Moodle

# Microfabrication technologies

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| **Completed on** | Friday, 21 October 2022, 15:32 |
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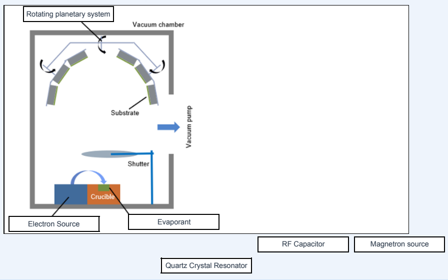
| **Grade** | **12.0** out of 13.0 (**92**%) |

Question **1**
Correct
Mark 1.0 out of 1.0
Flag question

Below is a schematic drawing of an evaporation tool. Some components are not labelled. Drag and drop the corresponding part into the figure.



Your answer is correct.

Question **2**
Correct
Mark 1.0 out of 1.0
Remove flag

In a so-called lift-off process, a thin gold (Au) film is deposited by PVD on a patterned resist layer. Which of the following proposition is correct?

○ Sputtering is better suited than thermal evaporation for an application such as lift-off.
○ Using a rotating planetary system is required in order to have good step coverage.
○ An e-beam evaporator should be used because the boiling point of gold is too high for a resistive-heating evaporator.
● An evaporator with a large source-substrate distance should be used for line of sight deposition. ✓

Your answer is correct.

Using an evaporator with a large source-substrate distance makes the deposition more directional, and thus avoids depositing gold on the walls of the photoresist as discussed in the slide about lift-off process in the second video of the thermal evaporation section. A resistive-heating evaporator can very well evaporate gold. The main advantage of using an e-beam evaporator is the purity of the deposited film and is not related to the gold boiling point. Sputtering is not directional and is thus not well suited for lift-off deposition. Using a rotating planetary system enables good step coverage. However, for the specific case of lift-off process, we don't want good step coverage as we want to avoid having material deposited on the walls of the photoresist.

The correct answer is:
An evaporator with a large source-substrate distance should be used for line of sight deposition.

Question **3**
Correct
Mark 1.0 out of 1.0
Flag question

It is known that sputtering has better step coverage than evaporation. Related to this fact, which of the following explanations are correct?

☑ The pressure in the sputtering chamber is higher than in the evaporation chamber during the deposition. ✓
☑ The incidence angle of sputtered atoms is random. ✓
☐ Co-sputtering from multiple targets enables good step coverage.
☐ The deposition rate of sputtering is higher, which results in a better step coverage.

Your answer is correct.

As discussed in the slide about film growth and control parameters in the fifth video of the sputtering section, deposition pressure is higher for sputtering ($10^{-1}$ to $10^{-3}$ Torr) than for evaporation ($10^{-6}$ to $10^{-7}$ Torr). As a result, the mean free path in a sputtering chamber is a few mm only and atoms ejected from the target will collide with many gas particles/ions before depositing with random incidence angles on the substrate. This leads to a better step coverage than with evaporation. As discussed in the film growth section, the deposition rate affects thickness uniformity, internal stresses and adhesion of thin films deposited by PVD. However, it does not influence the step coverage of the different PVD techniques. Co-sputtering is used to simultaneously deposit different materials but not to improve step coverage.

The correct answers are:
The pressure in the sputtering chamber is higher than in the evaporation chamber during the deposition.,

The incidence angle of sputtered atoms is random.

Question **4**
Correct
Mark 1.0 out of 1.0
Flag question

The pressure in the chamber during deposition is higher for sputtering than for evaporation. What is the reason for this?

○ Sputter chambers are larger than evaporation chambers and it is thus not possible to reach ultra-high vacuum.
○ The magnetic field used with magnetron sputtering limits the vacuum level.
○ Sputtered atoms must undergo more collisions in order to have a better step coverage.
● Plasma cannot be created at very low pressures. ✓

Your answer is correct.

The correct answer is that at too low pressure stable plasma cannot be established because of the lack of gas molecule. Detailed explanation is given in the slide about Paschen's law in the second video of the sputtering section. The fact that sputtered atoms undergo many collisions and enable good step coverage is a consequence of the higher pressure. It is not a reason why to use higher pressure. The magnetic field has absolutely no influence on the vacuum level. The chamber volume doesn't play a role on the final pressure in the chamber but simply on the time it will take to reach this pressure. In addition, sputtering chambers are often smaller than evaporation chambers. Indeed with evaporation we want to take advantage of the line-of-sight characteristic to perform lift-off and stencil depositions. To do so, source-substrate distance is maximized.

The correct answer is:
Plasma cannot be created at very low pressures.

Question **5**
Correct
Mark 1.0 out of 1.0
Flag question

After the deposition of a thin gold (Au) film directly onto a glass wafer by using an e-beam evaporator, the subsequent tape pull-test is not successful (i.e. the gold delaminates). What could you do to overcome this problem and improve the adhesion of the gold layer?

☑ Use a sputter tool instead of a thermal evaporator to deposit the gold film. ✓
☐ Add a Pt adhesion layer before the gold evaporation.
☑ Deposit a Cr adhesion layer before the gold film deposition. ✓
☐ Use a planetary substrate holder.

Your answer is correct.

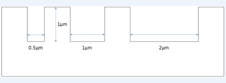
The tape pull-test is a simple method to test adhesion of thin films on the substrate. See slide about adhesion in the film growth section for detailed explanations. Depositing a Cr adhesion layer before the gold film or using sputtering instead of evaporation are the correct solutions. As discussed in the slide about adhesion in the film growth section, the purpose of an adhesion layer is to improve adhesion of noble metals to the substrate. Cr and Ti layers can be used as adhesion layers but platinum is a noble metal and cannot be used as adhesion layer. With sputtering, more energetic atoms impinge on the surface which knock out surface contamination and loosely bound atoms, thus increasing the deposited film adhesion. As discussed in the slides about vapor flux toward substrate in the first video of the evaporation section, using a planetary substrate holder improves film thickness uniformity. However, it does not play a role in the adhesion of the thin film.

The correct answers are:
Deposit a Cr adhesion layer before the gold film deposition.,

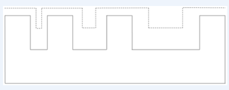
Use a sputter tool instead of a thermal evaporator to deposit the gold film.

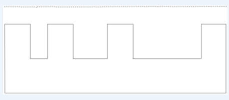
Question **6**
Incorrect
Mark 0.0 out of 1.0
Remove flag

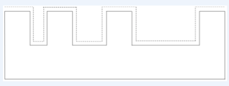
$Al_2O_3$ is sputtered with a deposition rate of 17 Angstrom/s onto the substrate cross-section shown below.

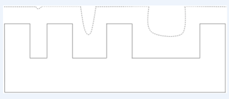


What would be the deposited film profile after 4 minutes deposition time?

●  ✗

○ 

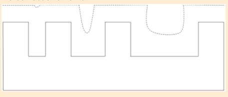
○ 

○ 

Your answer is incorrect.

17 Angstrom/s during 4 minutes = 17*4*60 = 4080 Angstrom = 408 nm. It is clear that in the first cross-section the deposited film is too thin. The second cross-section might be possible in terms of thickness but the straight angles are not realistic. Indeed, as discussed in the slide about atoms arrival in the film growth section, atoms tend to bind at a kink. This results in cross-section which typically looks like the third answer. Finally, the fourth cross-section is not realistic in terms of the thickness of the right groove which is more than 3 time the nominal thickness of the deposited film.

The correct answer is:



Question **7**
Correct
Mark 1.0 out of 1.0
Remove flag

You need to deposit by DC sputtering a 975 A thick layer of gold (Au) on a silicon substrate. The sputter equipment is set to have a deposition rate of 10 A/sec for gold. How long (in sec.) does it take to deposit your Au thin film?

Answer: 97.5 ✓

Deposition time = thickness / rate

The correct answer is: 97.5

Question **8**
Correct
Mark 1.0 out of 1.0
Flag question

Let us consider a silicon wafer that contains high aspect-ratio 3D microstructures on the surface. You need to cover these structures with an electrically insulating layer. The choice of the dielectric is a $SiO_2$ layer that should entirely cover all the structures. Which of the following deposition method is the most suitable for this purpose?

○ E-beam evaporation
● RF magnetron sputtering ✓
○ Evaporation through a stencil
○ DC sputtering

Your answer is correct.

DC sputtering enables depositing only electrically conductive materials because of charging effects discussed in the slide about DC sputtering in the third video of the sputtering section. It is thus not possible to deposit $SiO_2$ with DC sputtering. As discussed in the slide about condensation on the substrate and in the conclusion slide of the second video of the evaporation section, thermal evaporation is a line-of-sight technique and has poor step coverage capability. This technique is then not well suited for high-aspect ratio 3D microstructures. Using a stencil doesn't make sense to deposit a layer on the whole surface of a wafer. The only possible solution is to use RF magnetron sputtering.

The correct answer is:
RF magnetron sputtering

## Quiz navigation

Emilie Grace Grandjean

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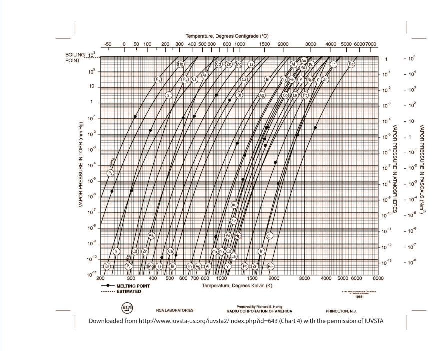
Question **9**

Correct

Mark 1.0 out of 1.0

Flag question

Please have a look at this graph (click the link or see below image in high resolution) illustrating equilibrium vapour pressure of different materials as a function of the temperature. Which of the statement below is correct?



Downloaded from http://www.iuvsta-us.org/iuvsta2/index.php?id=643 (Chart 4) with the permission of IUVSTA

*Hint: the Hertz-Knudsen equation states that the vapour flux is proportional to (Pv-P) with Pv the vapour pressure of the evaporant and P the pressure in the chamber.*

○ Sputtering gold (Au) at 1500 K and $10^{-8}$ Torr is possible

● Evaporating silver (Ag) at 1000 K and $10^{-6}$ Torr is possible. ✓

○ Evaporating platinum (Pt) at 1500 K and $10^{-6}$ Torr is possible

○ Evaporating aluminum (Al) at 1000 K and atmospheric pressure is possible.

Your answer is correct.

To be able to evaporate a material at a given temperature, the pressure in the chamber should be below the vapor pressure of the material at this temperature. Evaporating silver at 1000 K and $10^{-6}$ Torr is possible. Evaporating platinum at 1500 K requires a chamber pressure below ~$10^{-9}$ torr. This chart is relevant only for thermal evaporation not for sputtering. Sputtering gold at 1500 K and $10^{-8}$ Torr is not possible because plasma cannot start at this pressure.

The correct answer is:
Evaporating silver (Ag) at 1000 K and $10^{-6}$ Torr is possible.

Question **10**

Correct

Mark 1.0 out of 1.0

Flag question

When depositing thin film by PVD techniques, it is important to measure the film thickness *in-situ* during the process. How do modern evaporation equipment perform this real-time monitoring?

○ By using an ellipsometry system to measure the changes in the light reflected from the substrate's surface.

○ By using a profilometer to scan the substrate's surface.

○ By measuring the change of the substrate's mass through a weight sensor under it.

● By measuring the changes in the oscillation frequency of a quartz crystal resonator. ✓

Your answer is correct.

In modern evaporation tools, thickness of the deposited layers is monitored using quartz crystal resonators as explained in the slide about other equipment specs. Ellipsometry is a powerful tool to measure the thickness of deposited films as well as other thin films properties such as refractive index, electrical conductivity and roughness among others. However it is not possible to integrate an ellipsometry system inside an evaporation chamber. Integrating a weight sensor in the substrate holder would make the substrate clamping system a lot more complicated and the mass measurement itself would also be difficult; we would need to detect the addition of a few nanometer of material onto a 500 µm thick substrate. Finally using a profilometer to scan the substrate surface is not possible as it would alter the deposition of the material and be complex to implement

The correct answer is:
By measuring the changes in the oscillation frequency of a quartz crystal resonator.

Question **11**

Correct

Mark 1.0 out of 1.0

Flag question

PVD can be used to deposit uniform thin films of a variety of materials. The most prominent methods are evaporation and sputtering. What is the advantage of sputtering over evaporation?

● Sputtering eases the deposition of refractory materials such as Hafnium carbide (HfC). ✓

○ Higher film purity can be achieved with sputtering.

○ With sputtering the substrate is less prone to damage.

○ Stencil lithography is better suited for use in a sputter tool.

Your answer is correct.

Due to the fact that mechanical and not thermal energy is used to eject atoms from the target, sputtering enables the deposition of refractory oxides, nitrides and carbides. Because of the plasma, sputtering requires higher pressure than evaporation; $10^{-1}$ to $10^{-3}$ Torr for sputtering instead of $10^{-6}$ to $10^{-7}$ Torr for evaporation as mentioned in the slide about film growth and control parameters in the fifth video of the sputtering section. As a result, film purity is lower with sputtering than with evaporation. Energetic sputtered atoms and plasma secondary electrons collide on the substrate which generate heat and might create surface damages. Finally, because of the random angle of incidence of sputtered atoms, this technique is not well suited to perform stencil lithography.

The correct answer is:
Sputtering eases the deposition of refractory materials such as Hafnium carbide (HfC).

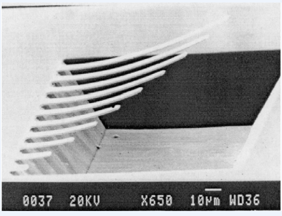
Question **12**

Correct

Mark 1.0 out of 1.0

Flag question

The image below shows a SEM micrograph of free-standing Ti/$SiO_2$ cantilevers (Ti on the top of $SiO_2$). The cantilevers are bent upward due to intrinsic stress. Please choose the correct stress level for both materials.



The stress in Ti is ... [... tensile] ✓

The stress in $SiO_2$ is... [... compressive] ✓

Your answer is correct.

Heating the Ti/$SiO_2$ beam (top image) would reverse the bending since Ti CTE is larger than $SiO_2$ CTE. The curvature is the result of internal stresses in the thin films. The film with the shortest radius of curvature is under tensile stress while the film with the largest radius of curvature is under compressive stress. See slides about stress in thin film in the film growth section for detailed explanations. In the image, $SiO_2$ is under compressive stress. It is possible to know that Ti is under tensile stress by simply looking at the image; Ti has the shortest radius of curvature in the image.

The correct answer is:
The stress in Ti is ... → ... tensile,

The stress in $SiO_2$ is... → ... compressive

Question **13**

Correct

Mark 1.0 out of 1.0

Flag question

Physical vapour deposition (PVD) exists in various variations and allows for addressing a multitude of applications. Drag the corresponding missing words into the corresponding spots in the following phrases.

- With [RF sputtering] ✓ , substrate cooling is required.
- [DC sputtering] ✓ can only be used to deposit electrically conductive materials.
- With [E-beam evaporation] ✓ the deposited material has poor step coverage.
- With [RF magnetron sputtering] ✓ , the target wear is not uniform.

Your answer is correct.

When depositing electrically insulating materials, RF sputtering requires very efficient cooling of the target during the deposition because these materials are often poor heat conductors. DC sputtering techniques can only be used for electrically conductive materials because the charging in insulating materials stops the creation of plasma. The evaporation technique leads to poor step coverage due to the line-of-sight evaporant trajectory. With RF magnetron sputtering the plasma is localized along the magnetic field lines. As a result, the target wear is non-uniform.

The correct answer is:
Physical vapour deposition (PVD) exists in various variations and allows for addressing a multitude of applications. Drag the corresponding missing words into the corresponding spots in the following phrases.

- With [RF sputtering], substrate cooling is required.
- [DC sputtering] can only be used to deposit electrically conductive materials.
- With [E-beam evaporation] the deposited material has poor step coverage.
- With [RF magnetron sputtering], the target wear is not uniform.

Finish review