Sensors and Actuators
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Lecture - 42
Discussion on Fabricated Sensor with Silicon as Substrate

Hi, welcome to this lab module. In this lab module, we will be talking about fabricated sensor on silicon substrate with a gold deposition interdigitated electrodes and micro heaters. So, how can we fabricate the material on a silicon substrate.

Now, I told you, substrate does not confined to only silicon. Substrate can be glass, substrate can be polymer; in principle, substrate can be any material on which you are growing a device or you are fabricating a device all right. So, if I talk about silicon as a substrate and I talk about gold depositions inter digitated electrodes and micro heater, then what I am talking about. First you had to deposit a metal and metal would be nichrome or platinum.

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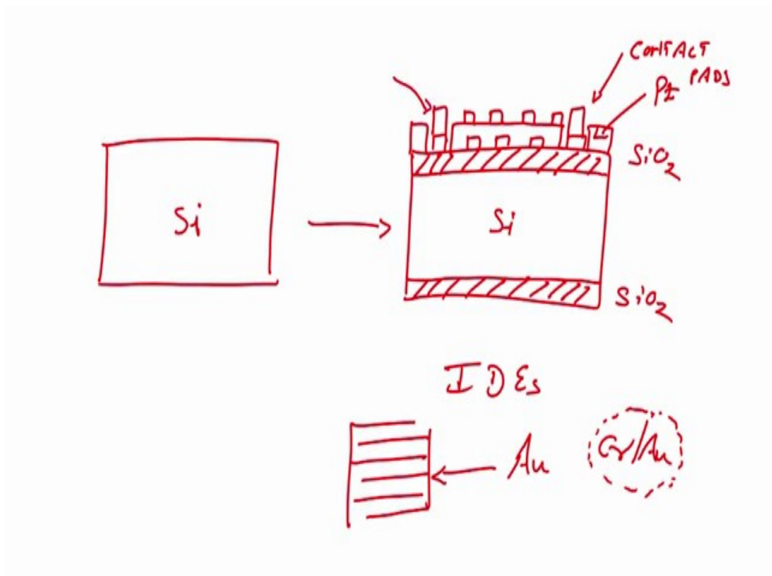

So, if I if you see the screen, what we are talking about is if you take an silicon wafer. Now, all of you are kind of a expert in understanding the process flow. So, I am not going detailed of the process flow. But if you have silicon wafer and if you oxidize the silicon wafer right, then this is called oxidized silicon wafer. This oxidization can be done using thermal oxidation right Si O 2, Si O 2, this is silicon.

Now, on this, you need to form a heater. So, how can you form the heater? You can form heater by depositing a metal and then performing lithography. So, if I deposit a metal and perform lithography, I will have my heater material as shown in figure. And this one would be let us say platinum, all right. Now, on this how can I have interdigitated electrodes. So, if I directly deposit interdigitated electrodes or fabricated in interdigitated electrodes IDEs right, you know IDEs look like this, finger electrodes like this.

So, if I want to deposit and fabricate IDEs right, how can I use that and this IDEs are made up of gold right. We always say chrome gold because chrome would be helping in the addition of gold. So, I if I deposit metal on metal, it will short. So, I have to deposit an insulating material and then perform lithography to open the window. Window is only for contact pads here right, contact pads contact pads.

Now, on this, if I deposit a metal which is my chrome gold right, if I deposit a metal which is chrome gold and I pattern it, then I will have my inter digitated electrodes right. Why I am depositing metal on metal here? Because this is a contact pads, contact pads, thicker the contact pad better it is because it will have a ohmic contact versus rectifying contact.

So, how to create this kind of platform or how to create this kind of device this is what will be taught or will be shown to you in the lab class. And I will request my teaching assistant Anil to show it to you this particular lab component of the subject. So, till then you take care and I will request Anil to please take it out.

Welcome. So, what we are doing from past few small, small modules is that we are trying to see actually fabricated sensors and how they are working, what is the rationale behind the design that has been employed for them and such things ok.

And now last few two modules you have seen devices that we are fabricated on glass substrate correct. And you have seen microfluidic channel based devices and you have seen micro heaters and microfluidics combined; so such devices you have seen. Now, we will see a few devices that are been fabricated on silicon wafers ok. Majority of the devices would be on silicon wafer and a few microfluidic devices are mainly done on glass wafers generally.

Now, as I told you, before you make any device you clean you have to clean the wafer as professor would have told you clean the wafer, then you deposit a specific metal especially sensing materials like electrical sensors, mostly we use some metal. So, it is like you may you might use platinum, you might use gold you might use aluminium, so different you might use nickel you might use nichrome for micro heater.

So, many different types of; many different types of might metals may be deposited on silicon wafer. So, to start off, I will show you a silicon wafer where a blanket deposition of gold has been done.

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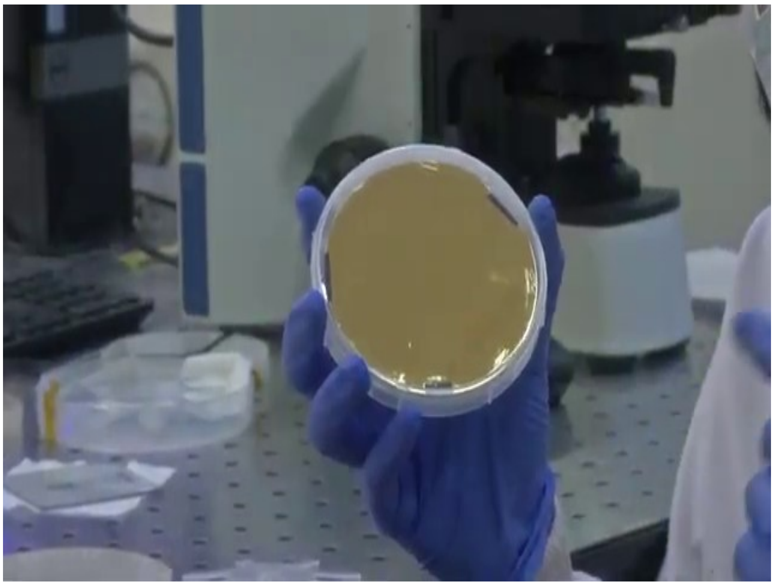

So, this is a silicon wafer with gold deposited. You can see how smooth the surface is, you can see the amount of refraction from it. You can see the gold, I can see the gold reflecting on the camera itself and creating light. The light falling from the top is reflecting from the gold and going on to the camera. So, this is gold deposited, blanket deposited gold on silicon wafer.

The silicon wafers thickness is so if I come to the parameters of deposition. So, this has been deposited. So, such gold material can be deposited using either sputtering method or E beam evaporation method ok. So, in sputtering, as you know there will be a target and the gold will be spurt like it is a active process where actively the gold atoms will be bombarded by argon atoms and the gold atoms should be taken out from the target and they will be deposited on to the substrate. This is our substance that is sputtering.

And another method of depositing gold is e-beam evaporation which is a more tender method where electron beams do the process in a vacuum environment and deposit gold ok. So, this has been deposited using e beam evaporation. Now, how much thickness of gold is there? So, this has actually 195 nano meter of gold and below that 195 nano meter of gold, you have 25 nano metre of chrome. Why is chrome used chrome is used for better. So, gold by default has very less adhesion or stiction or attachment to the silicon substrate.

So, to improve the adhesion, so you might have learnt this in the theory classes. So, we are just showing it to you. So, improve this addition of gold on to the silicon substrate, we use a 25-nano meter layer of chrome. So, first we take the silicon wafer, then we will deposit 25-nano meter of chrome and then we will deposit 195 nano-meter of gold.

Now, people even deposit higher thicknesses of gold; they can go up to 400 nano meter 500 nano meter. But when you do that what you have to take into account is that as you increase the thickness of gold that you deposit on silicon, the stiction, the adhesion of that gold layers will be reducing as and when the thickness goes up.

Because the affect of chromes pull on gold will be lesser as a thickness goes up. On top of that, material cost is something else that you should be worried about. So, we have done this deposition using a central facility in the campus in IISC. There are constraints that if you are depositing gold or platinum or such precious metals, you cannot cross 200 nano meters.

You cannot deposit more than 200 nano meters, because you are paying a definite amount for the material right. If you just deposit 500 nano meter of gold, it is a lot of material and it is expensive. So, they have put this rule, so that is, so then so that is the process constraint.

So, whenever in life or especially in engineering and technology, you will always have process constraints, like you are trying to make a system; this is the course in sensors and actuators right, making a sensor or an actuator is one part, but for that sensor or actuator to be useful to a real world scenario, it has to be packaged in your system. Now, you are trying to make a system. Let us say you have you are integrating the sensor into a system, and you have packaging in that and you are make making metal parts for doing that.

Now, metal machining view, you will do from outside, let us say. You have found 3, 4 vendors who do specific machining and if you want specific feature size on that metal. Now, your process, your design will be defined by the minimum feature size that the vendor can provide for you. Accordingly, so, before you design only, because there is no point in doing a wonderful deign of extremely nice features which you cannot fabricate.

So, first thing that you have to do is be practical and especially when you are looking to product development, be prime, be practical and you have to make a reasonable judgement or a what you call that trade of. You should make a trade off between the available resources and technologies and the design that you want.

So, first thing you do is you will have a rough idea of your design in your mind, then you will go to the vendors that will do it for you ok. You ask them, what is the minimum feature sizes, what are the minimum cutting that you can do, what are the minimum dimensions that you can work with. Accordingly, they will give you the parameters that they can work with. Using those parameters, you go ahead and make your design; that is how you do the product development design, then you do these parts individual parts ok. And then you assemble them together in integrated with your sensor to make the product.

Likewise, this 200-nano meter constraint on gold is also a process constraint. You are using one equipment in a central facility and where there are rules. So, you have to follow those rules and you make your devices. So, you accordingly you your device constraints, you do your assistance calculations if you are making a micro heater accordingly and then do your design accordingly, so that is the whole point. So, we have a gold deposited four-inch silicon wafer. The wafer thickness is 500 microns or 0.5 mm wafer and the deposited gold is 195 nano meter of gold with 25 nano meter of chrome ok. This is one silicon wafer ok.

Now, next thing what we do we pattern on this and make our sensors correct. Now, the sensor that I am going to show you we have fabricated using platinum; I am showing you gold, because right now this is available to you, available to us to show it to you, the sensors can be fabricated on gold also. Why we choose different materials is depending on the design constraints again.

So, gold will have a very good conductivity, platinum will have good conductivity as also, we have thermal properties or a thermal coefficient conduction coefficient that will be different between platinum and gold. So, platinum can also be used as a micro heater, gold does not perform that well as a micro heater, because golds conductivity is extremely high that it cannot dissipate heat, the efficiency is more. So, people do not use gold as micro heaters, but platinum people use. Nichrome any way is very standard material for micro heater.

When you are using platinum, you can use platinum for as both the micro heater as well as a electrode structure, IDE structure, it is a advantage of platinum. So, when we have a design where there is a micro heater and an electrode structure together integrated into one design, we would prefer to go with platinum. This is how you prefer to go with platinum. This is how you make material choices in your, these things, design.

So, like what material to use how many layers of material to put all those things and how much should be the feature size. So, feature size again comes from the thickness that you deposit how. Because resistance. So, thick may let us say your decide designing a micro heater. So, you make a micro heater like this winding structure will be there you make it ok.

Just I am doing in my hand, just making a winding structure, you make a micro heater. Now, you how do you design, your design is that this much resistance should be there in the micro heater, when this resistance when this much resistance is there, I apply a voltage, this much current will flow through that resistance and there will be i squared r losses.

This i squared r losses will be dissipated as heat. So, m c p dt. So, m c p dt, c p is a specificity of capacity specificity the capacity detail, m is a mass of the material. So, i squared r is equal to m c p d t, roughly. So, d t will be the temperature change that you get, this is how you mathematically formulate your micro heater.

Now, what is the resistance if you are making a micro heater? Resistance is as you know rho l by a, rho is a resistivity, l is a length of the material and a is a area of cross section correct. I am trying to tell you how the thickness that you deposit comes into play ok. So, resistivity is rho l by a correct. Now, resistivity I mean resistance is rho l by a, where rho is resistivity. Resistivity of a material is constant you cannot change it. So, your length you define by the winding pattern that you put on the micro heater.

Now, how does a get affected? A is the cross-sectional area correct. Now, if you deposit a higher thickness of the material, your cross-section area will increase correct? Rho l by a will increase, that means, when a increases because it is an inverse relationship because r is equal to rho l by a when a increases r reduces. So, that means, for a diff given 2D design of the windings structure of your micro heater, I again repeat, for the given two-dimensional design of the winding structure of your micro heater.

If you increase the thickness of the deposited layer of your metal, your resistance comes down. That means, for you to attain a particular temperature using your micro heater, it becomes even more difficult that or you have to apply a even higher voltage to a thick to a thicker layer as compared to the thinner layer. So, if you want to attain very high temperatures, it is good to have a thinner layer of the material because a will be less. These are the tradeoffs.

But then if you have a thicker layer of material, if you are looking electrode, thicker layer of material make sense because resistance its inherent resistance will be low. If you are looking into an electrode, the electrode should be able to sends the impedance of the resistance of the substance that is on top of it correct. The electrode should be able to sense the impedance or the resistivity or the resistance of the substance that is on top of it.

When you are measuring such a property, the inherent resistance of the electrode cells should be as low as possible correct, that should be as low as possible. If that is the case your resistance should be less correct then it make sense to have a higher area. So, rho l by a if you make it higher a, then resistance will be less.

So, for electrodes, for inter digitated electrode structures as you might have seen in the lectures for IDEs, it is good to have a thicker material. So, now, you have seen two cases. If you are making a micro heater, you understood that it is good to have a thinner deposited metal layer. If you are making an IDEs structure, it is good to have a thicker material layer ok. But what if your design or a sensor has both these things you have an electrode and a micro heater in your sensor. I will show you one such sensor that we have made.

So, in that case, you go a mid way, somewhere in between the thickness will be is it too low, it will not be too high, it will be somewhere in between that is what we have done with platinum and titanium. So, we have made one sensor like that. In next module, I will show you such a sensor. So, I think you understand what I have told you right now.

We have shown you how wafer which is having the deposited with blanket deposited with metal looks like, what is the design constraint, how much thickness of the metal was deposited, why what is the requirement for a stiction layer or an adhesion layer, what materials will be used and what is the design approach, if you are making a micro heater and how it is different when you are trying to make an inter digitated electrode.

So, with these ideas in mind, we will look at a sensor that they have made in our lab where both these structures co-exist and how we have designed them, I will show you under the microscope how they look like ok. So, that we will see in the next module.

Thank you.