Lec 2. Fabrication

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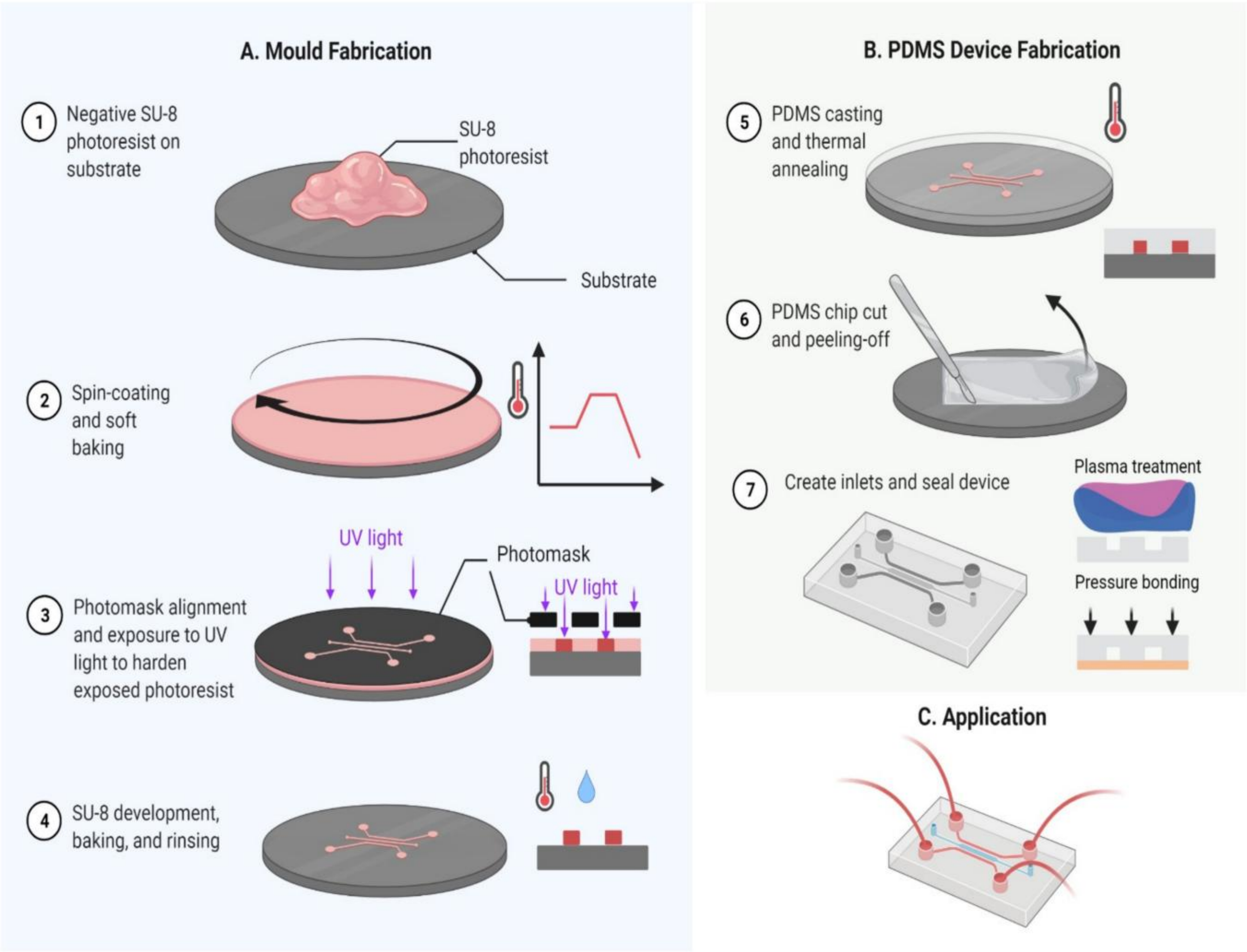
Lecture overview

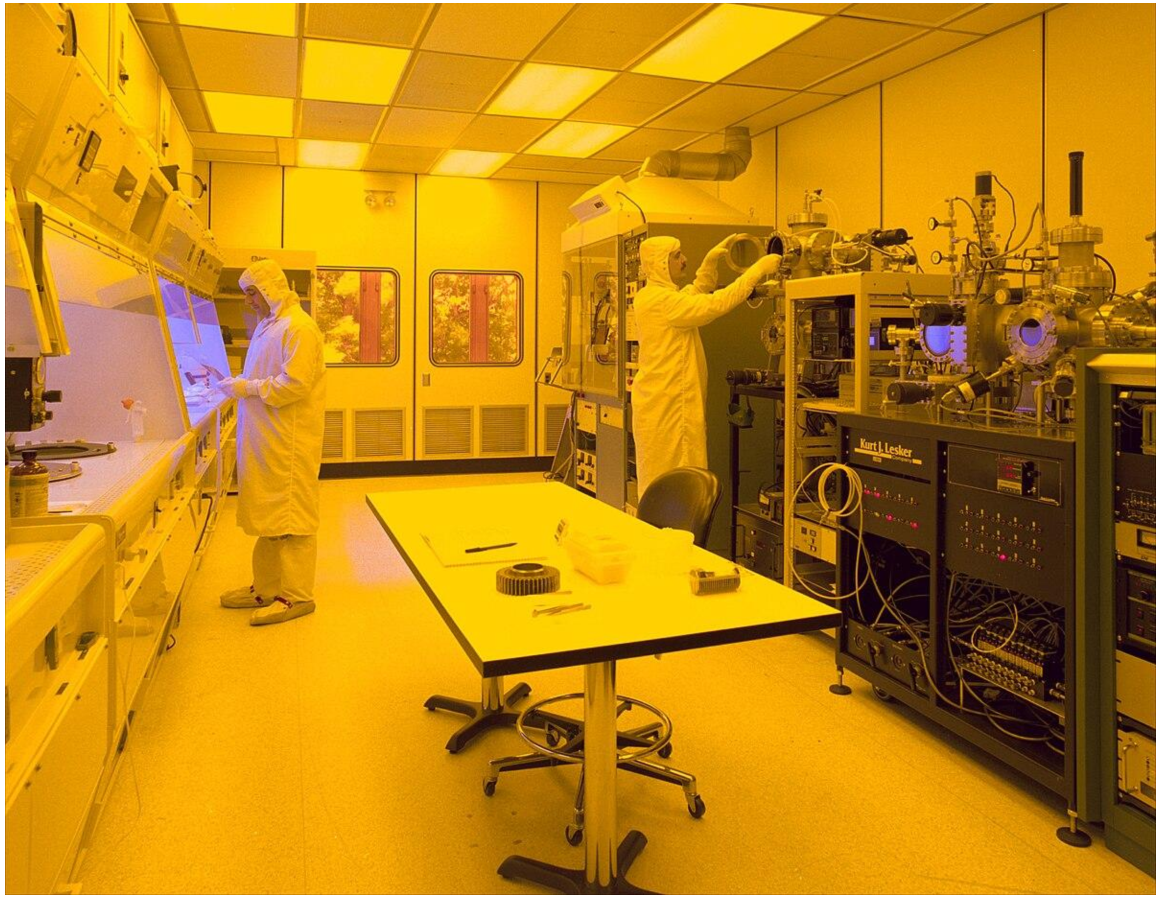
1. Photolithography using SU-8
2. Soft lithography

Process Overview

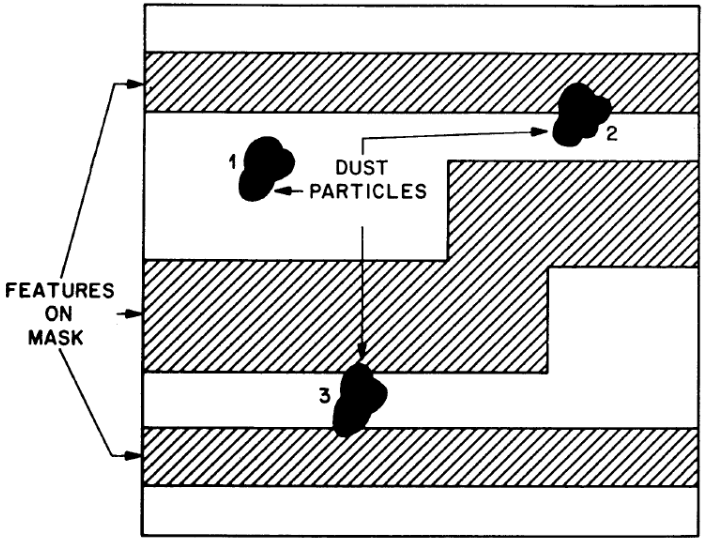


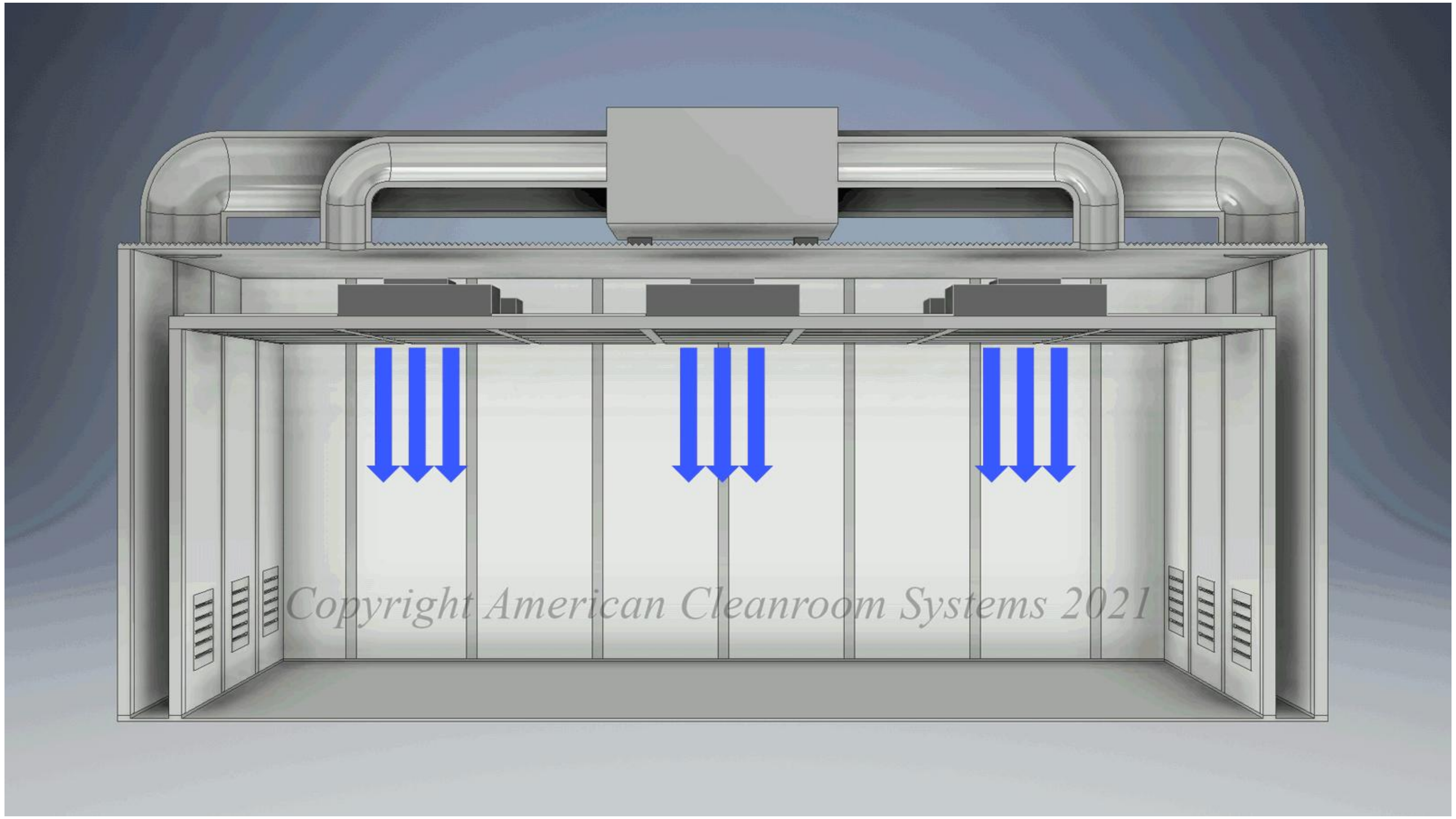
Clean room

- Clean
- Yellow light
  - minimal UV exposure



Clean room-Why





Clean room class

- A class X clean room is usually defined to be one that has a dust count of X particles (diameters of 0.5 μm or larger) per cubic foot

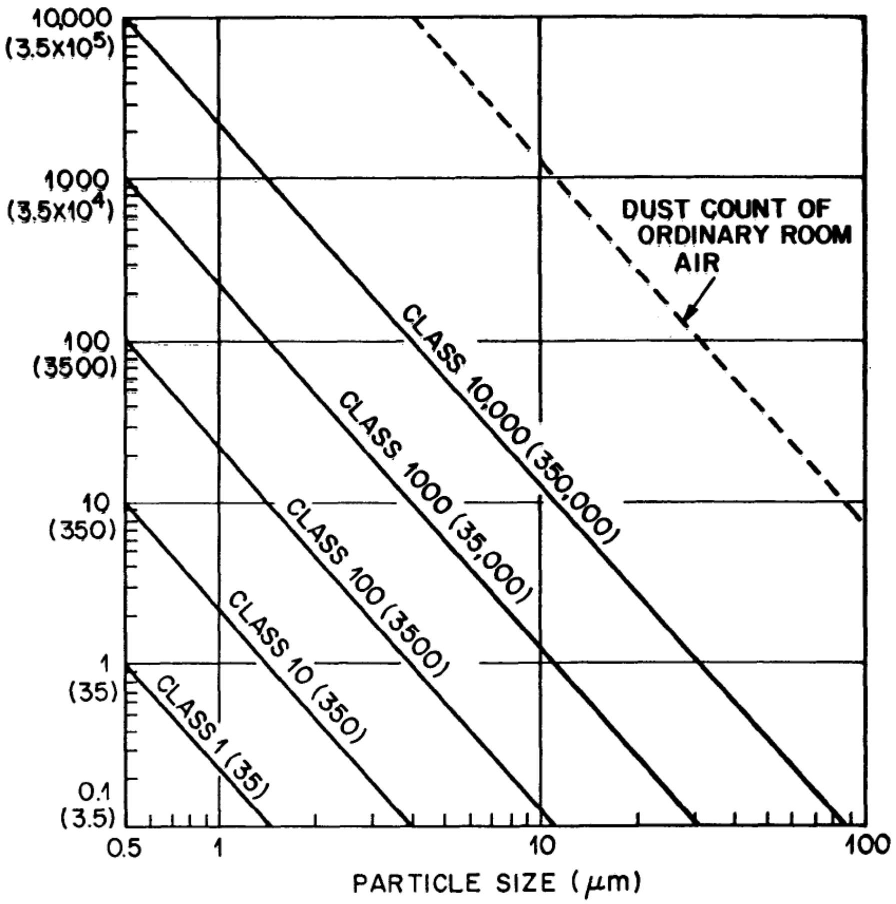
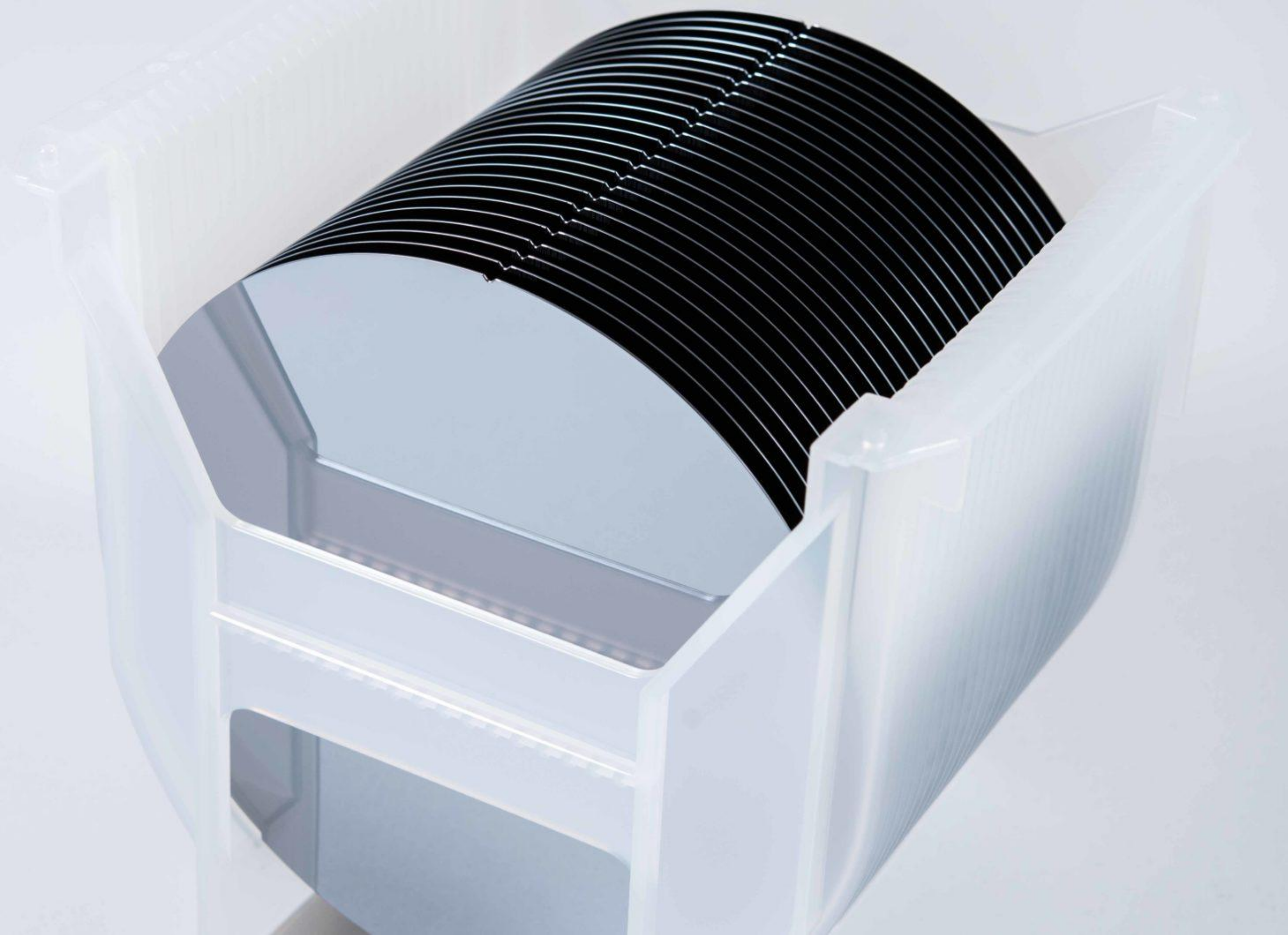


Figure 5.3: Particle-size distribution curve.

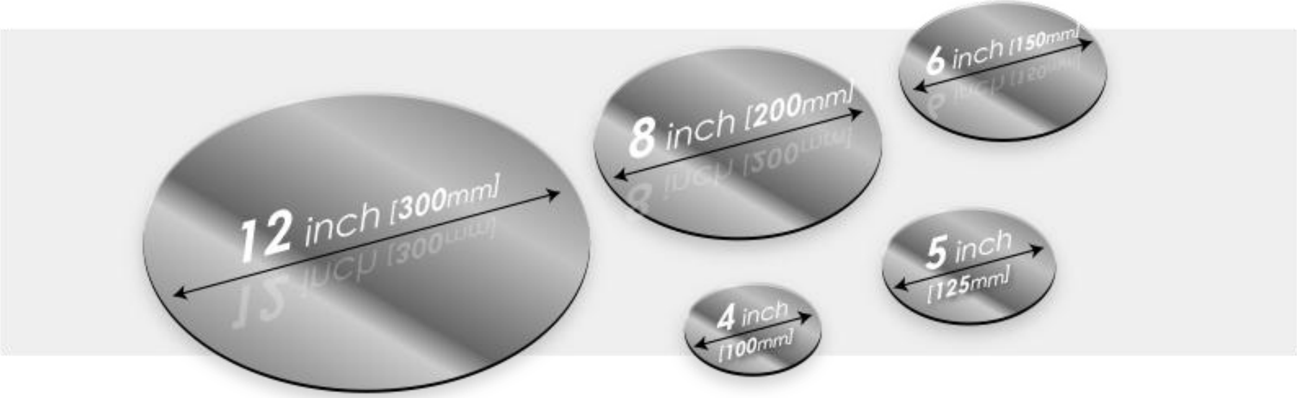
- What if you don’t have a clean room for fabrication?
  - Lower resolution: probably OK!
  - Try to keep things clean minimize contamination

Silicon wafer



Wafer comes with various size

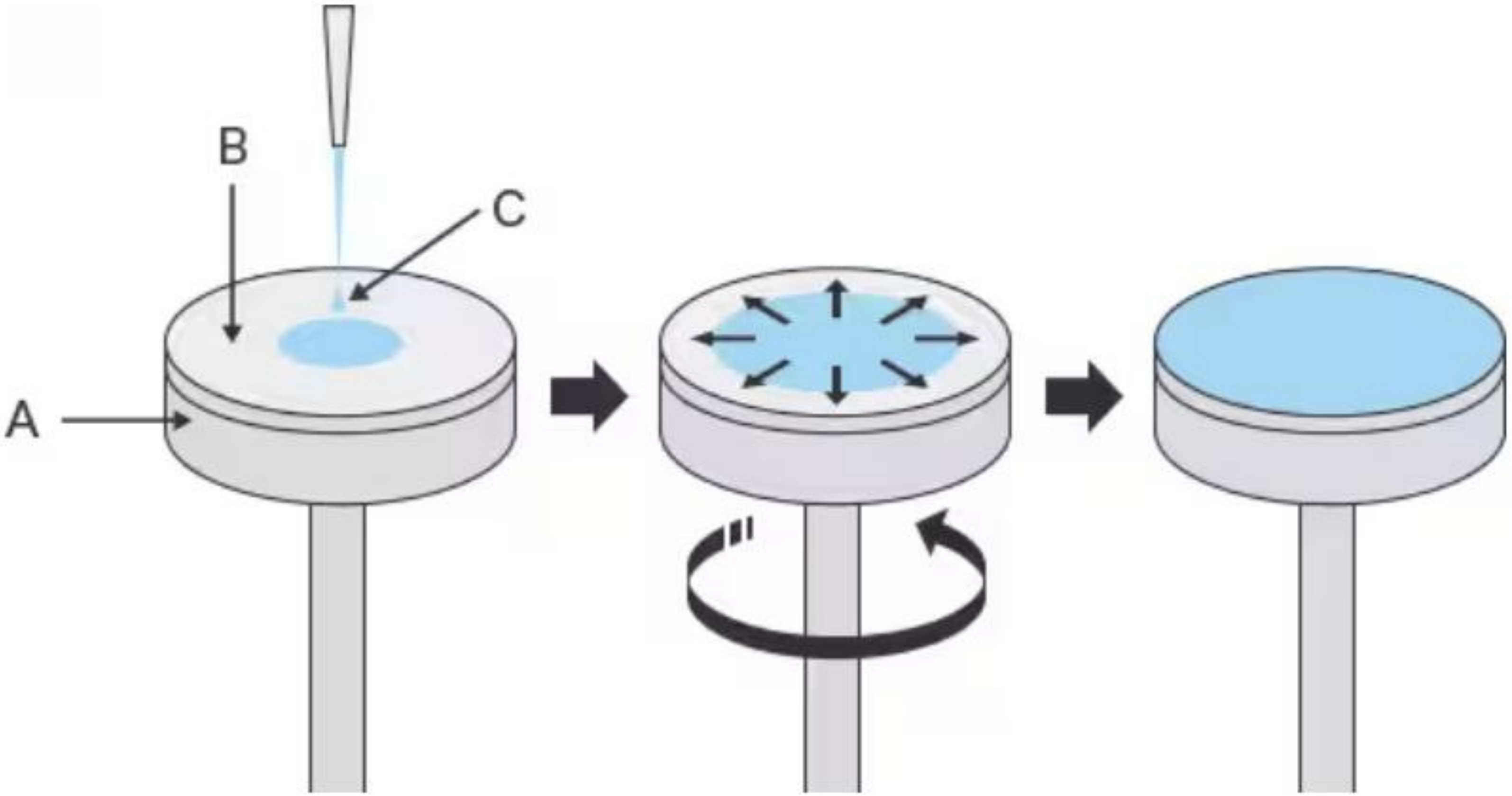
- 4-inch (100mm): ~¥50/piece; 25 pieces per box.
- 5-inch (125mm)
- 6-inch (150mm)
- 8-inch (200mm)
- 12-inch (300mm)



Tips

- Use new wafer for each fabrication

Spin Coating



A. Rotating stage B. Target surface C. Coating fluid

Spin Coating

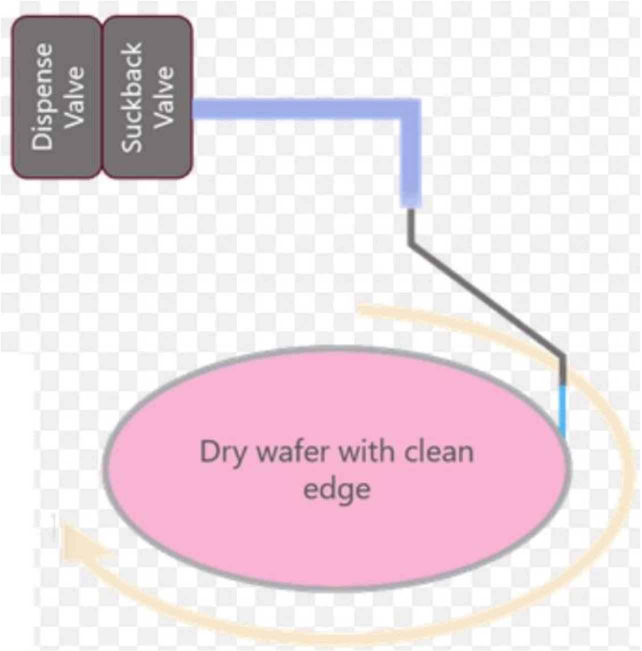
- https://www.bilibili.com/video/BV1q467YSEVu/

- https://www.bilibili.com/video/BV1j467YSE8s/

Edge bead

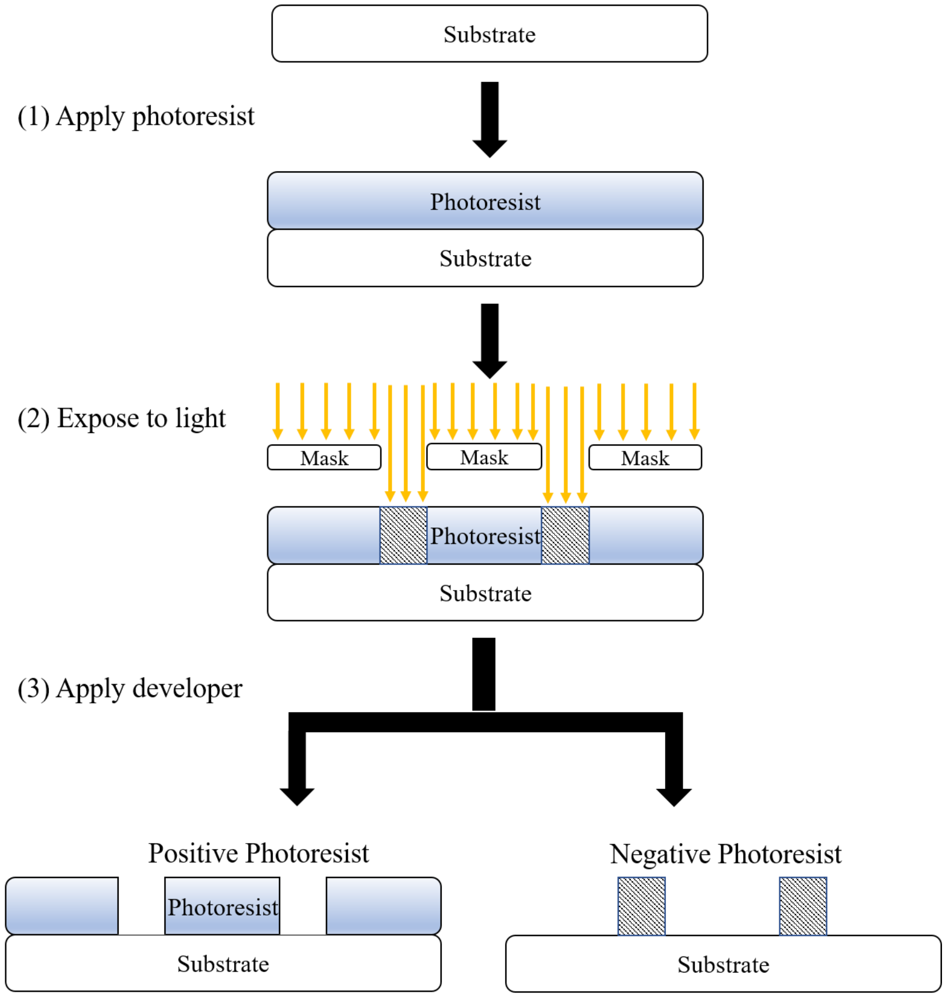

Edge bead
Edge bead
Photo-resist
Wafer


Before Edge Bead
Removal

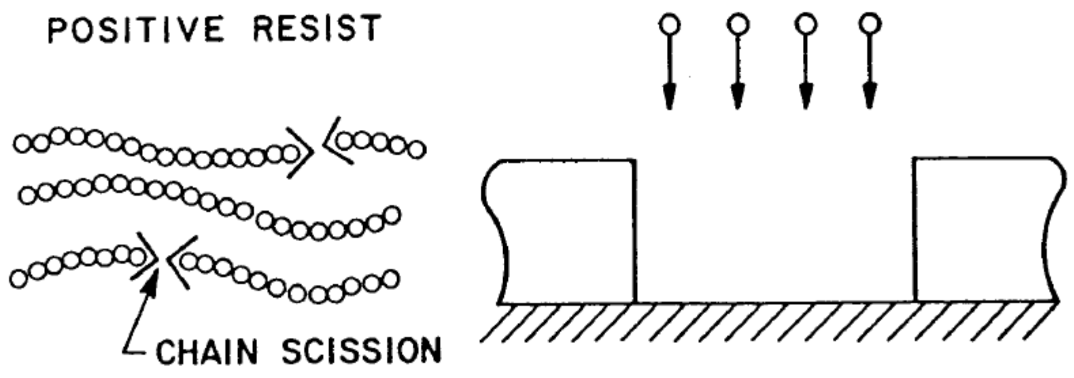

Dispense Valve
Suckback Valve
Dry wafer with clean edge

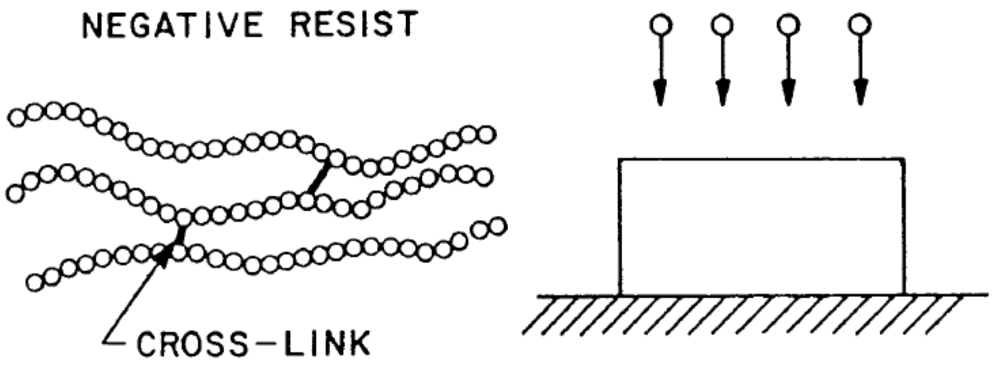
Photoresist

- A photoresist is a light-sensitive material, usually a polymer, used in photolithography to create precise patterns on a substrate's surface, like a silicon wafer, for electronics manufacturing.



Photoresist





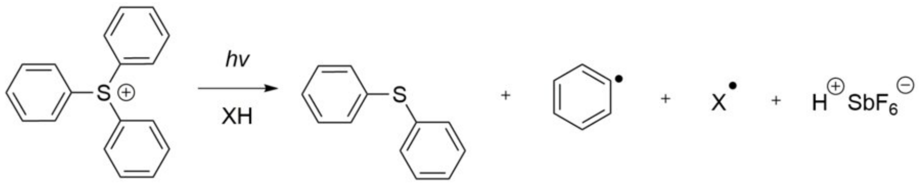
Photoresist

Typical three components

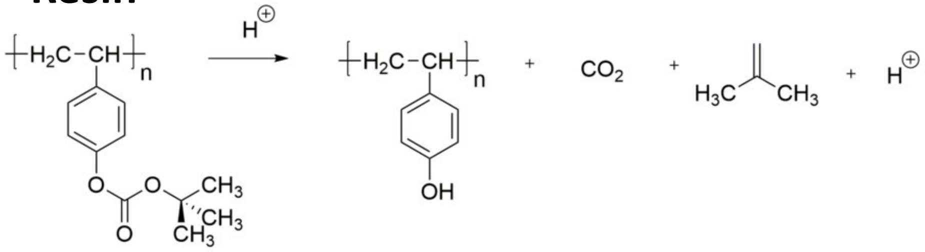
- **Resin**
    - a binder that provides physical properties such as adhesion, chemical resistance, etc)
- **Sensitizer**
    - which has a photoactive compound)
- **Solvent**
    - which keeps the resist liquid).

Positive photoresist

Photo-sensitizer (PAG)

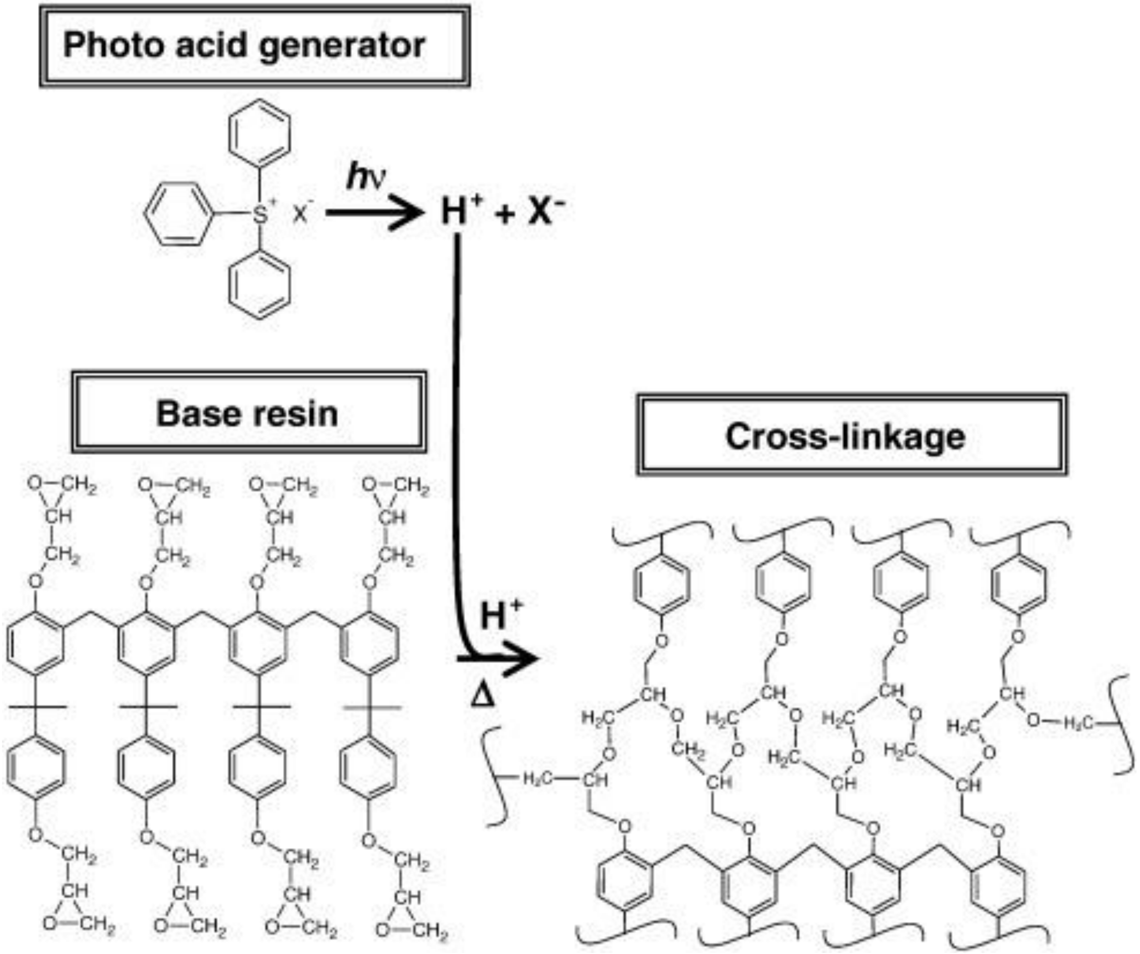


Resin

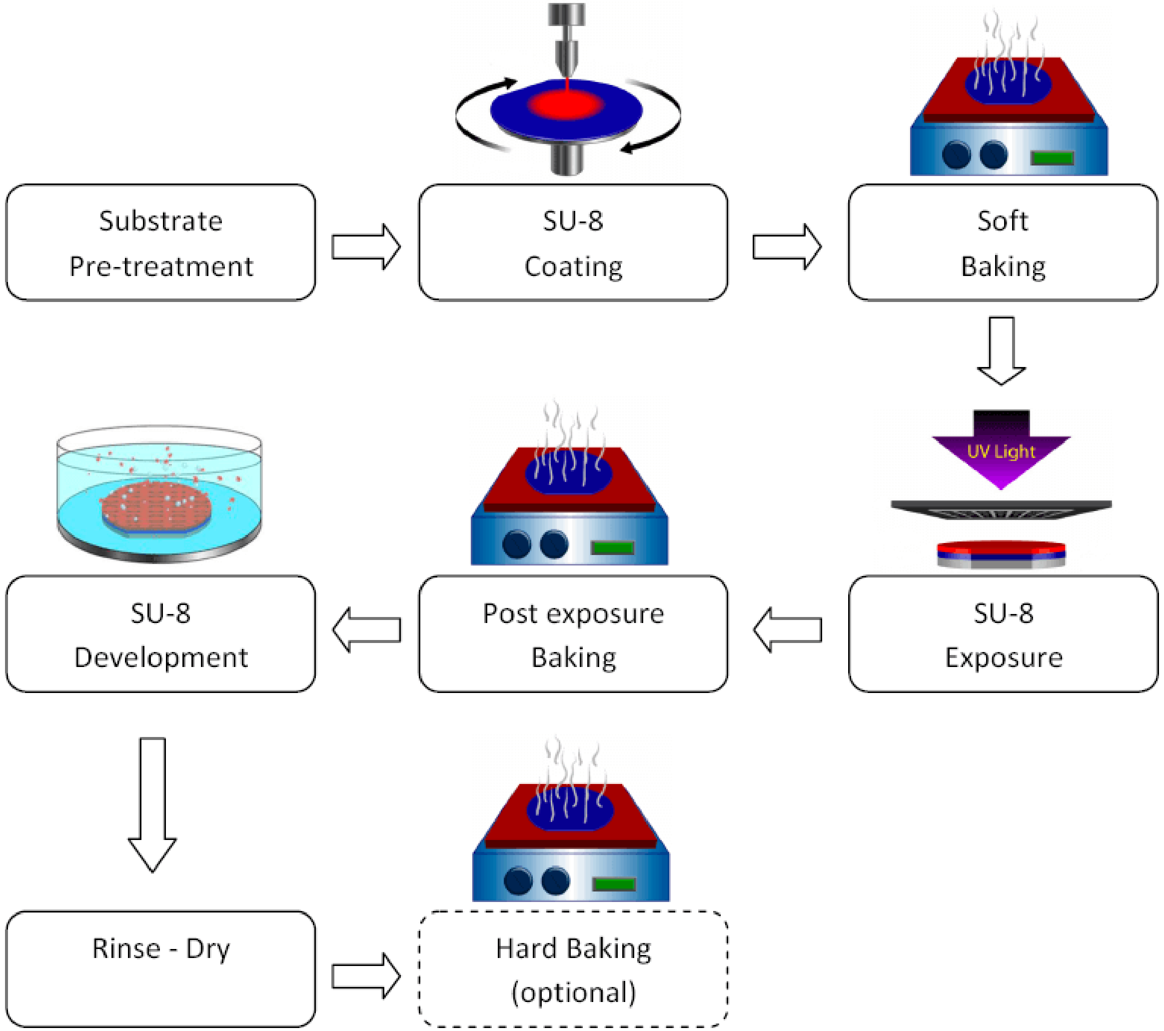


Negative photoresist

- SU-8
- **Resin:** SU-8 oligomers (an epoxy-based novolac resin, multifunctional glycidyl ether with eight epoxy groups per monomer).
- **Sensitizer** (PAG): A triarylsulfonium salt (like triphenylsulfonium hexafluoroantimonate or hexafluorophosphate).
- **Solvent**: Typically cyclopentanone, γ-butyrolactone, or similar, to allow spin-coating.

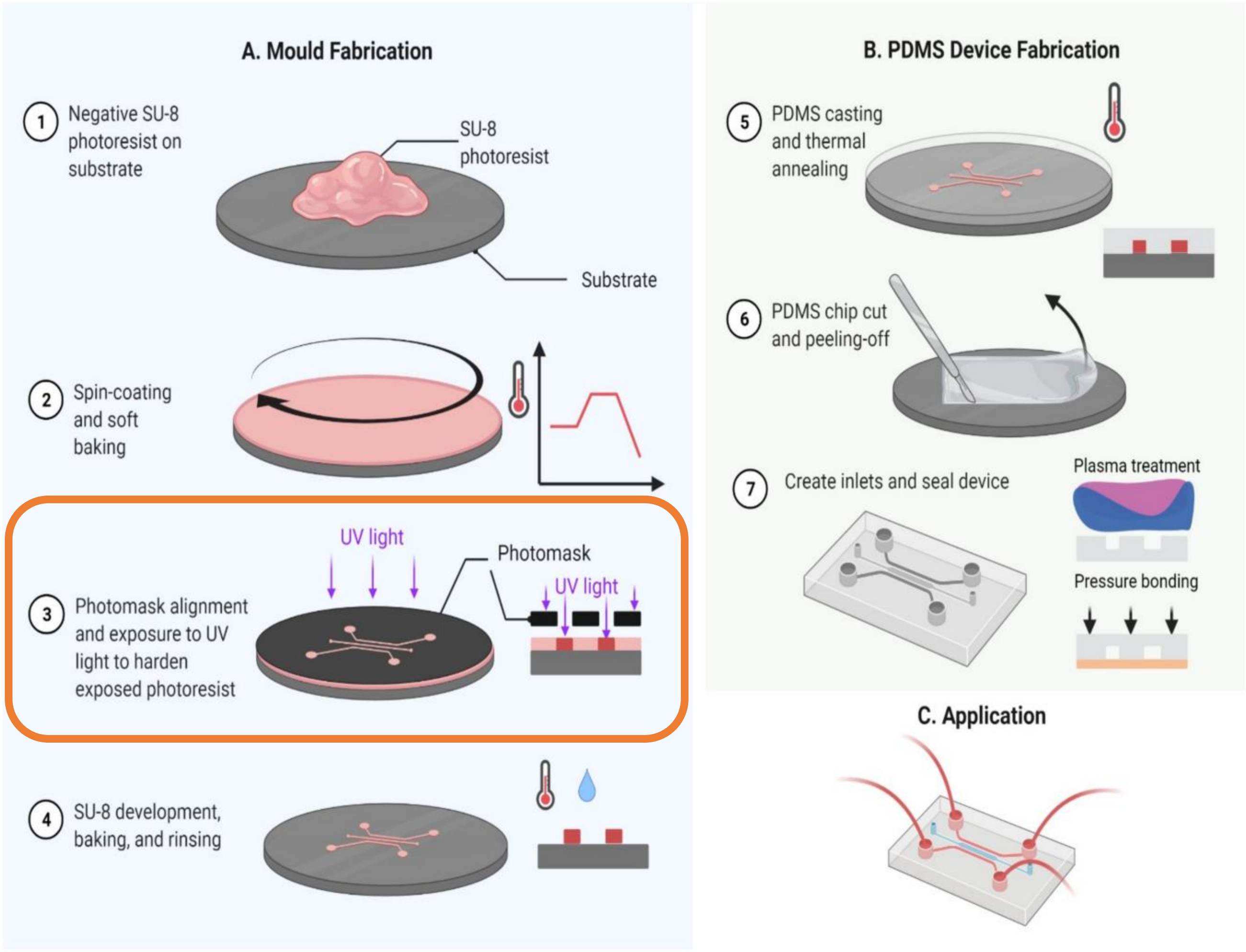


Typical process of SU-8



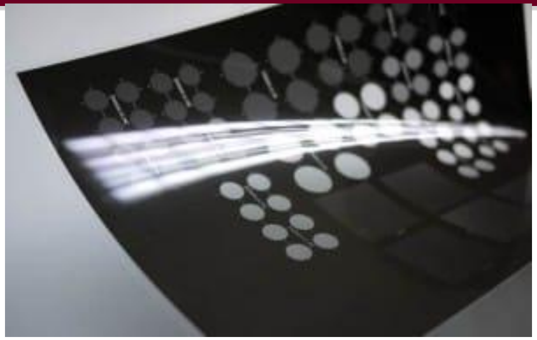
Photolithography

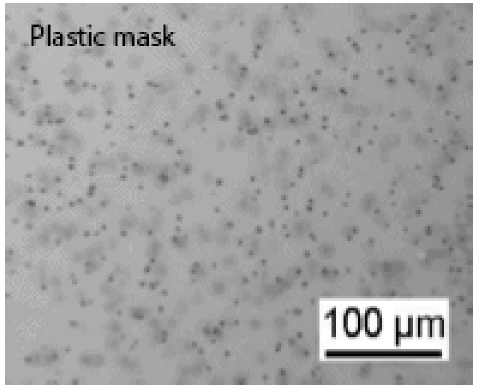
- Photomasks
- UV exposure

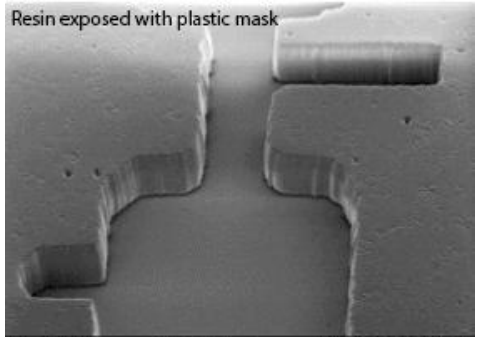


Photomasks

- Film photomasks ~￥100
  - **Description:**
    - A transparent plastic sheet (polyester or PET) with the desired pattern printed in black (usually by a high-resolution laser printer or photoplotter).
    - The black regions are opaque to UV light, while the transparent regions let UV pass through to expose the SU-8.
  - **Advantages:**
    - **Low cost** — inexpensive to produce.
    - **Fast turnaround** — can be designed and printed within hours.
    - **Good for prototyping** and iterative design changes.
  - **Limitations:**
    - **Lower resolution** (~10–20 µm features typically).
    - **Edge roughness and defects** due to printing quality.
    - **Not very durable**; prone to scratches, dust, and warping.
    - UV transmission can be inconsistent if the film is not perfectly flat against the resist.
  - **Applications:**
    - Early-stage research, rapid prototyping, proof-of-concept experiments, or when feature sizes are relatively large (>20 µm).



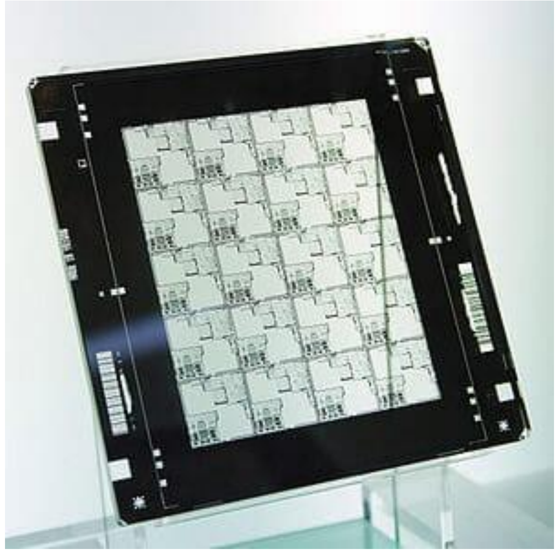




Photomasks

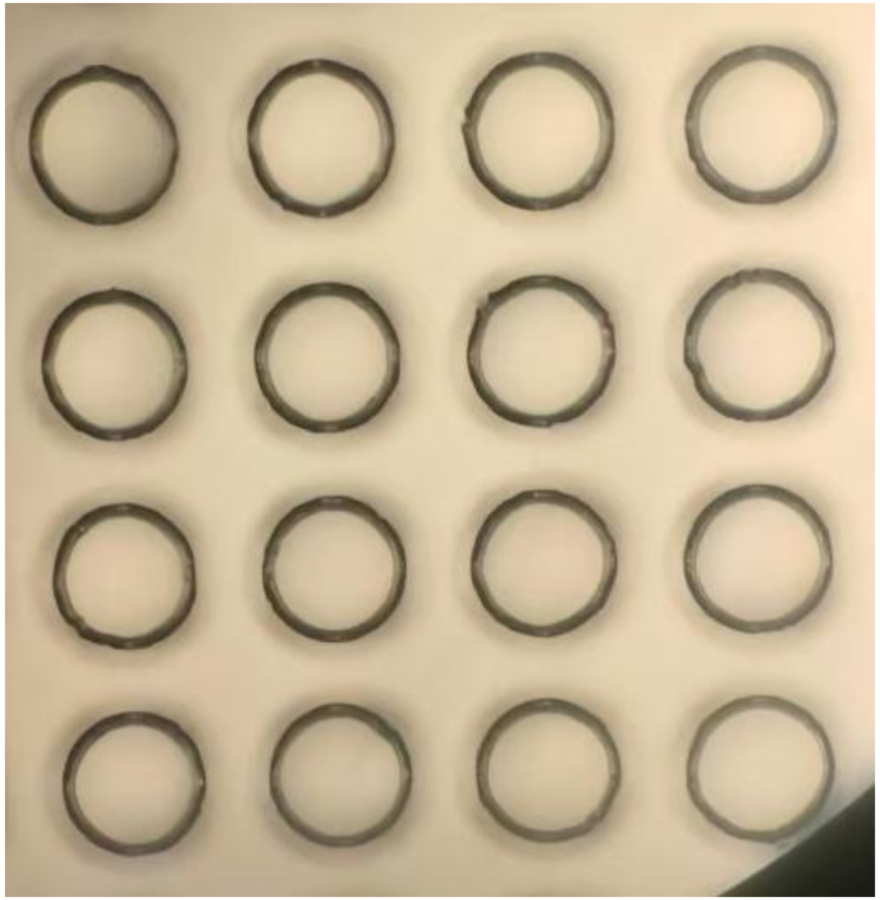
• Chrome photomask

~￥1000

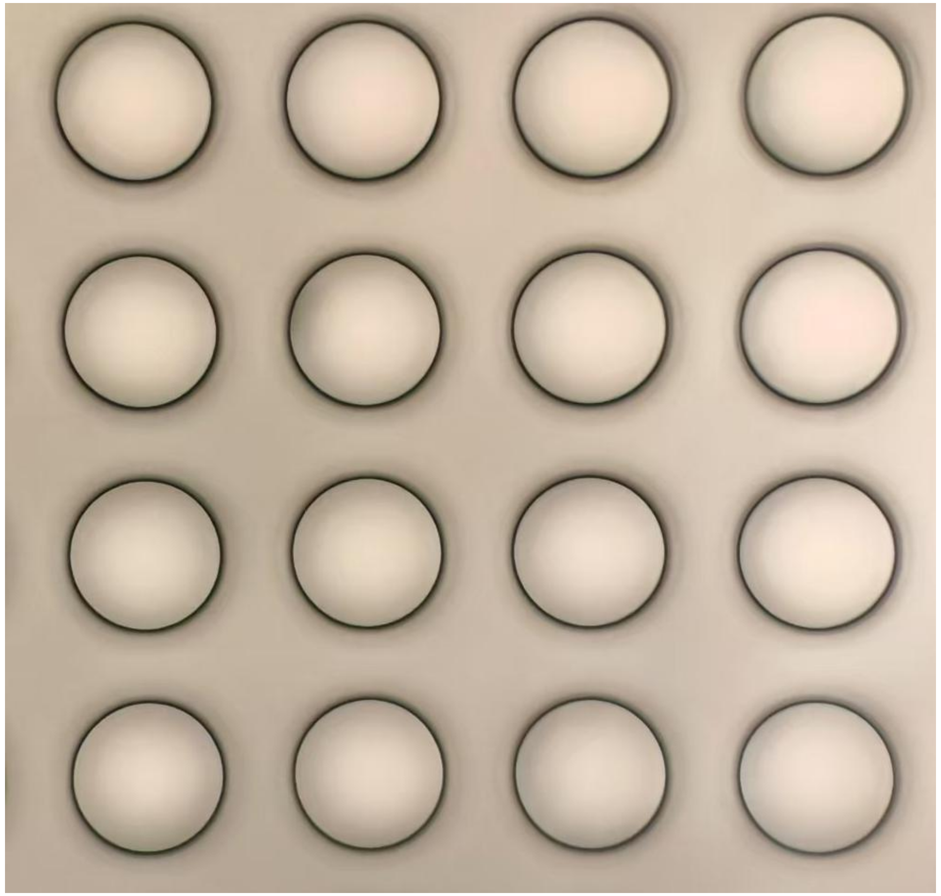


- **Description:**
  - A high-precision glass (quartz or soda-lime) plate coated with an opaque **chromium layer**.
  - The chromium is patterned via photolithography or e-beam lithography to create highly accurate transparent and opaque regions.
- **Advantages:**
  - **High resolution** (sub-micron features possible).
  - **Excellent edge definition** and pattern fidelity.
  - **Durable** — resistant to scratches and stable over many exposures.
  - **Uniform UV transmission** through the transparent glass areas.
- **Limitations:**
  - **High cost** — fabrication is expensive compared to film masks.
  - **Longer lead time** — requires professional mask fabrication services.
- **Applications:**
  - Critical patterning in MEMS, microfluidics, photonics, and high-resolution microfabrication where precision is essential.

Film

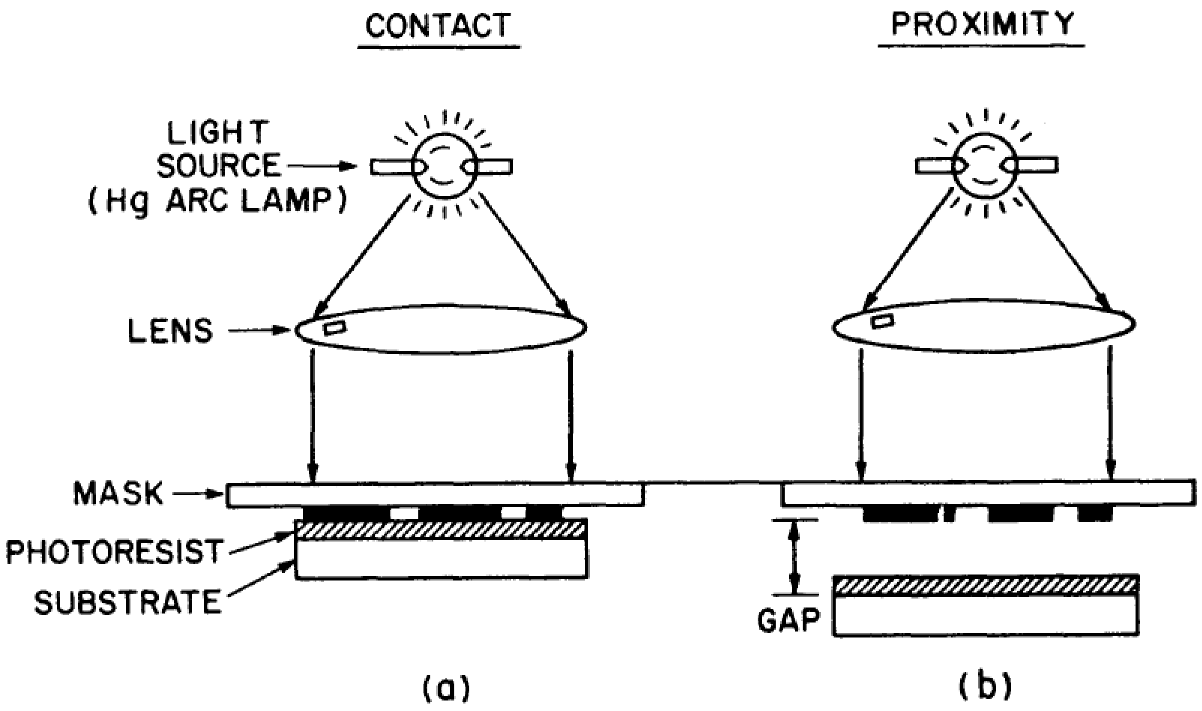


Chrome

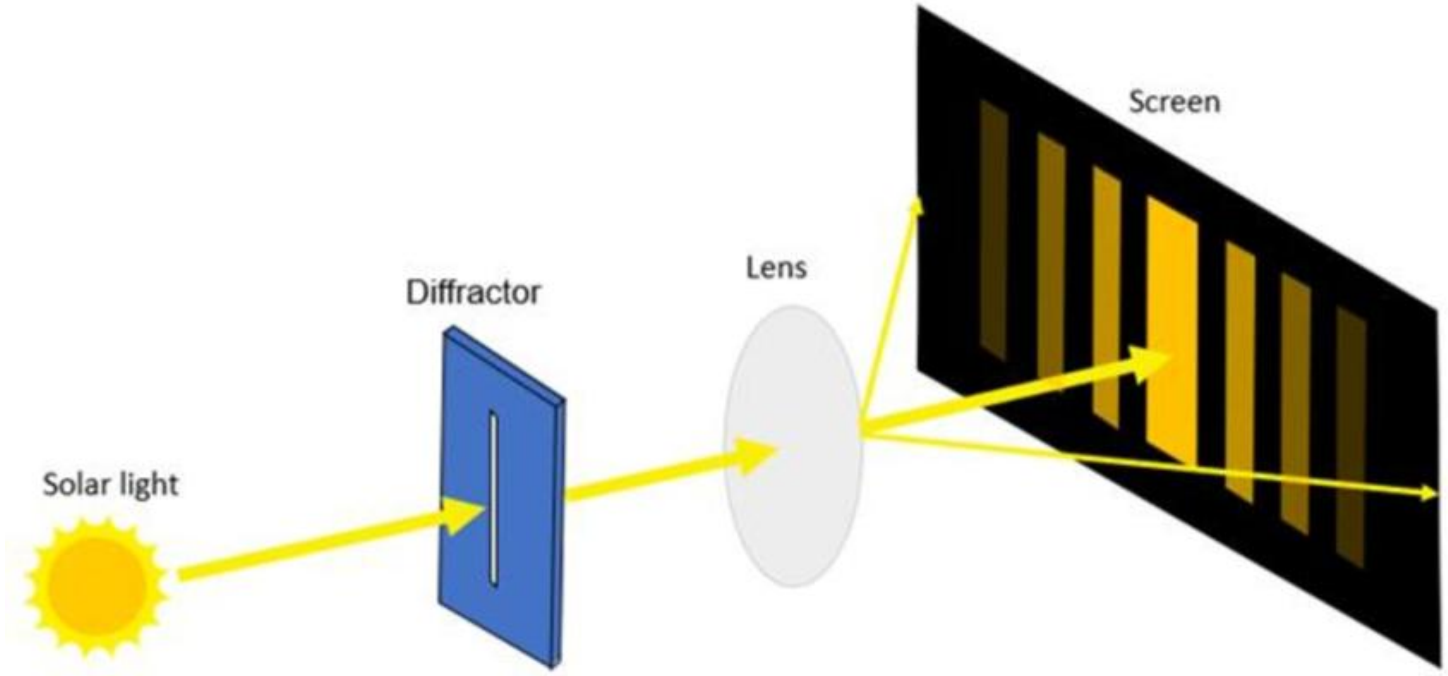


Exposure

- contact printing, proximity printing



Fresnel diffraction



- contact printing, proximity printing

The resolution b depends on the wavelength and the distance s between the mask and the photoresist layer

$$b = 1.5\sqrt{\lambda s}$$

Table 3.1

Spectrum of Mercury Lamps

Types	*I-line*	*H-line*	*G-line*	*E-line*	—	—	—
Wavelength (nm)	365.0	404.7	435.8	546.1	577.0	579.1	623.4

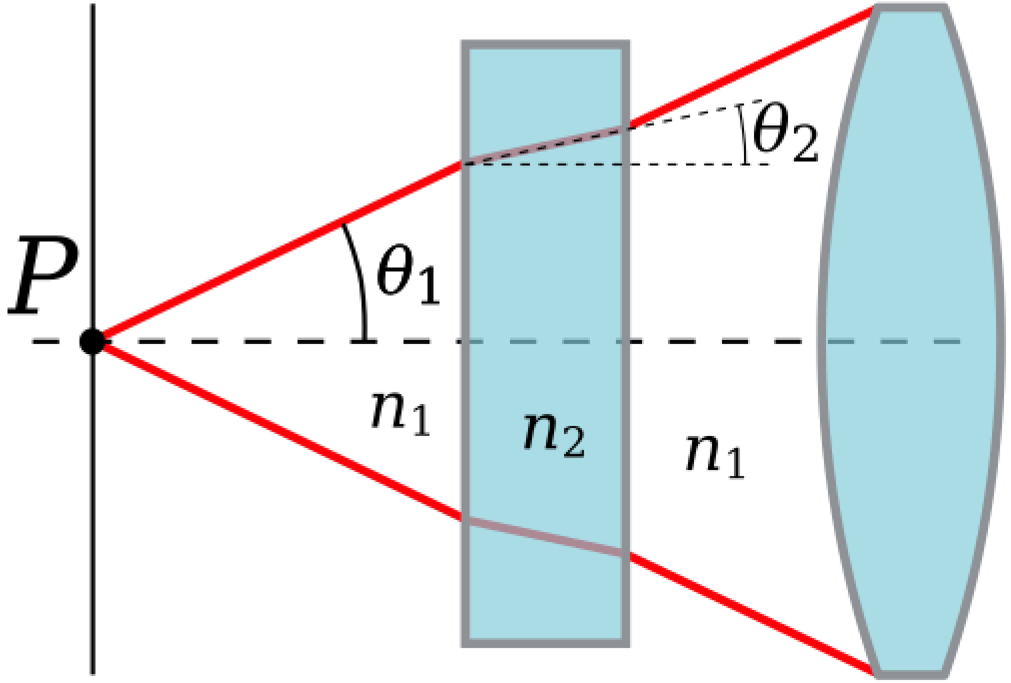
Example 3.1: Resolution of Proximity Photolithography

A resist layer at the bottom of a 5-mm-deep channel and a 20-mm-deep channel is to be patterned. The photoresist is exposed to ultraviolet (UV) light of a 400-nm wavelength. Compare the resolutions at the bottom of the two channels.

Solution. Following (3.1), the resolutions at the bottom of the two channels can be estimated as:

$$b_1 = 1.5\sqrt{\lambda s_1} = 1.5\sqrt{0.4 \times 5} = 2.1\ \mu\text{m}$$
$$b_2 = 1.5\sqrt{\lambda s_2} = 1.5\sqrt{0.4 \times 20} = 4.2\ \mu\text{m}$$

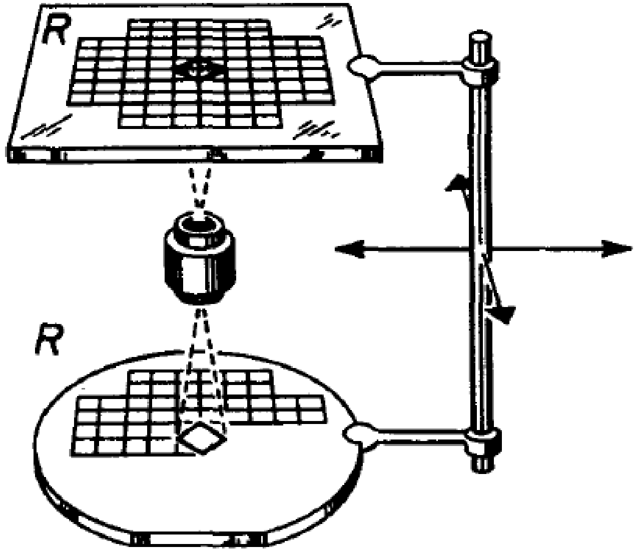
Numerical aperture



$$\mathrm{NA} = n_1 \sin\theta_1 = n_2 \sin\theta_2.$$

where n is the index of refraction of the medium in which the lens is working (1.00 for air, 1.33 for pure water, and typically 1.52 for immersion oil;[1] see also list of refractive indices), and ϑ is the half-angle of the maximum cone of light that can enter or exit the lens.

Projection printing



1:1 RASTER-SCAN

(b)

The resolution of projection printing system is estimated as:

$$b = \frac{\lambda}{2\mathrm{NA}}$$

Light source

Table 3.1

Spectrum of Mercury Lamps

Types	*I-line*	*H-line*	*G-line*	*E-line*	—	—	—
Wavelength (nm)	365.0	404.7	435.8	546.1	577.0	579.1	623.4

Various light sources

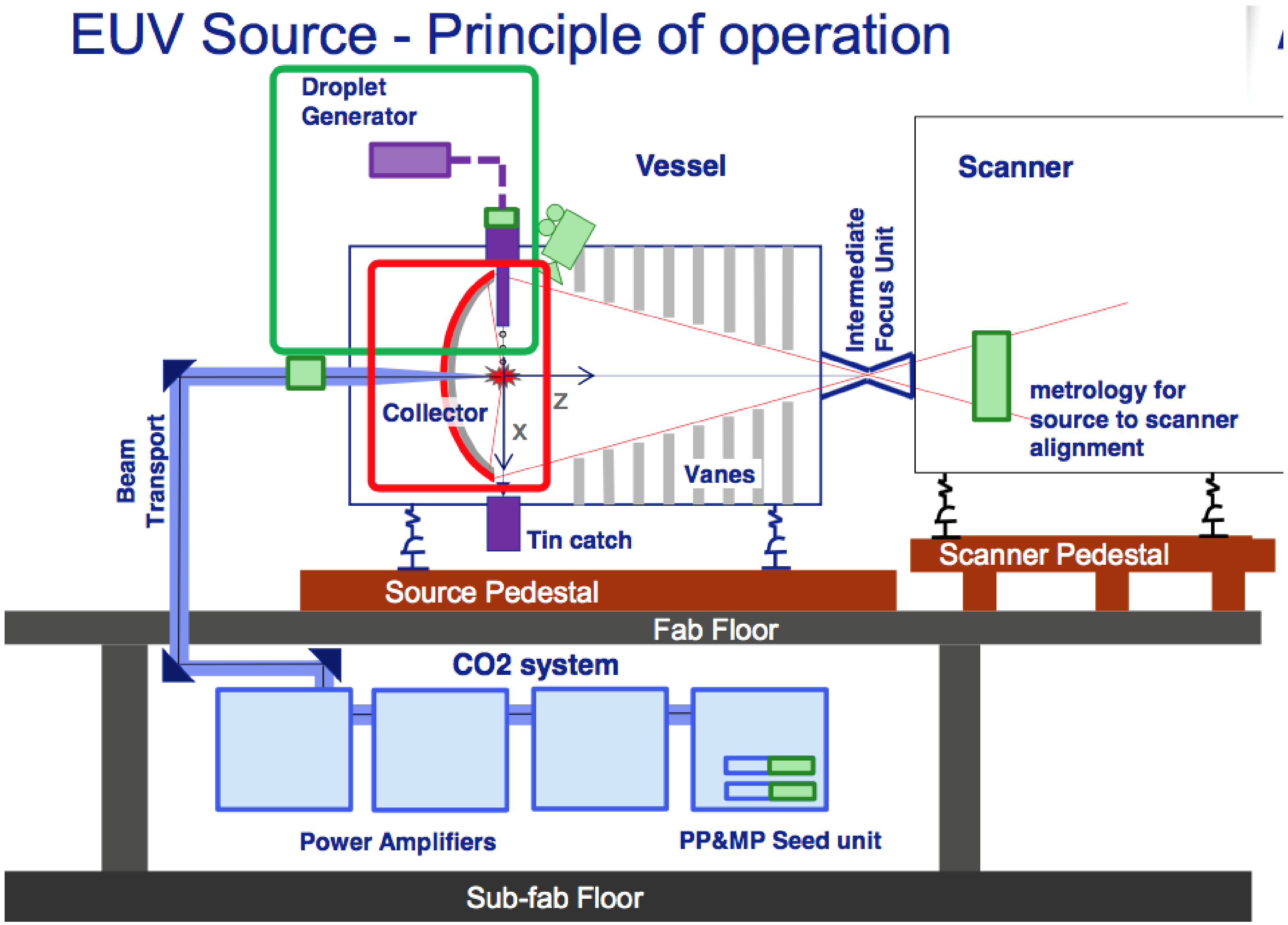
- Deep UV

Excimer Laser Basics

- **Excimer** = "excited dimer"
  - These are molecules that exist only in an excited (high-energy) state, not in a stable ground state.
  - Common pairs: **Krypton + Fluorine (KrF)** and **Argon + Fluorine (ArF)**.
- **Process:**
  1. A **gas mixture** (rare gas + halogen + buffer gas like neon or helium) is placed in the laser chamber.
  2. A **high-voltage electrical discharge** excites the gas, creating excimer molecules (e.g., KrF*).
  3. When these unstable molecules decay back to their separate atoms, they release a photon with a precise wavelength:
     - KrF → **248 nm**
     - ArF → **193 nm**

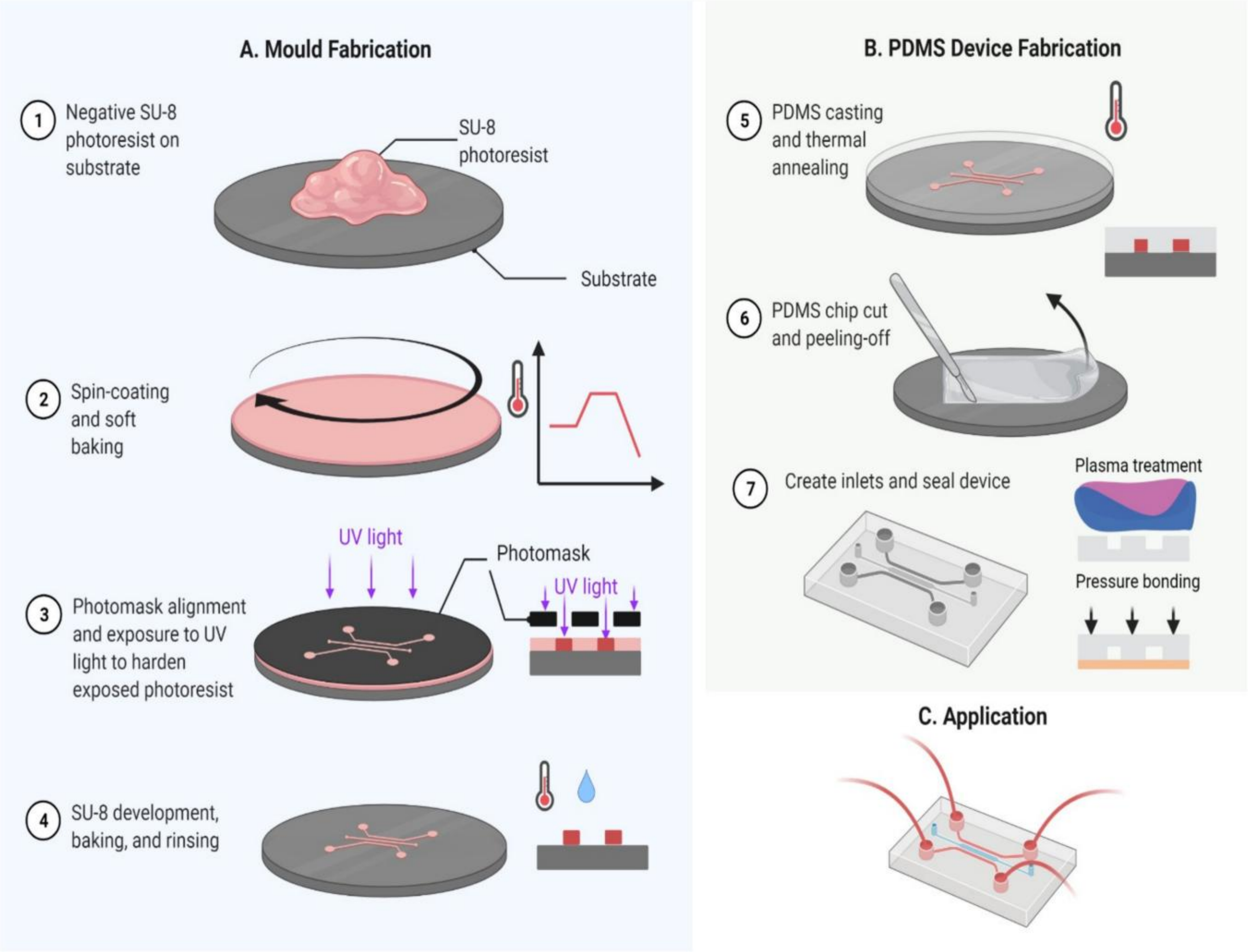
Extreme ultraviolet (EUV)

- 13.5 nm



Extreme ultraviolet (EUV)

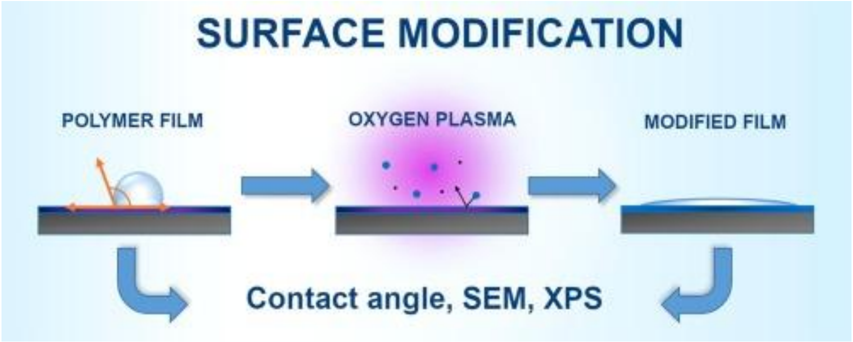
Process Overview

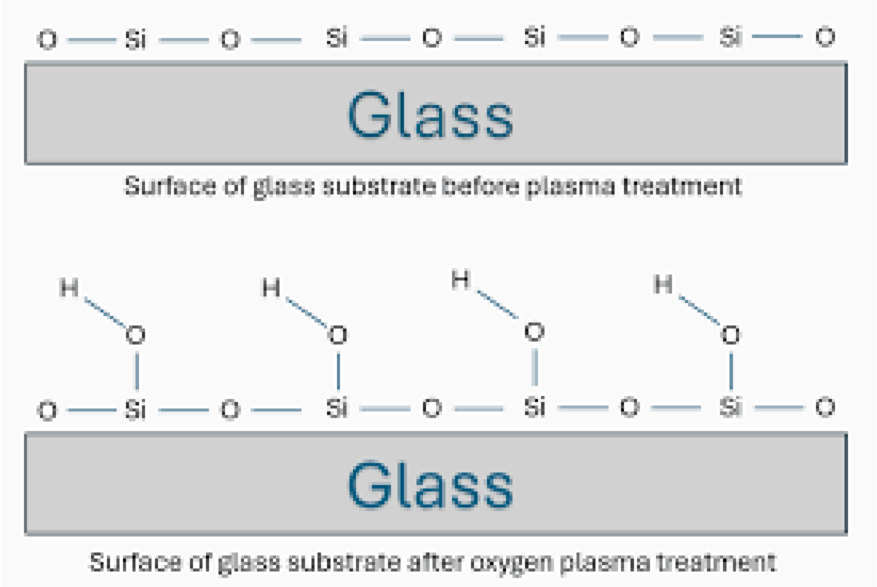


Surface treatment: oxygen plasma

Principle of Oxygen Plasma Treatment

- **Plasma** is a partially ionized gas containing electrons, ions, and reactive species.
- When oxygen gas (O_2) is energized in a plasma chamber (typically by RF power), it forms **reactive oxygen species** ($O\cdot$, O_2^+, O_3, etc.).
- These highly reactive species bombard the surface, breaking chemical bonds and introducing new functional groups.

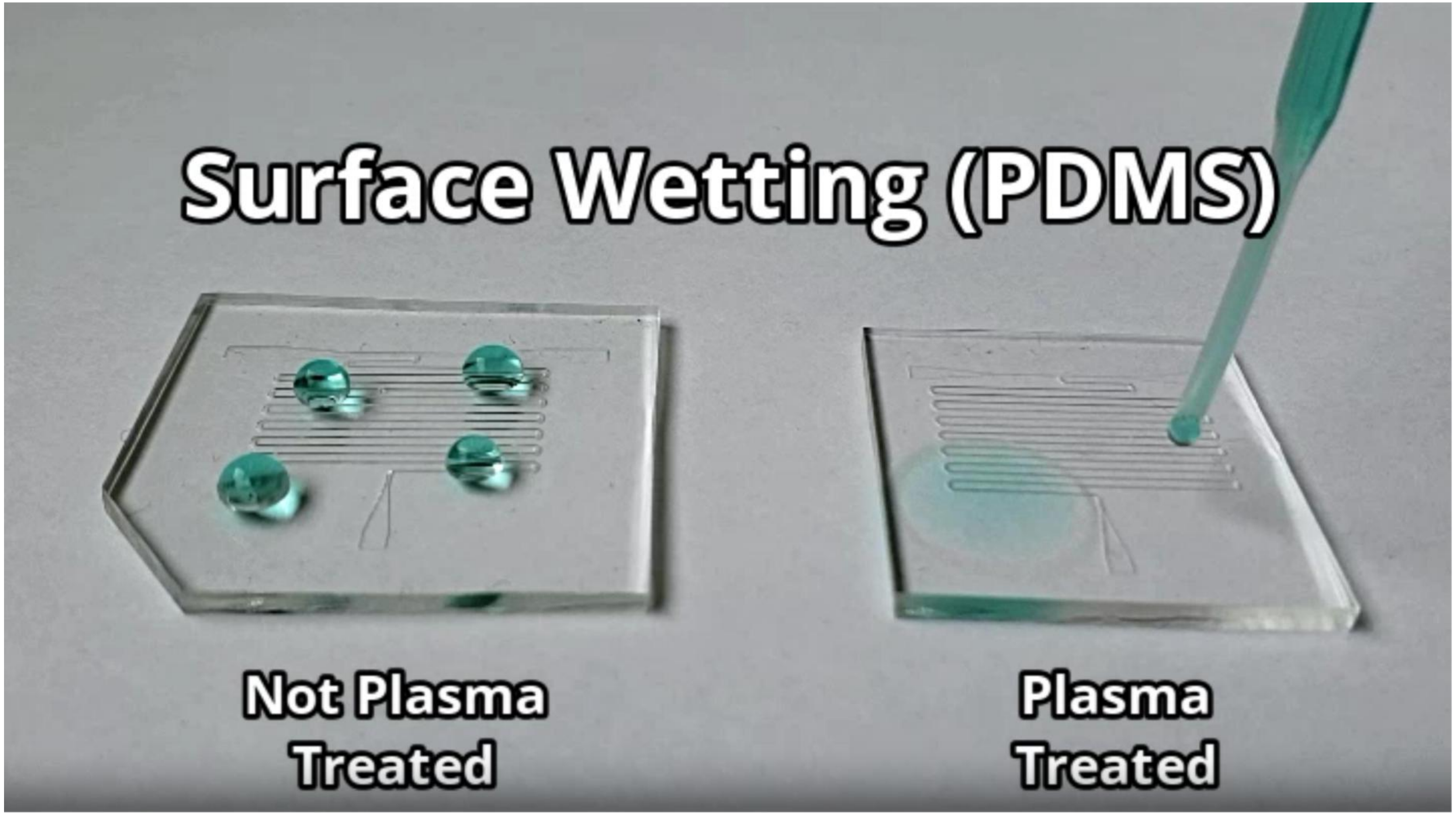





PLASMA CLEANER
PDC-001
OFF
LOW
MED
HI
RF LEVEL
ON
OFF
PUMP
POWER
HARRICK
PLASMA

On PDMS Surfaces

- Untreated PDMS is hydrophobic because its surface is dominated by **–$Si(CH_3)_2$ groups** (siloxane backbone with methyl side groups).
- Oxygen plasma:
  - Breaks the –$Si–CH_3$ bonds on the surface.
  - Converts them into **silanol groups (–Si–OH)**.
- Result: PDMS surface also becomes **hydrophilic** and chemically active.


Surface Wetting (PDMS)
Not Plasma Treated
Plasma Treated

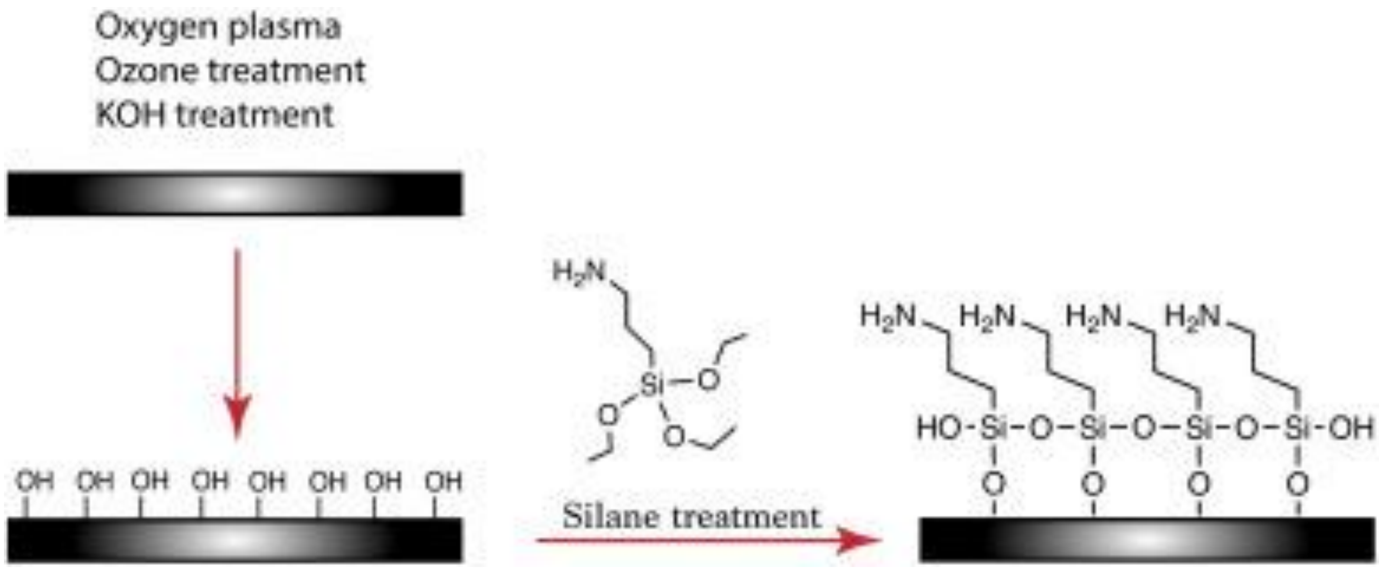
Limitations

- The hydrophilic effect on PDMS is **not permanent**:
  - The surface gradually recovers its hydrophobicity due to reorientation of polymer chains and migration of unmodified PDMS oligomers to the surface.
  - This process is called **hydrophobic recovery** (happens within hours to days).
- To extend bonding effectiveness:
  - Use freshly treated surfaces.
  - Bond immediately after plasma treatment.
  - Store treated PDMS in water or perform further surface coatings (e.g., PEG, silanes).

Silanization

- **Why Silanization is Needed**
- When fabricating PDMS microfluidic devices, PDMS prepolymer is poured over a **master mold** (often made of SU-8 patterned on silicon).
- **Problem:** PDMS strongly adheres to SU-8 and glass after curing, making demolding difficult and risking damage to the fragile SU-8 structures.
- **Solution:** Silanization coats the master with a thin **anti-adhesive monolayer**, preventing bonding and allowing easy PDMS release.

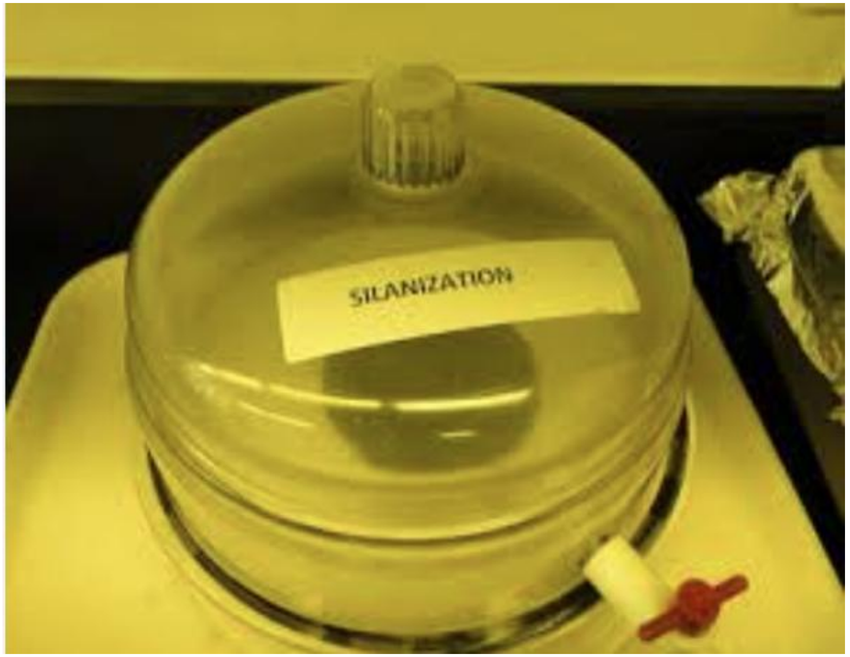
Silanization



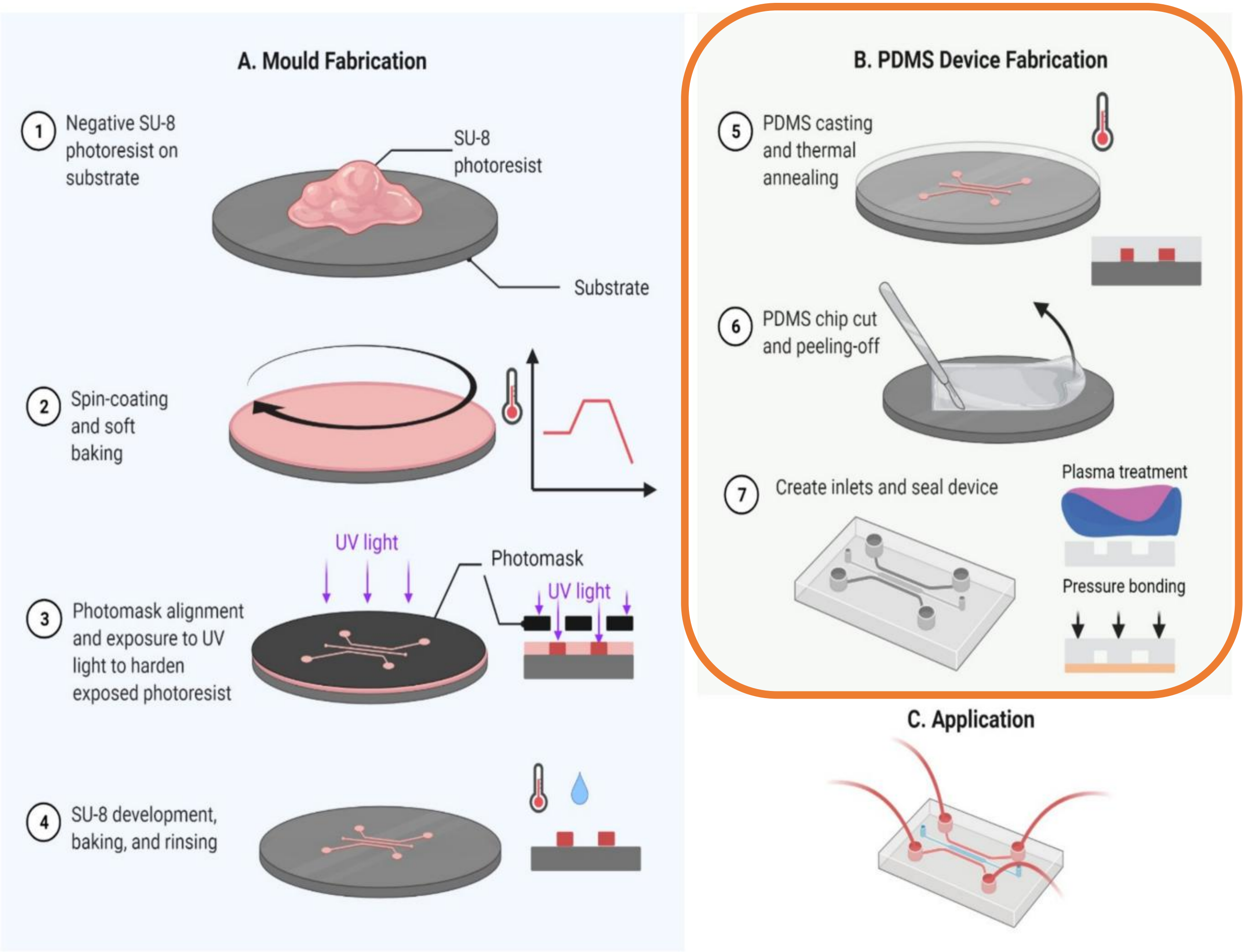
Methods of silanization

Methods of Silanization

- **Vapor-phase silanization** (common for SU-8 molds):
  - Place the substrate in a desiccator with a few drops of silane.
  - Under vacuum, silane vapor coats the surface uniformly.
- **Liquid-phase silanization:**
  - Immerse the substrate in a dilute silane solution (in ethanol or toluene).
  - Rinse and dry after reaction.



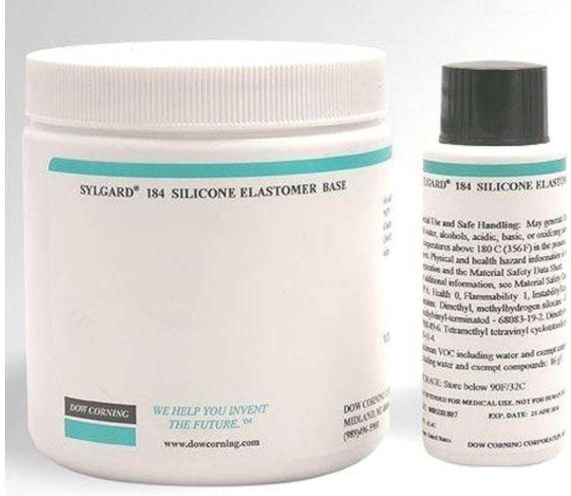
Soft lithography



A. Mould Fabrication
1 Negative SU-8 photoresist on substrate
SU-8 photoresist
Substrate
2 Spin-coating and soft baking
3 Photomask alignment and exposure to UV light to harden exposed photoresist
UV light
Photomask
UV light
4 SU-8 development, baking, and rinsing
B. PDMS Device Fabrication
5 PDMS casting and thermal annealing
6 PDMS chip cut and peeling-off
7 Create inlets and seal device
Plasma treatment
Pressure bonding
C. Application

Key materials: PDMS

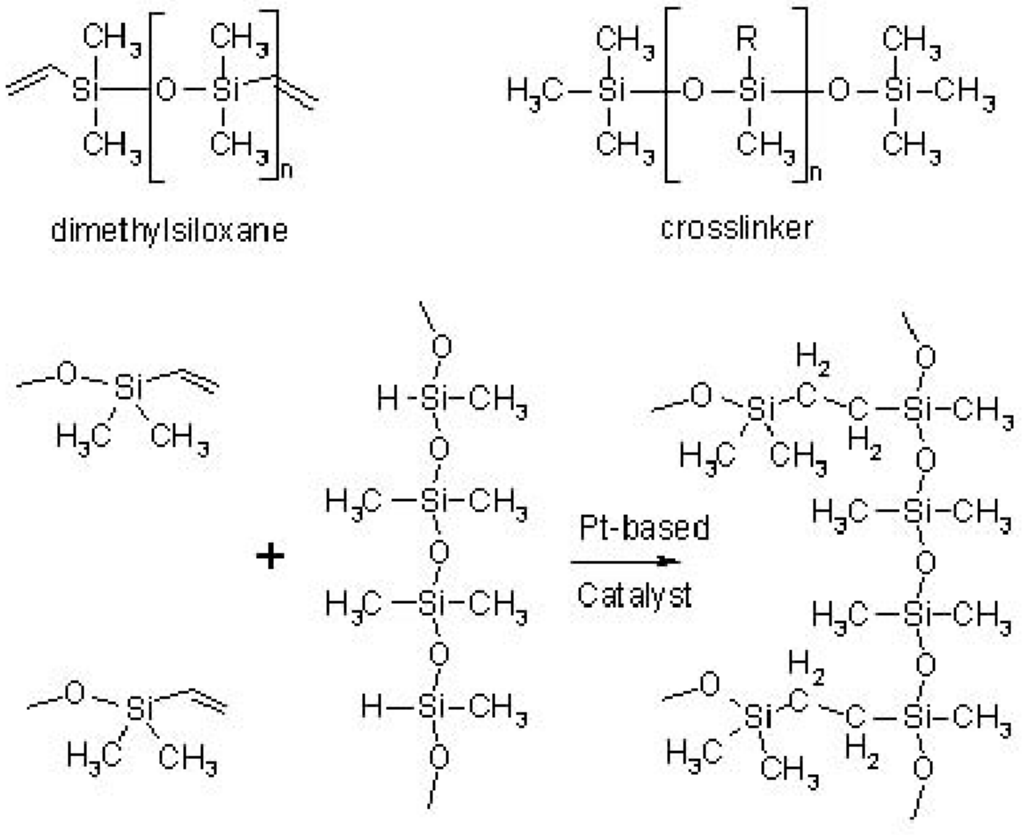
- Polymer
  - Monomer + cross-linker
  - Base + curing agent (hardener)



Crosslinking of PDMS

Reaction (Hydrosilylation)

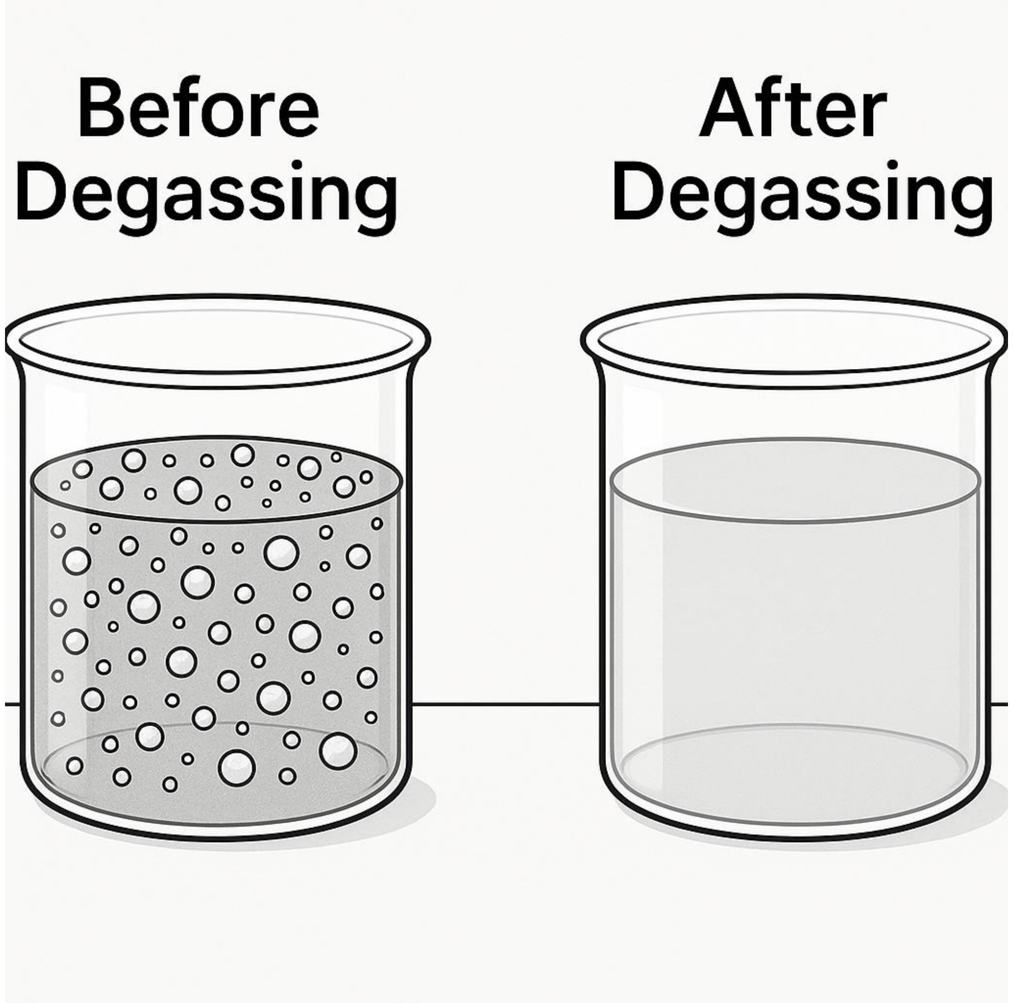
- **Reaction type:** Platinum-catalyzed **hydrosilylation**.
- **Catalyst:** A Pt-based catalyst (e.g., Karstedt's catalyst, platinum divinyltetramethyldisiloxane complex).
- **Mechanism:**
- A **Si–H group** from the crosslinker reacts with a **vinyl group (–CH=CH$_2$)** on PDMS.
- The Pt catalyst facilitates **addition of Si–H across the C=C double bond**.
- Result: a new **Si–C bond**, effectively linking two polymer chains.



Result of Curing

- Multiple crosslinking reactions occur throughout the bulk material.
- The PDMS chains become interconnected into a **3D elastomeric network**.
- This network gives PDMS its characteristic properties:
  - Elasticity (soft, rubbery).
  - Transparency.
  - Chemical inertness.
  - Gas permeability.
- Different base:curing agent ratio:
  - 10:1 vs 20:1
  - More curing agent makes stiffer PDMS

Degassing

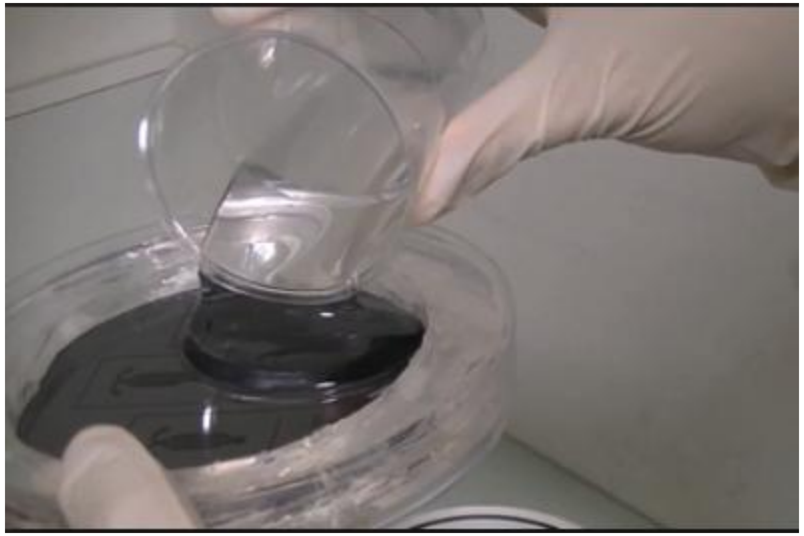

Before
Degassing
After
Degassing

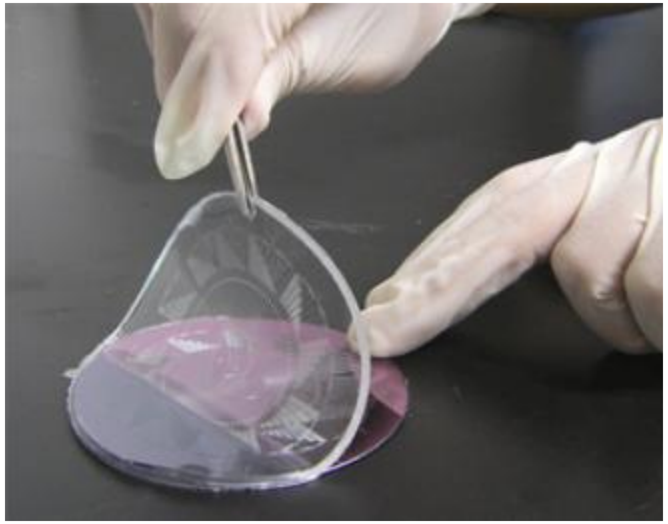
Why Degassing is Needed

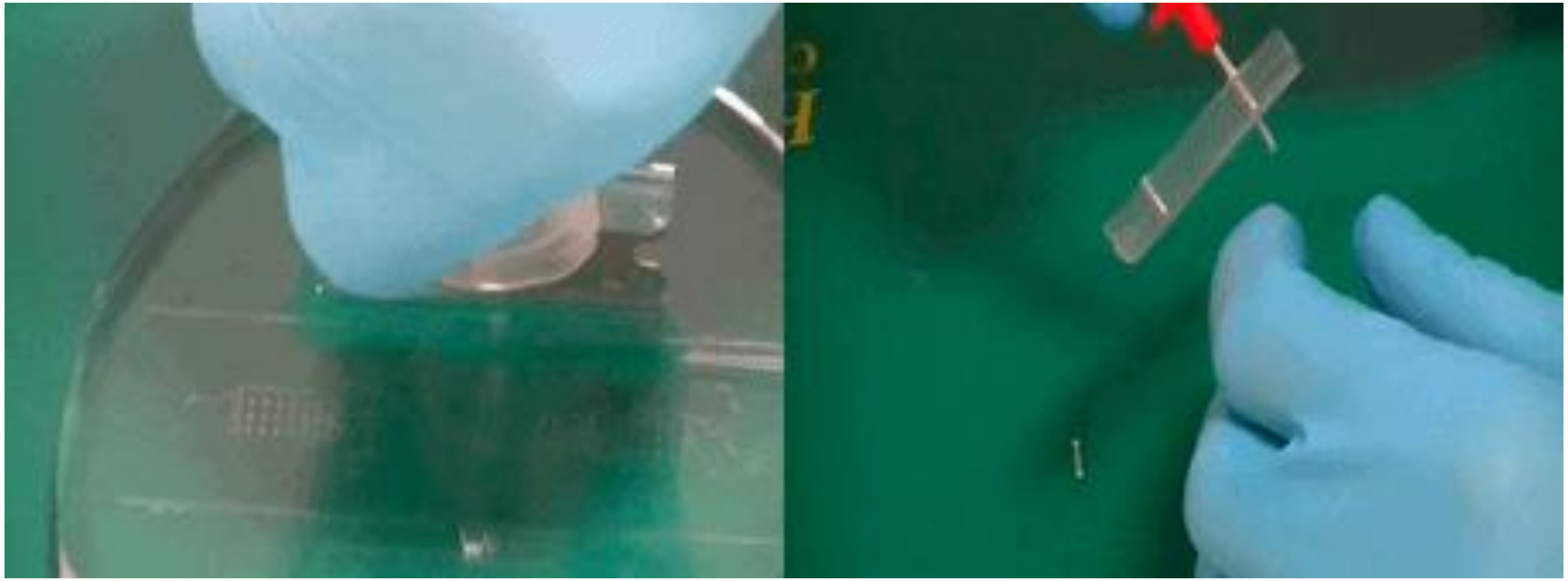
- PDMS is supplied as a **two-part kit**:
  - **Base polymer** (vinyl-terminated PDMS oligomer).
  - **Crosslinker** (siloxane with Si–H groups + Pt catalyst).
- When these two are mixed:
  - Air bubbles are introduced (by stirring/handling).
  - The mixture has relatively **high viscosity**, so bubbles cannot escape easily.
- If not removed:
  - Bubbles remain trapped in the cured PDMS → weak spots, optical distortions, microchannel blockages.

Mechanism of Bubble Removal

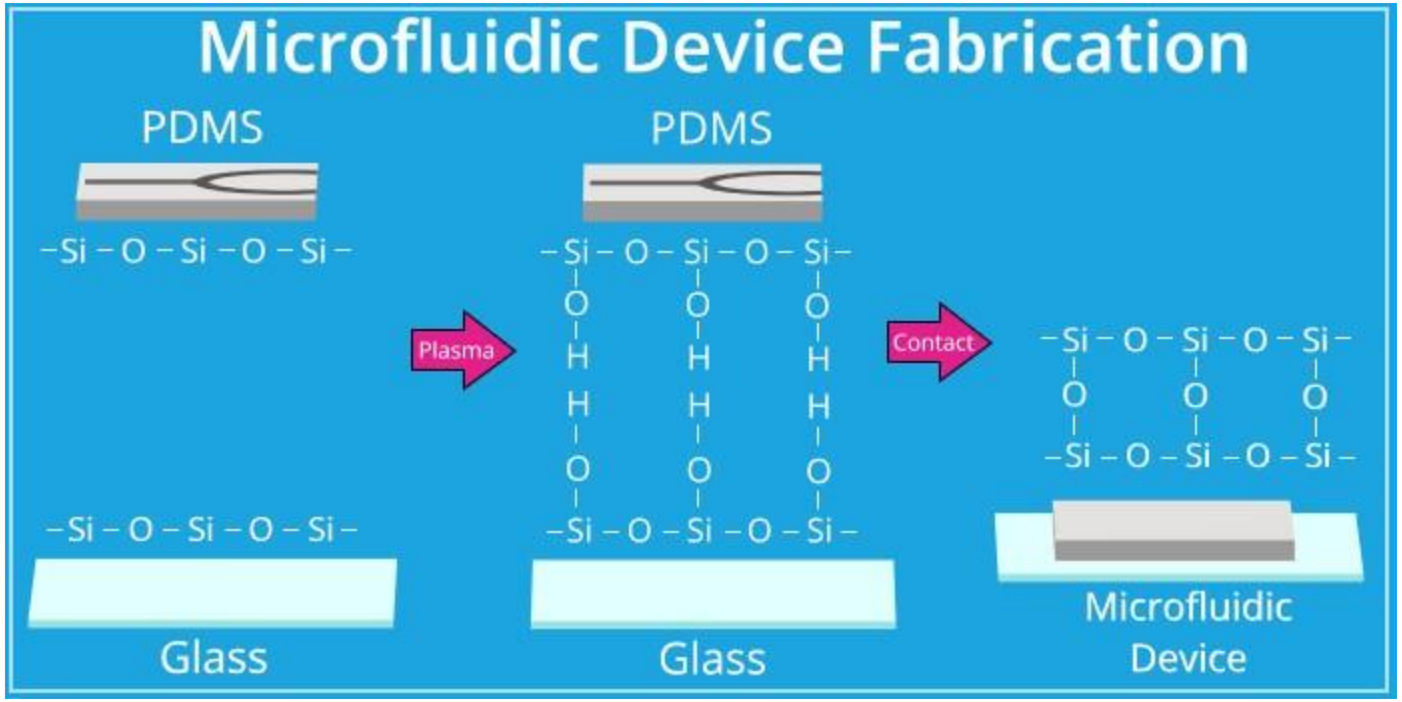
- **Gas solubility principle:** At lower pressure, gases are less soluble in liquids (Henry's law). Vacuum lowers the partial pressure of air above PDMS, so dissolved gases escape.
- **Bubble growth & release:**
  - Trapped bubbles expand under vacuum (Boyle's law).
  - Expanded bubbles experience buoyancy and rise to the surface, where they burst.
- **Viscous medium:** PDMS is thick, so bubbles move slowly → vacuum must be applied long enough.
- **Observation:** During degassing, the mixture often "foams up" initially (bubbles expand greatly), then collapses as bubbles escape.

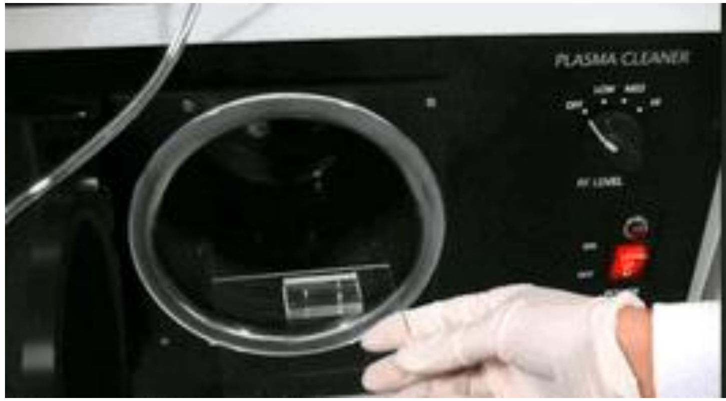


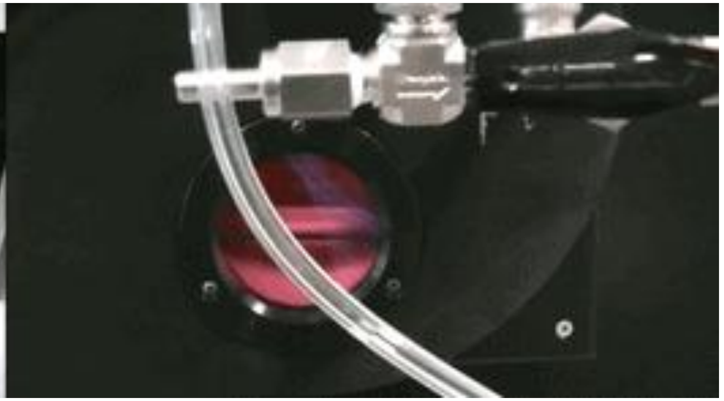




Bonding


Microfluidic Device Fabrication
PDMS
−Si − O − Si − O − Si −
−Si − O − Si − O − Si −
Glass
Plasma
PDMS
−Si − O − Si − O − Si −
O O O
H H H
H H H
O O O
−Si − O − Si − O − Si −
Glass
Contact
−Si − O − Si − O − Si −
O O O
−Si − O − Si − O − Si −
Microfluidic
Device

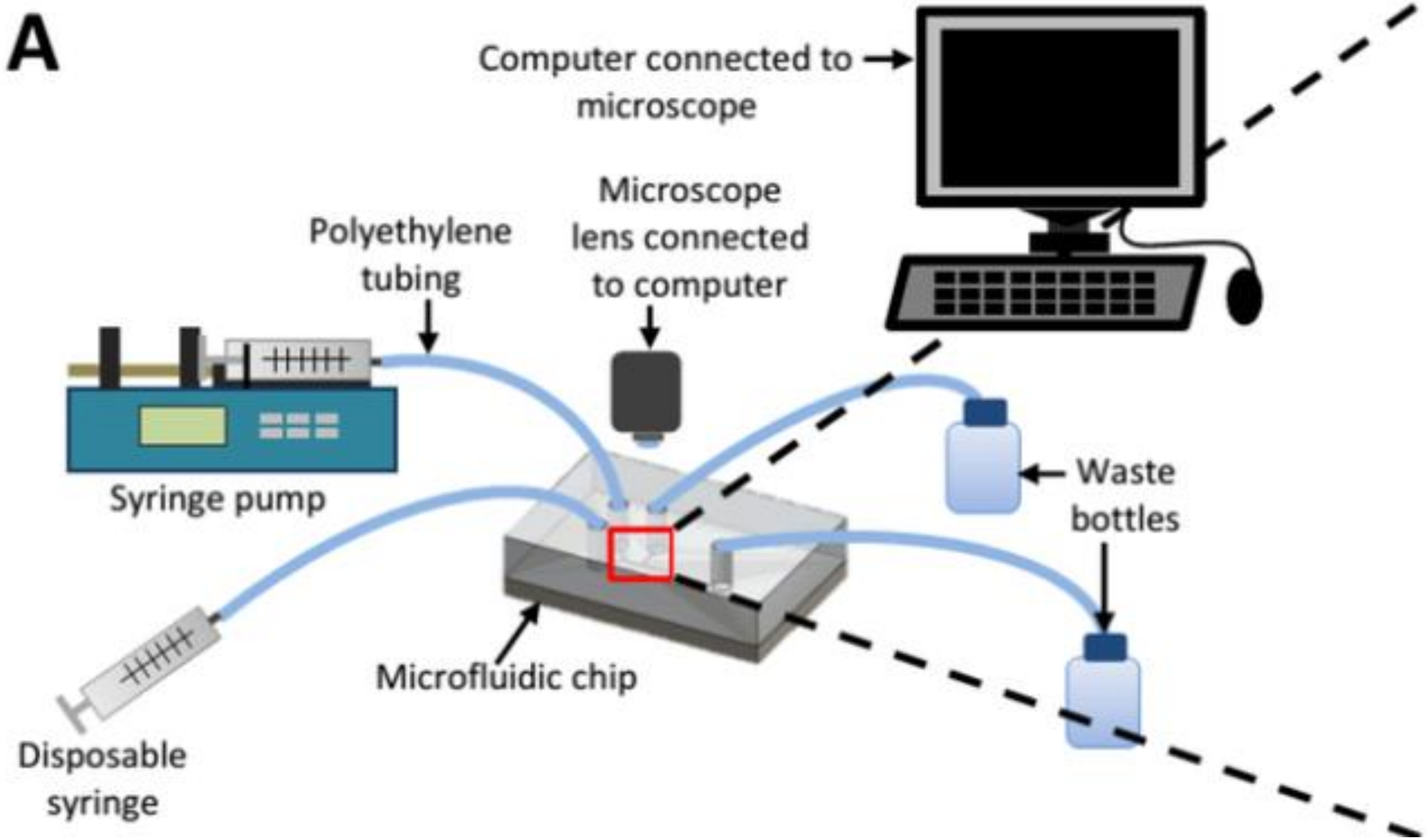

PLASMA CLEANER



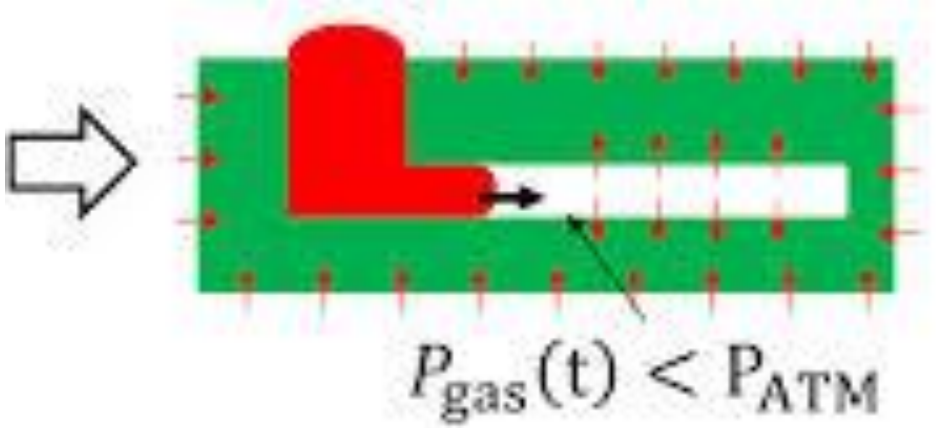
Tips

- Keep surface as clean as possible

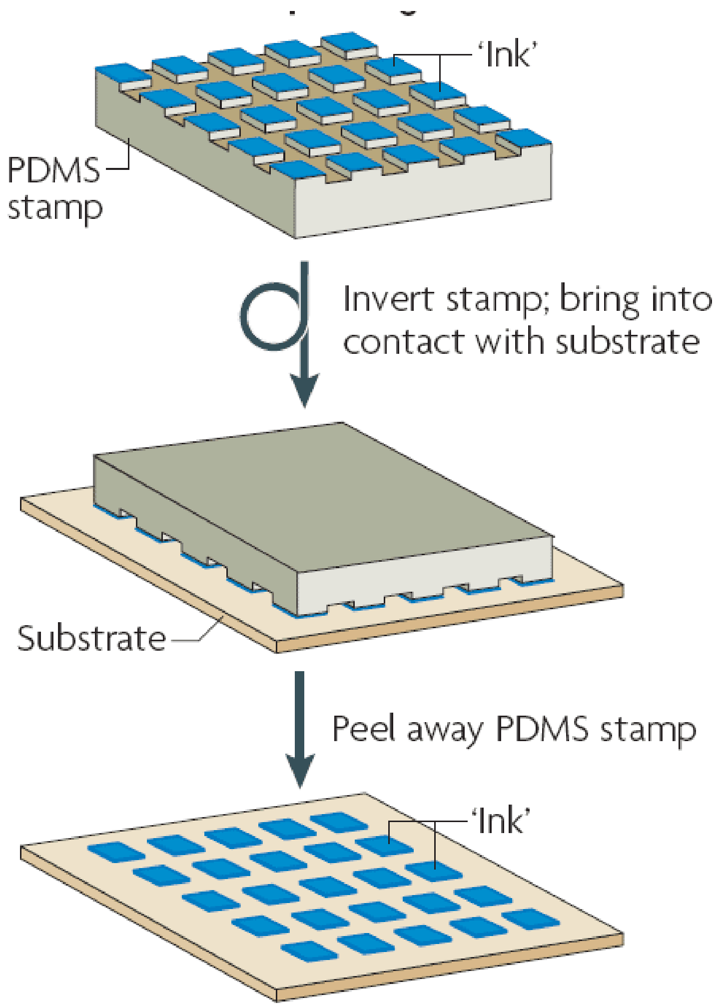
Experimental setup

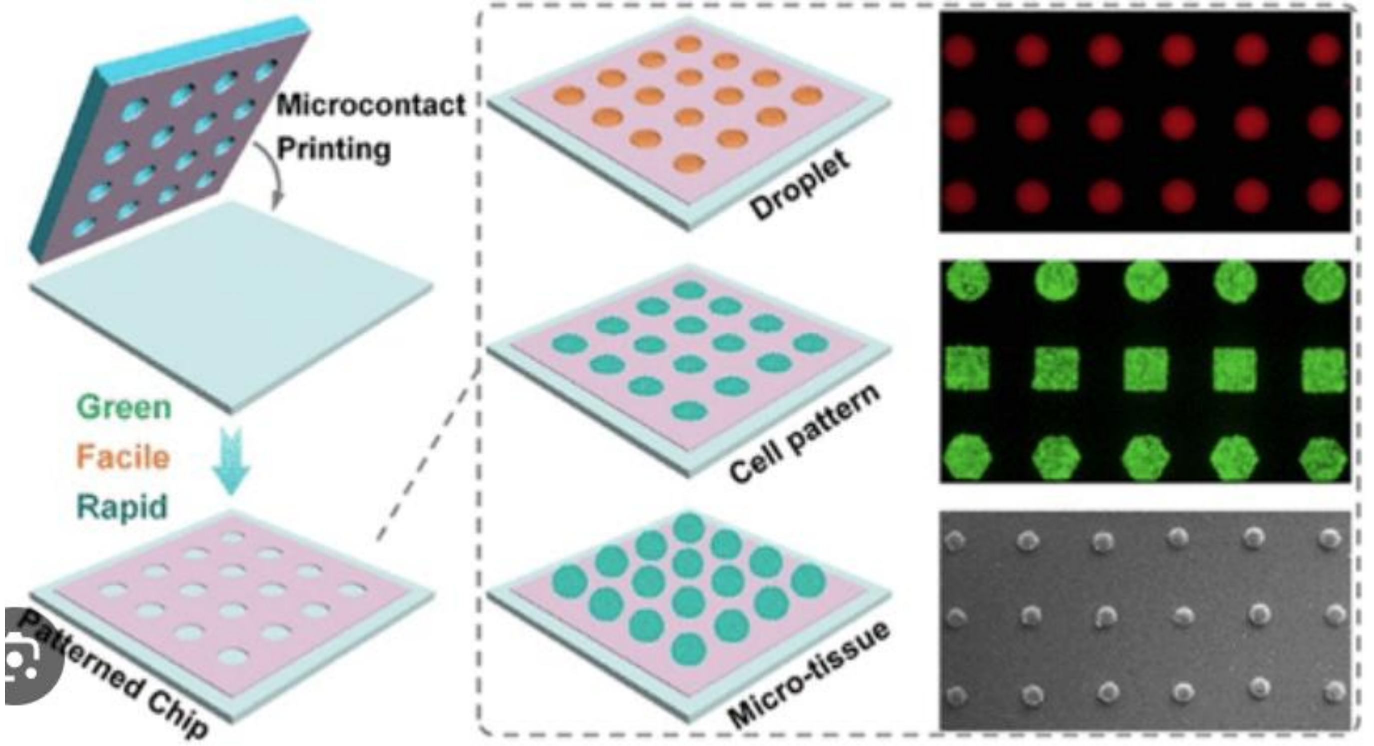


PDMS is gas permeable



Microcontact printing





Steps in Microcontact Printing

- **Master Fabrication**
  - A rigid master mold is created using photolithography (commonly SU-8 on silicon).
  - This master contains the relief features (raised and recessed regions).
- **Stamp Preparation**
  - PDMS prepolymer is poured over the master and cured.
  - After peeling, you obtain a PDMS stamp with the **negative relief pattern** of the master.
- **Inking**
  - The PDMS stamp is coated with “ink,” typically:
    - **Alkanethiols** for gold substrates.
    - **Proteins, DNA, polymers, or silanes** for other applications.
  - Inking is done by dipping or dropping a solution onto the stamp.
- **Printing (Contacting)**
  - The inked PDMS stamp is gently placed in contact with the target substrate.
  - Molecules transfer from the raised regions of the stamp to the surface.
  - This creates a **chemical pattern** that matches the relief features of the stamp.

Proteins for Cell Patterning (Biointerfaces)

- **Ink:** Extracellular matrix proteins (e.g., fibronectin, laminin, collagen).
- **Substrate:** Glass, PDMS, or tissue-culture plastics.
- **Goal:**
  - Pattern adhesive proteins on a non-fouling background (e.g., PEG-coated surface).
  - Cells only attach where proteins are present.
  - Used to **control cell shape, migration, and differentiation** in tissue engineering.
  - Example: Printing fibronectin islands to guide stem cell differentiation based on cell geometry.

DNA Oligonucleotides (Biosensing)

- **Ink:** Single-stranded DNA (ssDNA) probes.
- **Substrate:** Glass or silicon oxide functionalized with silanes (e.g., APTES).
- **Goal:**
  - Pattern capture probes in arrays.
  - Used to create **DNA microarrays** for gene expression analysis or biosensors.
  - Example: Complementary fluorescently labeled DNA hybridizes only to printed regions.

Practice:

- Design the fabrication flow for microcontact printing