EEL3050: Biosensors

Fabrication Lab Report

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Experiment-1X: Thermal Evaporation

1 | Objective

To observe and understand the process of Thermal Evaporation in the laboratory.

2 | Theory

Thermal Evaporation is a fundamental technique in microfabrication used to deposit thin films on substrates. In this process, a material in a crucible is heated to its vaporization point, forming a vapor that condenses onto a substrate, creating a uniform thin film. This technique is extensively used in semiconductor manufacturing for the precise deposition of metals, dielectrics, and organic materials. Its versatility and cost-effectiveness make it essential for fabricating microelectromechanical systems (MEMS), integrated circuits, and coating complex three-dimensional structures.

3 | Materials Required

- Silicon wafer samples
- Tweezers
- Aluminum (as deposition material)
- Inert gas connection
- Thermal evaporation setup

4 | Procedure

1. **Cleaning the Chamber:** Ensure the vacuum chamber is clean and free from contaminants.
2. **Vacuum Pumping:** Pump down the chamber to achieve a vacuum level of approximately 10^{-6} to 10^{-7} Torr.
3. **Loading the Material:** Load the evaporation source material (Al) into a crucible compatible with the material.
4. **Substrate Placement:** Position the silicon substrates on the holder, ensuring proper alignment and distance from the evaporation source.
5. **Heating:** Apply power to the resistive heating source to reach the material's vaporization point.
6. **Deposition Monitoring:** As the material evaporates, monitor vapor deposition on substrates, forming a thin film.
7. **Thickness Monitoring:** Track the film thickness using a thickness monitor or calculate based on deposition rate and time.

5 | Observations

- **Target material:** Silver
- **Substrate:** Silicon wafer
- **Deposition thickness:** 59.953 nm
- **Time:** 600 sec
- **Deposition rate:** 0.3 Å/sec

- **Working pressure:** 4.6×10^{-6} mbar
- **Temperature:** 25-27 °C
- **Set Speed:** 100 %
- **ACP 40 Swirch:** ON
- **Crystal Life:** 71 %
- **Current Applied:** 85 Amp
- **Voltage:** 38 V

6 | Results

The thermal evaporation process was successfully completed, demonstrating the deposition of a thin aluminum film onto a silicon substrate. The final deposition thickness and other relevant parameters were recorded.
The experiment demonstrated the significance of thermal evaporation in microfabrication, showcasing its role in achieving precise material deposition essential for advanced device manufacturing.

7 | Precautions

1. **Ensure a Clean Chamber:** Clean the chamber thoroughly to prevent film quality contamination.
2. **Wear PPE:** Use gloves, lab coats, and eye protection to avoid exposure to high temperatures and fumes.
3. Ensure the vacuum level is stable to avoid contamination during deposition.
4. **Avoid Overheating:** Control the heating power to prevent substrate damage or altered material properties.
5. Use tweezers to handle wafers to avoid fingerprints or dust, which can affect film quality.
6. Ensure Proper Ventilation to disperse any released gases safely.
7. Track film thickness closely to achieve the desired deposition and prevent defects.

8 | Extra Points

8.1 | Q. Why vacuum is created inside the chamber?

Ans-

- In a vacuum, the air pressure is significantly lower, which reduces the number of air molecules inside the chamber.
- **To Avoid Unwanted Chemical Reactions:** This helps prevent unwanted interactions between the evaporating material and air molecules, such as oxygen or nitrogen, which could otherwise contaminate the film or cause oxidation.
- **Reduce Mean Free Path of the evaporating material:** When the chamber is at low pressure, the evaporated material can travel in a straight line from the source to the substrate without colliding with air molecules. This improves the efficiency of the deposition and results in a more uniform coating.
- **Enhanced Evaporation Efficiency:** In a vacuum, the deposited material can evaporate more efficiently because fewer gas molecules can scatter the evaporated atoms.

8.2 | Q. Why do we rotate the substrate during thermal deposition?

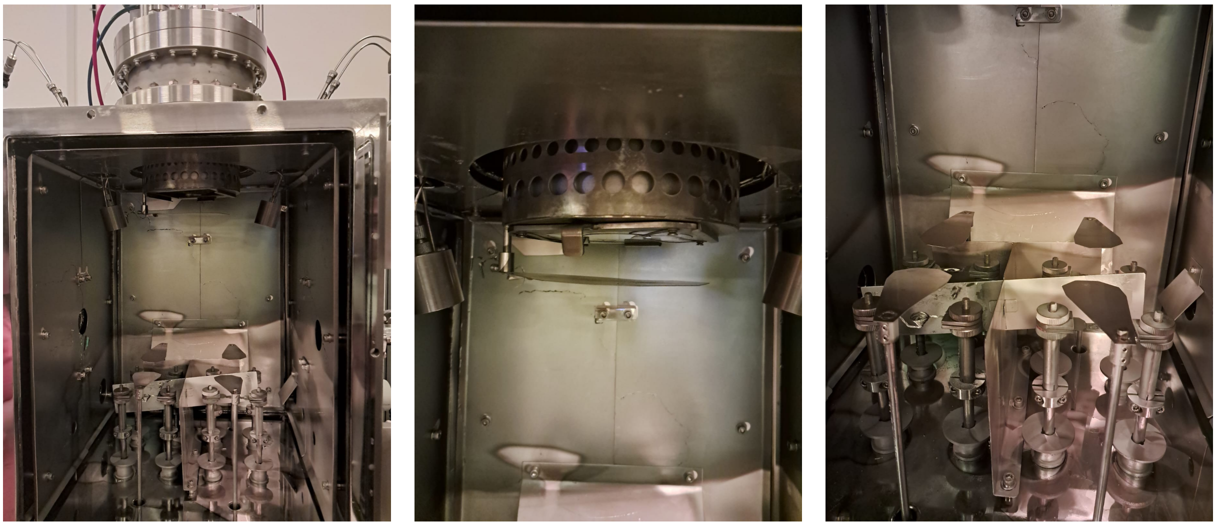
Ans- Rotating the substrate during thermal deposition helps us achieve uniform film thickness.

8.3 | Q. Why is the substrate provided with some temperature before deposition occurs?

Ans- Preheating the substrate in thermal deposition:

- Improves film adhesion by allowing better bonding between the substrate and the deposited material.
- Reduces thermal stress and helps achieve more uniform film growth.
- may also improve the properties of the deposited film (e.g., crystallinity, density).

Figure 8.1: Thermal Evaporation Deposition System

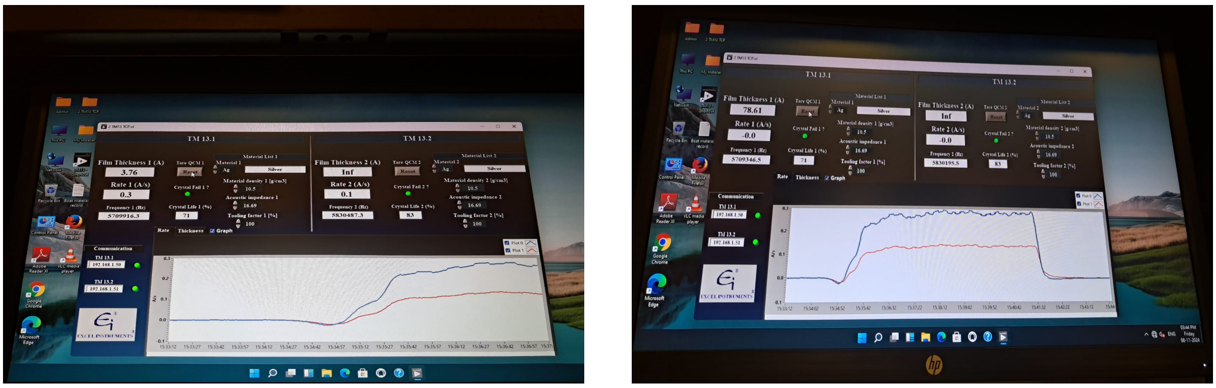


(a) Inside View of TED System (b) Rotator & Substrate Shutter (c) Target Metal Placement

Figure 8.2: Various components inside the TED Chamber

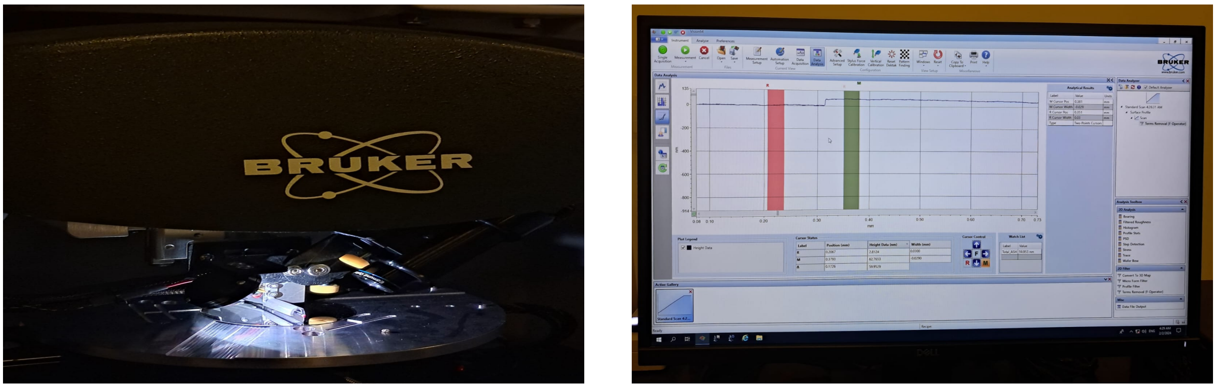
(a) At Beginning (b) At the Beginning of Deposition (c) After the Deposition

Figure 8.3: Parameters of TED System



(a) At the Beginning of Deposition (b) After the Deposition

Figure 8.4: Deposition Curves



(a) Profilometer (b) Step Height

Figure 8.5: Profilometer Curves

(a) Upon heating the Target (b) Silver Deposition on Si Wafer

Figure 8.6: Process & Results

(a) Current and Voltage Parameters (b) Turbo Molecular Pump

Experiment-1Y: Sputtering

1 | Objective

To observe and understand the process of sputtering deposition.

2 | Theory

Sputtering is a critical thin-film deposition technique used in micro-fabrication. The process involves high-energy ions bombarding a target material, causing the ejection of atoms or molecules, which then deposit uniformly on a substrate's surface. This technique is crucial for applications requiring precise coatings, such as semiconductors, solar cells, and other advanced microelectronic devices. **Sputtering** provides excellent adhesion, precise material control, and enhanced film properties, making it an essential method in modern technology development.

3 | Materials Required

- Sputtering system setup
- SiO2 (as target material)
- Silicon wafer sample
- Gas supply (e.g., Argon)

4 | Procedure

1. **Preparation:** Clean the sputtering chamber to remove contaminants and pump it to a high vacuum level (10^{-6} to 10^{-7} Torr).
2. **Target Loading:** Place the target material in the sputtering system, ensuring proper alignment with the substrate holder.
3. **Substrate Placement:** Position the substrates on the holder at an optimal distance from the target material.
4. **Plasma Creation:** Introduce a working gas (e.g., argon) into the chamber. Energize the gas with a power supply to generate plasma.
5. **Sputtering Process:** Apply high voltage to ionize the gas. The ions bombard the target, dislodging atoms. These atoms travel in the vacuum and deposit onto the substrates, forming a thin film.

5 | Observations

- **Target material:** SiO2
- **Substrate type:** Silicon wafer (p-type)
- **Deposition thickness:** 9.921 nm
- **Time:** 20 min
- **Deposition rate:**

$$\frac{9.921\,\mathrm{nm/min}}{20} = 0.49605\,\mathrm{nm/min} \approx 0.5\,\mathrm{nm/min}$$

- **Working pressure:** 1.6×10^{-2} mbar
- **Deposition pressure:** 1.9×10^{-7} mbar

- **Back pressure:** -1 mbar
- **Power:** 100 W
- **Mass Flow:** 30 SCCM
- **Motor Speed:** 100 RPM
- **Temperature:** 24 °C
- **Set Speed:** 100%

6 | Precautions

- Ensure the sputtering chamber is thoroughly cleaned to avoid contamination of the thin film.
- Wear appropriate safety equipment, such as gloves and safety goggles, to protect against high voltage and vacuum conditions.
- Verify the alignment of the target material and substrate to ensure uniform deposition.
- Monitor the vacuum level and working pressure consistently to maintain optimal conditions.
- Avoid prolonged exposure to plasma or energized systems without proper shielding.

Result

The sputtering process was successfully demonstrated. Observing plasma generation, material ejection, and thin film formation reinforced the theoretical principles of the sputtering deposition method.

7 | Extra Points

7.1 | Q. Why load lock chamber is needed?

Ans- A load lock chamber is needed to maintain the vacuum integrity of the main chamber in a sputtering deposition machine. It allows the loading and unloading of samples without exposing the main chamber to atmospheric pressure, ensuring consistent vacuum conditions, reducing contamination, and minimizing pump-down times.

7.2 | Q. RF vs DC Sputtering Pump

RF (Radio Frequency) Pump	**DC (Direct Current) Pump**
Used for insulating or non-conductive targets.	Used for conductive targets only.
Alternating electric fields prevent charge build-up on the target surface.	Target surface must conduct electricity to prevent charge accumulation.
More complex and requires additional equipment for generating RF signals.	Simpler and less expensive compared to RF sputtering.
Lower deposition rates compared to DC sputtering.	Generally offers higher deposition rates for the same material.

Table 7.1: Comparison of RF and DC Sputtering Pumps

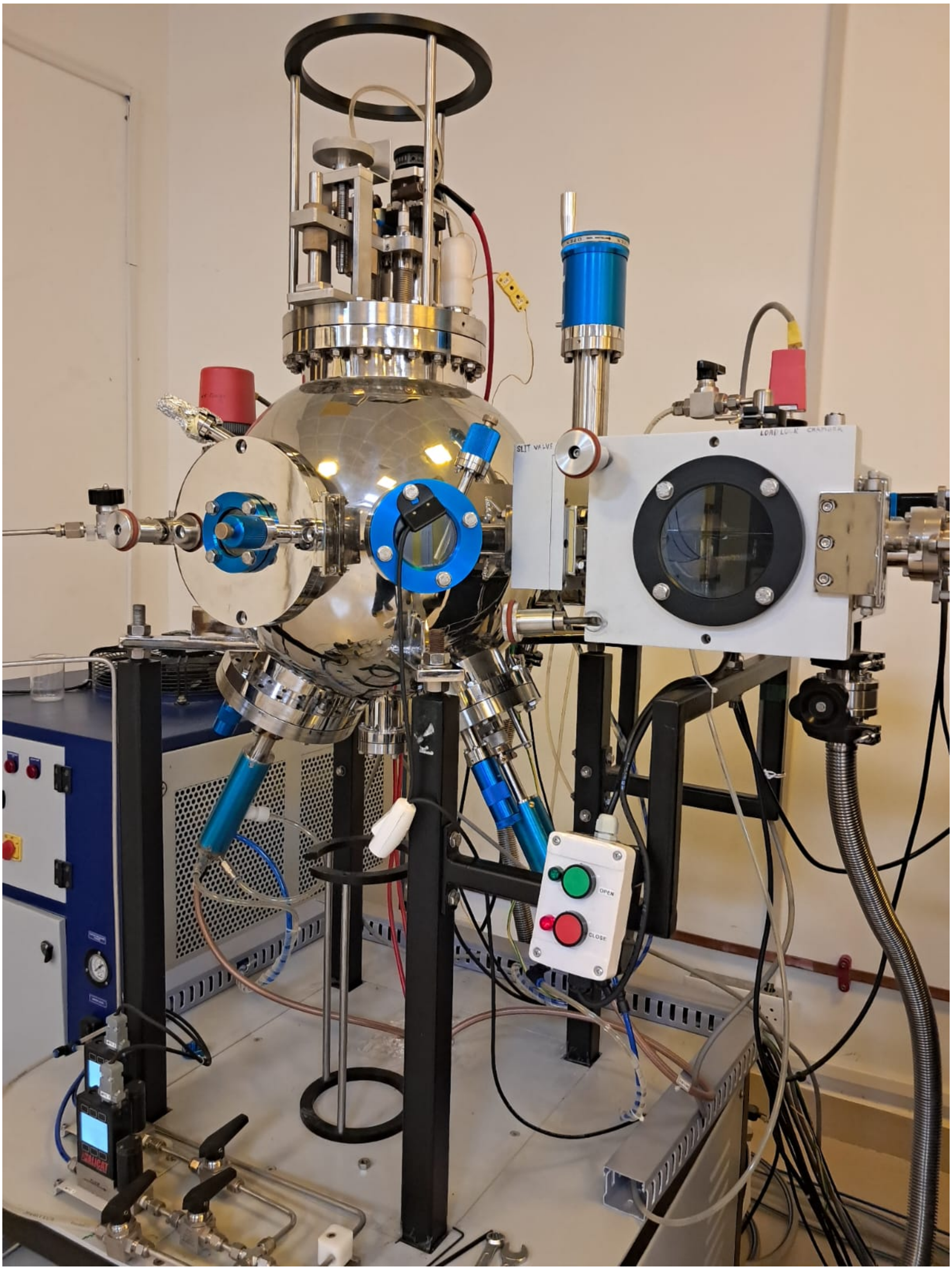
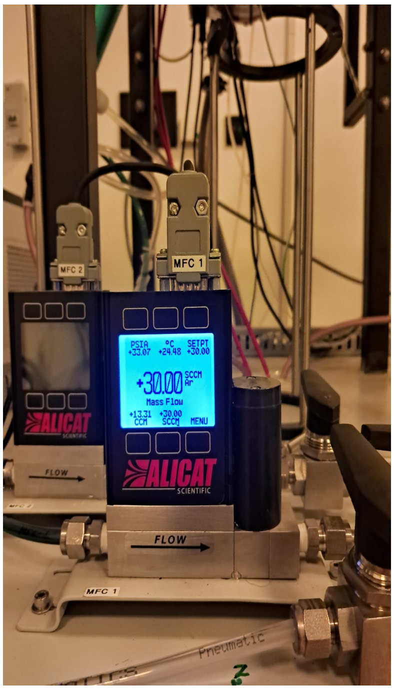


Figure 7.1: Sputtering System



(a) Mass Flow

(b) Initially

(c) At the start of Deposition

Figure 7.2: Experiment Parameters - Mass Flow, Pressure, Temperature and Power

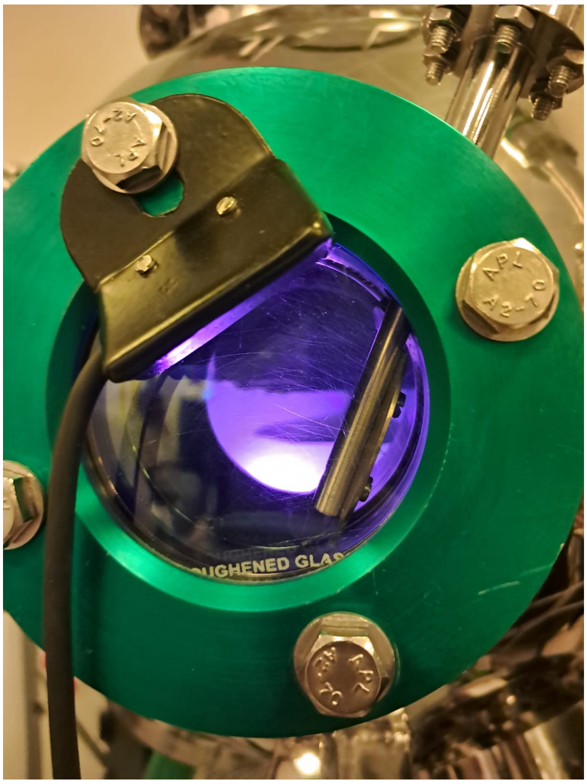


Figure 7.3: Plasma

Experiment-2X: Spin-Coating

1 | Objective

To observe and learn the process of Spin-Coating.

2 | Theory

Spin coating is a method for depositing uniform thin films onto flat substrates like silicon wafers. In this process, a small amount of liquid photoresist is deposited at the center of the substrate and rapidly rotated to spread the resist across the surface, forming an even layer. Film thickness is controlled by spin speed and photoresist viscosity.
Positive photoresist is UV light-sensitive, undergoing a chemical change when exposed, which makes exposed areas more soluble in the developer solution. This enables precise patterning in photolithography, widely used in semiconductor manufacturing and MEMS.
A **"soft bake"** stabilizes the film by evaporating solvents and improving adhesion following spin coating.

3 | Equipment Required

- Positive photoresist
- Silicon wafer or glass substrate
- Spin coater
- Dropper or pipette
- Acetone, IPA (Isopropyl Alcohol) for cleaning
- Hotplate
- Nitrogen gas blower or air gun
- Nitrile gloves
- Tweezers

4 | Procedure

1. **Substrate Cleaning:** Clean the substrate with acetone or IPA, then dry it using nitrogen gas.
2. **Application of Photoresist:** Secure the substrate on the spin coater and apply a few drops of photoresist. Here, we have used a positive photoresist- *S1813G*.
   We are making two samples- (1) By dropping a sufficient amount of PR at the centre of the wafer [Uniform Spreading] and (2) By randomly dropping PR on the wafer [Non-Uniform Spreading].
3. **Spin Coating:** Spin the substrate at 3000-4000 rpm for 30-60 seconds to reach the desired thickness.
4. **Soft Bake:** Place the coated substrate on a hotplate at 90°C for 60 seconds.
5. **Inspection:** Check the substrate under a microscope to assess uniformity and defects.

5 | Results

The experiment produced a uniform photoresist layer on the substrate with the desired thickness and minimal defects. The final layer's properties, as summarized in Table 5.1, met the requirements for subsequent photolithography steps.

Table 5.1: Summary of Experiment Results.

PR Name	Spin Time (s)	Speed (rpm)	Thickness (nm)	Soft Bake Temp (°C)
S1813G	30	4000	500	90
S1813G	30	4000	450	90

6 | Observations

The experiment highlighted the impact of spin speed and time on the film's thickness and quality. Faster spins yielded thinner layers, and consistent soft baking was critical for defect-free films. A surprising observation was the sensitivity of the process to minor changes in spin speed, affecting uniformity.

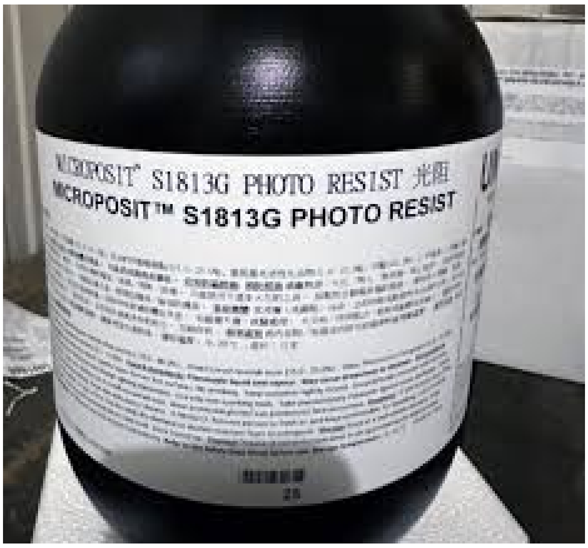
7 | Precautions

1. **PR Application Safety:** It is important that we pour the PR using the dropper bulb in one go to avoid any air bubble formation hindering the uniformity. Dropping the PR at the centre of the wafer with a sufficient amount is necessary to ensure uniformity.
2. Wear nitrile gloves when handling photoresist, acetone, and IPA to avoid skin contact and irritation.
3. Ensure good ventilation or use a fume hood while working with volatile solvents like acetone and IPA to avoid inhaling fumes.
4. Ensure the substrate is securely attached to the spin coater to prevent it from detaching during high-speed rotation.
5. **UV Protection:** Avoid direct exposure to UV light when working with a photoresist to prevent premature curing.
6. **Temperature Control:** Maintain an accurate temperature setting on the hotplate during the soft bake to avoid overheating the resist.
7. **Cleaning:** Carefully clean and dry the substrate to prevent contaminants from affecting film uniformity.
8. Use tweezers to handle the substrate to avoid fingerprints or oils that may interfere with the coating.
9. Use Profilometer carefully. Do not use it if the film thickness exceeds 1 nm, as it can break the probe.

8 | Points To Remember

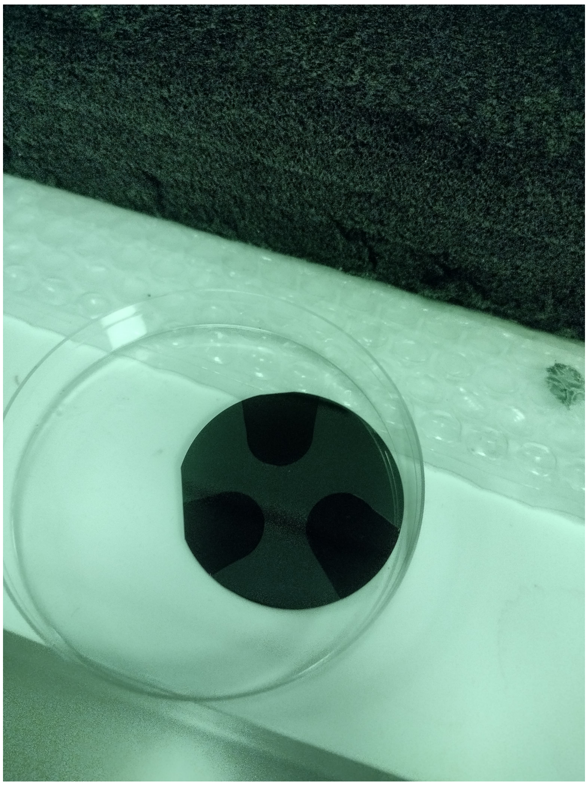
- Film thickness and uniformity of PR depend on spin speed, photoresist viscosity and environmental factors (dust, unintended air currents, temperature fluctuations).
- Vacuum is created inside the spin coating chamber to avoid any moment of the wafer during the spin.
- Here, the chunk in the machine consists of 3 sections of diameter size- 2 in., 4 in., and 6 in.
- The Si Wafers are polished from one end and generally rough on the other. We use the polished surface generally to coat the photoresist.
- We find 2 different colour of curves in the graph- "Blue/Black" represents the ideal/predicted scenario and the "Red" represents the actual readings.
- **Sequence of PR Cleaning**
  Dip in Acetone → Dip in Isopropyl alcohol → Spray DI Water → Dry it using Air Gun
- Q. Why isopropyl alcohol sprayed during cleaning of PR?
  Ans- When in contact with de-ionized water (DI water), Acetone leaves spots on the wafer. That is why we spray isopropyl alcohol to remove any trace of acetone on the wafer.

(a) Spin coat Machine



(b) PR

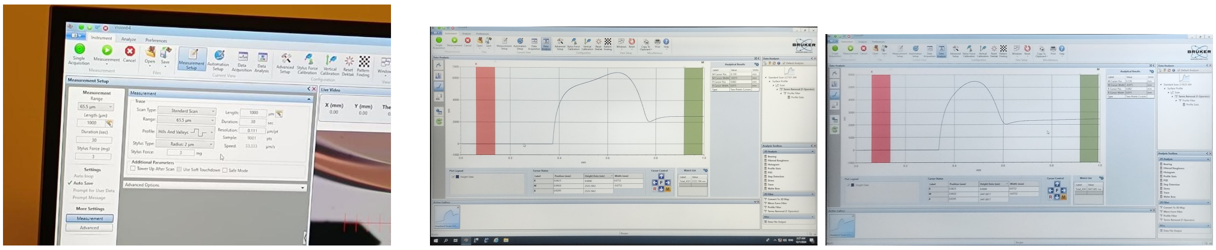
Figure 8.1: Components of Spin-coating



(a) Non-Uniform PR Coating

(b) Cleaning of PR

Figure 8.2: Steps



(a) Parameters of Profilometer (b) Thickness Reading 1 (c) Thickness Reading 2

Figure 8.3: Profilometer Readings

Experiment-2Y: Lithography

1 | Objective

To observe and learn the process of Lithography in the laboratory.

2 | Theory

Lithography is a fundamental technique in microfabrication used to create intricate patterns on a substrate. In this experiment, we used laser writer lithography, a maskless process where patterns are directly written onto a photoresist-coated surface using a focused laser. This technique enables high-resolution and flexible prototyping.
In laser lithography:

- **Positive photoresists** become more soluble upon laser exposure, allowing exposed regions to be removed during development.
- **Negative photoresists** become less soluble, so unexposed areas are washed away during development.

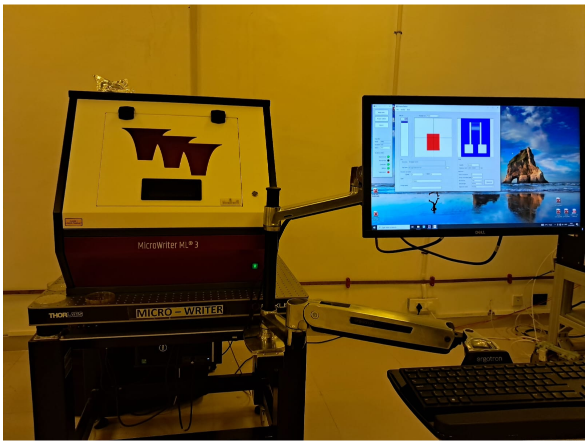
3 | Materials Required

- Positive or negative photoresist (e.g., Shipley S1813)
- Substrate (e.g., Silicon wafer, glass)
- Laser writer lithography system
- Developer solution (e.g., MF-319 for positive resist)
- Spin coater
- Acetone, IPA (Isopropyl Alcohol) for cleaning
- Hotplate
- Nitrile gloves, tweezers
- Nitrogen gas blower or air gun

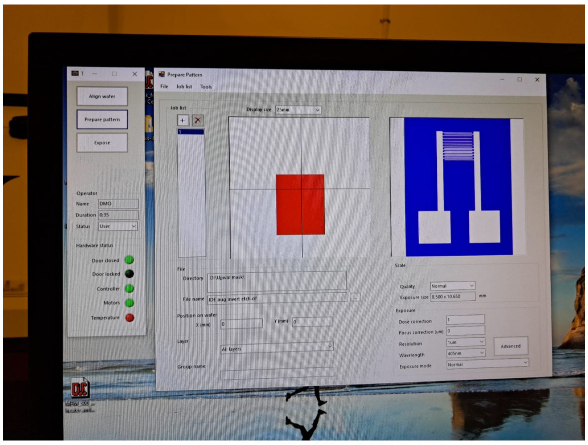
4 | Procedure

1. **Cleaning:** Clean the substrate with acetone or IPA, then dry with nitrogen gas.
2. **Coating:** Spin coat the substrate with positive or negative photoresist.
3. **Soft Bake:** Place on hotplate at 90°C for 60 seconds to remove solvent.

4. **Laser Writing:** Place substrate in lithography system; adjust laser power, focus, and exposure time for desired resolution.



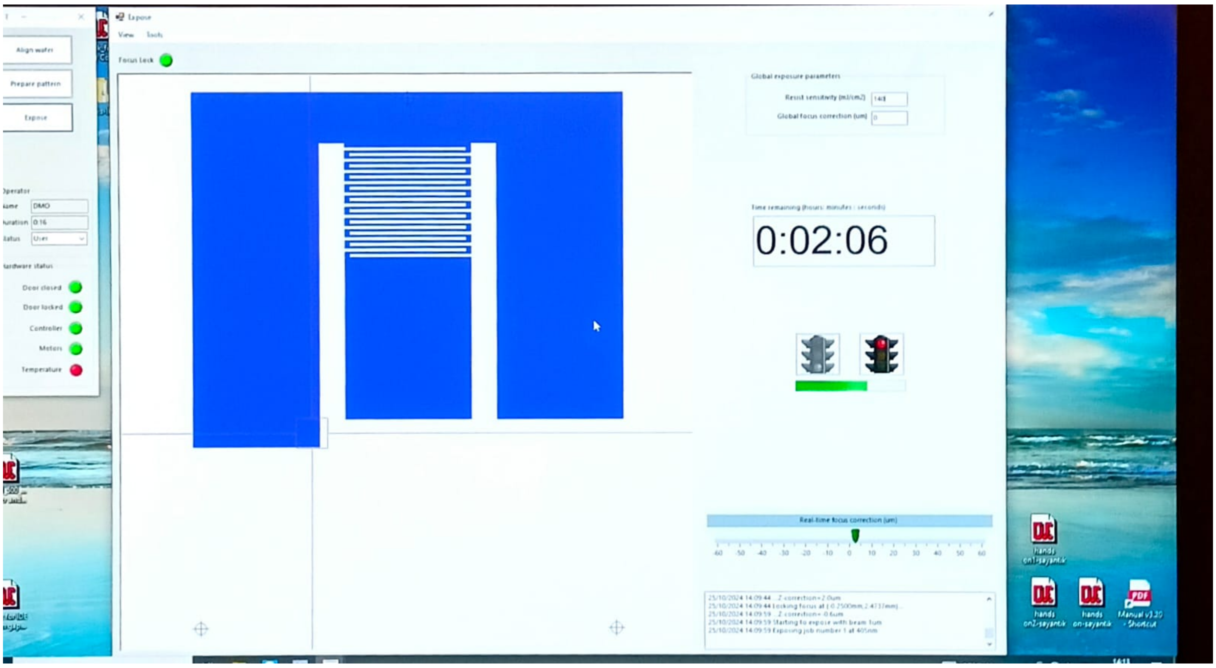
(a) MicroWriter Machine



(b) Mask

Figure 4.1: Setting Up the Mask

5. **Exposure:** Expose photoresist to the laser to create the pattern.



6. **Development:** Develop the substrate in the developer solution for 30-60 seconds. Here, we dipped in AZ726 developer medium for about 40 sec.
7. **Rinsing:** Rinse in deionized water and dry with nitrogen gas.
8. **Hard Bake:** Heat at 120°C for 90 seconds to stabilize the pattern.
9. **Inspection:** Examine substrate under a microscope for defects.

5 | Observations

Laser Power	Laser Exposure Time	Laser Spot Size	Developing Time	Pattern Resolution	Hard Bake Temp.	Hard Bake Time
140 mJ/cm^2	6 min 16 sec	1 μm	40 sec	0.6 μm	120 °C	60 sec

6 | Precautions

1. **Handle Chemicals Carefully:** Work in a well-ventilated area and wear nitrile gloves to prevent skin irritation.
2. **Avoid Overexposure:** Use proper laser power settings to prevent damage to the photoresist or substrate.
3. **Prevent Contamination:** Use tweezers to handle substrates and ensure complete cleanliness before applying photoresist.
4. **Temperature Control:** Follow recommended soft and hard bake temperatures precisely for proper adhesion and pattern stability.
5. **Protective Gear:** Wear goggles, gloves, and lab coats to protect against chemical splashes and laser exposure.
6. **Avoid Touching Exposed Surfaces:** Handle substrate by edges only after coating with photoresist to prevent contamination.

7 | Results

The experiment successfully demonstrated high-resolution lithographic patterning, showcasing the efficiency of laser writer lithography for custom designs and intricate patterning.

8 | Extra Points

8.1 | Silicon Wafer Orientation and Crystal Structure

Reference Link

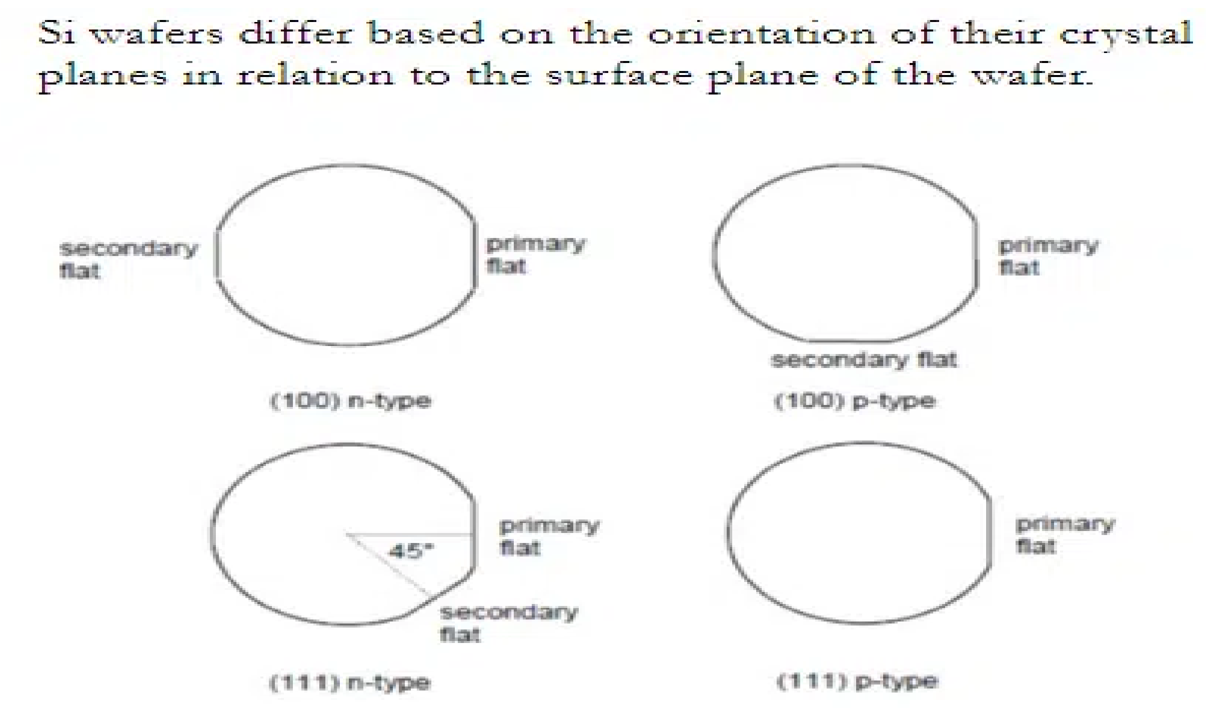


Figure 8.1: Configuration of Si Wafers

8.2 | Steps of Lithography

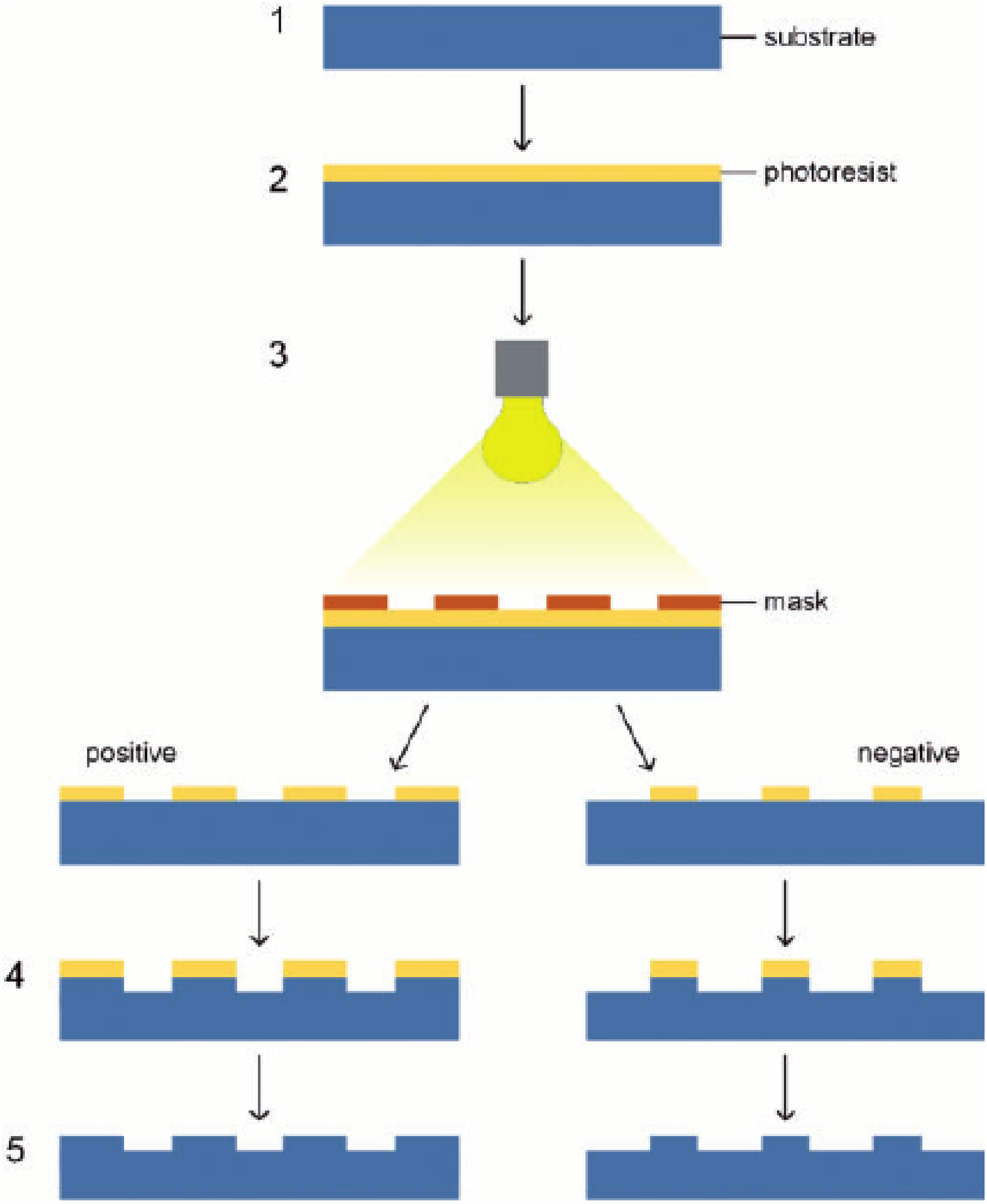


Figure 8.2: Workflow of Photolithography

Step 1: Surface Preparation

- **Purpose:** Clean the wafer to ensure it's free from particles, dust, or organic contaminants.
- **Process:** The wafer is often cleaned with chemicals (such as piranha solution or acetone) and may undergo dehydration baking to remove moisture.

Step 2: Photoresist Application

- **Purpose:** Coat the wafer with a light-sensitive material, called photoresist, which will form the pattern.
- **Process:** Photoresist is applied on the wafer using a spin coater, which spreads it evenly by spinning the wafer at high speed.

Step 3: Soft Baking (Pre-bake)

- **Purpose:** Partially dry the photoresist to improve adhesion and remove solvent.
- **Process:** The wafer is heated at a controlled temperature, often between 90-100°C, for a short period.

Step 4: Exposure

- **Purpose:** Transfer the desired pattern onto the photoresist layer.
- **Process:** The wafer, covered by a photomask with the desired pattern, is exposed to UV light. The UV light alters the chemical structure of the photoresist in the exposed areas.

Step 5: Post-Exposure Bake (PEB)

- **Purpose:** Stabilize the chemical changes in the exposed photoresist and reduce standing waves.
- **Process:** A second baking step to improve the resolution and contrast of the pattern in the photoresist.

Step 6: Development

- **Purpose:** Remove the exposed or unexposed photoresist, depending on the type of photoresist used.
- **Process:** The wafer is placed in a developer solution that selectively dissolves either the exposed areas (for positive photoresist) or the unexposed areas (for negative photoresist).

Step 7: Hard Bake

- **Purpose:** Finalize the adhesion and durability of the remaining photoresist pattern.
- **Process:** A higher temperature bake to further solidify the pattern and prepare it for the etching process.

Step 8: Etching

- **Purpose:** Transfer the photoresist pattern to the wafer material beneath.
- **Process:** Using techniques such as wet or dry etching, material is removed from areas unprotected by photoresist, creating the desired structures on the wafer.

Step 9: Photoresist Removal (Resist Stripping)

- **Purpose:** Remove any remaining photoresist from the wafer.
- **Process:** The wafer is cleaned with a chemical solution (such as a solvent or plasma) to strip off the remaining photoresist, leaving only the etched pattern on the substrate.

8.3 | Q. What do the last 2 digits in the PR name signify?

Ans- In photoresist naming conventions, especially those used in semiconductor manufacturing, the last two digits often refer to the thickness of the photoresist layer in micrometres (µm) when applied under standard spin-coating conditions.
For example, in a photoresist named AZ 1512: "12" indicates that the thickness of the resist layer is approximately 1.2 µm when it is spin-coated at a recommended speed.

8.4 | Types of Lithography

Lithographic Technique	Description	Process	Resolution	Applications
Photolithography	Uses light to transfer patterns from a photomask to a photoresist-coated substrate	Photomask with pattern placed over photoresist; UV light exposure alters photoresist, which is developed to reveal pattern	~100 nm (sub-10 nm with advanced techniques)	Semiconductor manufacturing, integrated circuits (ICs)
Electron Beam Lithography (EBL)	Uses focused electron beam for fine patterning	Electron-sensitive resist exposed to electron beam, altering resist chemically; exposed regions developed to reveal pattern	Sub-10 nm	Research, prototyping, quantum dots, nanowires, photonic structures
Ion Beam Lithography (IBL)	Uses a focused ion beam to etch or implant patterns	Ion beam directly writes onto resist/substrate, removing material or modifying surface structure	Sub-5 nm	Defect repair, mask making, nanoscale prototyping
Nanoimprint Lithography (NIL)	Mechanical technique using molds to replicate nanoscale patterns	Hard mold with pattern pressed into resist, then cured; mold removed, leaving pattern impression	Sub-10 nm	Optical devices, MEMS/NEMS, biochips
Soft Lithography	Uses elastomeric stamps for patterning surfaces	Patterned PDMS stamp pressed onto substrate to transfer pattern via microcontact printing or microtransfer molding	Micron to sub-micron	Biological applications, microfluidics, flexible electronics
Extreme Ultraviolet Lithography (EUV)	Utilizes extreme ultraviolet light (13.5 nm wavelength) for ultra-fine patterning	EUV light exposure with specialized optics in vacuum; similar process to photolithography	Sub-10 nm	Advanced semiconductor fabrication, next-gen processors, and memory chips
X-ray Lithography	Uses X-rays for pattern transfer with deeper penetration	Mask with X-ray-opaque pattern selectively exposes resist; resist developed to reveal pattern	Sub-10 nm	Semiconductor industry applications requiring ultra-fine patterns
Interference Lithography	Creates periodic structures via interfering laser beams	Coherent laser beams intersect on resist-coated substrate, forming interference pattern; pattern developed for periodic structures	Sub-micron	Photonic crystals, diffraction gratings, periodic nanoscale structures

Table 8.1: Comparison of Different Lithographic Techniques