WELCOME!!

Presented by Steven Martinez

August 2017 CHAMP Program

Lecture Day 1 Cleanroom Fundamentals

Lecture Day 2 Characterization and Back End Processes

Lecture Day 3 Photolithography

Lecture Day 4 Deposition

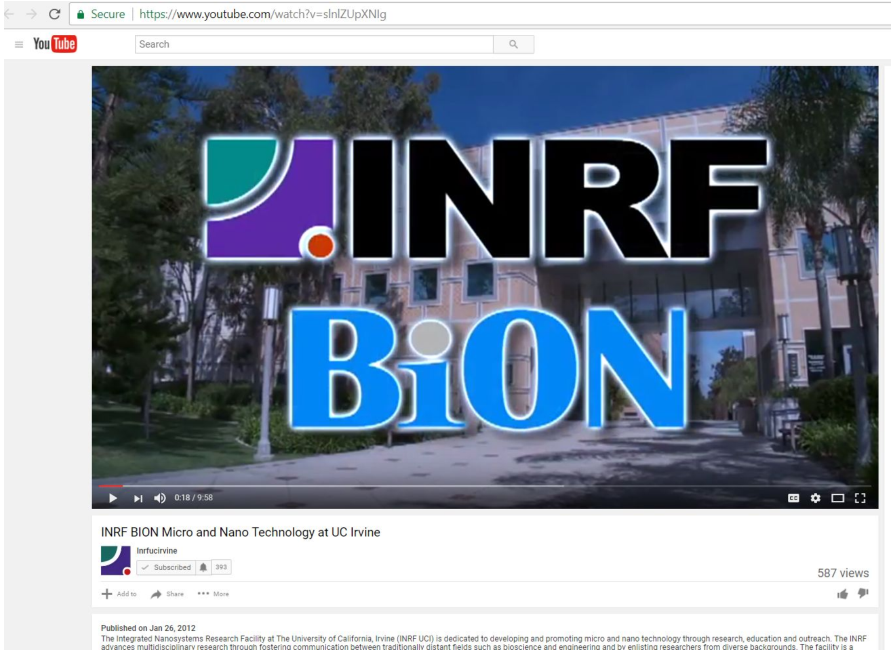
Lecture Day 5 Etching

Lecture Day 1 Cleanroom Fundamentals

Intro to INRF & BiON at UCI
Example Applications
Intro to Cleanroom Design
Intro to Cleanroom Safety
Intro to Wafers and Starting Substrates

Intro to Deposition
Intro to Photolithography
Intro to Etching (Wet and Dry)
Intro to Characterization
Intro to Back End Processes

Intro to INRF & BiON at UC Irvine

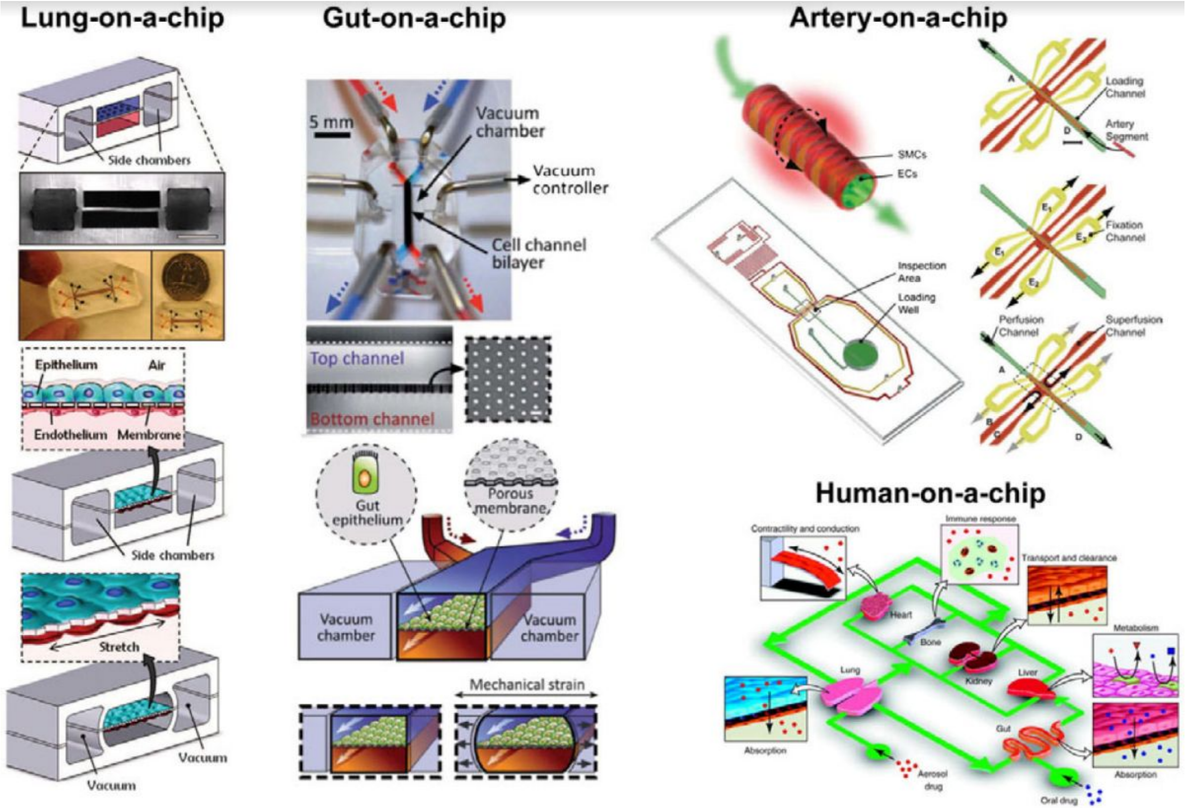


https://www.youtube.com/watch?v=slnlZUpXNIg

Intro to INRF & BiON at UC Irvine

https://youtu.be/FwORvSckQGk

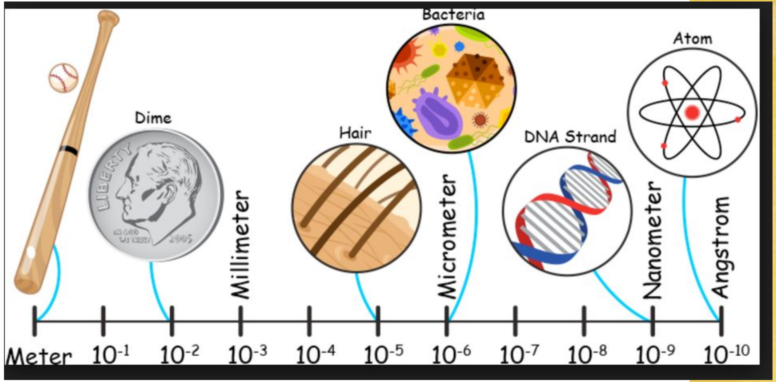
Example Applications

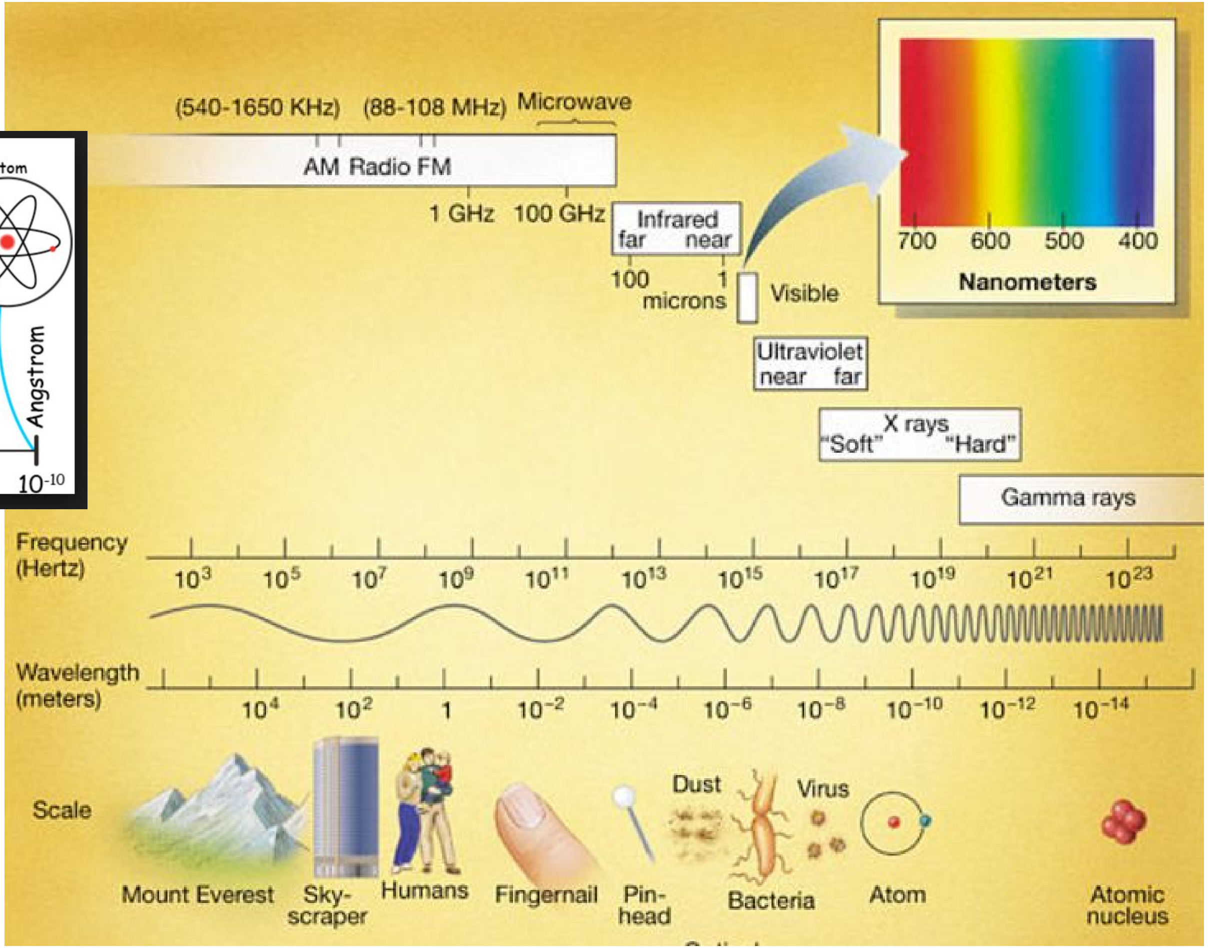



INRF
BiON
CLEANROOM
FUNDAMENTALS

Intro to Cleanroom Design

Scale Reminder





Classification of Cleanroom

ISO 14644-1 and ISO 14698 [edit]

ISO 14644-1 and ISO 14698 are non-governmental standards developed by the International Organization for Standardization (ISO).[11] The former applies to clean rooms in general (see table below); the latter to cleanrooms where biocontamination may be an issue.

Class	maximum particles/m^3 [a]						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10[b]	[d]	[d]	[d]	[d]	[e]	
ISO 2	100	24[b]	10[b]	[d]	[d]	[e]	
ISO 3	1,000	237	102	35[b]	[d]	[e]	Class 1
ISO 4	10,000	2,370	1,020	352	83[b]	[e]	Class 10
ISO 5	100,000	23,700	10,200	3,520	832	[d,e,f]	Class 100
ISO 6	1,000,000	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7	[c]	[c]	[c]	352,000	83,200	2,930	Class 10,000
ISO 8	[c]	[c]	[c]	3,520,000	832,000	29,300	Class 100,000
ISO 9	[c]	[c]	[c]	35,200,000	8,320,000	293,000	Room air

[a] All concentrations in the table are cumulative, e.g. for ISO Class 5, the 10 200 particles shown at 0,3 µm include all particles equal to and greater than this size.

[b] These concentrations will lead to large air sample volumes for classification. Sequential sampling procedure may be applied; see Annex D.

[c] Concentration limits are not applicable in this region of the table due to very high particle concentration.

[d] Sampling and statistical limitations for particles in low concentrations make classification inappropriate.

[e] Sample collection limitations for both particles in low concentrations and sizes greater than 1 µm make classification at this particle size inappropriate, due to potential particle losses in the sampling system.

[f] In order to specify this particle size in association with ISO Class 5, the macroparticle descriptor M may be adapted and used in conjunction with at least one other particle size. (See C.7.)

[g] This class is only applicable for the in-operation state.

US FED STD 209E [edit]

US FED STD 209E was a United States federal standard. It was officially cancelled by the General Services Administration on November 29, 2001,[12][13] but is still widely used.[14]

Class	maximum particles/ft^3					ISO equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥5 µm	
1	35	7.5	3	1	0.007	ISO 3
10	350	75	30	10	0.07	ISO 4
100	3,500	750	300	100	0.7	ISO 5
1,000	35,000	7,500	3000	1,000	7	ISO 6
10,000	350,000	75,000	30,000	10,000	70	ISO 7
100,000	3.5×10^6	750,000	300,000	100,000	700	ISO 8

Cleanrooms

American Physicist Willis Whitfield at Sandia Laboratories invented the modern cleanroom in 1960.

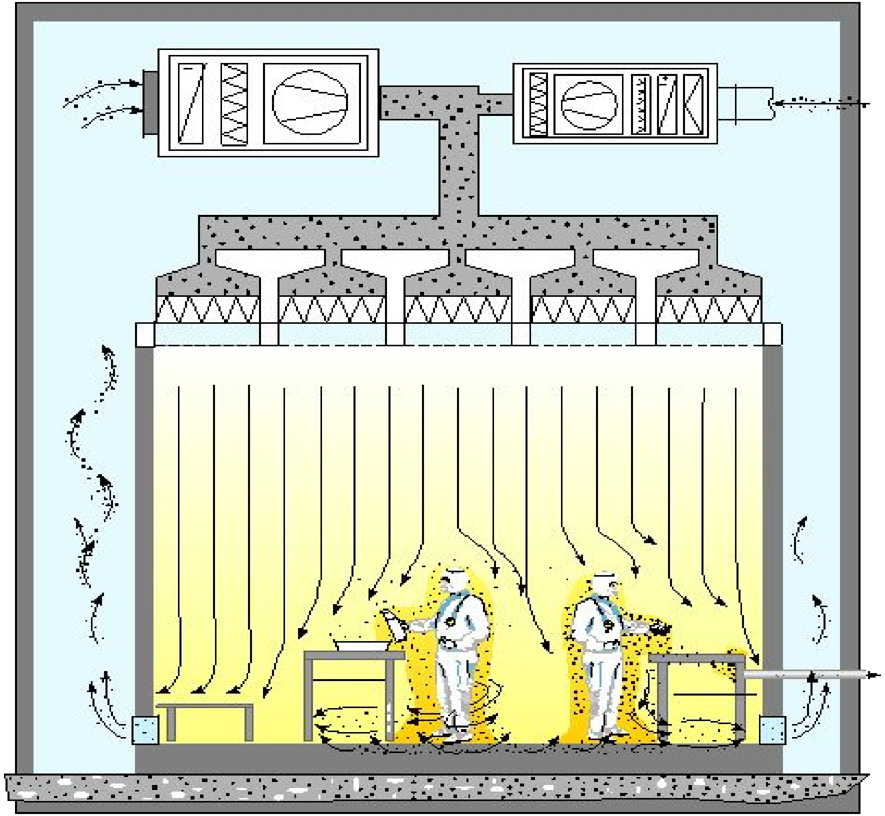
A cleanroom is typically used in semiconductor manufacturing, scientific research, biotechnology, hospitals, pharmaceutical industries, and other industries sensitive to particles contamination. (Ex. NASA Facilities, INTEL manufacturing, universities, biotech companies, etc.)

Cleanrooms have generated over 50 billion dollars in sales and entire manufacturing facilities contain a cleanroom environment covering thousands of square meters.

Cleanrooms uses HVAC systems to pull outside air into the room and filter the intake air in the first stage by an Air pre-filter and the second stage air is filtered thru a filter (called a HEPA Filter).

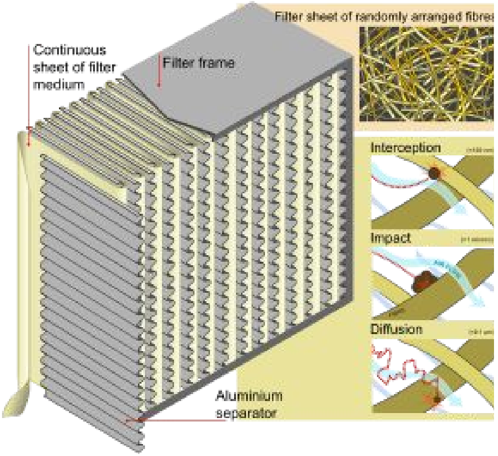
The pre-filter in the first stage removes particles 25 microns or greater. The second stage HEPA Filter removes particles from 0.3 micron to 25 microns.

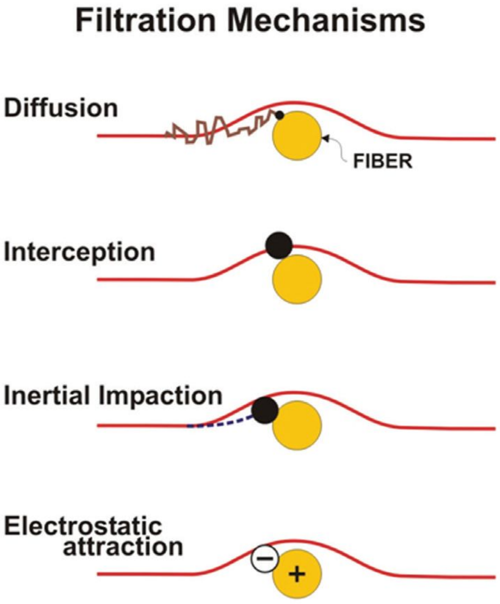
In ambient outside air there are over 35,000,000 particles in the size range from 0.5 microns and greater in diameter.

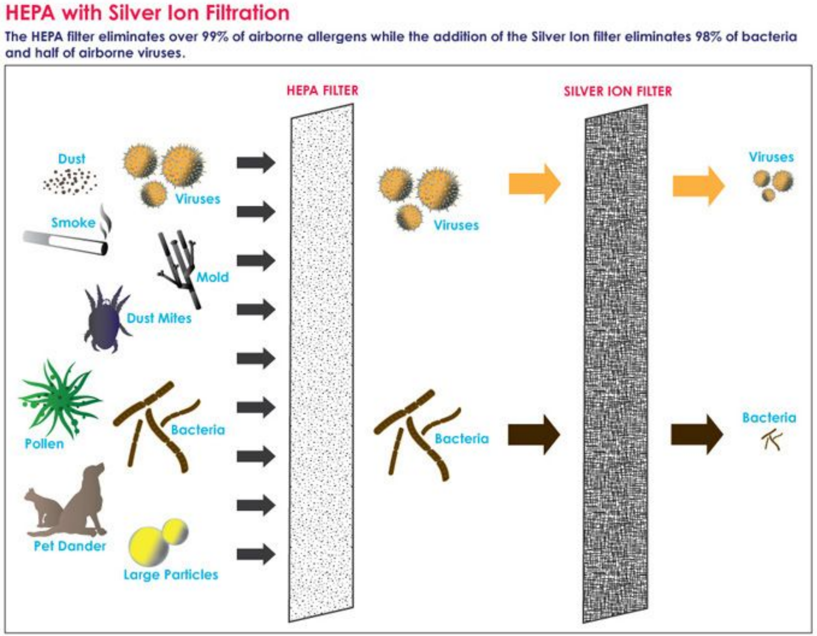


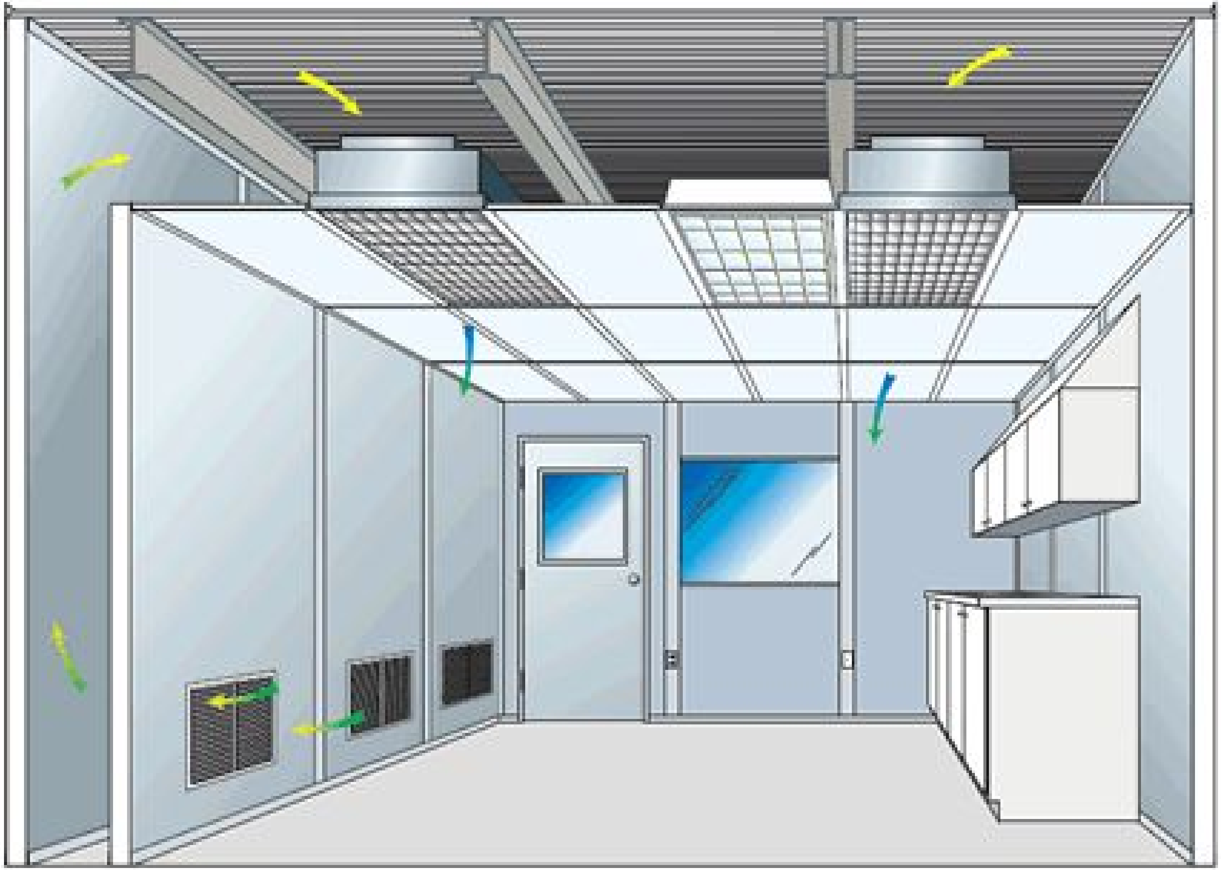
What is HEPA Filter

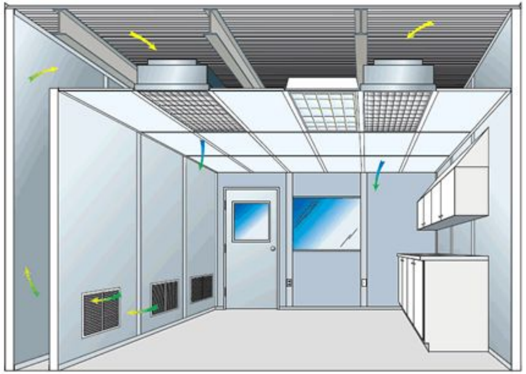
- High Efficiency Particle Arrestor (HEPA) can trap particles upto 0.3 microns or even smaller – Traps the tiniest of pollutants
- The quality, efficiency and life of a HEPA filter largely depends on the thickness, folded area and the material used in it

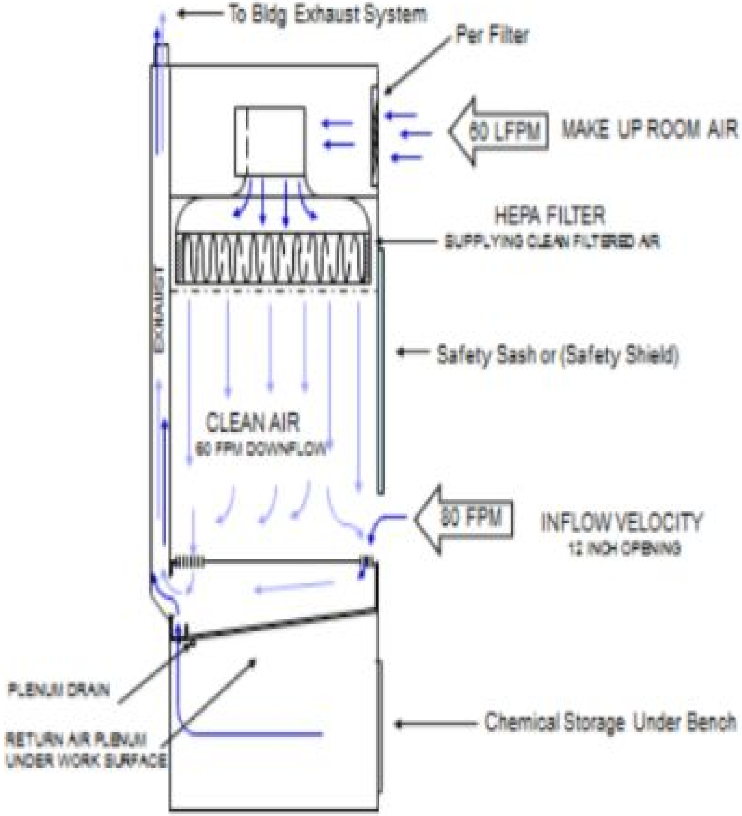










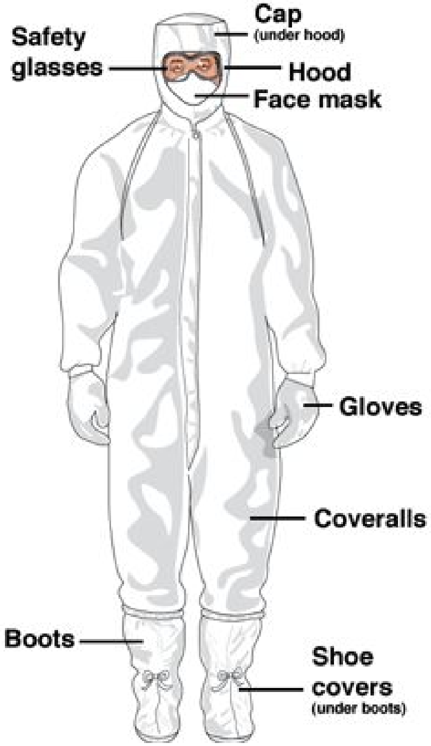

To Bldg Exhaust System
Per Filter
60 LFPM
MAKE UP ROOM AIR
HEPA FILTER
SUPPLYING CLEAN FILTERED AIR
EXHAUST
Safety Sash or (Safety Shield)
CLEAN AIR
60 FPM DOWNFLOW
80 FPM
INFLOW VELOCITY
12 INCH OPENING
PLENUM DRAIN
RETURN AIR PLENUM
UNDER WORK SURFACE
Chemical Storage Under Bench

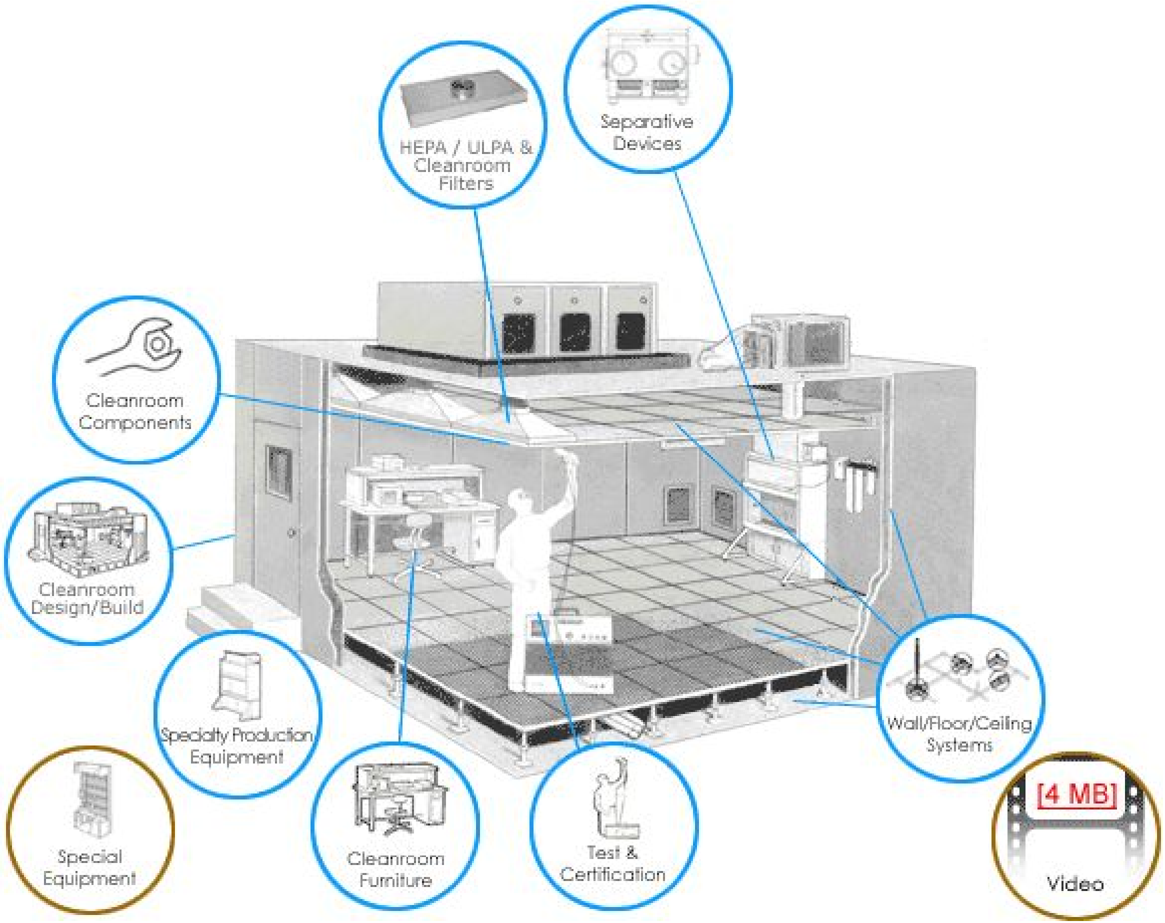
Very special protocol has to be followed once inside the cleanroom in order to maintain cleanliness classification.

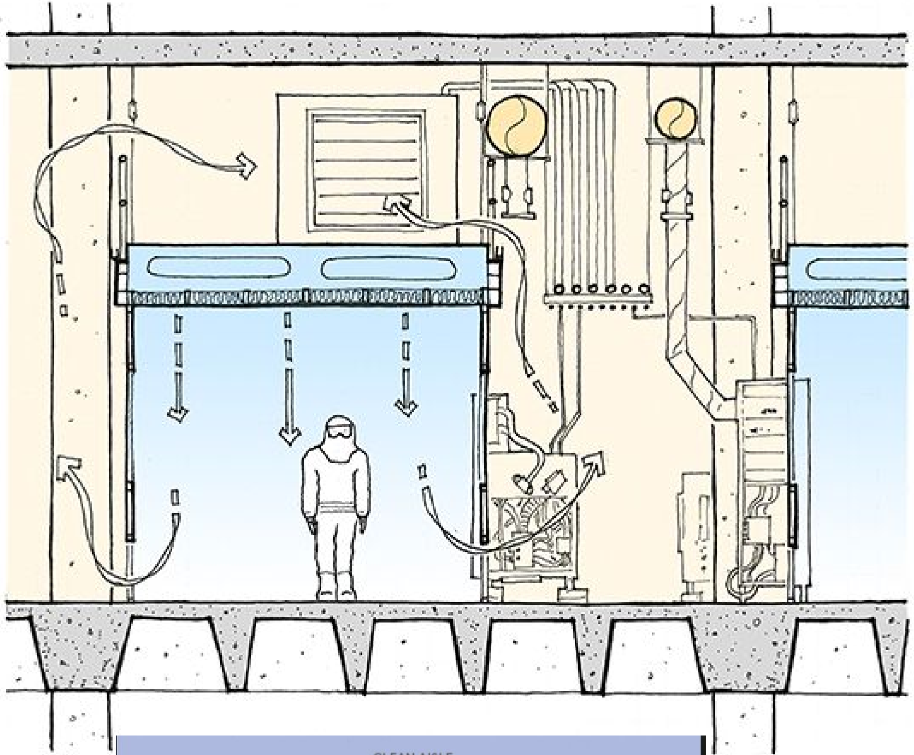
The user of the room must wear **protective** clothing such as coveralls, hoods, boots, masks, and gloves.

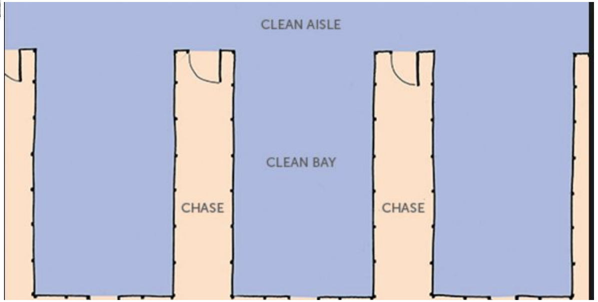
No paper and fabric materials are allowed in the room.

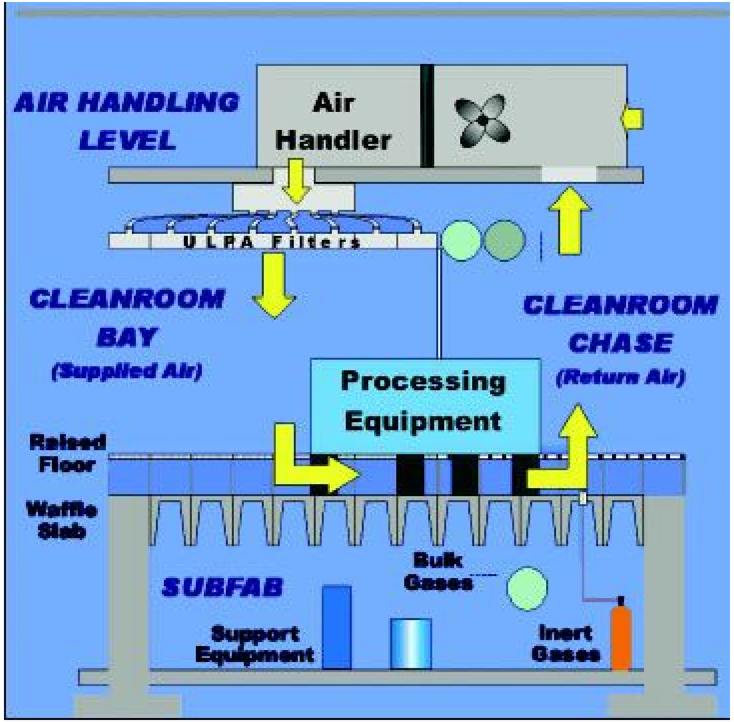
The water is purified for contamination and bacteria for maintaining the yield in processes performed in the cleanroom.

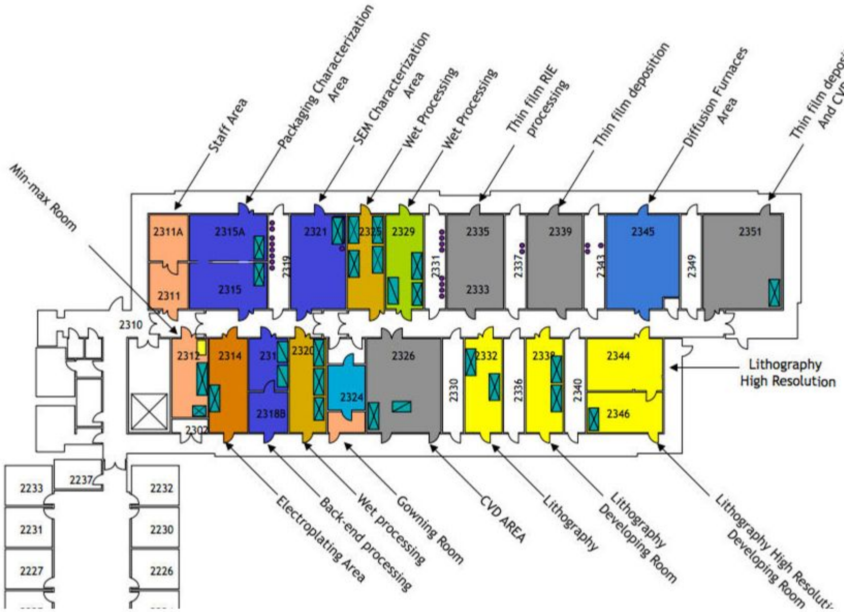


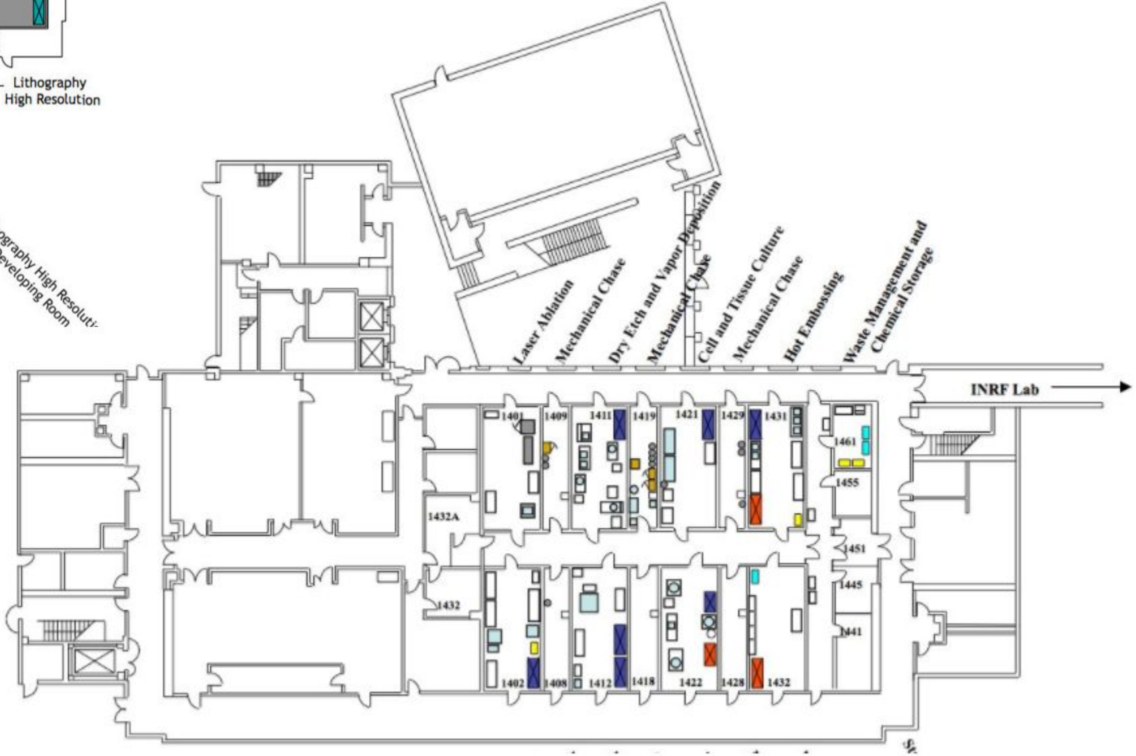

HEPA / ULPA & Cleanroom Filters
Separative Devices
Cleanroom Components
Cleanroom Design/Build
Specialty Production Equipment
Special Equipment
Cleanroom Furniture
Test & Certification
Wall/Floor/Ceiling Systems
[4 MB]
Video



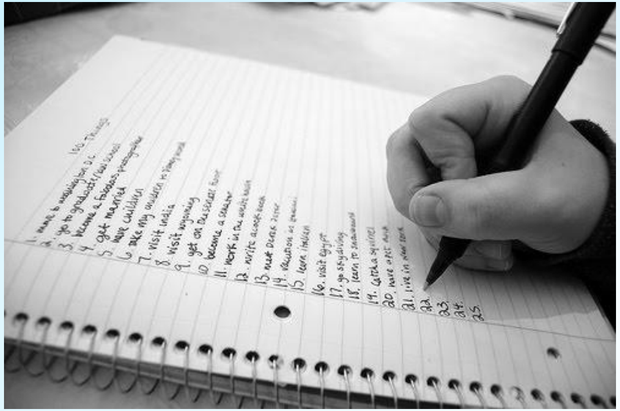

CLEAN AISLE
CLEAN BAY
CHASE
CHASE


AIR HANDLING LEVEL
Air Handler
ULPA Filters
CLEANROOM BAY
(Supplied Air)
CLEANROOM CHASE
(Return Air)
Processing Equipment
Raised Floor
Waffle Slab
SUBFAB
Bulk Gases
Support Equipment
Inert Gases


Staff Area
Packaging Characterization Area
SEM Characterization Area
Wet Processing
Wet Processing
Thin film RIE processing
Thin film deposition
Diffusion Furnaces Area
Thin film deposition And CVD Area
Min-max Room
Lithography High Resolution
Electroplating Area
Back-end processing
Wet processing
Gowning Room
CVD AREA
Lithography
Lithography Developing Room
Lithography High Resolution Developing Room
2311A
2311
2315A
2315
2319
2321
2325
2329
2331
2335
2333
2337
2339
2343
2345
2349
2351
2310
2312
2314
2318B
2320
2324
2326
2330
2332
2336
2338
2340
2344
2346
2302
2237
2233
2231
2227
2232
2230
2226


Laser Ablation
Mechanical Chase
Dry Etch and Vapor Deposition
Mechanical Chase
Cell and Tissue Culture
Mechanical Chase
Hot Embossing
Waste Management and Chemical Storage
INRF Lab
1401
1409
1411
1419
1421
1429
1431
1461
1455
1432A
1451
1432
1445
1441
1402
1408
1412
1418
1422
1428
1432

Safety in Cleanrooms



* There are a lot of important things to consider when planning a safe cleanroom environment.

People

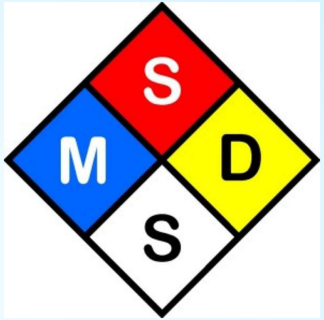
- Irreplaceable
- Health (short term and long term)
- Customers (should feel safe)
- Trained
- Access to knowledge / resources

Facility

- Safe environment for people to conduct research/work/etc.
- Policies and Regulations of the University, the State, Federal
- Secure
- Equipment uptime
- Health of equipment; minimize cost of repairs to damage caused by lack of safety

- Appropriate PPE (Goggles, Glasses, Gloves, Face Shields, Aprons, etc.)

*Bunny suits protect the cleanroom from the human, they DO NOT protect the human inside them



- Chemical Handling (Transport, Incoming, Storage, Use, Waste/Disposal)

- Prevention (Procedures, Posted Notices/Signs, Training)
- Response (Procedures, Posted Notices/Signs, Training)

- Knowledge (Regular Training, Literature Access(MSDS, Contact Info, etc.), Open Dialogue...)

Miscellaneous Hazards: Sharps and Heavy Objects, Pinch Points, Hot/Cold Surfaces, Solid/Liquid/Gas Hazards, Flammability, Explosion, Implosion, Asphyxiates, Corrosion, UV Exposure, RF Exposure Electrical Shock, Biohazards, Electromagnets, Cryogenics, Earthquake

Waste/Disposal: Toxic Waste Disposal, Decomposition/Oxidation, Wet Scrubbing Systems, Pollution Control

Resources: Accessibility (hard copies of MSDS in the lab), Safety Training, Hospital Info, Emergency Contacts

Knowledge: Safety Manuals, Postings, Certifications (Quizzes, Courses), Refresher Training, Evacuation Plan

Chemistry: Use of Hydrofluoric (HF) Acid and other hazardous chemicals, Chemicals being brought into the lab, Groups/users sharing bottles/beakers/waste containers, Proper Drainage, Compatibility with Labware, Proper Labelling (pre, during, and post use), Separation of Acids & Bases, Oxidizers

Other: PPE, Lockout/Tagout Procedures, Buddy Systems, Medical Emergencies, Relationship and Collaboration with EH&S department and other safety departments, Health Conditions(Pacemakers, Reproductive Health/Pregnancy Concerns, Allergies), Gas Cylinder Change Outs, Smells, Toxicity, Work benches, Exhaust, Air Flow, Lab Tidiness/Upkeep, Eyewashes & Showers, Fire Extinguishers, Smoke Detectors, Toxic Gas Detector Systems, Emergency Exits, Alarms (Sight and Sound), Proper Attire

Hydrofluoric Acid (HF) Safety Awareness

Hydrofluoric acid (HF) is a clear and colorless corrosive liquid.

Though a weaker acid, HF is highly potent and physiologically active chemical.

- As little as 7 milliliters (mL) of anhydrous HF in contact with the skin and untreated can bind all the free calcium in a normal sized adult.*
- With burns involving greater than 25 square inches there is a significant risk for serious and potentially fatal systemic toxicity.*
- **There is no concentration of HF would can be relied upon as safe!**
- **There is no material that is completely resistant to HF degradation.**

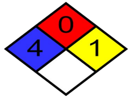
* from: Baird D. and Cooper C., "Hydrofluoric Acid Safety", Fermilab.

GHS/HCS Hazards

Acute toxicity (H300,H310,H330): Fatal if swallowed, in contact with skin, or if inhaled.

Skin corrosion (H314): Causes severe skin burns and eye damage.
Serious eye damage (H318): Causes serious eye damage.

NFPA Fire Diamond



- Health (4): Can be lethal.
- Flammability (0): Will not burn under typical fire conditions.
- Instability (1): Normally stable, but can become unstable at elevated temperatures and pressures.
- Special: No NFPA 704 special hazards.

How is HF different from other acids?

Strong, inorganic acids (such as hydrochloric or sulfuric acid) on contact with live tissue produce immediate necrosis. Similarly, exposure to concentrated solutions of HF will produce significant tissue damage at the exposure site.

Additionally:

- HF is readily absorbed through the skin.
- Fluoride ions move rapidly through the skin causing deep tissue damage.
- HF binds to the available calcium and magnesium in the body. Depletion of the calcium reservoirs can induce hypocalcemia.
- Potassium ions (K+) enter the extracellular space to compensate for the loss of the calcium.
- Nerve endings are irritated by the altered K+ levels and produce severe pain.

Safe Work Practices

- Never use HF alone (buddy system).
- Training for both the hazards of HF and the manner in which it will be used:
    - Approved Standard Operating Procedures (SOPs)
    - Enhance with Job Safety Analyses (JSA) or Risk Assessments
- Always wear appropriate Personal Protective Equipment (PPE).
- Always use HF in a laboratory fume hood.
- Confirm that there is antidote (calcium gluconate) before handling HF.
- Use signs to designate areas and provide warning where HF will be in use.
- Use only with appropriate containers for handling HF reagents and wastes and accurately label the containers

Recommended PPE

- Long Neoprene gloves (avoid exposed wrists)
- Saranex coated coveralls or other chemically resistant body protection
- Face shield and goggles (acid resistant recommended)

Baird D. and Cooper C., "Hydrofluoric Acid Safety", Fermilab.

Container Resistance to HF

Not resistant:

Do not store HF in glass containers. Hydrofluoric acid reacts with many materials. Use one of the two recommended types of storage containers to store HF reagents and wastes.

Best resistance:

Teflon (PTFE)

- HF(48%) at 70°F for 6 months
- No notable change or deterioration of the container.

Moderate resistance:

High Density PolyEthylene (HDPE containers)

- HF(48%) at 70°F for 30 days
- Less than 15% swelling, less than 20% loss in tensile strength, and only minor evidence of chemical attack.

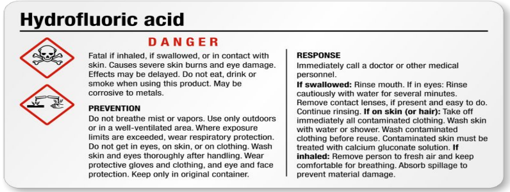
All primary HF containers must be labeled and in secondary containment.

Container Labels and Warning Signs

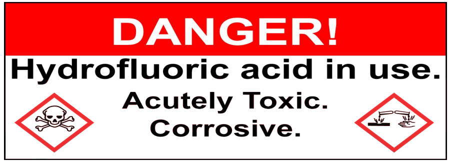
Any container that holds an HF solution should be clearly labeled.

Label should include:

- Chemical Name
- Associated Hazards
- Date created
- Recommended: Use a GHS formatted label



Place labels on areas where HF solutions are used or being stored.



What to do if an HF exposure occurs:

- Do not panic!
- Provide assistance
  - Help exposed individual to eyewash/safety shower
  - Take care to avoid spreading the contamination to unexposed parts or the assistant
  - Flush the exposed area with water for 5 minutes
  - Remove any contaminated clothing while under the shower
- Administer HF antidote (calcium gluconate)
- Call for emergency assistance and seek medical attention

Remember:

The best treatment for exposures is prevention.

- Explore the possibility of eliminating or substituting the HF for a less hazardous material
- Properly use Engineering Controls when handling HF
- Develop effective administrative controls for handling HF
- Use appropriate PPE when handling HF
- Continue to develop and refine your procedures and training practices when procedures change or when improvements are found

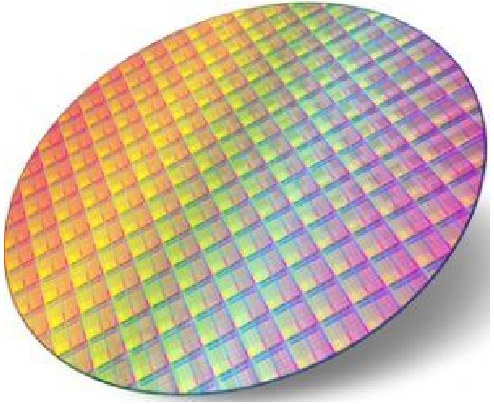
Back to the research…..

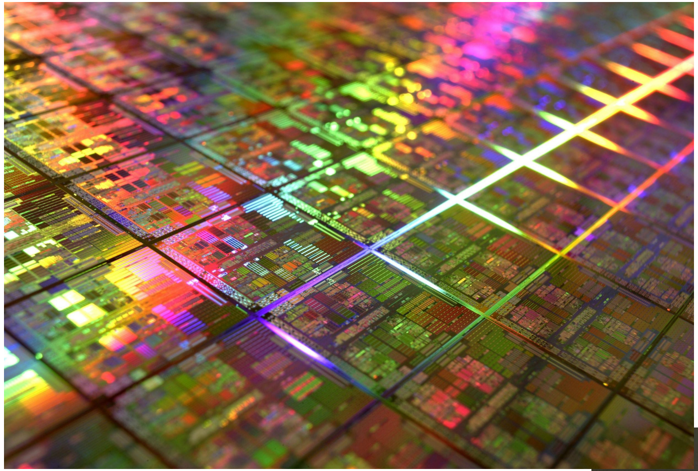
Semiconductors and Biotechnology research cleanrooms facilities utilize Photolithography, Dry etching, wet etching, Metal Deposition, Dielectric Deposition and back-end packaging rooms to preform fabrication-processing steps.

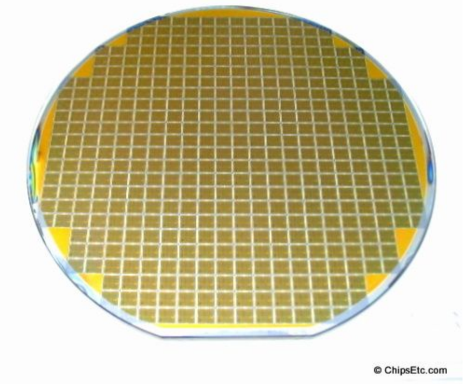
The UCI INRF and BION have 16,000 square feet of cleanroom space dedicated for semiconductor and biomedical device processing.

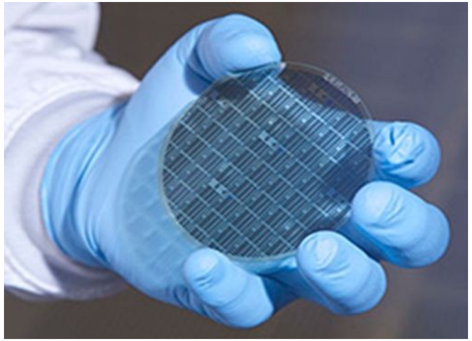
http://www.inrf.uci.edu/orientation

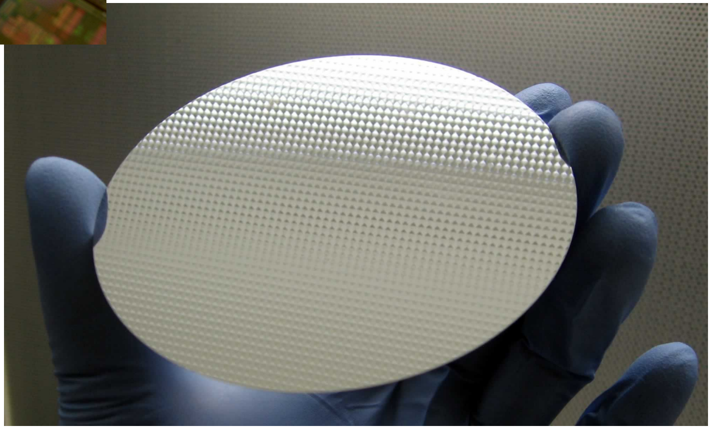
Intro to Wafers and Starting Substrates

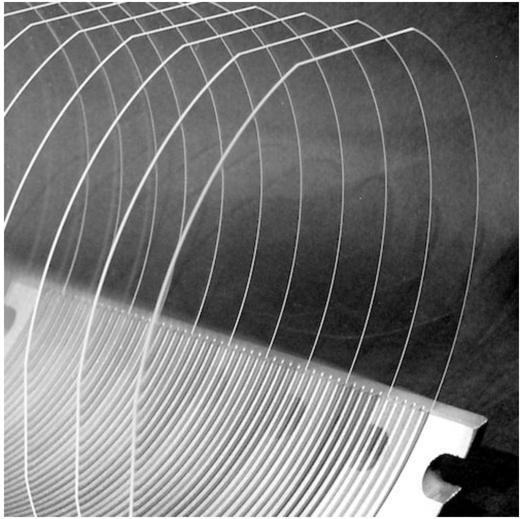
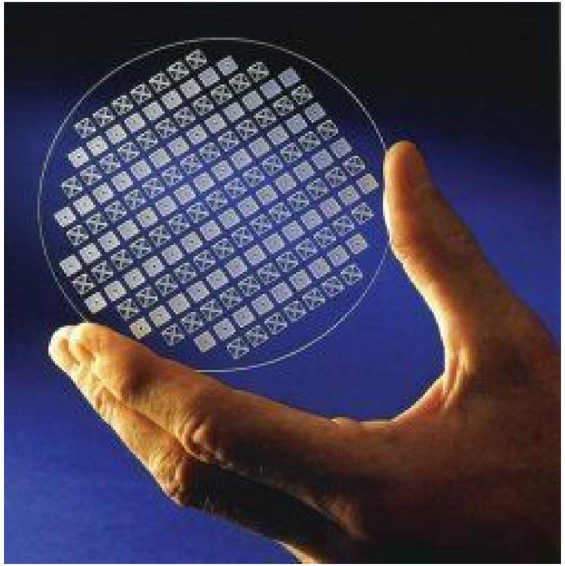
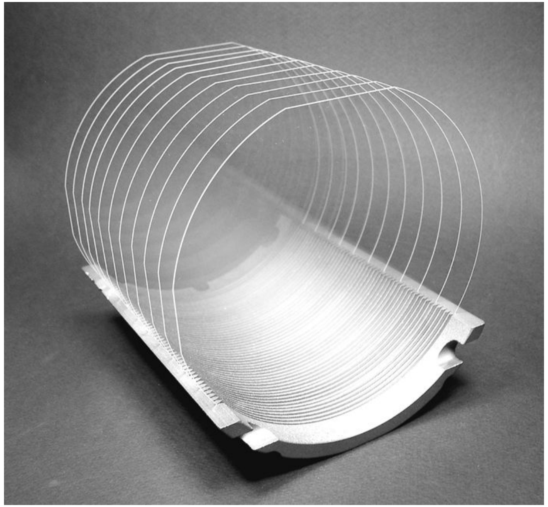
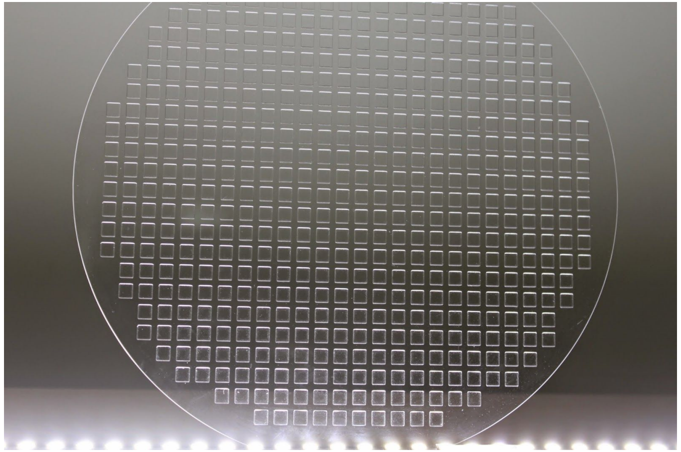
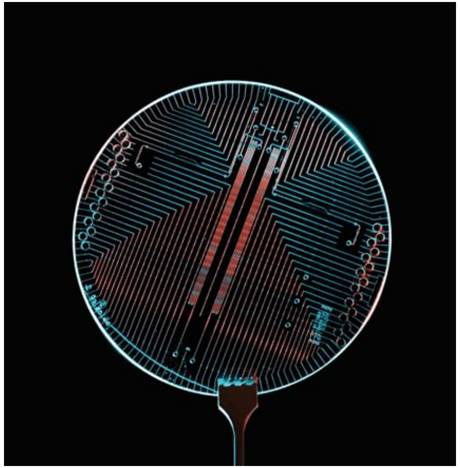


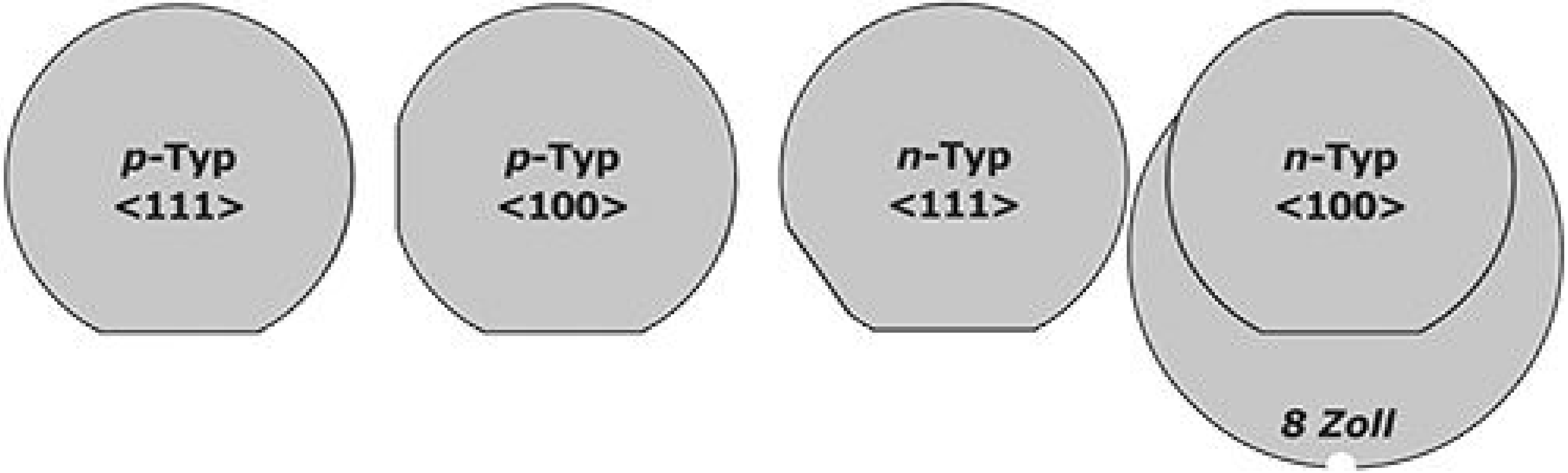




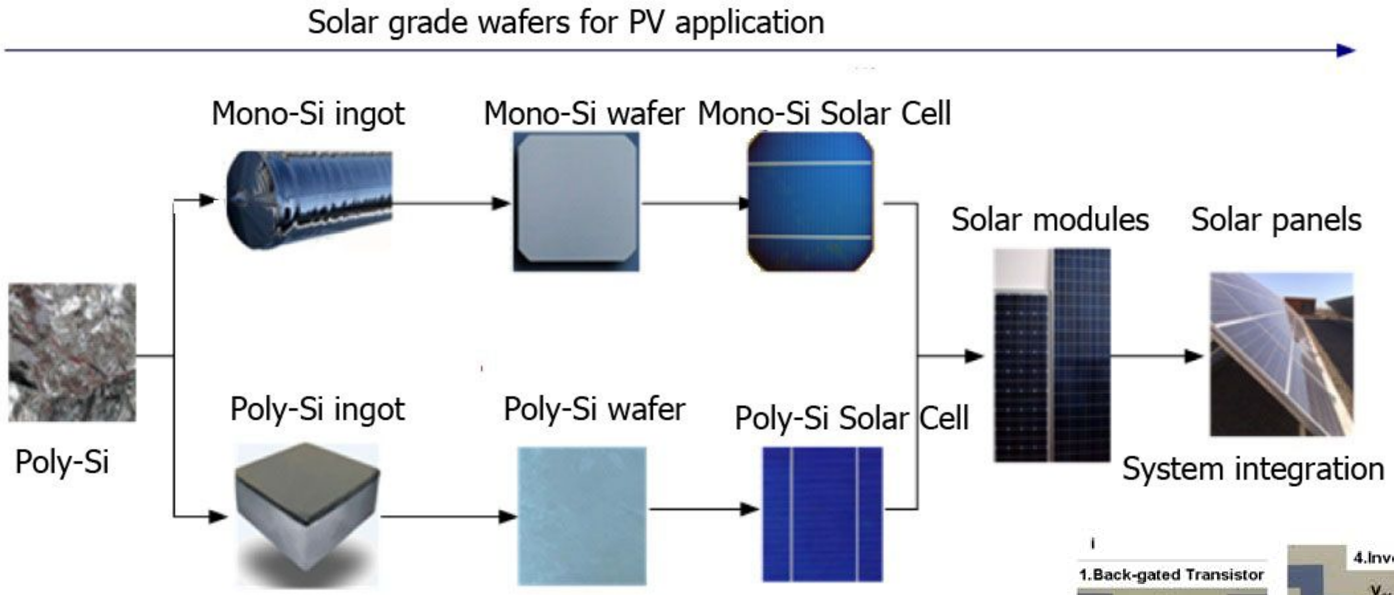


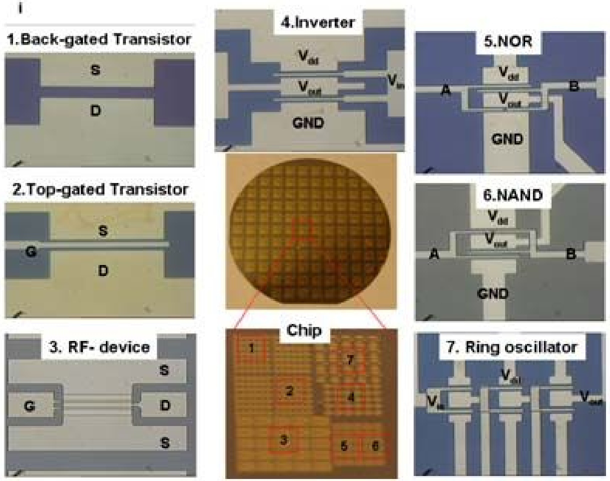


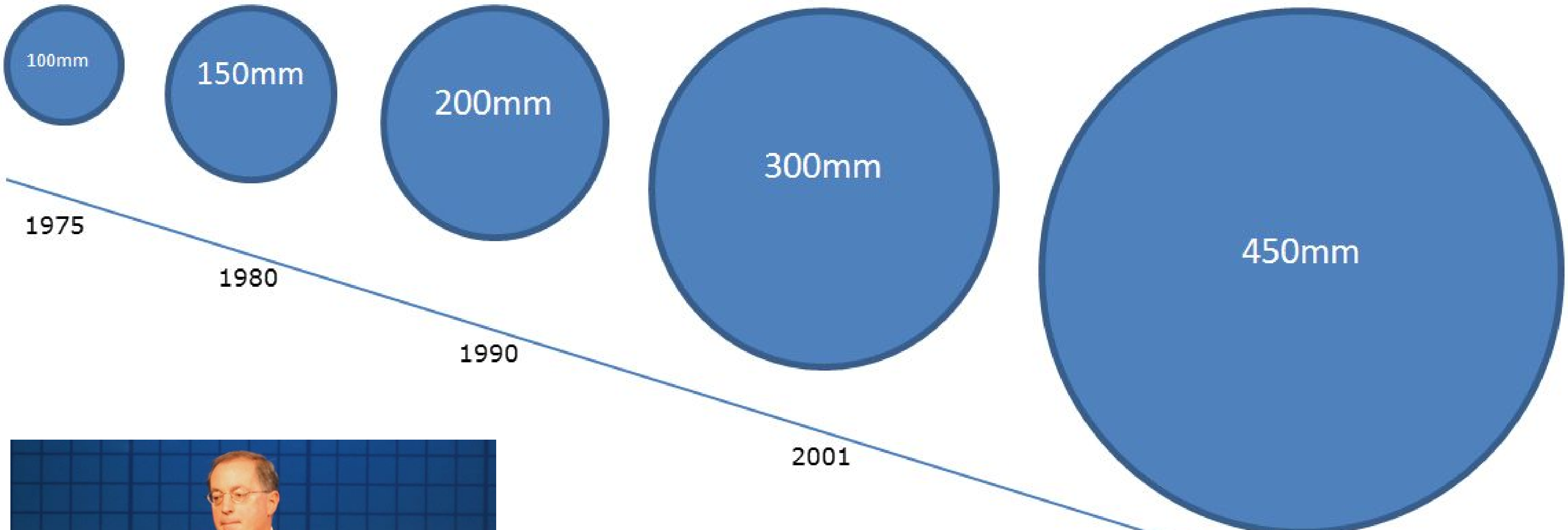








p-Typ
<111>
p-Typ
<100>
n-Typ
<111>
n-Typ
<100>
8 Zoll

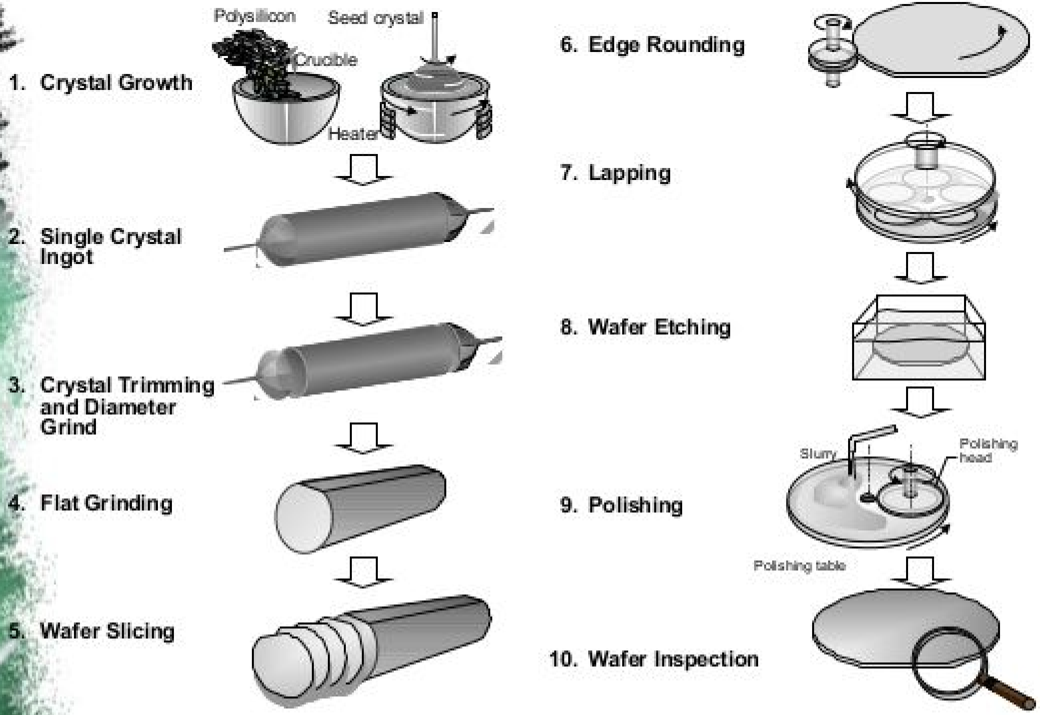

Solar grade wafers for PV application
Mono-Si ingot
Mono-Si wafer
Mono-Si Solar Cell
Poly-Si
Poly-Si ingot
Poly-Si wafer
Poly-Si Solar Cell
Solar modules
Solar panels
System integration

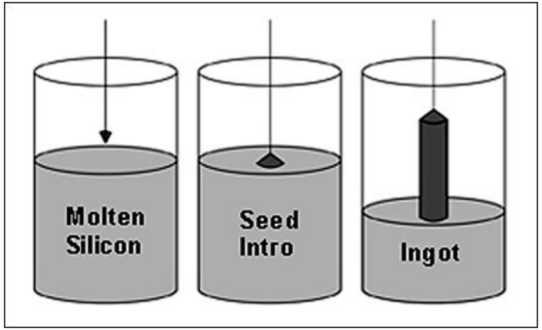

1.Back-gated Transistor
S
D
2.Top-gated Transistor
G
S
D
3. RF- device
S
G
D
S
4.Inverter
GND
Chip
1
2
3
4
5
6
7
5.NOR
A
B
GND
6.NAND
A
B
GND
7. Ring oscillator

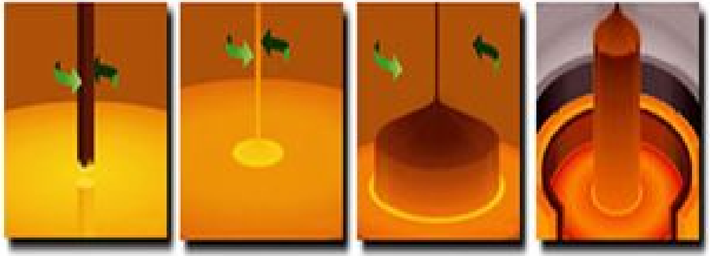

100mm
150mm
200mm
300mm
450mm
1975
1980
1990
2001
2017

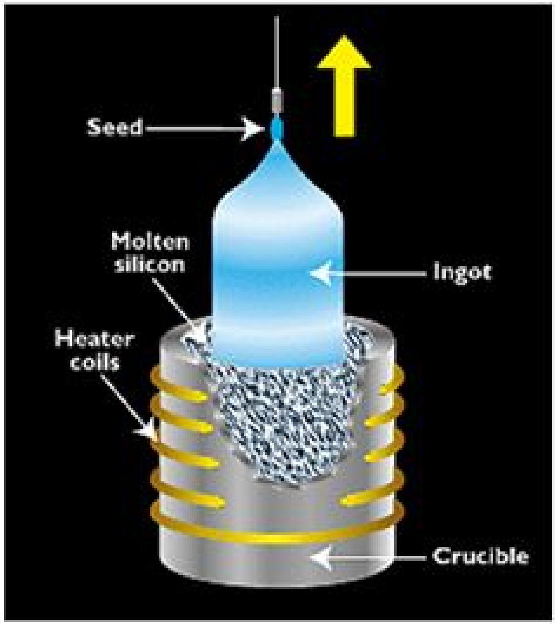
Czochralski Growth

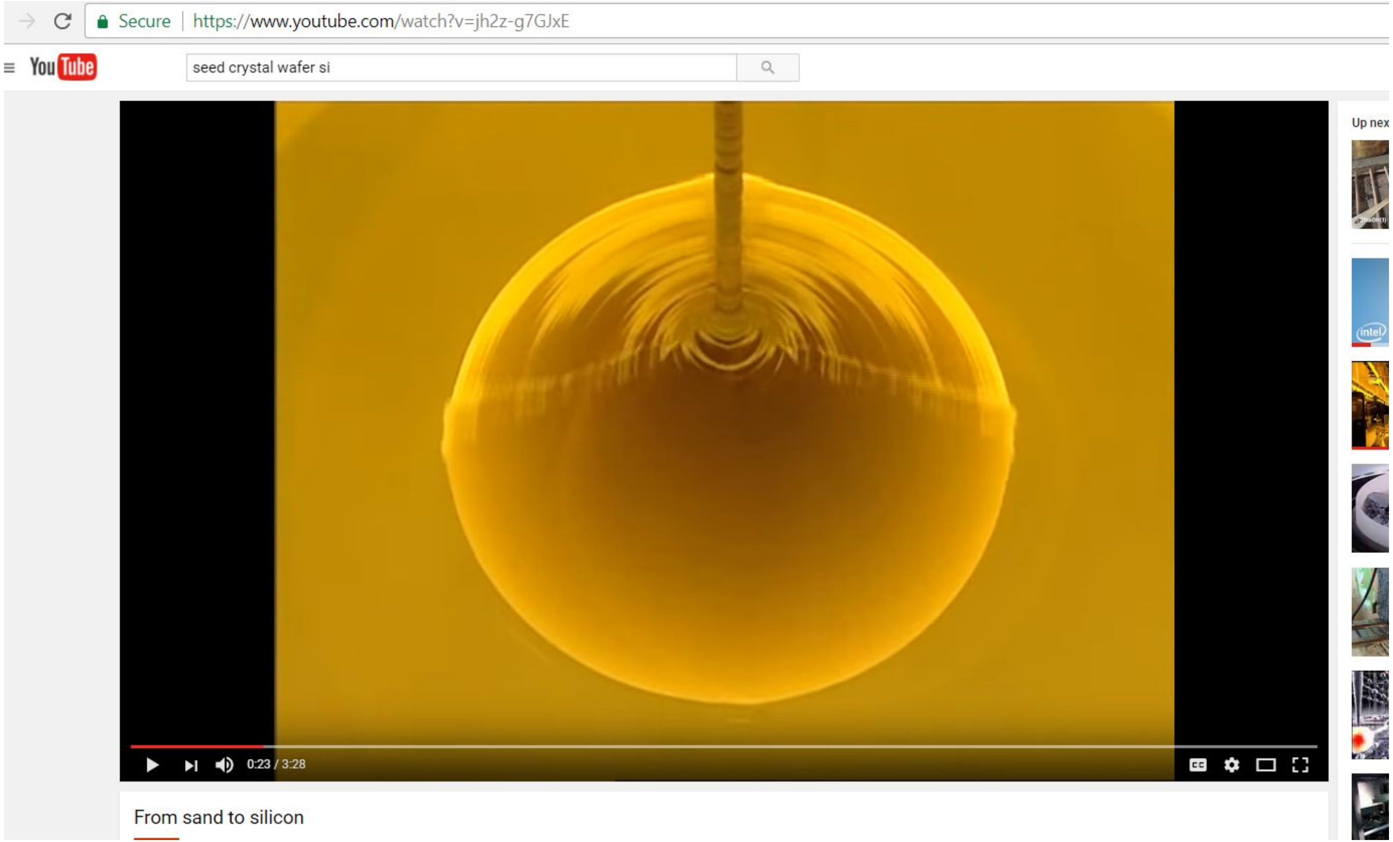
Preparation of Silicon Wafer








Seed
Molten silicon
Ingot
Heater coils
Crucible



3min: https://www.youtube.com/watch?v=jh2z-g7GJxE

Intro to Deposition
Intro to Photolithography
Intro to Etching (Wet and Dry)
Intro to Characterization
Intro to Back End Processes

Intro to Semiconductor Processing

Quick Version

2min: https://www.youtube.com/watch?v=JDROPMoNZpk

Intro to Deposition → **Adding Material**

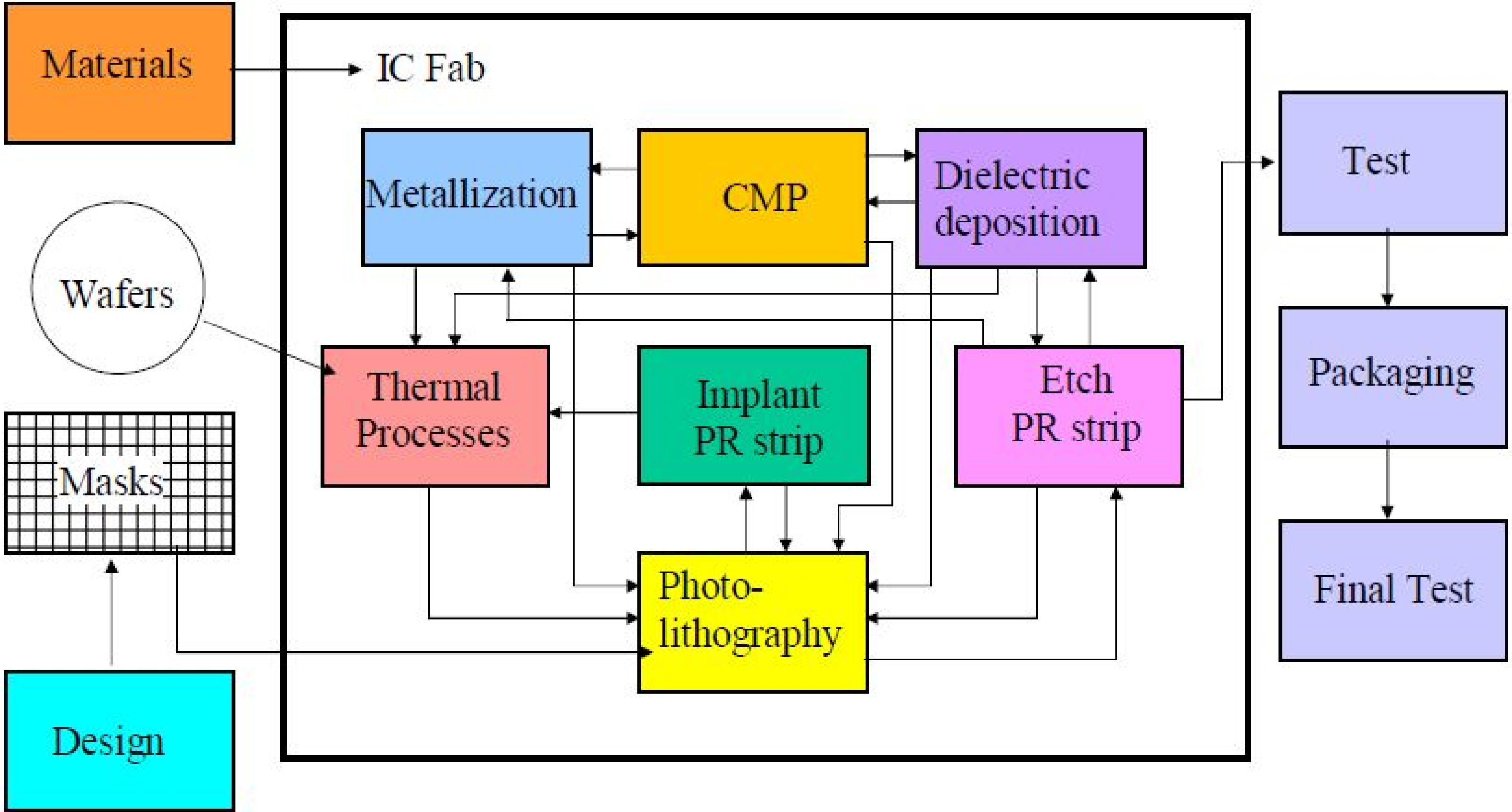
Intro to Photolithography → **Transferring Pattern**

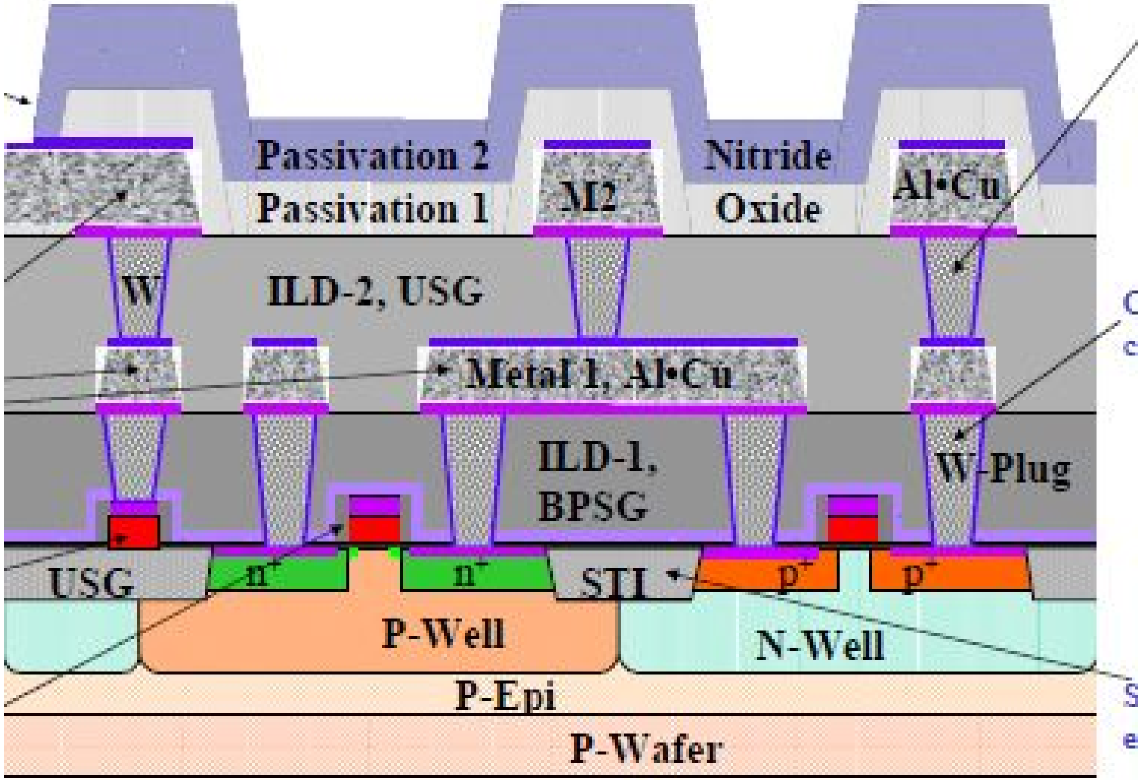
Intro to Etching (Wet and Dry) → **Removing Material**

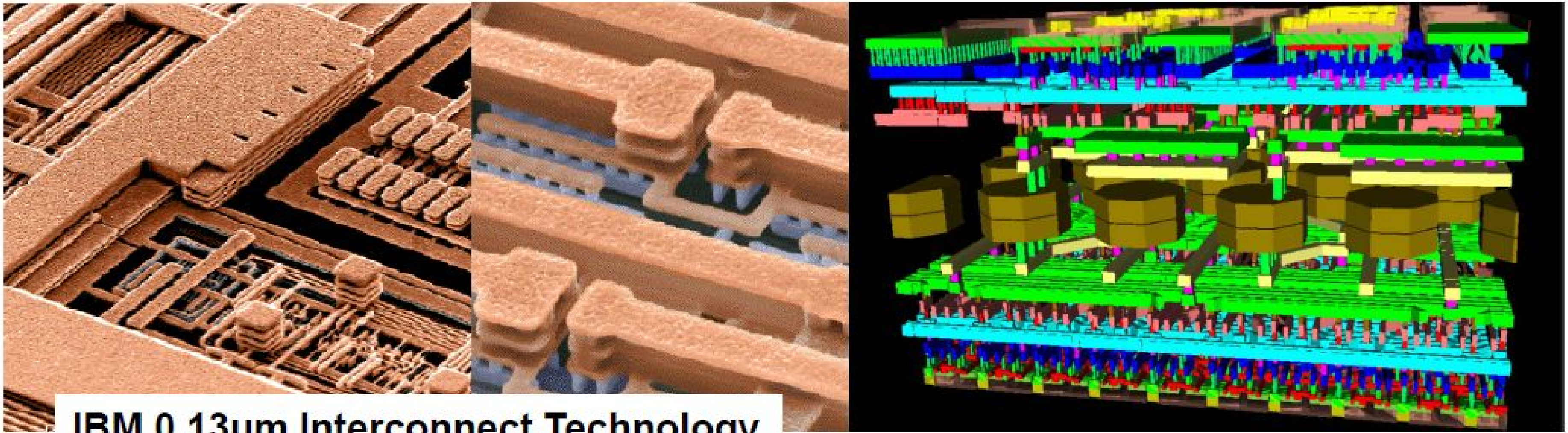
Intro to Characterization → **Observing and/or Measuring**

Intro to Back End Processes → **Final Steps, Transfer from Wafer to chip or final device state**

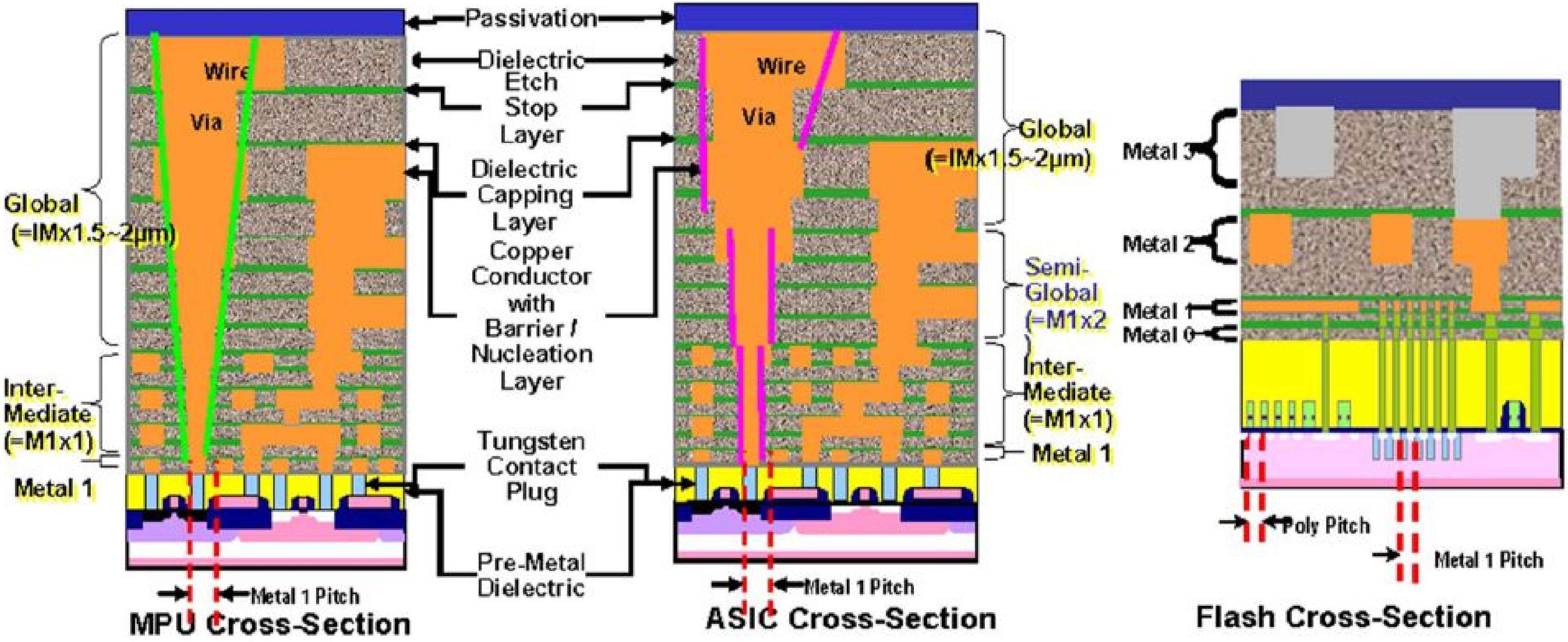
Wafer Process Flow



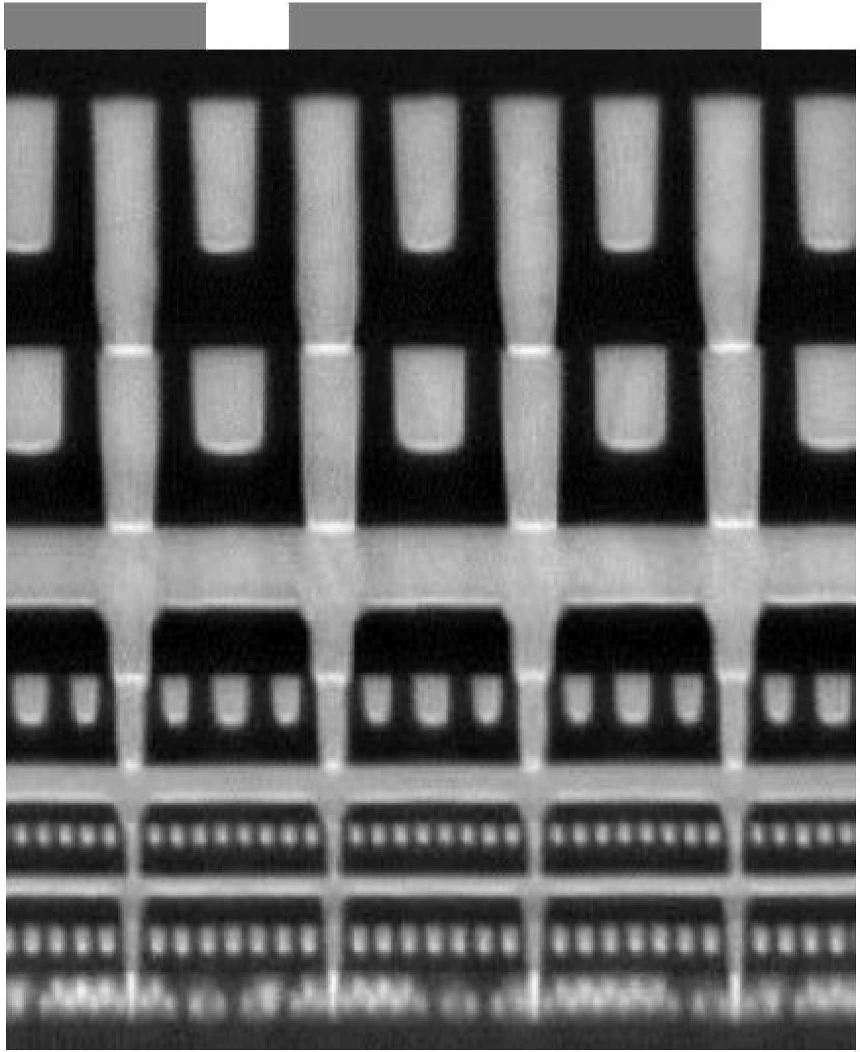

Passivation 2
Passivation 1
Nitride
Oxide
M2
Al•Cu
W
ILD-2, USG
Metal 1, Al•Cu
ILD-1,
BPSG
W-Plug
USG
n+
n+
STI
p+
p+
P-Well
N-Well
P-Epi
P-Wafer

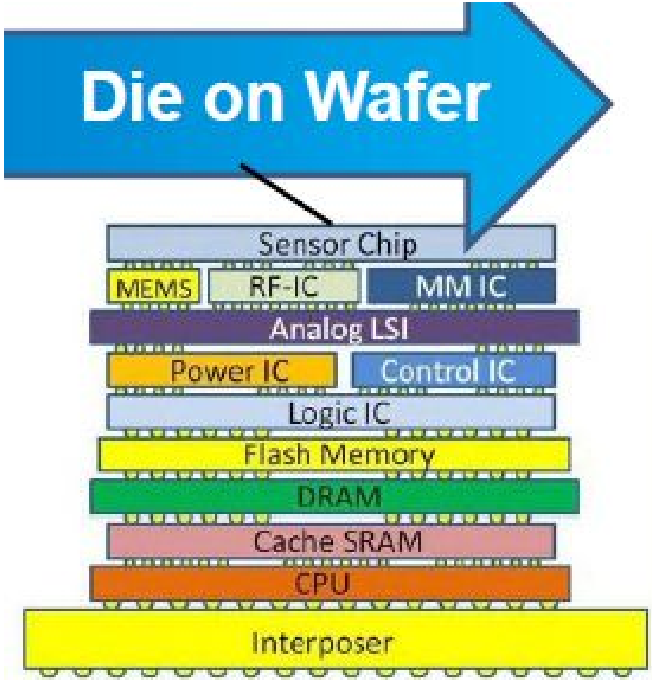


IBM 0.13um Interconnect Technology



Passivation
Dielectric
Etch
Stop
Layer
Dielectric
Capping
Layer
Copper
Conductor
with
Barrier /
Nucleation
Layer
Tungsten
Contact
Plug
Pre-Metal
Dielectric
Wire
Via
Global
(=IMx1.5~2μm)
Inter-
Mediate
(=M1x1)
Metal 1
Metal 1 Pitch
MPU Cross-Section
Semi-
Global
(=M1x2)
ASIC Cross-Section
Metal 3
Metal 2
Metal 1
Metal 0
Poly Pitch
Flash Cross-Section



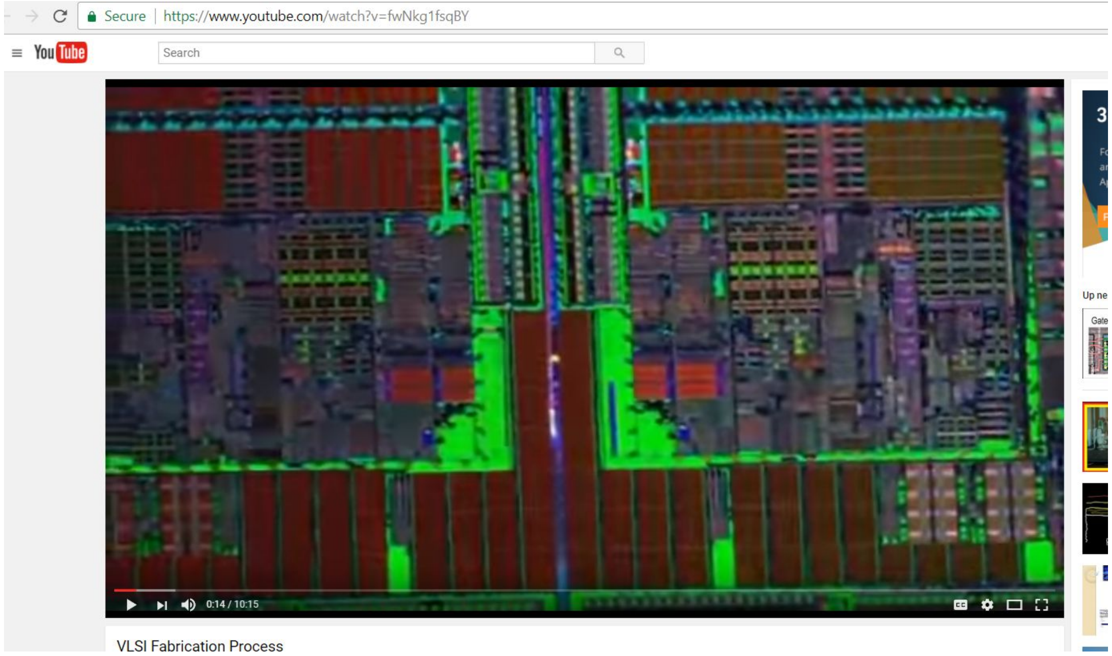


Si Interposer

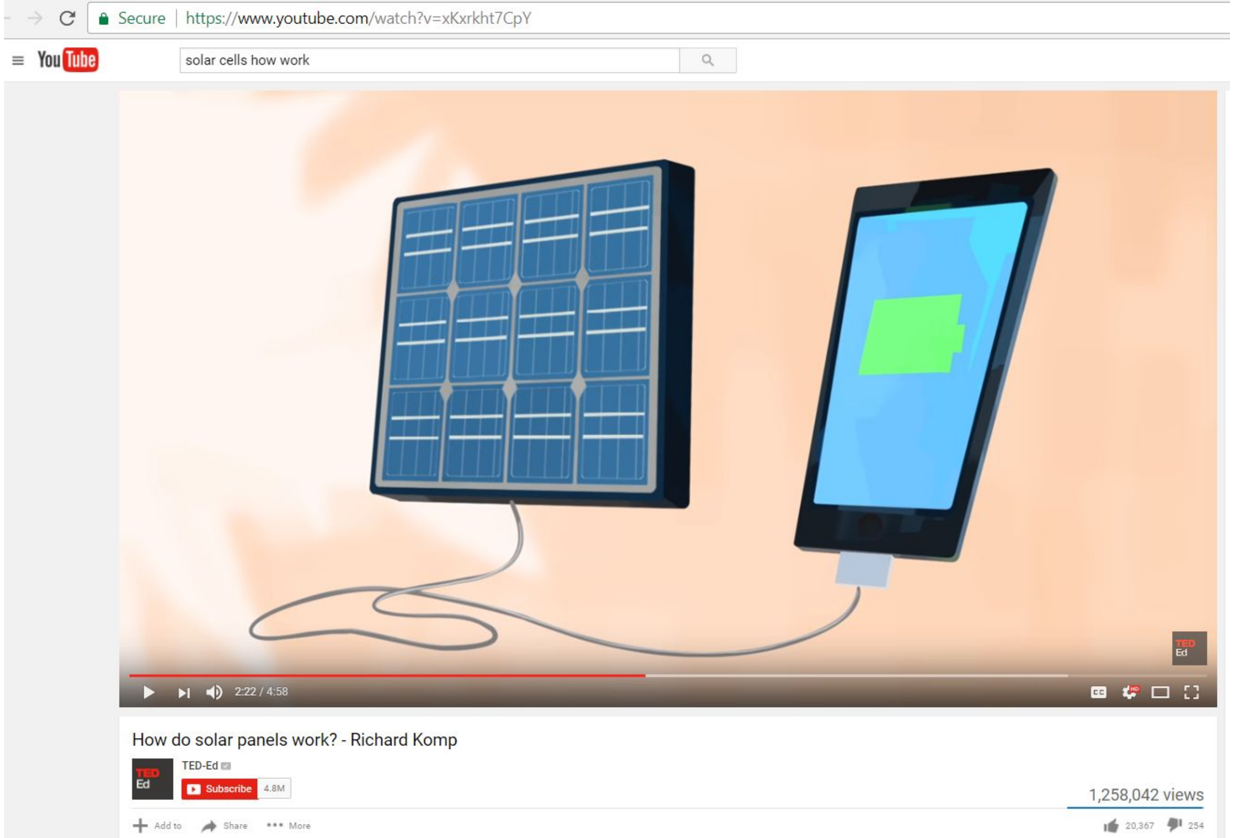
https://www.youtube.com/watch?v=Fxv3JoS1uY8 Zooming into a microchip quick video

And with just a microscope (optical): https://www.youtube.com/watch?v=XEEE1uvkiH0

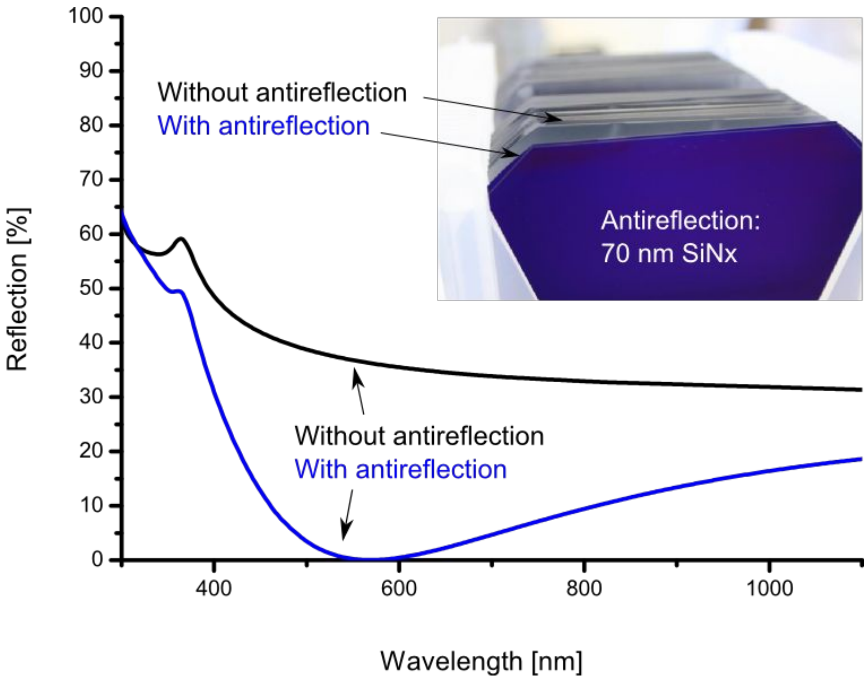
More Exciting Version



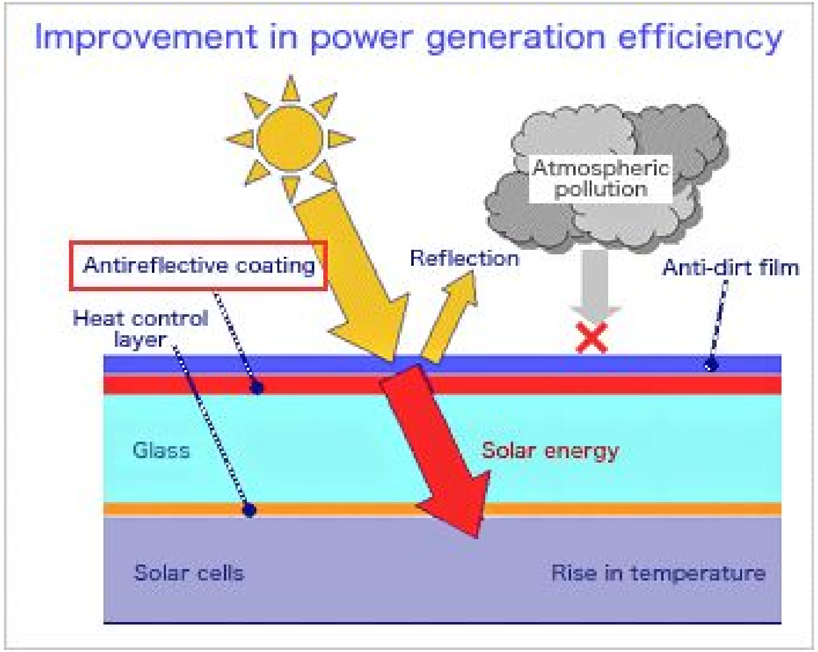
10min: https://www.youtube.com/watch?v=fwNkg1fsqBY



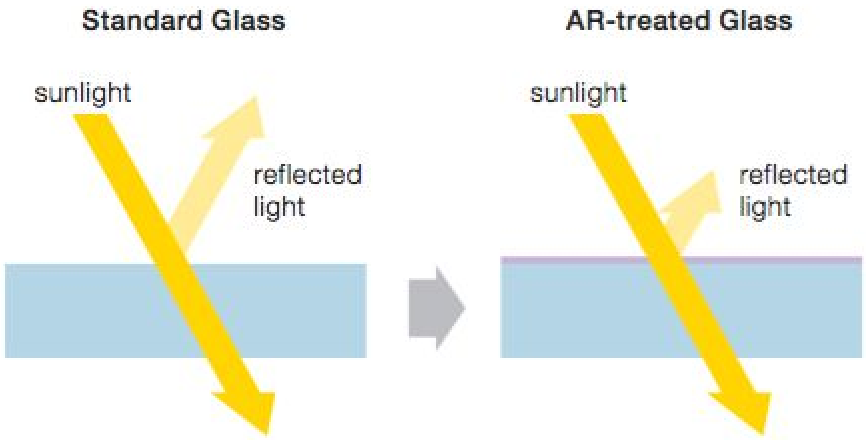
5min: https://www.youtube.com/watch?v=xKxrkht7CpY

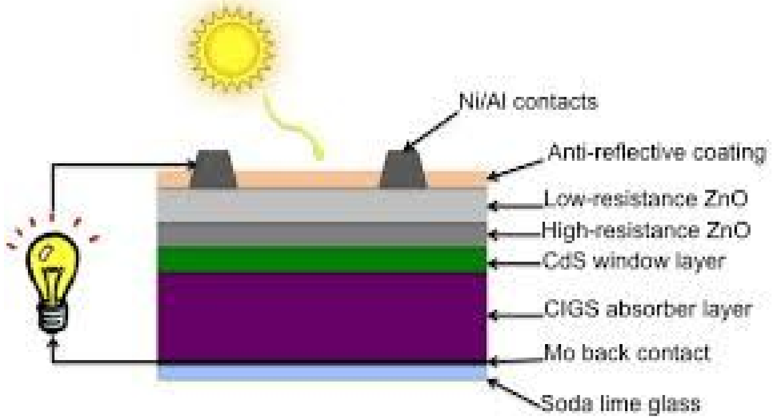


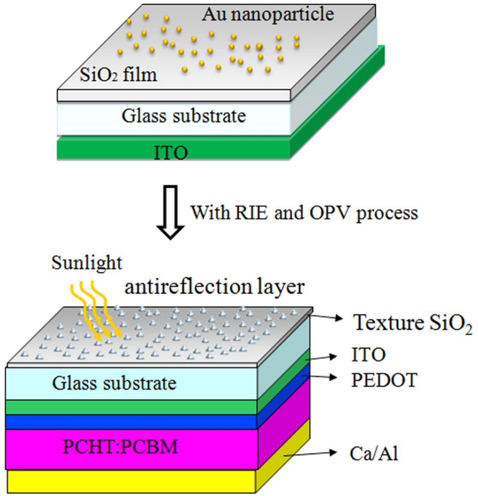
Without antireflection
With antireflection
Antireflection:
70 nm SiNx
Without antireflection
With antireflection
Reflection [%]
Wavelength [nm]
100
90
80
70
60
50
40
30
20
10
0
400
600
800
1000

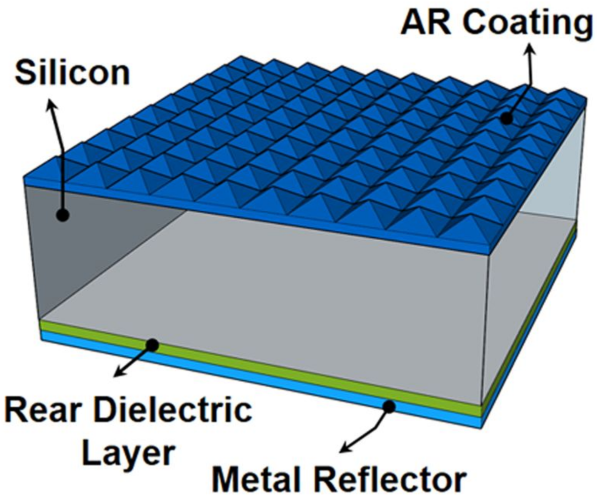


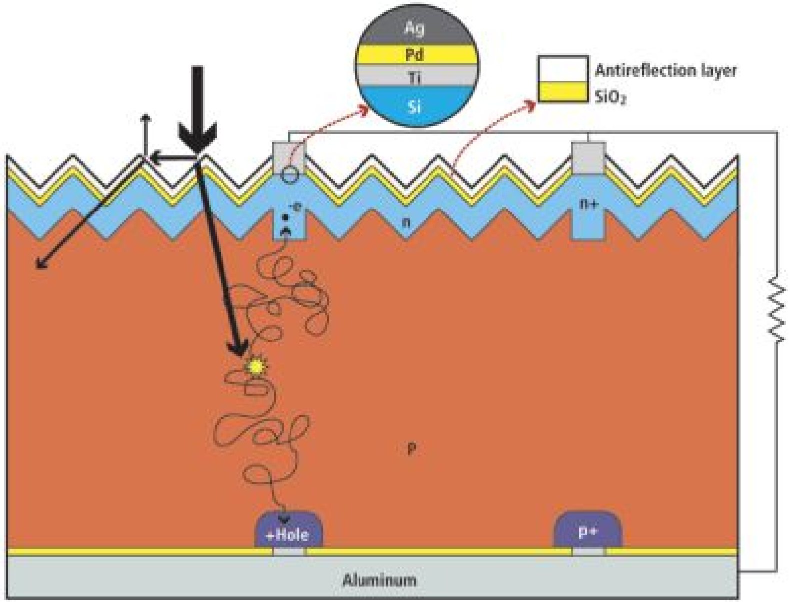
Improvement in power generation efficiency
Atmospheric pollution
Antireflective coating
Reflection
Anti-dirt film
Heat control layer
Glass
Solar energy
Solar cells
Rise in temperature

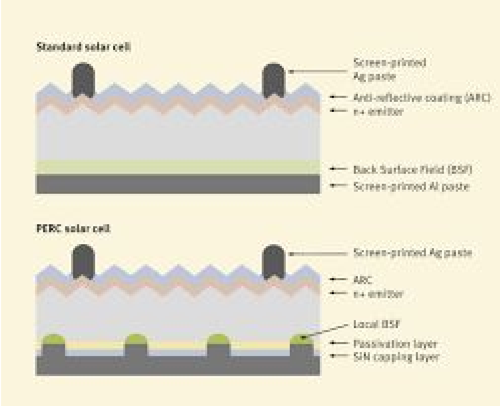

Standard Glass
sunlight
reflected light
AR-treated Glass
sunlight
reflected light

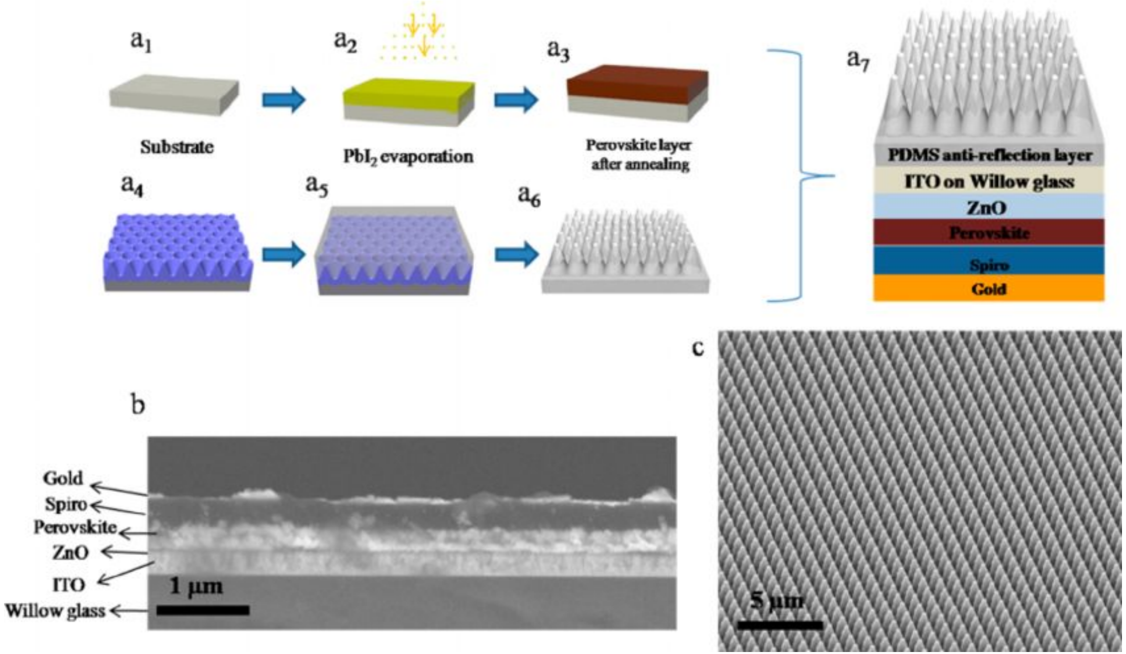

Ni/Al contacts
Anti-reflective coating
Low-resistance ZnO
High-resistance ZnO
CdS window layer
CIGS absorber layer
Mo back contact
Soda lime glass

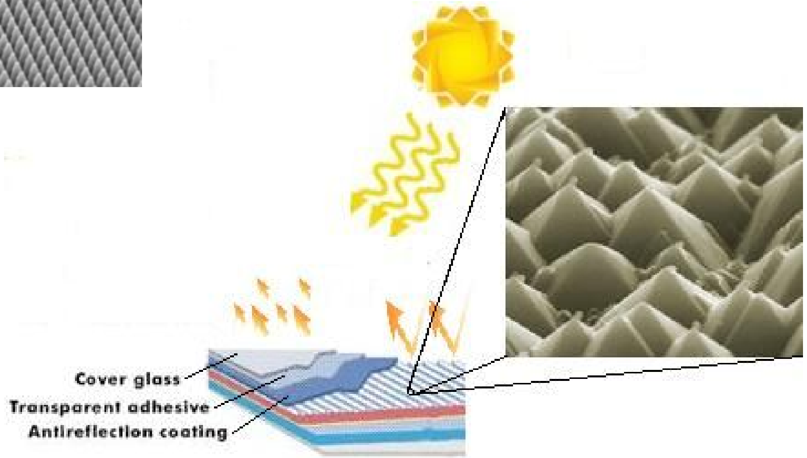

Au nanoparticle
SiO2 film
Glass substrate
ITO
With RIE and OPV process
Sunlight
antireflection layer
Texture SiO2
ITO
PEDOT
Glass substrate
PCHT:PCBM
Ca/Al

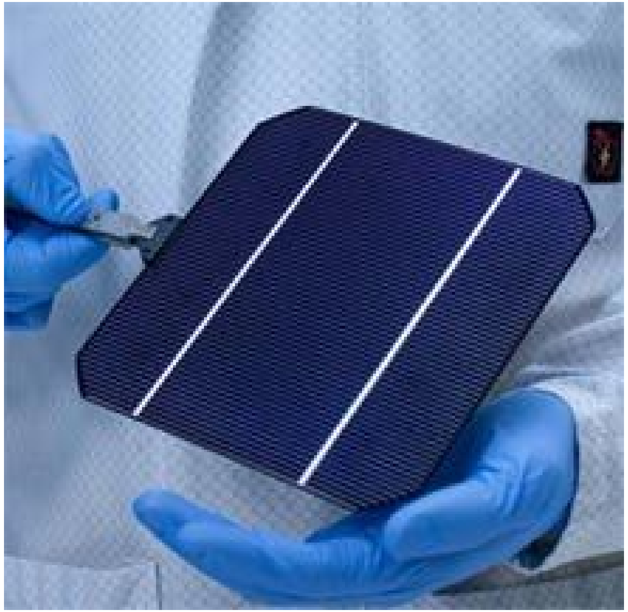

AR Coating
Silicon
Rear Dielectric Layer
Metal Reflector


Ag
Pd
Ti
Si
Antireflection layer
SiO2
n+
n
p
+Hole
p+
Aluminum


Standard solar cell
Screen-printed Ag paste
Anti-reflective coating (ARC)
n+ emitter
Back Surface Field (BSF)
Screen-printed Al paste
PERC solar cell
Screen-printed Ag paste
ARC
n+ emitter
Local BSF
Passivation layer
SiN capping layer


a1
Substrate
a2
PbI2 evaporation
a3
Perovskite layer after annealing
a4
a5
a6
a7
PDMS anti-reflection layer
ITO on Willow glass
ZnO
Perovskite
Spiro
Gold
b
Gold
Spiro
Perovskite
ZnO
ITO
Willow glass
1 µm
c
5 µm


Cover glass
Transparent adhesive
Antireflection coating



Intro to Deposition → **E-beam & Thermal Evaporation, Sputtering, CVD, ALD, MVD, MBE, Plating**

Intro to Photolithography → **Spin Coating, UV Exposure, Developing, E-beam Lithography, Nanoimprinting**

Intro to Etching (Wet and Dry) → **RIE, ICP-RIE, DRIE, Ion Milling, CMP, O2 Ashing**

Intro to Characterization → **AFM, SEM/FIB, TEM, Surface Profilometry, Ellipsometry, Optical Microscopes**

Intro to Back End Processes → **Wire Bonding, Dicing, Packaging**