1. Fabrication of MOS-Caps (contd..)

In the previous lab session, we’ve learnt how to grow a dry oxide on a given silicon wafer. Now, our wafer is ready for forming top and bottom aluminum contacts to form a MOS capacitor. Capacitance voltage measurements on this MOS Capacitor will be discussed in the final lab session.

Fig 1. Finishing MOScap fabrication
2. Introduction to Vacuum Systems

Most of the semi-conductor deposition processes are performed in vacuum chambers, as they provide an environment of minimal contamination. These processes can be roughly classified as:

(i) Medium vacuum process (10 torr – 1 mtorr) e.g. Sputtering, Chemical Vapor deposition.
(ii) High vacuum process (1e-5 torr or less) e.g. Thermal evaporation, e-beam evaporation.

The vacuum level needed for the process is created and maintained inside a chamber using a vacuum pump. In addition to the vacuum pump, the plumbing connected between the vacuum chamber and the pump also plays a major role in determining the ultimate pressure that can be achieved in the vacuum chamber.

To maintain a chamber under high vacuum, we employ the use of a high-vacuum pump such as turbo-molecular pump, which operate in the molecular flow regime of the gas. These pumps however need to be “backed up” by a medium vacuum pump such as a rotary-vane pump, which can maintain a lower pressure differential across the high-vacuum pump. Medium vacuum in a vacuum chamber, can however be achieved using a simple medium-vacuum pump that operate in the viscous gas flow regime. Fig 2. shows a general construction of a high vacuum chamber.

The following procedure is used to reach a high-vacuum state in the chamber
1. Samples to be coated are first loaded into the chamber, following which the chamber is physically closed from atmosphere using vacuum seals such as O-rings.

2. **Roughing**
   (i) Make sure the VENT valve is closed (7 in fig) before roughing.
   (ii) The roughing pump (which is usually a rotary vane pump) is then connected to the chamber by opening the roughing valve (5 in fig) to bring the chamber down to a medium vacuum pressure (~10 mtorr), known as the “cross-over pressure”.
   (iii) DO NOT leave the system in roughing for a long time. In most cases, the “fore-line pump” (3a in Fig) and roughing pump (3 in Fig) are one and the same. So, as the chamber pumps down to medium vacuum, the roughing/back

3. **High Vacuum**
   (i) Now that the chamber has reached the “cross-over” pressure (~10 mtorr), it is time to pump it down to high vacuum (~1e-6 torr). This can be done by closing the roughing valve (5 in fig) and opening the high vacuum valve.
   (ii) It is important to keep an eye on the foreline pressure (10 in fig) when opening the high vacuum valve. If there’s a high foreline pressure spike when opening the high vacuum valve, the backing pump may not be able to catch up, thereby damaging the high vacuum pump.
   (iii) The chamber then eventually can reach a final high-vacuum base pressure, which can be measured using an Ionization Gauge (IG) (9 in fig)

4. **Venting** – Once the deposition process has been completed, the chamber can be vented to atmosphere by shutting OFF the high vacuum and IG and opening the VENT valve (7 in fig)

**3. Backside Metal contact**

3a. **Thermal Evaporation**

For the process of metallization, the first step involves thermally evaporating the backside of the wafer with Aluminum, to form metal contact with the p-type silicon substrate. The following video can help briefly illustrate the process of thermal evaporation.
Since, thermal evaporation happens past the melting point of the metal, the current through the tungsten boat controls the rate of deposition of the metal on our substrates. The higher the current, the higher the deposition rate. However, an old/used boat can have a higher resistance due to corrosion, which can cause a higher $I^2R$ heat when higher current is applied, thereby breaking the boat.

4. **Top Aluminum contacts**

4a. Al sputtering

The top gate final top gate contact can be deposited by shadow masking a dot pattern (~1 mm dia) using sputtering for a direct pattern transfer.
As opposed to thermal-evaporation, which is a line-of-sight process, sputtering is a 3D deposition process. The following videos demonstrates the operation of a simple thermal evaporation system.

The following video shows how a sputtering process works. The video to the right shows the operation of an ATC AJA Orion sputter tool.
Sputtering is a 3-dimensional process and as a result, every surface in the chamber is coated with the desired film. A typical sputter tool consists of a high-vacuum chamber attached to a “load-lock” chamber (where samples are loaded in from atmosphere) and separated from each other by a high-vacuum valve such as a butterfly valve. The load-lock serves an important purpose of loading/unloading of samples from atmosphere, thereby circumventing the need of opening the main chamber to atmosphere and preventing it from external contamination.

(i) Once, the sample has been transferred into the main chamber using a transfer arm, the butterfly valve is closed shut.

(ii) The inlet of the main chamber’s high vacuum pump is then “throttled”, which involves partially closing the orifice to this pump to prevent damage to the pump’s blades, when the process gas is introduced in the next step.

(iii) Also, make sure to close the butterfly valve between the main chamber and the load-lock to avoid leaking the process gas into the load-lock.

(iv) The process gas, which is usually an inert gas like Ar, is then introduced for sputtering a metal. This raises the pressure of the main chamber to that of medium vacuum (~20 mtorr).

(v) A DC/RF voltage is then introduced (can be kept track using plasma power parameter) to accelerate any free electrons/ions in the gas and strike plasma.

(vi) Once the plasma is struck (which can be seen as a colored glow), the process parameters can be tuned before opening the shutter on the sputter target metal and start the sputtering process.

(vii) The thickness of the film can be calculated using equation (1)

\[ \text{Film thickness} = \text{Sputter time (min)} \times \text{Sputter rate (Å/min)} \]  

The following basic parameters determine the sputter rate (Å/min) of a film of a sputter coated sample,

(i) **Power (W)** – Determines the kinetic energy of ions striking the sputter target. Sputter rate generally increases with increase in pressure until a certain point.

(ii) **Process gas pressure (mtorr)/flow rate (sccm)** – More the pressure, the more ions available for sputtering and hence a faster sputter rate.

(iii) **Throw distance (cm)** - Distance from the sample to the target. The closer the sample to the target, the higher the sputter rate.

**Appendix: Additional Resources (Not included in quiz)**

1. Vacuum Know-hows – [Pfeiffer Vacuum systems](#)