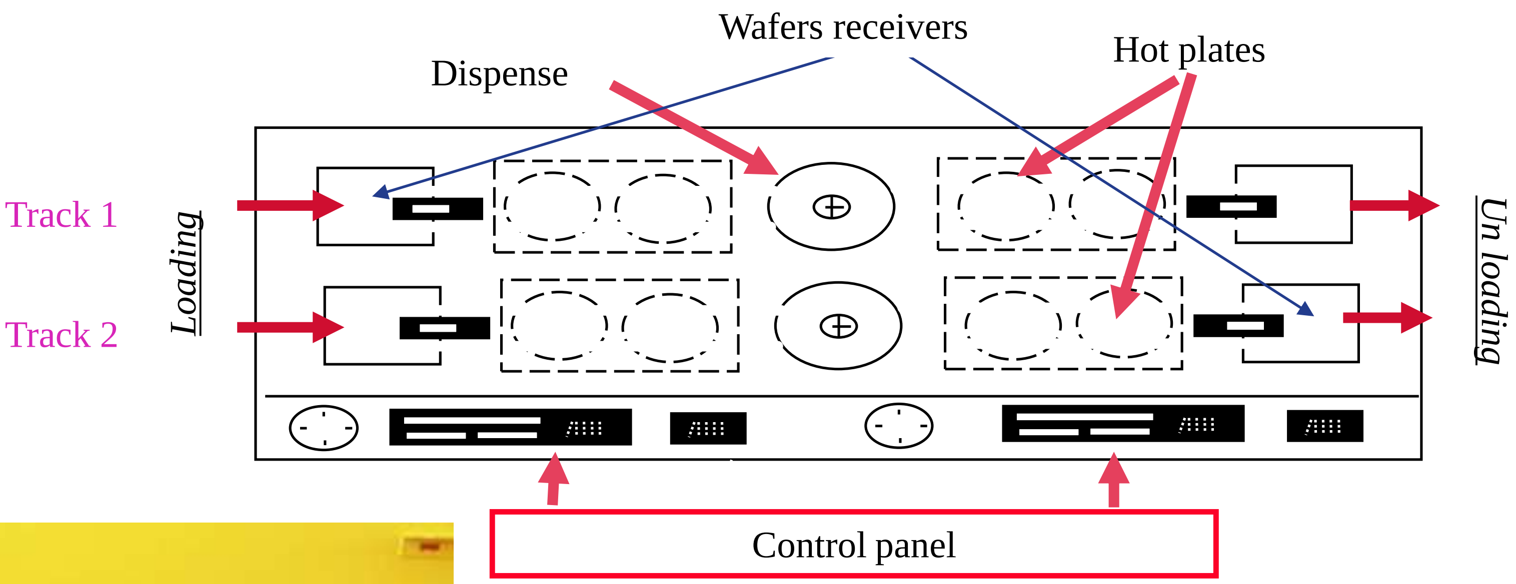




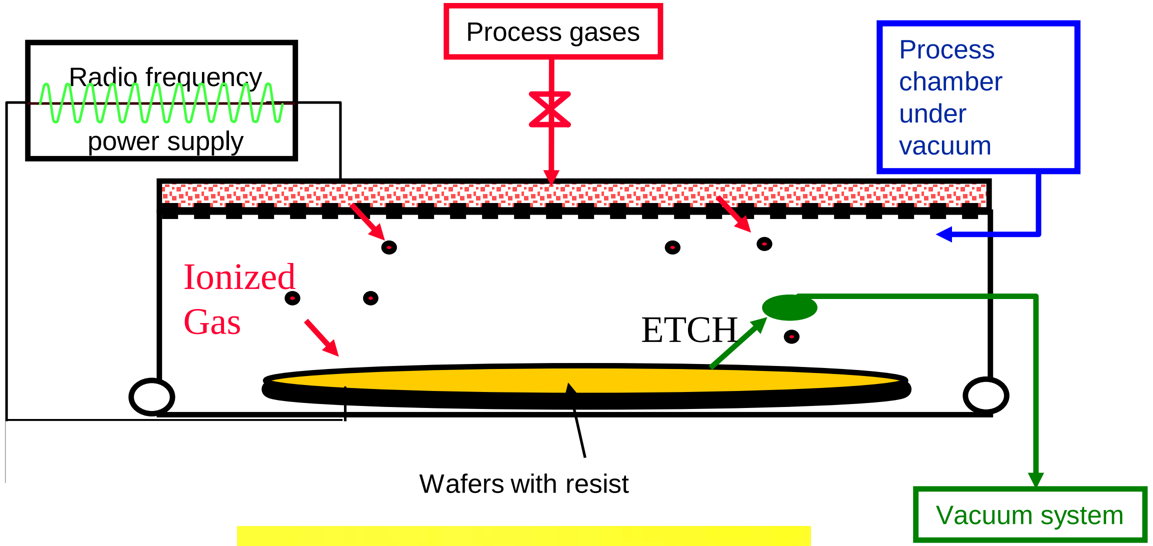
Exposure

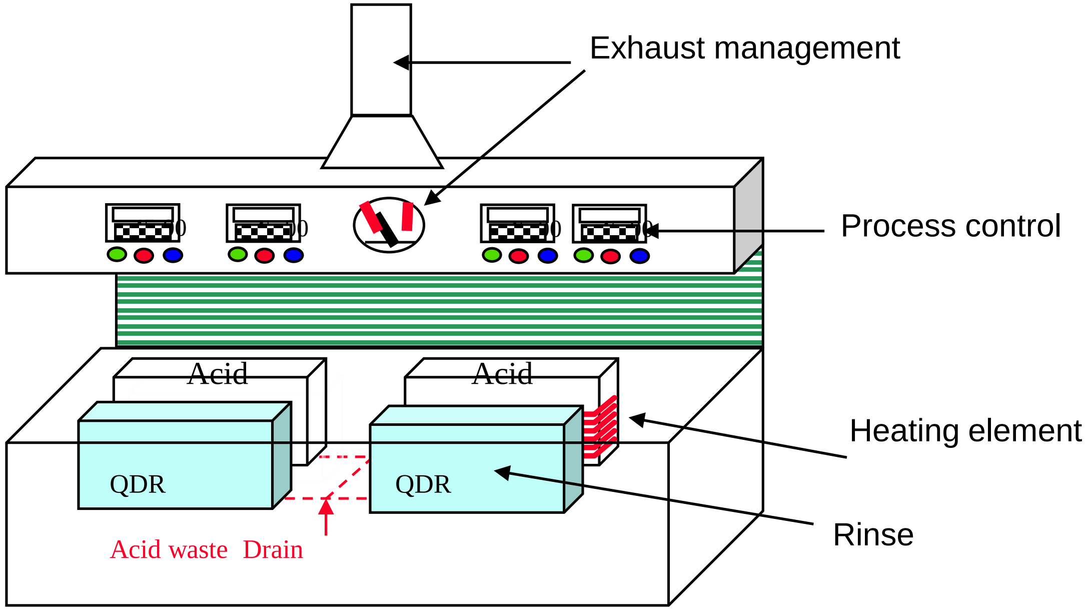

Mercury Lamp
Shutter
Reticles
Storage
Reticle
Lens
Wafer Stage
Wafer
Loading /Unloading

Develop


Wafers receivers
Hot plates
Dispense
Track 1
Track 2
Loading
Un loading
Control panel

Etching (Chemical and Reactive Ion)

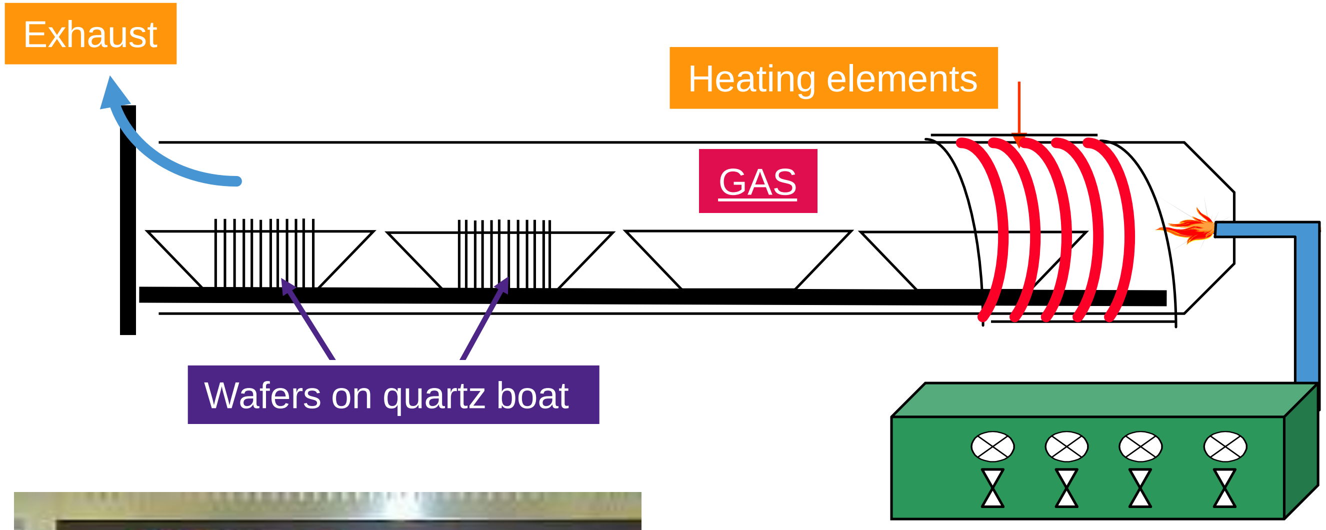




Diffusion Furnace

- Diffusion furnaces are classified as either *horizontal* or *vertical.*
- Vertical gives better process control and tends to be cleaner but takes up more space.
- Changing the process gases allow us to grow films (oxide, nitride, poly) or dope the wafers to change the electrical characteristics.
- They operate at temperatures generally between 650°C and 1200°C.
- Temperatures in furnaces are controlled to better than +/- 1°C.
- Furnaces can process 50-200 wafers per run depending on type of process.
- Process times can vary from 4-20 hours (thicker films take longer to grow/deposit).

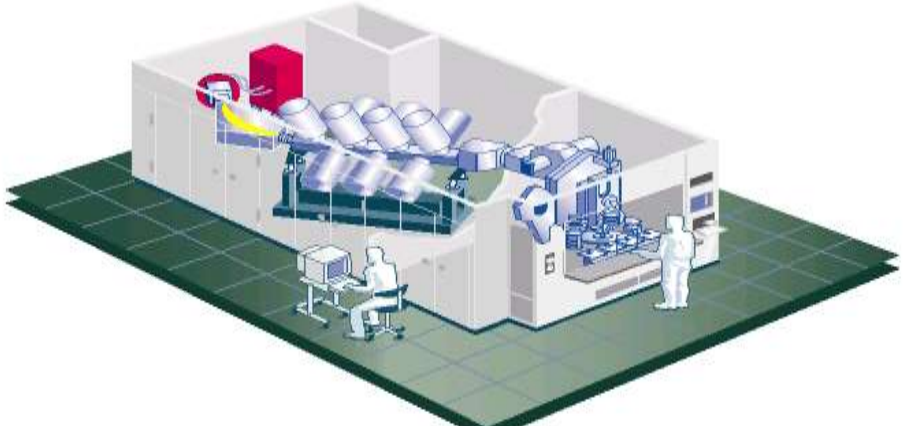
Atmospheric Pressure Furnace

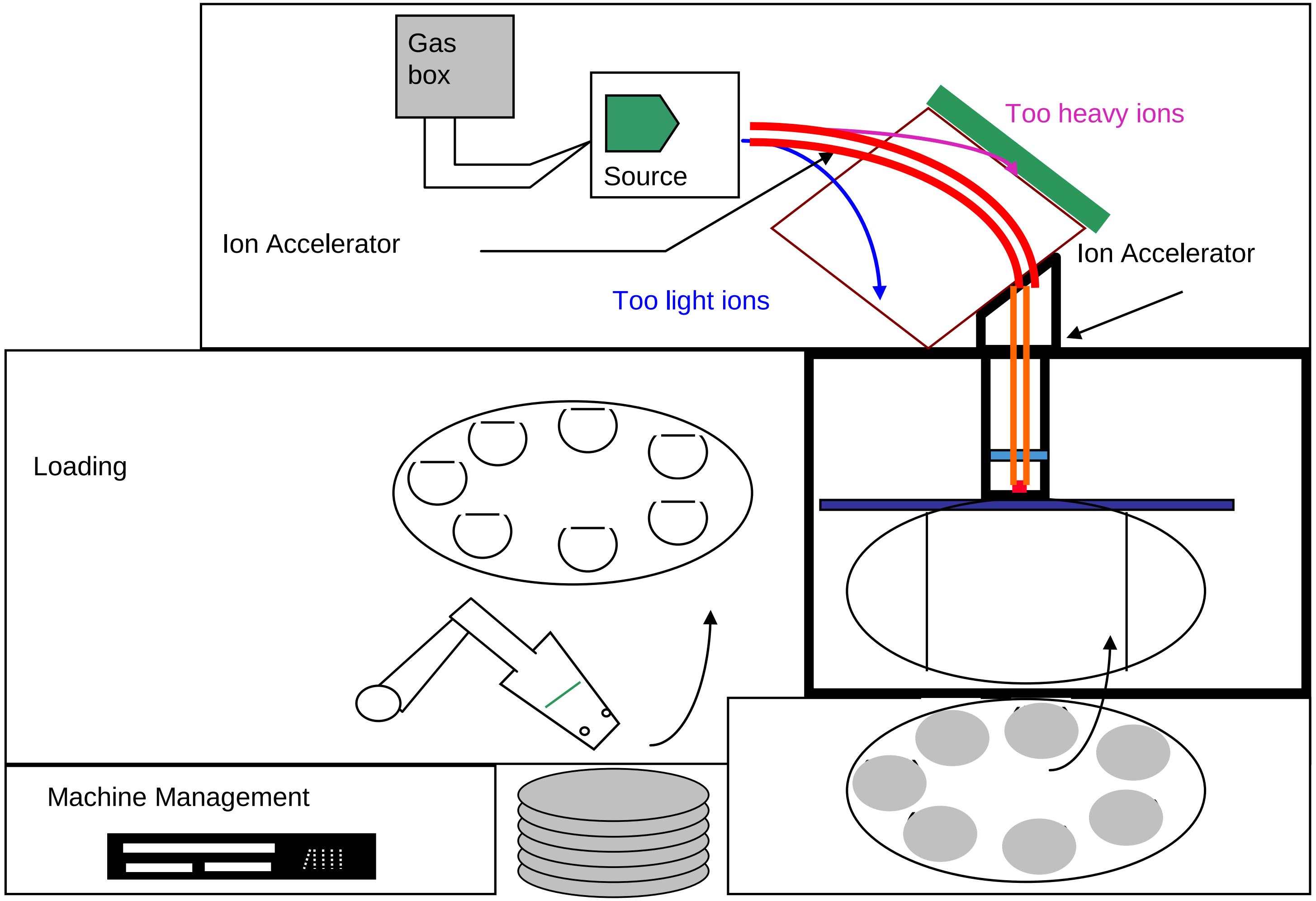


Gases Management

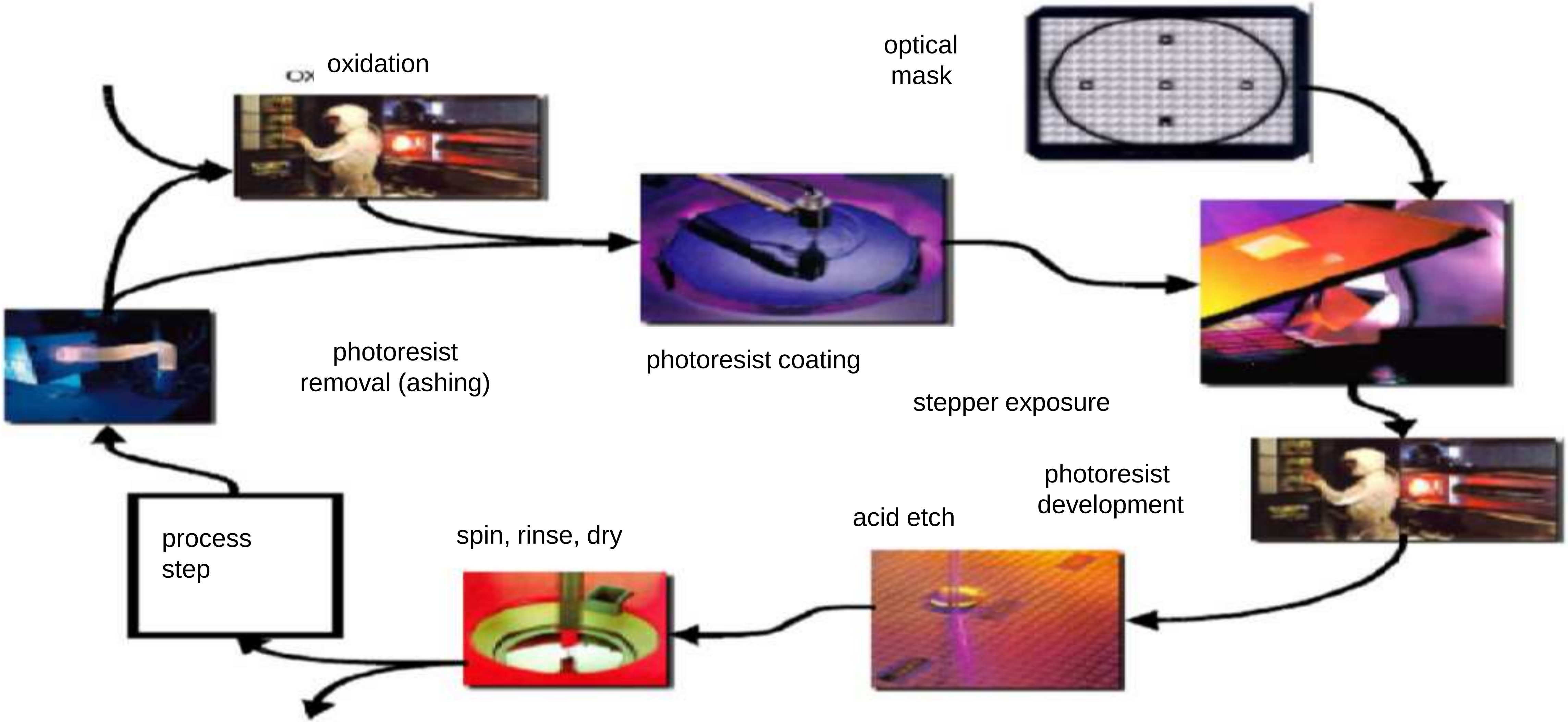
Vertical Furnace

Ion Implantation and Annealing

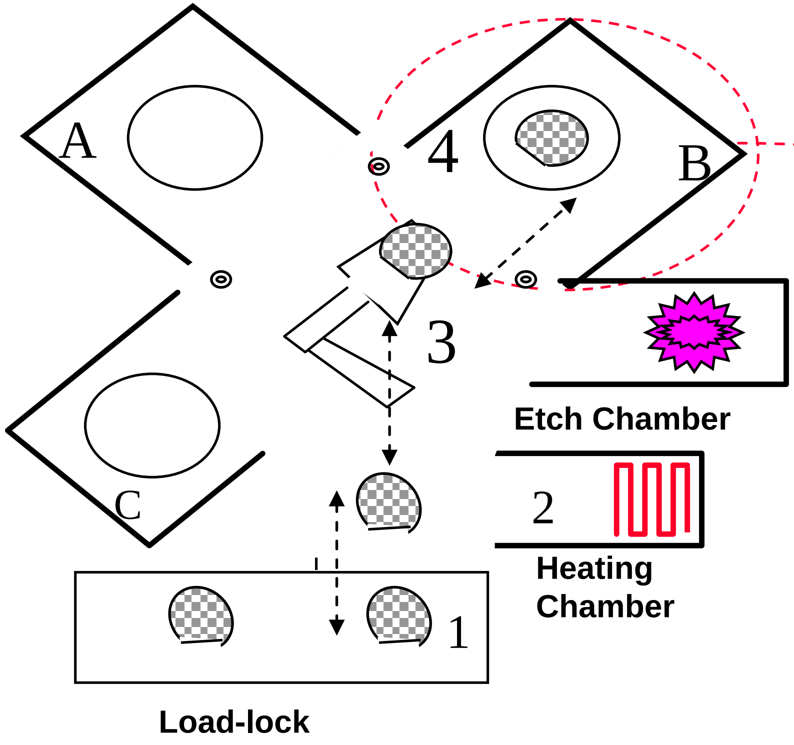

GSD/HE three dimensional view

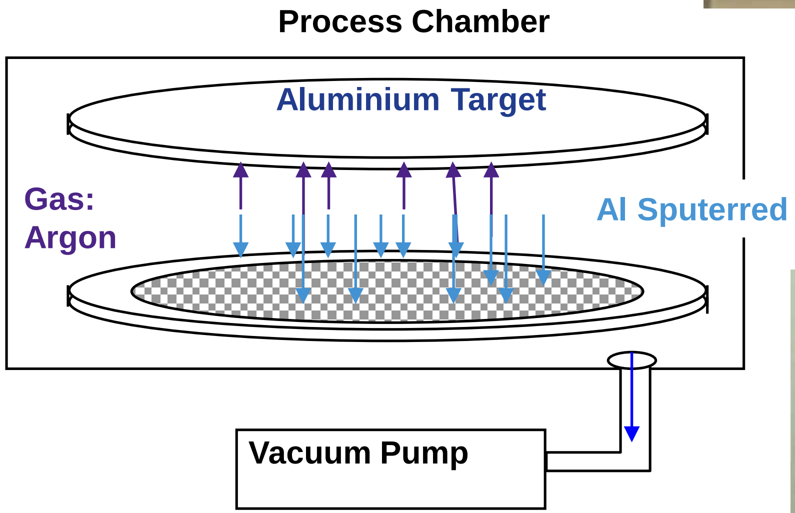


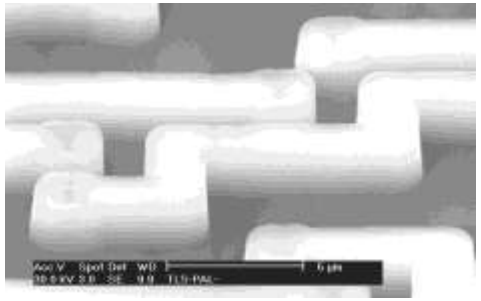
Typical Photo-Lithography Process



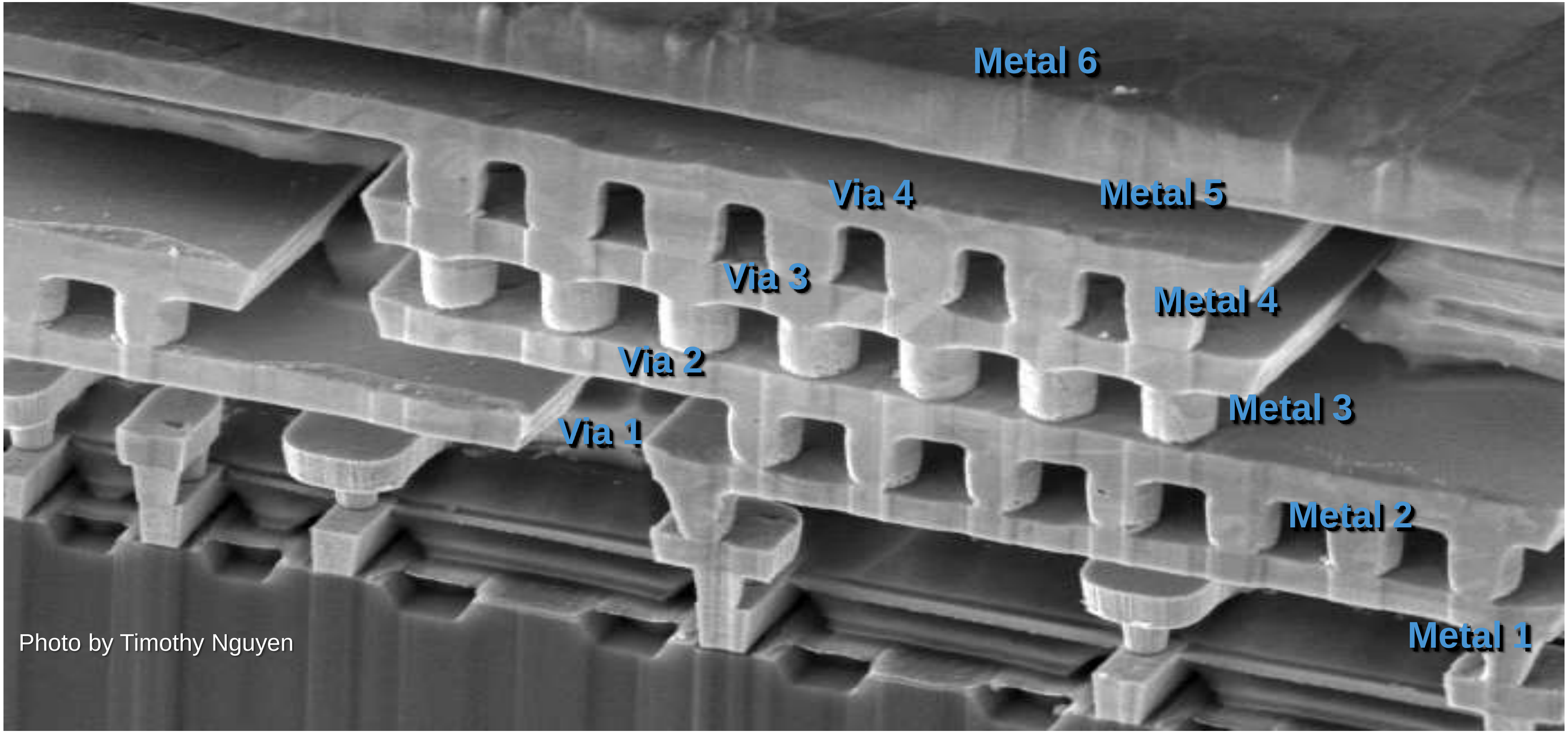
Metal Deposition



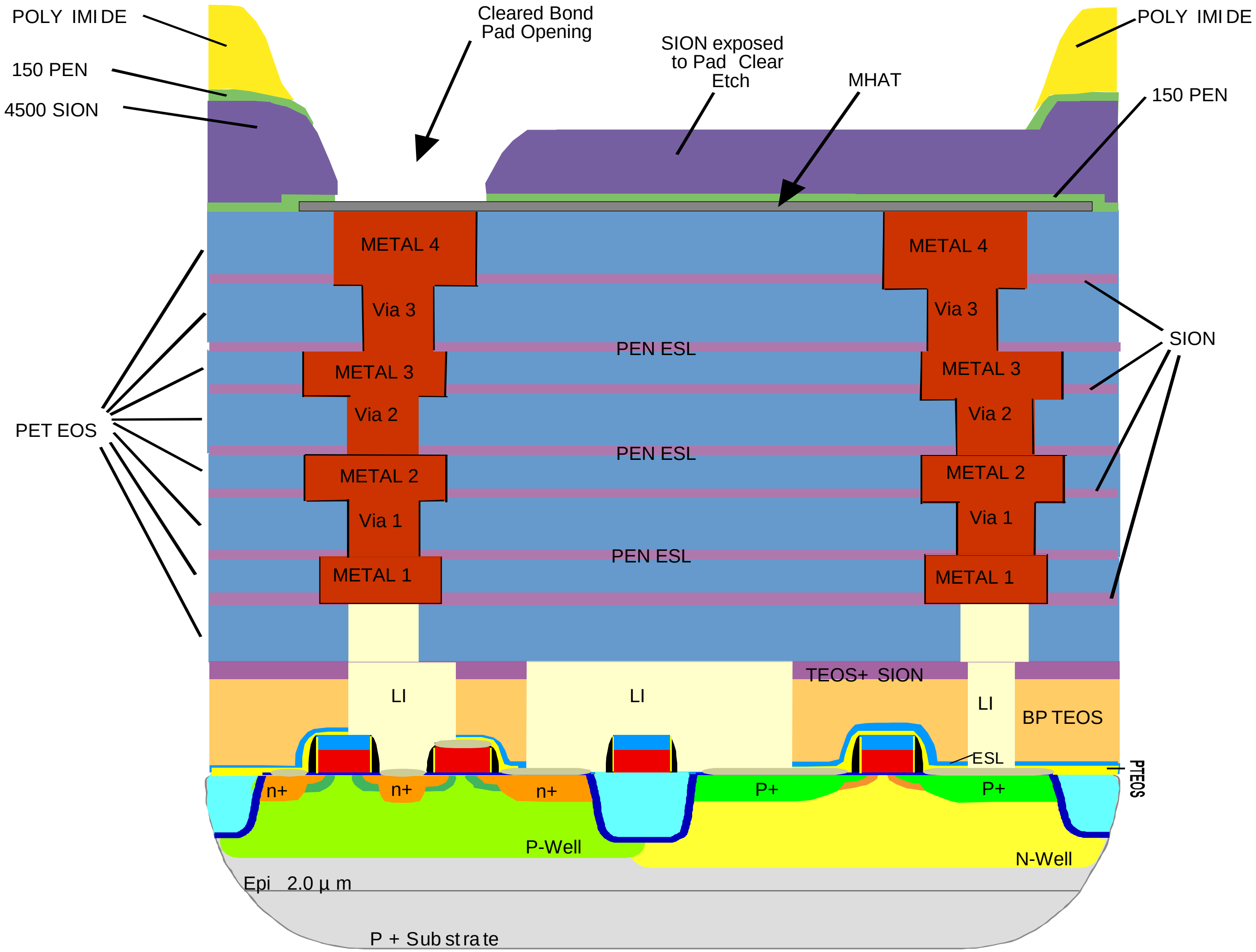




Copper Metallization



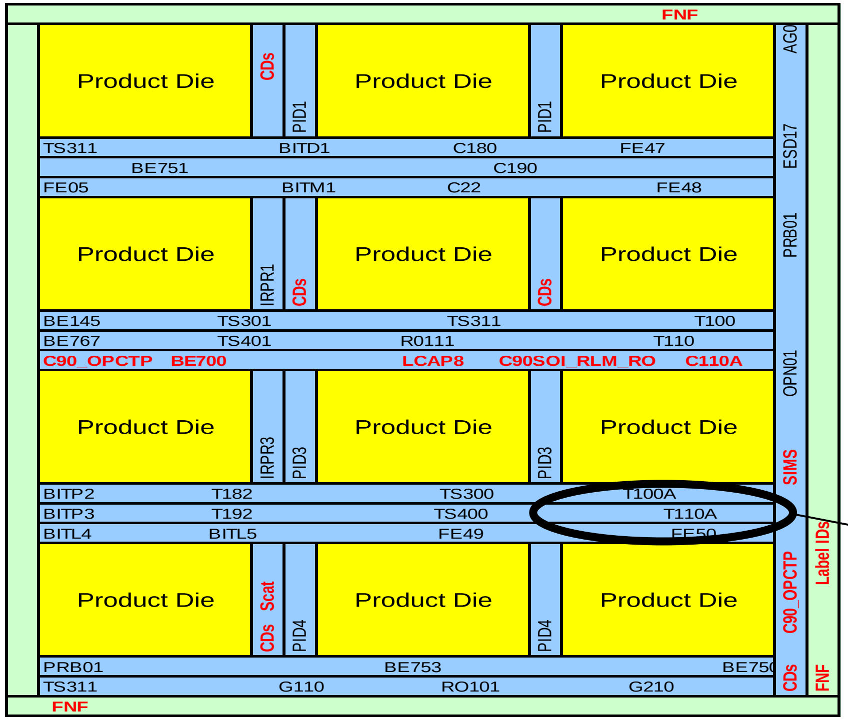
Typical Processor Cross-Section

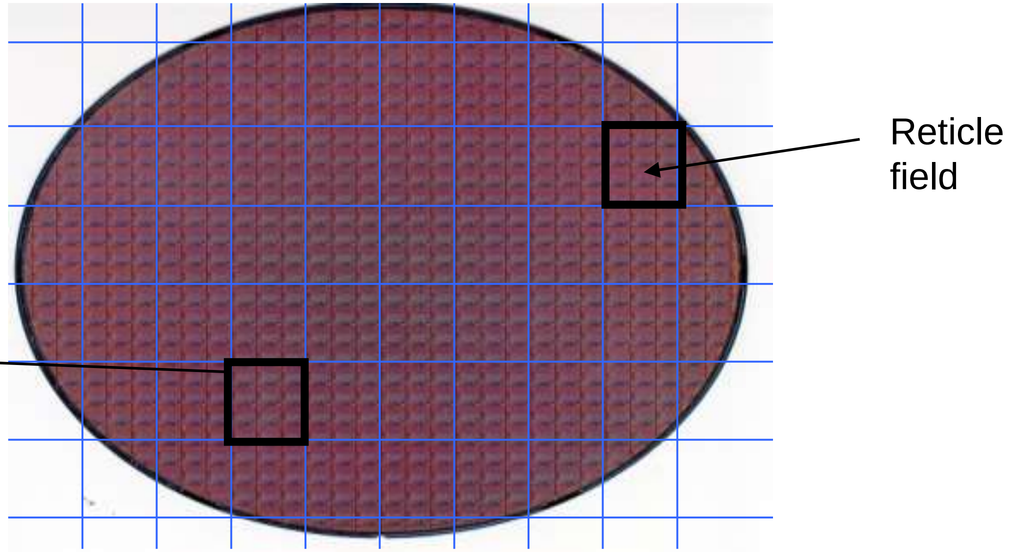


This process requires more than 190 stages. Each stage contains multiple sub-steps.

Class Probe

- Parametric testing of test structures
- Test structures in scribe lines between product die



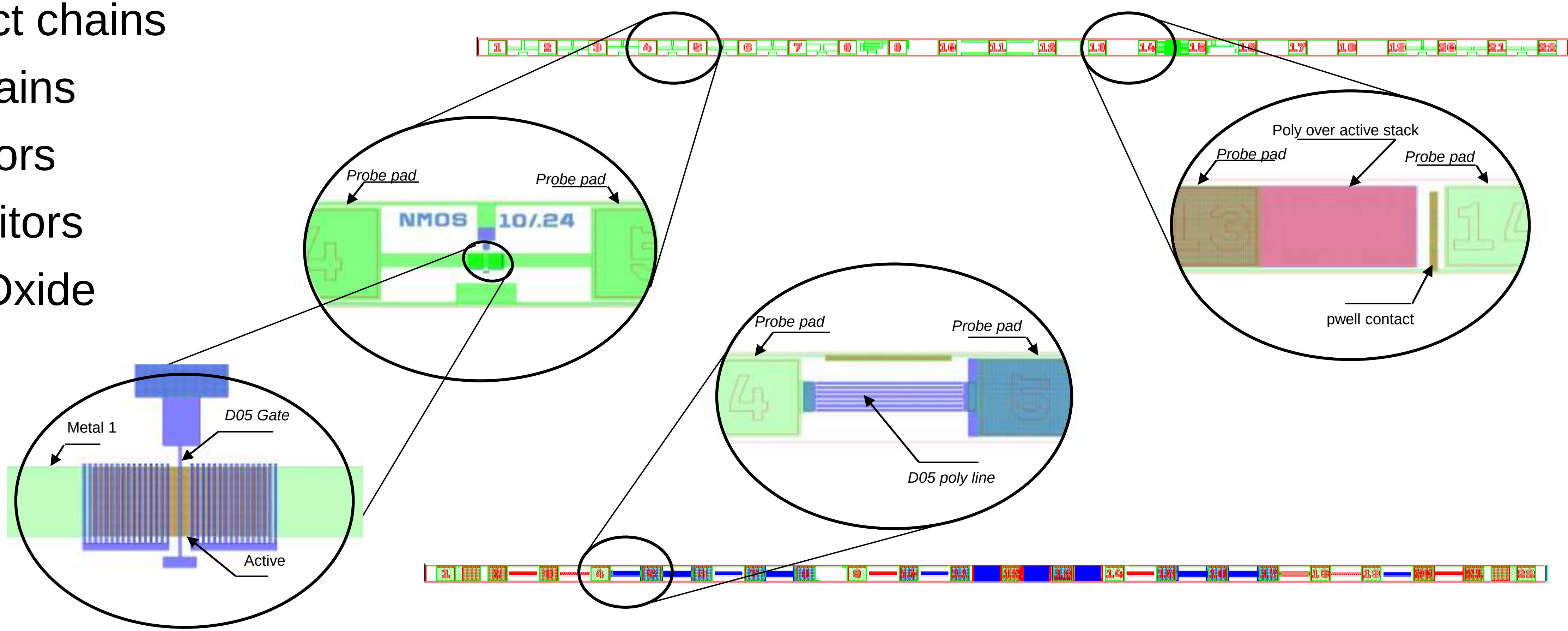


SGPC = scribe grid process control

Not to scale (~0.1mm)

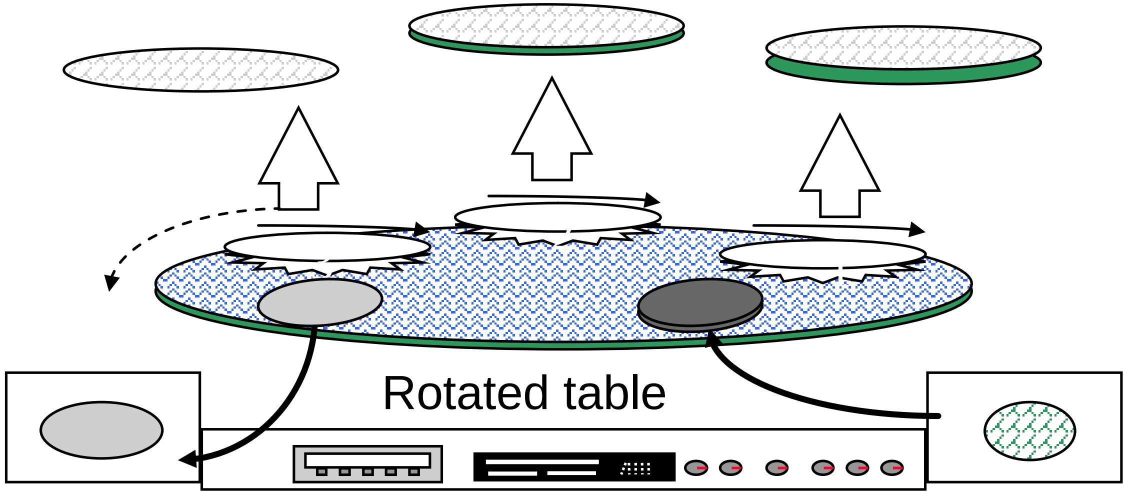
Typical Class Probe Structures

- Transistors
- Metal to metal linkage
- Contact chains
- Via chains
- Resistors
- Capacitors
- Gate Oxide

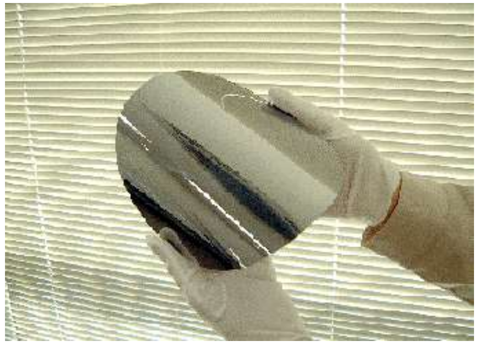


Backgrind

Wafer thickness is reduced from 640 μ

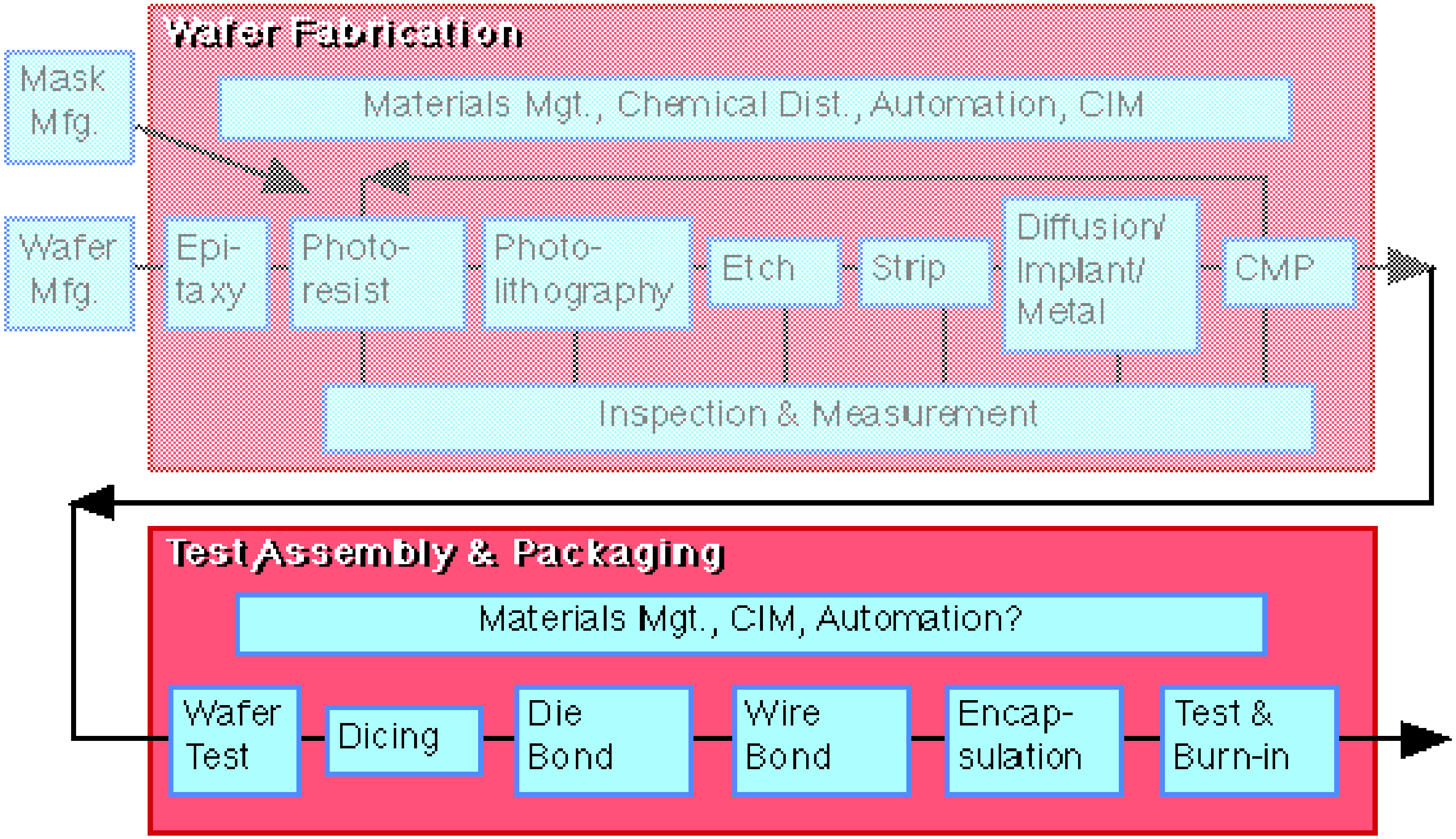


100 um thickness wafers
Can be bent like paper

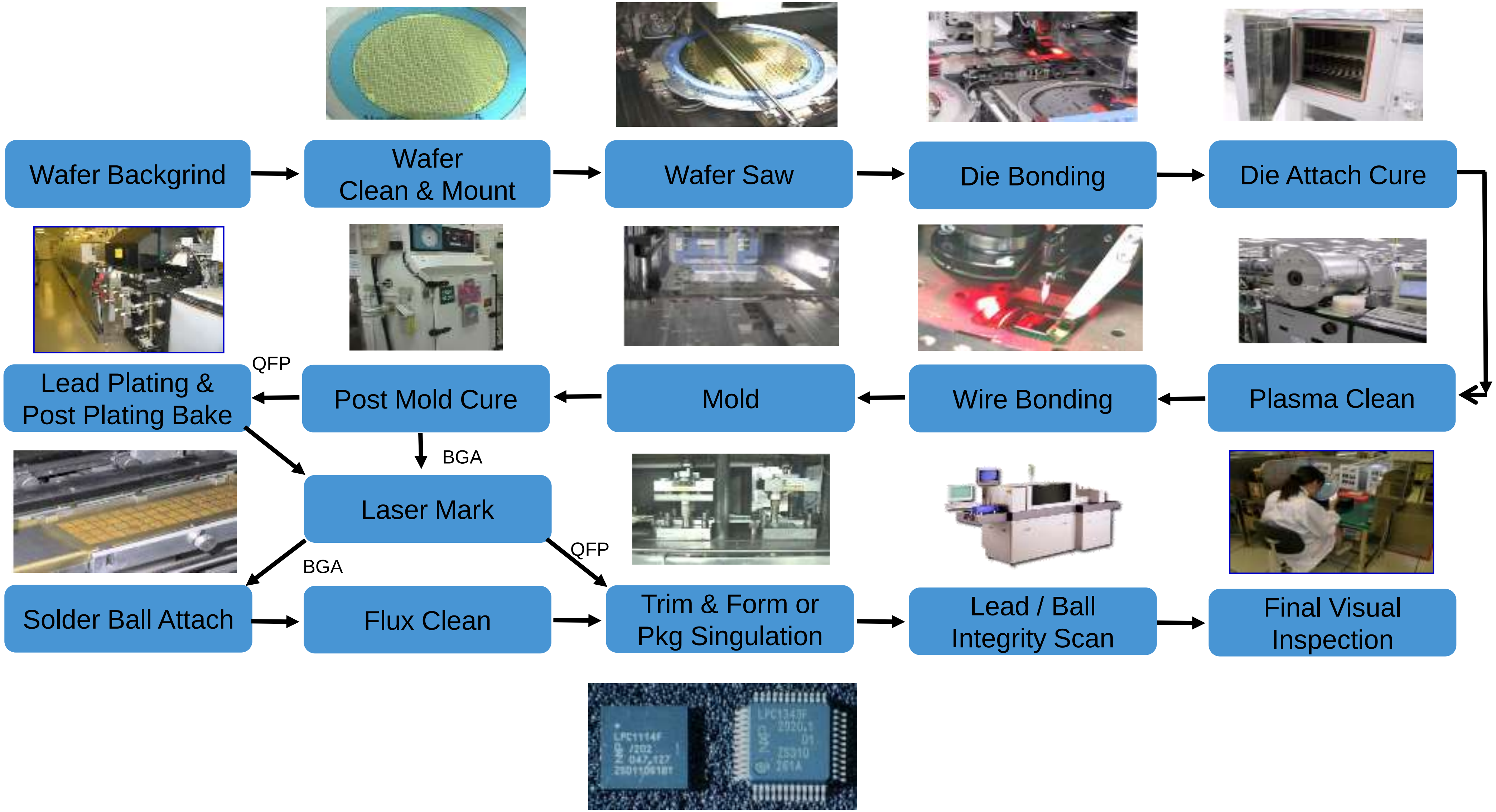


5 um thickness wafer

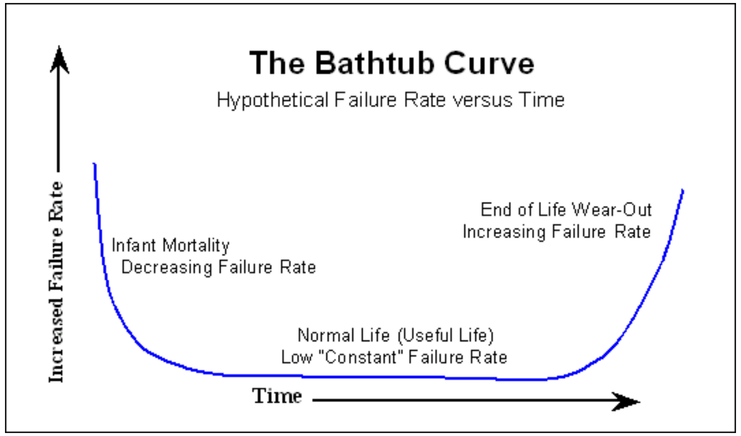
Test and Assembly Process



Assembly Package Process Flow



Burn-In


The Bathtub Curve
Hypothetical Failure Rate versus Time
Increased Failure Rate
Infant Mortality
Decreasing Failure Rate
End of Life Wear-Out
Increasing Failure Rate
Normal Life (Useful Life)
Low "Constant" Failure Rate
Time

Final Test Process Flow

Burn-in
24 hrs, 125º C or Equivalent

↓

Functional Test – Cold

↓

Functional Test – Hot

↓

Functional Test – Room

↓

QC RHC Gate

→

Bake

↓

Lead / Ball Integrity Scan

↓

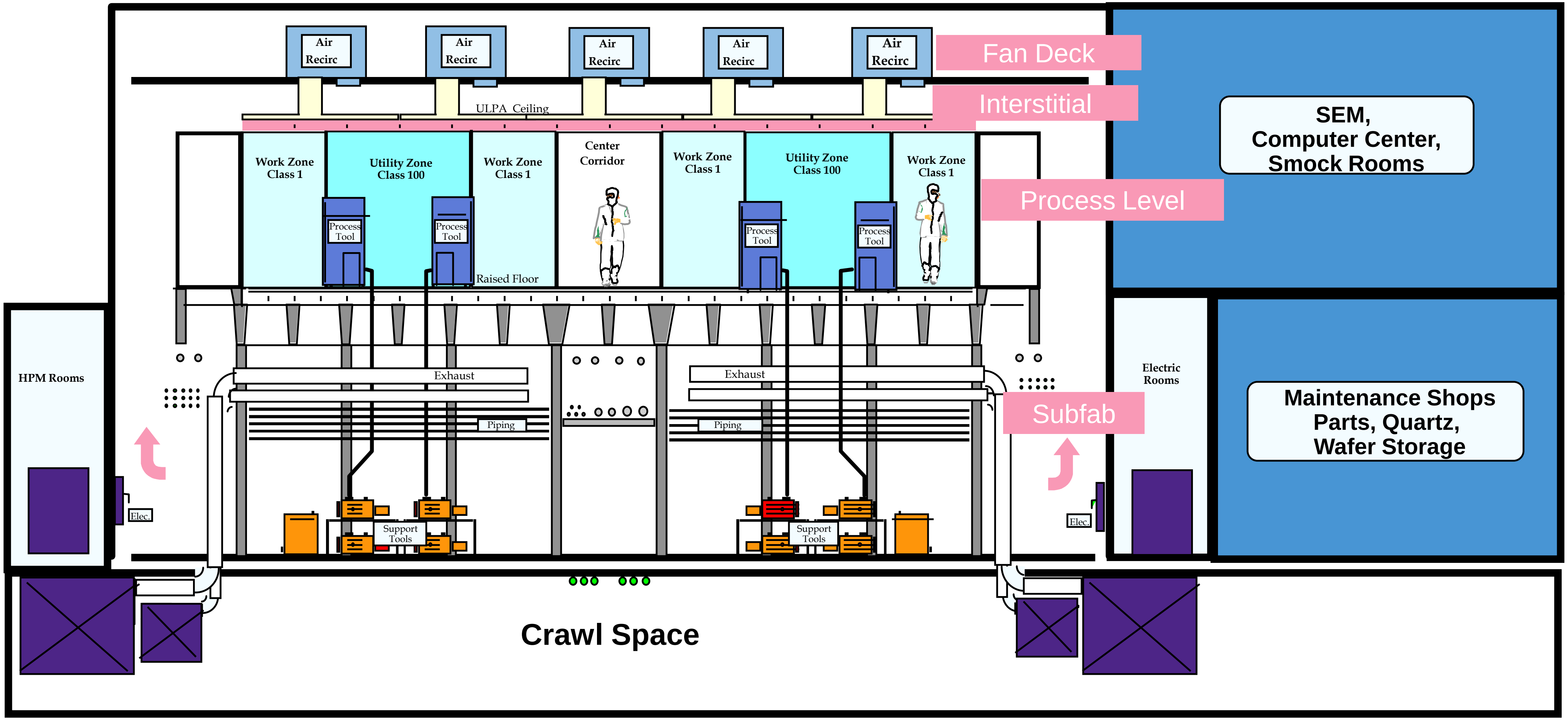
Tape & Reel (optional)

↓

Dry Pack & Ship

TOOLING, EQUIPMENT, AND INVESTMENT NEEDS FOR IC DESIGN AND MANUFACTURE

NXP ATMC Factory Configuration



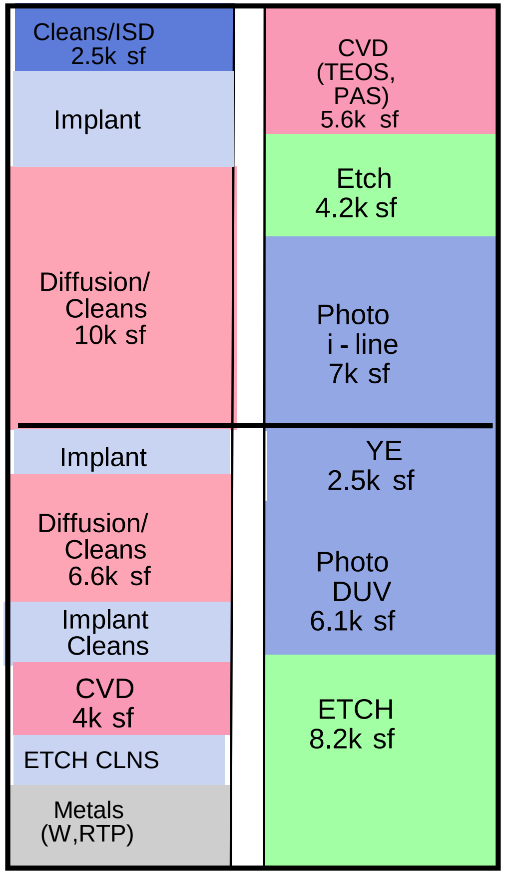
ATMC Cleanroom Airflow Filtration

- First stage makeup air pre-filters are 30% efficient for 3-10 um sized particles
- Second stage makeup air pre-filters (inside makeup air units) are 95% efficient for 0.3-1 µm sized particles
- Final stage filters (cleanroom ceiling grid) are Ultra Low Penetrating Air (ULPA) filters that are 99.9995% efficient for 0.1 um sized particles
- 100% cleanroom ceiling ULPA filter coverage in work zone (40% coverage in utility zone)
- Average laminar airflow velocity is 90-110 ft/min
- Cleanroom Airborne Particle Monitoring
  - Portable laser sensors are used to measure airborne particles at 561 locations throughout the cleanroom
  - Cleanroom Classification criteria specifies a maximum of 35 particles/ft3 (0.1 um) to achieve Class 1 designation – ATMC averages < 1 particle/ft3

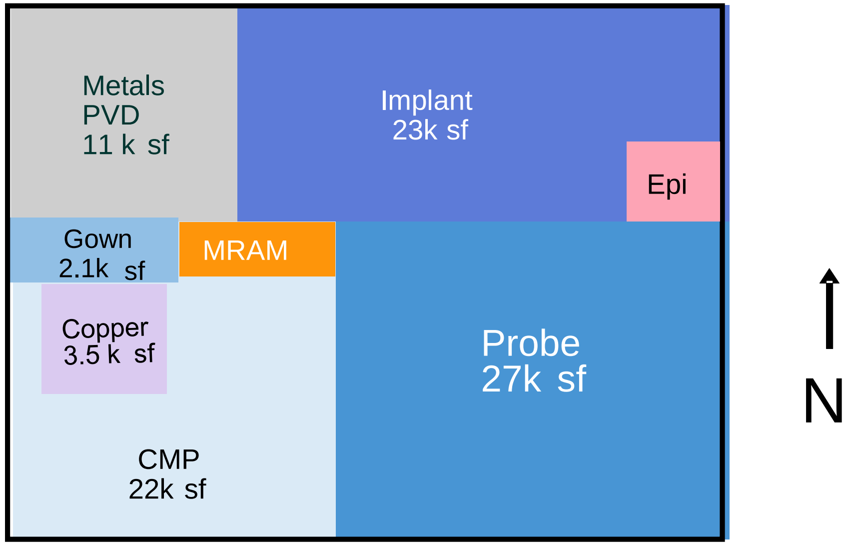
NXP Chandler Fab Macro Layout

“C” Bldg

North & South



East Module (Bldg “M”)



“A” Building to the East of “M” Building has additional 8k sqft of Probe

Oak Hill Texas Fab Facts

- 85,000+ square feet of sub-class 1 clean room space supporting wafer capacity of 6,000 WPW
- Factory operates 24 hours per day, 364 days per year
- Factory moves ~6,400,000 CFM, enough to fill 120 hot air balloons every minute
- 9,300 tons of refrigeration capacity, sufficient to cool 2,800 homes
- Factory uses 44,000,000 gallons of water/month, equivalent to 4,400 homes
- Factory uses ~215,000,000 KWH per year, equivalent to 6,000 homes
- Factory has more than 17 miles of stainless steel piping and more than 50 miles of electrical wiring

Typical Equipment Costs

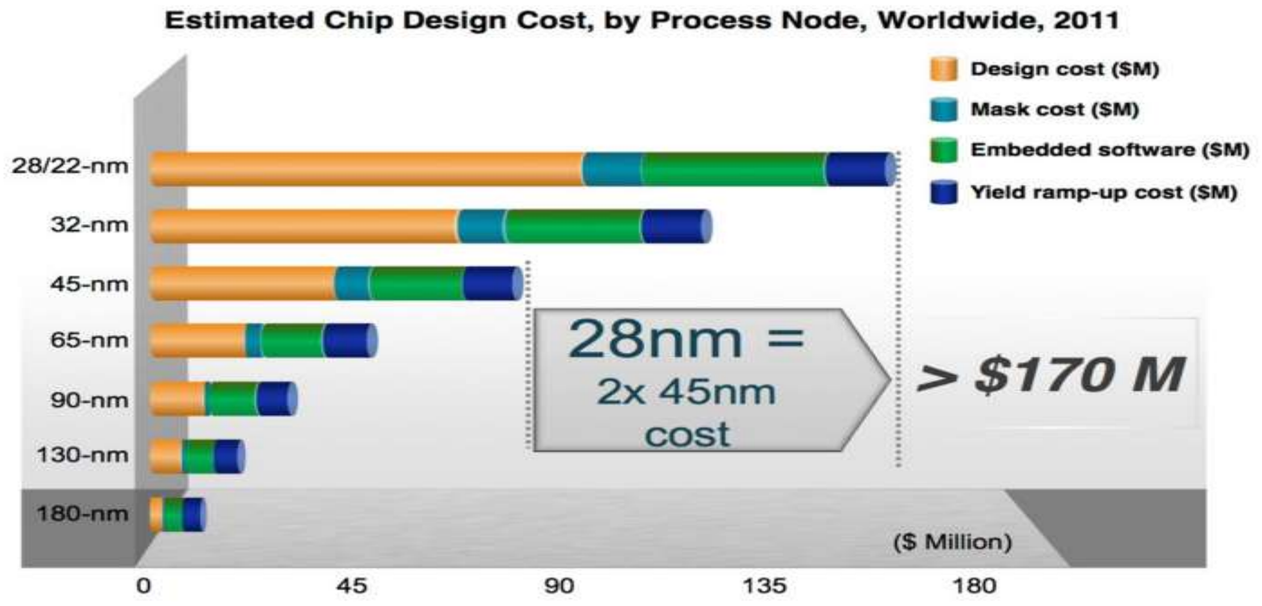
200MM Equipment List for .18 Micron Facility

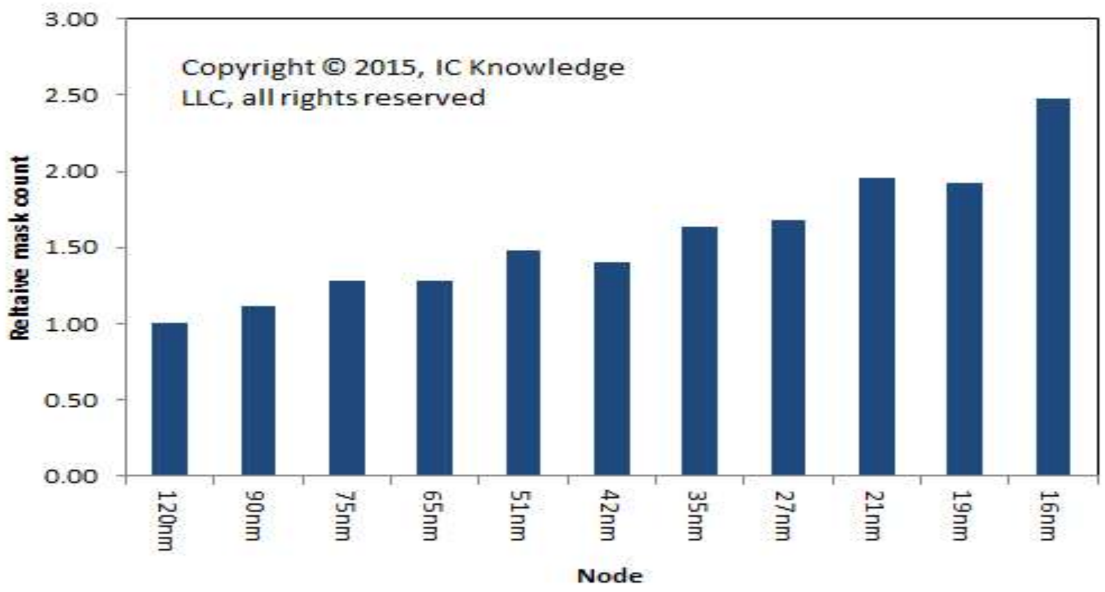
Equipment	Number	Price ($M)	Total ($M)
Chemical Vapor Deposition	24	3	60
Physical Vapor Deposition	23	4	81
Steppers	54	8	432
Photoresist Processing	54	2	108
Etch	55	3	187
Cleaning- Strip	30	1	18
CMP	20	1	24
Diffusion - RTP	32	1	32
Ion Implant	13	3	43
Process Control	-	-	60
Automation/Handling	-	-	15
Miscellaneous	-	-	67
		Total	1,126

A new Stepper costs ~ $80M and the total equipment cost is ~$12B

BUSINESS ASPECTS OF SEMICONDUCTOR FABRICATION

Staggering IC Design and Tooling Costs

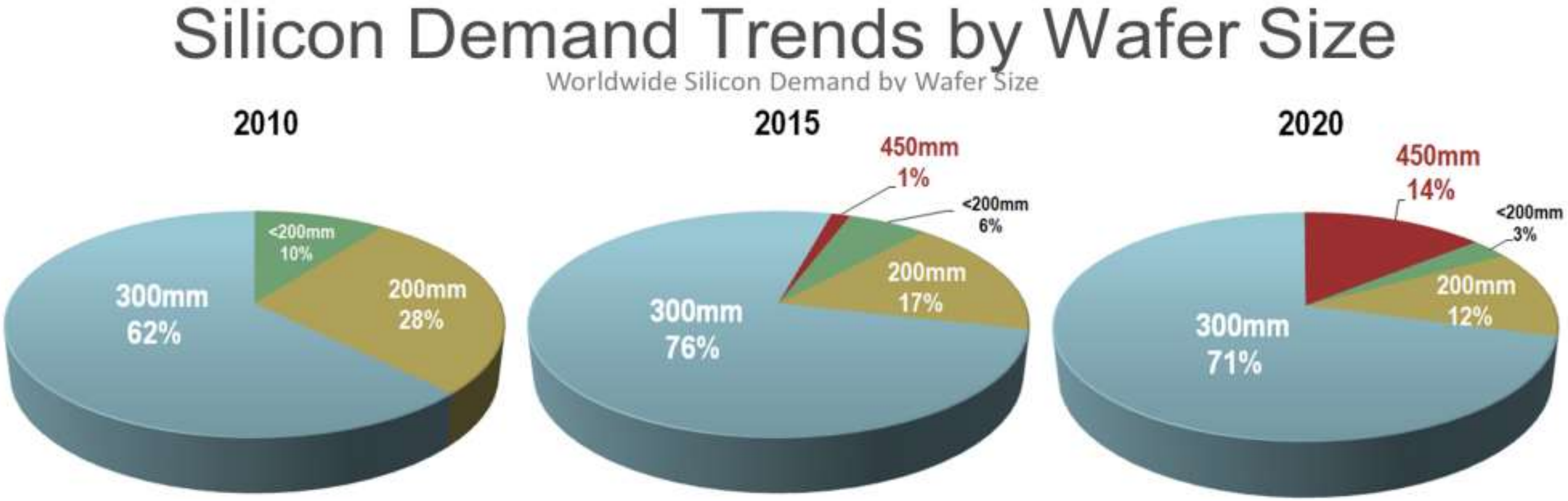




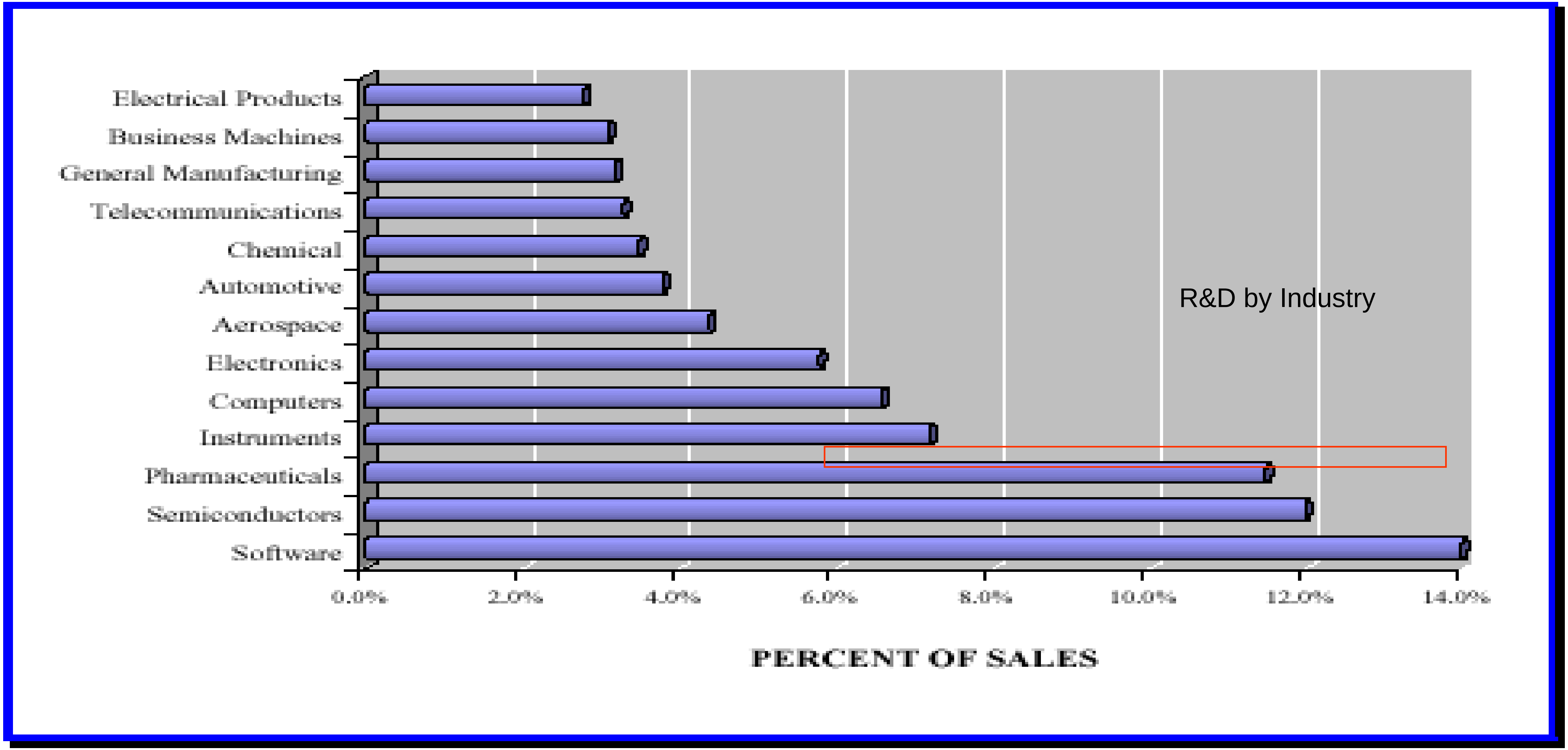
Source: IBS

Wafer Size

Increased wafer size brings volume efficiencies.



Research and Development



Source: ICE/SIA

Research and Development (2)

R&D Spending as a % of Sales

Top Semiconductor R&D Spenders (Companies with ≥$1B in Spending)

2015 Rank	2014 Rank	Company	Region	IDM	FABLESS	FOUNDRY	2014 Semi Sales ($M)	2014 R&D Exp ($M)	2014 R&D/Sales (%)	2015 Semi Sales ($M)	2015 R&D Exp ($M)	2015 R&D/Sales (%)	2015/2014 % Change in R&D
1	1	Intel	Americas	•			51,400	11,537	22.4%	50,494	12,128	24.0%	5%
2	2	Qualcomm	Americas		•		19,291	3,695	19.2%	16,032	3,702	23.1%	0%
3	3	Samsung	Asia-Pac	•			37,810	2,965	7.8%	41,606	3,125	7.5%	5%
4	4	Broadcom	Americas		•		8,428	2,373	28.2%	8,421	2,105	25.0%	-11%
5	5	TSMC	Asia-Pac			•	24,975	1,874	7.5%	26,439	2,068	7.8%	10%
6	7	Micron	Americas	•			16,720	1,598	9.6%	14,816	1,695	11.4%	6%
7	6	Toshiba	Japan	•			11,040	1,853	16.8%	9,734	1,655	17.0%	-11%
8	9	MediaTek	Asia-Pac		•		7,032	1,430	20.3%	6,699	1,460	21.8%	2%
9	12	SK Hynix	Asia-Pac	•			16,286	1,340	8.2%	16,917	1,421	8.4%	6%
10	8	ST	Europe	•			7,384	1,520	20.6%	6,840	1,409	20.6%	-7%
		Top 10 Total					200,366	30,185	15.1%	197,998	30,768	15.5%	2%

Source: Company reports, IC Insights' *Strategic Reviews* database

Wafer Costs for Advanced Nodes

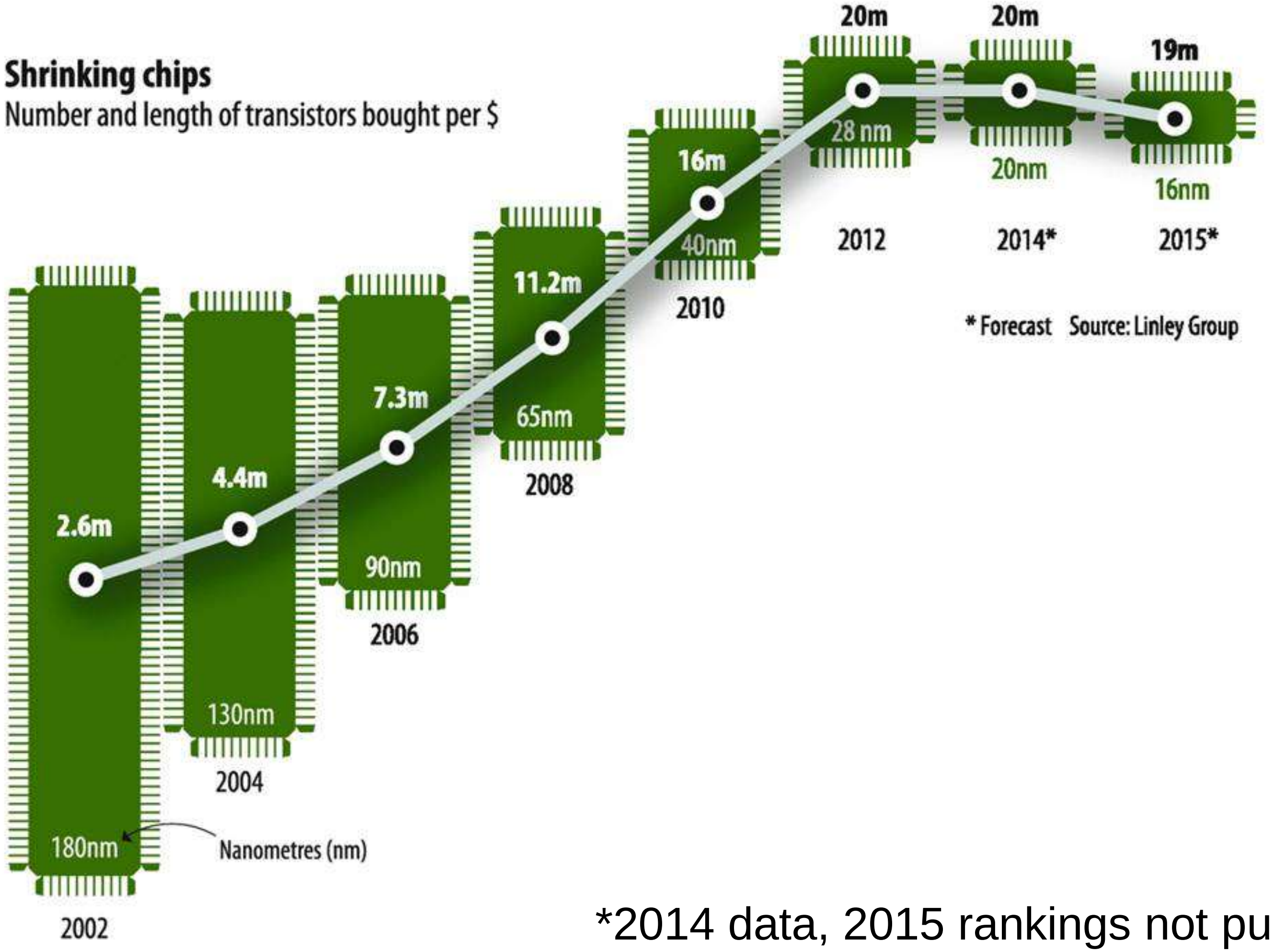
WAFER COST COMPARISON

IBS

($)	Q4/2015	Q4/2016	Q4/2017
28nm bulk CMOS	2,428.90	1,786.34	1,601.75
28nm FD SOI	2,401.35	1,825.46	1,645.37
20nm bulk CMOS	3,048.31	2,889.14	2,775.45
16/14nm FinFET	4,775.85	4,426.14	4,017.39
14nm FD SOI	3,598.42	3,369.36	3,099.87

Source: IBS

Financial Benefit of New Fabrication Processes is Slowing

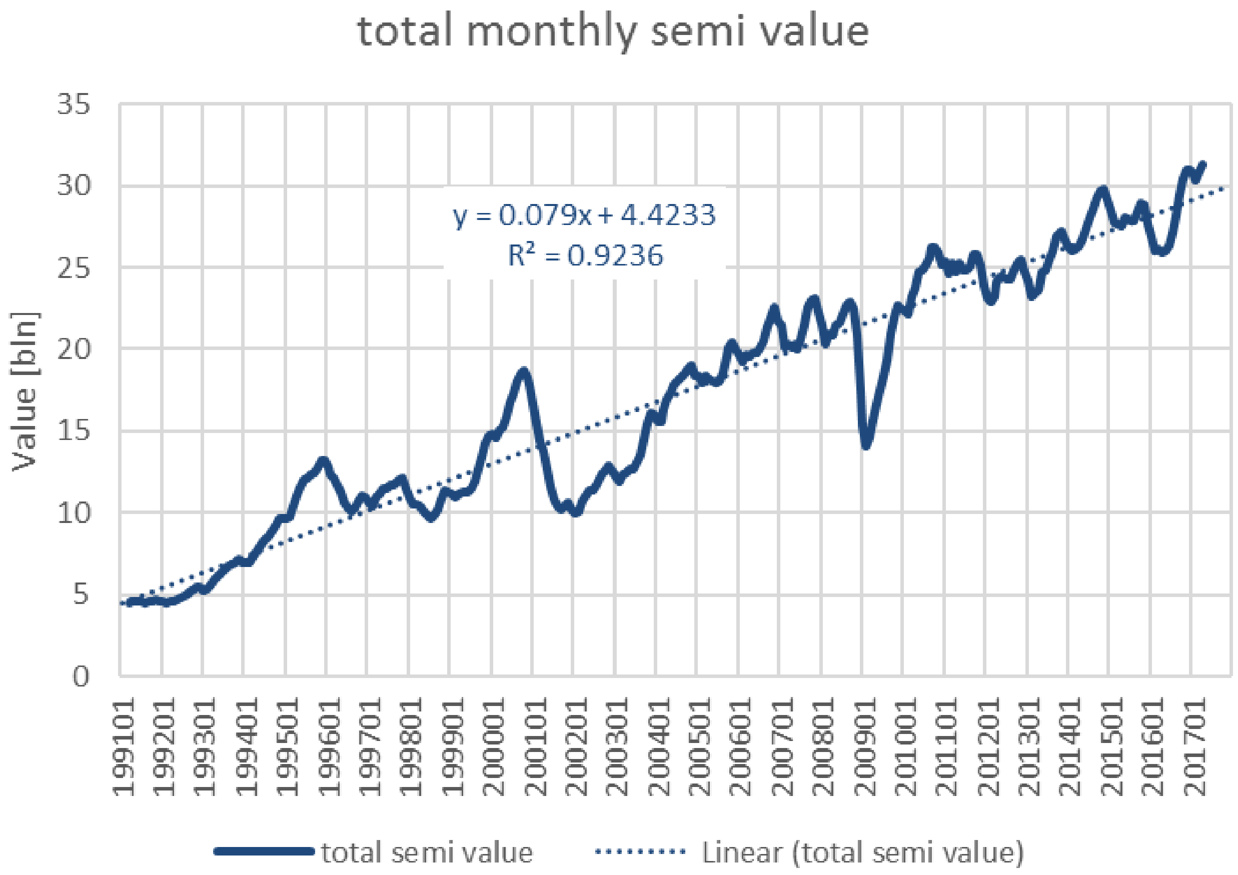


*2014 data, 2015 rankings not published yet

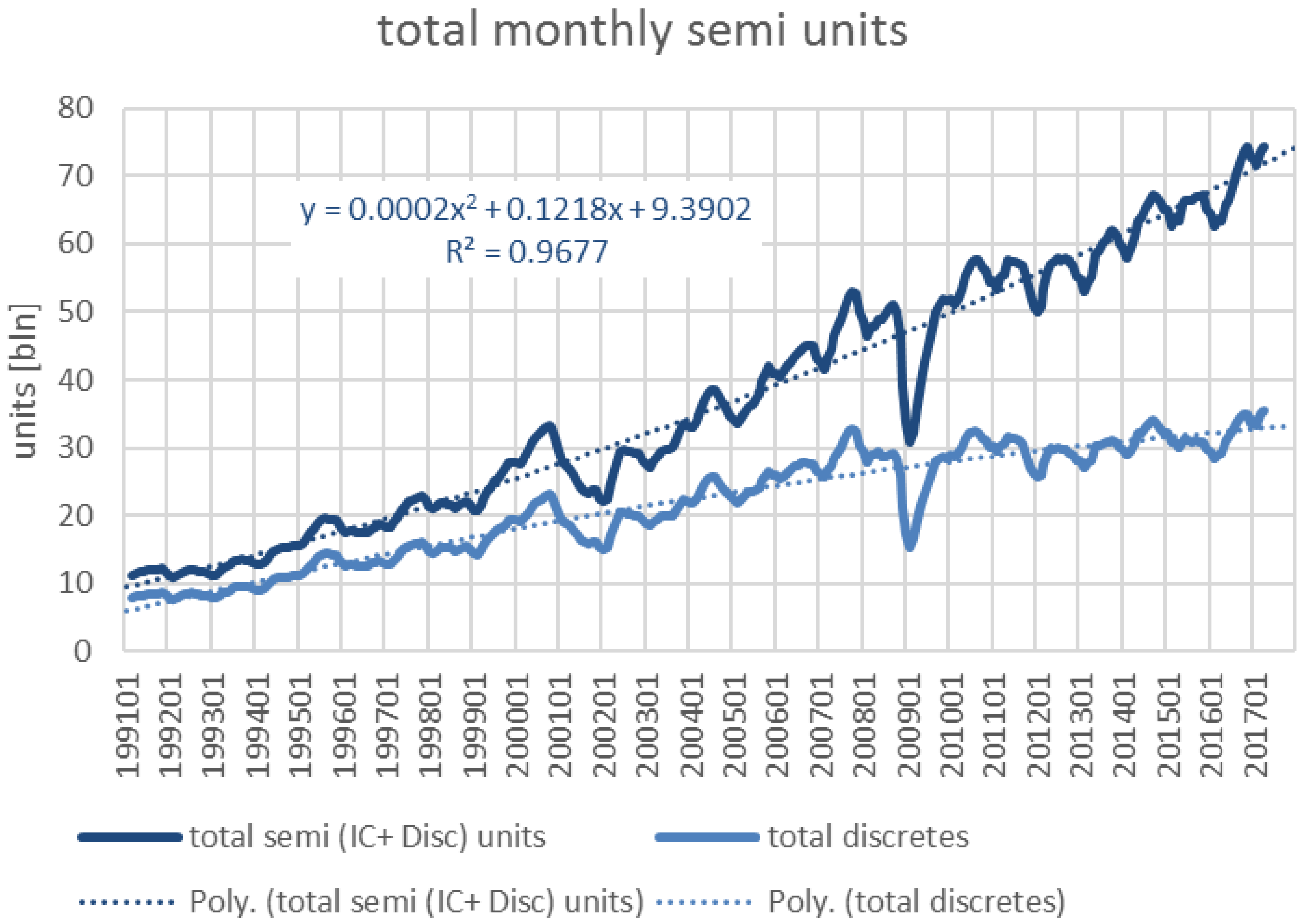
SEMICONDUCTOR MARKET DYNAMICS

SEMICONDUCTORS HAVE GROWN TO A $335 BLN MARKET

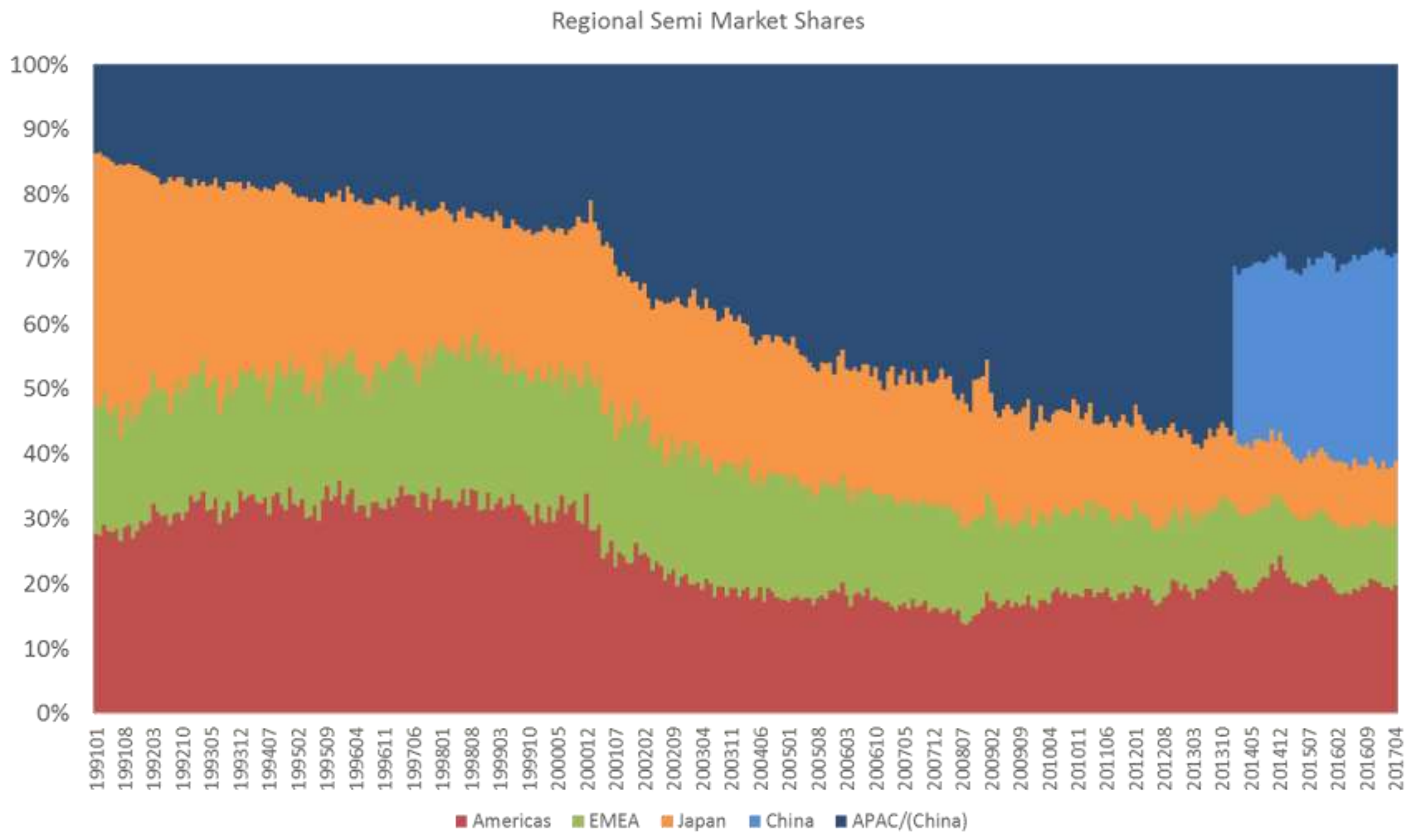
- Semiconductor market is more volatile than overall market it is upstream in supply chain (Bull Whip Effect)



AND MONTHLY UNITS PRODUCTION HAS GROWTH 400% OVER LAST 20 YEARS

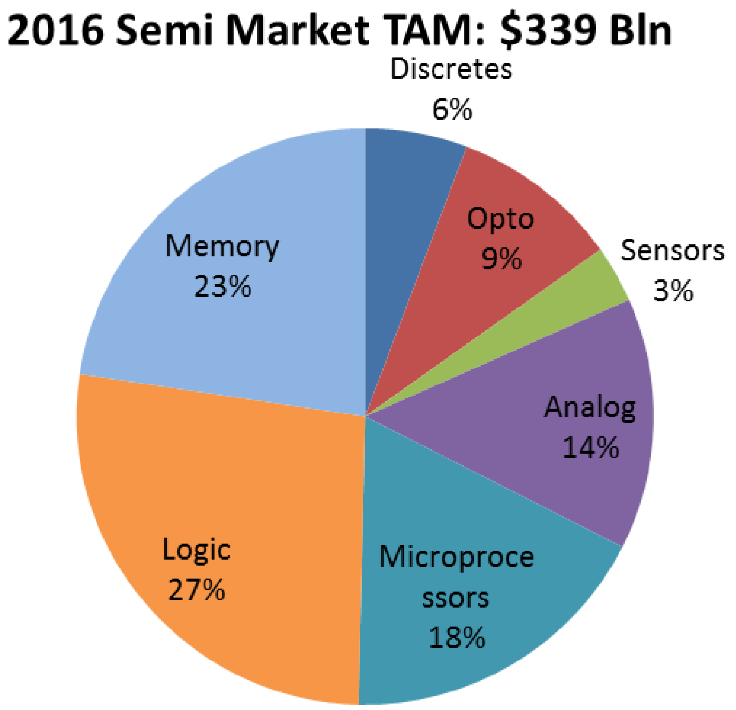


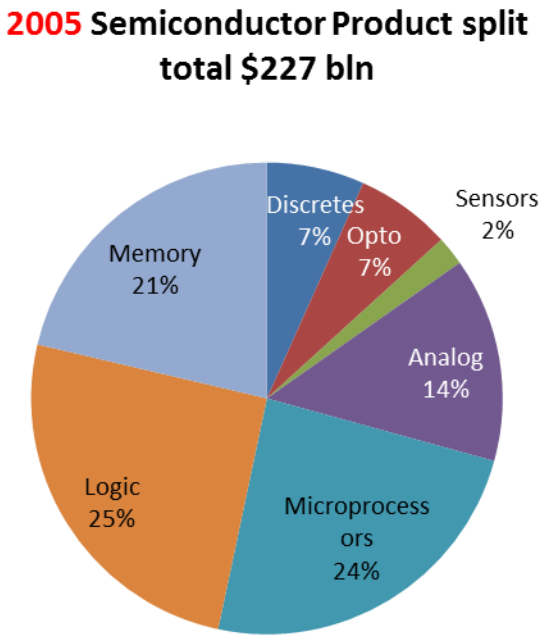
Market has moved from mature economies to emerging countries



Memory and Logic have taken share from Microprocessors in the last decade

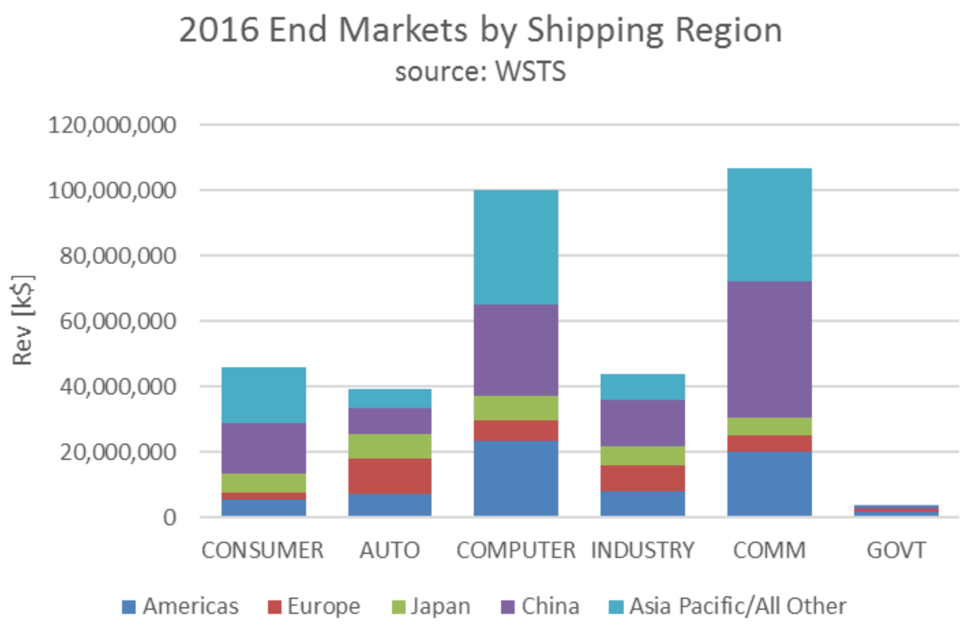
- Smartphones have been growth driver while PC market has been stable

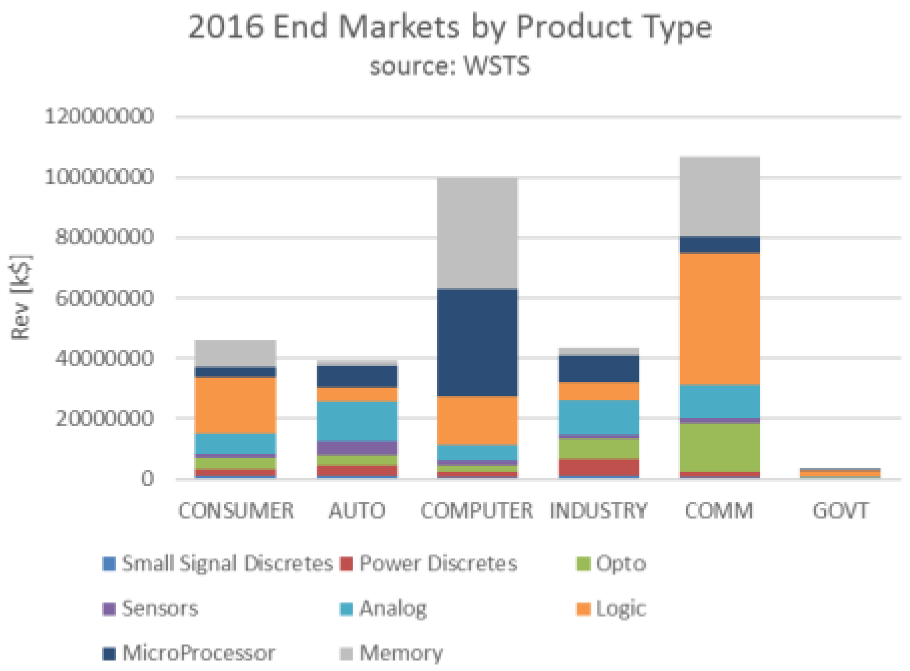




Communications market the largest end market

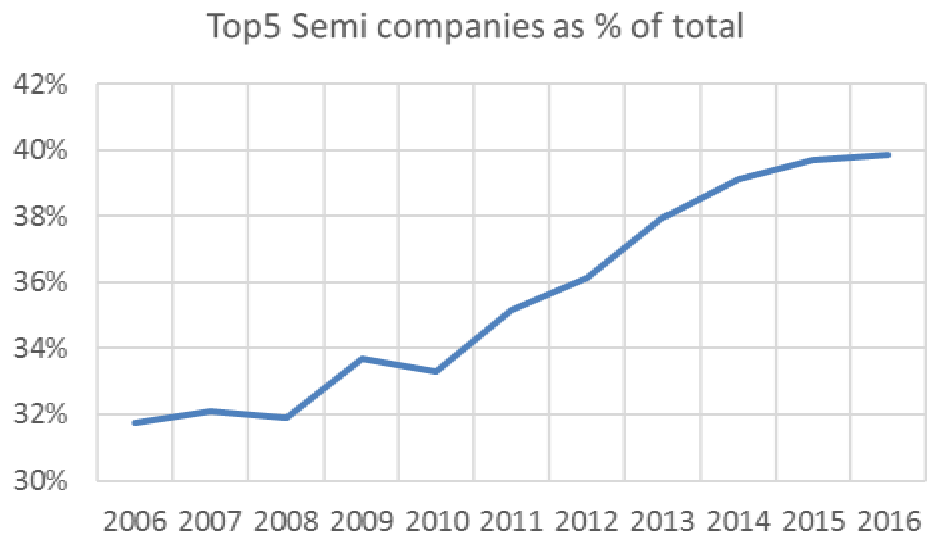
- With ~1.5 (smart)phones, the communications market is the leading end market in semiconductors. Maturing now
- Automotive and IoT considered to be future growth drivers
  - Automotive and Industrial market still much more analog oriented than Mass consumer market (PC, Smartphone, TV)

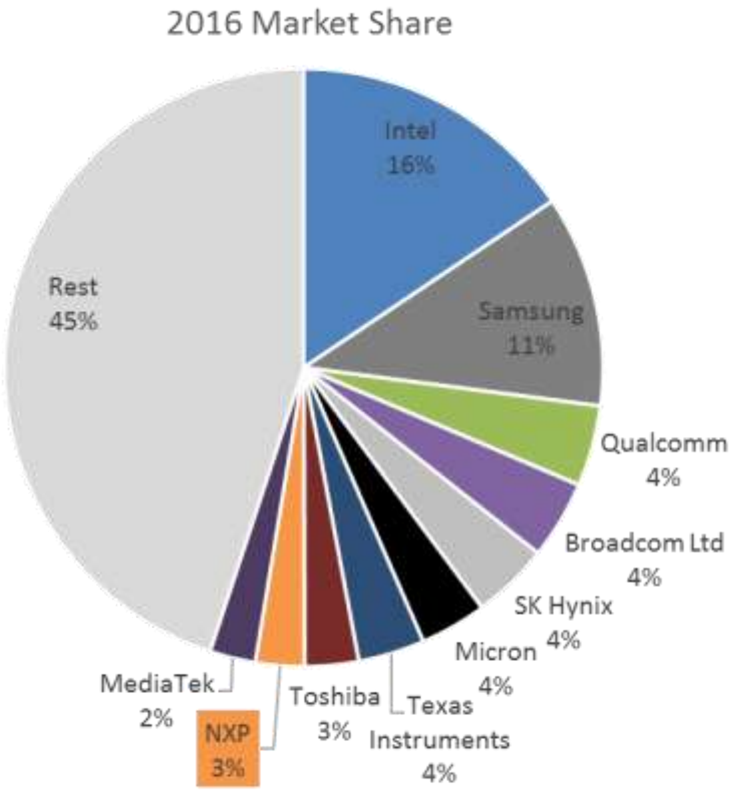




Market is consolidation. Continued strong M&A activity in 2016

- Memory companies (Samsung, Micron, Hynix) have grown together with a selective group of fabless SoC players (Broadcom, Qualcomm)





Source: IHS

SEMICONDUCTOR MANUFACTURING VIDEO

QUESTIONS

SECURE CONNECTIONS
FOR A SMARTER WORLD