EECE5606 Laboratory Template

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Title: lithography **Lab week: 2**

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

In this lab lesson, students were taught the process of photolithography to pattern microstructures on a silicon wafer. The following processes were discussed: applying HMDS and photoresist and spinning, soft baking, mask aligning, wafer patterning, wafer development, optical microscopy, surface profilometry and wafer cleaning were discussed. Students were trained in the various processes in photolithography.

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

This laboratory class was aimed at training the students to use photolithography to produce microstructures on silicon wafers in the George J. Kostas Nanoscale Technology and Manufacturing Research center cleanroom facility. The main objects of this class were to teach the students the basics of photolithography to pattern and develop silicon wafers, to measure PR thickness using profilometry, and to identify between over underdeveloped wafer using an optical microscope.

3. **Methods (20 points)**

1. Applying HMDS and photoresist on the silicon wafer:
   The photoresist (PR) is a light sensitive material that is used as a patterned coating for silicon wafer. HMDS is adhesive what improves the photoresist equal spreading of PR. There are two types of PR: positive and negative. The former softens in reaction with light such that the light exposed regions become dissolvable. The latter hardens in reaction with light such that the regions other than the light exposed regions become dissolvable. The PR which we used was S-1827 and S-1827
   A. First, the silicon wafer is placed on the wafer spinner using tweezers and is roughly centered by eye on the wafer stand.
   B. Then using the machine, a vacuum is applied between the wafer and the wafer stand; this enables the wafer to remain fastened on the stand when it is spinning.
   C. Then a dropper is used to take liquid HMDS from its bottle and apply it on the wafer. Care must be taken to produce a centered circular drop on the wafer.
   D. Immediately after the application of the layer on the wafer, the spinner hood is closed and the spinning is started using the machine interface. The wafer is spun at 40,00 rpm for 60 seconds.
   E. After the spinning cycle is complete, the vacuum seal is removed using machine interface and the wafer is removed from the wafer stand using tweezers.
   F. The next step after coating the surface of the wafer with HMDS is to do soft baking for 60 sec at 115^{o}C.

G. Repeat the A – F steps but use PR in place of HMDS and care must be taken to produce a centered circular drop[on the wafer. The liquid PR must not contain any bubbles as they reduce the quality of the thin PR layer.

2. Soft baking the wafer:
   The next step after coating the surface of the wafer with PR is to do soft baking. Soft baking is essentially the process of heating the wafer to make sure that the PR coating on the wafer surface dries and does not come off it on contact. The soft baking is done on a hot plate, which has four small pillars on it (shown in Figure 2). The pillars are present to help the user adjust the position of the wafer using tweezers. This is necessary as the hot plate is very smooth making it difficult to get a hold of the wafer as it would keep sliding away. The wafer is placed on the hot plate and its position is adjusted such that it touches the pillars. Then, it is heated for 1 minute at 115 ℃ beyond which it is taken off the plate and kept aside for another minute to cool down.

3. Patterning the wafer:
   The mask aligner is a machine that helps the user align the mask with the wafer so that the devices are properly produced in the right locations. The mask aligner has a sliding plate where the wafer with the PR coating is placed with respect to the wafer is adjusted such that the mask makes contacts with the wafer. The wafer is patterned using the same machine for mask aligner. Once the mask is positioned correctly, the machine is pulled forward to bring the light source directly above the mask and wafer. First the load button is pressed and then contact button is pressed then the expose button is pressed then the aligner would close its shatter and then the UV light would expose for 20 sec, 60 sec, 100 sec (under exposed, exposed, over exposed). The wafer can be removed immediately.
4. Developing the wafer:
   Once the PR coated wafer has been patterned, the next step is to develop the wafer and dissolve the soft part of the PR that had been exposed to the UV light. Development is done by submerging the wafer in a beaker solution made with 1:1 ratio of the Microposit developer concentrate (a strong base) to water. Once placed the beaker is slowly the soft part of PR is dissolved away in the solution revealing complex micro-scale patterns. Development is an important process that affects the microstructures in the silicon wafer. Every PR recipe has its own optimal development time and, in this case, it was 1 minute. After a minute wait, the wafer is taken out of the developer solution and placed in a beaker of deionized (DI) water for few seconds. Then it is taken out and placed on water absorbent paper and dried with a pressurized nitrogen gun.
5. Optical microscopy:
   After development, the wafer is ready to be observed and analyzed under an optical microscope (shown in Figure 9a and 9b). One way to find out whether the wafer is correctly developed is by looking at microstructures such as interdigitated electrodes. The clearness is the wafer will let us know if the wafer is underdeveloped, overdeveloped, or properly developed.
6. Surface profilometry:
   The thickness of the PR film can be analyzed using a surface profilometer. The instrument in the Kostas cleanroom facility is the Dektak^{3}ST Surface Profile measuring System. It works by

scanning a micro tip needle on the surface of the wafer and sensing its movement as it moves vertically. The thickness of the PR was found to be 2.7 µm for the wafer developed for 1 minute.

4. **Outcomes and Measurements (15 points)**

The outcome of this laboratory class was that the students were introduced to various photolithography processes. Furthermore, the effect of wafer development on the microstructures were studied and the surface profile of the wafer was analyzed.

5. **Comments (5 points)**

It was observed that the development time of the wafers influenced the thickness of microstructures, which was quite interesting.

6. **Analysis Questions (30 points)**

1- Lithography is a fundamental step in micro and nano fabrication processes. Identify the most suitable lithographic process (tool and wavelength) and discuss your choice for the following situations:

(a) Large scale manufacturing of 15 nm CMOS transistors

For large-scale manufacturing of 15 nm CMOS transistors, the most appropriate lithographic technique would be extreme ultraviolet lithography (EUVL). EUVL uses a very short wavelength of around 13.5 nm, which allows for extremely high-resolution patterning suitable for the 15 nm node and beyond in semiconductor manufacturing. EUV lithography has been developed specifically to address the challenges of patterning features at these small scales.

(b) Research-level fabrication of infra-red plasmonic sensors with minimum feature size of 120 nm

For research-level fabrication of infra-red plasmonic sensors with a minimum feature size of 120 nm, deep ultraviolet (DUV) lithography would be suitable. DUV lithography typically uses a wavelength in the range of 193 nm to 248 nm, which can achieve the required resolution for features around 120 nm.

(c) Large scale manufacturing of silicon accelerometers (minimum feature size: 2 µm)

For large-scale manufacturing of silicon accelerometers with a minimum feature size of 2 µm, optical lithography using i-line or g-line (365 nm and 436 nm, respectively) could be employed. These wavelengths are suitable for larger feature sizes and are commonly used in semiconductor fabrication for less dense patterns.

(d) Research-level fabrication of resonators with minimum feature size of 900 nm

For research-level fabrication of resonators with a minimum feature size of 900 nm, advanced optical lithography techniques such as advanced i-line or g-line lithography, or even advanced DUV lithography, could be employed. These techniques offer higher resolution than standard optical lithography and could achieve the required feature size.

(e) Research-level fabrication of piezoelectric acoustic micromachined transducers with minimum feature size of 5 µm.

For research-level fabrication of piezoelectric acoustic micromachined transducers with a minimum feature size of 5 µm, standard optical lithography techniques using i-line or g-line could be used. These wavelengths and lithography techniques are suitable for larger feature sizes and are commonly available in research laboratories.

2- According to your experience, which factors could impact the over or under-exposure of feature obtained via lithography?

Ans

- Exposure Dose: The amount of energy delivered to the resist during exposure affects the degree of chemical change in the resist material.
- Exposure Time: The duration of exposure also influences the amount of energy received by the resist.
- Mask Quality: Defects or imperfections within the photomask can bring about uneven publicity throughout the substrate, main to over or underexposure in specific regions.
- Uniformity of Light Source: Inconsistent light depth across the exposure field can motive versions in exposure, resulting in over or underexposure of features.
- Focus and Alignment: Improper consciousness or misalignment of the mask and substrate at some stage in exposure can cause distortions in the pattern and have an effect on the exposure uniformity, ensuing in over or underexposure.
- Temperature and Humidity: Variations in temperature and humidity during the exposure process can affect the performance of the resist and the exposure system, leading to over or underexposure.
- Developer Solution and Development Time: The choice of developer solution and the duration of the development process can affect the contrast and resolution of the developed features, potentially leading to over or under development.

7. **Attendance (10 points)**

Leave this answer blank – to be used by TAs.