Advanced Neural Science for Engineers
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Lecture 30
Fabrication of Neural Implants

Greeting, students. Let us welcome to the NPTEL course on Advanced Neural Science for Engineers. My name is Sreenivas Bhaskara. I am one of the TAs of this course.

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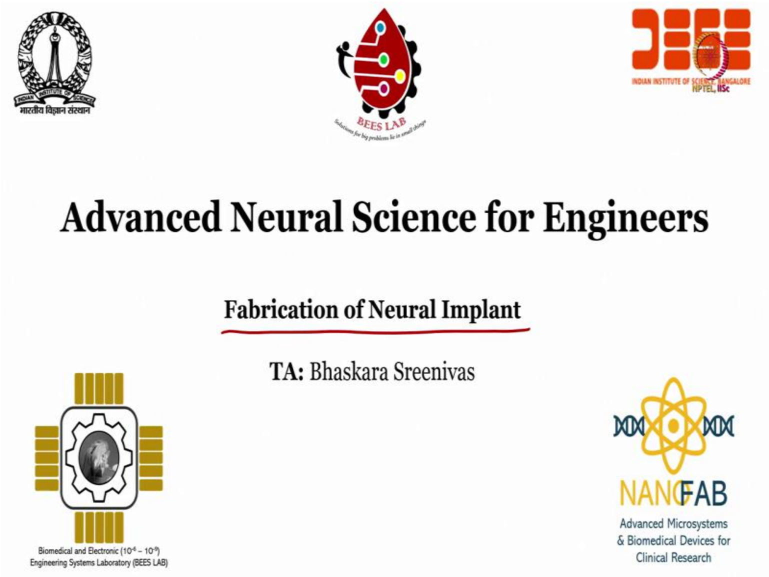

Advanced Neural Science for Engineers

Fabrication of Neural Implant

TA: Bhaskara Sreenivas

So let us look at, we discussed about neural implants, like in the last lecture about design phase and specifications and all it. Let us look at how it is fabricated, that is the first step, how the fabrication is done. So what we will do is we will discuss about neural implants and we will talk about little bit of electronic systems. Then we will talk about characterization and all those things. So let us see one by one.

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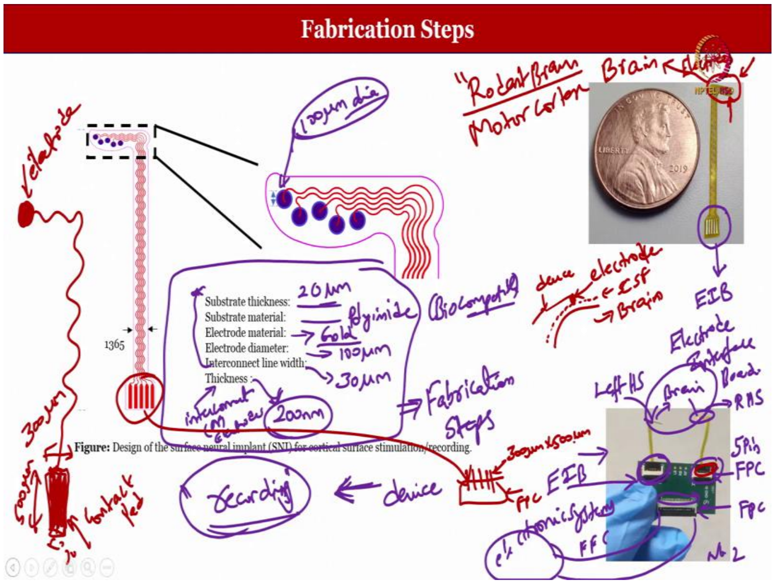


Fabrication Steps

Substrate thickness: 20 µm

Substrate material: Polyimide (Biocompatible)

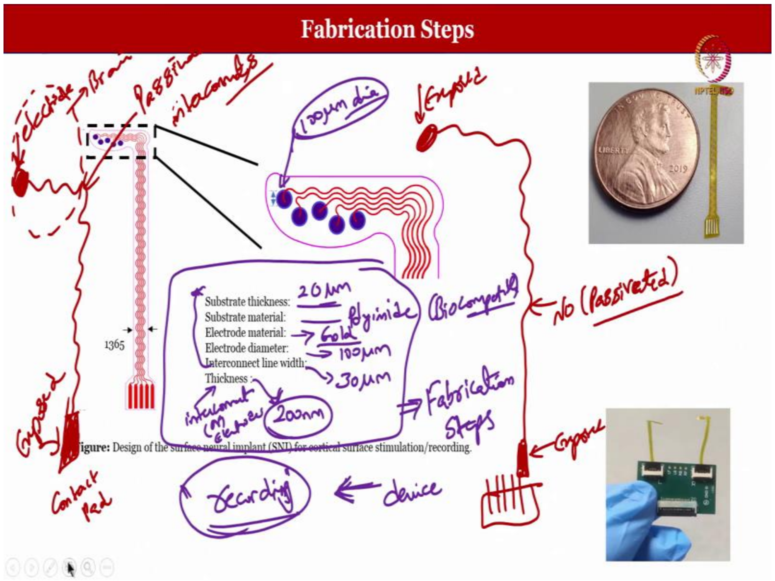
Electrode material: Gold

Electrode diameter: 100 µm

Interconnect line width: 30 µm

Thickness: 200nm

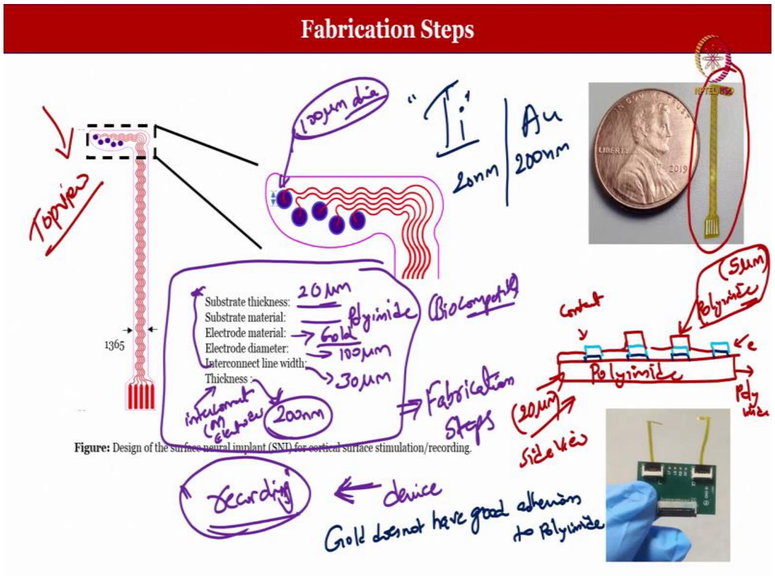
Figure: Design of the surface neural implant (SNI) for cortical surface stimulation/recording.



Fabrication Steps

Substrate thickness:
Substrate material:
Electrode material:
Electrode diameter:
Interconnect line width:
Thickness :

Figure: Design of the surface neural implant (SNI) for cortical surface stimulation/recording.



Fabrication Steps

Substrate thickness:
Substrate material:
Electrode material:
Electrode diameter:
Interconnect line width:
Thickness :

Figure: Design of the surface neural implant (SNI) for cortical surface stimulation/recording.

Now, this is what we have discussed in the last lecture that the design and then what are the different conditions that may impose to restrict your design to few things. And if you look at this, actually, this is what I have fabricated here at IISc, and thanks to our facilities and all those things that are available. And if look at it, these are the dots, that you can see, which are highlighted here.

I am sure, I am not messing it up. So, here you see this now, follow the arrow like the dots, those are all electrodes. Those are electrodes. And if you can zoom in a bit, you can have a fine tuning, if you see. If you follow it, there are some serpentine shaped interconnects. Are you getting it?

And they are not shorted, they are separated by some distance of around some 50 micron or something, and there are five shapes.

And one can count it easily. And if you look at the other one, other side. One is electrodes actually and those electrodes, these electrodes are there. This part will go to the brain. What is the brain that we are talking about? This is a rodent brain, okay? It is not a human brain. This is rodent brain. And specifically, what is that Motor Cortex. That is this side, this part which is highlighted or which is encircled with, what is this colour, dark red. Then what about the other side, what is this? This side will be going to EIB. What is that EIB stands for?

Electrode Interface Board. You can see that here. Now, you look at this figure. Okay, let us say this is figure number 2. Now, in the figure number 2, you have these electrodes here, and you see this connector, this is called as FPC connector, and this is also FPC connector. This is 5-pin FPC. This is, I think 20-pin FPC, the one can see. There are 20 pins you can accommodate. So actually, what is idea is here we are having two microelectrodes arrays or a neural implants. We can also call it as microelectrodes arrays.

This is array of electrodes. Now, this is on the left hemisphere. This is for the right hemisphere. And that is how the electrodes, this will go to the brain. This will go to the brain, and the other side will come to the FPC connector of the EIB. And of course, this is only EIB, do not get confused. That is it. Electrode interface board. From this, there is a FFC cable. That will connect to electronic systems. I understand, now what is missing here is just a brain, if you put a rat's brain, then our circuit is going to be complete.

Now, if you look at the electrodes, these only the electrodes, the dots, the five dots, there are five circle. Just a minute, I remove this part. So these dots are there, five electrodes. That should touch the brain tissue. So let us say there is a brain. Let me take another colour. I am just giving you the emphasis of this device such that the fabrication will look easy. There is a brain and there will be some CSF and all those things. Cerebrospinal fluid, if I am right.

On top of that your electrode is going to come. This is a device, and electrode is going to sit. Now, only this electrode should touch this part. Our electrode must come in contact with the brain and CSF. And if you look at this actually, so you have electrode and there is a serpentine shaped interconnect. Why serpentine shape? Just guess it. Because, you will be using this device during fabrication, during the implantation. And there will be bending and all those things will happen.

Suppose if there is a straight line like this. There is a chance of breaking it when you try to bend the device, because this is a flexible device. And you can bend it also. And then in next slide, I have some photo to show you, how does that look like? When you bend that then when it is straight, when interconnect is going to be straight, then there is a chance of breaking it. So we do not want to do that. So we will use serpentine shape to accommodate those traces and all those things. That is one of the reasons.

There are multiple other reasons as well. I am just giving you briefing in one. Now, this is electrode. This is electrode, and this is a contact pad. Now, this contact pad, so is, typically this width is around, you know, I will write here. This width of this contact pad is around 300 micron. This is 500 micron, something like that. Now, once who is, one who is familiar with these FPC connectors, they might have already guessed it, that FPC connector dimensions are whatever the FPC connector has the dimensions with, I mean the connector.

This is FPC connector and the contact pad dimensions are exactly the same, 300 by 500. 300 by 500 means when I say 300 width and then 500 length, something like that. Now, we designed this contact area, contact pad area according to that will match the footprint of this FPC connector. That is one of the criteria. This also important, which connector you are using and all those things also plays a major role. Now, this electrode area and this contact pad area, let me erase the other things right now.

So after establishing enough understanding on this, let me erase the ink. Okay, let me erase all the ink. So you have electrode area. This is electrode. And there is interconnect. And there is a contact pad area. This is contact pad. Now, the question is when you are designing something, should I expose this electrode area? Or should I expose the interconnect area? Or contact pad area? Or should I expose only something or not something or something like that? Now, one question is, where are you putting this electrode?

You are putting it over a brain. There is a brain, on top of that you are putting this. Now, only this electrode should pick up the signals from this particular area of interest. So what we generally do is, we passivate. Passivate interconnects. And what about contact pad? Should I expose the contact pad, when I say expose the contact means what? Should I make it available or should I passivate away it with something? So the entire interconnection understood, we have to passivate that and the contact pad, again is to be exposed means that contact needs to be available.

Why? Because this, I told you already, FPC connector has five contact pads, and this pad should touch this. This pad should touch the pad of this. Means this should be exposed and this electrode area should be exposed. Interconnects? No. That means it has to be passivated from electrical connection. So now, what is going to be here is this, so let me erase all these things.

I established most of the conditions of designing it. So the base material that is substrate is going to be polyimide. So if I draw the side view, so the base material is going to be, this is polyimide. On top of this, what is going to be, let me take blue colour on top of this. Let me rewrite the dimensions a bit because it is very, very important too. So you have a polyimide layer. This is a bottom layer. Here is a top view. This one is a top view. Now, for the same thing, I am writing a side view here, side view. Now, what is this material? This is polyimide.

Then on top of this, you have something colour, say gold, you need to have gold. But one more thing is you cannot have gold directly. Because, gold does not have good adhesion to polyimide. So what we use is we use the intermediate material called titanium, Ti. So first we will have titanium a bit, let us say 20 nanometre, thick titanium, then followed by 200 nanometre gold. Now, this is fine. So you will have a bit of titanium.

Then on top of that the gold is going to coming. Now, on top of this, is it? No. Right? On top of this, you have to passivate some areas, like wherever the interconnects are there, you have to passivate. Let us say this is interconnect area, you have to passivate. And let us say this is electrode area and this is a contact pad area. Just think like that, okay? Do not get confused, we will just think about it a bit and remaining else everything should be passivated.

Only the electrode area which is going to attach the brain and the contact pad area, I know it is little bit difficult to contemplate, but the thing is understand. Some areas will be exposed, some areas will not be exposed. So we have to have a provision for that as well. So these are the different stack of layers that you can see. Polyimide is there, titanium is there, then gold is there.

Then you will have something called as again polyimide as a passivation layer. Let us say this polyimide is around 20 micron.

This passivation layer is around 5 micron. So if you increase the thickness of the polyimide for a passivation layer, then obviously what happens is, you are going to distance yourself from the tissue, the electrode and the tissue. It is very difficult, we will try to maintain the polyimide thickness for a passivation layer as small as possible. And you look at it, that this is how it looks like from the top view.

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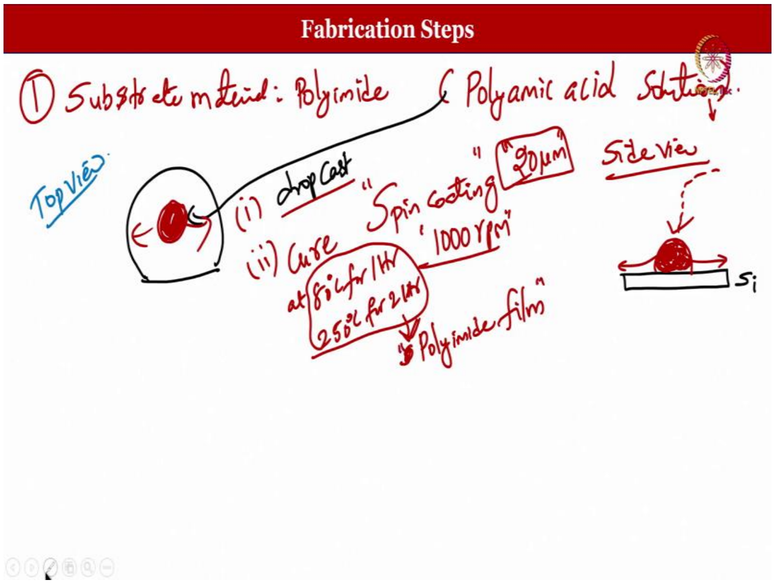


Fabrication Steps

① Substrate material: Polyimide (Polyamic acid Solution.

(i) drop Cast

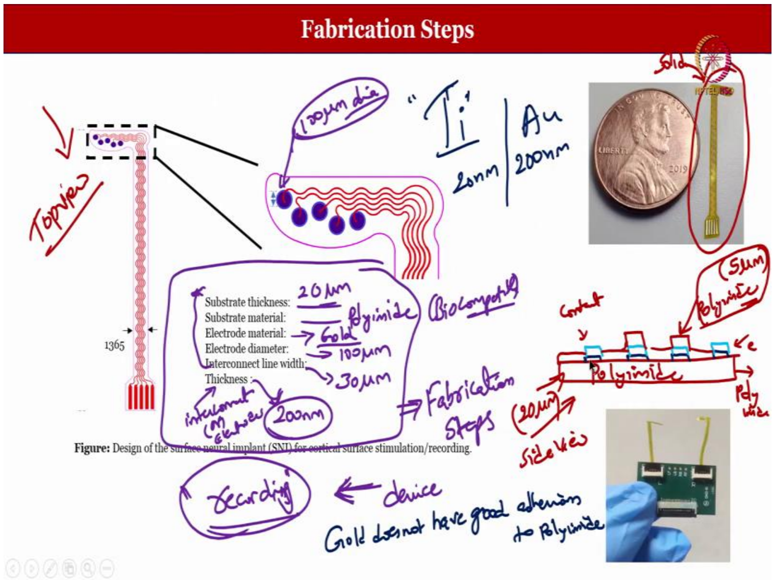
(ii) Cure

"Spin coating" "20 µm"

'1000 rpm'

at 80°C for 1 Hr
250°C for 2 Hr

"Polyimide film"



Fabrication Steps

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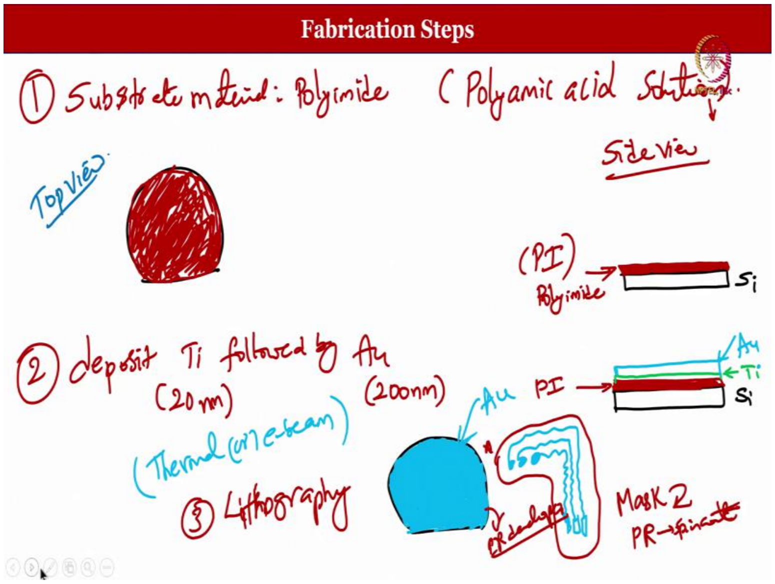
Figure: Design of the surface neural implant (SNI) for cortical surface stimulation/recording.

"Ti" 20 nm | Au 200 nm

Gold does not have good adhesion to Polyimide

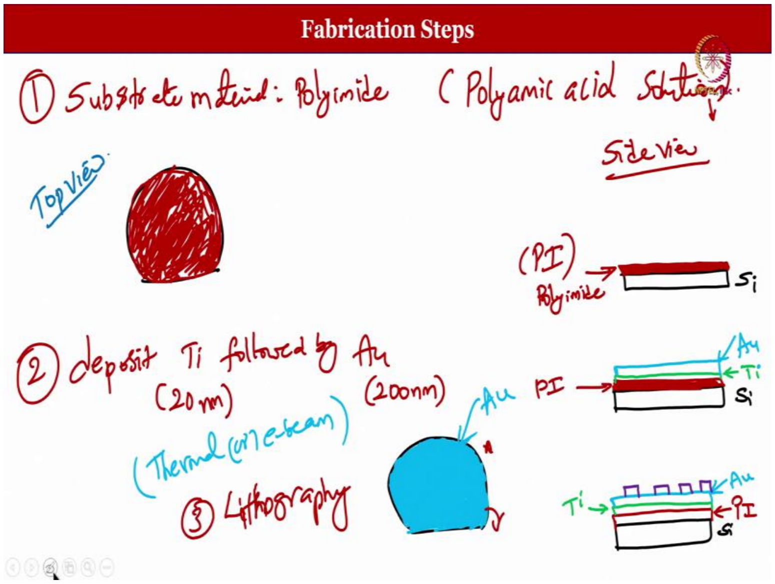


Fabrication Steps

① Substrate material: Polyimide (Polyamic acid Solution.

② deposit Ti followed by Au
(20 nm) (200nm)
(Thermal (or) e-beam)

③ Lithography



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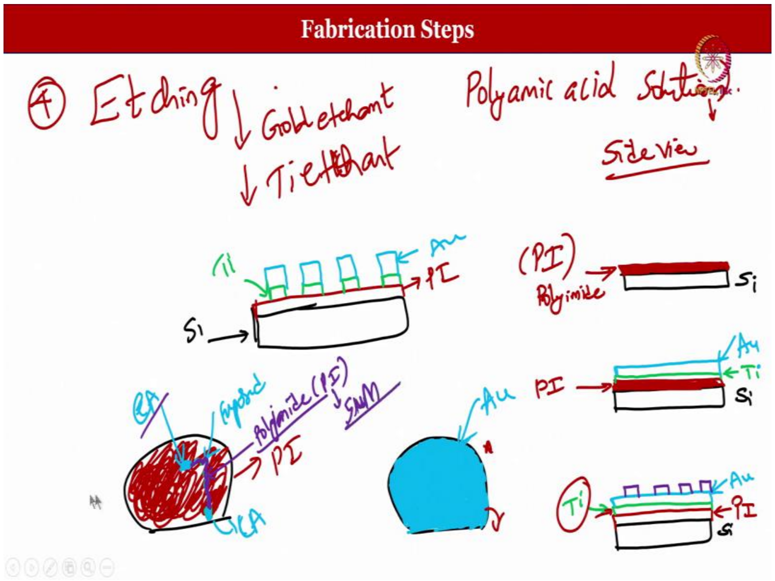


Fabrication Steps

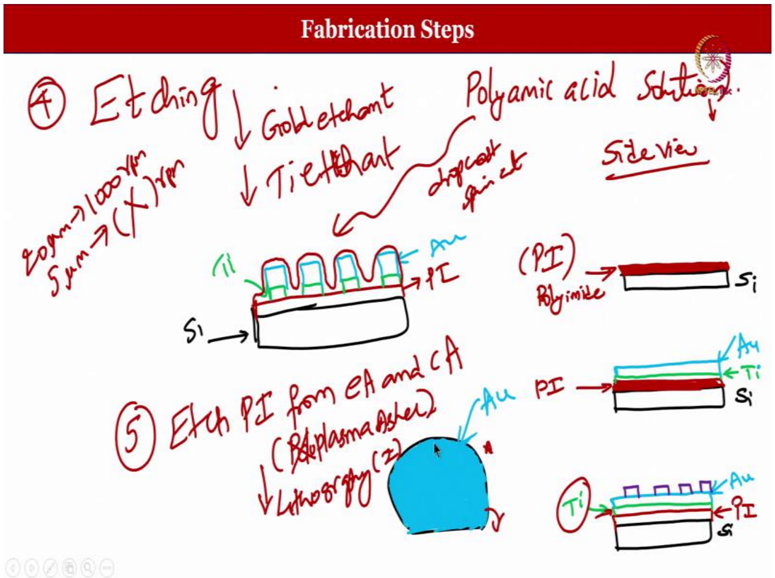
④ Etching

↓ Gold etchant

↓ Ti etchant

Polyamic acid Solution.

Side view



Fabrication Steps

④ Etching

↓ Gold etchant

↓ Ti etchant

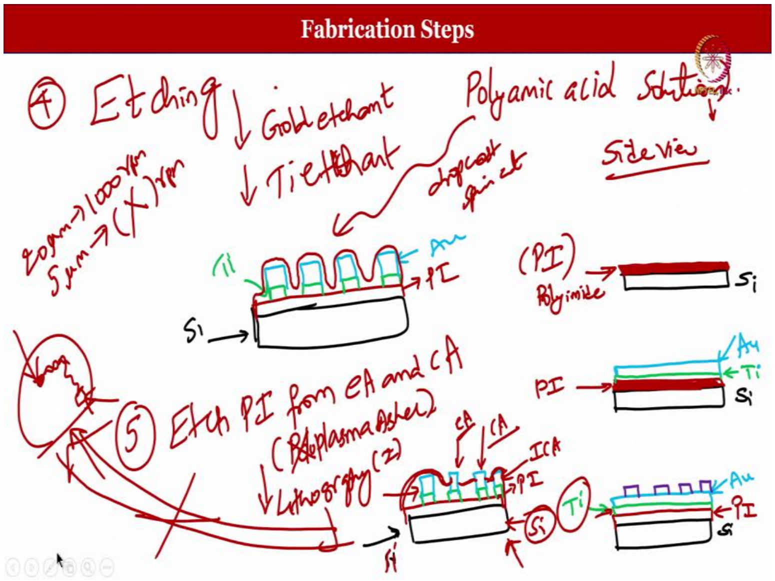
Polyamic acid Solution.

dropcast
spincoat

Side view

20 µm → 1000 rpm
5 µm → (X) rpm

⑤ Etch PI from eA and CA
(plasma Asher)
↓ Lithography (2)


Fabrication Steps

Now, let us look at what are the fabrication steps for this. So the first step is you need to form a substrate material. Substrate material. What is the substrate material that we have is polyimide. Now, the polyimide is available as polyamic acid solution. So this, people can buy it from Sigma-Aldrich, from Mark solutions and all those things. Now, this is a solution and I am talking about a harder material substance, when I say harder, do not think that, it is very much harder compared to silica and other. What I meant to say is this is a solvent that I am talking about. And this device that I showed here is a solid device.

How to make it? So what you do is you take a silicon wafer. So it is a silicon wafer. Then you might have seen by now, a spin coater. So let me take different colour. So you spin coat. What you do first you drop cast the polyamic acid solution. You drop cast, so let us say I am talking, this is a top view and parallelly I will also draw the side view because that is very, very important, and this is side view. From the side view, I am drawing from this angle, so you have a silicon wafer of some thickness.

So in order to avoid the confusion, because for polymide I took dark red colour. So let me erase these things. For silicon wafer, I take care, black colour. So there is a silicon wafer and you have a silicon wafer here as well. Pardon me for my handwriting, it is terribly good, I know. So this is silicon. On top of the silicon, now you drop cast, drop cast polyamic acid solution. Now, that solution is drop casted on this, when you drop cast the solution, you will have a solution in the middle, something like this.

You drop cast using whatever the mechanical arrangements that you have. So now, it is little viscous, that is why it is confined to the middle. Now, you have to uniformly distribute it. How to make it uniformly distributing? Wow. You might have guessed it by now, I told you already. I gave the hint also, spin coating. Now, you decide, let us say I want 20 micron thick and all these things will come with some kind of understanding about spin coating and curing and all those things.

So spin coating, what you do, you run the spin coater at 1,000 RPM or something. Then, these things will be uniformly distributed like this. Like you, you visualize, you have a silicon wafer in the hand and then you just, let us say you are spin coating it. Then whatever the solution is in the middle, we will try to distribute. But still, it is say a solution. Now, what we do is something called as, this is a first step. Like these are intermediate steps, I am just telling you.

In the first step, these are intermediate like drop cast, you do. Then second thing is what you do, then cure it. Heat this entire sample at let us say 80 degree centigrade for 1 hour followed by 250 degree centigrade for 2 hours. Directly, we cannot take it to 250 degrees centigrade as if, because the thermal stresses will be more, so we will take to 80 degrees first, then we will make it to 250 degrees centigrade. Then you will get a, what do you call that, a solid film.

Or you can also you will get a polyimide film. You will get a polyimide film. So let me erase these things. So what you are supposed to do first, drop cast polyamic acid solution that we purchased from Sigma-Aldrich or somewhere. Then you use a spin coater to spin coat to form a polyimide film. So after forming a polyimide film, how does it look like? So how does it look like is, now no more you can see the silicon wafer.

So here entirely polyamic acid, polyimide film. Now, it is solid. Now, why silicon wafer is required? Waste question. What is that? Why? You thought about it? Because you cannot use a flexible material for especially, polyimide for other steps. You need to have some carrier wafer for that. Let us say for example, how do you spin coat something without any carrier wafer. It makes sense, right? And also, when it is flexible, when I say flexible, we can able to bend it also.

Now, for lithography, it has to be as flat as it can be. So in that way, you need to have some carrier wafer like silicon. Finally, we have to remove that silicon from there, I will tell you what to do with that at the end. Now, first step is done. Now, what is second step? Then you deposit Ti followed by gold. How much thickness? 20 nanometre thick Ti and 200 nanometre gold. You might have seen thermal evaporation and all those things. So right now, what you can do is, assuming that you know all those things, I am just skipping those steps.

I will just draw the side view. So for that, what I am supposed to do, what is this we have? Now, we have silicon wafer. Then you have polyimide film on top of that, it is a solid. We also call it a PI, Polyimide, I can write it as PI. Polyamic acid. Polyimide, I can write it as PI. And on top of that, what is that you do did and you deposited, what is the colour that we used in the last slide, okay? Okay. So we used the titanium, some blue or something. Okay. It is okay, fine. It is in our hand, we can assume whatever we want.

So let us say there is a titanium, thin layer of titanium and these are not drawn to scale. Do not get confused on all, okay? Why he is drawing all those things in different angle, these are not drawn to scale. I am just giving a disclaimer now. Now, this is Au, gold. Now, if you look at from the top view. If I write again, so from the top view, how does it look like? You have a silicon wafer, then on top of that, we have polyimide. I am just drawing this side view and the top view.

Then you have, it is a little difficult but still, I want you guys to get it. It is okay. Then this is titanium, why titanium? To form a good adhesion. Then on top of this, you have something called as gold. That is how you got the gold. Now, the entire thing will be filled using the gold. You cannot see anything below that. Yes or no? Correct. From when you are looking from the top view, because I am drawing all these things that I am taking some time. Otherwise, if you look at it right, you cannot see anything below the gold.

Can you see that? Nothing. You cannot see anything. This is how it looks like once the gold is deposited, on the top you just see gold. Now, is it what, what we want? You know the shape, what is the shape that you have? This is the shape that you want. In this, you want to have this shape like this. Like this one more is there. Like this one more is there. Like this one more is there. Like five electrodes are there. So now, how to do that? How to get that? Now, it is uniformly deposited. When you do something called as thermal or e-beam operation.

These are physical wafer deposition techniques. If you do that, you will get a gold deposited all over the wafer. Now, how to get this pattern? Now, you guessed it. So the next step is going to be the third step. So the third step is going to be lithography. So I will just quickly explain what is lithography? I think, the professor of this lecture has already have explained earlier how lithography works and all. What you do? You need to have a mask.

You need to have a mask, then photo resist. You spin coat the photo resist. Before that, prepare the sample and then spin coat the photo resist. Then, you heat the sample. So that the solvent can be evaporated. Then through mask, you expose. And then put this wafer entire thing in the photo resist developer. Then what will happen? Whatever, according to the nature of the mask or according to the nature of the photo resist, some areas the material will be there and some areas material will be have evaporated. So what is leftover is the pattern that you are interested in.

So whatever is a pattern that is left over, I mean it is not on the metal, but on the photo resist. Now, what will happen is this, silicon and you have PI. This is PI. Polyamic acid. Then what? Then TI, then gold. This is gold and I am telling you again, I am not drawn to scale. So next is the photo resist. So you have spin coated photo resist and then exposed it and then removed. Now, this is how the pattern after development, after putting this entire sample in the photo resist we developed.

We have not removed a gold and titanium yet. Now, what you do, then the final step is. So can I remove some of the things here? So what I can do is the left side, I am just removing it, just keep following. The third step is lithography you did. And then you removed the photo resist from the place where you do not want it to be there. Why you want to do that because you want from a pattern.

So, the first step is going to be what is that? You might have guessed it by now. You might have, something called etching. Because photo resist developer removes only photo resist. Whichever is soluble, when I say whichever is soluble, whichever the photo resist that is soluble. Because when you expose some of the photo resist to gets exposed to the light and then become chemically modified. That chemical nature will be modified and it may become soluble or it may become insoluble.

So let us assume that wherever the pattern we want to form, become insoluble. The remaining areas will become soluble and then we etched it by using photo resist developer. Now, what is there here? You have something called as gold. Now, you have to put, the second thing is you put it in a gold etchant. So it is a combination of potassium iodide and iodine and H2O, I mean the DI water. Then once you have a gold etchant, what is beneath that? You have to remove the titanium etchant, otherwise, it is going to be a short circuit, because metal can act as a shot. Then after that, you put it in a titanium etchant. What is the spelling? E-T-C-H-A-N-T. Etchant. E-T-C-H-A-N-T.

Then you remove titanium also. So after removal, what will happen? How does it look like? So let me take the colour. So you have silicon, then you have polyimide. I told you already, PI stands for polyimide. Then you have titanium. Titanium only few places. Remaining places, it is etched by titanium. Then you have gold, on top of that. Then you have, what else is there photo resist we have not removed. This is photo resist. This is PR, photo resist. PR stands for photo resist. This is called then this is titanium. So what is the next step?

We have to remove the photo resist. So what you do, you put it in the acetone solution, dip it in acetone solution, then this photo resist will be removed. So we are assuming that we dipped it in the acetone solution. You might know all these and that is why I am not boring you with all these again and again. Done. Now, this is how it looks like. Now, look at the top view, how does it look like? So you have a silicon wafer, then all over this PI is there all over. Because you have not etched PI, I mean polyimide.

Then according to the pattern, then what happens then you have titanium. This pattern is formed. On top of that titanium, exactly, your gold is sitting. So you cannot see the titanium. Obviously, if you see the titanium, something wrong. Exactly on the top of the titanium, gold is sitting. Now, entire thing is exposed, this entire thing is exposed. Do you see? But what you need to expose only this electrode area and the contact area, only those things. EA stands for electrode area. CA stands for contact area. Only those two things will be exposed.

Remaining things should be covered, passivated or electrically isolated. So means, I use this colour. From here, this entire stretch of the interconnect has to be isolated. Only the electrode and what we use for isolation, we use again polyimide. Again, one more layer, but this time the thickness of this polyimide layer to be 5 micrometer, 5 micron. So what is the next step to do? We know what we did in the first step. So if I erase this, so what we do is again, how to form a polyimide film? Go back to the first step.

Spin coating. You have polyamic acid solution. You have polyamic acid solution, drop cast, spin coat. Now, earlier, for 20 micrometer thick, I told you around 1,000 RPM. This is intuitive question for you, for 5 micrometer thick, what should be the speed? What will be the rotation speed? Is it more than 1,000 or less than 1,000? You think about it. I will not disclose it. Let us say according to that RPM, X RPM, we are going to deposit, we are going to spin coat and then the layer will be formed.

The layer will be formed all over. And we do 80 degree, 250 degree and all those things. Now, in these areas you need to expose only few areas and then we keep that other things that are not exposed. Means you need to etch the polyimide. The next step is etch polyimide from electrode area and contact area. You need to etch it. So for that you can wet itching techniques and dry etching techniques and all those, but I am going to introduce something called as a dry etching technique.

This is called Plasma Asher. So again, what you do again, you do litho 2, lithography. Lithography, second step. First step, we have done and second step, that is where the alignment markers, everything will come into picture. So again, you have to spin coat photo resist. Then heat it up a bit. So that the solvent will be evaporated. Then you will get a photo resist there. Then you need to expose it. When you are exposing it, you have to align properly with the first layer.

Otherwise, this is going to be a mess. So once you do that, you are going to remove the polyimide from the places where you do not want it. So I am assuming that everything you have done. So what happens is you have silicon, then this is silicon and this is polyimide, then titanium. I am just hurrying up a bit because you might be bored with all this again and again. And wherever you want, it to be exposed, you did all photo lithography and all those things and then otherwise these things are not exposed.

So this is exposed. This is not exposed. These two areas are not exposed, maybe those are interconnect areas. This could be electrode area. This could be contact area. See, now, we are looking from the side view. Otherwise, how does it look like? So you have a silicon wafer and this is I think. Now, you are looking from this side. So you want this to be exposed, this to be exposed, this to be not exposed. I am just drawing view. I am trying to show in that way. So do not take this two in a parallel sense.

Just try and try to understand. My idea is to convey, do not take the similarity between this and this directly. My point is, I am just telling you, let us assume that this is active area and this is a contact area and this interconnect area. Means interconnect area means it should be covered and if it is electrode area, then there should be exposed. And still on the top, there will be photo resist, correct? Because you use photo resist.

And again, you put it in the acetone solution that photo resist will go away. Then what is this something called as, there is something still the device is not ready. The final step is still silicon is there. How to get the device from the silicon? Now, what you do is either, there are two ways. What we generally do is we just, we can one of the two steps, we can do. We can take RAE and then get the device out.

Again, etch the polyimide, but if some process does not allow, what we can do is we can just take a scalpel and then cut the device accordingly. So that the device will be out and then now, you are out of this silicon is also removed. So if I take this, you are ready with the device. So I think, I will stop it right now, and then I will summarize these things in the coming classes. Okay. Thank you. See you soon.