Device Fabrication
(or how the detectors for your experiment get made) - Part 2

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UK Instrumentation Lectures

Outline of Lectures

Lecture 2

- Brief look at why Silicon detectors* are used
- Outline of the steps used to fabricate a microstrip detector
  - PhotoLithography
  - E-beam Lithography
  - Resists
  - Applications of E-beam lithography
  - Additive/Subtractive Processes
    - Lift Off
  - Etching
    - Wet
    - Dry (Plasma & ICP)
    - FIB
  - Doping
- Cleanrooms and Specifications
- New Detector geometries (3D, edgeless, TSV)

** Other semiconductors are available*

What Now?

Two types of process are possible after a lithography step

- Additive
  - Putting down metals
  - Adding to surface of material in any way
- Subtractive
  - Removal of metals or dielectric layers from exposed areas

Metal Deposition

The first task of the processing is deposit metal on the surface of your sample

There are a range of systems that can do this:

- load-locked electron beam evaporation tools
- multi-target sputtering systems

Common metals deposited by evaporation include Au, Ti, Pd, Pt, Al, Ge, Ni and NiCr.

Can deposit ~10nm-150nm of metal

Metal Deposition - Preparation

- Before or depositing or 'flashing' any metal on to a surface, the surface itself must be very clean
- Example, Si will naturally form an oxide layer on top over time, which would be a barrier to the conducting material deposited on top
- We need to clean (etch) the surface of the material before deposition
- Usually, for Si we use HF – Hydrofluoric Acid

HF – An Aside

- HF (Hydrofluoric Acid is a particularly nasty chemical
  - Used for wet etch on Si
  - But often used in samples to prepare/clean surface before metal deposition

Guidelines for the Safe Use of Hydrofluoric Acid

A. Introduction

Hydrofluoric acid (HF) has a number of physical, chemical, and toxicological properties that make it especially hazardous to handle. Both anhydrous hydrofluoric acid and aqueous solutions are clear, colorless, and highly corrosive liquids. When exposed to air, anhydrous HF and concentrated solutions produce pungent fumes, which are also dangerous. HF shares the corrosive properties common to mineral acids, but possesses the unique ability to cause deep tissue damage and systemic toxicity.

Prevention of exposure or injury must be the primary goal when working with HF. However, any HF user must be intimately familiar with the appropriate first aid in case of an exposure.

Lesson?

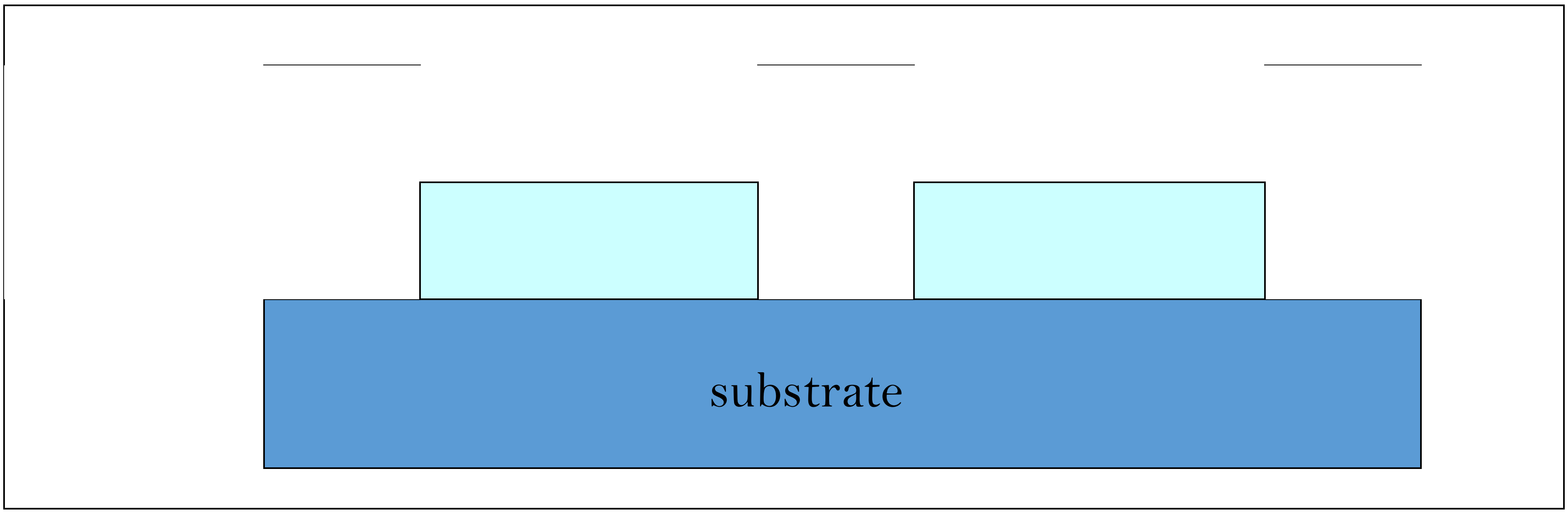
- As 'boring' as it may seem, aways pay attention to safety, and hazard issue cleanrooms

Control of Substances Hazardous to Health (COSHH)

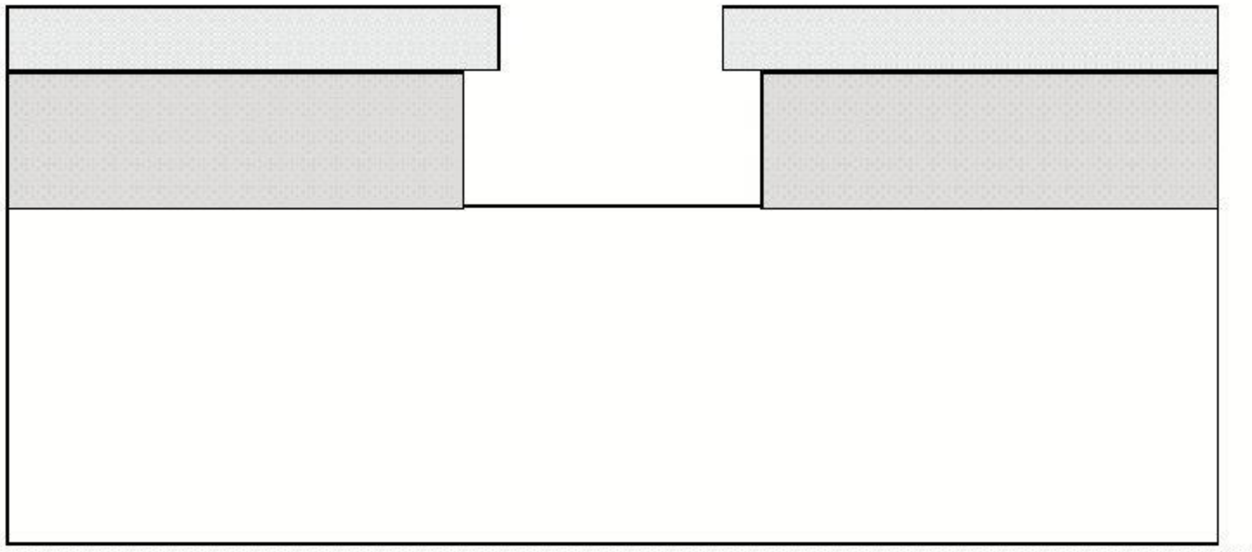
- COSHH is the law that requires employers to control substances that are hazardous to health. You can prevent or reduce workers exposure to hazardous substances by:
- finding out what the health hazards are;
- deciding how to prevent harm to health (risk assessment);
- providing control measures to reduce harm to health;
- making sure they are used ;
- keeping all control measures in good working order;
- providing information, instruction and training for employees and others;
- providing monitoring and health surveillance in appropriate cases;
- planning for emergencies.

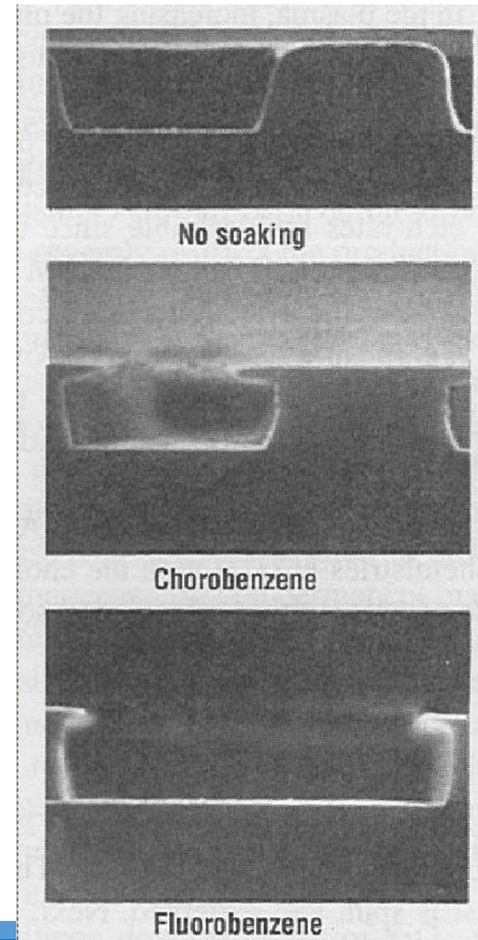
Additive Processes

The most common additive process is lift-off



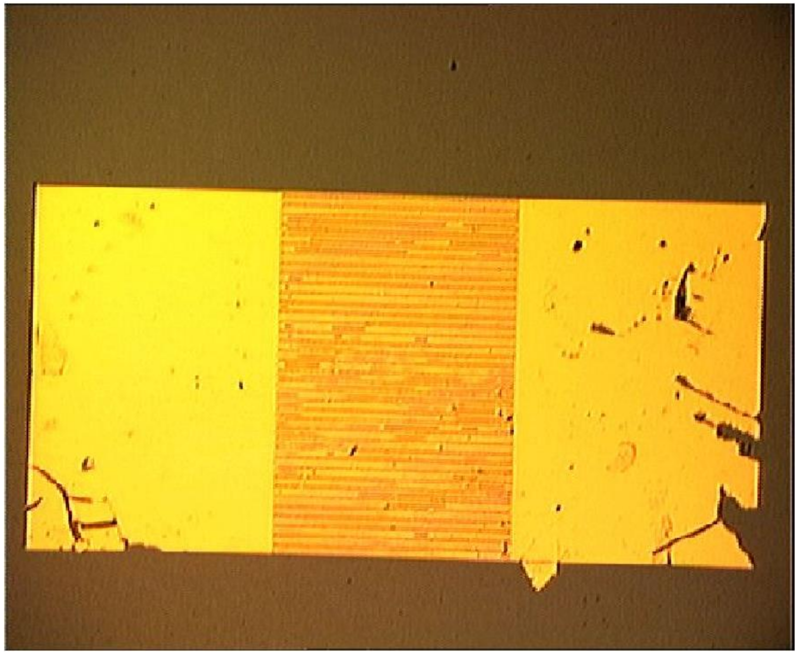
Additive Processes

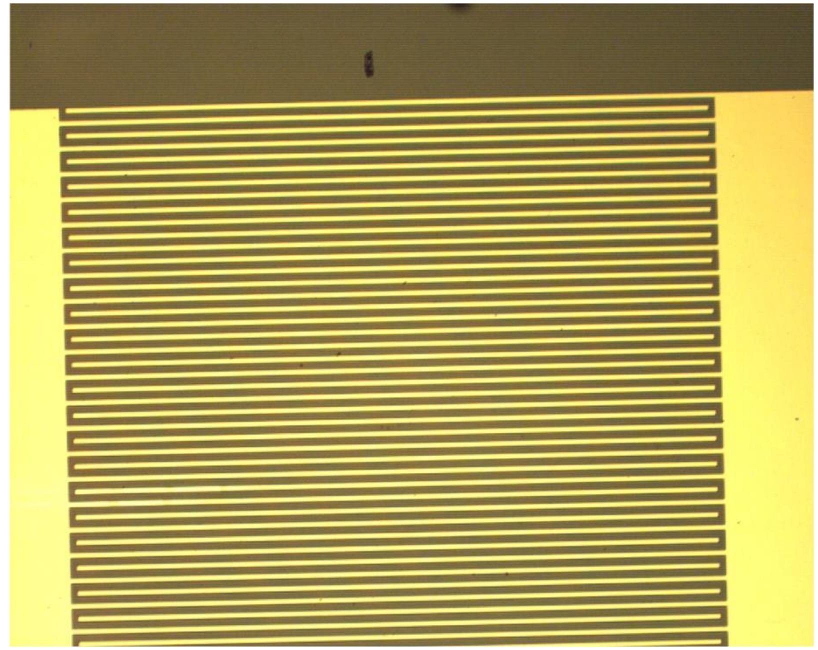




Above: bi-layer of resist for e-beam resist
Right : Effect of chemical soaks on photoresist

Lift off – Good + Bad





Improvement in lift-off using (right) bi-layer resist

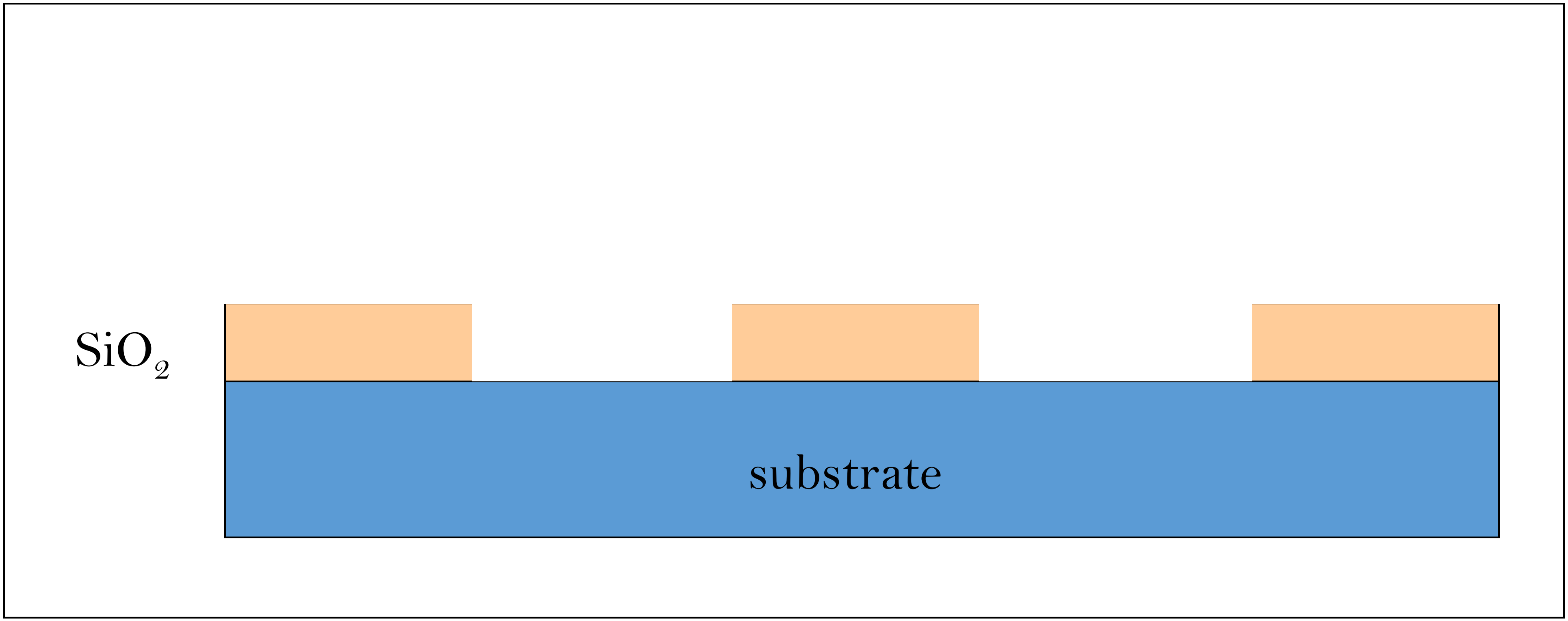
Additive Processes

Lift off is mostly used for defining metal layers.

- Advantages
  - No strong/ corrosive chemicals
  - Accurate edge definition
- Disadvantages
  - Significant failure rate
    - There are ways to improve the repeatability

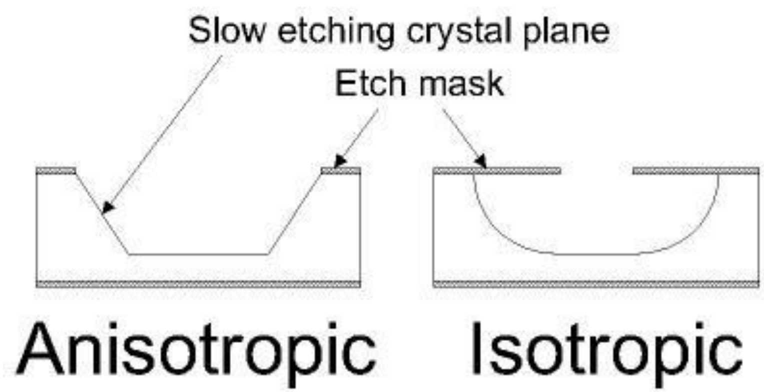
Subtractive Processes

Etching using wet or dry chemistries



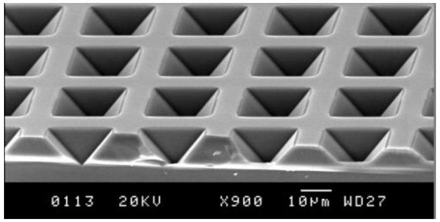
Subtractive Processes

- Can be used to pattern most materials
  - Metals, di-electrics, semiconductor materials
- Two separate processes are used
- **Wet** chemical etch (isotropic) or **Dry** plasma etch (anisotropic)



Wet Etching

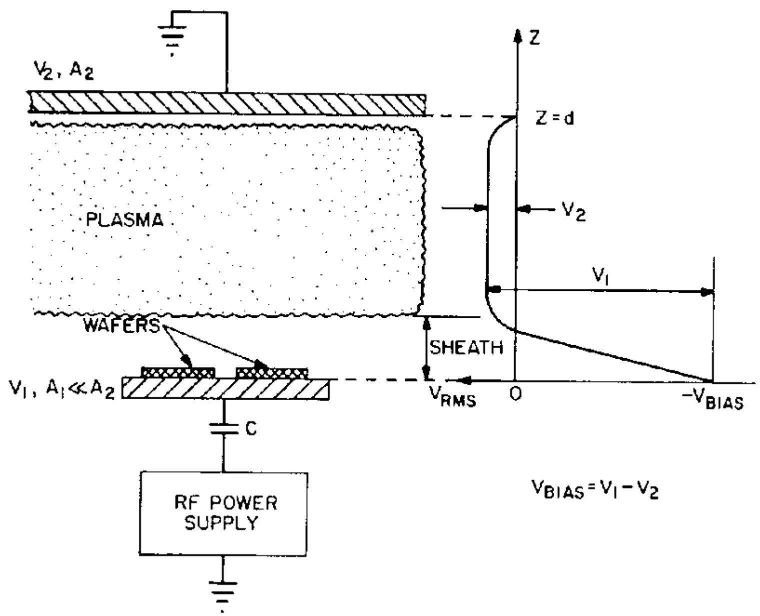
- Wet etching: uses liquid chemicals to transfer pattern
  - Acid or alkaline solutions used depend on material being patterned:
    - HF for SiO_2, KOH for Si, any alkali for Al etc
- Fast process with very well-known chemical processes available for most materials
- Wet etching is isotropic
  - Etches at the same rate in all directions, unsuitable for very small features
- Not all materials have a suitable wet etch chemistry available



HCl wet etch

Dry Etching

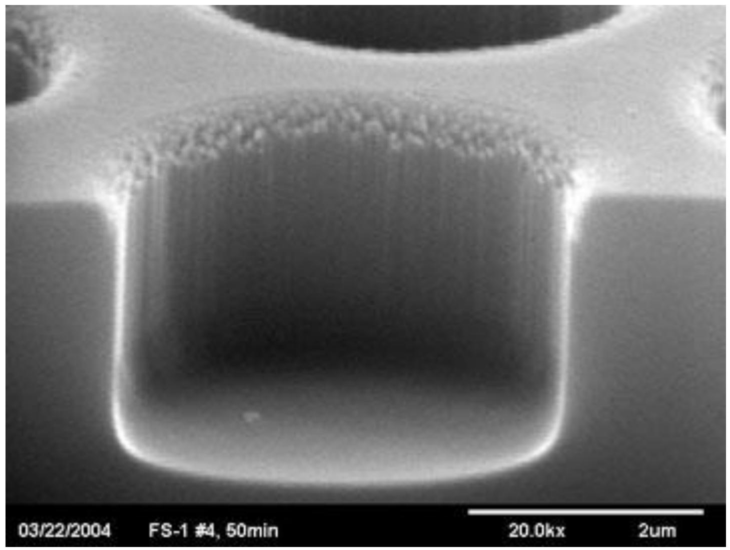
- Dry etching: uses a 'dry' plasma to remove unwanted material
  - An RF discharge is used to crack a pressurised gas into a number of reactive and neutral species
  - The electrical field accelerates the ions toward the sample material, causing physical sputtering and chemical removal



Schematic of reactive ion etching (RIE) plasma reactor

Dry Etching

- Process is anisotropic
  - Suitable for small or densely packed features
- Everything can be etched using plasma
  - Even if it is sometimes very slow
- Process is very hard on masks



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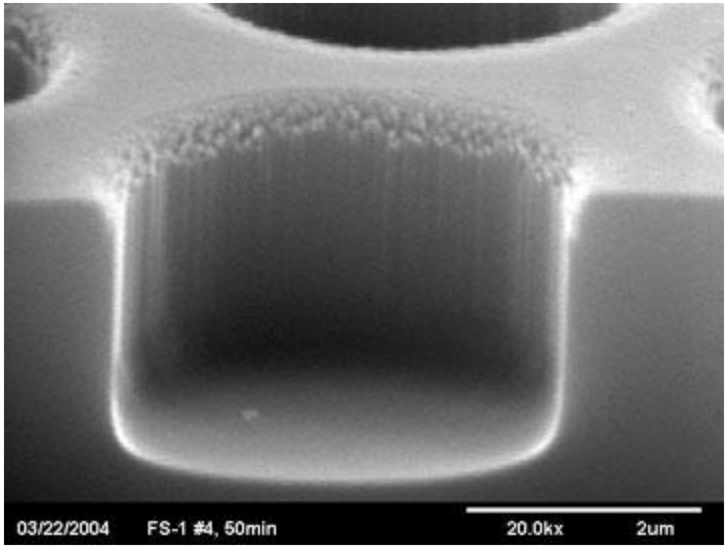
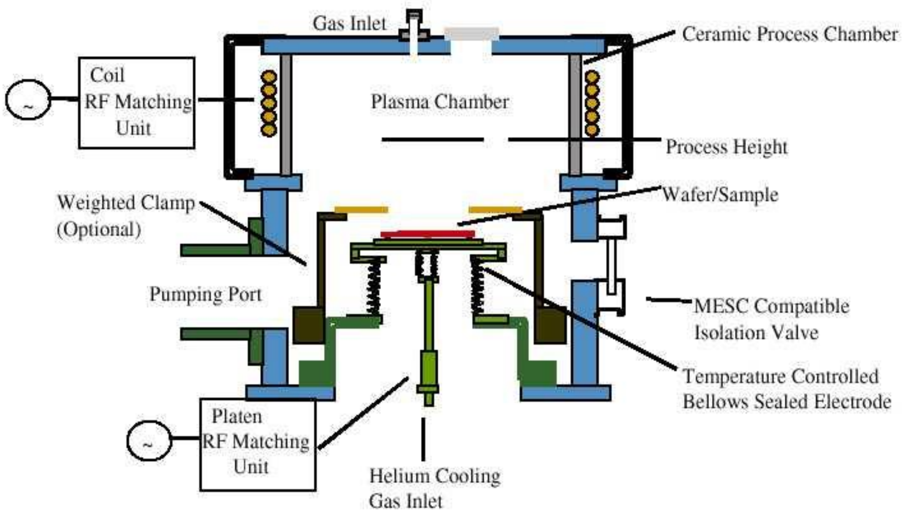


ICP Etching

- Inductively Coupled Plasma
  - High density plasma source for deep reactive ion etching of materials

- Bosch Process
  - Use of alternative gases for cycles of passivation and etching

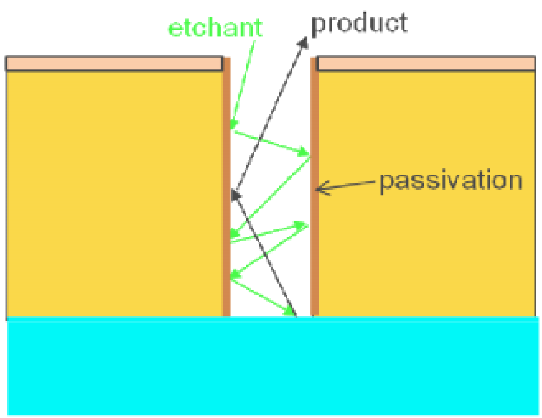


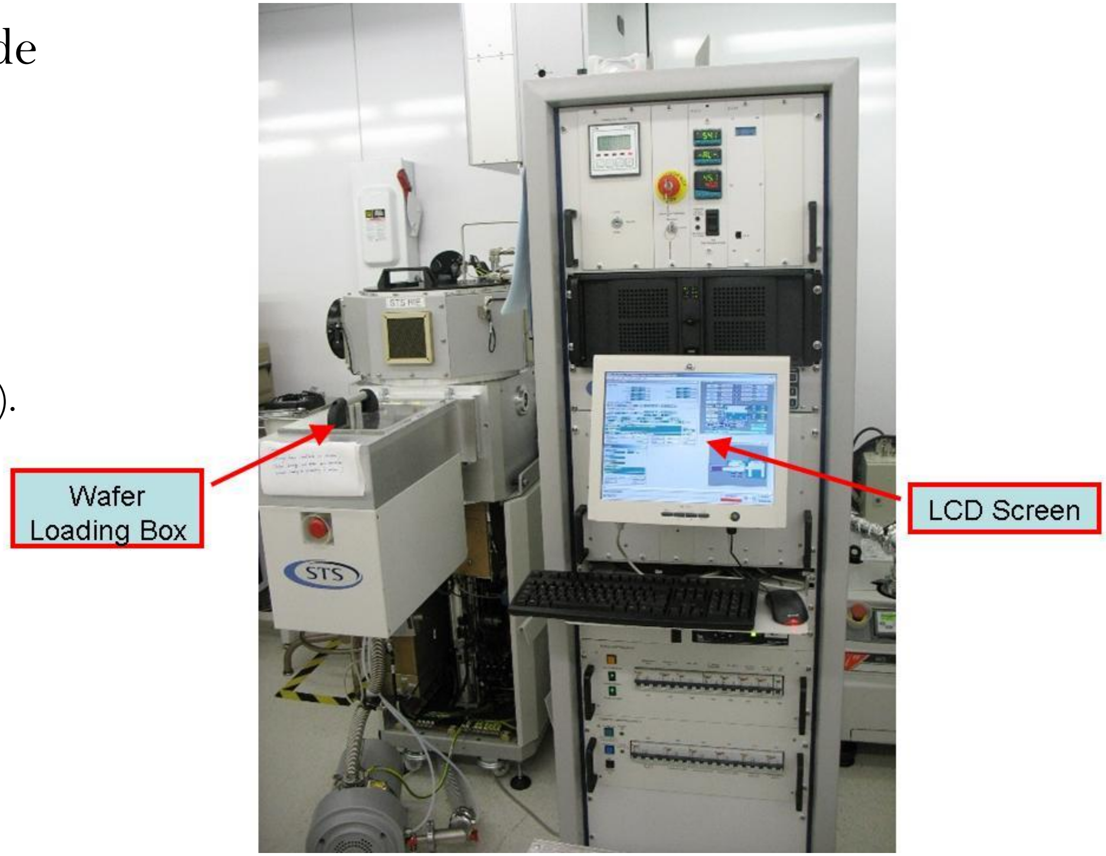
- ICP used to produce denser plasma and faster etching
  - Uses 2 RF discharges, one to excite the plasma & one to accelerate the ions
- Faster etch rates
- Tougher on mask material

Inductively Coupled Plasma

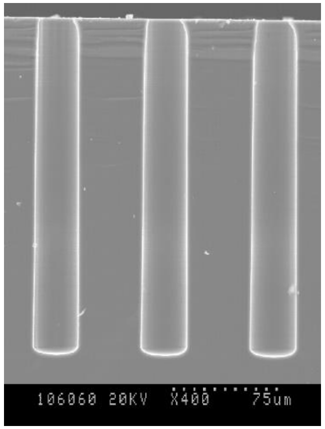
- These machines have 1 major advantage
- They can operate in a 'switched' mode
  - 1 Cycle etches the surface
  - 1 Cycle passivates the sidewalls

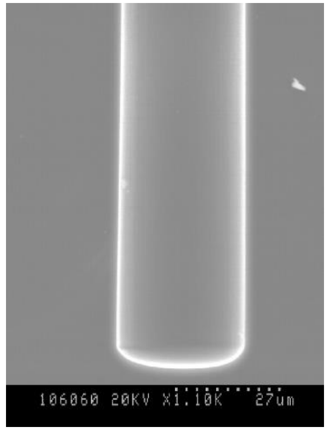
Typical Etch mechanisms:
sulfur-hexafluoride (SF_6) or the combination of tetrafluoromethane (CF_4) mixed with oxygen (O_2).

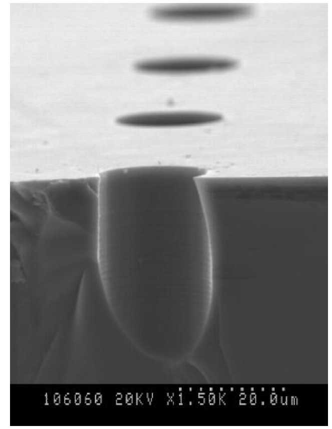


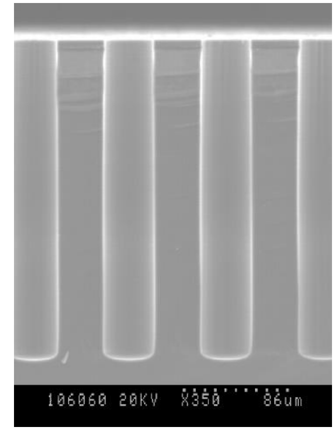


ICP Etching

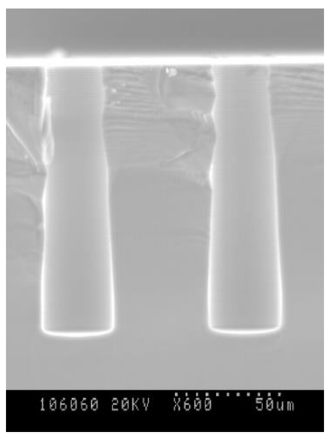

106060 20KV X400 75um


106060 20KV X1.10K 27um

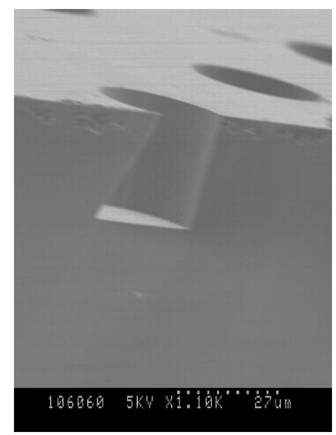

106060 20KV X1.50K 20.0um


106060 20KV X350 86um


106060 20KV X2.50K 12.0um

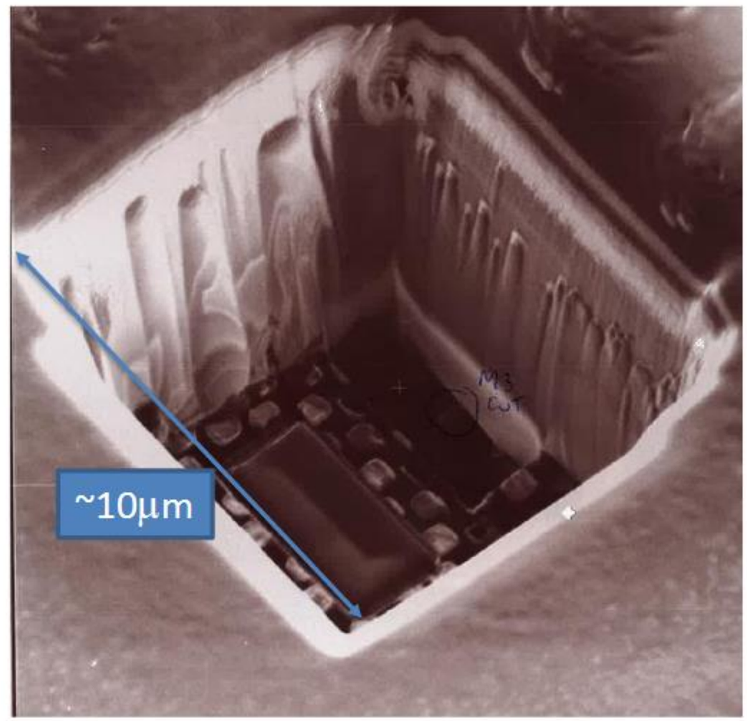

106060 20KV X600 50um


106060 20KV X2.49K 12.5um


106060 5KV X1.10K 27um

Focus Ion Beam (FIB)

- FIB: uses Focused Ion beam (Ar) to remove (with precision) areas of a sample
  - Most commonly ASICs
  - An example below is a CMOS chip where the wrong connect made in one of the metal layers below the oxide layer
    - Remove oxide layer
    - 'Cut' metal track



Next Step

- How do reduce our leakage current and noise sourced from our surfaces?

- How do we isolate our doped areas?

Introduce an insulator

$$SiO_2$$

SiO_2 layers

- Thermal growth
  - Increases thickness of natural oxide
- Deposition
  - Uses a chemical process to produce thick layers of SiO_2

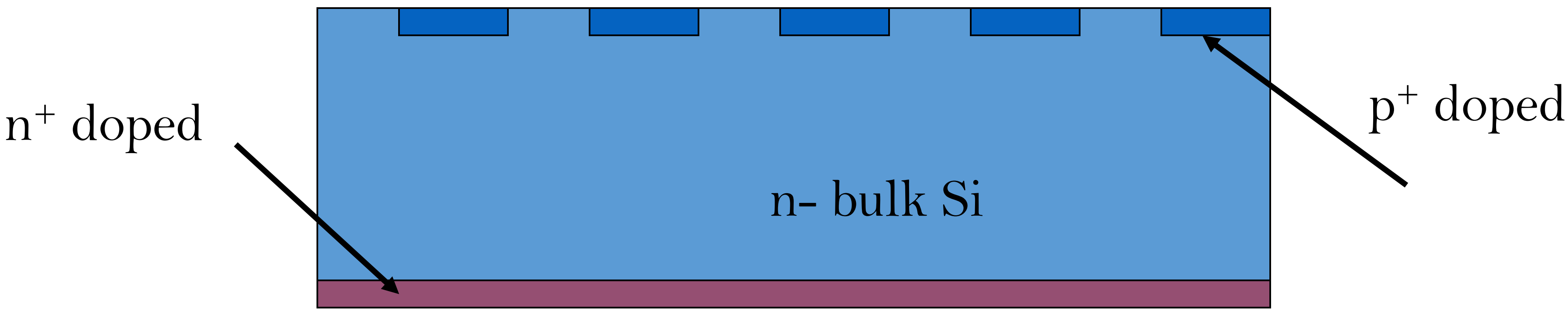
Final Stage

- We've made our metal contacts
- We've made out oxide regions
- We've etched out bulk silicon
- What's left?

Doping

Doping Silicon

Heavily doped p^+ layer
$\sim 10^{18}$ cm^{-3} concentration of boron (B)



phosphorous (P) doped to produce n^+ region

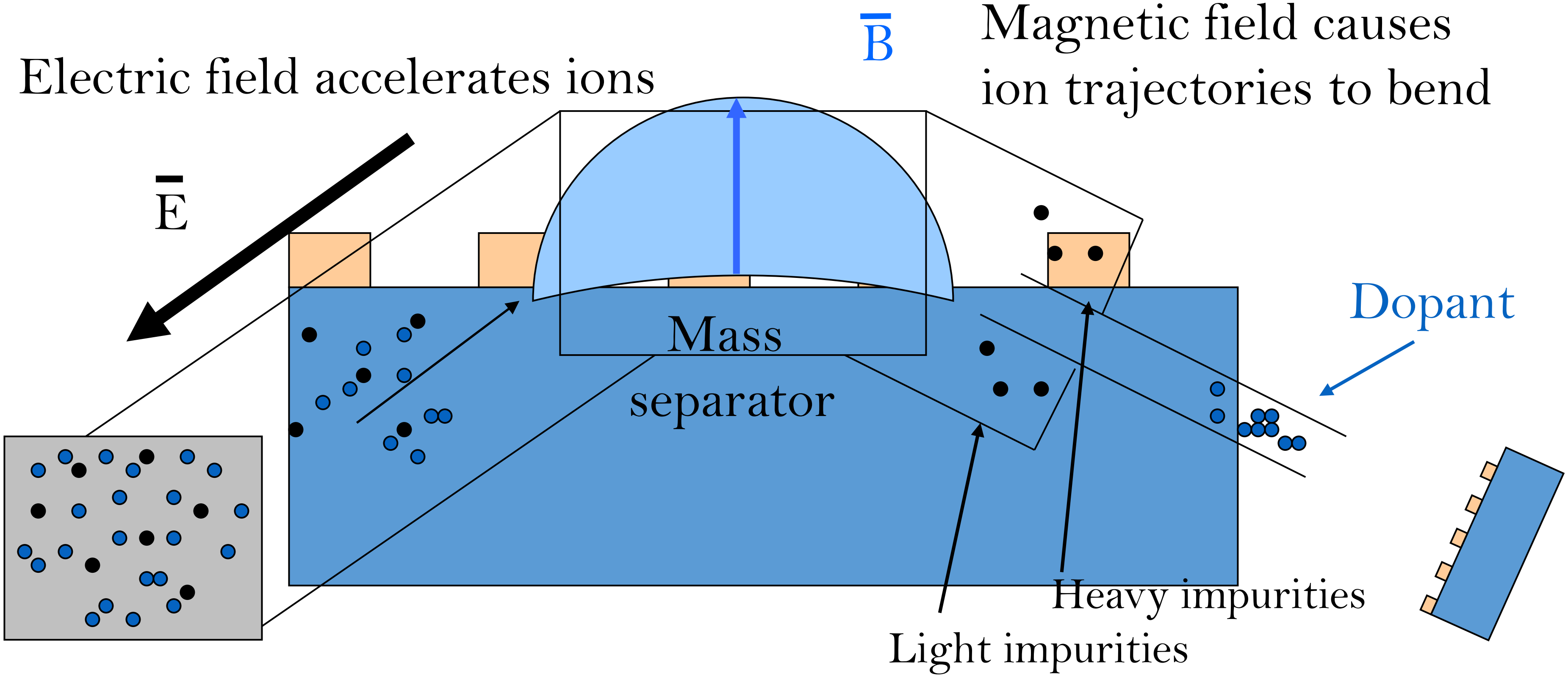
Doping Silicon

Three main methods

- Gas diffusion
- Diffusion from a solid
- Ion implantation

Doping Silicon

Ion implantation



Ion source creates +ve charged ions

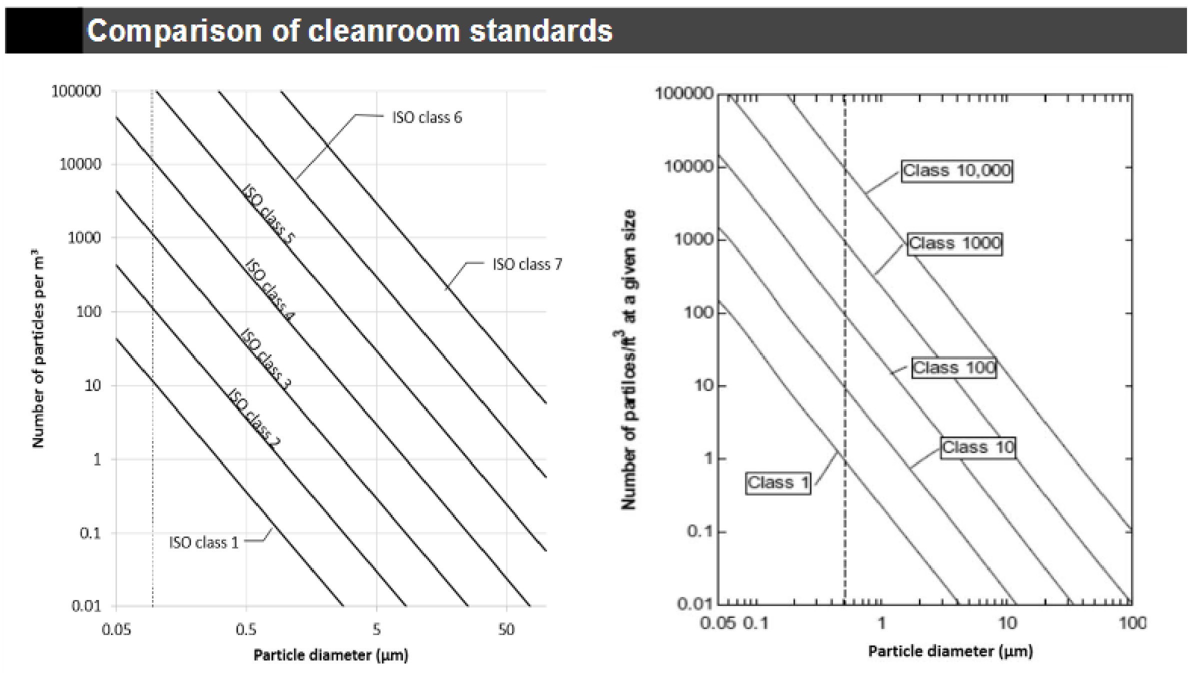
Doping Silicon

Implants are produced using ion implantation

- Implant geometry is very precise
  - In all three dimensions
- Dopant element is uncontaminated
  - Single chosen element due to mass separation
- Higher concentrations are possible than other methods of doping
  - Infinite source and no reliance on thermal processes to move dopant into Si

Were does this all happen?

- In very, very, clean rooms
  - Appropriately called '**cleanrooms**'
- How clean?



Cleanrooms

Class 10 000 area (Bio, Photochemical, MEMS, Photolith cabinets)

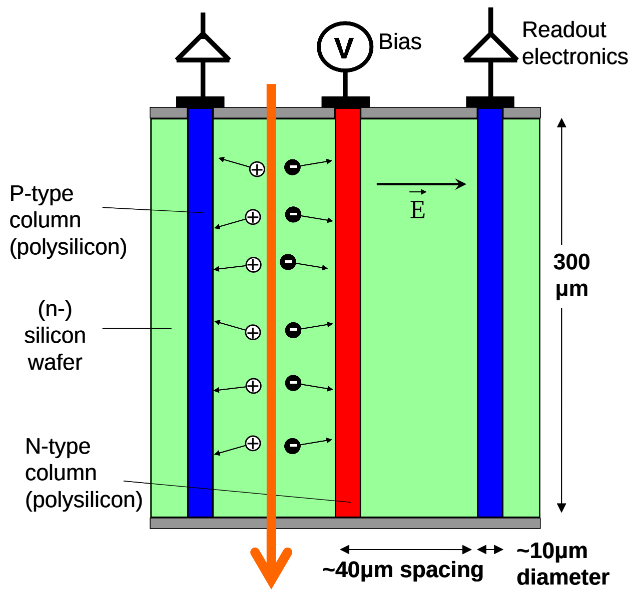
New Geometries

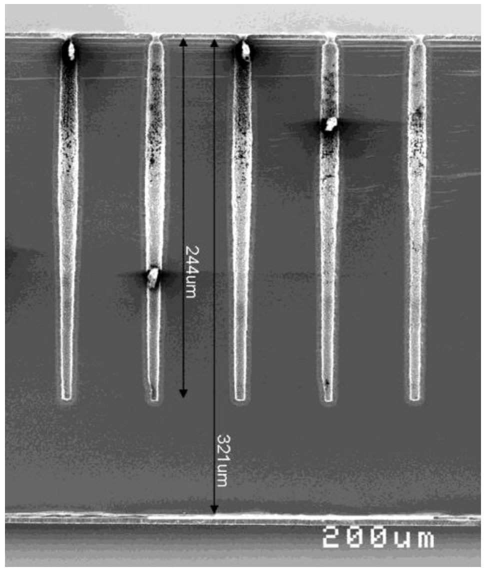
- Several new types of detectors are under research for their use as particle detectors
  - All utilise fabrication techniques

- 3D Detectors
- Edgeless Detectors
- Thru Silicon Vias (TSV)

3D Detectors

- A 3D detector is a photodiode with closely-spaced electrode columns. This leads to very fast charge collection and low depletion voltages.
- Due to their high radiation tolerance, 3D detectors are being developed as pixel detectors for the HL-LHC.
- Different 3D structures are being designed in collaboration with other institutions, simulated, and tested with LHC-speed readout electronics





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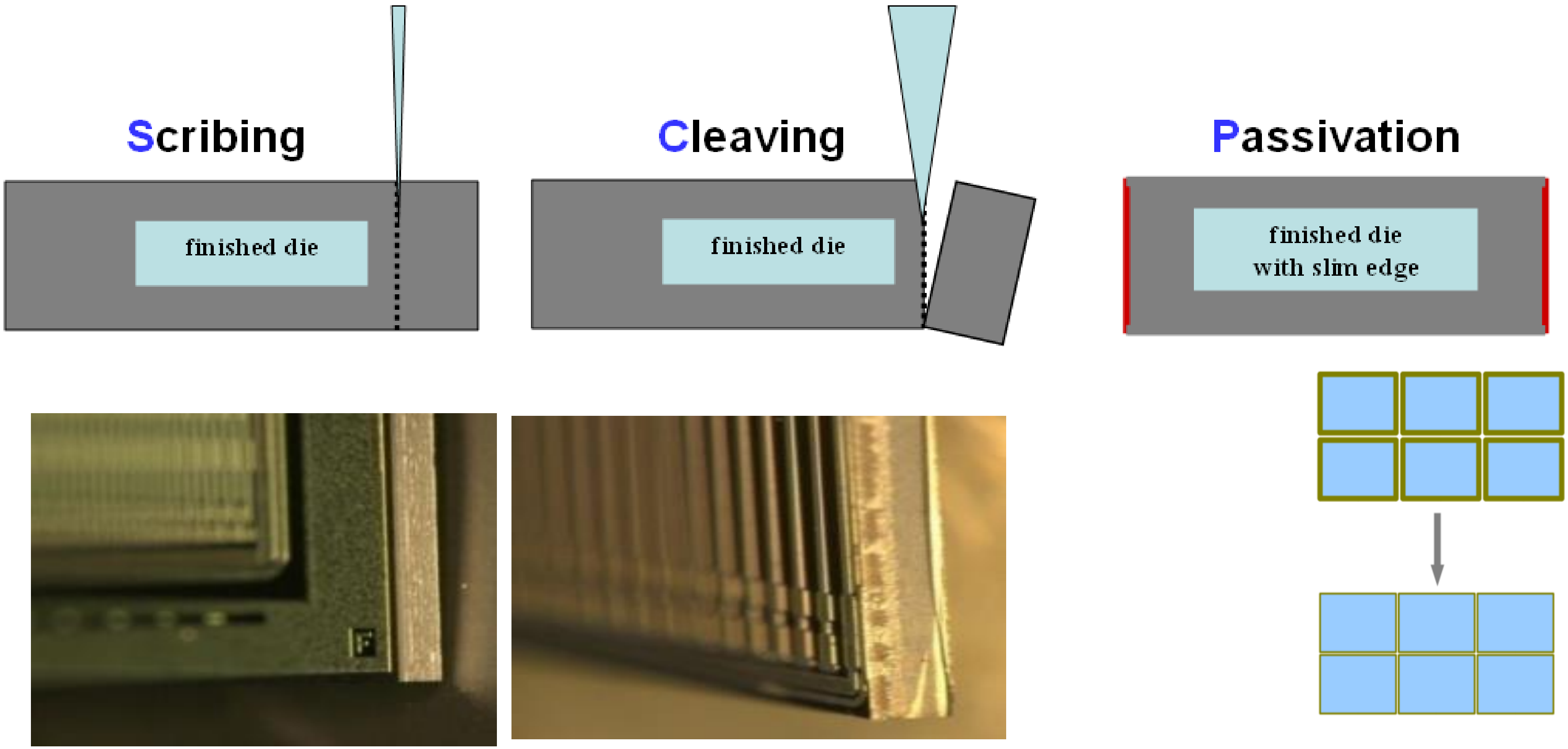
Edgeless Detectors

- To minimize the dead areas between the end of the detecting area and the cut edge, the dead areas is “Scribed”, then “Cleaved”, then “Passivated” to readuces edge effects



ATLAS ITk

TSV (Thru Silicon Vias)

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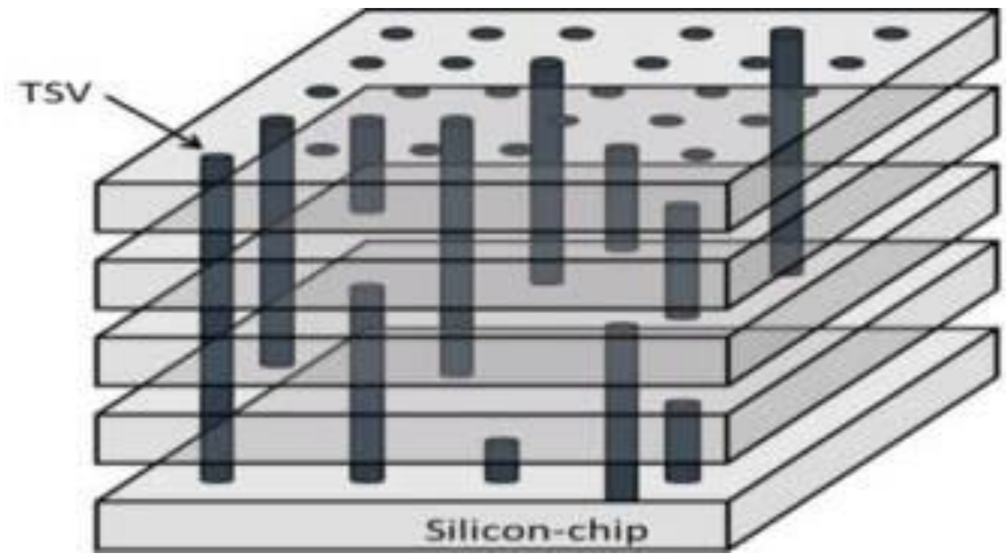
- A through-silicon via (TSV) is a vertical electrical connection (via)(Vertical Interconnect Access) passing completely through a silicon wafer or die.
- TSVs are a used to create 3D packages and 3D integrated circuits



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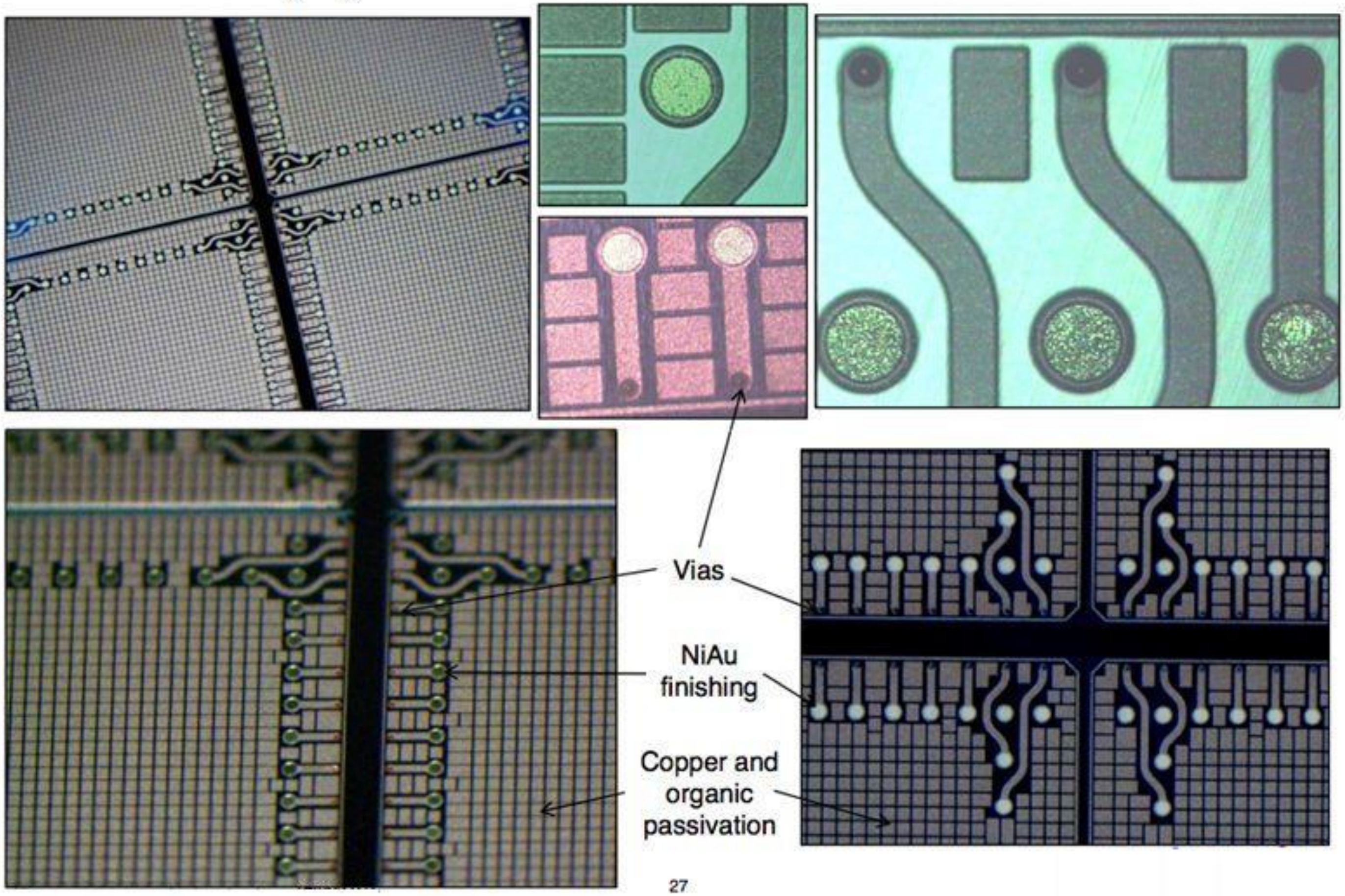
HDI Example: TSV



All Together Now..

- All of these processes are carried out for **every single detector**.
  - Each wafer will go through multiple lithography/ metal and SiO_2 deposition steps.
  - Multiple etching steps are also used
- A wafer will go through over **100 individual steps** before it is complete

All Together Now..

- One single failure at any stage can cause a wafer to be discarded.
  - A single grain of dust can destroy an entire wafer

In Conclusion

- Most of you won't be doing any fabrication
  - This is an attempt to make you appreciate it
- You will all probably be analysing data gathered using detectors fabricated this way
  - That bit is your problem ;)