Microsensors, Implantable Devices and Rodent Surgeries for Biomedical Applications
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Lecture - 11

Hi, welcome to this lecture. As I promised in the last session, today we will delve into lithography, specifically photolithography, where photons are used to carve or pattern the material deposited onto the wafer. The term 'photolithography' originates from the Greek words 'photos' and 'lithos,' meaning carving from a single stone. However, in this context, we are not using stone; we are using a substrate. What are we carving? We are patterning different materials deposited onto the substrate. Therefore, the first thing we need to understand in photolithography is its step-by-step process.

We begin by taking a wafer and pre-cleaning it to remove any residual oxygen or oxide resulting from the atmosphere's oxygen reacting with the silicon wafer. Now, let's focus on the standard photolithography technique, where we use a silicon wafer as the substrate. When using silicon, if the silicon is stored in a lab and there is a native oxide present, the first step is to remove the native oxide using hydrofluoric acid because hydrofluoric acid is an etchant for etching the native oxide. After taking the wafer, the initial step is to pre-clean it. During the pre-cleaning process, DI water (deionized water) or DINS water (deionized non-silicate water) is used. Following pre-cleaning, the wafer needs to undergo pre-baking. Pre-baking helps in evaporating any water droplets or moisture present on the wafer due to the high temperature during the pre-baking step. After pre-baking, you may proceed with primer coating, although it's optional.

Now, why opt for primer coating? It's because it enhances the adhesion of photoresist onto the wafer. However, primer coating is not necessary every time. There's a difference when using primer coating, which often includes materials like HMDS. The primary purpose of photolithography, if you understand it, is to print precise features directly onto a wafer or by using photoresist. This can be achieved through direct printing or by utilizing photons. As mentioned earlier, we will focus on UV photolithography, although other techniques like X-ray photolithography, EB photolithography, and various others exist. Typically, the features on the top surface of any sample are patterned using photoresist through exposure to UV light.

Next, we will observe how this is accomplished through developing and etching. As mentioned earlier, we start by cleaning the wafer, followed by the prebake process and then applying the primer coating. After completing these steps, we move on to the photoresist spin coating process. Speaking of photoresist, what exactly is it? Well, it's a type of polymer, specifically a photosensitive polymer. This is why it's called photoresist—because it's sensitive to light. There are two main types of photoresist.

So, if I abbreviate photoresist as SPR, there are two main types: positive photoresist and negative photoresist. Let's delve into the details of negative photoresist. There are advantages to both positive and negative photoresists, and we'll discuss how they can be utilized. Once you've applied the photoresist or completed the spin coating of the photoresist, the next step is to perform a soft bake. Typically, a soft bake for common photoresists is carried out at 90 degrees Celsius for 1 minute on a hot plate. However, while the temperature remains the same, the process may vary when using an oven.

Yes, soft bake can also be carried out in an oven, but in this discussion, we are specifically focusing on soft bake using a hot plate. When performing a soft bake on a hot plate, the temperature is typically set to 90 degrees Celsius. As for the pre bake temperature, it can range anywhere from 100 degrees Celsius to 120 degrees Celsius, and again, we are considering silicon substrates. So, the sequence of steps includes wafer cleaning, prebake, primer coating, followed by photoresist spin coating, and then the soft bake process. After soft baking, the next steps involve using a mask for alignment and exposure.

Now, let's understand these terms regarding photoresist, both negative and positive, and how they work, as well as how the mask appears. But first, let's discuss how the wafer looks. Please bear with me as I put on gloves to handle the wafer; this is to ensure there's no contamination. There we go. Now, if you could focus on the substrate instead of the slide for a moment, that would be great. Thank you. What I'm holding here is the wafer. You can see it in my hand, and this side is the polished side. How can we tell? Well, you can see the reflection, almost like a mirror finish. If I turn the wafer or place something on it, you can clearly see the reflection, demonstrating its polished surface.

If you turn it, you'll notice this is the unpolished side. Can you see the tweezer now? It's very difficult to see, right? This is the unpolished side. So, the polished side, polished side here, unpolished side — that means it's a single-sided polished wafer. To hold it, there's a tweezer. I'm using the tweezer to hold the wafer. You should not use your gloves to hold the wafer; sometimes it's okay, but I'm just saying that it's better to use tools to hold your wafer as much as possible. Now, there's a proper way to hold the wafer because if it falls, it will break. Here you can see there's a primary flat and a secondary flat. You might not be able to see the primary flat clearly, but if I lift it a bit, you'll notice that it's not circular; there's a flat area here. The same goes for the bottom; there's a small flat area here. So, this wafer isn't perfectly circular; it has flat areas. The secondary flat, which is smaller than the primary flat, is generally smaller.

So, now I am putting the wafer back. This is about the substrate, silicon. This was a 4-inch silicon wafer, 4 inches in diameter. Now let me show you the mask, and then we will go back to see why we are doing all these things so that we understand the role of this mask and the role of the photoresist and how we are going to use it. The mask that I am holding is a bright-field mask. See, you can see through the mask; isn't it interesting? So, this is a bright-field mask, and if you look a little further or with focus, you can see some patterns. There are two patterns here. So, you see, there are some patterns on the mask. Can you see them clearly now?

So, these patterns within the bright field, within the field, the patterns are there, right? So, this is called a bright-field mask. A mask that is bright-field is bright, and the patterns are dark. Bright-field mask, easy. Now let me show you the dark-field mask. It will be even easier for you to understand. And we will use this bright-field mask and dark-field mask while we are going to fabricate these implantable devices for the brain.

We are not straying away from what the course is all about, but these are some of the important steps you need to understand before you can fabricate these neural implants, okay. Now, look at the mask that I am holding. Can you see? So, most of the area is dark, but the patterns are bright. It's kind of okay. So, most of the area—no transparent things are there, these are brighter field patterns. So, the area is dark, the patterns are bright; it's called a dark-field mask. When the field is dark and the patterns are bright, it's called a dark-field mask. Conversely, when the field is bright and the patterns are dark, it's called a bright-field mask.

By simply examining the mask, you can distinguish between what constitutes a bright field and a dark field, okay? This appears to be a bright field at first glance, and while it still retains that appearance, there's a possibility, albeit uncertain, that it might not be one. An easy way to grasp this is that everything appears dark except for the patterns, which are brighter, allowing for clear differentiation. A dark field mask can even appear darker due to its fewer discernible patterns. However, to quickly convey this concept, let's clarify that this is indeed a bright field and a dark field mask before proceeding to the next phase. Now, let's delve into the patterned wafer and examine how it appears after the growth of silicon dioxide, gold deposition, and subsequent patterning. I'll show you this, so please take a look. Here, you can observe several devices on a 4-inch wafer, correct?

So, here we have an oxide layer onto which gold is deposited, and patterns are formed, resembling a microchip, correct? It shares similarities with a semiconductor microchip, but we're focusing on devices rather than circuits. We're not discussing ADCs or op-amps. Instead, we're exploring devices like microheaters, sensors (including integrated sensors, thermistors, force sensors, and temperature sensors), interdigit electrodes, and many other possibilities using semiconductor technology within a semiconductor fabrication lab process. While we're not claiming to fabricate a complete circuit, the overall process remains quite similar to silicon-based circuit fabrication, with shared techniques such as thermal oxidation and deposition methods. The beauty of understanding microfabrication lies in its versatility; once you grasp the fundamentals, you can apply them across various domains such as agriculture, space exploration, healthcare, semiconductor fabrication, and beyond.

Let's stay focused on our topic of understanding photolithography without getting sidetracked, even though I'm passionate about microfabrication technology. Continuously discussing other topics might lead us away from our main goal of grasping photolithography. It's crucial to note that once you've used gloves, they should be discarded and not reused. Similarly, after using masks, they should also be disposed of properly. Therefore, please remember not to reuse gloves but to discard them after use. During this demonstration, I'm showing you these steps, but in a real fab lab environment, you'll need to gown up properly. Detailed instructions on gowning procedures and lab protocols can be found in the recording.

I aim to provide you with real-life experience, simulating your presence at IISc, attending a specific course and conducting lab experiments. My goal is to make this experience as realistic as possible using the NPTEL platform. However, please note that there may be some gaps, and I apologize for any inconvenience caused. Let's continue exploring further to understand the concept of photoresist and the advantages of using it with masks.

So far, we have covered positive photoresist and negative photoresist. Next, we will delve into how positive photoresist is utilized and how negative photoresist is utilized. Specifically, we will explore what happens when using a bright field mask or a dark field mask with positive and negative photoresist, which we will discuss in a subsequent slide. For now, let's focus on the sequential steps: wafer cleaning, pre-bake, primer coating, photoresist spin coating, soft bake, and alignment. I'll demonstrate what alignment entails briefly to avoid any confusion with the terminology used.

Let me demonstrate the concept of alignment to you. Here, we have a mask, specifically a bright field mask. Now, consider this as an alignment mask, and let's discuss its role. Imagine these patterns on the bright field mask.

Now, assuming we have a wafer that has been spin-coated with photoresist and undergone soft bake, we move on to the alignment process. Here, we place the mask on the wafer in such a way that a specific pattern, like this triangle, is positioned centrally on the wafer. This initial alignment step is straightforward, but if we introduce another mask, aligning it becomes more complex.

These are your alignment marks. So, we call them alignment marks, and how this is spelled correctly is ALIGNMENT. So, alignment marks are there, and then you align this with respect to the wafer. Now, for the one mask, this process is fine. What happens if you have one more mask? Let's say you have one more mask.

So, let me draw one more mask, and in this mask, I am having a circle like this. This is my mask 1, and this is mask 2. Now, once you align this, let's say you align here, and then exposure. So, when there is UV exposure, what will happen is you have to take out the mask and develop the wafer. Develop the wafer; the wafer is this silicon wafer.

The silicon wafer, when you say develop, is where you are actually developing the photoresist. So, after the photoresist developer, certain areas will become stronger, while others will become weaker. Then you perform the hard bake, which is at 120 degrees Celsius for 1 minute on a hot plate, and finally, inspect the wafer. Now, let's go through each step so that we understand, and I will show you what I mean by alignment, development, hard bake, and pattern inspection.

Firstly, let's talk about photolithography as a term. Photolithography is derived from "photo" and "litho" and "graphic." It's a single term, photolithography. Now, let's start with a silicon wafer. The next step is to clean this wafer and then pre-bake it. After pre-baking, you spin-coat the photoresist.

So, I've spin-coated the photoresist, assuming it's a positive photoresist. After spin coating, you can either apply primer coating and then spin coat the photoresist or directly perform the spin coating of the photoresist. Following the spin coating of the photoresist, the next step is the soft bake at 90 degrees Celsius for 1 minute on a hot plate. Once this is done, we have our photoresist, which has undergone the soft bake process.

Moving on to the next step, as we discussed in the previous slide, it involves alignment and exposure using the mask we've seen. Now, let's align the mask with respect to the wafer. These are bright field masks, and this represents our positive photoresist, while this represents our silicon wafer. The process involves alignment and exposure, specifically exposure with UV light.

After the exposure step, the next action is unloading the mask and proceeding with the development process. However, it's crucial to note that you cannot develop the entire mask while it's loaded. So, you need to unload the mask and then immerse the wafer in the photoresist developer solution. This step involves developing the photoresist. When you unload the mask and dip the wafer in the photoresist developer, a specific reaction occurs. The areas of the photoresist that were exposed to UV light become stronger or hardened, while the unexposed areas remain relatively weaker or softer. Let's denote these areas as 1, 2, and 3, where 1, 2, and 3 are the unexposed regions.

In the case of positive photoresist, the unexposed areas become stronger while the exposed areas become weaker. This results in a patterned photoresist layer, where the unexposed areas are stronger and more resistant. Regardless of whether we use a bright-field or dark-field mask with positive photoresist, this behavior remains consistent. Now, let's introduce a variation. Instead of using the regular positive photoresist, let's consider a modified version denoted as "A star". This modified photoresist is still applied on the silicon substrate, but it behaves differently.

Let me illustrate this scenario by drawing a box. Here, instead of using positive photoresist, I'm opting for negative photoresist, designated as A. Whether we use a bright field mask or a dark field mask doesn't significantly impact the choice between positive and negative photoresist. However, it's important to note that the selection of the mask type depends on the specific pattern requirements, not on whether we're using positive or negative photoresist. So, in this case, we're working with negative photoresist (A) instead of the positive photoresist we discussed earlier (A star). The next steps involve exposing the negative photoresist to UV light and then developing it. After unloading the mask, we proceed with the development process to reveal the desired pattern.

Now, let's consider B as the counterpart to B star. When working with negative photoresist, regions 1, 2, and 3—those that remain unexposed—become weaker. This is a notable difference compared to positive photoresist, where unexposed regions become stronger. This contrast highlights the unique behavior of positive and negative photoresists. Another way to express this is that with positive photoresist, the unexposed region strengthens, while with negative photoresist, the unexposed region weakens. Some textbooks may also describe this as the exposed region weakening or strengthening, depending on the type of photoresist used. To summarize, positive photoresist strengthens the unexposed region while weakening the exposed region, whereas negative photoresist does the opposite by weakening the unexposed region and strengthening the exposed region.

So, as we examine the exposed regions (1, 2, 3, and 4), we can see that in the case of negative photoresist, the pattern shifts. The exposed regions become stronger, while the unexposed regions become weaker. This contrast in behavior is characteristic of negative photoresist. Conversely, with positive photoresist, the opposite occurs: the unexposed regions strengthen, while the exposed regions weaken. I trust that this clarifies the distinction between positive and negative photoresists for everyone, showcasing how they behave differently in terms of region strength and weakness.

Now, let's focus on positive photoresist after development, which brings us to the next step. It's crucial to understand that lithography, especially photolithography, is often referred to as the heart of microfabrication. Mastering photolithography simplifies patterning wafers, making various device fabrications easier, whether it's for implantable neural applications or something as straightforward as a micro heater. This segment of the course is elaborated upon because it's highly relevant for fabricating devices, particularly neural implants. Moving forward from development, our next step is... Where were we? Ah yes, we loaded the mask, exposed the photoresist through the mask using UV light, unloaded the mask, developed the photoresist with the developer, and achieved the final pattern of the photoresist.

The next step in the process is the hard bake, which we will cover in the next lecture. Until then, take care, and I'll see you in the next class. Goodbye for now!