Tutorial 5

1. **You are required to sputter deposit Ag film over a silicon oxide layer on a silicon wafer substrate.**

   (i) Draw a schematic diagram of such a sputtering system with the anode and cathode clearly labelled. Identify the electrode in which the silicon wafer substrate is to be placed.

   (ii) Discuss the effect of substrate bias voltage on the step coverage of the Ag film.

   (iii) You want to increase your sputter deposition rate for a silver (Ag) electrical contact. You had been using Ar sputtering gas. Discuss how the following changes would help to increase Ag deposition rate:

   - **Switch sputtering gas to Kr (with a much heavier atomic mass unit than Ar).**
   - **Increase the anode-cathode potential difference.**
   - **Reduce the pressure in the chamber.**

   (iv) What changes should be made to the system if we need to sputter deposit a SiN film?

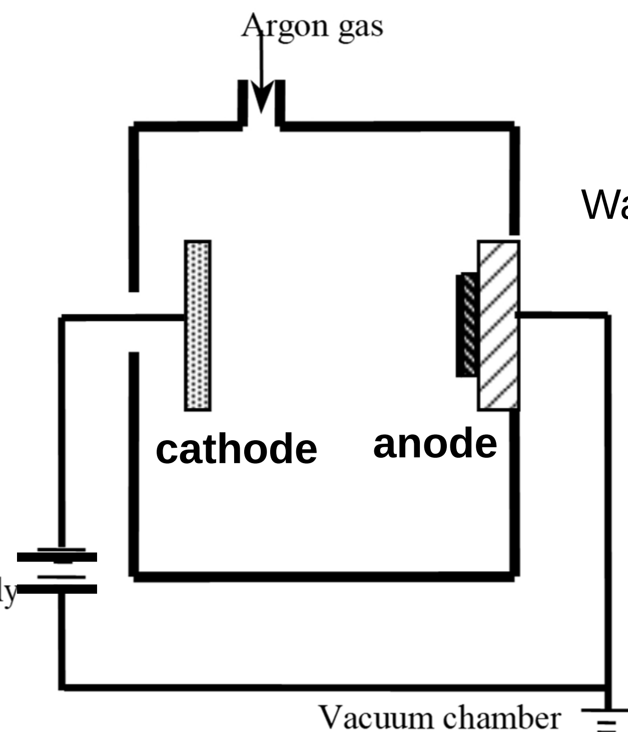
Tutorial 5

1. You are required to sputter deposit Ag film over a silicon oxide layer on a silicon wafer substrate.

(i) Draw a schematic diagram of such a sputtering system with the anode and cathode clearly labelled. Identify the electrode in which the silicon wafer substrate is to be placed.

(i)

Sputter Targets



Wafer placed on anode

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1.

(ii) Better step coverage is achieved with a broader angular distribution of incoming Ag target atoms approaching the substrate. This occurs when the incoming species have lower energy, hence lower bias voltage is better

(iii)

- Switching to Kr (better mass match to Ar) will increase the sputtering yield of Ag at the target.
- Increasing the anode-cathode potential difference will increase the rate of sputtering from the target and increase the deposition rate.
- Reduced pressure in the chamber increases the deposition rate because there are fewer collisions for Ar between the target and substrate.

(iv) Introduce a RF power supply at the cathode for insulator target

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2.(a) Figure 2 shows a schematic diagram of a physical vapour system.

i. What is the name the physical vapour system?

ii. Name the electrode in which the target was mounted.

iii. Explain why magnets are deployed in the electrode.

iv. Name the gas used, explaining why such gas is deployed in such system

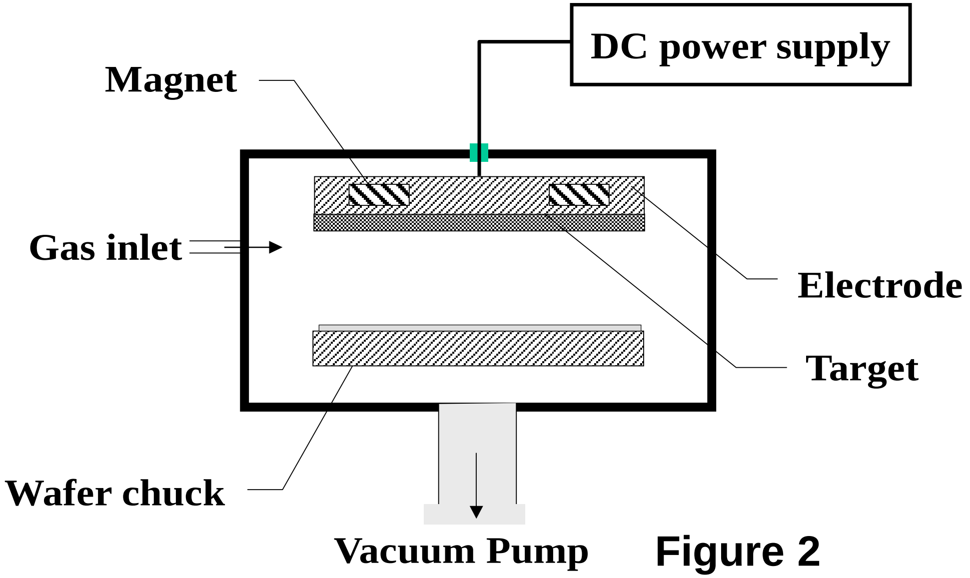

Figure 2

v. Explain what modifications need to be implemented if this system is to be used for reactive ion etching of SiO2 on a wafer?

(b) Explain how plasma is generated inside a vacuum system and list the various plasma reactions arising from the inelastic collisions of the electrons with the gas molecules.

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2. a) i. What is the name the physical vapour system?

Magnetron Sputtering System

ii. Name the electrode in which the target was mounted.

Cathode

iii. Explain why magnets are deployed in the electrode.

Magnetron sputtering employs magnets configured around and behind the target to capture and restrict the electrons in front of the target. This serves to increase the ion bombardment rate on the target in order to produce more secondary electrons, which then increases the ionization rate in the plasma. The end result is that more ions causes more sputtering of the target, which increases the deposition rate.

Magnetic field is applied to increase electron-gas molecule collisions and produce more ions without increasing gas pressure. This results in a higher deposition rate.

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2.

iv. Name the gas used, explaining why such gas is deployed in such system

Argon

v. Explain what modifications need to be implemented if this system is to be used for reactive ion etching of SiO_2 on a wafer?

- Argon gas replaced with C_2F_6 (or CH_4) and O_2
- DC power supply replaced with RF Generator
- Cathode connected to RF Generator
- Anode connected to Ground
- SiO_2 on Wafer placed on Cathode

b)
- A neutral gas placed within a tube with a dc potential across two electrodes.
- The released electrons accelerate toward the +ve electrode, or anode, and along the way undergo a series of elastic and inelastic collisions and the plasma is, therefore, formed

Plasma Reactions – Inelastic Collisions

- Ionization, Recombination
- Excitation, Relaxation
- Dissociation, Fragmentation

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3. In a PECVD system, a reaction gas is metered into a 30-litres chamber at flow rate of 50 sccm. The resulting steady-state pressure is 50 mtorr. Given that 1 torr litre/s = 78.9 sccm

(i) Define the residence time of the gas.

(ii) Calculate the residence time of the gas.

(iii) Determine the pumping speed of the vacuum pump.

(i) Residence time of a gas molecule is the mean time it remains in the process chamber before being pumped away.

(ii) 1 torr litre / s = 78.9 sccm; 50 sccm = 50/78.9 = 0.6329 torr litre / s;

$$t_r = \frac{V.p}{Q}$$

$$= \frac{30x50x10^{-3}}{0.6329}$$

$$= 2.37s$$

(iii) Here,

$$t_r = \frac{V}{S}$$

$$S = \frac{V}{t_r}$$

$$= \frac{30}{2.37} = 12.65 litre / s$$

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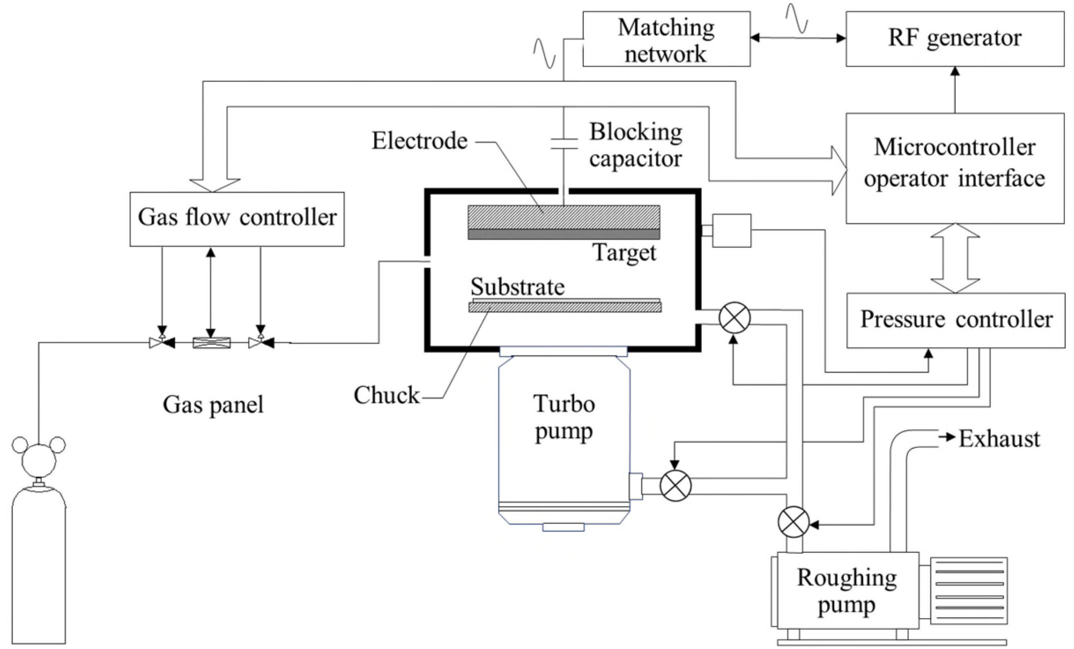
4. **Figure 3 shows the schematic of physical vapour deposition system.**
   (i) What is the name of the deposition system?
   (ii) Why a RF generator instead of a dc power supply is being deployed in such deposition system?
   (iii) Name the chuck/electrode on which the substrate is placed.
   (iv) Name the gas used, explaining why such gas is deployed in such system
   (v) Explain what modifications need to be implemented if this system is to be used for reactive ion etching of SiO2 on a wafer?
   (vi) Explain what modifications need to be implemented if this system is to be used for chemical vapour deposition of SiO2 on a wafer?



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(i) RF Sputtering System

(ii) Sputtering of insulator become possible because of the RF on the target.

(iii) Anode

(iv) Argon is used as the sputtering ion species because it is relatively heavy and is a chemically, inert gas, which keeps it from reacting with the growing film or the target.

(v) For reactive ion etching of SiO2 on a Si wafer ,

- Target is to be removed from cathode
- Substrate is to be removed from the anode (chuck) . Anode to be connected to the chamber wall for faster etching rate
- Wafer substrate with SiO2 is placed onto the cathode
- Argon gas to be replaced with fluorocarbon based gases

(vi) For chemical vapour deposition of SiO2 on a Si wafer

- Target is to be removed from cathode.
- Attach a heater to the cathode
- Substrate is to be removed from the anode (chuck)
- Wafer substrate (for deposition of SiO2) is placed onto the cathode.
- Argon gas to be replaced with silane and oxygen gases

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5. Compare and contrast the thermal evaporation to that of the sputtering technique used for the metallization of integrated circuits.

Properties	Evaporation	Sputtering
Rate	1,000 atomic layer/s	1 atomic layer/s
Thickness control	Possible	Easy
Materials	Limited	Almost unlimited
Contaminants	Low	High
Surface roughness	Little	High (ion bombardment)
Adhesion	Medium	Good (higher energy adatoms)
Film properties	Difficult to control	Can be controlled
Step coverage	Poor	Good
Equipment cost	Medium	Expensive

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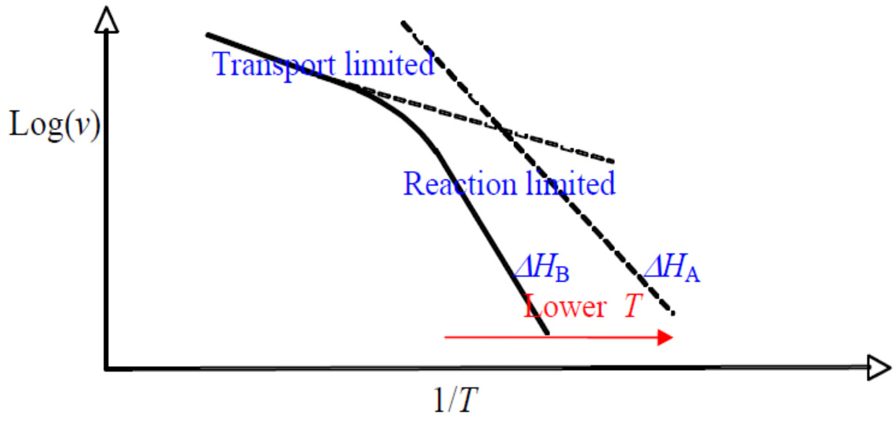
6. You are about to grow a film by CVD and want good process control. Briefly explain the advantages of film growth in the regime that is limited by *gas transport* (as opposed to reaction limited).

Gas Transport limited growth

(i) is always faster than reaction-kinetic-limited growth,

(ii) it can be controlled by reactant gas pressure and flow rate, as well as depending weakly on temperature $\left(T^{1/2}\right)$, and

(iii) it is more stable against thermal drift because it depends more weakly on temperature than does reaction-limited growth.



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7. Name the CVD system shown in Figure 4

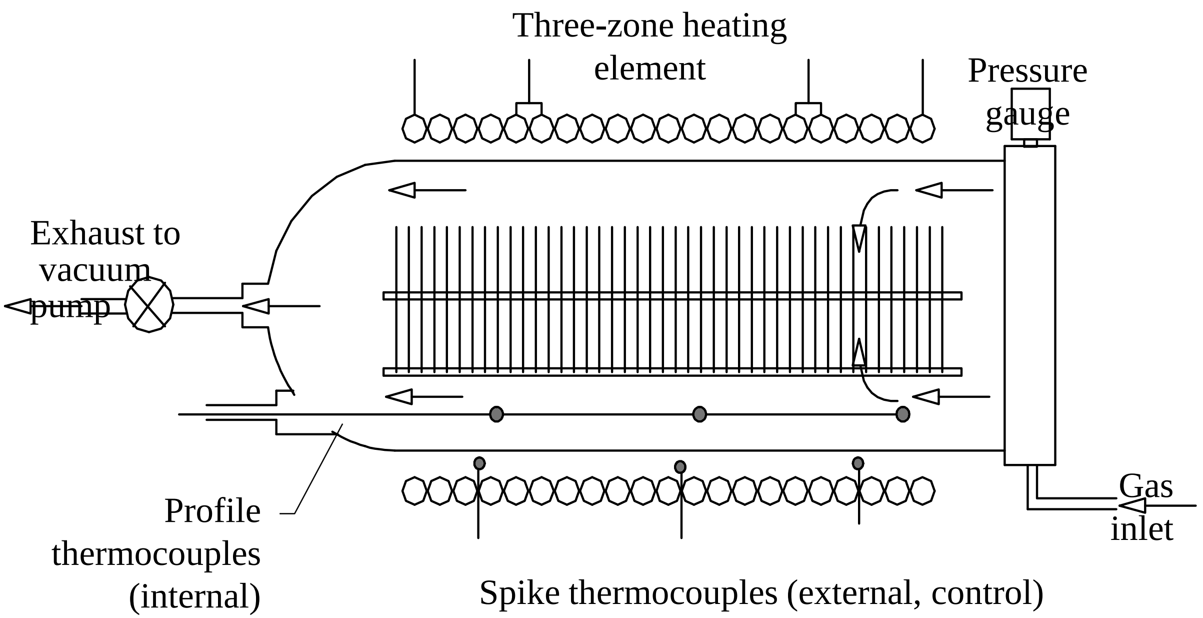

Figure 4 : A typical CVD System

(i) Under what mechanism is the system operating under? Explain why.

(ii) Why the wafers are stacked vertically and not horizontal as in some other system?

(iii) What gases are required for deposition of silicon nitride?

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LPCVD

(i) Surface Reaction Limited. In an LPCVD reactor (~ 1 torr), the diffusivity of the gas species is increased by a factor of 1000 over that at atmospheric pressure, resulting in one order of magnitude increase in the transport of reactants to the surface. Hence the rate-limiting step becomes the surface reaction.

(ii) LPCVD reactors enable wafers to be stacked vertically at very close spacing as the rate of arrivals of reactants is less important

(iii) Silane and Ammonia gases

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8.

(a) The thin film deposition for the horizontal CVD reactor is usually carried out in the gas phase mass transport limited regime. Why? Give 2 reasons.

(b) In a different experimental run, the total pressure of a CVD method was lowered from 760 torr to 1 torr

- **(i) Sketch the growth velocity vs 1/T graph for both pressures.**
- **(ii) Explain the differences between the plots.**
- **(iii) Describe the usefulness of the CVD mode operating at 1 torr (with respect to film growth).**

(c) As an engineer, you have been tasked with forming thin films of Mo-Ti alloy for electronic applications. You have access to three equipment – a thermal evaporator, an e-beam evaporator and a sputtering machine. Both the evaporators can allow for co-evaporation.

- **(i) What equipment would you utilise for deposition the Mo-Ti alloy thin film? Explain the reasons for choosing the equipment and eliminating the alternatives.**
- **(ii) List the advantages and limitation of the e-beam evaporation.**
- **(iii) What is sputter yield? List the 3 parameters that affect sputter yield.**

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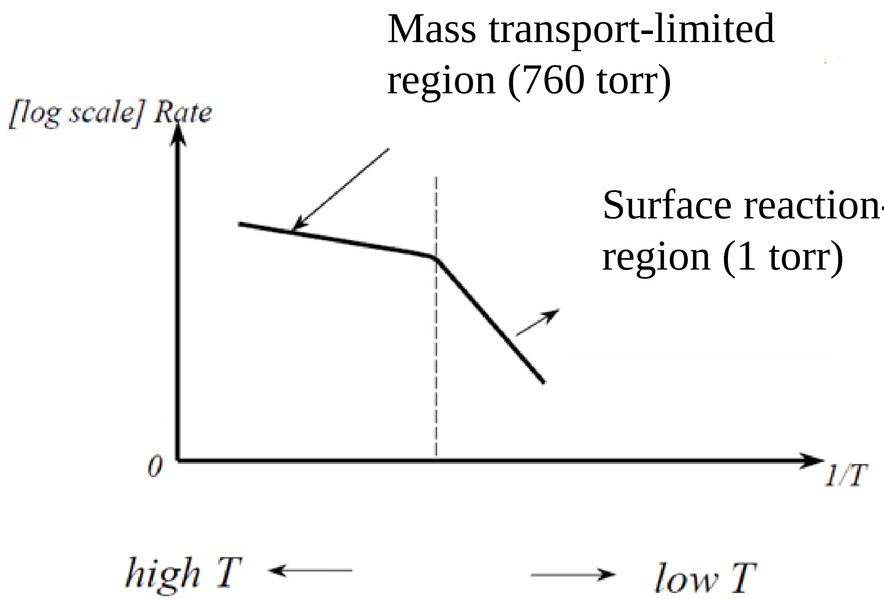
(a)

- An horizontal CVD reactor runs at atmospheric pressure. Hence there will be collision between the gases and the air molecules.
- High temperature needed to decompose the gases, especially at atmospheric pressure.

(b) (ii)



(ii)

- **Mass transport-limited region:** Occurs at high temperature (temperature is needed to decompose the gases and move the species easily to the substrate).
- **Surface reaction-limited region:** Occurs at low temperature, but sensitive to temperature change. A small change in temperature can greatly affect the chemical reaction rate.

(iii) Lower growth rate than atmospheric pressure mode. But better film uniformity and step coverage, with fewer defects

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(i) Equipment chosen is sputtering. In the case of thermal and e-beam evaporation, accurately controlled alloy compounds are difficult to achieve because each element have different melting point

(ii) Advantages:

- Films can be deposited at high rates (up to ~100 Å/s)
- Low energy atoms (~0.1 eV) leave little surface damage.
- Little residual gas and impurity incorporation due to high vacuum conditions.
- Very little substrate heating.

Limitations:

- Accurately controlled alloy compounds are difficult to achieve.
- Poor step coverage.
- X-ray damage.

(iii) Sputter yield is the number of sputtered atoms per bombarding (impinging) ion. The higher yield, the higher sputter deposition rate.
The sputter yield depends on: (a) ion energy; (b) ion incident angle; (c) ion mass