Neural Science for Engineers

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Lecture - 51

Microfabrication Process for Multi Electrode Array

Hello everyone. This is the second module of the lecture on the micro engineering devices that can be used to acquire signals from brain. So, we say it is a bio potential. We know what the difference between EEG and IEG is, we also know what ECOG is.

So, as discussed in the last module ECOG is electrocorticography when we take signals directly from the brain. EEG is electroencephalogram when you take signals from scalp and we have also seen about 10 20 system, right. Now, to develop micro engineering devices whether it is a surface micro electrode array or it is deep brain stimulation electrodes or recording probes from the brain, we need to understand how the fabrication process works and we need to understand that what kind of metals or materials are used for designing the probes.

So, one of the standard materials that people use is silicon and then over the silicon we use silicon dioxide. So, to understand how silicon dioxide can be deposited I have given a just a peripheral viewpoint of CVD techniques and CVD stands for chemical vapour deposition techniques. Now since CVD we have just understood that there is a ALDP, CVD, LPCVD, MOCVD and so on. Now, the second aspect of it is the thermal evaporation or EBeam evaporation or sputtering. Those thing falls under physical vapour deposition.

Now, we want to deposit a metal or deposit a semiconductor onto a substrate. Substrate is any material on which you are going to deposit several materials or design or develop a device or fabricator device. So, if you want to deposit a metal and you want to pattern the metal, patterning the metal will give us different shape of the electrode, for finally fabricating or realizing a device, we need to understand PVD techniques and last time we understood thermal, EBeam and sputtering.

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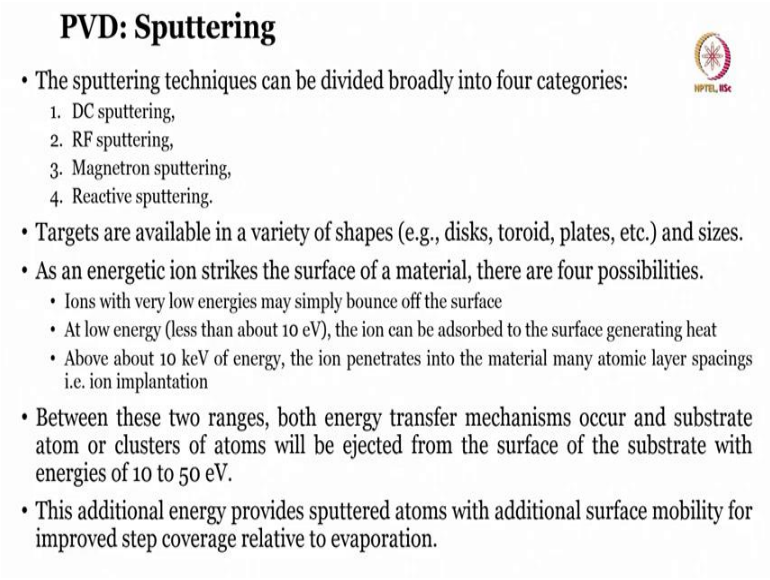

PVD: Sputtering

- The sputtering techniques can be divided broadly into four categories:
  1. DC sputtering,
  2. RF sputtering,
  3. Magnetron sputtering,
  4. Reactive sputtering.
- Targets are available in a variety of shapes (e.g., disks, toroid, plates, etc.) and sizes.
- As an energetic ion strikes the surface of a material, there are four possibilities.
  - Ions with very low energies may simply bounce off the surface
  - At low energy (less than about 10 eV), the ion can be adsorbed to the surface generating heat
  - Above about 10 keV of energy, the ion penetrates into the material many atomic layer spacings i.e. ion implantation
- Between these two ranges, both energy transfer mechanisms occur and substrate atom or clusters of atoms will be ejected from the surface of the substrate with energies of 10 to 50 eV.
- This additional energy provides sputtered atoms with additional surface mobility for improved step coverage relative to evaporation.

Now, I told you that within PVD techniques or within sputtering itself there are 4 basic types of sputtering, or these are divided into broadly 4 categories. The 1st one is called DC sputtering, 2nd one is radio frequency sputtering, 3rd one is magnetron and 4th is reactive ion sputtering.

And in this sputtering, we have seen that it is not like we are melting source material, but we are actually dislodging the atoms from the source material. So, it is a mechanical way of depositing a film compared to EBeam or thermal evaporation. So, targets are available in various shapes can be disk, it can be toroid, it can be plates and different sizes.

As an energetic ion strikes the surface of material, there are four possibilities; ions with very low energies may simply bounce off the surface, second is at low energy that is less than about 10 electron volts, the ion can be absorbed or to the surface generating heat and above 10 kilo electron volts the ion penetrates into the material, many atomic layer spacing’s and that is your ion implantation.

So, you need to understand how to keep the energy above or below 10 electron volts. Between these two ranges, both energy transfer mechanism occurs, and the clusters of atoms will be ejected from the surface of the substrate with the energies of 10 to 15 electron volts.

So, there is a range in which we generally use sputtering, this additional energy provides sputtered atoms with additional surface mobility and finally, to improve the step coverage and it deposit is on the substrate. So, compared to EBeam and thermal evaporation if you go for sputtering this step coverage is better.

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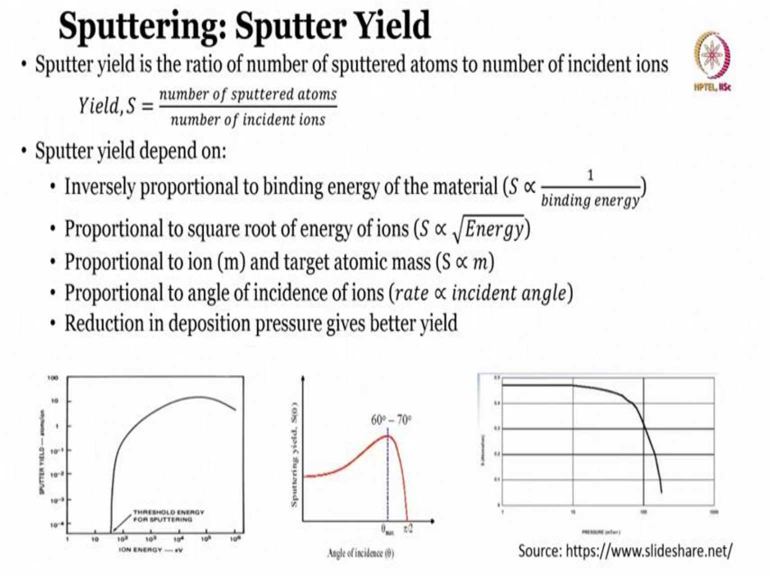

Sputtering: Sputter Yield

- Sputter yield is the ratio of number of sputtered atoms to number of incident ions

$$Yield, S = \frac{number\ of\ sputtered\ atoms}{number\ of\ incident\ ions}$$

- Sputter yield depend on:
    - Inversely proportional to binding energy of the material ($S \propto \frac{1}{binding\ energy}$)
    - Proportional to square root of energy of ions ($S \propto \sqrt{Energy}$)
    - Proportional to ion (m) and target atomic mass ($S \propto m$)
    - Proportional to angle of incidence of ions ($rate \propto incident\ angle$)
    - Reduction in deposition pressure gives better yield

Source: https://www.slideshare.net/

So, if you want to understand the yield of sputtering, then you need to understand how many number of sputter atoms versus how many number of incident ions. The higher the yield, that is S is higher; that means, better the sputtering efficiency, sputtering yield. Sputter yield depends on one inversely proportional to the binding energy of the material that is S is inversely proportional to the bind binding energy.

Second, it is proportional to square root of energy of ions. How many ions are bombarded? So, the sputtering yield is proportional to square root of the energy of those ions, it is proportional to the ion mask and target atomic mask, it is proportional to the angle of incidence and finally reduction in deposition pressure gives a better yield.

So, these plots here shows sputter yield, the first one on the left side versus ion energy and you can see that as you keep on increasing energies, sputter yield increases at certain point it starts saturating and in this same thing here sputtering yield versus angle of incidence is shown, here sputtering yield versus pressure is shown. So, several factors come into the picture when you want to go for sputtering based deposition.

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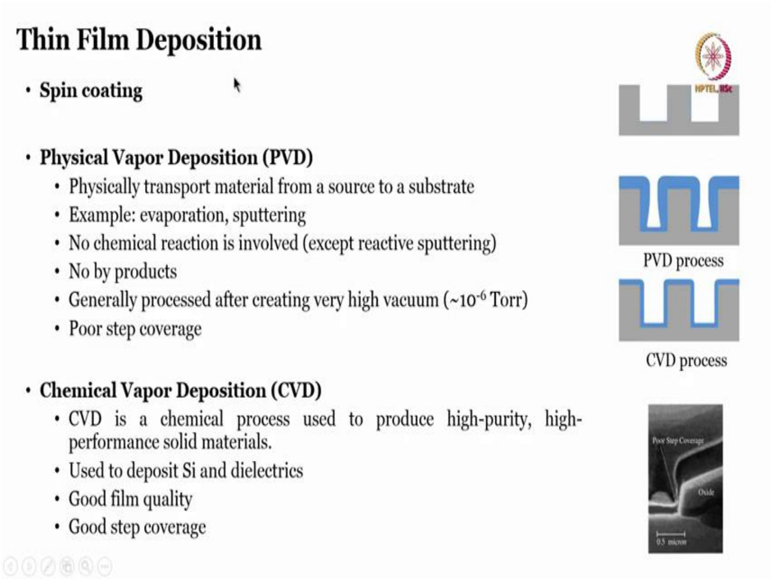

Thin Film Deposition

- **Spin coating**
- **Physical Vapor Deposition (PVD)**
  - Physically transport material from a source to a substrate
  - Example: evaporation, sputtering
  - No chemical reaction is involved (except reactive sputtering)
  - No by products
  - Generally processed after creating very high vacuum (~10^{-6} Torr)
  - Poor step coverage
- **Chemical Vapor Deposition (CVD)**
  - CVD is a chemical process used to produce high-purity, high-performance solid materials.
  - Used to deposit Si and dielectrics
  - Good film quality
  - Good step coverage

So, again there are two different things, one is a thin film deposition another one is thick film deposition. So, if you know screen printing, by which our greeting cards were initially produced, those screen technique techniques can be considered as a thick film technology. While thin film deposition, we have spin coaters, we have physical vapor deposition, we have chemical vapor deposition.

And you can see very clearly that if you have pits, then this pit can be covered with PVD, but a complete step coverage may or may not be available. When in CVD it is for sure that you can cover the complete step, the reason is because the gas reactance will react with different parts of this particular pit compared to PVD techniques because there is a shadowing effect.

So, physical vapor deposition or physical transport of material from a source to substrate, example of PVD is evaporation or sputtering. There is no chemical reaction involved, there are no by products and generally processed after creating very high vacuum, there is 10^{-6} Torr and there is a poor step coverage.

In CVD, which is chemical vapor deposition, CVD is a chemical process used to produce high purity, high performance solid materials. CVD is used to deposit silicon and dielectrics; good film quality is obtained using CVD and finally the step coverage is also good.

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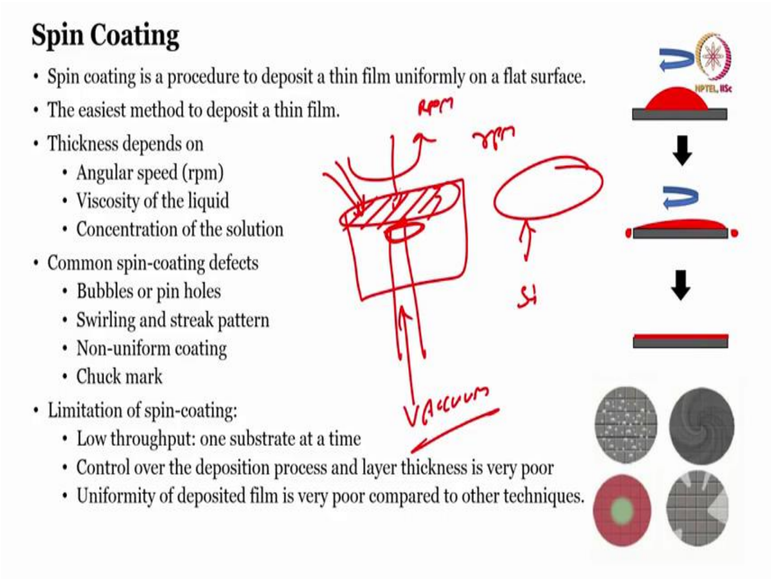

Spin Coating

- Spin coating is a procedure to deposit a thin film uniformly on a flat surface.
- The easiest method to deposit a thin film.
- Thickness depends on
  - Angular speed (rpm)
  - Viscosity of the liquid
  - Concentration of the solution
- Common spin-coating defects
  - Bubbles or pin holes
  - Swirling and streak pattern
  - Non-uniform coating
  - Chuck mark
- Limitation of spin-coating:
  - Low throughput: one substrate at a time
  - Control over the deposition process and layer thickness is very poor
  - Uniformity of deposited film is very poor compared to other techniques.

So, if you start with the spin coater spin coating is a procedure to deposit the thin film uniformly on a flat surface. Generally, we go for a photo resist coating. So, and there are several things that we need to understand, first is that this is the easiest method to deposit a film. So, what you do is, you take a spin coater, you load the wafer, there is a vacuum chuck which will hold the wafer and you spin this the wafer right at a given rotations per minute.

So, you load the solution, and you spin it on the substrate, this can be a silicon substrate. So, loading silicon substrate onto a spin coater which has here a vacuum and you are rotating at certain rotations per minute, will yield you a thin film. But what we need to understand is that the thickness of this film depends on several factors again in this case, the first and foremost as you may have guessed is the angular speed, rotations per minute.

If the rotations per minute is higher, the film the film thickness is lower. Second is viscosity of the liquid. If the film is viscous then the thickness is higher. Next is concentration of the solution. Then, common spin coating defects. What kind of defects you will observe? You can see defect 1 2 3 and 4.

So, what are these four defects? So, bubbles or pinholes right you can see here, then you have swirling a stick pattern, you can see here; then you have non uniform coating, you can see here and finally, chuck mark, you can see this one. So, these are some of the defects that may occur while depositing the thin film using spin coating technique.

Limitations of spin coating: now the advantage it is like it is very easy. What are limitations? Low throughput, one sub state at a time you cannot use more than one sub state. Control over the deposition process and layer thickness is very poor. Uniformity of the deposition film is very poor compared to other techniques. So, that is about the spin coater.

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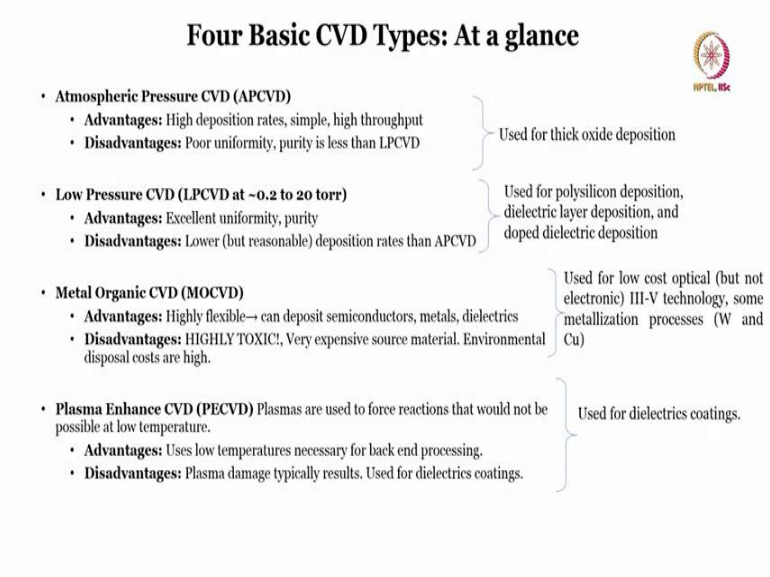

Four Basic CVD Types: At a glance

NPTEL, IISc

- **Atmospheric Pressure CVD (APCVD)**
  - **Advantages:** High deposition rates, simple, high throughput
  - **Disadvantages:** Poor uniformity, purity is less than LPCVD

Used for thick oxide deposition

- **Low Pressure CVD (LPCVD at ~0.2 to 20 torr)**
  - **Advantages:** Excellent uniformity, purity
  - **Disadvantages:** Lower (but reasonable) deposition rates than APCVD

Used for polysilicon deposition, dielectric layer deposition, and doped dielectric deposition

- **Metal Organic CVD (MOCVD)**
  - **Advantages:** Highly flexible→ can deposit semiconductors, metals, dielectrics
  - **Disadvantages:** HIGHLY TOXIC!, Very expensive source material. Environmental disposal costs are high.

Used for low cost optical (but not electronic) III-V technology, some metallization processes (W and Cu)

- **Plasma Enhance CVD (PECVD)** Plasmas are used to force reactions that would not be possible at low temperature.
  - **Advantages:** Uses low temperatures necessary for back end processing.
  - **Disadvantages:** Plasma damage typically results. Used for dielectrics coatings.

Used for dielectrics coatings.

Now, in CVD we have seen four basic types of CVD. Like in PVD there are four categories in CVD also there are basic four categories. The first one you call is the atmospheric pressure CVD. And the advantages of it is high deposition rates, simple, high throughput, but the disadvantages are poor uniformity, purity is less than LPCVD. The low-pressure CVD is a second type of CVD in which we have the excellent uniformity and purity.

The disadvantages are lower deposition rates than APCVD. MOCVD, its full form is metal organic chemical vapor deposition, here the advantage is highly flexible, can deposit semiconductors, metals, dielectrics. Disadvantage and limitations are, it is highly toxic, very expensive source material, environmental deposition cost is really high. So, APCVD is used for thick oxide deposition, LPCVD is used for polysilicon deposition, MOCVD is used for low cost optical or III to V technology.

PECVD which is plasma enhance chemical vapor deposition, in which the plasmas are used to force reaction and that would not be possible at low temperature. The advantages of PECVD are low use with low temperatures necessary for backend processing, this is the biggest advantage of PECVD, and we will see that at certain point of time you have to go for PECVD instead of other CVD techniques.

The limitation is that there can be a physical plasma damage which may result in damaging the film and also used for dielectric coatings, that is advantage actually, that PECVD can be used to deposit silicon dioxide, silicon nitrite and so on.

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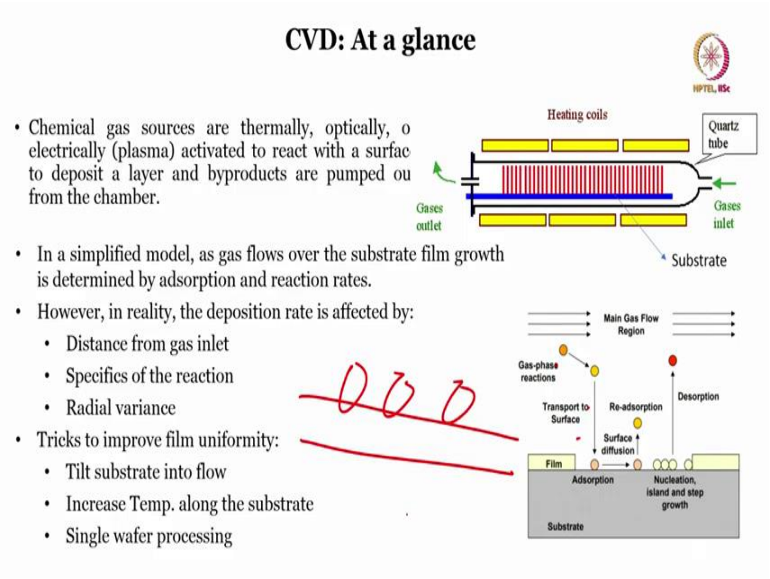

CVD: At a glance

- Chemical gas sources are thermally, optically, o electrically (plasma) activated to react with a surfac to deposit a layer and byproducts are pumped ou from the chamber.
- In a simplified model, as gas flows over the substrate film growth is determined by adsorption and reaction rates.
- However, in reality, the deposition rate is affected by:
  - Distance from gas inlet
  - Specifics of the reaction
  - Radial variance
- Tricks to improve film uniformity:
  - Tilt substrate into flow
  - Increase Temp. along the substrate
  - Single wafer processing

So, if you want to see the CVD at a glance then you know that there is a chamber, either this is vertical tube furnace, or it is a horizontal tube furnace in fact not vertical. Vertical tube furnace will come in this particular form, horizontal tube furnace is this one. So, this is a horizontal tube furnace and then, within that furnace we can load the wafers, these red lines are all wafers and then there are heating coils because you need to go for very high temperature.

The material that is used for this horizontal tube furnace is quartz, the gas enters through one side and gas leaves on another side while there is a reaction on the surface of the wafers. Now, the next step is that when the gas phase reaction occurs, what happens?

So, there is an adsorption then, so there is transport to surface and then there is an adsorption, then there is a re adsorption, there is a surface diffusion finally there is a desorption and desorption it can again go out as a byproduct.

So, gas phase reactions, what are reactions? Forces transport to surface, then there is an absorption on the surface, there is a surface diffusion so this film will form, there are some of the re adsorption and then remaining are the nucleation and step growth occurs and also desorption also forms. Now, so the point is in a simplified model as gas flows over the substrate, film growth is determined by adsorption and the reaction rates. So, in reality, deposition rate is affected by several factors.

The first one is the distance from gas inlet, second one is specifics of the reactions, third one is radial variants and the tricks to improve this uniformity are multiple: the first one is single wafer processing, if you go for one wafer at a time then you can have a better deposition, increase temperature along the substrate and tilt the substrate into the flow; that means that if you have a tilted substrate like this then the reaction would be better.

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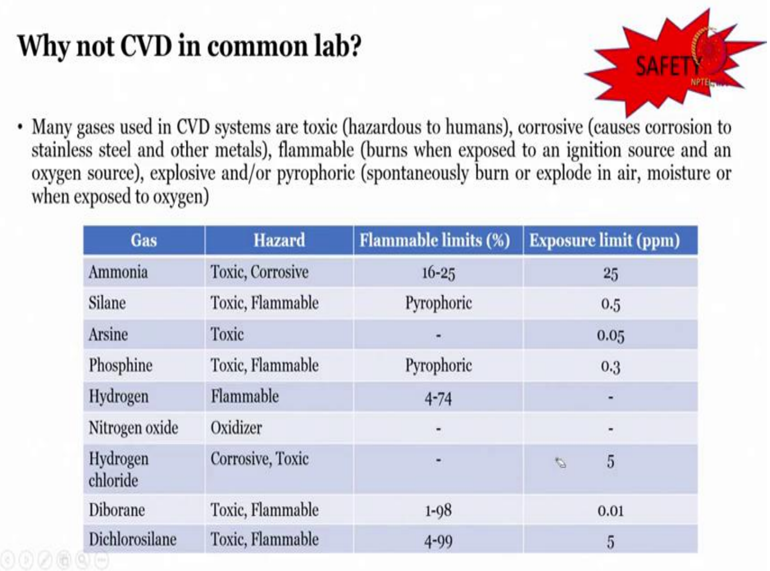

Why not CVD in common lab?

- Many gases used in CVD systems are toxic (hazardous to humans), corrosive (causes corrosion to stainless steel and other metals), flammable (burns when exposed to an ignition source and an oxygen source), explosive and/or pyrophoric (spontaneously burn or explode in air, moisture or when exposed to oxygen)

Gas	Hazard	Flammable limits (%)	Exposure limit (ppm)
Ammonia	Toxic, Corrosive	16-25	25
Silane	Toxic, Flammable	Pyrophoric	0.5
Arsine	Toxic	-	0.05
Phosphine	Toxic, Flammable	Pyrophoric	0.3
Hydrogen	Flammable	4-74	-
Nitrogen oxide	Oxidizer	-	-
Hydrogen chloride	Corrosive, Toxic	-	5
Diborane	Toxic, Flammable	1-98	0.01
Dichlorosilane	Toxic, Flammable	4-99	5

So, there are lot of equations that will govern this particular stuff, we will not go into that because I want to give you an example of different kind of techniques and then it will actually go into how to fabricate some of the devices. So, many gases used in CVD systems are toxic that is hazardous to humans. They are corrosive in nature, flammable and explosive or pyrophoric right, that is spontaneously burn or explode in air moisture or when exposed to oxygen.

So, in terms of gas hazard flammable limits and exposure limit you can see this table right from ammonia, silane, arsine, phosphine, hydrogen, nitrogen oxide, hydrogen chloride, diborane and dichlorosilane, there are several hazards that are involved, and the corresponding flammable limits, and exposure limits are also given in the table.

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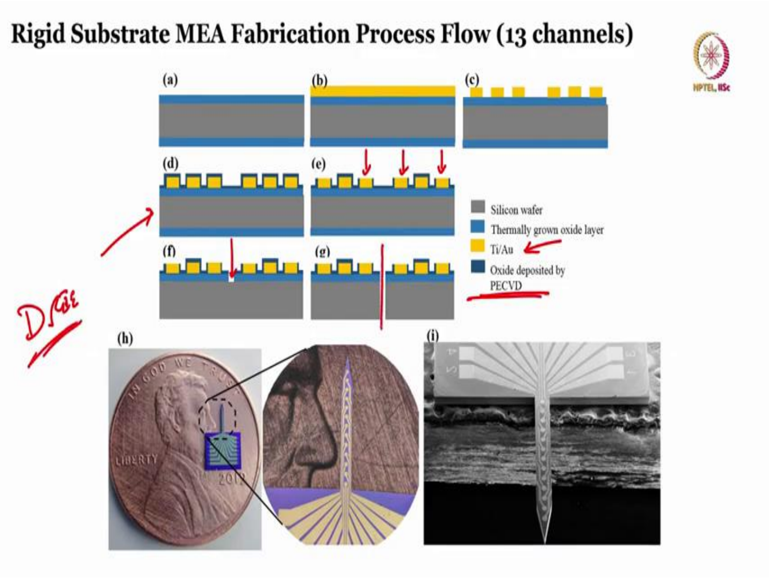

Rigid Substrate MEA Fabrication Process Flow (13 channels)

So, let us now understand how to quickly fabricate a micro needle right or an electrode or a probe with several electrodes integrated onto it. So, before we understand it, let us understand a bit on the lithography. So, what I will do is, I will just create separate slides right and I will teach you a little bit about lithography. So, you do not miss out the important point.

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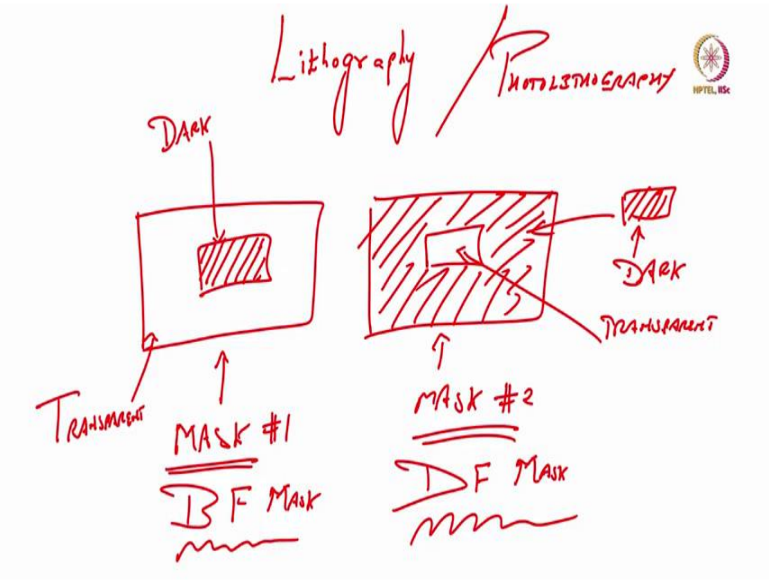

So, we are talking about lithography. And in lithography we are talking about photo lithography. So, lithography stands for carving from single stone, but here we are using photons which is light to create different structures. So, I will give you certain examples. So, let us start with two different examples, these are two different masks, what are these, mask.

And this mask has this pattern; this mask has an opposite pattern. What do you mean by opposite pattern? That all the lines that you see like this structure, is completely dark, is completely dark, assume that this is completely dark and this one is transparent. In this one, this structure is completely dark and this one is transparent. So, this mask, mask 1 let us say mask 1, this is mask 2. Mask 1 is called bright field mask. Mask 2 is called dark field mask.

What is it? Bright field mask and dark field mask. You understood this much? Bright field mask and dark field mask. Now, let us delete everything and I will show you an example of how this mask will help us to pattern different materials on to a substrate, it is very easy but very important because, photolithography is considered as a heart of micro engineering techniques.

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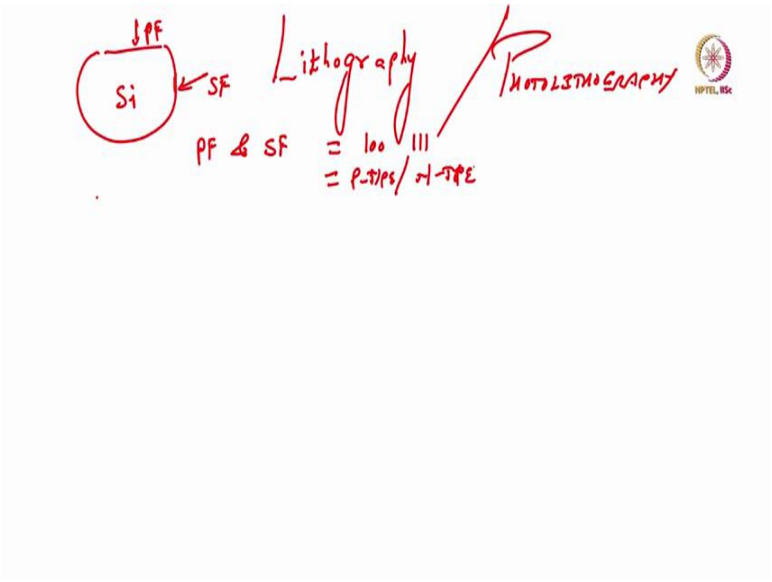

So, if I take a silicon wafer right, this is a silicon wafer, this is a primary flat, and there can be a secondary flat or there may not be a secondary flat. Depending on the primary flat and secondary flat, the wafers are identified as 100 or 111. They are identified as P type or N type.

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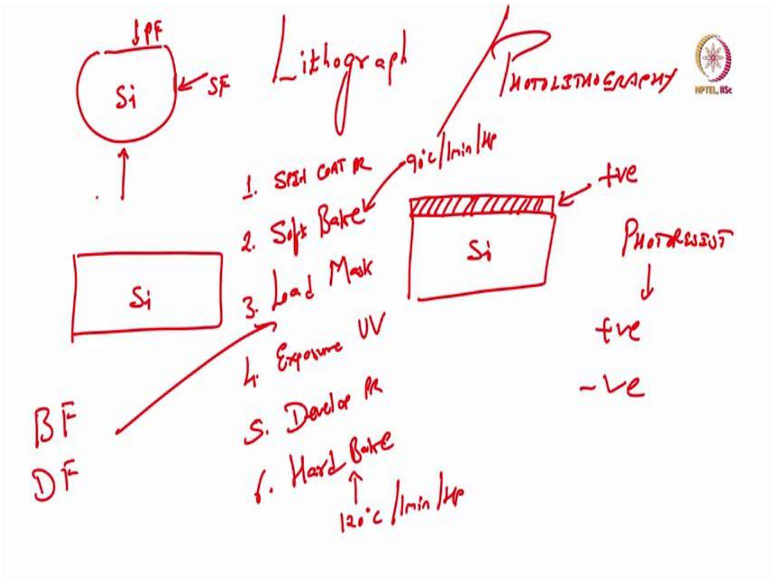

So, let us not worry about the type of the wafers at this point of time, the point of showing you this particular image is that if I take a cross section of this, it is this one. So, this is my silicon wafer. Now, before we again go further let me just quickly explain you the mask versus the photo resist. So, one thing we have seen is a mask, bright field and dark field. Second thing we need to understand is a photo resist.

Photoresists are of two types: positive photoresist or negative photoresist. Now, I will spin coat the photoresist onto this substrate, spin coat the photoresist onto a silicon substrate and let us understand it is a positive photoresist.

Now, the point of lithography or how to perform lithography or steps of lithography are, 1st is spin coat photoresist, 2nd is soft bake soft bake, 3rd is load mask, 4th is exposure of ultraviolet light, 5th is developed photoresist, 6th is hard bake.

These are the steps, remember first step is spin coat the photoresist using what, spin coater. Soft bake generally is done at 90 degrees centigrade for 1 minute on hot plate. Mask you are saying either there can be a bright field mask or there can be a dark field mask.

Photoresists develop for positive or negative photoresist are different, hard bake is done at 120 degree centigrade for 1 minute on hot plate. So, what are the steps? Spin coat, soft bake, load mask, exposure, developer and hard bake, remember. I am deleting it from here. So, you remember. So now what we have done, we have taken a silicon wafer and we have quoted a photoresist. So, let us assume it is a positive photoresist. Photoresists are of two types, positive and negative. So, we remember this one also.

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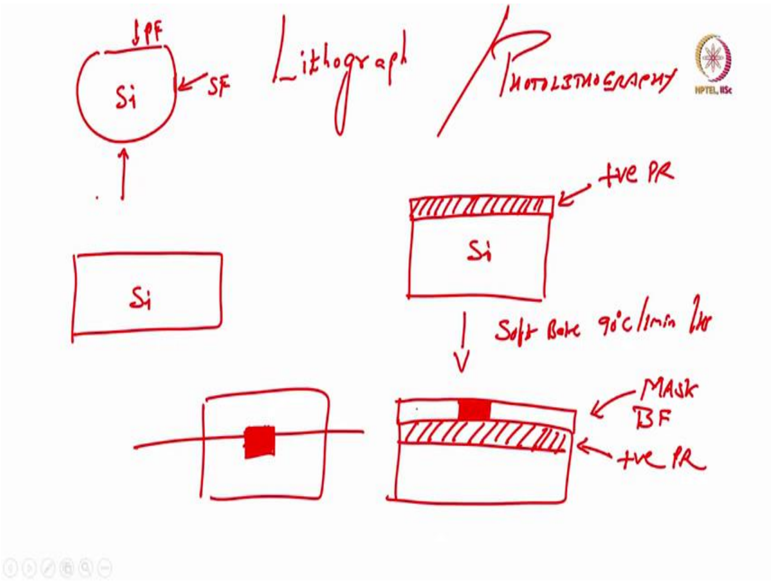

So, the next step is next step is, you soft bake it, soft bake at 90 degree for 1 minute on hot plate, after soft bake next step is you load the mask. So, I loaded the mask. What kind of mask? Bright field mask. This is again cross section of a mask, if I draw the top view this will look like this.

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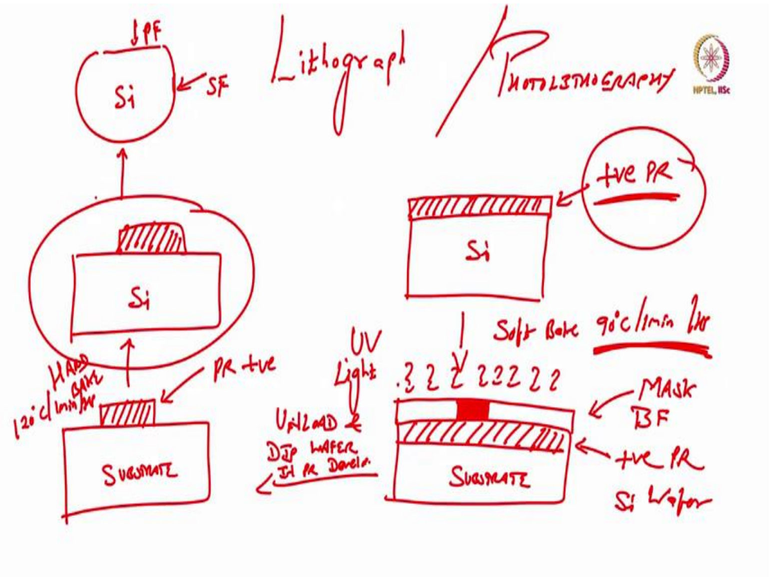

So, these are bright field mask. After bright field mask, next step is you expose this wafer to UV light. After exposing the wafer, you have to unload the wafer, unload the wafer and dip wafer unload the mask ok, unload the mask, do not unload the wafer. Then unload the mask and dip wafer is what the substrate right, generally we use silicon, so I say silicon wafer.

So, dip substrate or wafer in photoresist developer. So, spin coat positive photoresist, soft bake at 90 degrees for 1 minute on hot plate, then load the mask, then UV exposure, then unload the mask and dip the wafer in photoresist developer. Next step, after this what is the next step? So, when you do this, you will have you have pattern the photoresist.

After this next step is hard bake. Hard bake is done at 120 degrees centigrade for 1 minute on hot plate. This is what kind of photoresist? Positive photoresist. So, what you are getting here? You are getting that if there is a positive photoresist, then whatever the pattern is there on the mask, same pattern you can transfer to your substrate.

But in case of negative photoresist, whatever the pattern there is on the mask, opposite pattern will come on the subset. So, if you see the slide what I mean is. So, this is for positive photoresist, what you get is this one. Now, let us understand negative photoresist.

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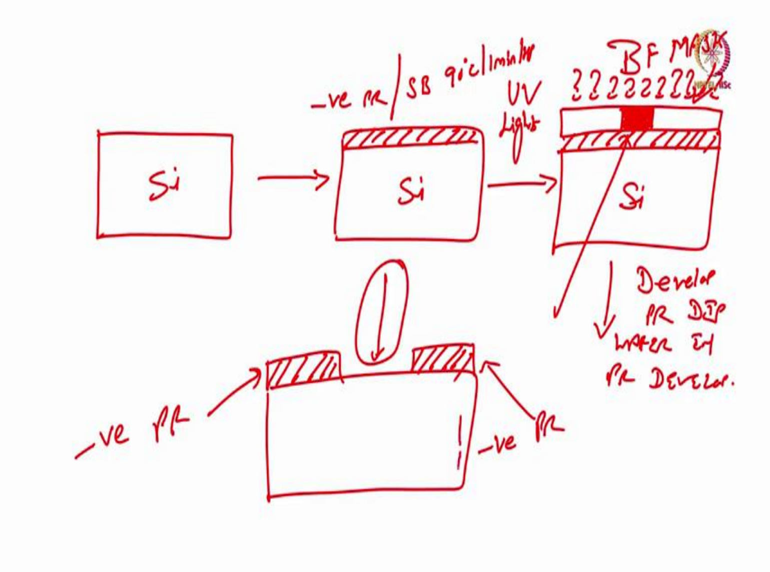

So, same process, I take a wafer, I coat the wafer with a photoresist, this time it is negative photoresist, next is I will spin, after coating the wafer, I will perform soft bake is the next 90 degree centigrade 1 minute hot plate. Next step is, load the mask. What kind of mask we have? We have a bright field mask.

After this loading the bright field mask, the next step is you have to expose the wafer with UV light. This is your substrate. Then unload the mask and develop photoresist by dipping the wafer in photoresist developer.

If you do that what you will get you, you guys can tell. I told you right earlier that absolutely opposite pattern you will get, you will see. If you consider the previous case, you see this one and mask was same. Consider this case, you see here the photoresist is intact on the area, which was not exposed, the photoresist got etched. On the area, which was exposed, the photoresist is intact, is solid. This is your negative photoresist.

In this case, you have a positive photoresist. In positive photoresist, the area which is not exposed is stronger. In negative photoresist, the area which is not exposed which is this area, the area which is not exposed by UV light is weaker you can see here. So, now we understand the difference between positive and negative photoresist.

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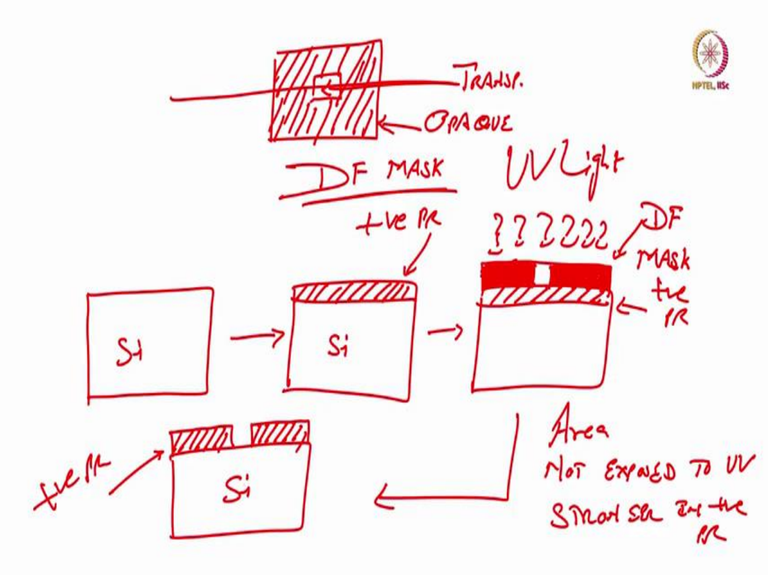

Now, let us take an example of everything is same we change the mask and then I will quickly tell you why we are looking at all these things because, we are interested in understanding how to fabricate a micro needle and then possibly the flexible microelectrode array and understand it further.

So, if I take a dark field mask in this case, earlier we used to use bright field mask. Let us understand now if you have a dark field mask. So, if you see the screen and I have this design, but all these areas that I am drawing with lines are completely dark, and this area is transparent, this area is opaque. Transparent and opaque.

What is this kind of mask? Dark field mask. In this case what will happen let us see? We have photoresist, we quote the photoresist with a positive photoresist. This is a silicon wafer, it is a photoresist that is coated onto silicon wafer, which is positive photoresist.

On this we load a mask; if I take a cross section of this mask then it will be like this. What we have? We have a dark field mask. What kind of photoresist we had? Positive photoresist.

So, if I expose this wafer with UV light and then unload the mask and develop the wafer. What will I have? This is a positive photoresist. So, my photoresist will stay in this region, you see.

Because the area which is not exposed is stronger, area not exposed to UV is stronger in positive photoresist. But area, which is not exposed gets weaker, area which is not exposed to UV will get weaker in negative photoresist. So, because the area which is not exposed gets stronger you can retain the positive photoresist. This region a silicon is here. So, this is how the lithography works.

So, the point is whether you are going for of a bright field mask or you are going for dark field mask, it all depends on the photoresist that you are using. So, depending on the photoresist that you may have, you can select a positive or negative photoresist, depending on the sorry mask that you have you can select a positive or negative photoresist.

Again, for a bright field mask, and dark field mask it is not that if you use bright field mask always you have to go for positive photoresist or dark field mask you have to go for negative photoresist, it depends on the process that you are going to select.

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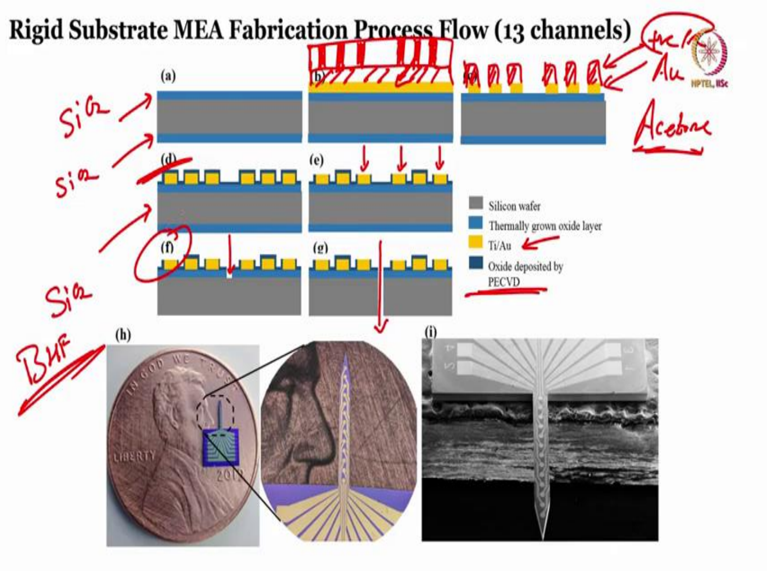
Rigid Substrate MEA Fabrication Process Flow (13 channels)

- ▨ Silicon wafer
- 🟦 Thermally grown oxide layer
- 🟨 Ti/Au
- ■ Oxide deposited by PECVD

So, let us take an example of such a process and here is one of the processes so, what we have done is, you take a silicon wafer then you have an oxidized silicon which is blue colour is oxide deposited by PECVD, you know what is PECVD, plasma enhance chemical vapor deposition.

And then what we are doing next is, we are coating titanium and gold. So, titanium is used to improve the addition of gold, then you pattern this titanium gold in a certain fashion. Then, you protect this area with another silicon dioxide which is depositing using PECVD. So, you can see in this case d it is protected, then you open only the area which you want to take the context, these are your electrodes.

Finally, you can do the DRI which is called deep reactive ion etching DRIE to form this spit and then you can go all the way through to create your or actually you can this DRIE is not required in this case because, you need to just remove silicon dioxide in this particular case, which is case number f.

So, to add silicon dioxide we are using buffer hydrofluoric acid or BHF. So, you use photoresist, again how you get this particular thing? Because, we are loading a wafer, we are loading a wafer with a mask which is a bright field mask having this pattern like this.

I will just give you an example, so that you can get this kind of pattern. So, what we are doing again I am repeating, we have taken a silicon wafer on which this blue colour thing is oxide, this is silicon dioxide. On this you have your titanium gold which is patterned using photolithography as I have earlier taught you how to do it, you can spin coat photoresist on it, photoresist and then on photoresist. So, after doing soft bake you load the mask, mask to look having pattern like this 1 2 3, 1 2 3, right.

And then since it is a bright field mask, the area which is not exposed which would be stronger. The photoresist below this particular region would be stronger and the photoresist where the area is exposed will get weaker.

Then, you can do the hard bake and you can then etch the titanium gold from the area which is not protected by photoresist. So, what will happen is, if I do this particular process my photoresist will stay in this region and from other regions photoresist will get stripped off, photoresist will get stripped off.

So, this is my positive photoresist, and this is my titanium gold. After this, I strip off the photoresist. Stripping off the photoresist can be in acetone. You dip the wafer in acetone, and you can strip off the photoresist. When you strip off the photoresist you get this particular thing which is d and not really d, but you what you will have is this particular stuff like this.

And then what you do is you do PECVD to grow silicon dioxide as you can see in d, after that you remove silicon dioxide from certain region, where you want to take the measure the signals which you can see here. After that, you add silicon dioxide again using the photolithography and then finally you go for DRIE, finally you go for deep reactive ion etching. Now, if you do that what you have is this particular probe with multiple electrodes and you can use this probe for measuring several signals in the brain.

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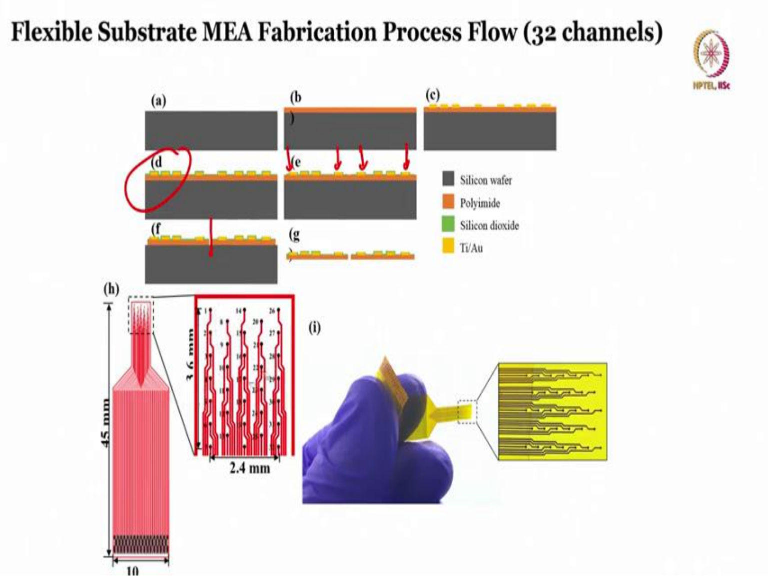

Flexible Substrate MEA Fabrication Process Flow (32 channels)

Let us take another example. Here we have a flexible substrate micro electrode array. So, you start with a silicon wafer, you load a polyamide or spin coater polyamide which is shown in orange colour then on that you have your titanium gold and then, on that titanium gold you pattern that titanium gold using photolithography, then form oxide using PECVD which is green colour silicon dioxide as you can see in d; then you have your e where you are again etching silicon dioxide from the area where you want to record the signal, you see here and here.

And then, after that you remove p i from this particular region and then you can strip off this p i from the wafer and you will have a flexible device as shown in figure here. So, these are 32 electrodes microelectrode array. And all this thing is completely covered with silicon dioxide, this entire thing is completely covered except these dots.

All these dots that you can see with label 1 to 32 they are not covered with silicon dioxide. And what is dot made up of? Dot is made up of a metal which is your chrome gold or titanium gold and that means, that you can acquire the signal through this electrode. And you can place this electrode onto the rat's brain to understand your ECOG signal.

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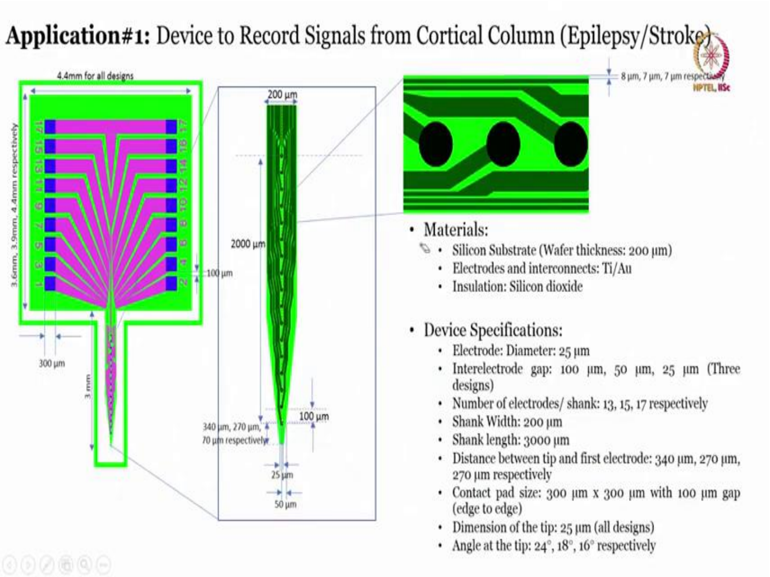

Application#1: Device to Record Signals from Cortical Column (Epilepsy/Stroke)

- Materials:
  - Silicon Substrate (Wafer thickness: 200 µm)
  - Electrodes and interconnects: Ti/Au
  - Insulation: Silicon dioxide
- Device Specifications:
  - Electrode: Diameter: 25 µm
  - Interelectrode gap: 100 µm, 50 µm, 25 µm (Three designs)
  - Number of electrodes/ shank: 13, 15, 17 respectively
  - Shank Width: 200 µm
  - Shank length: 3000 µm
  - Distance between tip and first electrode: 340 µm, 270 µm, 270 µm respectively
  - Contact pad size: 300 µm x 300 µm with 100 µm gap (edge to edge)
  - Dimension of the tip: 25 µm (all designs)
  - Angle at the tip: 24°, 18°, 16° respectively

So, there are several kinds of devices that one can see. I am not going into detail because it is very complicated this it is self can be a course. So, just running through the slides. Maybe in one of the courses where we go into detail, I will be teaching this fabrication process in detail.

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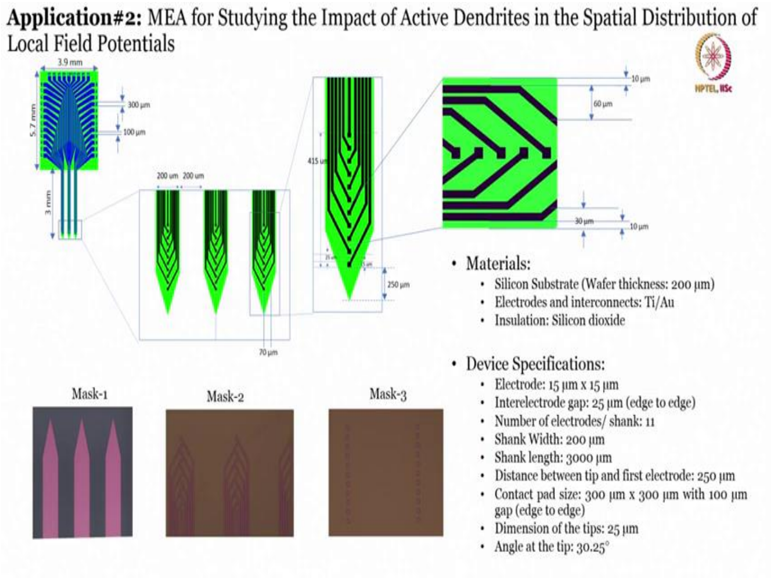

Application#2: MEA for Studying the Impact of Active Dendrites in the Spatial Distribution of Local Field Potentials

- Materials:
  - Silicon Substrate (Wafer thickness: 200 µm)
  - Electrodes and interconnects: Ti/Au
  - Insulation: Silicon dioxide
- Device Specifications:
  - Electrode: 15 µm x 15 µm
  - Interelectrode gap: 25 µm (edge to edge)
  - Number of electrodes/ shank: 11
  - Shank Width: 200 µm
  - Shank length: 3000 µm
  - Distance between tip and first electrode: 250 µm
  - Contact pad size: 300 µm x 300 µm with 100 µm gap (edge to edge)
  - Dimension of the tips: 25 µm
  - Angle at the tip: 30.25°

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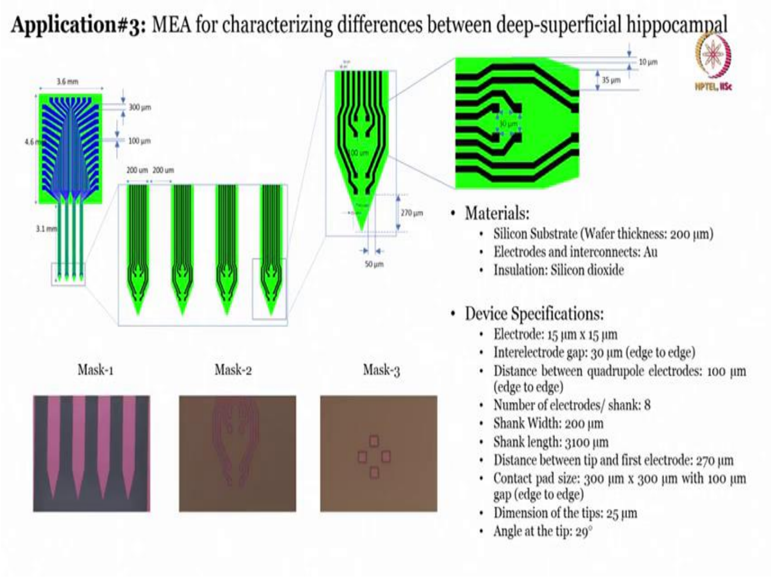

Application#3: MEA for characterizing differences between deep-superficial hippocampal

- Materials:
  - Silicon Substrate (Wafer thickness: 200 µm)
  - Electrodes and interconnects: Au
  - Insulation: Silicon dioxide
- Device Specifications:
  - Electrode: 15 µm x 15 µm
  - Interelectrode gap: 30 µm (edge to edge)
  - Distance between quadrupole electrodes: 100 µm (edge to edge)
  - Number of electrodes/ shank: 8
  - Shank Width: 200 µm
  - Shank length: 3100 µm
  - Distance between tip and first electrode: 270 µm
  - Contact pad size: 300 µm x 300 µm with 100 µm gap (edge to edge)
  - Dimension of the tips: 25 µm
  - Angle at the tip: 29°

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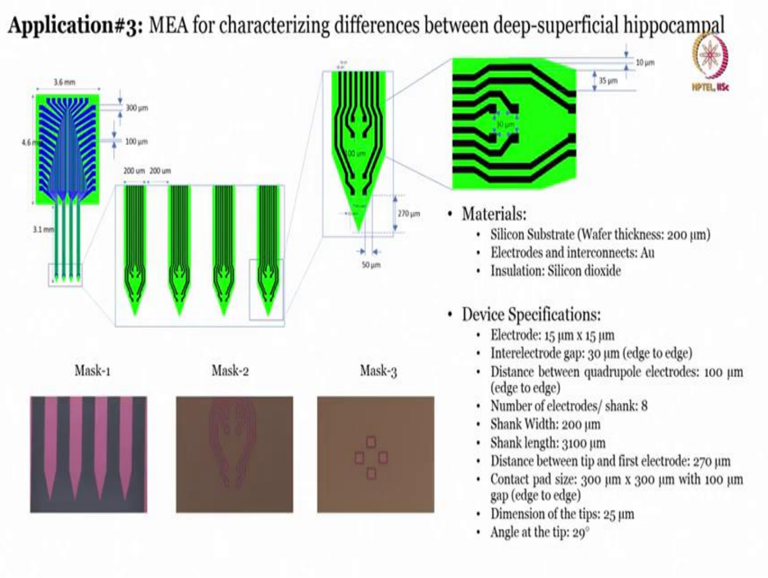

Application#3: MEA for characterizing differences between deep-superficial hippocampal

- Materials:
  - Silicon Substrate (Wafer thickness: 200 µm)
  - Electrodes and interconnects: Au
  - Insulation: Silicon dioxide
- Device Specifications:
  - Electrode: 15 µm x 15 µm
  - Interelectrode gap: 30 µm (edge to edge)
  - Distance between quadrupole electrodes: 100 µm (edge to edge)
  - Number of electrodes/ shank: 8
  - Shank Width: 200 µm
  - Shank length: 3100 µm
  - Distance between tip and first electrode: 270 µm
  - Contact pad size: 300 µm x 300 µm with 100 µm gap (edge to edge)
  - Dimension of the tips: 25 µm
  - Angle at the tip: 29°

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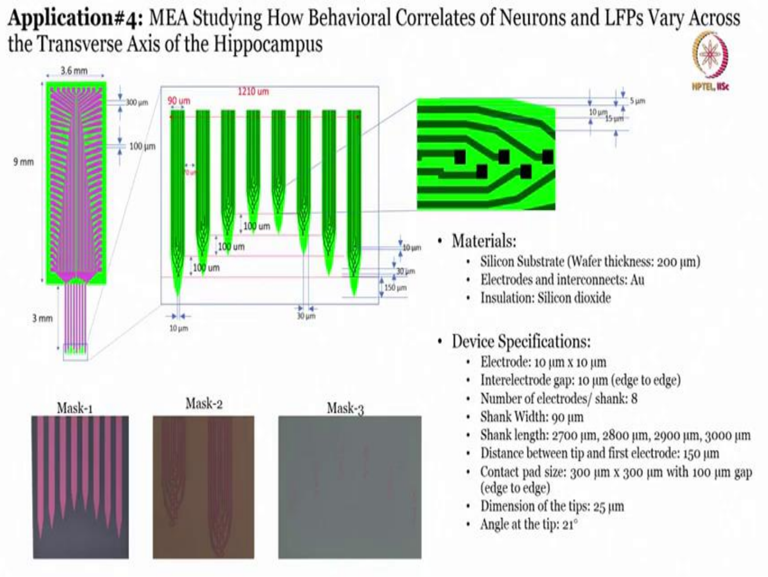

Application#4: MEA Studying How Behavioral Correlates of Neurons and LFPs Vary Across the Transverse Axis of the Hippocampus

- Materials:
  - Silicon Substrate (Wafer thickness: 200 µm)
  - Electrodes and interconnects: Au
  - Insulation: Silicon dioxide
- Device Specifications:
  - Electrode: 10 µm x 10 µm
  - Interelectrode gap: 10 µm (edge to edge)
  - Number of electrodes/ shank: 8
  - Shank Width: 90 µm
  - Shank length: 2700 µm, 2800 µm, 2900 µm, 3000 µm
  - Distance between tip and first electrode: 150 µm
  - Contact pad size: 300 µm x 300 µm with 100 µm gap (edge to edge)
  - Dimension of the tips: 25 µm
  - Angle at the tip: 21°

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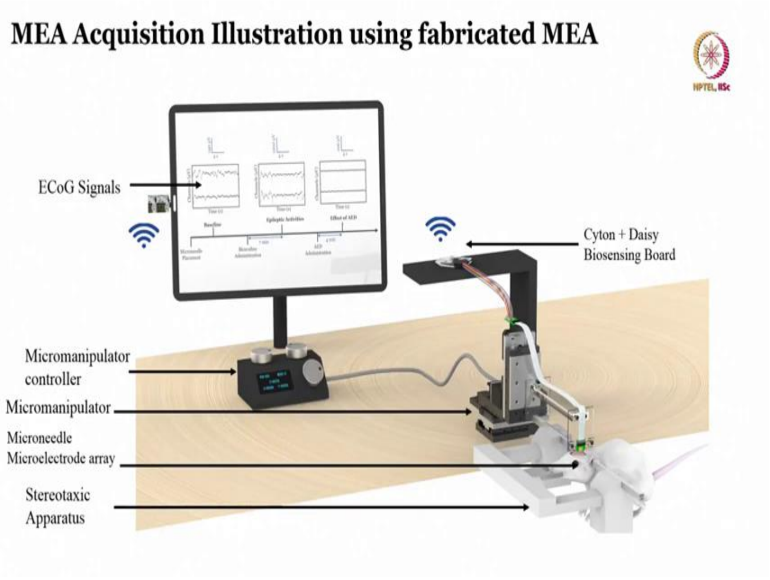

MEA Acquisition Illustration using fabricated MEA

So, 1 shank versus 3 shank versus 4 shank versus 8 shank different electrodes are used for different regions. Here this particular region is hippocampus and then, if you want to acquire the signal, this is a schematic where you can load the micro electrode array onto the rat's brain.

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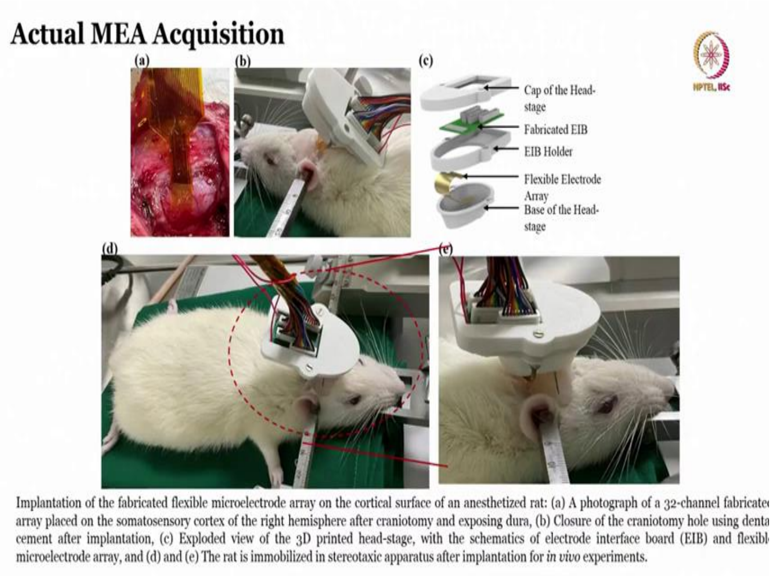

Actual MEA Acquisition

Implantation of the fabricated flexible microelectrode array on the cortical surface of an anesthetized rat: (a) A photograph of a 32-channel fabricate array placed on the somatosensory cortex of the right hemisphere after craniotomy and exposing dura, (b) Closure of the craniotomy hole using denta cement after implantation, (c) Exploded view of the 3D printed head-stage, with the schematics of electrode interface board (EIB) and flexibl microelectrode array, and (d) and (e) The rat is immobilized in stereotaxic apparatus after implantation for *in vivo* experiments.

And you can acquire the signal, this signal is ECOG signal since we are taking the signals from the brain rather than scalp and this is an actual schematic of what we do in the lab with Dr. Vikas and that is why Dr. Vikas wanted to teach about how engineers would be benefited from understanding the neural science.

And you can see here that once we operate the rat, we do the craniotomy, we can open the dura and we can place the device onto rats’ brain which is A. We had to cover it with the dental cement, we take the signals from the electrodes that is micro electrode array which I have shown it to you earlier which is 32 channel array, 32 electrode array and then from there we connect it to the acquisition system to measure different signals.

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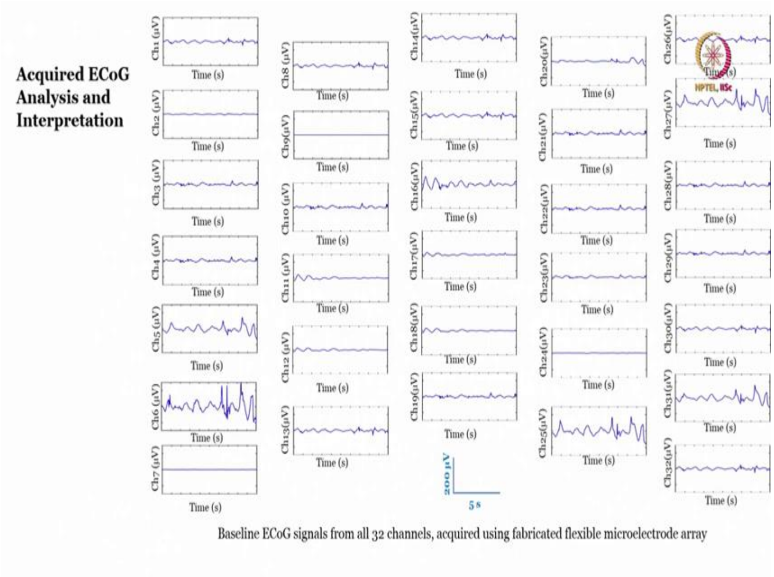

Acquired ECoG Analysis and Interpretation

Baseline ECoG signals from all 32 channels, acquired using fabricated flexible microelectrode array

So, these are 32 signals acquired from all 32 electrodes, you have to see that the left side or the y axis is the voltage and x axis is time, time is in seconds and voltage is in micro volts you can see it is 200 microvolts and second is about 5 seconds.

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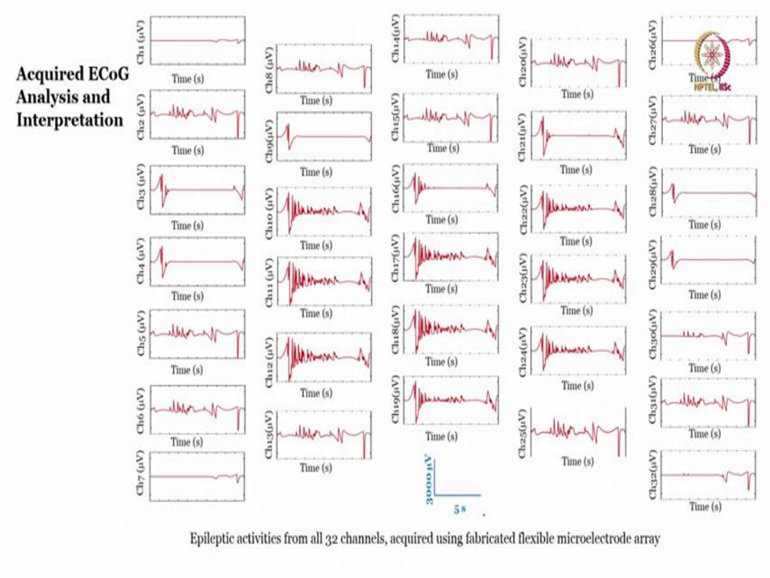

Acquired ECoG Analysis and Interpretation

Epileptic activities from all 32 channels, acquired using fabricated flexible microelectrode array

But when we go for an epilepsy by creating or by giving a drug to rats brain then you can see that there is seizure in several electrodes and here the value is 3000 micro volts. What was the value here? 200 microvolts which is normal ECOG signals versus 3000 microvolts because of the creation of the epilepsy and these are the seizures.

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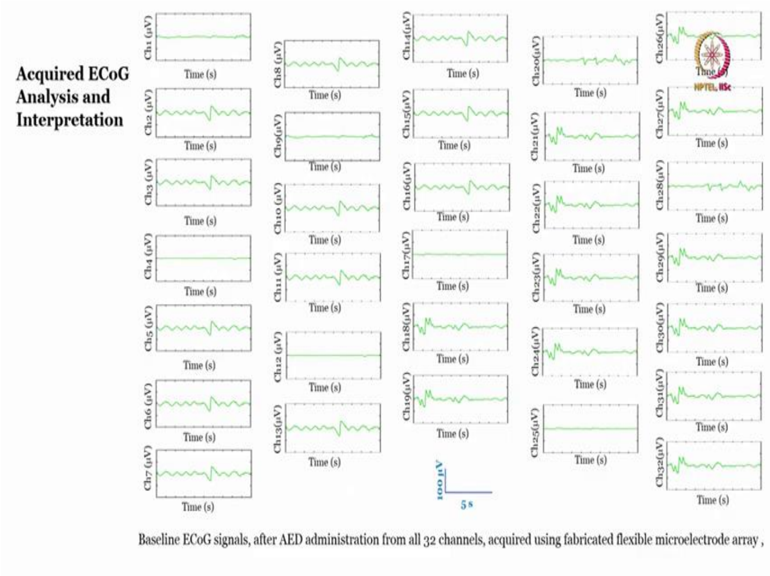

Acquired ECoG Analysis and Interpretation

Baseline ECoG signals, after AED administration from all 32 channels, acquired using fabricated flexible microelectrode array ,

Now, if you load the anti epileptic drug onto rats brain or you administer the AED into the rat, then you can recover the signal and this is again in hundreds of microvolts; that means, that we can understand the efficacy of an antiepileptic drug using this particular flexible device onto the rats brain and thus we have a model to test different kind of drugs, which is here in this case is used for understanding or treating epilepsy.

But we can also use different kind of drugs for understanding different kind of efficacy or we can understand different efficacy of drug for certain applications related to brain but let us stick to epilepsy only. So, what we have done is not only you have created, or we have created together 32 electrodes, but also, we have acquired the signals with ECOG. We have created an epilepsy and then we have understood the AED whether the AED is useful or not. AED is stands for antiepileptic drugs.

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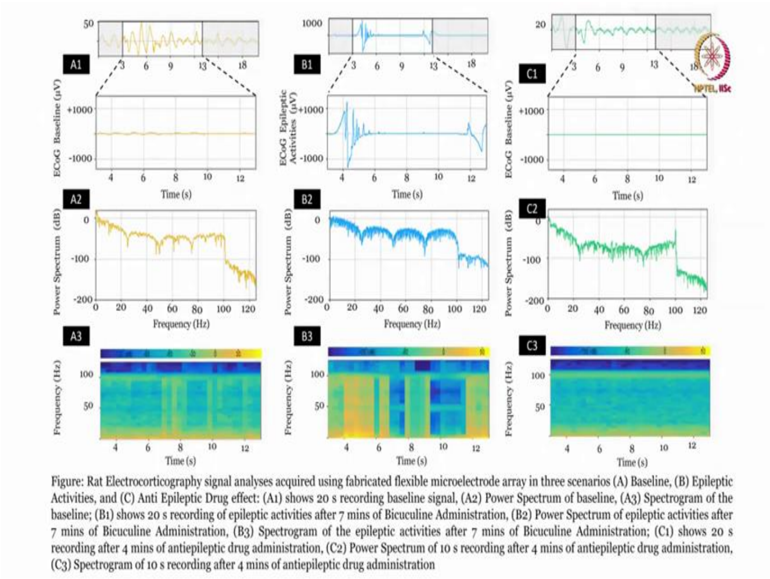

Figure: Rat Electrocorticography signal analyses acquired using fabricated flexible microelectrode array in three scenarios (A) Baseline, (B) Epileptic Activities, and (C) Anti Epileptic Drug effect: (A1) shows 20 s recording baseline signal, (A2) Power Spectrum of baseline, (A3) Spectrogram of the baseline; (B1) shows 20 s recording of epileptic activities after 7 mins of Bicuculine Administration, (B2) Power Spectrum of epileptic activities after 7 mins of Bicuculine Administration, (B3) Spectrogram of the epileptic activities after 7 mins of Bicuculine Administration; (C1) shows 20 s recording after 4 mins of antiepileptic drug administration, (C2) Power Spectrum of 10 s recording after 4 mins of antiepileptic drug administration, (C3) Spectrogram of 10 s recording after 4 mins of antiepileptic drug administration

So, what you can see here is A, B and C. So, the first one A is a base line, B is an epileptic signal and C is an antiepileptic drug effect. Then we can see the power spectrum of the baseline, we can see the spectrogram of the baseline.

And finally, we can see the power spectrum for 10 seconds recording after 4 minutes of AED. Then finally C3 shows the spectrogram of 10 second recording 4 minutes after the antiepileptic drug administration. So, this is how we can see how the things are done and how we can use this 32 channel electrode for acquiring different signals and to study the effect of AED.

So, with that guys I will stop it here I hope you understand a bit on the micro fabrication technology, since we are focusing on neural engineering right and to understand how the brain works for this anatomy, I am not stressing too much on the engineering part.

But, I am giving a kind of a peripheral view to understand how process technologies or microfabrication technologies can be used to study different signals in the brain and not only different signals where we can create or design or fabricate a micro electrode array and we can also fabricate a single versus an array of microprobes with electrodes indicated onto it which can be used not only for acquiring signals deep within the brain; but can alternatively be used to give the electrical stimulation which we call as a deep brain stimulation.

Here we are taking an example of epilepsy, but the same electrodes can be also used for understanding Parkinson and treating Parkinson to an extent. So, I hope that you understand a bit on this and then if you have any questions as you know you can always ask in the NPTEL forum. We will be very happy to answer questions around these topics and all the best for your exam.

Thank you.