EECE5606 Laboratory Template

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Title: Sputtering **Lab week: 3**

1. Lab Description (10 points) *(What is this lab about?)*

In this lab lesson, the students were taught the process of sputtering, a form of physical vapor deposition (PVD) to deposit thin-films on silicon wafers. Cleaning, pre sputtering, and post sputtering.

2. Lab Objective (10 points) *(Why are you doing this lab?)*

This laboratory class was aimed at training the students to use sputtering, a form of PVD to produce a thin-film coating on a silicon wafer in the George J. Kostas Nanoscale Technology and Manufacturing Research Center cleanroom facility. The main objectives of this class were to teach the students the basics of PVD: to use sputtering to coat aluminum on a silicon wafer.

3. Methods (20 points)

Sputtering stands as a pivotal process within Physical Vapor Deposition (PVD), whereby atoms from specific materials are dislodged from their surfaces through bombardment by energized particles from plasma. This method finds extensive use in depositing thin films onto substrates across various applications. Sputtering typically operates at pressures on the order of Torr, facilitated by cryopumps. Cryopumps function by chilling gases and vapors to temperatures where molecules condense on chamber walls, effectively trapping them.

The sputtering system utilized in the Kostas cleanroom facility comprises the ATC 2200 UHV sputtering system by AJA Instruments, featuring two chambers. The initial chamber, known as the load-lock, serves as the entry point for wafers from ambient air pressure conditions into the primary vacuum processing chamber, which is the sputtering chamber. The latter, a sizable metal cylinder, accommodates the targets crucial for the sputtering process. The load-lock incorporates internal arrangements, including a wafer holder designed to secure wafers upside down for deposition, considering that targets are located at the chamber's bottom. Operating pressures in the load-lock and sputtering chambers are approximately and Torr, respectively. The sputtering chamber can accommodate up to nine targets, each equipped with a shutter and power supply connection tailored to the specific target material. The power supply varies depending on the target, encompassing DC supply for materials like aluminum or both DC and RF for others like platinum. The control unit utilized by the sputtering system is illustrated in Figure 3a. During laboratory sessions, argon serves as the plasma ion source for sputtering. Argon, being of high molecular weight, along with other noble gases like krypton or xenon, is preferred to ensure high-energy collisions between gas ions and the target surface. Argon, in particular, is favored due to its cost-effectiveness and moderate weight, making it a popular choice for sputtering applications owing to its chemical inertness.

In this laboratory class, we used a mixture of argon and oxygen (Ar + O2) to produce plasma for sputtering. This blend of gases is commonly utilized for surface activation before physical bonding. Oxygen, being highly reactive, is an excellent choice for this purpose, but its tendency to oxidize metals is a disadvantage. To counteract this, argon is used to prevent surface oxidation by breaking the oxygen-metal bond with the help of plasma and removing it from the chamber. When oxygen gas is employed, it has a considerable etching effect, which removes surface atoms individually, resulting in a pristine, bondable surface that is ready to receive the sputtered metal atoms so that permanent physical bonds between the two layers are produced.

Figure 1: The sputtering chamber.

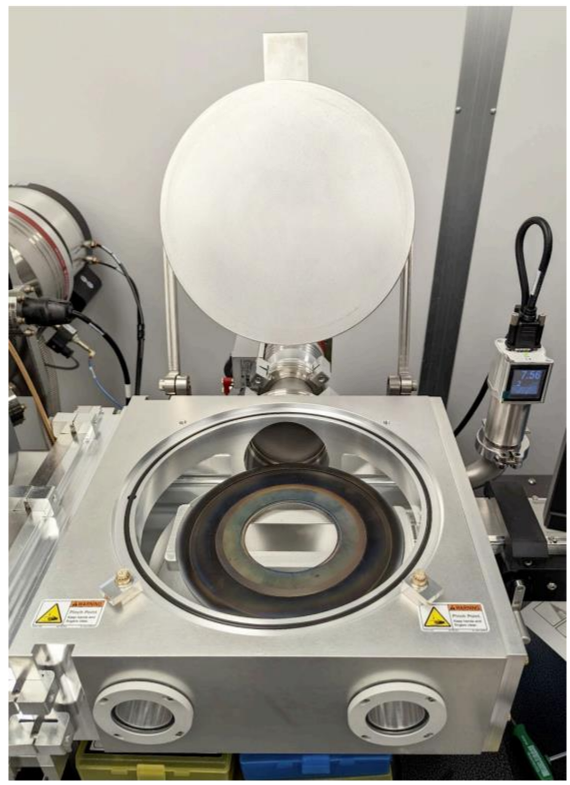


Figure 2: The load-lock chamber.

The various steps involved in the sputtering process are as follows:

a. Firstly, the load lock must be brought to ambient pressure (approximately 760 Torr) for it to be opened. It is then opened, and the wafer is placed inside the chamber. The chamber is designed to fit 8-inch wafers and if a smaller wafer must be placed, a carrier (8-inch wafer with a slot in the centre to place a smaller wafer) is used. Once the wafer is safely fastened in the load lock, the cryopump is used to vacuum the load-lock and bring the pressure down to 7.2 × 10 Torr.

b. Next, the sputtering chamber valve must be opened to the load-lock so that the wafer may be inserted into the wafer holder for sputtering. A linear actuator assembly is used to load the wafer into the sputtering chamber, onto the wafer holder. Once the wafer is secured in the wafer holder, the holder is set to rotate at 60 revolutions per minute and vertically descend such that it is 42 cm above the target. The pressure inside the sputtering chamber is also brought down to Torr (shown in Figure 3b).

Figure 3a: (Left) The AJA Instruments sputtering system control unit.
Figure 3b: (Right) Close-up of the system.

c. Next, the AlSiCu target is selected using the AJA International computer software user interface and the power is set to 30 W. All the targets have shutter lids to control the deposition. Argon is filled into the sputtering chamber at a flow rate of 30 sccm (standard cubic centimeters per minute) to produce a pressure of 30 mTorr. Then, the power is increased from 30 W to 300 W in 270 seconds.

d. Once the power supply has reached the value of 300 W, the plasma is created and the flow rate and pressure of argon is brought to a value of 10 sccm and 10 mTorr respectively. This reduces the intensity and color of the plasma from bright and pink to dim and purple. The window shutter is then closed to prevent coating of the glass window of the sputter chamber with aluminum and the sputtering shutter is opened, allowing deposition to take place. The process is done in around 10 minutes.

e. After about 10 minutes, the power is brought down to 30 W from 300 W in 270 seconds and the sputtering is complete. Then the sputtering chamber valve is opened to the load-lock and their pressures are equalized. The height of the wafer holder is adjusted, the wafer is moved to the load-lock chamber using the linear actuator assembly, and the sputtering chamber valve is closed. The flow of argon and oxygen into the sputtering chamber is stopped. The load-lock is brought to ambient pressure and the wafer is removed.

4. Outcomes and Measurements (15 points)

The outcome of this laboratory class was that the students were introduced to the process of sputtering to deposit thin aluminum films on silicon wafers.

5. Comments (5 points)

It was observed that the sputtering process in the AJA sputtering system is not automatic, and that the process must be manually stopped after the desired time. Furthermore, the targets used in the Evatech are expensive (about 40,000 USD for platinum targets) and that these targets last for about a year.

6. Analysis Questions (30 points)

Sputtering and evaporation are useful for different situations. Determine which deposition method is best for the following situations and describe why:

a. Low temperature process: Sputtering is better than evaporation in this case as the latter uses a heat source to raise the temperature of the target until it gets vaporized whereas the former uses energized ions from a plasma to bombard the target causing it to eject atoms.

b. Minimum surface disturbance: Evaporation is preferred over sputtering in this case due to the latter's use of plasma to generate high-speed atoms that can harm the substrate. Evaporation, which operates at high temperatures, produces few high-speed atoms due to the Maxwell Boltzmann distribution of atom speeds. However, electron beam evaporation can potentially cause substrate damage through the creation of X-rays and stray electrons.

c. Multiple wafers, thick metal layer: Evaporation is better in both cases.

- Evaporation is better than sputtering for large batch processing while the opposite is true for automated high-volume production of thin films with short deposition times
- Flash evaporation produces the thickest films amongst any kind of PVD.

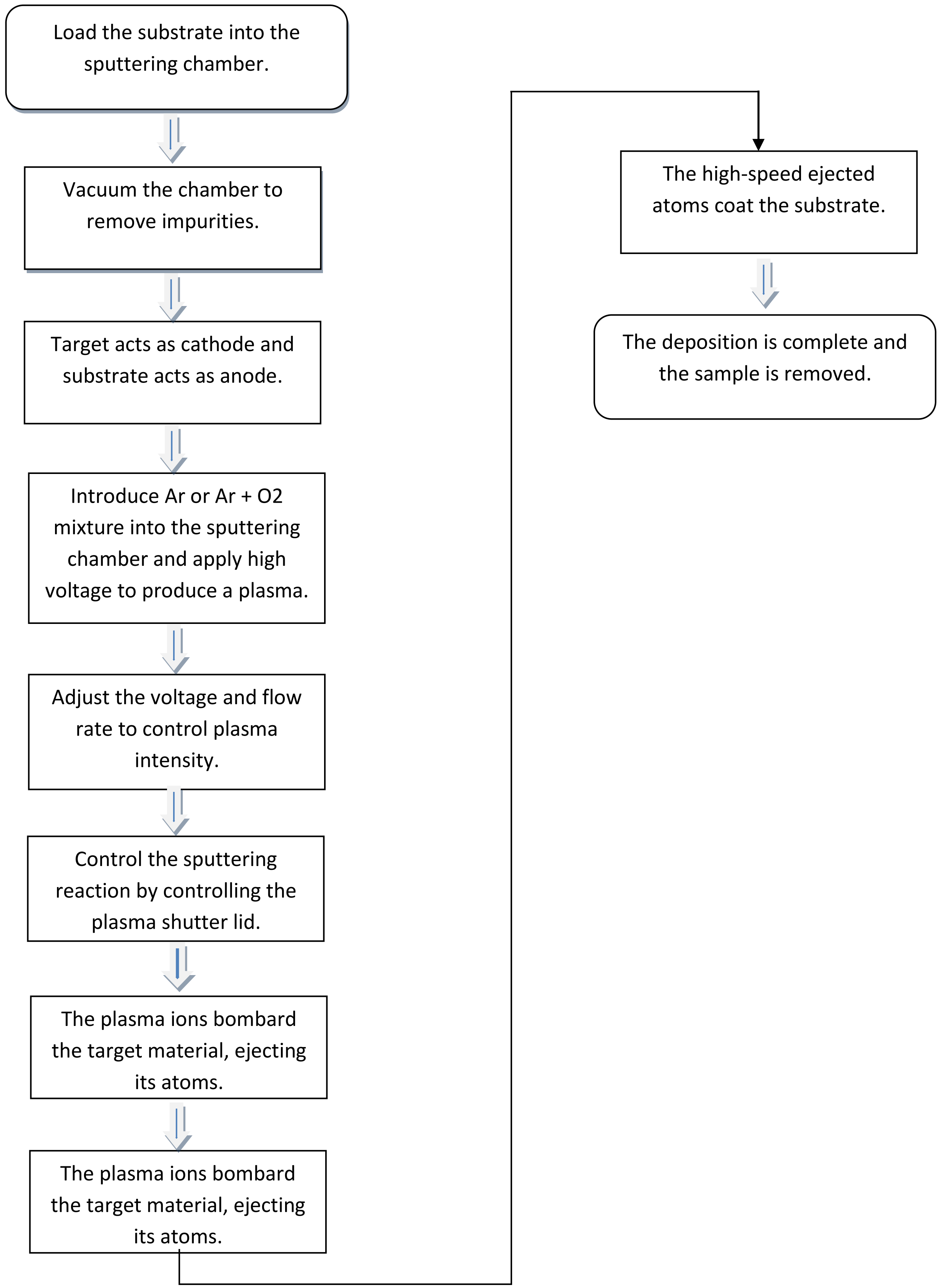
d. Multiple layers of different materials: Sputtering is preferred over evaporation in this case it is easier to switch between different target materials, allowing for more precise control over the layer stack.

e. Lowest possible contamination: Sputtering is better than evaporation in this case, as the former's growth parameters can be more precisely controlled than the latter's. Furthermore, in PVD, the highest impurity levels are found in resistive thermal evaporation, while the lowest are found in ion beam sputtering.

f. Extremely accurate thicknesses: Sputtering is preferable to evaporation in this case as it is possible to produce better quality thin films with more uniformity. Furthermore, sputtering has lower deposition rates, better step coverage, and offers more controllability over deposition.

g. Vacuum conditions during deposition: Evaporation is better in this case as it is usually done in vacuum conditions in pressures of the order of 10^{-7} Torr, whereas sputtering is done in a gaseous medium such as argon in pressures of the order of 10^{-1} to 10^{-2} Torr.

Draw a flow chart to describe the inner workings of either a sputtering or evaporation tool.



7. **Attendance (10 points)**

Leave this answer blank – to be used by TAs.