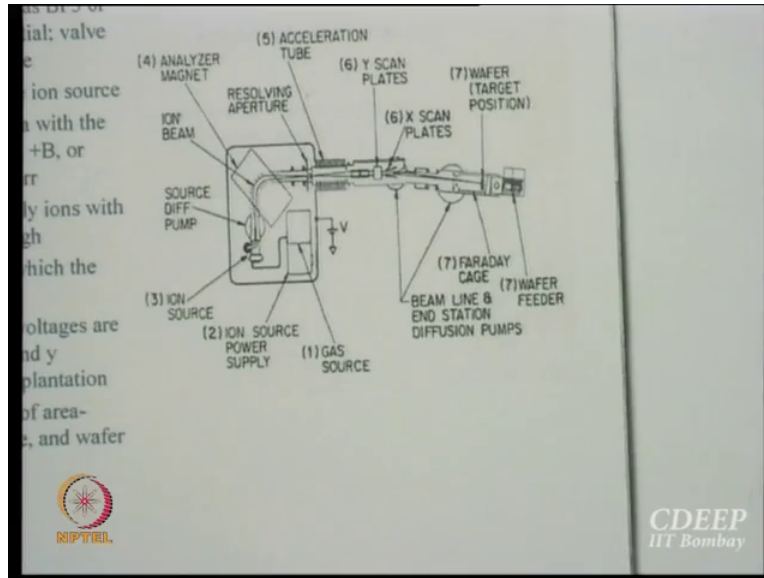


Fabrication of Silicon VLSI Circuits using the MOS technology
Professor A. N. Chandorkar
Department of Electrical Engineering
Indian Institute of Technology Bombay
Lecture no 21
Module no 01
ION Implantation

(Refer Slide Time: 0:37)



So far we have seen theory of implantation, we have also seen the profiles which ions can get into silicon or further any material these sheets are taken from website from (0:39) University of Ryan, I hope some of you must be knowing someone is here from that university. Those who are doing their projects, many of them may be knowing there is someone who is here in our faculty who is from Ryan the same university. I have just once thought what is the university so I found this slide so I just I took its photograph okay. Okay we are trying to know something what is an ION implanter, the basic ion implanter is something like this.

We have a source of impurity which is normally in the gaseous form for example, in the case of boron we have boron chloride BF_3 , in the case of arsenic it is $AsCl_3$, in the case of phosphorus it is PCl_3 okay, or in the case of antimony or any other you have to 1st create its gaseous source okay. Now this gas is then such as BF_3 or $AsCl_3$ is accelerated at high potential in a chamber which is shown here, and as this gas (1:59) there is a large electric field which actually break those

ions into BF_3 gas into chlorine as well as boron ions. And now if we get arsenic, boron or antimony or phosphorus, ions of either of these species along with hydrogen okay.

So 1st thing is I must separate RC or anything from or some part may not be even ionised so there will be some gases which will be unionised, there will be some hydrogen and some species which we want to implant and there is some impurity is well in the gas field. Now since I want only 1 impurity to come out okay that is I want arsenic to be implanted so the chamber may have all kinds of ions but I must take out only one of them which I want to implant okay, so that is called mass analyzer we will see what is it, mass analyzer so I must somehow get out of this whole magnetic system which we will soon discuss, only those species which I want okay. And that when it comes out then I accelerate them by large electric fields then there is a deflecting system scan system which is also electromagnetic system and the beams then moves along accelerated ions are beam and there is a vapor holder here on which they impinge okay.

So you have to understand that the 1st thing I must get some kind of source of impurities in a gaseous form so that is I have solid form. Okay fine so then (())(3:47) inside heat and see to it that you get vapors or gaseous form, these are then introduced in the chamber called plasma chamber and in this large electric field breaks the gas and it releases ions. These ions then passed through a magnetic which is electromagnet as shown here and somehow then only those ions which I want okay, rest will be hit elsewhere and only in this slit only those ions which I am looking for probably will pass through, they will pass through a large electric field so they get accelerated ions get energy from the electric field and they essentially get $\frac{1}{2} m v^2$ which is Kinetic energy which essentially is equal to $Q V$ okay energy due to electric fields.

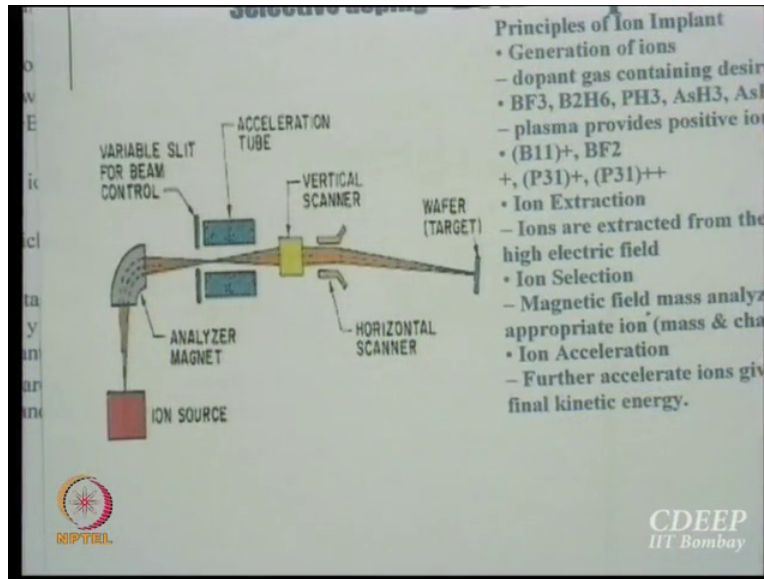
Now if we go through this, they will accelerate larger energies, this is what it acquires energy so you say I want 10 KV, 100 KV, 300 KV, it is this acceleration system which is typically a periodic system which accelerate these ions to an energy of your choice okay maybe any amount it can, of course larger the energy base this electric field here will be very high and any transforming system which puts may not be able to stand that high voltages so therefore no more than 300-400KV implanters can be made easily not impossibility. Then of course as I said there is a standard deflecting system you have done through this all CRT systems you have magnetic field and electric field which can scan the beam X and Y okay.

And this beam passes and there is a place where the wafers kept is called Faraday cup, it was given an honour to Faraday okay so why it was given this tube kind of system is essentially a normal cathode to anode kind of electron going or ions going from one place to the other and that has faraday discharge system, so the place where ions are picked upon the wafer is essentially called Faraday cup. Okay so and of course there is a positioner where we can actually change the position of wafers in the sense the beam itself can be scanned or some mechanical motion also can be given to the wafer holders okay I will show you the (())(6:25) which we have. So this is typically what an ion implanter does okay so few things you must understand that how only one kind of particle one kind of ions only come out and how they are accelerated and how they impinge on the target wafers, which may be more than 10s or 20s or 100s okay.

There must be some wafer feed mechanism through which... Why wafer feed because please remember gas can only be ionised if there is a low-pressure okay, gases can be only ionised if there is a low-pressure so typically pressure makes the order of 10 to the power - 3 Torr, whole Torr related to atmospheric pressure 760 tor is one atmospheric pressure, 1335 Pascals is 1 Torr so there are 6 units of pressure okay so look for I may give you any, I may give you a change also do not worry. So typically this is 10 to the power - 3, vacuums are normally expressed in terms of pressure which is Torr and one can see from here that needs some kind of evacuation system called vacuum system.

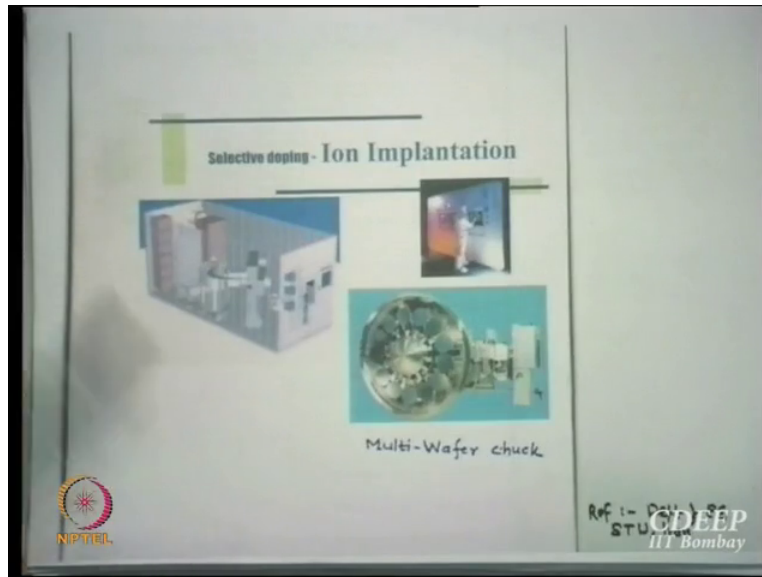
So this chamber has (())(7:42) and it has to be evacuated by Pumps, so there are 2 kinds of Pumps; rotary pump followed by diffusion pump, if you want much lower vacuum then you will have to put some kind of carob pump some kind of turbo pumps, but as of now diffusion pumps can go up to 10 to the power - 6 Torrs so that is sufficient for ion implanters okay. If you go to the lot, all rotary pumps are kept outside but diffusion pumps are sitting just below the vacuum system okay. So a rotary pump is required to start a diffusion pump, at least it should give some Torr lower tor then only infusion pump starts acting okay, some other day when I will show you actually an operations, I may show you what is a diffusion pump.

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So this is a machine, the only relevant parts have been shown here, it is the same thing what I said, this is an ion source, there is an analyzer, there is an accelerator, there is a scan horizontal vertical scanner and this is the wafer target, so this is a brief what an implanter is trying to do. It starts with an ion source, pass through a magnet which is electromagnet which is analyzer and then you get particular ions you actually accelerate and focus using these vertical and horizontal scanners and a pointed beam is actually hitting the target. These are electrostatic mechanical lenses, which is actually can focus any ion beam, so this is typically an ion implanter is is a machine Works, maybe if I have a figure I just quickly show you.

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You can see this is 20 by 15 kind of a room which can take care of one implanter, larger the energy implanter you want and larger the ion mass, you will have larger magnets so larger area, larger acceleration tube length has to be larger so everything becomes larger, large, ion numbers, larger energies and you also want large mass ions to be separated, so larger the everything it will also require larger space, typically implanter room is of this size. This is the panel and this is the chuck you can see from here, on that chuck right now for example they have shown some 12 or 14 wafers you can see from here, so what is the through put at a time I can at best put 12 wafers or 14 wafers. In any other diffusion furnace 200 is the minimum lot so I can put diffusion 200, here well, 14 or 16.

Of course nowadays there are chucks which are 48, but 48 means such big, 8 inch wafer think of it 48 so how much implanter will be large enough, it should be able to scan such a large length and width so huge money okay, this is what an implanter looks like.

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The slide contains the following content:

- Title:** Selective doping - Ion Implantation - Plasma source
- Schematic:** A diagram showing a 'Plasma Chamber' at 'mT level pressure' with 'Gas feed' and 'Ti pump' connections. It also shows a 'Magnetron sputtering source' with 'Ion beam' and 'Substrate' labels.
- Pressure:** Pressure: 10^{-4} to 10^{-2} Torr
- Handwritten Text:** Ion source is characterised by Ion current density
- Equation:**

$$J_{ion} = \frac{5.5 \times 10^{-8} V_m^{3/2}}{d^2 \cdot M^{1/2}} \text{ Amp/cm}^2$$
- Logos:** CDEEP IIT Bombay (top right), NPTEL (bottom left), and CDEEP IIT Bombay (bottom right).
- Reference:** Ref: Dutt, EE STU, IIT Bombay

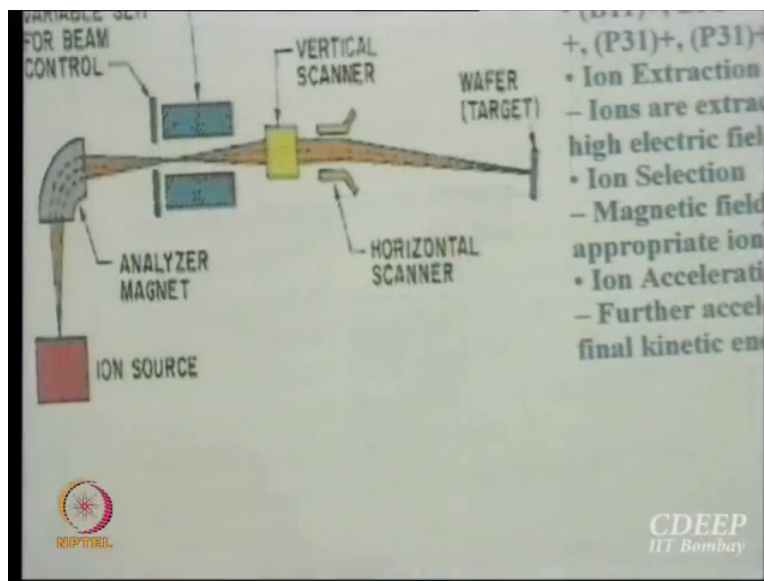
As I said we look into the each part, the 1st is the plasma source; typically I have just now said a plasma chamber you have a gas treat from here and you have a pump system which evacuates the chamber okay and one can apply electric field the external voltage here between the plates and this space. And as you actually start ionising the gas, there is a slit here which also should have some electric field so that ions can, which kind of field it should be? Positive ions have to come out, negative split must come so that they are accelerated outside okay so there is another chamber out which has the negatively bias so ions come out. Now as I said the pressure inside this chamber is around 10 to the power - 4 to 10 to the power - 2 Torr and ion source is characterised by ion current density okay.

This D distance is essentially between the extractor and the source, this is called extractor so from extractor to the slit the distance is called D. So the ion current density is $5.5 \times 10^{-8} V_m^{3/2} / (d^2 \cdot M^{1/2})$ Amp/cm². Extractor means which extract the ions out okay is that clear, extractor so those extractor voltage to the power 3 by 2 D square the gap M to the power half and it is unit of course Ampere per centimetre square. Please remember, the area is not very large here, slits are very thin small so the currents are relatively larger so if you have larger current, the cost of implanter increases typically can be say hundred or 1 milliampere or 1 amp current implanter will be cheaper than 10 amps and 100 amps okay because larger the ion current density you are looking out, larger will be the cost of the equipment which we require.

So typically I can decide, the decision of ion density is decided by what extractor voltage is I am allowed, what is the distance between slit out and the external extracted chamber and of course the mass of the ions which you are taking out, which ion like arsenic is 72 or 73, after this 31 so depends on which specie or boron is 11 so which specie is taking out that is precisely the ion current density. D is the distance between slit to the extractor chamber, YAHA SLIT HAI BAHAR AANE KE LIYE KITNA DUR this is the sum slit to the extractor is the D . Okay so the 1st part is ionise the gas and extract out ions. The next part is as I said is plasma chambers have all kind of possible impurity gases along with the...

You thought that you have got all ultrapure gas introduced but the species that we are introducing RC now this may be ultrapure but ultrapure is only say 69 or 89 purity that means there is residual impurities. The chamber itself is made of steel... the gases for it also releases impurity and the many other source of impurities inside and they will be small amount, part per billion or less than parts per billion but they are there but I do not want anyone of them to come out of the slit that is what I am really looking. But they were right now the extractor will pull all ions, whichever ions is there it will pull out okay. Now these ions I want to some now see that only specie of my choice comes out okay.

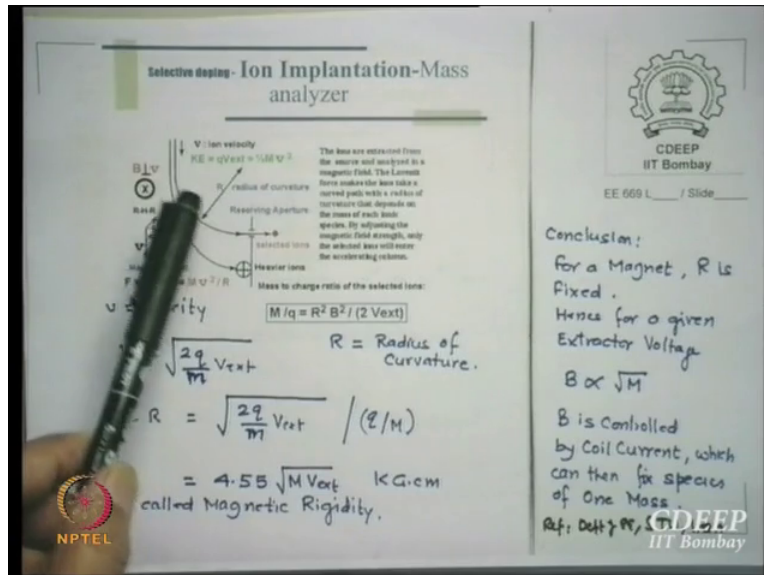
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So I passed through a magnetic system, let us look at an electromagnet maybe 1st sheet again, okay this is an cylindrical electrical electromagnet and since it is a magnetic is taken in a ring

form, it has a radius of curvature, its radius of curvature is known the magnet size and its radius of curvature is actually known to me okay. Now this means if an ion is entering this magnetic field it will experience magnetic field force, what is that force called?

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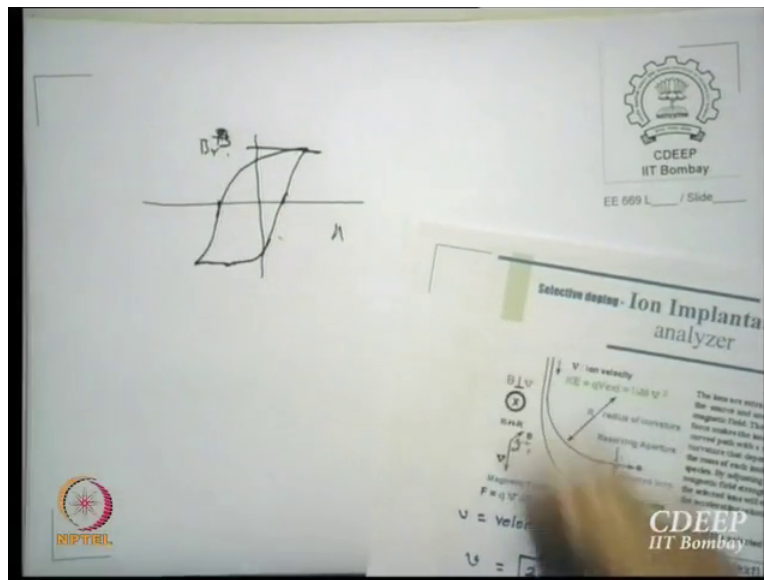


Lawrence force and since it has also accelerated, it has passed it has a Kinetic energy of half $m v$ square which was also equal to $Q V$ external voltage extracted voltage that is the energy which you give them okay. When they pass through a slit through a magnet, they will be actually passing through and they will have a motion which is which receives a force called centrifugal force, so it actually moves in a direction which is decided by $m v$ square by R , v is the velocity okay each must be balanced by Lawrence force which is velocity cross B or $v H B z$, if H is the direction of motion across orthogonal to the is the magnetic field so v is $q V$ Cross B $m v$ square by R , by solving all these I can get a term R is the radius of curvature, B into v is the magnetic flux available with this, it is expressed in gauss, what does gauss means?

How much lines per square inch? 6.4 magnetic force lines per square inch is the density which is equal to 1 gauss value okay. Okay so if I calculate V into R is the radius of curvature where $m v$ square by R is R is the radius of curvature through which they are bending okay, so if B into R is $2 q V$ external by m divided by $q m$, $q q$ will cancel so it actually can be written as 4.55 under root m times V extracted voltage. Now this B into R is essentially called magnetic rigidity and that is the feature of any permanent magnet, this has nothing to do this but there is another small

B r, anyone has done 2nd years (())(17:20) I hope so. There you have B r of magnet which is small r not capital R, what is it?

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Just now I said, B R is the magnetic flux density or so many lines per square inch or per centimetre square that is if I plot B-H curve okay maybe little bit of... What do you do... This will be Hysteresis, so the maximum value of this is B r, what is this value called? H c, what is H c? H c is your magnetisation current density at which the magnetisation becomes 0 okay, H c these are the numbers which are given for a given magnet okay and the whatever energy store is B cross H inside this B-H curve okay. Some other time since I have designed a permanent magnet motor way back I studied lot many magnetic systems. Okay so once of course so this B R and that B r should not be confused, this R is the radius of curvature.

So if R is fixed for the magnet is that clear if R is fixed for the magnet, I can now say that this magnetic intensity B or magnetic flux density B is proportional to the root of mass, is that clear? Anything else if I keep extractor fixed, this is constant, R is constant so B is proportional to root of m, m means atomic mass or atomic weight of that specie. So if I want it is any specie to come through radius of curvature of R, which is fixed by me all that I have to do is to adjust B, which means the curve and how do I just B, B is proportional to what? How do I(())(19:32) core which is normally iron or steel and I put a wire around, what is the law it follows? Amperes law okay. If N is the number of turns, I is the current flowing in this in the called N I Mu by L, L is the length

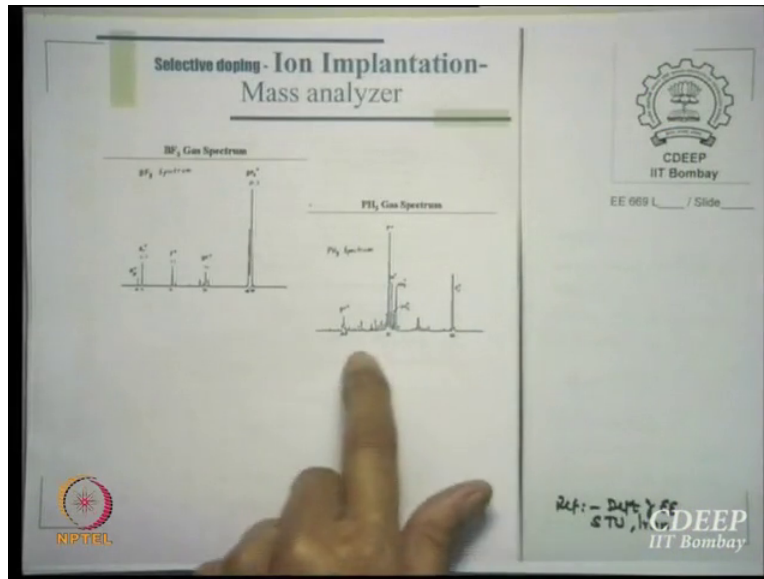
of the core so $N I \mu$, μ is the permeability, $N I \mu$ by L is the magnetic flux which it can receive, this is ampere's law very old ampere's law.

So this simple ampere's law tells us how much is the magnet, so what is that other things are constant so B will change I , since everything is fixed for electromagnet all that I change is the current in the electromagnetic coil and that decides my B . If that decides my B that decides my M , is that correct? For a given B there is only one M is possible come through R okay. So if I want arsenic, so I figure out so much ampere this current I pass through this coil so many amperes this arsenic will come, I change the current boron may come, I change the current phosphorus may come is that clear? So all that I do is fix currents are known to us and for each specie which I want to take out, is that clear?

However, if you want to change further if you change the extractor voltage which you are not allowed, but there are systems in which they allow extracted voltage to change then the $B R$ changes and then the different currents you have to plan web current and now I should have this region is there are 2 regions, it is called pre-acceleration and post acceleration, extractor will accelerate ions then there is accelerating voltage also further ahead of it. So how much pre-acceleration should be done and how much should be post there may be additional post acceleration pre-acceleration system, so nowadays it is decided that this voltage itself is variable, you can actually vary it okay but then your currents will also proportionately different for different M because B will be varying for that, is that clear.

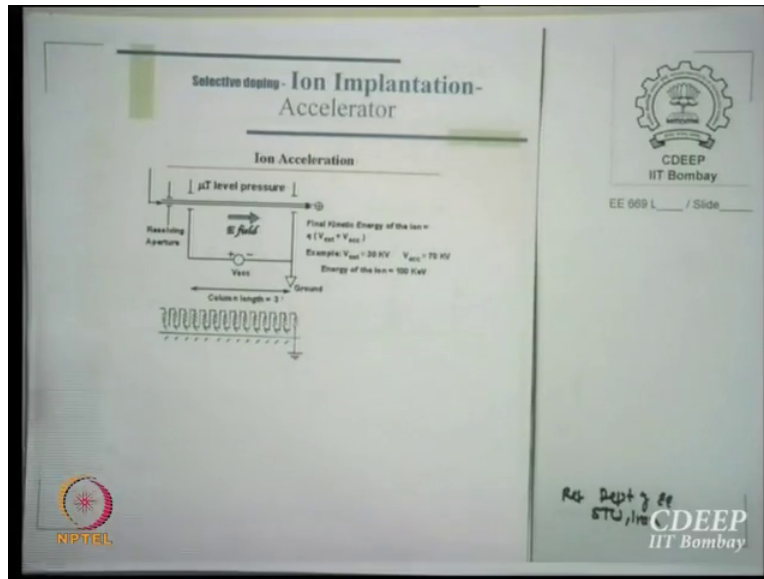
So B has to be changed the corresponding to M required and that is how called mass analysis, is that correct the system is called mass analyser. So any specie may come but through the area of curvature which have slit inside the magnet only one specie will come out because we have picked the current through which only it will bent to up okay. This normal angle is 45 degree around like this but it can be 60 degree then you will have to recalculate how much where you want to take it out, but there is no harm of any angle, generally it is 45 degree which you know, the ions come and then through 45 degree they become 90, $45 + 45$ okay, so normal it is 90 degree it moves out okay.

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Now how do I know that which gases coming also so I can actually take a Spectra through a mass, I do not know how much your chemistry there is a infra based vector can be obtained and I can see for Spectra for each of the gases Spectra base, so I know if I have the gas I want this specific specie, please remember these are isotopes of (F)(23:02) there will be fluorine, there will be BF₂, there will be so which specie also is to be decided through what is the maximum mass it is going to give as that you will have to evaluate a priori okay. So this Spectra for each gas I get it 1st I get the spectra for it, for fast system boron system as well as for... Of course these are provided by the people who (F)(23:26) gas you do not have to analyse.

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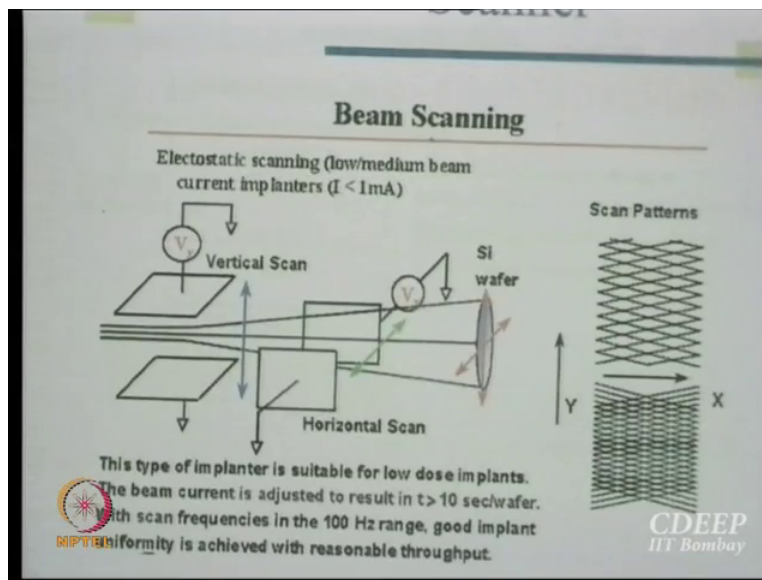


These analytical graphs are always provided to know which species has what amount of what amount of impurities or other spectra it has okay. Now this then next of course as I said you after I know which species I analyse, I also know I passed through magnet I got one species out and then I apply some kind of ion acceleration through electric field, electric field coils are shown here, you have this called revolving aperture then you have to maintain certain amount of pressure inside okay and you accelerate the ions to... What is the acceleration? Kinetic energy is q times V extractor + v which you now apply, is that how much energy it will pick up? q into V extractor + whatever v accelerating voltage now we will apply for net energy now is $q V_{ex} + v$ you have further applied okay.

So that is the net energy and that energy is what is provided to the ions, is that clear? I repeat, we already accelerated partly through extractor so extractor + additional voltage which you apply q into that is the energy which ions will actually receive. So for example they are given an example if external voltage is 30 K, extractor is 30 kV then I apply accelerator voltage as 70 KV and the ions will have energy of 100 KV, so this that is why I say nowadays this also is adjustable okay in some implanters. V extractor is already you have extracted out + whatever accelerating voltage you will put, $q V_{ex} + v$ accelerator is the net energy is ion will receive okay. So you have energetic ions okay which are coming out, is that okay gas is ionised, accelerated by

extractor voltage, passed through magnet, reaccelerated and your ions are specific ions with a given energy which you actually want to implant on okay, is that okay.

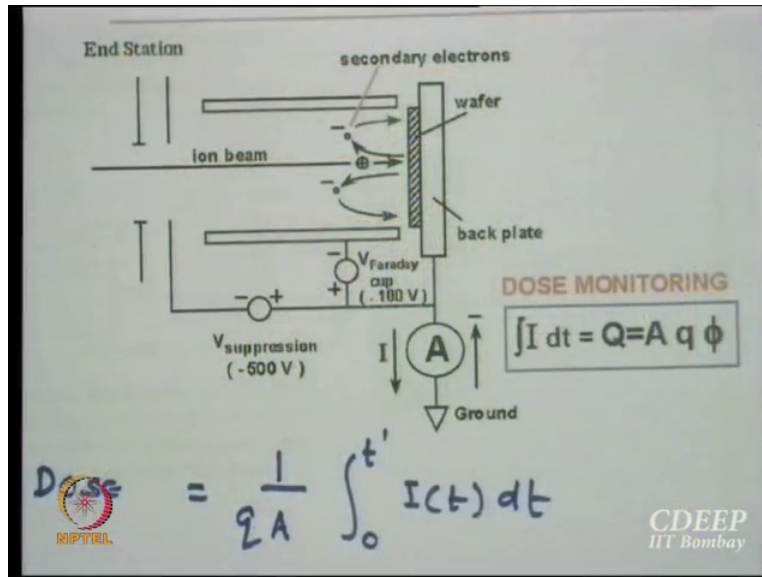
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Then we have X-Y scanner, this is a vertical scan and this is a horizontal scan, right now it is both electrostatic but it could be magnetic as well and then there is a some kind of a chuck where these wafers are holding okay maybe the system is also decided with the current of ions which you are actually picking up is that correct, larger currents will require larger deflection because so many ions. What does that mean, number of ions per centimetre square will be very high, current density is higher so now you require much higher voltages to deflect them out okay, smaller currents smaller displacement okay smaller number of ion so this is something a deflecting system which you will have to design for a given ampere which you want.

What is the current to do something is more important because my we are constantly talking of current, I 1st today talked about but let us say again why are we worried about current in the implanters okay. What does current means? It essentially measures the ions per unit time moving is not it that is the current. So larger the current means larger number of ions are flowing through this okay so the number of ions which will impinge silicon will be larger, larger current means number of ions will be impinging in a larger numbers okay and that is what we want to say. How much, what would we say dose, how many impurities I want to push in per unit area is decided by current which I will pass through okay, is it okay?

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Okay so here is the last part of the implanter, the ion beam is coming, there is some kind of cylindrical system which is called the Faraday cup or Faraday chamber, please remember in the earlier version the wafer holder... How do we measure the current, as the ion strike the wafer since they are charged and if the wafers are grounded then the charge flows through and current is monitored, is that correct? So this is the ammeter which I have shown here, this is how the current is monitored, but as the ions keep coming this current will be also time function is that correct it is a time function. And what I need after a given time I want to see how many impurities have gone in per centimetre square okay that is called dose.

So we say $1 \text{ upon } q A$, $0 \text{ to } t$ dash is the time for which implantation was performed $I t dt$, so what is this circuit should be? And integrator, and integrator is required to actually find the dose is that clear, $\int I dt$ is essentially used integrator, so this integrator along with this is a constant we know $q A$ which is scaled down directly so direct measurement on a meter you can see how many how much is the dose, (28:49) because you know area where the beam has strike how much area and you also know this integral will actually integrate the $I t dt$ is what essentially.

I is charge per unit time is that correct, so this is the net charge received is that correct this is the net charge received for unit area. I will give only charge okay, (29:15) is current okay so this is how actually we involve so normally how do I know, can I keep monitoring what is it, there

will be some kind of comparator, you fix a dose value for a given voltage equivalent and you keep monitoring this, not monitoring but you fix that value and when you turn on then the comparator will switch ON the ion source whenever that dose is same as this. This is a very simple technique which allows you to actually fix the dose okay, so you set the dose, start implanter and after when the dose is same as what you said the machine will switch off. So is that point clear so what is an ion implanter, essentially I can put number of...

And those has been in our case what is the name we gave for dose, $N S$ in our profile $N S$ is the dose we were talking about in the Gaussian part. And what is the value we said, $\int_{-\infty}^{+\infty} N \times D \times dx$ – infinity to + infinity is the amount that impurity per unit area gone in so that is the dose, is that clear? So any profile should be integrated from – infinity to + infinity because it is a Gaussian goes to – infinity to + infinity. So this... Did you get the point how I there are fix dose, I actually set one of the comparator value of fix dose whatever I want, then the integrator gives output correspondingly and it keeps comparing with the set value. As soon as the set value matches that, comparator changes the state and switch off the... Creates a pulse switch off the ion source so automatically dose stops I mean implantation stops.

So this is what ion implanter is all about and what is the advantage of ion implantation we said, impurities can be put below surface is that clear, any other decision it starts from the surface there is no other way I can do that is that clear, so the 1st thing I got advantage that I can go below the surface anywhere. I can fix the dose that any position, some device I said I want lower concentration, I mean higher concentration on lower side and lower concentration on higher side that is also possible called hyper abrupt because I can put impurities higher dose below lower dose above. I can change, I can take any arbitrary profile you give me this is the profile I want, I can adjust number of multiple implants and I will give any kind of profiles okay. I can adjust any amount of dose by adjusting the time okay till I have some damage so I will (())(32:01) that damage and I also expect during that impurities will also get into substitution side.

So essentially an ion implanter has replaced solid-state diffusion as a source of impurity, but after impurities have gone in it still follows the diffusion norm, please remember dt product is not neglected, dt is same so (())(32:23) so much about solid-state diffusion because we were looking for diffusion as a theory. The source that time was constant so it is limited source but we actually

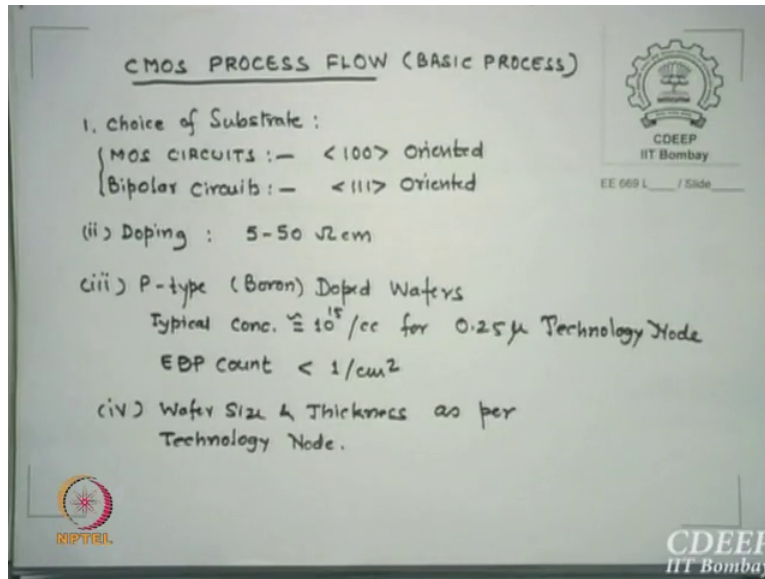
looked into how impurities get into silicon or diffuse into silicon. Implantation there is only one job you put fix amount impurities per centimeter square at a place where you want that is the only difference between the 2.

However, energy smaller and lighter can also decide or heavier can decide how much is the depth you want okay that is the another advantage I can decide just below so much all impurities at the surface slightly below much below, these are the advantages which ion implanter arose at the solid-state diffusion furnace with 4 tubes may cost around 30-40 lakh rupees and not even dollars and ion implanter may cost 30 million dollars so that is the kind of money which you have to understand. So if I define my lab I may not buy implanter I may still work with solid-state diffusion THEEK HAI DEVICE ITNA ACHCHA NAHI HAI okay.

So this so far we have discussed now almost all this, there are 2 or 3 more processes which I have to do first before I start other things but I thought that should wait and I should 1st show you how the ICs are made because the purpose of this course is to show how the IC are (())(33:57) so we will 1st do this and wherever the word deposition comes say I can do it I will say yeah I can do it okay then we will look at, we have to see physical wafer deposition we have to see chemical wafer deposition and we have to look into etching okay. Can you think etching and deposition are same? After if I etch something this material will go somewhere, if it deposits someone else so that is the deposition, this is etching okay. I do not think the same thing I will use it okay, KAHI SE HATA KE KAHI AUR DAAL DENGE , YAHA DEPOSIT HOGAYA NAHI NEECHE HOGAYA OKAY.

Okay let us start that and maybe tomorrow I hope I will be able to finish, I want to see the process flow of an IC making particularly using CMOS okay. Okay so we start with IC processing and as I said there are 2 process mode deposition are there but we assume we know and continue with this okay. So this is the crux of the course this is what we are trying to learn and to do this whatever processes we have to do we will do that okay, so we have learned so far 3-4 one and maybe 2 are still remaining. Which is the major step in the case of circuit? Lithograph lithography, if you cannot print correctly all your gain is over okay that is the major crux, why I keep telling in exams also lithography.

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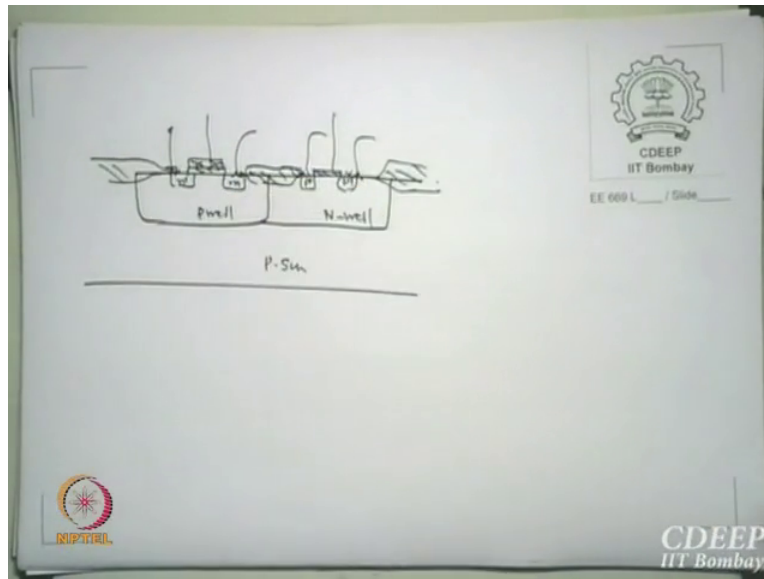
I will just talk about basic process given in Plummer's book and of course at the end maybe after the other 2 process time permitting I will also show you how FinFETs are actually fabed okay. FinFET because most past transistors are now replaced by at least 3D is not 3-D at least normal FinFETs with at least few fins okay. Choice of suspect, 1st thing we have to do is substrate choice; MOS circuits are normally 100 oriented wafers, Bipolaris normally use 111 papers okay. Why? 90 percent bipolar transistor action is vertical is that correct, emitter, base, collector okay, MOS transistor is always lateral so look for mobility which direction it is maximum and therefore utilise it for your advantage also of course there are many other reasons of bipolar using 111.

I do not have time otherwise I will show you bipolar process is even more interesting and little more difficult also okay, but since it is not having enough market I think we will go for MOS. typical doping of the substrate is around 5 to 50 ohms centimeter it is better to have a larger I mean wafers of higher this it should be more intrinsic, lower the sheet resistance it is better okay. If the wafers are intrinsic sometimes it is better but intrinsic is too bad and too difficult and too costly, so we do not buy. Why intrinsic wafers are costly? What is that intrinsic means? No impurities, so you will have to purify wafer for almost all impurities out that takes money so I said crystals are costlier than CZ crystals by 2 orders 100 times because it removes impurities okay.

I keep telling you money because you must realize why certain companies do only this much and certain do not do it, their volumes are such that they cannot afford okay. The wafers are normally P type boron doped lightly doped essentially and for typical 0.25 micron process which what Plummer is working about the concentration is about 10^{15} per cc. Then there is an EDP count what is it? It is essentially called Electronic Defect Count which is expressed in number per centimeter square, the wafers one I expect are 10^{10} per centimeter square is what is expected. No one will get this but if you have one, pay for it. What is it to do with, why we should have low EDP counts?

Number of chips on a wafer will be proportional to how many defects are on a crystal okay, so those many having defect will not be working so IDHAR PAISA BACHAOGA UDHAR LOSS MEIN JAOGA, you have to think how much money. 4th is the wafer size and the thickness of the wafer, please remember wafer sizes are decided by companies through their requirements, 8 inch wafers, 12 inch wafers, and now people are looking for 16 inch wafers okay 1 wafer of 16 inch. I have worked from half inch wafers, 1 inch wafers, 2 inch wafers, 3 inch wafers, 4 inch wafers and then I did not work okay, so best I have used is 4 inch wafer but nowadays they are talking of 16 inch wafers. Why they are looking for higher size? More chips out of one same processing because gas EKBAAR ANDAR DALA TOH UTNA HI HAI THEEK HAI so throughput may be better of course 10^{10} is also issue. The 1st thing we actually go through is called active area for the transistors okay.

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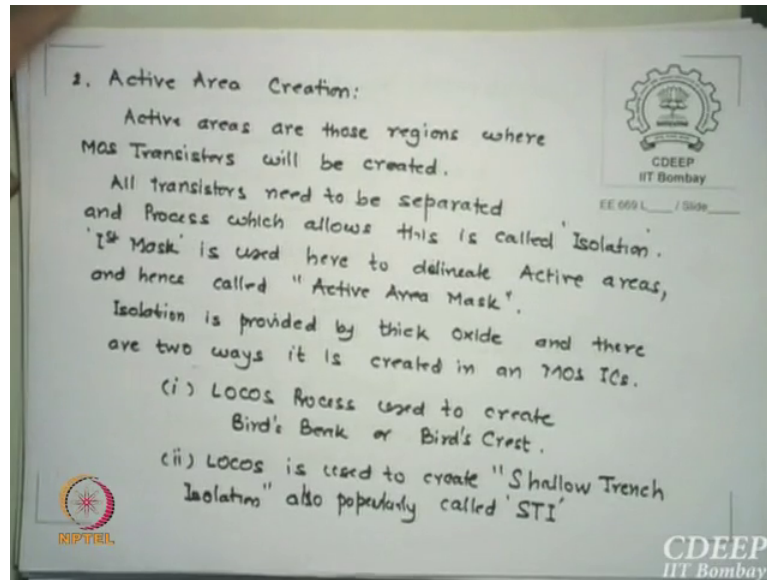
Now let me actually before I come to this, just a minute 1st let me get rid of these implant sheets okay, what we are really trying to do is something following like this. Of course this is rudimentary I am not showing fully okay just a minute I will come back to it, I am just trying to show you what is what about then I want some oxide right now I am not showing you how I do this okay. This is of course there is metallization also there has to be metallization here, here, here and here and of course from the gate. This is a CMOS process which I want to create that is my job, I want to have N-channel device, I also want to have P-channel device and of course I may connect one of these 2 to make a common complementary part in that.

And I must one thing important thing is each area of N-channel should be separated from the P-channel because the substrate has to be opposed it so this is done in the area which is called P well, this is done in the... P devices are made in the area which is N well. I also want each transistor to be separated from the other one okay so this is called isolation so they must get isolated from each other so the process which I need to know is isolation. This region where actually transistor appears is called active area is that clear? Wherever transistor occurs that area is called active area, the first mask is the one to create where transistors are going to come and where the other part get isolated from these areas is that clear.

I want one transistor here, one transistor here in between something should block so that they do not connect to each other okay, so this is what essentially 1st mask will do, it will allow me to

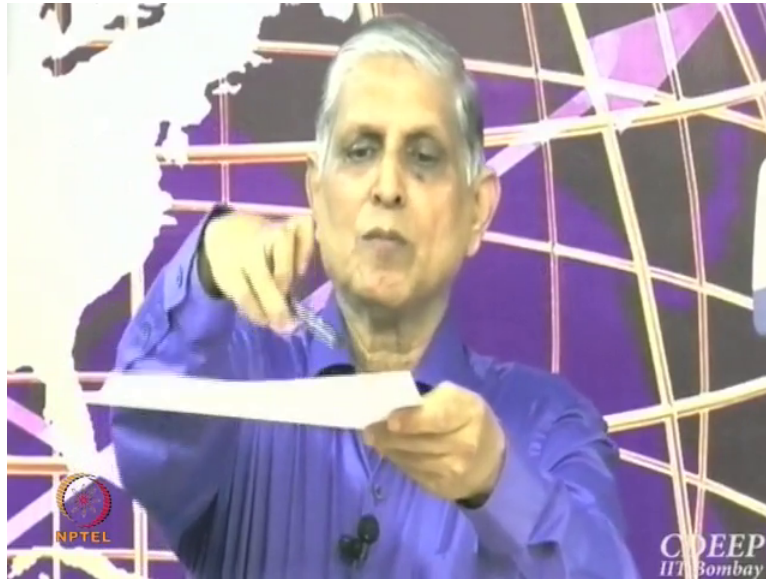
have individual transistor areas isolated okay and that is called active area mask, is that okay. So standard CMOS will go through and as the it is only 2 metal process they have done if we have 7 metal process and (0)(43:01) mask so 16 + 5 is only if same process with additional metals. If you add any other extra things it will keep increasing the number of mask so we will actually look into 16 mask process and then we will say YEH KARNA HAI EK MASK.

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Active areas are the region where MOS transistors will be created okay. All transistors need to be separated and process which allows this is called isolation. The 1st mask is used to have used to delineate active areas, in a silicon wafer I want these are the transistors, please remember I am only showing you cross-sections but in actually there will be wafer will be something like this.

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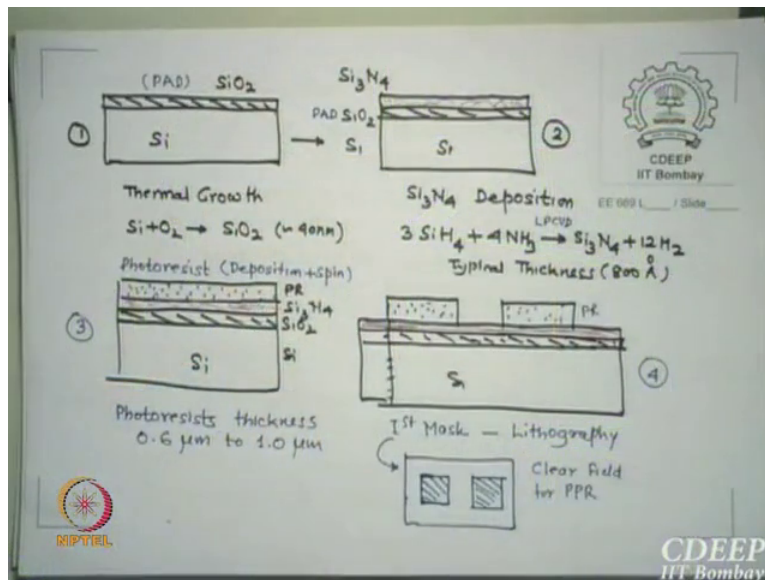


So one transistor will be here, one will be here, one will be here so it is the plant where number of transistors will be actually there but where I will see it, only on this side okay cross-section. So the 1st mask as I said is to delineate active area delineate means separate okay and the mask is therefore many times called “Active area mask” but some people call it isolation mask. Isolation is provided by thick oxide, easiest way to separate transistors are through thick oxide. Why oxide? Current cannot pass through insulators that is the hope. There are 2 processes of creating this oxide; of course process is same but one is called LOCOS process which is old one process, slightly modified version is the 2nd one. The 1st process which creates which is called what is LOCOS means? LOCOS oxidation of silicon which can create 2 kinds of figures very interesting figures if you see on the cross-section; one is called Bird’s Beak, the other is called Bird’s Crest okay, now it looks like that that is why the name.

But of course nowadays slightly different isolation have been tried in a lower down technologies and they actually created trench isolation shallow trench isolation, which is called STI, so almost every new technology will have STI isolation not just Bird’s beak or Bird’s crest okay. Not much difference not much difference but there definitely extra processing has been done in the second one. Why this was tried because this was not able to isolate, this oxide thickness could not be very thick so between 2 transistors there was still some leakage paths so I said okay ITNA deep oxide DAAL DETE HAI KE IDHAR SE UDHAR KOI DEKHE HI NA okay.

Okay so we start with the 1st one we do 1st this process is it okay, 2 possible ways of doing it of course process is still local oxidation, one earlier version we used to do what is called creating LOCOS and we choose to create Bird's crest or Bird's beak both have some problems, the 2nd one nowadays we actually only do is STI.

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Here is the flow, we start looking in the way I start, only one figure you 1st draw whichever I am discussing then draw the 2nd one. The 1st is you start with silicon okay and grow thin oxide then that, please draw the figure because this is the only way you can learn please draw the figure, you have a silicon substrate which is thermally oxidized $\text{Si} + \text{dry oxidation Si} + \text{O}_2$ is SiO_2 typically 400 Angstrom of oxide was used for 0.25 micron process. These thicknesses will be only true for 0.25, 0.35 processes, 90 nanometer down their values are different, 45 it is even very different, 12, 22 it is even very different, so do not you same values of all nodes. But this anyway the process will remain same, not much difference in the next (47:27).

Okay so the 1st oxide which I grew is called pad oxide okay something padding is to be done so I said okay I will call it pad over which this 2nd figure now you draw, I have silicon, I have silicon dioxide and I deposit silicon nitride I deposit silicon nitride, what do I deposit? Silicon nitride. The reaction is ISNE SOYE HUE KO JAGAH DIYA, $3\text{SiH}_4 + 4\text{NH}_3$ using a low-pressure CVD system at around 600 to 800 degree centigrade I can deposit silicon nitride + hydrogen will be released in the ambient okay. Typical nitride thickness please

remember these numbers are taken from Plummer's book and that technology is 0.25 to 0.35, so otherwise do not go by these numbers are valid numbers. For 22 nanometers then I will show you a FinFET at least for 45 these numbers I will tell you what are they are using.

So this 2nd step is, first is pad oxide on the top what is the process now, it is small growth this was silicon converted to SiO₂, now I am depositing silicon nitride by reaction this, this process will show low-pressure CVD chemical vapor deposition, so this is what we have not done, the position etching we have not done but we will do that.

After this deposition is done, I coat this with photoresist that is either by dispensing by tube or by dispenser called diffuser and then spinning the wafer on the Chuck okay, this is deposition + spin and I will get a thin layer of photo resist which can be different, if I want thicker what is the way I can change the thickness of resist? Spinning speed, larger the spinning speed thinner will be the resist layer okay, but 2 smaller speed also have problem, liquid does not dry out too thick resist actually the lower part does not dry okay then it creates bubbles so there are catchwords technology wise. So the 3rd process step is deposition, spinning, layer off photo resist okay typical resist requirement may be 0.6 micron to 1 micron.

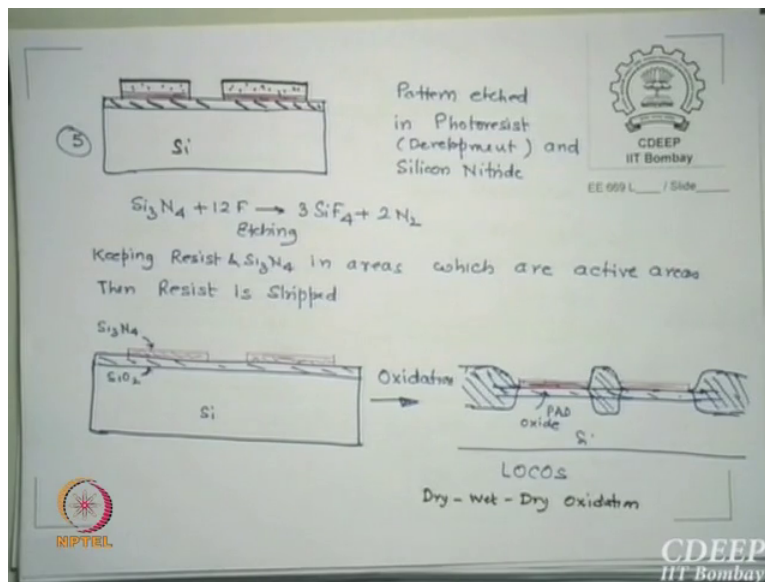
The 4th step is the 1st lithography, 4th step is the 1st mask has been used. If I am using a PPR this resistance is positive, what is the property of positive photoresist? It is hard initially, when exposed it become soft means it can be developed. So since it is a PPR and I want to retain certain areas, their life should not go so the mask has 2 windows for these 2 areas, this is the mask, 2 windows clear field with 2 dark windows, the light will not pass through the dark areas and therefore below the resist will remain hard and wherever the light will go through the clear region the resist layer is developed out is that okay. PPR property is it becomes soft when it receives photon. Essentially what does it do, you have a cross link (C-C) which actually breaks and therefore it is etch able. And pure is opposite, it has uncross link (C-C) it cross links when receives energy okay so unetchable.

Okay so the 4th step we now got after using lithography which I have not shown you, how do I do this? I put this mask on the top of this I discuss this shine light, when the light will not pass through dark areas, these areas will become soft that can be developed and only these areas resist will remain so this is called patterning; 1st pattern has appeared. This is your pattern is has

appeared, please remember this has cross-section Z is inside, this is only X-Y as shown, Z is inside maybe we should show something like this okay. So after the 4th step actually have delineation of... So what is this area is about, these areas are areas where the transistor is going to come, is that correct where transistor is going to come. How do I decide that area, one is channel length what else? Source length, real length, masking areas, so at least these 3 the minimum feature size and the length is some of the 3 which essentially decides the active area is that clear active area?

Channel length, source and drain this total area is essentially over transistor is going to come okay. Source length must come and channel must come gate must come so all 3 together should actually create a transistor so it is the area which you have delineated so below that only transistor will come and the most places transistor should not be allowed to happen. That means one transistor here, one transistor here should get separated by process what we call just now as isolation, the same figure is slightly better modified. In this case I forgot after the PPR is developed even the nitride is etched out.

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So here is the 5th one, the nitride is also removed from these areas, where area outside the active region are now only silicon dioxide thin-layer in which the active region has nitride as well as resist, how to etch nitride? Nitride is etched using hydrochloric acid which is same for SiO₂... yeah I mean that is the problem we have (())(54:26) the reason why it is adjusted, for SiO₂ you

need something called buffers, in nitride you do not need buffer, buffer means do not put in ammonium chloride, but for oxide you need some ammonium chloride okay. So anyway etching (54:42) so I have now after this I get outside and nitride okay, only resist have been is stripped out, why resist a stripped out? Because otherwise it was unetchable you said and even now I am removing so I say it is stripped okay.

Normally what are the strippers, either organics like (55:07) or some dark color resin like you know asphalt you use in the road making carbon jelly that also removes resist but that is bad so we do not use it. After this I start oxidation that is the local oxidation work, thin oxide nitride active areas, I started acting like a I start put this wafer into oxidation furnace. Typical it is normally this process... Because this thicker oxide is required what is this process called? What I am saying so? Any oxidation cycle normally is Dry wet and dry, initial oxide is good if you have dry oxidation no other species then you want to grow, you do not want to waste some (56:17) so we want a lower time so you do not waste oxidation.

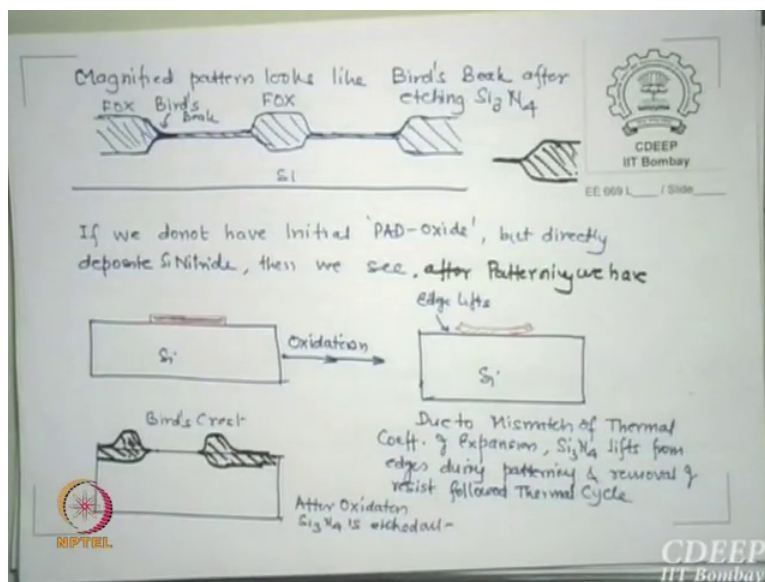
The final thing there will be some steam left out so you dry oxidation which oxygen rest of the oxygen picks up the vapors, so always late oxidation cycles are dry-wet-dry. Then these are oxide thicknesses due to dry maybe very very small maybe few Angstroms compared to the weight which you are growing. As soon as I start doing oxidation you can see this figure, oxygen does not pass through nitride, nitride is a must for oxygen okay. So any oxidation cannot take place below nitride regions is that clear, below nitride region oxidation cannot happen but oxygen will allow oxygen to get in, oxide will allow oxygen to grow they will grow model WOH BADHTA RAHE.

The problem now is you are holding this wafer holding this surface of nitride at one level this level okay pure oxidizing, but I already told you that 0.45 micron of silicon is consumed to create one micron of SiO₂ so the volume roughly doubles, is that correct? So if you consume 0.45 micron down, 0.55 must come up because you want 1 micron if totally you create so 0.45 will go below and 0.55 will go up why because nitride is holding the surface layer so half will go up, half will go down so that is the shape is that clear, so part of the oxide is above, part of the oxide is below. Now if you look at and then you remove strip the nitride now okay, how do I

remove as I say by using this method is that clear, okay this is 5, maybe 6, 7 maybe theek hai is that okay how this oxidation has taken place.

Why it is called LOCOS? Oxidation is taking place only in these regions but not in the active area so localized oxidation has been performed therefore LOCOS Local Oxidation of Silicon. As someone asked me if I would have etched oxide from here also it would not have mattered, there is some advantage of retaining thin oxide but it need not be retained because anyway I am going to do local oxidation is that okay. So it is not compulsory that if nitride during etching oxide work is okay but normally I will preferentially say so that some thin oxide is maintained okay because the new growth will be then better than fresh silicon. So I do this differential but if not nothing serious happens. Is that okay, everyone has drawn figures because these are the figures which will be asked in the exams as well.

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So if I look at little magnified version of this I find this and then there is a thin oxide here okay, I remove nitride from there and I see this area. So if I actually see this small area at the edges I see this right side figure that is essentially called Bird's beak. Now why this Bird's beak has appeared? Bird's beak appeared because when the oxidation was being performed for this, this below the thin oxide, what is below the thin oxide, some oxygen and that laterally below that nitride here okay so it created a thin line inside the transistor area. What is the problem with that? The active area is reduced okay, your gate length will not reduce but source, drain area it will

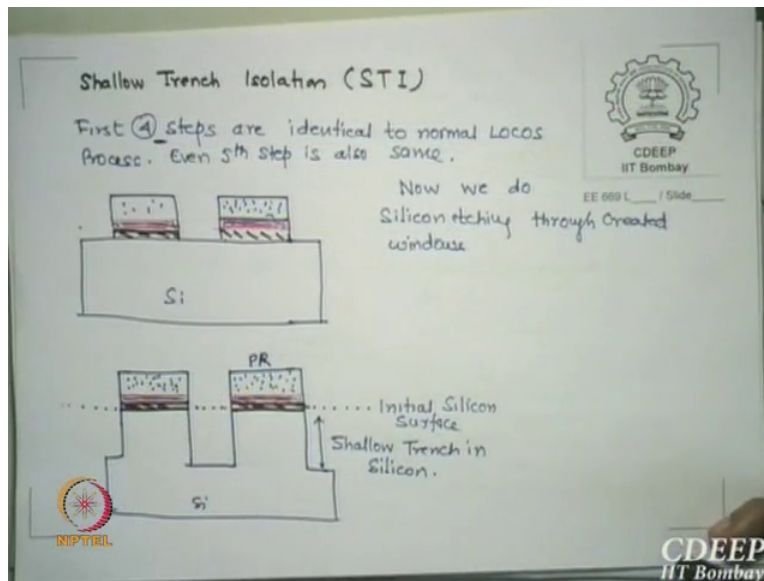
reduce so what is the problem if source, drain area goes down? Resistance increases so whole your speed goes down so it is not trivial, I am worried about because I may lose 6 to 4 by now okay.

So this (60:59) so we said okay why did you put a pad? I put a pad because nitride on Silicon has a very bad combination it has a different thermal coefficient for expansion so it is not sit very well okay. Its mechanical strength is different from oxide so I said okay between nitride and silicon I will put a material which matches both okay so I put a thin layer of SiO_2 , Si called pad it is like a buffer layer there so above is nitride, below is silicon, in between thin oxide of pad was used. But that created because there was oxygen here it entered from side way as well and created some oxidation inside also okay so their active area becomes smaller relating okay.

Of course we are all exaggerated things not so bad or something but just for (61:54) so we say okay if that is all that you are looking for then I remove the pad okay started with nitride without oxide masked everything and I have a wafer now which is active area on the nitride okay active area only on nitride sitting on silicon. But since there the thermal coefficient of expansion is different, so when I start oxidation these edges starts lifting okay, these edges because their thermal coefficient is different, the stress here is excessively high or we say sticking coefficient goes down, some other day more chemical, so the nitride layer from the edges actually lifts off. If this lifts off and when I am now doing oxidation, from here you can see it will go up and come down from that edge it will go up and then so this portion is like a crest of the bird, it is called Bird's crest.

Why are we so worried about these shapes? Because if this area is not uniform on a 1 plane, in next process may we have a problem of accuracy all around okay. Is that okay, and then I remove the nitride so what I got now is Bird's crest as isolating areas is that okay, is that why crest... I repeat, lift off nitride allows Oxidation to proceed like this and because of that will you see a huge pad oxide and that is called Bird's crest. So this is much non-planner than this but what is the problem here? It encroaches the active area, here it does not okay but it creates crest on non-planner surfaces. So ABHI TAK we have still not done 1st implant result, what we have done so far is only to check get the active area where transistors are going to come even then it is not over.

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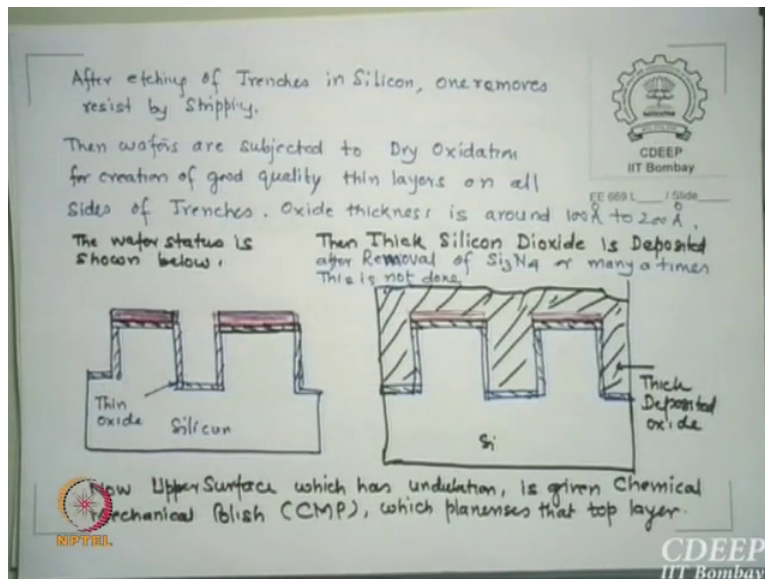
Okay the other possible oxidation isolation oxide isolation is done through what is called Shallow trench isolation called STI. The 1st 4 or 5 steps are identical as we did earlier, however I have now oxide, nitride, resist and isolator is same as what was done earlier for LOCOS. Before LOCOS starts oxidation starts this is the step which is common to both, now please remember this is my initial surface where this oxide is, is that okay this is my initial surface silicon, I start etching silicon itself okay. So if I start etching silicon, silicon will be seen here, seen here will be seen here so silicon will start etching. Now the question is normal etchants which we use which are liquid etching system is isotropic in nature, what does that mean? So its shape may not be vertical but some angle it will show 57 degree normal silicon okay V it will create a V.

Here I do a process of etching which is exactly vertical which is called ion etching okay, dry etching as the word, wet etching is always isotropic and isotropic etchings are done by dry etching so we will do dry etching. So this area silicon has been removed, this area silicon has been removed, this area of silicon has been taken away okay. So now I have oxide-nitride base and we have trenches side wise is that clear? These ions are now sitting in the trenches just about trenches. This depth of this trench can be a micron or even

lower this base okay because the device is within 1st thousand Armstrong now so even a micron is more than sufficient.

So once how do I etch silicon? Silicon has no etching etchant, either you do... dry etching is fine but if I do wet etching what is the etchant for silicon could be? (66:43) silicon dioxide, so I must convert into silicon dioxide, nitric acid does that, 5:3:3 is the ratio, 5 water, 3 nitric acid, 3 HF, if I make it 5, 3, 1 depends on company + water dilution if you want 10% of this, this is called silicon etchants or called RH, now this etching will do silicon, oxidizes silicon and HF removes the oxide. Okay but in the case of this we will use only fluorine ions 2H₂ okay. Once this is done trenches are created, is that okay figure? JAHAI USKO NEECHE TAK THIS DEEP trench, these are shallow but shown deep compared to this so they are called shadow trenches because it is less than a micron okay, wafer is 10,000 this millimeters and I am talking of few microns so it is very shallow.

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By 1 millimeter thick wafer will be preferred, larger the size larger will be thickness. Okay after etching up trenches in silicon one remove resist this by stripping and you are done, oxide-nitride oxide-nitride after this, then I oxidize this wafer in a dry ambience dry oxidation is performed, so thin oxide layer fills up the trenches thin oxide, please remember this is thin. You can also say that nothing will grow about silicon nitride so the silicon nitride does not oxidizes okay all that

trench edges now are filled up with thin oxide okay, typically this thickness will be 100 Armstrong to 200 Armstrong okay or 10 nanometer to 20 nanometers if you want nanometers AAJ KAL NAO MEAIN BOLNA CHAHIYE NA. After the initial trial oxide is done then you may go for weight oxidation and that wait cycle will be how much again? dry-we-dry so the first dry is this, the next is wet-dry cycle ahead but that will be very thin I mean wet instant of time because this is a trench which is to be filled up now so I do not use any growth techniques.

So what they I do, I dump that is I deposit silicon dioxide from the top, is that correct? This is a oxide deposition process not growth process, is that clear? So I have deposit silicon dioxide from the top such that and it is a gaseous system so gases goes down everywhere nitride does not allow oxygen to go through so it fills up all the trenches with oxide, it follows the contours okay. However on the surface I did not show you properly you will see this because the thickness proportionality will be seen on the surface. Dump KARENGE NA YAHA PAR ZYADA HAI TOH YE THODA NEECHE CHALA JAYEGA, you got it this is deeper, this is not deeper so it will actually show some one portion higher than slightly lower.

Student: On the top nitride will not allow the SiO₂ to go but sir on the lateral side from there it may be...

The reason is this, this thickness which is growing over this is not same as this, deposition rate is same everywhere but you are going through, the time taken to grow this should be same as time taken to deposit this.

Student: (0)(70:50)

The deposition processes ionic, it is not just LPCVT, it is ion deposition it will just go down okay just go down. Even if it does but silicon nitride is very thick okay so.

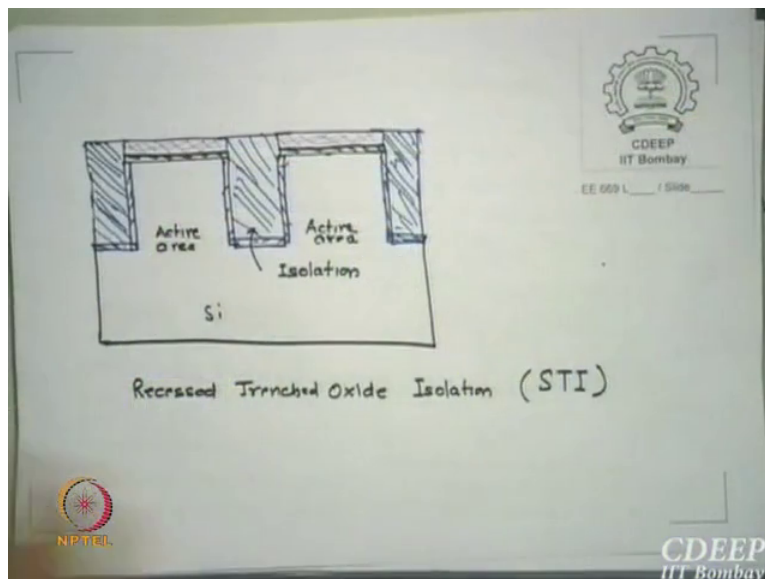
Student: (0)(71:13)

No no no, this way deposition lateral is very difficult because you are depositing, growth if it is a growth yes it will enter but there is no growth here, you are just pushing gas down okay so it goes like this. Okay so this is a non-planar surface okay and this non-planar I can make planarise by using a process which is called chemical mechanical CMP polish, what is the word I use?

Chemical mechanical polish CMP which is the most important process these days in almost all CMOS processes, we keep planarizing the wafer every now and then okay. What is chemical mechanical polish? You take the wafer, put it on a chuck which has some mechanical slurry like aluminum oxide and you put some chemical on that and you keep rotating it in 8 forming an 8 so it etches partly and scratch partly, scratch partly, etches partly so you get chemical mechanical polish.

And as fine the powder you take, finer is the polish okay, polish means, what is polish work? surface is planar as... a very best polish means completely uniform plane. So how much I remove, I will remove just above nitride kind just above. I can keep watching when it comes, you have drawn the figure, the last sheet for the day. Please remember etching, CMP of the wafer YADI YEH AISA HAI TOH AISA etch KARENGE actually rank KIYA JA RAHA HAI, is it okay? Is this figure okay?

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So here is the final this STI I have seen, I removed now all that non-planar, planar, everything has been taken care by single plane because polish will come on single plane, there is nitride, there is oxide base and there is an STI okay. This is called resist because it is now fixed to the surface is called resist, anything which is fitting with the surface is called resist, UPAR HAI TOH NAHI HAI resist, YEH resist HOGAYA so this is resist oxide, this is trench isolation so where are the active regions now? these are the active transistor areas they are separated by

trenched silicon dioxide the wafer PL everything will be much below, only the smaller areas so nothing these transistors can interact with this transistor anyway okay, is that okay?

So STI is a very standard process nowadays, CMP is a major processing step nowadays and therefore this is very very crucial in making any chips these says, is it okay. SO so far out of 16 marks how many marks we have done? 1, say imagine there are 15 more marks to go through if the minimum CMOS to be sure okay. So something I will hurry up, something I will show, I thought that this is first time I am showing you so how we actually keep doing things so all process steps I have shown you, everything in between, there also next I do this and I will get this because you know you have seen once, is that okay?

So far I have shown you every process step in between how it will happen but next time I will say here to here I can come okay you think of it, see you guys.