EECE5606 Laboratory Template

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Title: Etching **Lab week: 4**

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

In this lab lesson, the students were taught the process of dry etching, specifically, inductive coupled plasma reactive ion etching (ICP RIE) to etch a photoresist (PR), dry release using selective XeF2 vapor etch using the XACTIX tool.

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

This laboratory class was aimed at training the students to use the XACTIX tool to perform selective XeF2 vapor etch, and ICP RIE, a form of dry etching to produce a selectively remove particular regions of ScAlN on a silicon wafer in the George J. Kostas Nanoscale Technology and Manufacturing Research Center cleanroom facility.

3. **Methods (20 points)**

In this laboratory class, the PR was used as a mask as it protected the regions underneath it from being removed. A better alternative to PR is SiO2; in comparison with PR, SiO2 offers higher selectivity and produces much higher side walls. However, the downside to using SiO2 over PR as a mask is that the number of fabrication steps increases as the SiO2 layer must itself be patterned using etching.
The instrument used for the dry etching process was the Oxford Plasmalab System 100. It is a 100 mm reactive ion etching (RIE) tool designed for a variety of etches. It is an inductive coupled plasma (ICP) based etcher designed to etch pieces mounted to a 100 mm wafer. The diameter of the source only allows it to uniformly etch the center (approximately 1.5 inches) of the wafer, making it perfect for pieces. It has Ar, BCl3 , CH4 , Cl2, H2 , and O2 gases available. The tool also has a cryo chuck that can work in the temperature range of [-150 ℃, 400 ℃]. The Oxford tool is equipped with a single wafer load lock chamber which can accept 100 mm wafers. It uses a mechanical clamp to hold the wafer onto the chuck during processing.
The tool uses a simple software on the windows operating system to run recipes (shown in Figure 3). Most users will operate the tool from either the ‘Chamber,’ ‘Pumping’ or ‘Recipe’ screens. These are accessed via the top ‘System’ or ‘Process’ dropdown menus.
The various steps involved in the etching process are as follows:
1. The small trapezoidal sample is glued to a 100 mm low resistivity wafer using vacuum oil. Only a dribble of the vacuum oil is added to the wafer using a toothpick and then the sample is carefully placed on top of the oil with tweezers (shown in Figures 4a and 4b). Too much oil can affect the sample etching. The sample with the wafer is then soft baked on a hot plate for 1 minute.
2. The cooling system for the cryopump used in the Oxford tool is switched on so that the cryopump provides a high vacuum.

3. The desired recipe for the dry etching process is selected from the list of recipes in the software and the pressures of the various gases (Cl_2, O_2, BCl_3, and Ar) are also adjusted.
4. The pressure in the load lock chamber is brought to room pressure (750 Torr) using the software and it is opened to place the wafer.
5. Once the wafer is fastened in the load lock chamber and the lid is closed, the pressure in the load lock chamber is again brought to near vacuum to match the pressure of the main chamber.
6. The entry to the main chamber is then opened and a horizontal actuator slides the wafer into it. A mechanical clamp is used to hold the wafer onto a chuck to ensure its stability.
7. Depending on the recipe and the thickness of AlN needed to be etched, the entire dry etching process takes about 3 to 5 minutes.
8. Once etching is complete, the sample is removed from the load lock using the software.

2. XeF_2 vapor release etch:
In this laboratory class, the instrument used for the XeF_2 vapor etch release process was the XACTIX e1 XeF_2 silicon etcher system (shown in Figures 1a and 1b). This system is designed to expose samples to XeF_2 gas in a cyclic or pulsed mode. XeF_2 can be used to isotropically etch Si, Mo, Ge, Nb, poly-Si, Ti and W. XeF_2 can be used to make very long undercuts with little or no degradation of etch stop, mask or device layers.
Advantages of using XeF_2 vapor etch release process include:
1. Selectivity during etching: XeF_2 shows very high selectivity ratio for silicon to photoresist, SiO_2, Si_3N_4, and aluminum. Selectivity of silicon nitride is better than 100:1 and the selectivity to silicon dioxide is better than 1000:1.
2. No external energy or ion bombardment takes place, and this is the reason XeF_2 exhibits high selectivity to many metals, dielectrics and polymers. The etch reaction is exothermic and results in an increase in chamber temperature.
3. No release stiction: XeF_2 etching is a dry process so no drying is needed which avoids the sticking issues that often plague wet release processes. Since XeF_2 etching is a dry, room temperature process, delicate structures can be released.
4. The system can etch silicon from small samples to 4 inch wafers. The etch rate is dependent on the surface area of the silicon and decreases with increasing area.
The tool uses a simple software on the windows operating system to run the etch process. The various steps involved in the etching process are as follows:
1. The pressure in the load lock chamber is brought to room pressure (750 Torr) by clicking the "Load/Unload Sample" button on the software (shown in Figure 2). The chamber is brought to atmospheric pressure (760 Torr) and the lid is opened to place the sample. The sample used was a small square piece cut from a lithium niobate ($LiNbO_3$) coated Si wafer with Al/$LiNbO_3$ devices, i.e., resonators with interdigitated (IDT) electrodes made with an Al layer on $LiNbO_3$.
2. Once the sample is placed in the chamber (shown in Figure 3) and the lid is closed, the chamber is purged and pumped four times, until it reaches a value of 0.3 Torr.
3. Next, the "Etch Menu" button is clicked and the process parameter values are entered. The number of cycles is set to 18, the etch time to 1 minute, XeF_2 pressure to 3 Torr, and the N_2 gas pressure to 3.3 Torr (shown in Figure 4). The process is started by clicking on the "Start Etch" button.

4. Once the etch process begins, the “Machine Status” toolbar displays the message “Etching”. The “Etch time completed” toolbar begins to load green and a real-time graphical plot of XeF2 pressure vs time is displayed in the “Chart Recorder” window (shown in Figure 5).
5. After each etch cycle, the system cools down for an average time of 33 seconds before starting the next cycle. The real-time graphical plot of XeF2 pressure vs time for one full cycle increases initially, stays constant for majority of the cycle, and then falls off as the chamber is repeatedly pumped and vented (shown in Figure 6).
6. The total time taken to complete the etch process depends on the number of cycles and in this laboratory class, the process took 32 minutes and 10 seconds to complete (shown in Figure 7). Once the process is completed, the system comes back to the main menu.
7. Once etching is complete, the “Load/Unload Sample” button is used to bring the chamber pressure to 760 Torr and then sample is removed from the chamber.

4. Outcomes and Measurements (15 points)

The outcome of this laboratory class was that the students were introduced to the process of etching.

5. Comments (5 points)

The following were observed in this laboratory class:

• The XeF2 vapor release etch is isotropic, meaning it etches equally in all directions.
• Cool time influences the etching process as warmer temperatures produce faster etch rates.
• The etch rate increases with the size of the sample or wafer.
• Usually, release is done on individual dice or a collection of die in samples. Releasing an entire wafer can take days.
• The frequency of oscillations of the resonators increases with decrease in the width of the resonators.

6. Analysis Questions (30 points)

1- What is the difference between the two etches you saw in this lab?

ICP Etching:

Principle: ICP etching utilizes plasma, which is generated by coupling energy into a gas via radiofrequency (RF) energy. The gas becomes ionized and reactive species are created. These species then react with the material to be etched.

Advantages:

- High etch rates.
- High selectivity, allowing precise control over the etching process.
- Suitable for a wide range of materials including semiconductors, dielectrics, and metals.

Disadvantages:

- Requires complex equipment setup.
- May cause damage to sensitive materials or structures.
- Control parameters must be carefully adjusted to achieve desired results.

XeF2 Etching:

Principle: XeF2 etching is a chemical etching process where Xenon Difluoride gas is used to selectively remove silicon-based materials through a vapor-phase reaction.

Advantages:

- Isotropic etching, meaning it etches in all directions uniformly.
- High selectivity for silicon, making it suitable for releasing MEMS (Micro-Electro-Mechanical Systems) structures or etching silicon in integrated circuits.
- It is a dry etching process, meaning it doesn't involve liquid chemicals, reducing the risk of contamination.

Disadvantages:

- Limited to silicon-based materials.
- May require special handling due to the hazardous nature of Xenon Difluoride.
- Etch rates may vary depending on the material and geometry of the structures.

2. What could be another way to get isotropic etching of silicon? Could you get similar results using an anisotropic etch?

Another manner to achive isotropic etching of silicon, except the use of ICP etching, is by wet chemical etching process. Wet chemical etching includes immersing the silicon substrate in a chemical solution that selectively reacts with the silicon material. Unlike dry etching techniques like ICP etching, wet chemical etching has a tendency to be isotropic in nature, which means it etches in all directions uniformly.

One commonly used wet chemical etchant for silicon is potassium hydroxide (KOH) or tetramethylammonium hydroxide (TMAH). These solutions can etch silicon isotropically, producing smooth and rounded features on the substrate surface.

While anisotropic etching is excellent for creating precise and controlled features with sharp edges, it is not suitable for achieving isotropic etching results.

3. If you need to get a much deeper features, which etch can you use?

If we need to create much deeper features in a material, particularly in silicon, you would typically employ Reactive ion etching (RIE). RIE is a specialized form of dry etching, often used in microfabrication processes to create deep features with precise control over sidewall profiles.

7. Attendance (10 points)

Leave this answer blank – to be used by TAs.