UNIT 3

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Syllabus

- **Lithography:** photolithography and pattern transfer, Optical and non optical lithography, electron, X-ray and ion-beam lithography, contact, proximity and projection printers, alignment,
- **Photoresist & Etching:** Types of photoresist, polymer and materials, Etching- Dry & Wet etching, basic regimes of plasma etching, reactive ion etching and its damages, lift-off, and sputter etching

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Lecture Plan

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LITHOGRAPHY

MODULE 1

Introduction

- Process of transferring geometrical pattern from a mask to the Si Substrate.
- In this process, first of all coating the Si Substrate is done, with photoresist.
- **First step is to coat the Substrate with photoresist.**
- Photoresist is the radiation sensitive polymer.
- When the photoresist is exposed to UV light its properties changes.

Cond...

- So, in lithography process, 1 or 2 drops of photoresist are used.
- Put these drops in Si Substrate.
- Spin the Substrate very quickly.
- Hold the substrate in vacuum chuck.
- Spin it very fast (4000 rpm).
- Now, we have thin uniform coating of the photoresist film on the wafer.

Cond...

- By, varying the spin rate thickness of the coating layer (photoresist) can be adjusted.
- **Second step is to expose it to UV radiation.**
- This exposure may/may not be through a mask.
- Mask is a glass plate with opaque and transparent patterns on it.
- Mask has opaque and transparent patterns.
- Now allow the radiation to fall on it.

Cond...

- As, the photoresist is radiation sensitive material, so only regions, which are exposed to the radiation, their properties will change.
- The exposed regions get soften (+ve photoresist).
- **Third step is developing the substrate.**
- This substrate is now soaked in a developing solution.
- **Fourth step is Etching.**

Cond...

- Photoresist can be removed by photoresist removal solution.
- Now the exposed oxide can be etched away.

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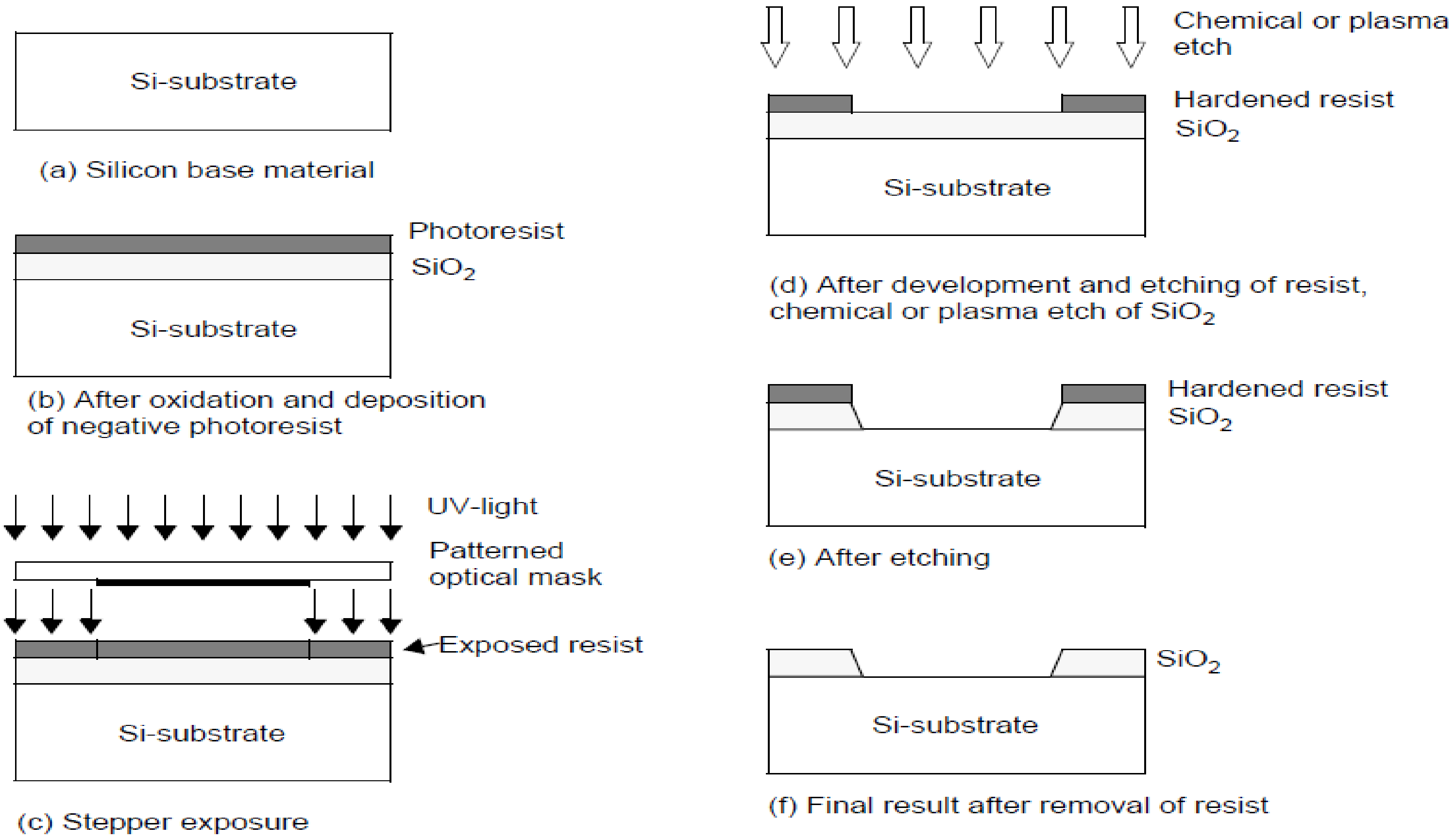

Classification of Lithography

1. Optical Lithography (Photolithography)
2. Non-Optical Lithography
   A. E Beam Lithography
   B. Ion Beam Lithography
   C. X Ray Lithography

Cond...

- In Optical Lithography, the resist is called Photoresist & UV rays are used.
- In E Beam Lithography, the resist is called e-beam resist & is electron beam is used.
- In X Ray Lithography, the resist is called x ray resist & x rays are used.

Optical Lithography

- It can be classified in 3 categories.

1. Contact printing
2. Proximity printing
3. Projection printing

Cond...

- **In contact printing**, the wafer is in the contact with the mask.
- There is no gap between the mask and the wafer, so the resolution will be high.
- The disadvantage of contact printing is that the life of the mask is reduced.
- Also, if there is some dirt on the mask, it can damage pattern on the mask.

Cond...

- In **proximity printing**, the wafer and mask have some gap between them.
- The life of mask is somewhat larger than contact printing.
- But the resolution is smaller than that for contact printing.

Cond...

- In **projection printing**, the mask is not in the contact with the wafer.
- Here the image of the mask is focused on the wafer.
- So, there is no problem of life reduction of the mask.
- Because of the highly focused image on the wafer, the resolution is high.
- A complicated optical setup is required in order to project the image of the mask on the wafer.

Cond…

- In **Contact Printing**, life of the mask is lower, but the resolution is high.
- In **proximity Printing**, life of mask is more than contact printing, but the resolution is smaller than contact printing.
- In **projection printing**, life of mask is higher and the resolution is higher.

Photoresist

- Photosensitive compound used in microelectronics is called photoresist.
- 2 kind of photoresist, -ve and +ve.
- Photoresist actually have 2 materials in it polymer and photosensitive compound.
- The photosensitive compound get activated when it is exposed to UV radiation.
- After getting activate it absorbs energy.

Cond...

- The energy is transferred to the polymer molecules.
- Let us consider –ve photoresist.
- When the polymer molecules get energy from activated photosensitive compound, the **molecular width of the polymer molecules increases.**
- So, when the width of the polymer molecules increases, it becomes more difficult to dissolve in any developer solution.

Cond...

- So, the regions which are not exposed to light, there is no absorption of energy.
- So, the width of the polymer molecules will not increase.
- So, the regions not exposed can be removed by developer solution.
- The +ve resist have opposite manner.

Requirement for photoresist

1. Uniform film deposition
2. Good resolution
3. Good adhesion to the wafer

Advantages & Disadvantages of Resist

- -ve and +ve resist are already discussed.
- Now consider, we have two substrate, one with –ve resist and other with +ve resist.
- Let we have exposed these two resist in UV rays.
- Now, we have to dissolve the softened resist using developer solution (solvent).
- The +ve resist will dissolve early as compared to –ve resist.
- First, the resist will absorb the developer solution.

Cond…

- Consider the case of –ve resist, the absorption of the developer solution will cause swelling of resist.
- So, the feature size will change.
- Therefore minimum feature size will get slightly distorted.
- **So, -ve resist offers poor resolution, i.e., +ve resist are better.**

Figure of merits of Lithography

- Figure of merits determines how good or bad the lithography process is.
- There are 3 figure of merits of lithography process.

1. Resolution
2. Throughput
3. Depth of focus

Cond...

- **Resolution** means what is the minimum feature size. It also means the precision at which the minimum feature size is achieved.

- **Throughput** means how many wafers can be processed in a given time.

- **Depth of Focus** determines the depth of penetration of the light in the resist.

E – Beam Lithography

- Electron beam (diameter 0.2 μm to 0.5 μm) is used instead of UV rays.
- In this kind of lithography, no need of mask, i.e., direct writing is possible.
- It has greater depth of focus.
- The scan system is computer controlled.
- The e beam can be switch on or off as per requirement.

Cond...

- The movement of the e – beam taking place on very small region called “scan field”.
- The resolution of e – beam lithography will be very good, if the beam diameter is small.
- So, for good resolution we should have very good focused e – beam.

Problems associated with e – beam Lithography

- There are 3 problems associated with e – beam lithography.

1. Slowness
2. Low Throughput
3. Proximity effect

Cond...

1. **Slowness:** Since, e – beam lithography offers direct writing the e – beam scan all over the surface of the substrate. If we use +ve e – beam resist, it has to be exposed to e – beam radiation to considerable amount of time.
2. **Low Throughput:** as every wafer need a longer time to process the radiation, so larger number of wafer can't be processed during a given time.
3. **Proximity effect:** as the e beam has high energy, so it may scatter the regular wafer atoms. It is proximity effect.

Ion – Beam Lithography

- Ions are used instead of electrons, as in e – beam lithography.
- Since, ions have very low energy as compared to electrons, so scattering problem is low.
- So, the ion beam lithography is usually preferred.
- For ion beam lithography, RF ion source is used.
- Ions may be, H^+, He^+ or Ar^+ in the 100 keV of energy.
- RF ion source is a very big system, so it is prone to vibration.

X – Ray Lithography

- X Rays are used in order to radiate the resist.
- It is usually done by proximity printing.
- So, instead of UV light X-Rays are used.
- X – ray don't has high energy so no problem of proximity defects.
- In X – Ray system, we have an e – beam focused on water cooled palladium target.
- When the e beam is focused on this target, it generates X – rays.

Cond…

- The X – Rays are generated and directed into a chamber.
- This chamber is filled with the Helium.
- The Helium is preferred because, it doesn't absorb the X Rays.
- Inside this chamber, the x – ray mask and the substrate are placed closer, but not in actual contact.
- The X – Ray mask is usually a membrane (aluminum oxide or silicon nitride) coated with gold.

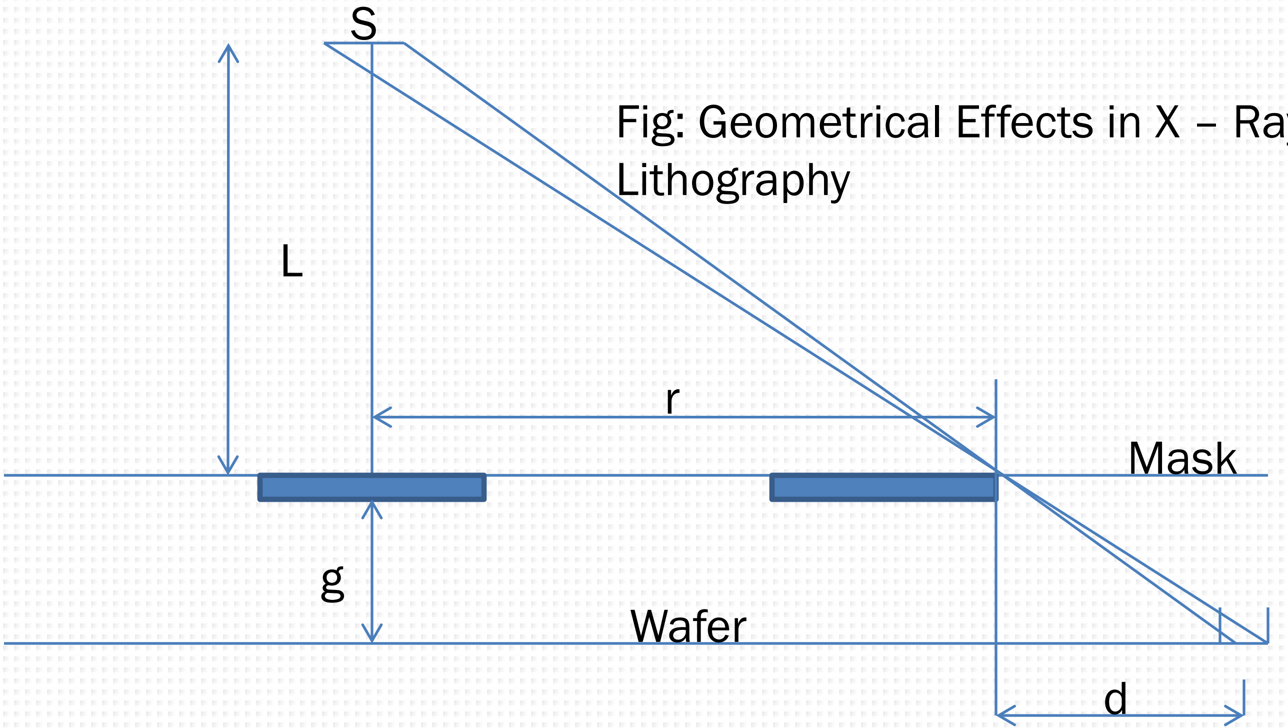

Fig: Geometrical Effects in X – Ray Lithography

Cond...

- The thin membrane material can be.
- Gold is usually used in order to absorb the X – Rays.
- Now, see figure at previous slide, X – Ray proximity printing arrangement is shown.
- g is the gap between the wafer and mask.
- If wee look at the pattern, then we see that the actual pattern is shifted with an additional amount of d.

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Cond...

- "d" is given by: $d = \frac{rg}{L}$;
- where, "g" is the separation between mask and the substrate & "L" is the distance of the X – Ray source from the mask.
- In order to make the geometrical effect as small as possible, the factor $\frac{g}{L}$ should be as small as possible.

Advantages of X Ray Lithography

- Faster throughput
- Good resolution
- No proximity defects due to low energy
- No contamination problem
- Low absorption

ETCHING

Module 2

Etching

- It is the next step after lithography.
- It is the process by which the material can be uniformly removed from the wafer surface.
- In Lithography, pattern from the mask are transferred onto the wafer.
- After the Lithography, selected regions from the wafer can be etched away.
- The etching is usually done by dilute HF acid.

Figure of merit

1. Anisotropy
2. Selectivity

1. Anisotropy

- Etching must be in preferential direction.
- Usually etching must be in vertical direction & not in horizontal direction.
- It is given by, $1 - \frac{dH}{dV}$
- *dH* is etch rate in horizontal direction.
- *dV* is etch rate in vertical direction.
- *If dH=0,* then it is perfectly Anisotropic Etching.
- *If dH=dV,* then it is perfectly Isotropic Etching.

2. Selectivity

- Let we have two material A & B.
- Selectivity means that, when material A is etched up to A – B interface, the etching must be stopped.
- It means etching system must be selective.
- It etches material A and not B.

Wet Etching

- Some chemical solution is used for wet etching.
- There are some chemical reactions involved, so it is also called “wet chemical etching”.
- For wet etching, put the substrate into etchant solution.
- There are following steps.

Cond...

- **First step is to transport of Etchant.**
- The etchants are in the solution.
- Let the sample is immersed in the etchant solution.
- The layer of the etchant solution adjacent to SiO_2 layer will react immediately.
- Let HF is the etchant solution.
- So, in order to etching process to keep in progress, fresh supply of etchant solution is required.

Cond...

- **Second step is surface reaction.**
- SiO_2 layer reacts with etchant.
- **Third step is transport of reaction products.**
- After etching reaction, products can be removed.
- Most commonly used etchant is HNA for Silicon.
- HNA is Hydro Fluoric Nitric acid Aqua (or Acetic Acid).

Etching of Silicon

- It is difficult process.
- It is done basically in 2 steps.
- **First step** is to convert Si into SiO_2.
- **Second step** is to etch the SiO_2.
- So, it means that etchants (HNA) have more than one component.
- One for oxidizing the silicon & other for etch that oxidized silicon.

Fig: Etching of Silicon

Cond...

- **In order to etching of silicon, HNO_3 (Nitric Acid) gives 2 holes.**
- Small amount of HNO_2 reacts with HNO_3.
- $HNO_2 + HNO_3 \rightarrow N_2O_4 + H_2O$
- $N_2O_4 \rightarrow 2NO_2$
- $2NO_2 \rightarrow 2NO_2^- + 2h^+$
- So, the purpose of HNO_3 is to give 2 holes to react with Si to form SiO_2 from Si_2^+.

Cond...

Oxidation of Silicon takes place as

- $Si + 2h^+ \longrightarrow Si^{2+}$
- $2H_2O \longrightarrow 2H^+ + 2(OH)^-$
- $Si^{2+} + 2(OH)^- \longrightarrow Si(OH)_2$
- $Si(OH)_2 \longrightarrow SiO_2 + H_2$
- This is basic anodic oxidation.
- Now, this SiO_2, can be etched away.

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Cond...

- In etchant HNA, the purpose of HNO_3 is to oxidize silicon to form SiO_2.
- The purpose of HF is to dissolve the SiO_2, which gives H_2SiF_6 and water, i.e.,

  $Si + HNO3 + 6HF \rightarrow H_2SiF_6 + HNO_2 + H_2O + H_2$

Problems with Wet Etching

- Etchant will react with both side wall as well as bottom surface.
- So, the side wall and bottom surface will be etched.
- Since the etchant can't distinguish between side wall and bottom surface.
- So, the etching in the vertical and horizontal direction will be identical.

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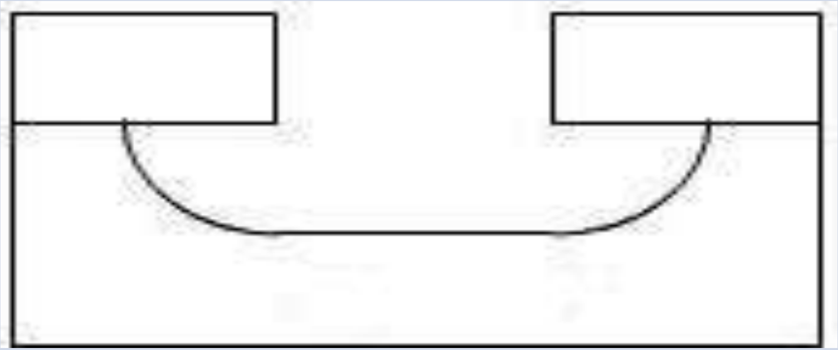
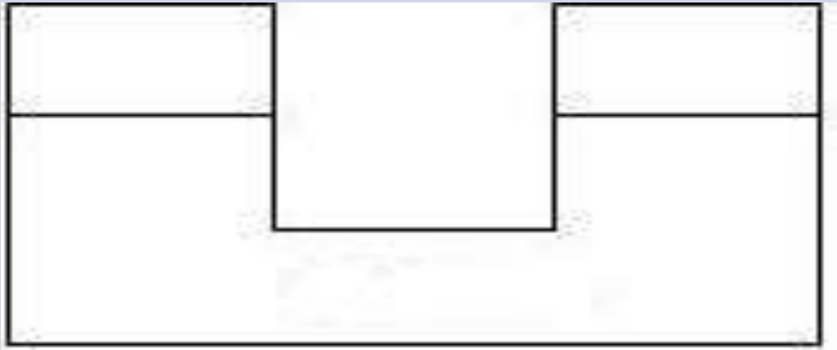
Isotropic Etching	Anisotropic Etching
	

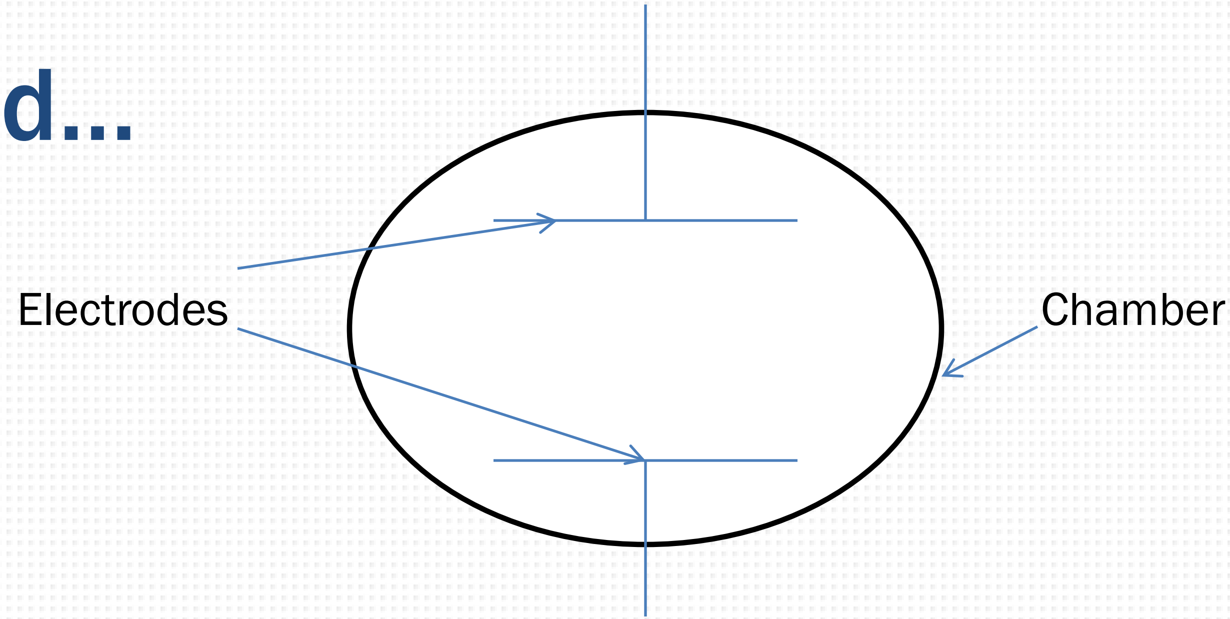
Dry Etching

- No chemical solution required.
- Actually in chemical etching system, it is hard to obtain anisotropy.
- Dry etching is also known as "**Plasma Etching**".
- So, in dry etching, the etching takes place in plasma, not in solution.
- Plasma is partially ionized gas.
- The overall charge neutrality is preserved.

Cond...

- + ve charges in the plasma are ions, and – ve charges are electrons.
- Since, the electrons have very low mass, so they are very light particles as compared to ions.
- So, the electrons can't transfer its energy to the plasma.
- The simplest plasma reactor is shown on next slide.

Cond...



- Fig: Simple Plasma Reactor

Cond...

- The pressure inside the chamber is very low.
- High frequency RF voltage between these two electrodes is applied.
- When this voltage is applied, the electrons starts to diffuse faster to the chamber walls.
- See next slide.

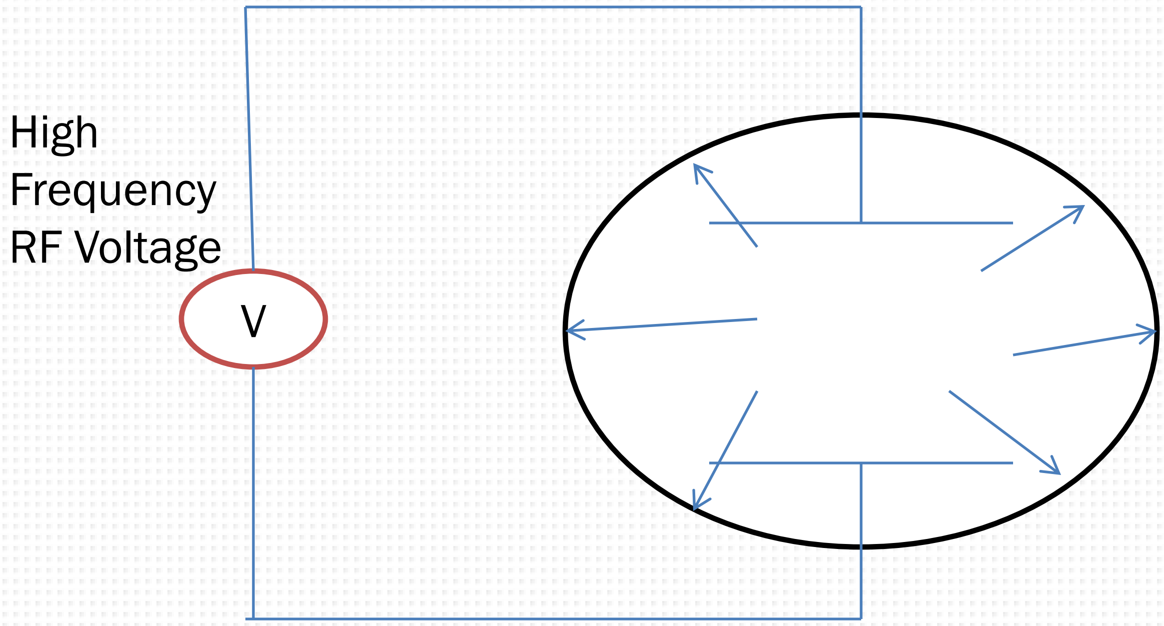


Fig: Electrons are getting diffuse

Cond...

- The electrons move faster, because of light mass.
- Ions have heavy mass, so they can't move so fast.
- So, there is net + ve charge at the Centre of the reactor.
- So, the plasma potential is + ve with respect to the chamber walls.

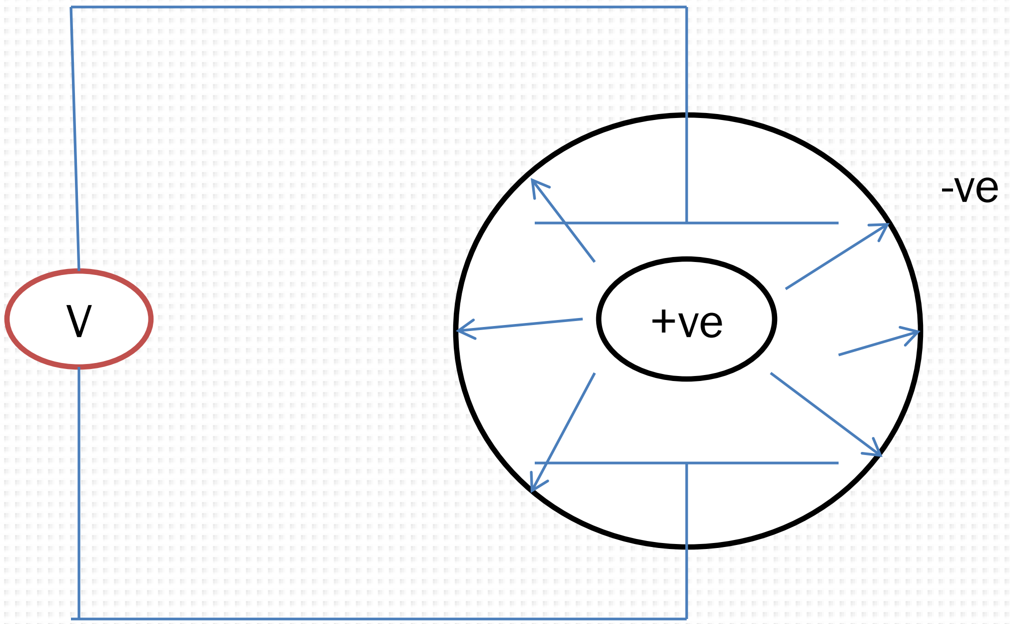


Fig: Net Charge on Plasma

Cond...

- Now, consider the two electrodes.
- We have applied the high frequency AC voltage.
- During the first half cycle one electrode is at + ve & the other is at – ve.
- So, the + ve electrode attracts the electrons.
- The – ve electrode will attract the ions but these ions will move slow because of the heavy mass.
- So, there is bombardment of the +ve ions on –ve electrode.

Cond...

- During one half cycle, there will be flow of electrons towards + ve electrode.
- During next half cycle, this electrode will behave like a capacitor. The equivalent circuit of a plasma reactor, can be viewed as a diode in parallel with a capacitor as shown on next slide.

Cond…

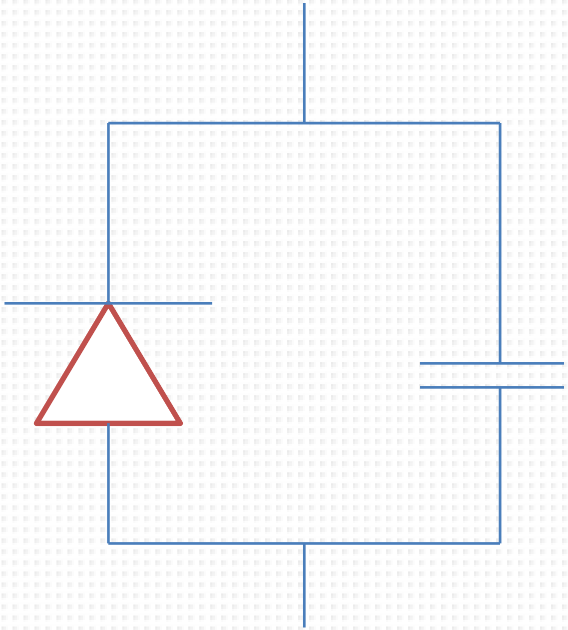


Fig: Equivalent circuit of Plasma Reactor

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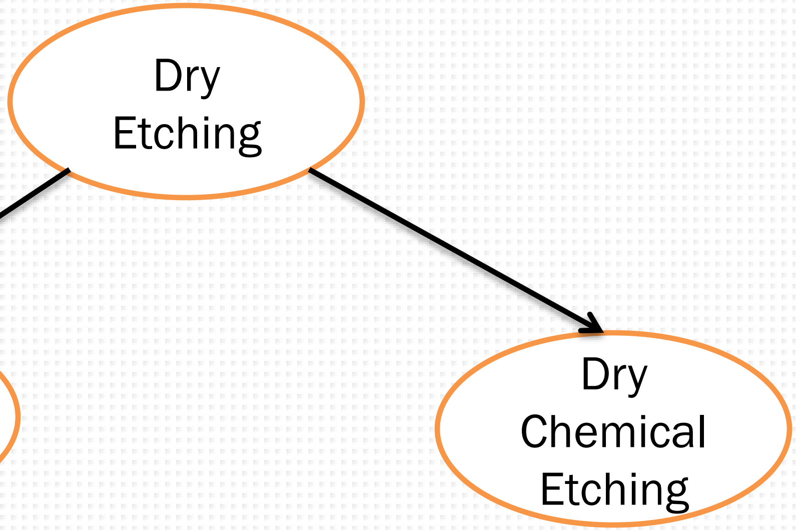
Classification of Dry Etching



1. Dry Physical Etching

- Technique for removing material from a substrate is by physically bombarding is with projectiles usually ions.
- In this approach, a gas discharge is used to impart energy to a chemically inert projectiles so that it is moving at high velocity when it impinges on the substrate.
- This process is called "**sputtering or ion etching**".

Cond...

- The maximum amount of energy T_M, that can be transferred from a projectile of mass M_1 and energy E_0 to a substrate of mass M_2 can be given by

$$T_M = \left[\frac{4M1M2}{(M1 + M2)^2}\right] E_0$$

- It is advantageous to use a heavy inert gas as argon for the projectile.

Cond...

- At high energies, the projectile has an increasing “**penetration depth**”.
- With sufficiently high energies, the projectiles can penetrate quite deeply into the surface of the substrate & may cause damage.
- So, the projectile energy kept usually below 2 keV, in order to minimize the damage problem.
- Angle of incidence of the projectile is also important parameter.

Cond...

- $$depth\ of\ penetration \ \alpha\ \frac{1}{Angle\ of\ incidence}$$

- For anisotropic etching, the angle of incidence must be normal.
- In, ion or sputtering etching low energy ions are usually preferred in order to avoid damage.

2. Dry Chemical Etching

- Dry process avoids problem of undercutting patterning film by liquid etchants.
- In Dry process, the amount of reagent gases is quite small.
- Usually gases chemical species (HCl & SF_6) are used for Dry Chemical Etching.
- Dry Chemical Etching takes place at room temperature.
- It uses of interhalogenic compounds such as, ClF_3, BrF_3, BrF_5 and IF_5.

Cond...

- For etching of SiO_2, mixture of F_2/H_2 gas in presence of uv is used.
- In this technique, energetic reactant species are used.
- These reactants can be produced by use of plasma.

Cond...

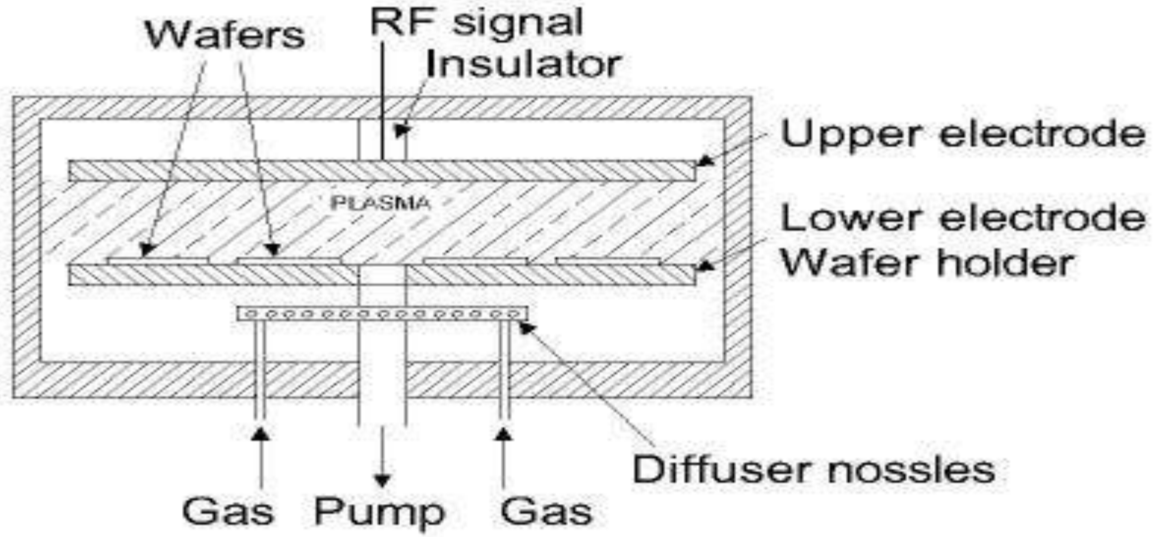
- **<u>There are 3 steps for dry chemical etching:</u>**

1. The generation of active species.
2. Transport them to the substrate.
3. Removal of the reaction products.

Reactive Ion Etching

- ***One or more chemical species*** are used in a RF sputtering system.
- When these chemicals interacts with plasma, they produce ***both, neutral and ionized energetic species.***
- These can etch the substrate.
- A planar reactor for RIE is shown in figure.

Cond...


Wafers
RF signal
Insulator
Upper electrode
PLASMA
Lower electrode
Wafer holder
Diffuser nossles
Gas
Pump
Gas

Cond...

- Here the substrate are normal to the gas flow, and are immersed in the plasma.
- The energetic species are normal to the RF field, so that the movement of ionized species is highly directional and rapid.

Cond...

- A **high degree of anisotropy** etching can occur.
- In RIE, ion bombardment results in **poor selectivity.**
- Energetic neutral chemical species also play role in etching.
- So, the successful etching is obtained, when there is a suitable balance between physical and chemical process.

Cond...

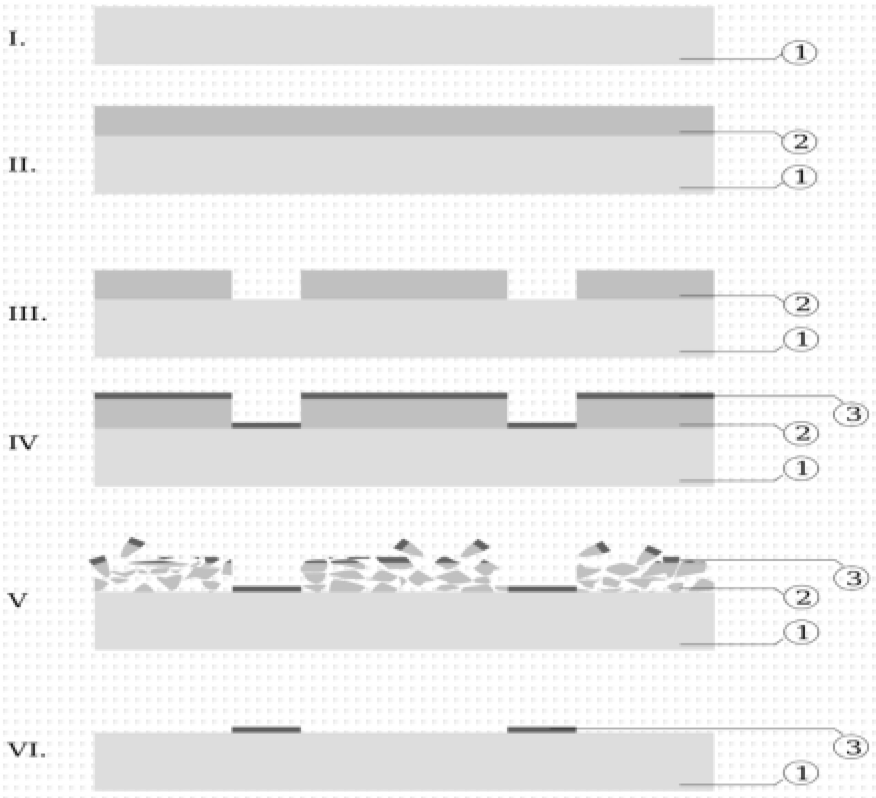
- The balance depends on the choice of chemical species and RF voltage.
- Pumps are used to remove the products.

Lift-off Technique

- In this technique, **first** a positive photoresist is placed on substrate and patterned where **no metal film is required.**
- **Next**, the metal film is deposited over the substrate-resist combination.
- **Finally**, the photoresist is removed from by a solvent which does not attach the metal film.
- Now the unwanted metal can be lifted off.
- It is called **lift-off** technique.

Advantages of Lift Off Technique

1. It can be used with metal films such as platinum, gold, silicide and refractory metals which are very difficult to etch.
2. It takes less time due to thick photoresist.



Review Questions

1. List the defects in pattern transfer.
2. List all process steps of pattern transfer with diagram.
3. What are PR materials? Describe all types of PR. What are the properties of PR?
4. Explain proximity printing and projection printing & compare these two.
5. List and compare different types of lithography techniques.

Review Questions

6. Explain ion beam lithography process.
7. What are the requirements of a photoresist? Which photoresist is preferred for better resolution and why?
8. Describe various printing techniques in lithography. Which one is better and why?
9. What is the difference between positive and negative photoresist? Which photoresist is preferred for better resolution and why?

Review Questions

10. List and explain all the steps of pattern transfer using photo lithography process.
11. What is X-Ray lithography? Describe advantages and problem areas associated with X-Ray lithography.
12. Describe ion beam lithography in brief.
13. What is plasma? Draw an equivalent circuit for RF plasma discharge.

Review Questions

14. What are the figures of merit of etching system? Compare anisotropy and isotropy etching.
15. Explain all properties of etchant.
16. What is reactive ion etching? Describe its damages. What is etching? Describe wet etching for silicon with all steps. Also discuss problems with wet etching
17. Describe the sputtering etching with neat diagram.

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