Microsensors, Implantable Devices and Rodent Surgeries for Biomedical Applications
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Hi, and welcome to this lecture. Now, if you remember in the last lecture, we took an example of lithography and how to pattern aluminum using a standard lithography process. We also looked at why PECVD can be used for materials like aluminum, which have a lower melting point. From the given CVD techniques like LP CVD, MO CVD, and PECVD, why do we choose PECVD? The reason is that at lower temperatures around 100 degrees Celsius or 200 degrees Celsius, we can deposit materials like silicon dioxide, silicon nitride, and so on. Additionally, I mentioned that we would explore etching techniques for creating a diaphragm.

There are multiple etching techniques: wet etching and dry etching. Wet etching requires chemicals, while dry etching requires gases. Wet etching can be isotropic, depending on the crystal orientation, and can also be anisotropic. On the other hand, dry etching can be isotropic or anisotropic, with anisotropic dry etching relying on plasma or being process-dependent. Generally, we use fluorine blaze plasmas for anisotropic dry etching and BrF3 and XeF2 for isotropic wet etching and alkaline etchants for anisotropic wet etching, while acidic etchants are used for isotropic wet etching.

Before we delve deeper into etching, it's essential to understand terms such as aspect ratio, selectivity, etch rate, etch profile, and isotropy. The aspect ratio refers to the ratio of height to lateral dimensions of the etch microstructures. Selectivity is the ability of the process to choose between layers to be removed and interleaving layers.

For example, assume this material is a photoresist. After curing the photoresist, exposing it to UV light, developing it, and hard baking it, we get the desired pattern. If we then dip the wafer in SiO2 etchant (hydrofluoric acid buffer), the SiO2 layer will etch, but the photoresist will protect the layer below it. Although it's incorrect to say that the photoresist doesn't get etched at all, its etching rate is much lower than the material being etched using a particular etchant.

So, in this case, the etching rate of silicon dioxide is much higher compared to the etching rate of photoresist. Thus, photoresist can work as a mask, or you can say that the selectivity of the photoresist is better. Etching rate refers to the speed at which the process progresses, and the etch profile is the slope of the etch wall. As you can see here, this is the etching rate, indicating how fast the material is etched from the standard even thickness of the substrate. N Isotropy refers to,

$$\text{N isotropy} = 1 - \frac{rlateral}{rvertical}$$

How much lateral etching occurs versus vertical etching occurs, right? So, this is the N isotropy that we can define, okay.

So, these are some of the terms that you need to remember. Let us understand some of the fundamentals, okay. So, there is chemical etching, there is physical etching, and then there is a combination of both chemical and physical, okay. So, the selectivity, etching rate, and damage to the material— if you take these three parameters— then chemical etching is isotropic etching, as you can see from the figure here. Sputtering can also be used to take out the atoms.

By bombarding the ions, the atoms are dislodged, and that will result in anisotropic etching. So, we will see different anisotropic etching processes. Similarly, there can be reactive ion etching, which is an isotropic etching, anisotropic etching, and if you compare all three—this is the third one, this is the second, and this is the first one or you can say, this is the first one here. Then the etching rate of the chemical etching is higher compared to the remaining two, selectivity is high compared to the remaining two, and damage is low compared to the remaining two. So, when I say remaining two, I mean the second and third processes; we are comparing them with the first process.

Now, this is isotropic etching. You can see an example when you etch this particular material—either it is isotropic, it can be directional etching, or it can be vertical etching, which is the ion isotropic etching. So, in the sputtering process or physical sputtering, which is an ion mill plasma sputtering, the ion isotropy is extremely high, the pressure required is low, less than 10 milliliters, the selectivity is poor, and high beam energy is required to dislodge the atoms from the substrate. One case of plasma etching—low anisotropy, high pressure, very good selectivity, and low beam energy. One case of RI, which is a dry etching technique—again, all three are actually dry etching processes—physical sputtering or plasma etching or reactive etching are the dry etching techniques, and when you use chemicals, it becomes wet etching techniques. So, for wet etching, suppose you are going to etch silicon, then for silicon, you have two different wet etchants, one is TMS (tetramethylammonium hydroxide), the second is potassium hydroxide or KOH.

KOH is used at 80 degrees Celsius to average under room temperature. This is neurotoxic and the walls are smooth, while here, the walls are rough. So, these are some quick understandings about if I go for wet etching, which chemical to use and what are the advantages of using that particular chemical. So, in silicon etching, we can use two different chemicals. When it comes to wet etching, KOH and TMAH each have their own advantages or limitations. Now, if you want to know how the etching is done, it is like everything: 100 silicon with a square mask film opening oriented parallel to 110.

So, you can see that when you open this window and you want to see if the final etching depth or the base is ω_b then what is the opening window ω_0. So, then if you want to calculate that then this is the equation that the final width or the window that you get is the $\omega_b = \omega_0 - \frac{2}{cot\,54.7}$, 54.7 is a degree that is created while you etch the 1 0 0 oriented silicon wafer. And the cavity is defined by the 1 1 1 direction planes and this plane suddenly the etching is slower compared to 1 0 0 which is a floor plane with fast etching and final shape depends on the mask geometry etching time and the shape of cavity can be truncated pyramid, and wagrou or pyramid.

So, the inlet and outlet where gasses that are used for plasma etching are argon CF_4 and O_2. So, the RF frequency is 13.56 megahertz the plasma contains positive ions and neutral species which is bombarded on to target layer and then when they are bombarded in target layer the ions bombards the target layer and the atoms are dislodged from the material and thus creating the etching. This process is highly directional, but it is only physical process selectivity is poor right. So, to overcome the problem related to selectivity chemical processes are to be introduced.

So, reactive ion etching is used to achieve directional etching with good selectivity. Now, in the case of plasma etching, only gases are used as you can see here, right, but if you go for some chemicals, of course, you can have this as chemicals also. But the point is that if you add the chemical etching, then the selectivity will improve over just using the plasma. So, for etching photoresist, O_2 or so, that is why these chemicals are used. So, oxygen is used for etching photoresist, or you can say oxygen plasma system, then for other materials halides such as Cl_2 or CF_4 and HBR are used, and sometimes H_2O_2 and AR may be added to the etching process. These are mechanisms by which you can etch the material, as you can see that there is a free radical created, and then that will either dislodge the atom or will react with the film or will adsorb from the film.

So, if it is dissociation, then you can see that CF_4plus electron, you see F_3 plus fluorine plus electron, this dissociative ionization, then we have ionization, then we have excitation, and we have recombination. So, there are several ways in which the typical reaction and this is present in plasma, and the plasma etching is shown. So, in a way, we have 4, 5 main reaction processes. One is dissociation, the second is dissociative ionization, the third one is ionization, the fourth one is excitation, and the fifth one is recombination. Just to understand again, do not worry too much about the equations, but there are 5 different types of processes. Now, if you talk about reactive and etching particle, there are chlorine etchers, there are fluorine etchers, and in the case of the chamber, it looks almost kind of similar whether you are using chlorine or fluorine as a gas. These are the reactive and etching systems, and you can see again here that there are electrodes, the process gases pass through the chamber. Initially, the vacuum is created, helium is used for the backside cooling because the plasma will heat the substrate, and if there is a material on the substrate, that will also get heated. We have to be selective and be careful that the material is not too much heated so as to create other reactions or also it should not get affected.

There is RF power, so we are using the 13.56-megahertz frequency, and then finally, the byproducts are sent through the pump to the outside or exhausted. So, reactive ion etching is a combination of physical etching and chemical etching. A high and controllable anisotropic etch rate can be obtained as it includes chemical reactions to etch; the selectivity of reactive ion etching is extremely high, okay. So, that is the advantage of RI. The etching gas is introduced into the chamber, RI power is used to generate plasma, reactive species are generated in plasma.

The radicals help in chemical reactions, and ions are used to bombard physically. You can see here the plasma; the ions are bombarded onto the substrate, and when the bombardment occurs, the reactive species diffuse onto a sample and are absorbed by the surface; the chemical reaction occurs and the reactant species create volatile byproducts that are exhausted from the chamber. So, it takes the atoms reactions and then it takes out and is exhausted through the pump here. So, this is the inlet input or inlet, this is the outlet. So, again let us understand the reactive ion etching process.

So, in RI, the etchant reacts with the target material, and alongside with the volatile byproduct, an inhibitor layer is also deposited. Inhibitors are the etch byproducts that impede further reactions, okay. So, you can see here there is a mask film; first, it is etched, then the inhibitor layer is deposited, then again it is etched, again the inhibitor layer is deposited, again it is etched, again the inhibitor layer is deposited. This keeps on forming, right? Why? What is the role of the inhibition layer? So, that the side walls are protected; you see the side walls are protected, and only the etching area, right, generally keeps on etching further down like this in a vertical direction. Lateral direction, the walls are kind of protected.

So, ions are bombarded to that inhibitor layer at the bottom of the profile to remove it, and that helps in further downward etching as inhibitors are removed from the side walls, lateral etching can be stopped, as I already told you. Inhibitor deposition rate may be fast compared to the etch rate or may be relatively slow compared to the etch rate. So, again on the left side, which is this particular process, right, let us say this process is process number 1; the inhibitor deposition rate is faster while in the case of process number 2, the etching rate is faster compared to the inhibition rate. So, you have a different final profile; okay, this is number 2. Now, we talked about reactive ion etching; what about deep reactive ion etching? In deep reactive ion etching, the etching helps in etching a structure with a high aspect ratio; very important, okay, and the process uses a switched-case scheme that includes both passivation and etch step.

So, once etching is, of course, then a passivation layer is formed; again, there is an etch, hence commonly known as a Bosch process. A typical DRA system consists of an inductively coupled power source to provide high-density plasma. It also has an independent substrate power bias to etch directional ion bombardment during the step. Finally, it is a protected layer of polymer formed with the help of C_4F_8, also called octafluorocyclobutane, and this is the case used for the passivation step, and it deposits on the substrate in a conformal manner, similar to PECVD. This is followed by the etch step by a controlled flow of SF_6. SF_6 is called sulfur hexafluoride, and that is the material to etch the silicon. So, if you see during this step, the side walls of the silicon trench are relatively protected by C_4F_8 - induced polymer layer, but the bottom layer is scratched etching. So, the bottom of the trench is also coated with polymer, but the directional ion bombardment removes the layer, and then etching takes place by means of the reaction.

The iterations of this passivation cycle etch cycles allow the desired and separate features to be etched. You can see here silicon; then we use SF_6 to etch; then we have C_4F_8 as a passivation layer, which is here C_4F_8 SF_6, and then we keep on doing it again SF_6 again C_4F_8, sorry, C_4F_8 then again SF6 and so on and so forth, okay, and so on and so forth. So, you keep on etching the silicon in this direction and create the protecting layer on the walls of the etchings. So, if you want to compare wet versus dry etching, wet etch processes can be batch processes. Dry etch is a single wafer or few wafers process at one time. Wet etch processes are limited to a feature size of 3 microns; fine etch feature size can be processed in the case of dry etching because wet etch is very fast, okay. So, it is difficult to have a few nanometers of etching; wet etch can be used to remove sacrificial layers present in MEMS devices, and we will take an example well, in the case of difficult to fabricate sacrificial layers using MEMS device it can be used for photoresist stripping; wet etching is also used for resist stripping. So, both can be used finally; wet etching is low cost because you are using chemicals; it has a good throughput because we can use many wafers at a time; it has good selectivity.

However, if you want to get a highly anisotropic etching, then you can go for dry etching. It is costly, but the output or throughput is average because you can use only one wafer or a few wafers at one time, okay. So, with this thing, we will stop, and I will quickly show you how the wet etching, how the dry etching creates a diaphragm, and in the case of surface micromachining, how you can create a diaphragm. So, bulk and surface micromachining I will talk about briefly in the next class before diving into the fabrication of neural implants. So, till then, I will see you in the next class, and we will talk about neural implant fabrication. Bye.