Bioelectricity

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Lecture – 29

Welcome back to the lecture series on Bioelectricity. So, we have finished most of the animals bioelectricity. So, today we will be having the last lecture on animal bioelectricity. So, this is lecture number twenty-nine;, and in this lecture, we will be talking about the interfacing of the neuron with solid state electronic devices. So, as of now, if you go through whole animal bioelectricity, we started with the basic architecture of the nervous system, then we talked about the eye channels, we talked about the anatomy of the neurons, and the transmission of the signal from one neuron to the other. We talked about neuromuscular junctions, and we also talked about the cardiac system, which is also the other excitable memory in of our body. And in that whole process, we must have observed that we have used different methods of recording using sharp electrode, using patch clamp electrode, using micro electrode arrays, and few are the techniques.

But all these techniques could be coupled under one heading. These were all the techniques where electro chemistry was involved. So, there is an electrode direct contact with a cell, and there is a electrolyte where that cell is growing, and whatsoever changes are there is sense by the electrode out here. So, these kinds of recordings are mostly invisible records borrowing a site the recording meet from the microelectrode arrays most of it is an invisible recordings. So, there always remain an effort to have a non invisible recording; one of the example what I showed you was micro electrode array, but the problem with microelectrode arrays or any kind of electro chemical methods of recording is that the signal lost is very significantly. So, whatsoever signals we are receiving in that whole process is a kind of compromise big time.

So, there remain a continuous efforts on the part of a people who are interested in interfacing neurons with the electronic system that we should have better, and better techniques in order to record from the neurons, because the better recordings we have the most signal we will be able to derive from neuron activities. So, in that same line, today's lecture the twenty-ninth lecture is about the interfacing of the neuron on a solid state electronic devices. So, in this situation, what we will be discussing on next thirty to forty minutes is how you can interface on neuron on a electronic circuit;, and any neuronal activity which is sense by semiconductor devices. As of now we only talked about the simple electrodes either you use patch electrode or you use a sharp electrode or you use a glass electrode or you use a extra cellular electrode; all these falls under, if I had to classify, I had to classify them under the two headings.

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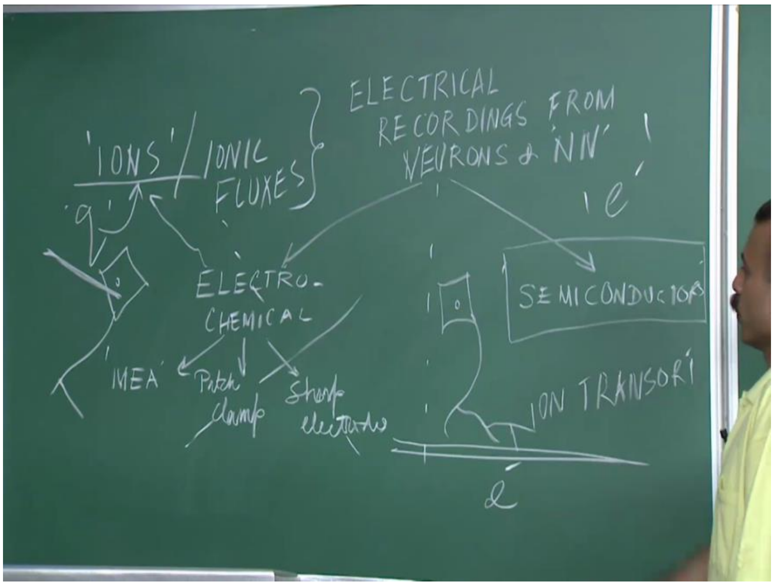

So, electrical recordings from neurons, and neuronal networks, and I am just put NN - neuronal network. So, these could be classified under two broad headings. One is the electrochemical methods, which we had discussed in the form of microelectrode arrays – MEA, we talked about patch clamp, we talked about sharp electrodes. So, now, will be talking about a different class; this is class we have already done. We will be talking about using semiconductors, where we are dealing with a different kind of charge transport.

So, in this situation if you see the all the electro chemical charge transport, they all involved ions. These are all the charges what we are talking about, if I represent charge by q, all the charge transport use in the form of ion, and we are dealing with ionic fluxes. So, in the neuron, we see a ionic flux which is being detected by an electrode, this is what is happening. But in this situation whenever we talk about a semiconductor device, we talk about electrons. So, whatsoever so now the interfacing is like this you have the neuron which is functioning as ion transport or ionic flux, and you have detector which involves electron transport. So, you are miring two different branch; one is the ionic transport, and your detecting use an using an electronic devices.

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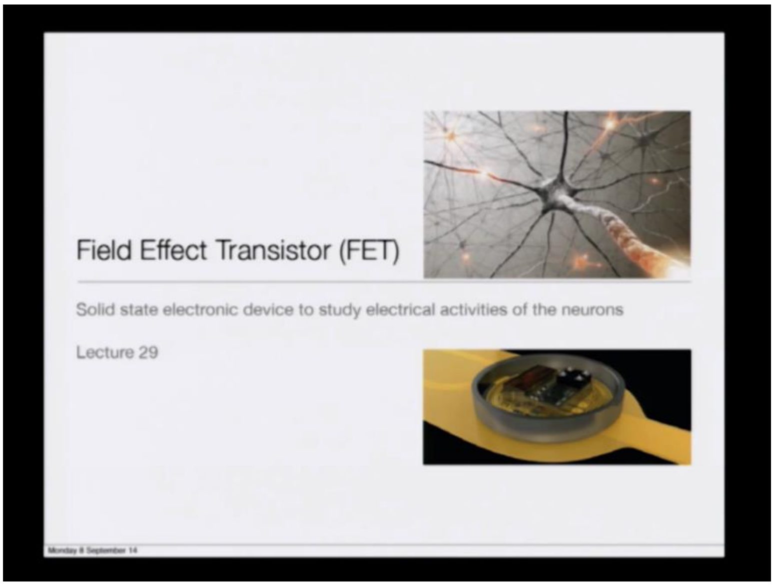

So, coming to the slide, so this is the first slide talk about the field effect transistors, in other words, the solid state electronic device to study neuronal activity or the electrical activities of the neurons. So, I just given nice picture of the neuronal network in close approximately a single neuron with all its processes. You could see, and the underneath there is a picture of field effect transistor at a very high resolution.

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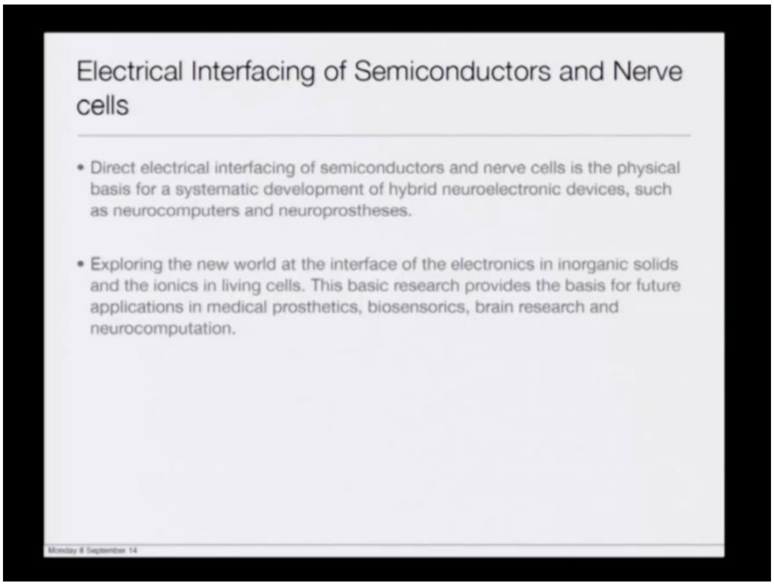

So, what really we are trying to do. So, if you see the second slide, it is basically what we are trying to do is electrical interfacing of semiconductors, and nerve cells. So, direct electrical interfacing of semiconductor, and nerves cell is the physical basis for a systemic development of hybrid neuroelectronic system. So, neuro part is out here, this is your neuro part, and this is your electronic part. So, that is what we talked about hybrid system, because these are two different systems which are making a hybrid neuroelectric devices, and which someday somewhere in a distant future possibly will have neuronal computers, neuro prosthetics governed by the interfacing of semiconductor devices with our own nervous system. This is basically we are exploring the new world at the interface of the electronics in an organic solids, and ionics in a living cells, that is what I was trying to explain. This is the ionic world we are about, and semiconductor is a electronic world we are talking about.

So, coming back to the slide, if you see basic research provides the basis for future application in medical prosthetics, biosensorics or biosensors, brain research, and neuronal computation which someday, the kind of algorithm which are followed by the neurons in their competition ability which you must have observed well. We were discussing of learning memory could be utilized for developing better electronic system, memory storage devices, and so on, and so forth. So, this is that is why I wanted to close down this segment of animal electricity with this interfacing part, where lot of research is going on all over the world.

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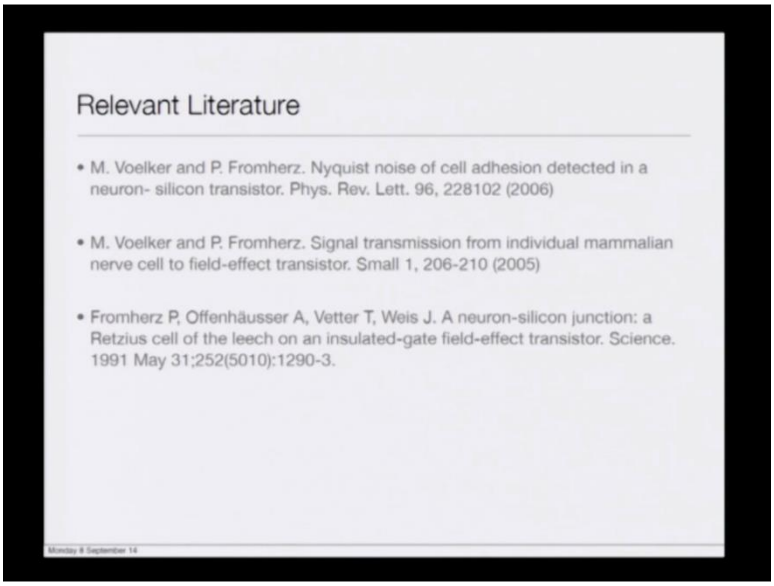

The relevant literature I have sited this last paper if you see from Peter Fromherz, and Ander Offenhausser, J Weis, and T Vetter. So, this is one of the seminal paper which is published in a journal science back in 1991 are neuron silicon junction a Retzius cell of the leech on an insulated-gate field-effect transistors. It was while another very very seminal discovery, and please go through the work for Peter Fromherz is a American professor now in the biochemistry institute of Max Planck institute, it is a biochemistry institute.

Let us go through some his word, because he is one of the pioneer, he worked along a several people Ander Offenhausser, and all these other people, and he was involved in giving birth to this extraordinary challenging area of interfacing neuronal system with the semiconductor devices. And which involves a lot of technical expiates, lot of understanding of device physic, because your story alive it when you are dealing with semiconductor you really have to understand the device physic very right. And, then on top of this, you have to in the one of the last slide, I show you how those chips were being made there keep on improving, but at this stage I will show you another primitive chips which are developed by Peter Fromherz.

So, and most importantly are dare to dream 1991, it is long time back almost now, and it is almost more than 20 years dare to dream for something which was not seen before. So, I will request you please go through this paper, and I will add few of the materials some of the patents which has been file by Peter Fromherz, and Max Planck go through this paper which was published very more recently that 2005 neuro several papers, but these are the kind of papers which are main tress those who of who were interested on understanding what we really meant by neuron silicon transistors. So, here in this section I will only touch the very basic fundamentals I am not going to get into the device physics, because that is beyond the scope of this codes, because that may consume another fifty or twenty lectures all by itself.

Sip I will just, because I am devoting only one lecture to give an over view. So, that you can build up on the story on this. So, you do not except that I am going to the all the details of the device. So, that I will give you the key points which will help you to develop the story for your further end able with this relevant literature I will move on to what we are trying to do.

So, basically now this it is clear it is a neuron silicon interface we are talking about a power full tool for brain research information technology, because that is what possibly, because if you look at it now coming back, and we look at the current state of art with the information technology we are releasing the size of the transistors or you know the computational hardware day by day, but there is a limit we cannot go beyond it, but look at your own brain that is small structure is making all the possible competitions.

If we really even understand twenty percent, if we could really mimic in the electronic industry of what the real neuronal network in the human brain is functioning. We could make a quantum jump from the current state of fears with our all the silicon based electronic system, and just to give you small detail from here whenever I am talking about silicon base systems.

So, if you look at the semiconductor, because this one of the lectures I will be giving at the fag in where I will be talking about some of these amorphous silicon’s. And so if you look at the semiconductor industry semiconductor most of us always associate it with during ninety forties, and fifties with barden britain, and shockley working on crystalline silicon, and made the discovery.

But it is interesting to note that semiconductor behavior is observed much much earlier than that it was initially observed by michael faraday while working with some of the sulfide molecule, but he really could not explain this normally in your behavior followed by that it is. So, some of the words by sir J C Bose with galena, and few other people at that point of time that they discovered this semiconductor effect at that time back in eighteen hundred, but the real success story in terms of commercializing it, and really formalize as I independent discipline start it since ninety forty that is why here will be talking about the neurons silicon interface, but just to remove a doubt this could be something else also any other semiconductors.

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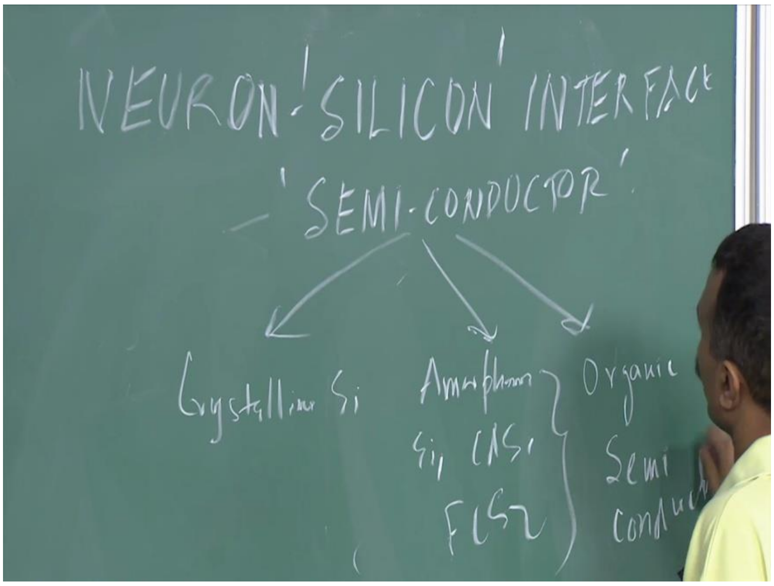

So, whenever we talk about just in a second let me just. So, this whole thing as far as imaginations can go. So, what you see here is something like this on your slide neuron silicon interfacing. So, this might as well could be written neuron semi conductor interface instead of silicon, and this will include everything you know you will have crystalline silicon you have amorphous silicon, then you have cadmium sulfide, then you have f e s two all the different sulfides, and everything, then you have organic semiconductors, and everything.

So, this part can go up, and up, and up, and up. So, any of these materials which could be used to detect the neuronal signal should fall under this broad heading of neuron silicon interface or neuron semi conductors sorry neuron semi conductor interface fine.

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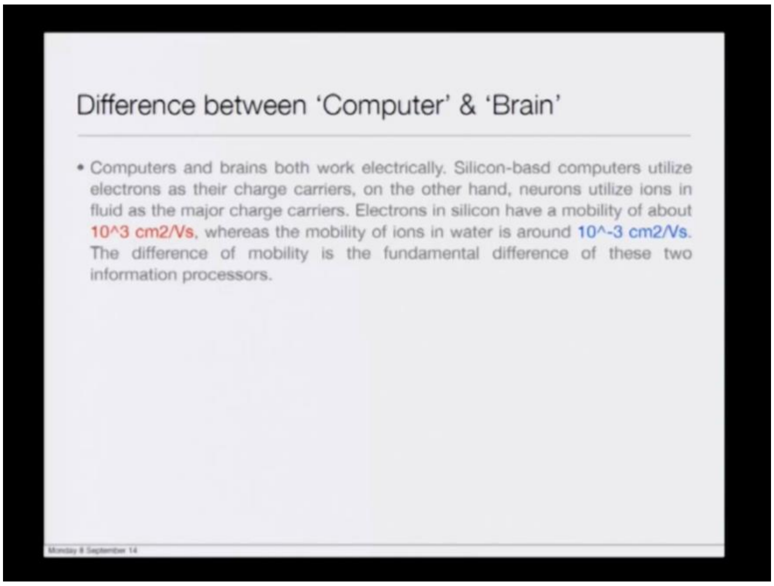

Now, coming back to the slides. So, what is the difference between. So, let we start from the basics what is the difference between brain, and computer. So, one of the fundamental def computer, and brain both worth electrical that we know. So, be both of them have electrical impulses, but problem is silicon base computers utilize electron as their charge carriers on the other hand neurons utilize ions sodium ions potassium ions magnesium ions calcium ions likewise. So, and. So, for fluid has the major charge carriers.

Now, if you will see the speed that is stunning on this electron in silicon have a mobility of ten to the power three meter square where has the mobility of the ions in water is far far less see the difference in the speed ionic fluxes are as I was showing in the previous as well as kind of you know putting it down on the board once give me second ionic fluxes are extremely speed wise this speed is very very high during interfacing two systems whose charge carrier, and mobility is totally different the difference of mobility in is fundamental difference of these two information processors

So, you are marrying a ionic system with an electronic system now here I just give an example on the slide how it looks like, and I will tell this story a neuron growing on a field effect transistors now what we will do?

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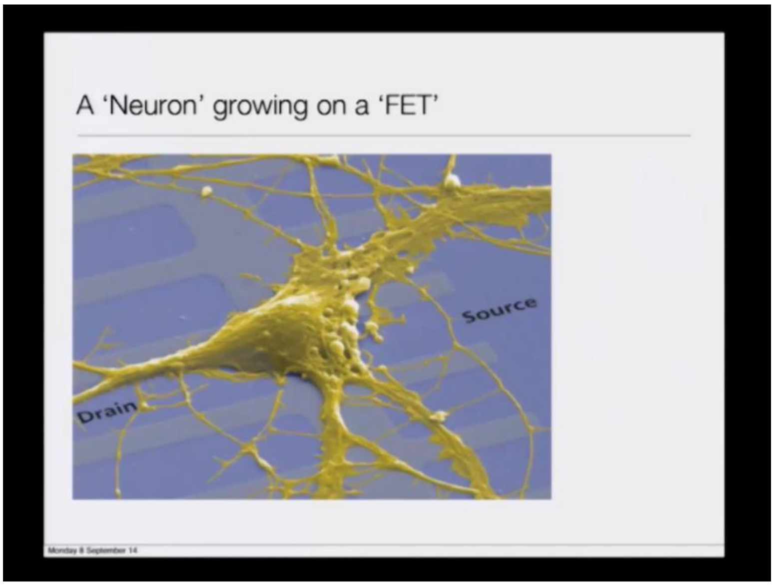

So, you see an field effect transistor there is a source there is a drain, and in between you see this whole yellow thing this nothing but a neuron growing on a semiconductor device now e will talk about the coming slides what is field effect transistor, and what is that the interface what are we really detecting.

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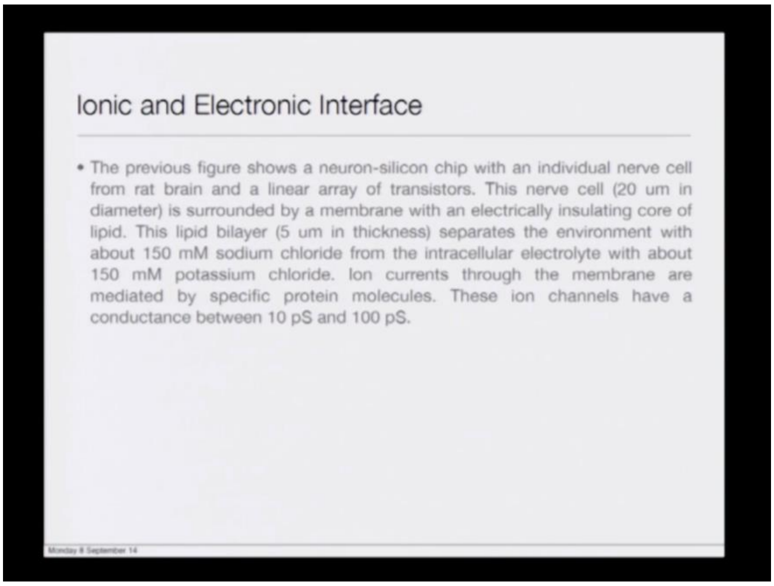

So, now starts our journey of interfacing neuron on semiconductor devices ionic, and electronic interface we have little bit talked about it here just recap the previous figure shows a neuron silicon chip the previous figure just, now I showed you this figure.

So, it is basically showing which you showing an individual nerve cell from the rat brain, and a linear array of transistors this nerve cell, which is twenty micron in a diameter is surrounded by a member membrane with an electrically insulating core of lipid as you know that it is lipid bilayer of around the neuron the lipid bilayer five micro meter in thickness separates the environment with about hundred fifty mili molar sodium chloride which is the extracellular solvent from the intracellular electrolyte with about hundred fifty mili molar of potassium chloride.

We know all these things ionic currents through the membrane are mediated by specific protein molecules which you know as the channels these ion channels have a conductance of ten pico seconds to hundred pico seconds. So, now this is the time line or this is the kind of current what we are trying to major now comes what is the field effect transistor.

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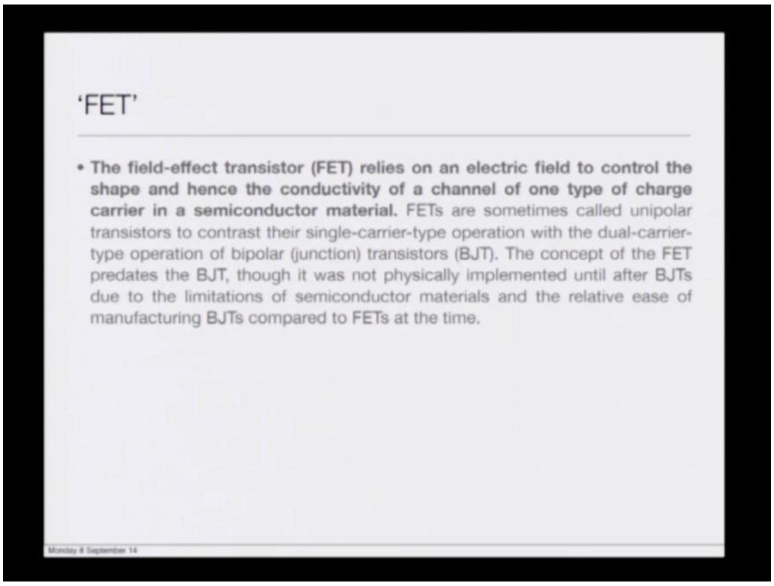

So, let us try to understand what is f f e t which is in short it is called f e t the field effect transistor relies on. Now this where I have highlighted is most important for you guides to understand on an electric field to control the shape, and hence the conductivity of a channel of one type of charge carrier in a semiconductor material this is the key point, and the key word is your electric field.

If there is a change in the electric field it changes the signal, if it is sometime also called unipolar transistor in contrast to single carrier type operation just for your understanding here let me tell you the the discovery of f e t is much before the discovery of crystalline cell silicon semiconductor devices it is as well go to the history you will observe that the discovery took place somewhere in ninety thirties, and much before that actually there patens much before that.

So, coming back to the f e t s are sometime called unipolar transistor in contrast their single carrier type operation with dual carrier type operation of bipolar junction, which is also called b j t s bipolar junction transistors the concept of f e t predates the b j t though it is not physically implemented until after b j t s due to the limitations of semiconductor material is one of the challenge what f e t s had.

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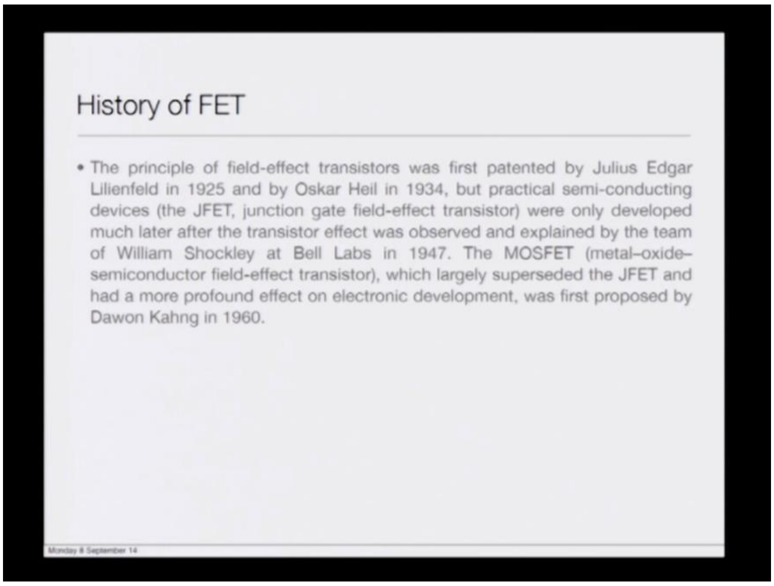

And the relative is manufacturing b j t s compare to f e t at that time at that time, and if you see the history the principle of field electric transistors was first patented by julius edgar lilienfeld in nineteen twenty five, and by oskar heil in nineteen thirty four, but practical semi conducting devices using the junction field effect transistors I am sorry the gate field effect transistors were only developed much later after the transistor effect was observed by the team of william shockley barden, and britain at bell labs nineteen forty seven.

So, you see I mean there is a technology, but the technology really could not pick up, because there are manufacturing problems there are problems of getting pure crystalline silicon, because those are really tough thing, and followed by the mosphate of the metal oxide semiconductor field effect transistors see which largely largely supersede the j f e t, and had a more profound effect on electronic development was first proposed by dawon kahng in nineteen sixty.

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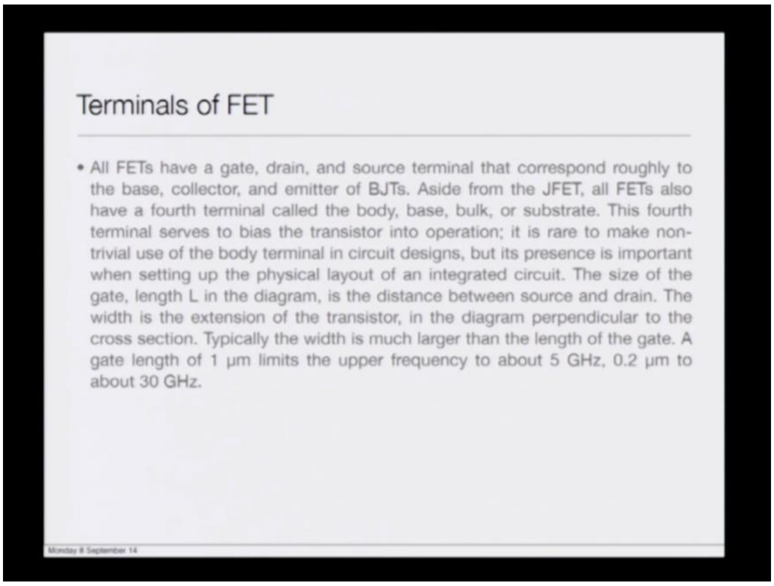

So, this is briefly the history of f e t now talking about you saw something out there there is a source, and a drain, and all those things what are those. So, what really are the terminals of f e t. So, those of you who have seen a simple transistors you remember that simple transistor has you know if you look at a second, if you see those old style transistor you will see there are sometimes three sometimes four leads coming out.

So, this is the transistor here, and that these are leads which are coming out. So, one is collector one is an emitter one is base similarly the f e t s also have different terminals, and will talk about the terminals in this slide if you look at this slide all f e t s have a gate they were drain, and there is a source terminal that correspond roughly to the base collector, and emitter of the b j t s.

So, you see the base collector emitter the corresponding are gate drain, and the source aside from the j f e t s all f e t s also have a fourth terminal called the body base or bulk or substrate these are all synonymous there is a body on which, and as man fact you see the body where all this cells where sitting on top of the gate, and all those things this fourth terminal serves as bias the transistor into operation it is rare to make non trivial use of the body terminal in circuit designs, but its presence is important when setting up the physical layout of an integrated circuit the size of the gate length l in the diagram is the distance between source, and the drain the width is the extension of the transistor in the diagram perpendicular to the cross section typically the width is much la larger that the length of the gate. So, again as let me tell you you really do not need to get to the physics of this device you have to understand the basic concept how you detect the neuronal signal that is the most important thing which I wish to highlight.

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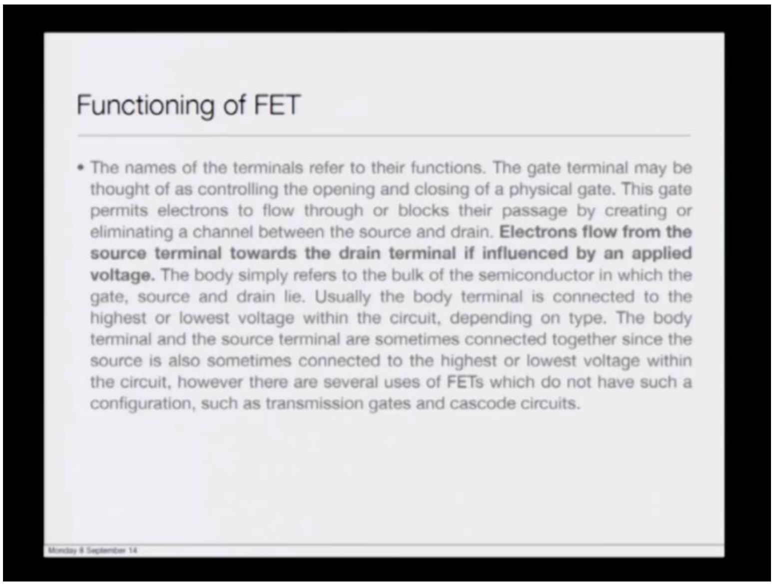

Coming to the next slide the functioning of the f e t the name of the terminals refers to their function the gate terminal may be thought of as controlling the opening, and closing of a physical gate this gate permits electrons to flow through through or blocks their passage.

So, it is gate is basically you know you open the gate there is flow of electron you close the gate the electron flow is being halted, now coming back to the slide this gate permits electrons to flow through or blocks their passage by creating or eliminating a channel between the source, and drain now here is the key line which is important for you people to understand electrons flow from the source electrons flow from the source terminal towards the drain terminal if influenced by an applied voltage. So, the electron flow is regulated by an applied voltage or a field the body simply refers to the bulk of the semiconductor in which the gate source, and drain lie which is kind of you know casing almost usually the body terminal is connected to the highest or lowest voltage within the circuit depending on the type the body terminal. And the source terminal sometimes connected together since the source is also sometimes connected to the highest or lowest voltage within the circuit; however, there are several uses of f e t's which do not have such a configuration. So, do not get into that what is most important is that if you look at between the source, and the drain. So, if you see the electron flow from the source terminals towards the drain terminal.

So, if you see this picture now from the source to the drain you see in the picture there's a source, and there is a drain, and in between on the gate there is an electron there is an neuron which is sitting out there. So, the flow of the electron from the source, and the drain is regulated by the applied voltage that is what was been shown here the electron flow from the source terminal towards the drain terminal is influenced by the applied voltage.

Now, how we get this applied voltage now if you realize here across this if the neuron is sitting that neuron is continuously you know cross tucking now let us see what is happening, because when it is this neuron is cross tucking there is a change in the field the change in the voltage at that particular side we will have a better page view as we will move through.

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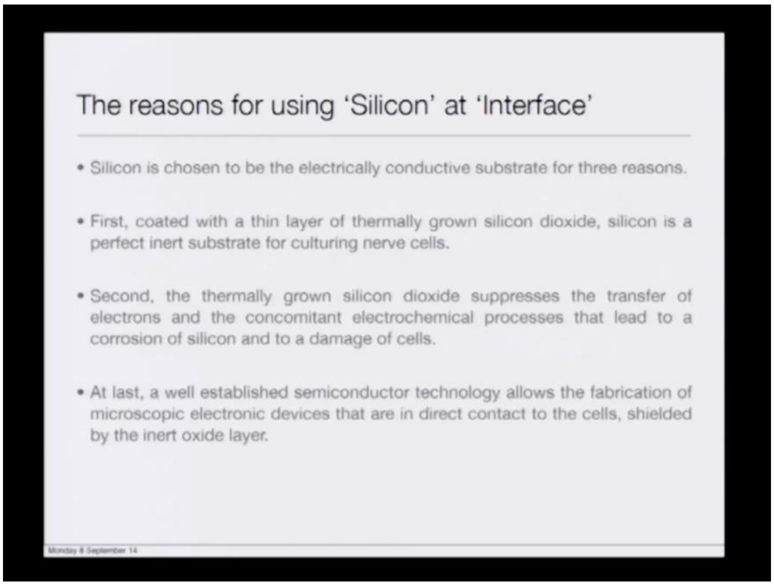

Now, coming to the reason for silicon at the interface this is just little off, and then I will again comeback silicon is chosen to be electronically electrically conductive substrate for three reasons. First coated with a thin layer of thin layer of thermally grown silicon oxide dioxide silicon is a perfect inert substrate for culturing nerve cells this is one of the reason why we are using, because you need a substrate where the neurons can grow you need a substrate which could be modified with different kind of proteins. So, that it supports the growth of the neurons.

Second a thermally grown silicon dioxide suppresses the transfer of a electron, and the concomitant electrochemical process. So, this essentially means is that there should be. So, if you see this picture when you are growing something like this you have to ensure that there is no leeching taking place, because you are on top of a semiconductor device there’s a lot of water, because whenever we talk about you know electronic device I mean think of this they always say you know do not go to water or you know your cell phone all of you carry a cell phone or likewise you know do not go to the water they will go you know bad, and all those things, because you know water will percolate there will be you know short circuit anything could happen.

So, now you are trying to have a dry electronic. So, whenever we talk about you know semiconductor we talk about a very dry system you have to this system you know away from water where as whenever we talk about ionic motion we are talking about the wet electricity say if this is the dry electricity, then this is the wet electricity now you are trying to interface the dry electricity on a wet electricity, because all the neuronal activities are all wet electricity. So, you need to choose a substrate which is which could suppress the transfer of electron, and the concomitant electrochemical processes that leads to a corrosion of silicon, and a damage to the cells. \

So, you have to realize this is a very tricky thing as a matter of fact for any kind of device you may you have to ensure that the device is not corroding out there, because of the continuous presence of a electrolyte on top of it, because here is an electronic device semiconductor on top of it I have this fluid continuously moving through, and there are cells which are secreting all kind of proteins, and what not. So, you have to ensure there is no corrosion there is no leeching there is no toxic, because underneath you have silicon you could have any kind of semiconductor material what I was showing you. So, you have to ensure that they are not getting corroded.

And the last a well established semiconductor technology allows a fabrication this is partly, because of the electronics industry since nineteen sixties has taking quantum gems in terms of the manufacture. So, there is a ease of manufacturing you really do not there are very well set clean rooms you can depending on the level of purity you want you really can place the semiconductor semiconductors, and you can place the transistors at specific geometry you can do a whole series of you know you could you know vary the size of the gate you can vary the size of the whole device, and there series of manipulation which you could do. So, that is why people prefer the silicon based systems.

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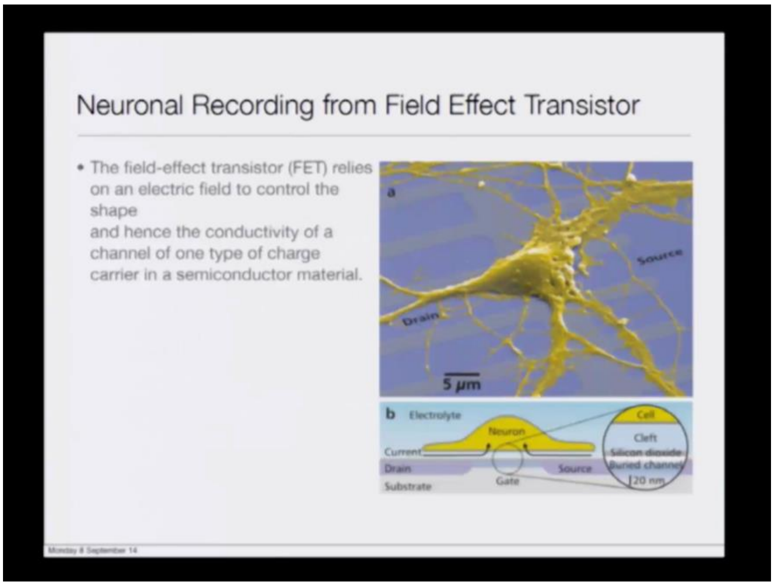

So, coming back what is? So, now, if you look at this picture this is very interesting picture. So, I showed you now you see the underneath what is there. So, you have this neuron which is in yellow underneath you see there is a source, and there is a drain, then there is a gate which regulates the flow of electron from the source to the drain.

Now, you see those two arrows from left hand, and right these are the currents which are basically the ionic fluxes which are moving in an across the cell. So, whenever there is a ionic fluxes moving. So, what is happening? So, if you try to you know imagine if you see this picture it'll make more sense now. So, here you have the cell sitting I am just redrawing what is there in your slide, and here you have the electronic device, and here you see this yellow arrow coming through, now if you refer to the slide again you will see that these yellow arrows are nothing but the influx or, and in this zone in this zone there is a change in voltage, and change in this showing the change change in field a change in electric filed I should put it no change in electric field.

Now, coming back a field effect transistors now read that on your left hand side the field effect transistors f e t relies on a electric field to control the shape, and hence the conductivity of channel of one type of charge carrier in a semiconductor material.

Now, you see that how the gate voltage could change, because depending on that opening, and closing of the gate it will decide how much current from the source to the drain will flow. So, this is the fundamental basic what you need to understand, and try to understand these things diagrammatically instead of getting to all the technical things, because you have to understand visualize the whole process, if you visualize the whole process, then you should go to the techno technical part of it without understanding the having the basics cleared do not jump into the technical jargons you will get lost completely onto this.

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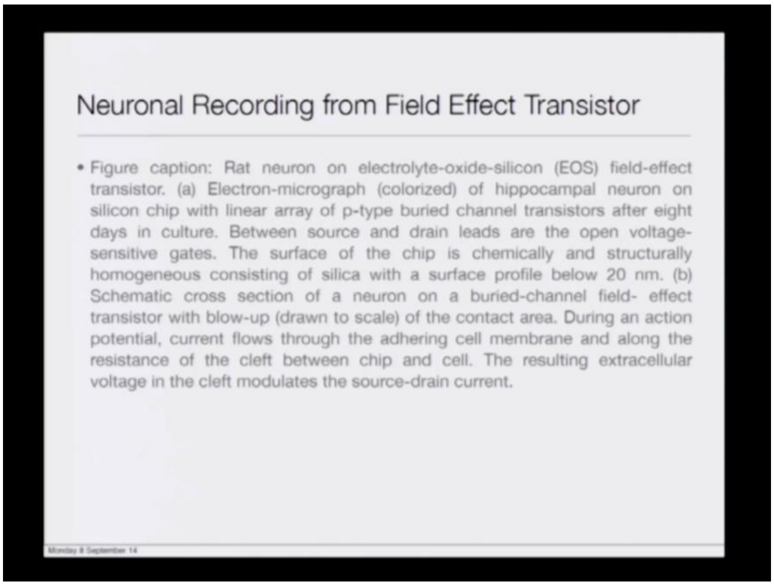

So, now neuronal recordings from field effect transistor the the caption what is the picture what you saw is basically there is a rat neuron on electrolyte oxide silicon field effect transistor the electron micrograph of hippocampal neuron, we have talked about it in the silicon chip with a linear array of p type buried channel transistors after eight days in culture. So, this was eight days the cells are going. Now you realize why it is important to ensure that there is no leeching taking place, because eight days twenty days you are growing a neuron on top of a silicon chip if there is a leeching this cell will die.

Now, coming back the surface of the chip is chemically, and structurally homogeneous consisting of silica with a surface profile below twenty nano meter the schematic cross section of a neuron on a buried channel will effect transistor with blow up drawn to scale of the contact area during an action potential current flows through the adhering cell membrane, and along the resistance of the cleft between chip, and cell the resulting extra cellular voltage in the cleft this is the most important line the resulting extra cellular voltage in the cleft modulate the source, and the drain current.

So, this is exactly what I was trying to tell this change here this change is this what this source, and the drain is sensing there is a gate out here that is it, and that is the most fundamental thing that is why I am repeatedly telling you try to visualize take a sheet of paper draw it, and try to visualize once this is clear, then you can read all these papers, and slowly slowly develop the technical know, how the rate. So, this last line the resulting in extra cellular voltage in the cleft modulates the source, and drain current, and this is where lies the catch.

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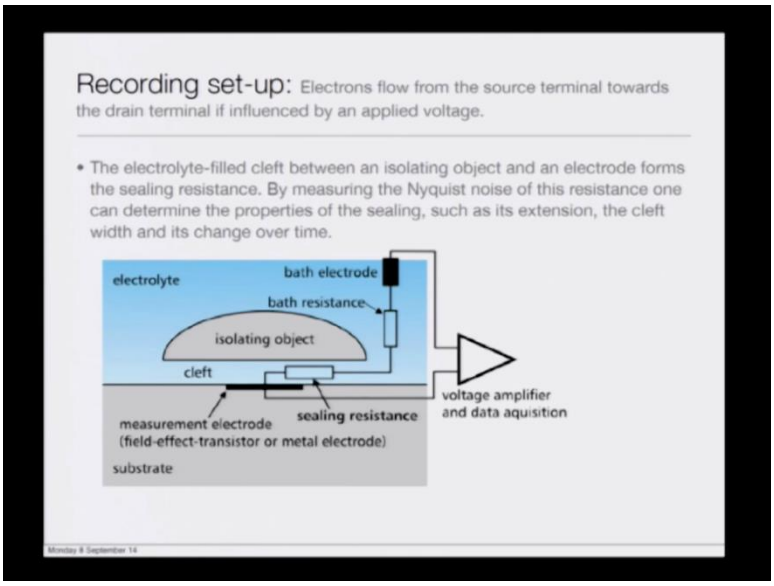

And if you look at the recording setup this is how the recording setup, and by the way these are all taken from peter fromherz peter, and some works which are published online. So, electron flows from the source, and drain terminal if influenced by an applied voltage applied voltage the influence is coming from this neuron or it could be anything you know it could be a cardiac cell, but it has to be an excitable cell which continuously you know changing its voltage extra cellular voltage the electrolyte filled cleft between an isolating object, and electrode forming the sealing resistance by measuring the nyquist noise of this resistance one can determine the properties of the ceiling such as it is extension the cleft width, and it is change over time. So, this is exactly how these measurements are being made.

Now, let us see what happens when the silicon. So, what is the process systematically lets go through it when nerve cells grow on a chip they deposit cell adhesion proteins secrete proteins to provide cell anchorage. So, these cells adhere to the surface these proteins keep the lipid core of the membrane at a certain distance from the substrate you look at it they are at a certain distance they are at a certain distance look at this they are at a certain distance where you see its current. So, there is a certain distance which is being maintained these protein can keep the lipid core at a certain distance from the substrate stabilizing the cleft between the cell and the chip that is filled with a electrolyte the conductive cleft shields the electrical field, and suppresses a direct mutual polarization of silicon dioxide, and membrane the silicon cell silicon junction forms a planar electrical core coat conductor the coat of silicon dioxide, and membrane insulate the core of the conductive cleft from the conducting environment of silicon, and the cytoplasm.

Step two the activity of a neuron leads to ionic, and displacement current through the membrane the concomitant current along the core gives rise to something which is called transductive extra cellular potential. So, this is what that change is this change in voltage is what is transductive extracellular t e p what you have seen in your slide now that is what we talked about transductive extra cellular potential mean while a voltage transient applied to silicon leads to a displacement current through oxide coat thus the t e p appears between the chip, and cells due to concomitant current along the cleft.

In the second stage of interfacing the t e p in the core coat conductor is detected by voltage sensitive devices in the chip or in the cell you could have voltage sensitive dyes here you know which could detect the change you could have a voltage sensitive dye here sorry voltage sensitive voltage sensor here which could you know see the change of the t e p ok.

Now, what happens when the nerve cells this is the last part the interfacing of the neuron, and semiconductors is mediated by transductive extracellular potential a large t e p results from high current through membrane, and silicon dioxide, and from a low conductance of a junction recording an stimulation of neuronal activity are promoted by a small distance high specific resistance p, and a large radius a of the cell chip junction efficient recording requires high ionic ion conductance’s g in the attached membrane efficient stimulation a high specific capacitance c of the chip.

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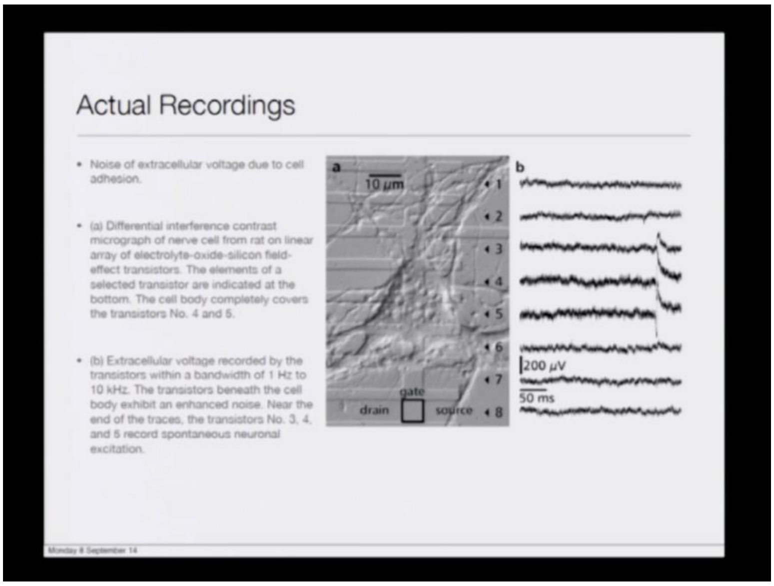

Now, coming to the actual recordings this is how the actual recordings look like. So, here again you see the neuron sitting out there this is in black, and white you just have to, and all those one two three four five six up to eight you see those are the gates those are where the source, and the drains source, and the drain source, and the drain likewise.

So, if you look at it at different source, and drain. So, from one single neuron now think of it while we were talking about the say for example, I talked about this cell, and I want to record from it I could put one electrode two electrode maximum three electrode, but every time there will be a lot of leakage, and there will be lot of loss of you know ions I cannot really do that I mean in the case of patch electrode you left this big a patch electrode you know I cannot it is very tricky to put maximum you can put four patch electrode if you are really really good you have to be absolutely amazing to do that.

But look here from one cell just from a single cell out here sitting out there how many gates are there at least there are eight I can guarantee you this could be reduced down to sixteen also. So, from one single neuron at one point of time you are recording from here recording from here recording from here recording from here from all the possible, and zones you can make the recordings this is the power of this technique with electronics which is far more smaller, then the ionic all these electrodes you can make multiple recordings. So, this is the profoundness of this technique why this technique is being followed. So, expensively is this.

You really can make a significant amount of recordings, and you see it. So, in the one you do not see a change two you do not see a change three do not you see three you started seeing the change if you look at it, and the third you'll see a change fourth fourth fourth gate you see a change on the fifth gate you see a beautiful change sixth gate again you are having an not decent able I mean it is kind of there seven eight you hardly see anything. So, the noise on the extracellular voltage due to cell adhesion, and and this is very important the extracellular voltage recorded by the transistor within a bandwidth of one hertz to ten kilo hertz the transistor beneath the cell body exhibit enhanced noise near the end of the traces the transistor number three, and four, and five recorded spontaneous neuronal excitation three four five.

It is a spontaneous neural activation which is very tough to pick up these signals have very very tough to pickup with an extracellular electrode or any other kind of you know electrochemical devices which you really cannot do, and if you see this is how the transient goes when the f e t signal during the depolarization followed by the relaxation tells this is what we call a cell transistor hybrids.

So, if you look I was telling in the in the one of the last slide I will show you this is how the chip look like encapsulated chip if you look at that encapsulated chip underneath this. So, there is a glass on which on top or there is a almost a glass I should say a teeny tiny glass plate you know or with the walls surrounding it. So, you plate the cells on top of this encapsulated chip this is the where the left hand bottom figure what you are looking at on top of this in in that small dish you culture this cells, and those cells underneath those cells are the embedded are the electrodes. So, those neuronal activity what is taking place inside that chip are being sensed by the chip or by the gates which are underneath it.

This is the in depth detail of the different gates you see those gates out here with the in the top left figure in the green, and yellow you see the gates you will see with a orange, and yellows will give you the where the source, and the drains are, and this is a individual gate. So, this is how where we are the modern semiconductor technology could provide suitable tool for massive parallel monitoring of neuronal activity at high spatial, and temporal resolution, because why it is an high temporal spatial resolution, because you could get recordings from both spatially as well as temporally over a period of time you see say for example, let us see an hypothetical situation say for example, in the neuronal network. If you could grow a wonderful network on top of an f e t say this is the neuronal cell body which is involved, and you have a gate here you have a gate here you have a gate here you have a gate here all these are different zones where the gates are now over a period the signal is moving like this over temporally you can measure this signal temporal measurements as well as you can measure different place in the space of it you can get it from the dendritic you can get it from the axom, and you can get it from cell body you can get it all the way to the down of the you know adjoin terminal likewise and so on and so forth.

So, you see all the signals what we obtained from f e t's far more powerful, then using an extracellular electrode, and it is very non process there is a technology which is slowly developing it will take time it is not easy to interface there is a lot of research which is needed in bio materials in which you interface this semiconductor materials, but this is where the future lies, and that is why I pulled this up last twenty ninth lecture of the animal bioelectricity this is what people are trying to do interfacing semiconductors with neuronal system.

So, I will close in my lecture here. So, I believe I request you people please go through the peter fromherz work, and under offenhausser work, and few other works some of the italian groups are working on organic semiconductors to interface cells using penticin, and all these kind of molecules please go through this.

Thanks a lot.