Microfabrication technologies

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Marks	11.83/18.00
Grade	**6.57** out of 10.00 (**66**%)

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Question **1**
Incorrect
Mark 0.00 out of 1.00
Flag question

Which of the following statement is correct for an Inductively coupled plasma (ICP) etching system?

- There are two RF power sources: one for generation of the plasma and one for stabilizing the temperature inside the chamber ✖
- The electrical impedance of an ICP source is an inductor in series with a small resistor
- A high voltage on the working electrode is needed, so that the plasma potential is kept at high values
- The plasma can only be activated when the pressure is set to an extremely high value

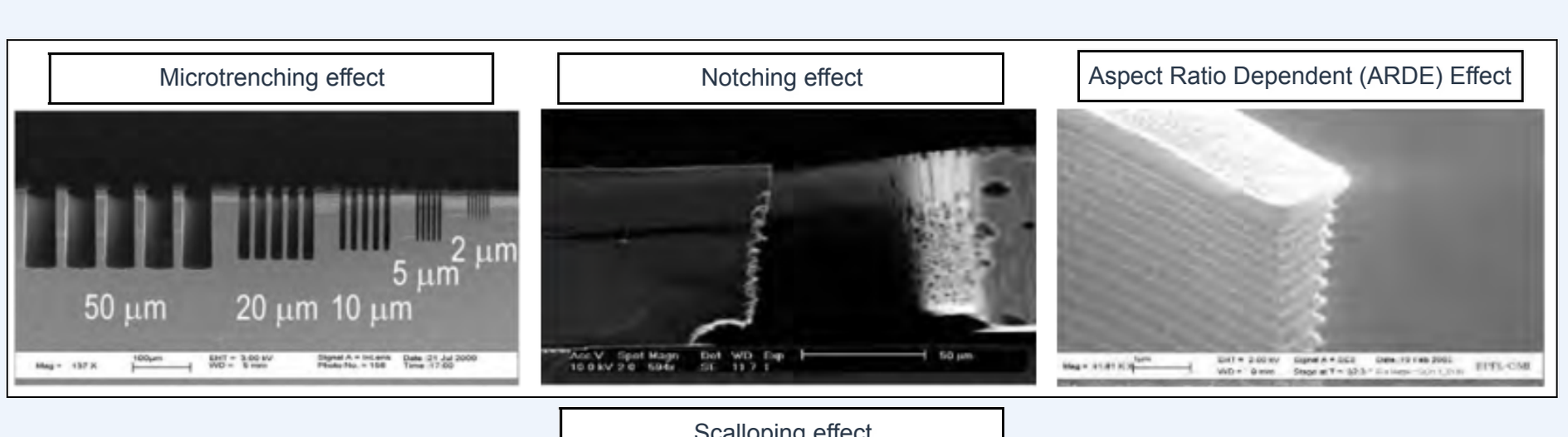
Your answer is incorrect.

An RF current in the ICP plasma is generated by one RF power source. The other RF power source is used to generate the surface voltage bias. The electrical impedance of an ICP source is an inductor in series with a small resistor. A capacitive coupling is needed to initiate the discharge. See "Types of dry etching equipment and plasma sources" video from 9:40 to 12:25 for more detailed explanations.

The correct answer is:
The electrical impedance of an ICP source is an inductor in series with a small resistor

Question **2**
Partially correct
Mark 0.33 out of 1.00
Remove flag

The Bosch process is a well-known process for etching silicon with a high aspect ratio. Below shows SEM images of the observed effects in the Bosch process. Please drag the name of the effect to the corresponding SEM image.



Scalloping effect

Grass formation

Your answer is partially correct.

You have correctly selected 1.

The "Scalloping effect" means the non-even surface of the sidewall of the etched silicon trenches because of the pulsed nature of the Bosch process, which originates from the alternating etching and polymerization cycles.

The "Aspect Ratio Dependent (ARDE) Effect" means the etch rate depends on the hole or trench width. If there is a wider mask opening, the etching goes deeper than if there is a narrow mask opening, and this is related to the fact that the gas has easier access into a larger hole than in a small hole, and etching is more favored in that way.

The notching effect means when reaching the embedded oxide layer, due to its insulating properties, it can be charged by the ions from the plasma so that further incoming ions are deflected and they give enhanced etching in side direction.

Question **3**
Correct
Mark 1.00 out of 1.00
Flag question

Our goal is to anisotropically etch 564 nm of Al with 1000 nm thick photoresist as a mask. Assume a constant etching rate of 400 nm/min for Al and an etching selectivity (Al/PR) of 2. How thick does the photoresist "remain" after etching 564 nm of Al? Please give your answer in "nanometer".

Answer: 718 ✔

The correct answer is: 718.00

Question **4**
Correct
Mark 1.00 out of 1.00
Remove flag

Our aim is to have silicon trenches with depth of 354 μm and width of 27 μm by using photolithography and the Bosch process. In a given recipe in the Bosch process, we have a constant silicon etching rate of 5 μm/min. Calculate how long in "minutes" the Bosch process lasts to achieve an etch depth of 354 μm?

Answer: 70.8 ✔

The correct answer is: 70.8

Question **5**
Incorrect
Mark 0.00 out of 1.00
Remove flag

In a CF_4 plasma to which hydrogen gas is added, an etched hole can be protected by the deposition of a fluorocarbon polymeric layer. How can the selectivity of dry etching be enhanced?

- ☑ By decreasing the pressure ✖
- ☐ By decreasing the H_2 concentration
- ☐ By increasing the monomer concentration
- ☑ By decreasing the temperature ✔

Your answer is incorrect.

A dry etching process can be selective, which means that it will only etch the target, not the mask material. Selectivity can be enhanced by tuning the polymerization point of the gas. More polymerization will lead to extra masking material that gets deposited so that the mask can withstand the etching longer. Increasing the monomer concentration, increasing H2 concentration, decreasing the temperature and increasing the pressure are some of the valid methods to increase the selectivity. See "Dry etching in a gas plasma; etching anisotropy" video from 13:20 to 14:15 for more detailed explanations.

The correct answers are:
By decreasing the temperature,

By increasing the monomer concentration

Question **6**
Incorrect
Mark 0.00 out of 1.00
Remove flag

Which of the following is true for a cryogenic deep dry Si etching process?

- The loading effect is eliminated for this process
- Etching and passivation steps are done simultaneously
- The chuck temperature does not have a significant influence on the etching profile
- There is no grass generation observed even with too much oxygen ✖

Your answer is incorrect.

In cryogenic deep dry Si etching process, first the silicon wafer is brought to -110 °C. Hereafter, SF_6 gas is used for etching and O_2 gas is used for passivation. Both of these operations are performed simultaneously. See "Examples of etching processes for Si-based materials" video from 17:35 to 18:45 for more detailed explanations.

The correct answer is:
Etching and passivation steps are done simultaneously

Question **7**
Correct
Mark 1.00 out of 1.00
Remove flag

What is the main advantage of Ion Beam Etching (IBE) over a plasma-based etching process?

- The wall reactor heating supplies a good attraction between ions and the wafer, which increases the etching rate
- The angle of incidence of the ion beam onto the sample can be varied and etching profiles with different angles with respect to the surface can be fabricated ✔
- The pulsed deep dry etching process of Si (Bosch process) is only possible by using IBE
- In sensitive processes with an ion energy below 100 eV, a high ion flux is provided to maintain the etch rate

Your answer is correct.

Inside an Ion Beam Etcher (IBE), it is easy to vary the angle of incidence of the ion beam onto the sample, which is impossible in a plasma-based process. This is the main advantage of this tool to plasma-based etching processes. See "Ion beam etching" video from 0:15 to 1:05 for more detailed explanations.

The correct answer is:
The angle of incidence of the ion beam onto the sample can be varied and etching profiles with different angles with respect to the surface can be fabricated

Question **8**
Correct
Mark 1.00 out of 1.00
Flag question

Sometimes, in Cl plasma etching, a corrosion phenomenon is observed in Al etching under the form of chlorine-containing residues remaining on the film sidewalls. Which chemical compound is at the origin of this corrosion?

- Diluted acetone in which the wafer is dipped before etching
- PGMEA that is used as a developer
- HCl that is formed on the Al surface ✔
- Nitrogen gas that is gently blown on the wafer surface to create AlN gas

Your answer is correct.

Sometimes a corrosion phenomenon is observed on the etched Al structures. This is believed to originate from Cl-containing residues that remain on the etched side walls. If these residues are combined with moisture absorption, HCl and $AlCl_3$ molecules are formed. The problem is even more severe for Al-Cu alloys. Corrosion can be prevented by rinsing well the wafer in de-ionized water after the removal from the Cl plasma. Also, one can apply a plasma etching step in O_2 to remove residual photoresist and Cl atoms and at the same time, restore a thin passivating Al_2O_3 layer. Another possibility is to expose the etched structure to a fluorine plasma during which the Cl atoms are replaced by F atoms. See "Examples of etching processes for organic films and metals" video from 8:45 to 10:10 for more detailed explanations.

The correct answer is:
HCl that is formed on the Al surface

Question **9**
Correct
Mark 1.00 out of 1.00
Flag question

Which of the following procedures can be performed to convert an isotropic CF_4 etching process to a purely anisotropic etching process?

- ☑ Decreasing the F/C ratio by using another gas ✔
- ☑ Adding 10% H_2 to decrease the F/C ratio ✔
- ☐ Adding 10% O_2 to increase the F/C ratio
- ☐ Increasing the process temperature
- ☐ Increasing the monomer concentration

Your answer is correct.

The horizontal to vertical etching rates are reduced by decreasing the F/C ratio. The removal of F radicals can be done by adding H atoms. At 10% H_2 addition, horizontal etching is completely eliminated. The polymerization rate in a way compensates for the etching in horizontal direction. See "Dry etching in a gas plasma; etching anisotropy" video from 11:20 to 13:15 for more detailed explanations.

The correct answers are:
Adding 10% H_2 to decrease the F/C ratio ,

Decreasing the F/C ratio by using another gas

Question **10**
Correct
Mark 1.00 out of 1.00
Flag question

Which of these equipments can be used for directional physical etching?

- A batch reactor
- A plug flow reactor
- A diode reactor ✔
- An atomic layer chemical vapor deposition system

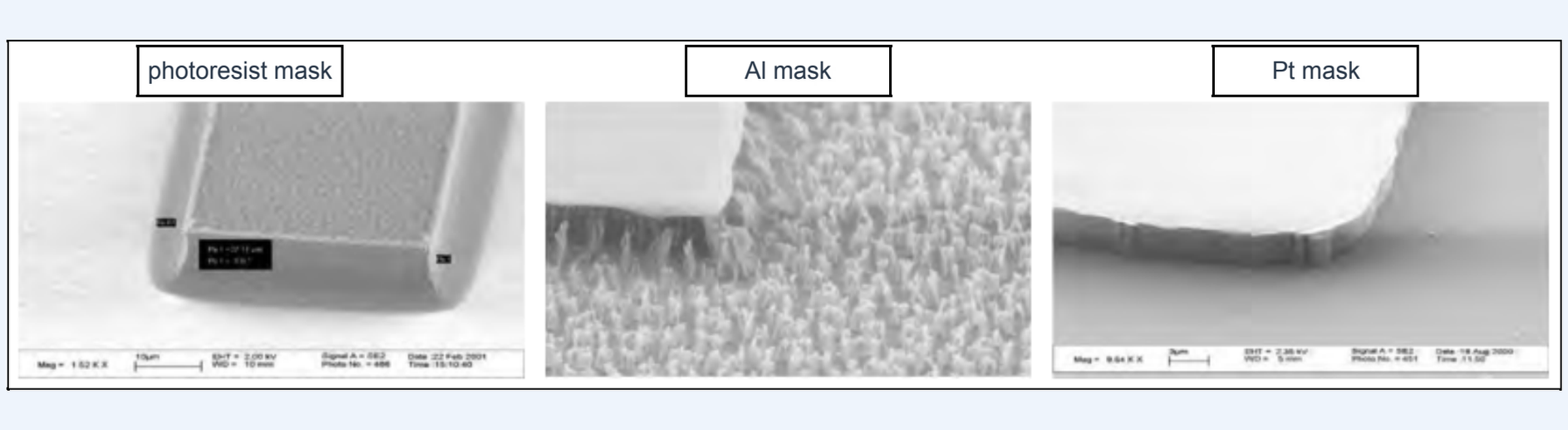
Your answer is correct.

Only the diode reactor is a viable directional physical etching tool, the rest of the answers are not related to this process. See "Types of dry etching equipment and plasma sources" video from 4:45 to 8:35 for more detailed explanations.

The correct answer is:
A diode reactor

Question **11**
Correct
Mark 1.00 out of 1.00
Flag question

Mask choice is crucial during an anisotropic etching process because the etchant gas may or may not attack the mask. Below shows the images after etching polyimide with different mask materials. Please drag the correct mask material into the corresponding etching result.



Your answer is correct.

Question **12**
Correct
Mark 1.00 out of 1.00
Flag question

What can be done in RF plasma etching to enhance the etching rate on the RF electrode side where the wafer is placed?

- The RF electrode area can be chosen smaller in size than the electrode on the opposite side ✔
- The gas flow rate must be reduced
- The pressure inside the chamber must be decreased
- The frequency of the RF voltage can be decreased

Your answer is correct.

The etching must be performed on the RF-powered electrode side. For this purpose, the voltage drop on the ion sheet must be increased which is inversely proportional to the fourth power of the electrode area ratios. In order to maximize etching on the lower electrode, one should choose the lower electrode area smaller than the upper electrode area. See "Theoretical concepts of plasma generation" video from 11:20 to 12:25 for more detailed explanations.

The correct answer is:
The RF electrode area can be chosen smaller in size than the electrode on the opposite side

Question **13**
Incorrect
Mark 0.00 out of 1.00
Remove flag

Al re-deposition during polyimide etching occurs when an Al mask is used. It results in 'grass' formation at the bottom of the substrate. How can this problem be solved?

- ☑ An erodible mask can be used on top of the Al mask ✖
- ☑ The wafer can be placed in an oxygen plasma chamber to remove this layer ✖
- ☐ A thin SiO_2 layer can be predeposited on the surface of the Al mask to avoid this accumulation
- ☐ A reduced gas pressure can be used so that diffusion distances in the etching chamber are enhanced

Your answer is incorrect.

When an Al mask is used during polyimide etching, because of the etching that occurs of the Al mask, Al atoms are re-deposited on the bottom of the etched features. Generally, this kind of re-deposition phenomena can be reduced when one uses a plasma at a lower pressure, which exhibits a higher mean free path of the sputtered material reaction products, so that these can be better removed from the etching area. See "Examples of etching processes for organic films and metals" video from 2:35 to 3:35 for more detailed explanations.

The correct answers are:
A reduced gas pressure can be used so that diffusion distances in the etching chamber are enhanced,

A thin SiO_2 layer can be predeposited on the surface of the Al mask to avoid this accumulation

Question **14**
Correct
Mark 1.00 out of 1.00
Flag question

Which of the following statements are true related to the pulsed deep dry etching process of Si (Bosch process)?

- ☐ A loading effect is observed when there are only wide mask openings on the wafer
- ☐ The etching rate can be decreased by adding Ar in between etching and passivation steps
- ☑ C_4F_8 is used in the sequence as the passivation gas ✔
- ☐ Ar is used in the sequence as the chemical etching gas
- ☑ The scalloping effect can be reduced by decreasing the duration of the gas pulses ✔

Your answer is correct.

In deep dry etching of Si (Bosch process), SF_6 gas is used for etching and C_4F_8 gas is used for polymerization. These gases are activated in the chamber alternatively to reach a desired etching depth with vertical side walls. Depending on the area opening of the mask, etching rates might be area-dependent. The etching gas has easier access into a large hole than a small hole and the reaction products can also be better removed. This phenomenon is known as "loading effect". Ar gas does not play any role in the etching process. See "Deep dry etching of silicon; dry etching without a plasma" video from 2:00 to 6:00 for more detailed explanations.

The correct answers are:
C_4F_8 is used in the sequence as the passivation gas ,

The scalloping effect can be reduced by decreasing the duration of the gas pulses

Question **15**
Partially correct
Mark 0.50 out of 1.00
Remove flag

When the pressure of the etching gas is too high in the Bosch process, the profile of initially vertical etched structures gets more tapered and less steep when etching deeper in the substrate. What are the main reasons behind this?

- ☑ The excessive etching gas turns the process into the redeposition mode and the reaction produces start pilling up at the bottom of the structures ✔
- ☐ The polymerization gas accumulates at the bottom due to the increased pressure in the etching gas and the decreased pressure in the polymerization gas
- ☐ Due to the low mean free path in the etching gas, the amount of the removal of reaction products from the bottom of the structure is reduced
- ☐ The overexcited etching gas causes the amount of atoms per volume to decrease gradually

Your answer is partially correct.

You have correctly selected 1.
When the etching gas pressure is too high, the mean free path in the gas is low, which can give rise to reduced gas access and removal of reaction products from the bottom of the structures. Therefore, there will be less vertical side walls towards the bottom of the etched structures. See "Examples of etching processes for Si-based materials" video from 11:25 to 12:05 for more detailed explanations.

The correct answers are:
The excessive etching gas turns the process into the redeposition mode and the reaction produces start pilling up at the bottom of the structures,

Due to the low mean free path in the etching gas, the amount of the removal of reaction products from the bottom of the structure is reduced

Question **16**
Partially correct
Mark 0.33 out of 1.00
Remove flag

Which of the following statements are true for a RF plasma? Assuming that the top electrode is connected to the ground and the bottom electrode is connected to the RF source.

- ☑ The current passing through the ion sheath is inversely proportional to the square of the thickness of the ion sheath ✔
- ☐ After a couple of RF oscillations, electrons tend to charge the top electrode
- ☑ After accumulation of electrons on the top electrode, the remaining electrons in the plasma are also pulled to the top and, after a while, an ion sheath is formed near the top electrode ✖
- ☑ DC self bias is formed on the bottom electrode thanks to the use of the capacitor in series with the RF source ✔
- ☑ Due to the loss of electrons to the walls, the bulk of the plasma becomes slightly negative ✖

Your answer is partially correct.

You have selected too many options.
Electrons initially will be attacking more the electrode to which the RF is applied than heavy positive ions. Therefore, a negative charge is formed on the RF electrode side after a few cycles after ignition of the plasma. Few electrons are present in the dark ion sheath near the working electrode as a result of repulsion from the negatively charged electrode. An electrical field is created, which is the ratio of the total voltage drop across the ion sheath to the ion sheath thickness. See "Theoretical concepts of plasma generation" video from 3:40 to 12:00 for more detailed explanations.

The correct answers are:
The current passing through the ion sheath is inversely proportional to the square of the thickness of the ion sheath,

DC self bias is formed on the bottom electrode thanks to the use of the capacitor in series with the RF source

Question **17**
Correct
Mark 1.00 out of 1.00
Flag question

Which of the following statements are the limitations of IBE?

- ☐ Because of the low operation pressure, sputtered material accumulates on the sample surface
- ☐ Ions tend to have a lot of collisions during their trajectory, which reduces the etching quality
- ☑ The etching is slow compared to a standard dry etching process (e.g., CF_4 plasma etching) ✔
- ☐ Long etching processes are quite instable as the operation pressure is too high
- ☑ Etching processes that consume or generate a significant quantity of gas are not possible ✔

Your answer is correct.

There are certain limitations of IBE which are a consequence of limited gas flow at an operating pressure of 0.1 mbar. In sensitive processes, to maintain the etch rate, a high ion flux is needed, which is difficult to obtain with a remote ion source. Additionally, etching processes that consume or generate a significant quantity of gas are not possible. See "Ion beam etching" video from 4:30 to 5:30 for more detailed explanations.

The correct answers are:
Etching processes that consume or generate a significant quantity of gas are not possible ,

The etching is slow compared to a standard dry etching process (e.g., CF_4 plasma etching)

Question **18**
Partially correct
Mark 0.67 out of 1.00
Flag question

Which of the following statements are true for a dry etching equipment?

- ☐ A scrubber gas treatment is necessary to adjust Ar flow in the chamber
- ☑ An electrostatic chuck can be used to clamp the wafer by electrostatic forces ✔
- ☑ A load chamber is utilized to load the desired gas for the etching process ✖
- ☑ There are at least two electrodes that are needed to maintain the gas in the plasma state ✔
- ☐ Optical end point detection is used to monitor the stability of the fixation of the wafer on the electrostatic chuck

Your answer is partially correct.

You have selected too many options.
In a typical example of a dry etching equipment, the load chamber is used as a wafer holder and this wafer is translated into the reactor without breaking the vacuum in the chamber. An electrostatic chuck is utilized to clamp the wafer in the chamber. A scrubber gas treatment is used to eliminate toxic side products. Optical End Point Detection (EDP) is utilized to provide information on the materials that are etched away. See "Deep dry etching of silicon; dry etching without a plasma" video from 9:35 to 11:45 for more detailed explanations.

The correct answers are:
An electrostatic chuck can be used to clamp the wafer by electrostatic forces ,

There are at least two electrodes that are needed to maintain the gas in the plasma state

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