Microsensors, Implantable Devices and Rodent Surgeries for Biomedical Applications

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Welcome to this lab class. In this lab class, we will see what photolithography is. We have covered in theory what photolithography is, how UV lithography works and we have touched upon how E-beam lithography works. You have seen masks, photoresists, and all other aspects in theory. Now, let me show you a video of a process that we have carried out in the cleanroom lab, demonstrating how we use the photoresist spin coater in a lab environment. You will learn how to use a photoresist, spin-coat the photoresist on a wafer, and how to use different types of masks.

You may recall from theory class the concepts of bright field and dark field masks. Here, you will see how to use either a bright field or a dark field mask and align the wafer onto the substrate. Then, you will see the exposure process, which involves the mask aligner with a UV source. The mask can be aligned in the X, Y, and rotational (theta) directions, providing three ways to align the mask onto the wafer. This is a contact-based lithography process, and we will demonstrate this in the lab. Finally, once you expose the photoresist, you will see how to develop the photoresist to transfer the mask's pattern onto the wafer.

This video will demonstrate the photolithography steps and how to process a wafer. We will also cover front-to-back lithography. By that, I mean that if you pattern something on the front of the wafer and want to create a diaphragm on the back side of the wafer, we will show you how front-to-back lithography is done because silicon is opaque. I hope you enjoy the lab session. I will come back at the end of the lab to review what you have learned from the video.

Hello everyone, greetings and welcome to this lab module on the demonstration of lithography and the cleaning process. As you all know, lithography is the heart of the microfabrication process, mainly responsible for determining the outcome, or parameter, known as pitch or resolution for a particular process. In today's lab class, we will cover both lithography and cleaning, which is an essential primary step for any process and can be repeated as needed in the process flow. Lithography in the microfabrication pipeline begins with thin film deposition, which can be done using PVD or CVD techniques. In PVD, we use thermal evaporation, E-beam evaporation, and sputtering to deposit the desired material with the desired thickness on the wafer, whereas in CVD, there are various other techniques available.

It is crucial to determine which process and material, as well as which thin film deposition or additive technique, needs to be used before sketching the process flow. Once the additive process is done and the desired material is deposited on the wafer, the next step is to pattern it before etching. Etching is a subtractive process, and thin film deposition is an additive process. Lithography falls between these two steps, helping to pattern the desired shape. The design for the desired pattern would have already been created using a computational software known as Kelvin. The design is then loaded, and UV light is exposed between the wafer and the mask. As a result, the pattern on the mask gets successfully transferred onto the wafer.

The lithography process begins with cleaning, followed by depositing the photoresist onto the wafer. The photoresist is deposited using a spin coater, and the spin speed and time determine the thickness of the photoresist. Each photoresist has an optimized time for a given spin speed, which can be found in the PR data sheets. For example, at spin speeds of 3000, 4000, or 5000 RPM, the photoresist should be coated for a specific time to achieve the desired layer thickness. Once the photoresist is coated, it is exposed to light to generate different responses. As the name suggests, the photoresist reacts chemically based on where the light is present and where it is absent, which will be further processed in the development step to obtain the final pattern. After developing the pattern on the wafer, characterization techniques are used to verify if the desired dimensions and pattern were achieved.

In today's lab module, we will cover the cleaning of the wafer, followed by patterning the photoresist on the wafer, exposure, and whether we can successfully develop the final pattern. So, let's proceed.

We now have a gold-coated glass wafer submerged in DI water. The first step in the cleaning process involves cleaning it in acetone. We have a glass petri dish containing acetone, as you can see here. The wafer is left in acetone for 5 minutes. Now, 5 minutes have passed, so I am removing the sample from the acetone and placing it in IPA (isopropyl alcohol). We will leave it in the IPA for another 5 minutes.

5 minutes are over. I am removing the sample from the IPA and placing it in DI water. Acetone removes contaminants, IPA ensures the acetone is gone, and the DI water removes any remaining IPA, leaving a clean wafer. Now that the sample has been thoroughly cleaned in DI water, the next step is to blow dry it using nitrogen. We have a nitrogen gun for this purpose, ensuring that no water marks are left after drying.

The sample is now clean, and we will place it for a dehydration bake, which is a crucial step before spin coating the photoresist. The wafer is clean, and we will proceed with the dehydration step, which involves heating the sample on a hot plate at around 100 degrees

Celsius for about 10 minutes. Any temperature above 100 degrees Celsius is good, but typically, we go for 110 degrees Celsius.

We will now place the sample for dehydration. You can see the hot plate maintained at 110 degrees Celsius. Let's wait for 10 minutes for the moisture on the wafer's surface to evaporate, preparing it for the lithography step. While the wafer is in the dehydration bake, let me introduce you to one of the most critical pieces of equipment required for the lithography process—the mask cleaner.

The mask cleaner we are introducing today is the MIDAS MDA 400 M6, a manual mask cleaner. Let's go over the different features of this mask cleaner. Why do we need a mask cleaner, and why do we have equipment like this for the lithography process? The goal is to create a pattern on the silicon or glass wafer. For example, in the sample I showed earlier, we have a glass wafer coated with gold.

So, what we are interested in is to create patterns like these, as you can see on this plate here. These are known as masks or photomasks. You can see the patterns here, which we would like to have on the wafer. This is like a master pattern. So, what is this thing? A photomask is like a master template, all right.

This is a master template of the pattern that we would like to have on the wafer. You can see something like a chocolate brown-coloured shade in this area, right? And then there are a lot of patterns there. These patterns that you see here are called interdigitated electrodes, which we are fabricating for a specific application in our lab. Otherwise, this dark area is chromium, and the transparent area is glass or soda lime glass. Now, there can be different materials for the photomask base, like soda lime or glass, but what we have is soda lime glass, and the opaque area is chromium.

Now, think about it this way: if we shine UV light through the transparent areas, the light will pass and reach the other side, while the chromium, which is the opaque area, will block the light.

So, when we think about it, if we have a wafer coated with photoresist and keep this mask on top of it and shine light, the light will pass through the pattern and reach different areas across the pattern, correct? Let's see how we use this mask in a while. Meanwhile, I would like to introduce another mask as well. In this mask, the majority of the area within the circle is transparent.

This is a 5-inch photomask, okay? So, the diameter of the circle that you see is 5 inches, and the majority of the area within it is transparent. While in the other mask, it is the other way around. The patterns in that mask are transparent, and the rest of the area is dark. This is known as a dark-field mask, and the other is known as a bright-field mask, okay?

In simple terms, in the dark-field mask, the pattern of interest is opaque, while in the bright-field mask, the pattern of interest is transparent. So, we have a dark-field mask and a bright-field mask.

On top, we have a UV light source in a chamber where the UV light is kept. This machine uses an I-line UV source, which is 365 nm. The machine can also use deep UV, but we currently have a UV lamp producing an I-line at 365 nm. The feature size we can achieve depends on the UV light source we use, but that's too detailed to cover right now.

Now, let’s see some components of this machine. We have a lot of optics here, like a microscope, but with cameras and everything. We have a UV light source, and then we have a stage here where we load the mask. You see a plate here where we can load these kinds of photomasks, and then there’s a chuck. This is where we place the wafer. Once the mask is loaded here, and the wafer is placed here, we close it like this, and the UV shines from the top. The UV light passes through the mask and reaches the wafer.

That’s how the process works. But if the process is just placing the mask and wafer and shining UV light, why is there so much complexity? The idea is that many times in microfabrication processes, we have multiple stacks of materials to pattern, and we don’t use just one mask. We might use five, ten, or even twenty masks in more complex cases. Especially in microelectronics, people use up to 20 or 30 masks.

In our case, if we need multiple masks and the patterns are very small, this machine can achieve feature sizes as small as three micrometres. When working with such small patterns, ambient vibrations can creep in, which is why this machine is suspended in the air. It minimizes ambient vibrations.

Another important feature of this machine is alignment. If we have a pattern already transformed on a wafer and a second mask to create a new pattern on top of it, we need to align them properly. This machine allows for that alignment.

Now, the dehydration bake is complete, and I’m removing the wafer. The next step is spin coating. Here’s the spin coater we use to load the wafer with photoresist and spin it at a very high speed. Let’s see how we use this equipment. I am opening the spin coating lid and placing the wafer on the chuck.

It’s a vacuum chuck, so once the wafer is placed and the vacuum is switched on, the wafer won’t move, which is very important because we rotate it at around 4000 rpm. If it’s not held properly, the wafer could fly out.

Now we select the recipe. We already have a recipe set based on the datasheet for the photoresist. We spin the photoresist at 4000 rpm for 40 seconds. Since we are using the 3012 positive photoresist, this rotation will give us a thickness of around 1.2 microns.

We have the wafer here, and now we switch on the vacuum. You can hear a humming sound. Now, if I try to move the wafer, it won't move because the vacuum is holding it in place. The next step is to add the photoresist, which we have here. The photoresist is a brown liquid. I am using a dropper to apply the photoresist.

You can see the photoresist covering the wafer. Now, we proceed to spin coat the photoresist. I am closing the lid, and the vacuum is already on. All we need to do is press start. Inside, it's a bit foggy, but you can see through the glass lid how the wafer starts rotating, and the excess photoresist flies away due to centrifugal force, leaving a very thin layer.

This process takes about 60 seconds. The excess photoresist has flown off, and the speed will now gradually increase to 4000 rpm. The physics behind spin coating is very interesting, and you can read extra materials to learn how viscosity, temperature, and humidity affect the uniformity of the coating.

The thickness of the photoresist is critical in the photolithography process, which we will see next. Getting a uniform photoresist coating from the centre to the edge of the wafer is crucial. According to the datasheet, when we spin coat this specific photoresist at the recommended rpm, we achieve about 95% uniformity across the wafer.

So, now the spin coating process is done, and you might be able to see a very thin, rainbow-like film on the wafer, which was previously pure gold. Now, you might be able to see a rainbow kind of shade. That is created by the photoresist we have spin-coated. Now, we will take the wafer from here and shift it to the pre-exposure bake on the hot plate, okay? We will do that process. So, I am switching off the vacuum and taking the sample out, okay?

We will slowly shift it to the hot plate, which is maintained at 110 degrees Celsius, okay? We have to keep it here for 60 seconds. This step is very crucial because the excess solvent in the photoresist evaporates, and all we will have left is the photosensitive material and the cross-linking polymer in the photoresist. We will keep it here for 60 seconds and then move on to the next step.

So, I have taken the sample out of the hot plate after 1 minute, okay? Now, let's proceed with the lithography process using the mask aligner equipment. Now, I am going to load the wafer. As I explained earlier, we have a mask holder here.

First, we will open the mask holder. So, now I have opened it. The next step is to load the wafer onto the chuck that is here. This is, again, a vacuum chuck like the one we have in the spin coater. So, I have placed the wafer centrally in the chuck, okay? To prevent the wafer from moving around, I am switching on the sample wafer vacuum.

So, now the wafer cannot move, and it is sitting stably there. The next step is to load the mask. I am opening the photomask I showed you earlier. As I said before, this is a bright field mask, and if you think about it, the pattern is on the dark side, right? The chocolate-brown side, which has chromium in it. Since the light comes from the top, we need to ensure that this pattern side, or the brown side, faces the wafer.

I will load the mask onto the mask holder, okay? Once I load the mask, I press this button here so that the mask vacuum will be on, and the mask cannot move further. The next step is to close the mask holder so that we have the mask on top of the wafer, okay? Now, we will proceed to the alignment step, where you can see what is going on in the display here. Now, the machine has moved forward, correct? So, now the optics are aligned on top of the mask, and you can see two different images on the left-hand side and the right-hand side. I am just adjusting a few of the micromanipulators here so you can see how the image changes. The micromanipulator controls the microscope, which is viewing the mask, and you can see different patterns. I am adjusting the zoom so that you can see the different patterns on the mask. These are all different patterns; you can zoom in and see them. I told you earlier that this is an interdigitated electrode, okay? I am adjusting the illumination a bit, but it is still blurry. I am adjusting the focus, and now you can see finger-like structures, which are known as interdigitated electrodes.

On the other side, you can also take a look. We have two microscopes with cameras so that we can do the alignment. What you see here are the alignment marks, okay? These are also very essential. You can see different patterns. As I mentioned earlier, during the previous explanation, if we have multiple masks, we need to ensure they are well aligned.

We use different patterns like this. These are like vernier marks provided on the mask design to ensure good alignment, okay? These are all different patterns. Now, I am zooming out a bit and adjusting the illumination. Now, do you see a shadow there? A shadow is being formed under the pattern.

That shadow is the wafer. The shadow of the pattern has fallen on the wafer. When I move the wafer up, you will see less and less shadow, and when the wafer touches the mask, the shadow will completely disappear. In the process we are trying to do, we are going to do a proximal lithography, okay?

First, we touch the wafer and the mask so that they align completely. Then, we do something known as a wedge lock, okay, so that it remains in place. Next, we move the wafer down by around 50 microns, okay? Once that is done, there will be a small separation between the mask and the wafer, and then we can move on to the exposure step, which is the next step. The next step is the exposure step.

Now, I am going into exposure mode here. You will see that the equipment moves forward, okay? Now, the machine has moved forward into the exposure mode. Before exposure, you can see here on this calculator that if we press the shutter button, the exposure will start. Before that, you can set the exposure time that you want.

This is directly proportional to the dosage we need, okay? The dosage is the amount of UV energy we need to provide to the photoresist so that the pattern of interest will be developed. Our patterning will happen, and that information is available on the datasheet. For our equipment, we have calibrated the UV energy, and based on that, we need to apply around 4.5 seconds of UV exposure to get the pattern developed.

I have set it to 4.5 seconds, and now I will press the shutter button. You can see the UV light shining on the mask and wafer. After 4.5 seconds, the UV light will turn off, and the machine will move back, signalling that the process is complete. Now that the exposure is done, I am removing the mask holder lock so I can open the mask holder. Then, I turn off the sample vacuum so I can remove the sample from the chuck. Now, the exposure is complete, and the next step is to do the post-exposure bake, okay?

We will again go back to the hot plate, which is again maintained at 110 degrees Celsius, and we will bake it for around 60 seconds, okay? So, I am loading it now. Now, I am removing the sample from the hot plate since 60 seconds have passed, and the next step is the development process, okay?

We will proceed with the development now. I am placing the wafer in water for now and adding the developer solution. The developer reacts with the photoresist and removes the exposed areas of the photoresist since we are using a positive photoresist. This typically takes around 20 seconds, okay? I am moving the wafer from the water to the developer, and you can see some colour changes happening. That is the excess photoresist being stripped off.

This process will take around 20 seconds, okay. So, I am just taking out the sample to see if the exposure development is complete, and I am shifting it to the water. So, yeah, the development process is complete, okay. So, I am just going to show it to you. So, what you can see are the patterns that have developed properly on the gold, okay?

This is how the lithography step works and you can see the results. Now, the next step is to dry the sample, and then we can proceed to the subsequent etching step, which is the next step. I hope you liked the video. In this video, what have you seen? You have seen how to use photolithography in the yellow room. The purpose of the yellow room is to avoid UV exposure, right? You know that a photoresist is a photosensitive resist, that's why it's called a photoresist. So, it will get exposed to UV light in white light.

Thus, we need to have a yellow room. The yellow room avoids UV or white light. And what else have you seen? You've seen how we use photoresist and how we coat the photoresist at different spin rates. First, you need to coat the photoresist at 500 rpm, around that value, so that you get a uniform coating, followed by changing the rotations per minute. If you increase from 1000 to 2000 to 3000 rotations, the photoresist will get thinner. If you increase the time, the photoresist gets thinner; if you decrease the time, the photoresist will get thicker, right?

If you reduce the rpm, the photoresist will get thicker. So, the role of the spin coater and photoresist is what you've seen in this video. You've also seen how to perform the soft bake, how to align the wafer with the mask, how to expose it, unload the mask, take the wafer, develop it in the photoresist, and then inspect it. So, what do you do once you develop the wafer? You dip the wafer in the developer, take it out, rinse it with deionized water, and then dry it with nitrogen. After that, you inspect the patterns that are on the wafer, right? That's photolithography. So, I hope you liked this video and understood exactly what photolithography is and how we can not only perform front alignment but also front-to-back alignment, right?

We don’t just have to focus on front alignment, but also on front-to-back. This is very important when you talk about MEMS. If you're just talking about sensors in general, and those sensors don’t have a diaphragm for micromachining, then in that case, or the case of rotational things like micro gears, you don’t call that MEMS, right? We already discussed this in the first lecture when we talked about what MEMS are. This particular photolithography process can be used for sensors and MEMS-based devices, which include sensors and transducers. For transducers, sometimes you have to create a diaphragm. For sensors, sometimes you also need a diaphragm. The lithography step remains almost the same, except for how you perform front-to-back alignment. I hope you liked the video, and I will see you in the next lab video.