Advanced Neural Science for Engineers
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Lecture 19
Lithography Optics

Hello everyone, welcome to the TA class on lithographic optics. Now, this is very important class considering the importance of micro fabrication in neural engineering that is first thing, second thing so, far PVD techniques or thin film deposition techniques including PVD and CVD thermal evaporation, E-Beam sputtering or CVD, all the types of CVD have been discussed, these all are thin film deposition technique.

After that the next thing is the patterning of deposited thin film where photolithography comes into the picture. Now, lithography also, it has been taught to you up to an extent, in this particular TA class and it is like a series of two TA class, I would like to give you an idea to realize that how this micro structures will ultimately pattern or realized on your desired substrate.

So, this is like a brief overview of the agenda of this particular course, this particular series of two TA classes, and that is why we have named it lithographic optics. So, this is like a more of interactive module. So, we will quickly see the basic lithographic techniques, how it works, and how optics plays the role in the lithography.

How optically the design on your mask will be reflected or pattern or transferred to your substrate how we can get a faithful reproduction of the design and the mask, what are the different techniques to get a finer and finer dimensions and how we can enhance that particular microstructures everything we will see in this part of two TA classes.

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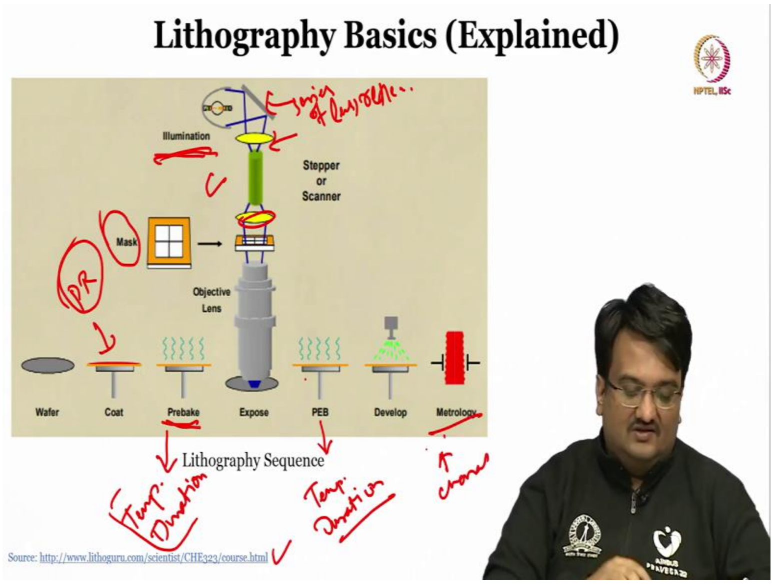

So, this is the overall idea. So, this I would suggest all of the people who are specifically interested in (lit) lithography and all you can go through this particular link it will give you a detailed picture of considering this course I will tell you first of all wafer would be there you will caught particular material prebake it this is nothing but PR coating photoresist coating.

Now, you all know what is photoresist it helps in patterning and all this thing again this is a mask now this mask is being made and this mask is kept here this is your elimination your optical source with some setting of this particular lens here only one thing is shown but there are a series of reflector is being used series of lenses or let us say a reflector is being used.

Again why this is being used is to guide your particular optical (illuminate) illuminated light in one particular direction then it will go to this particular lens further it will be go here and then once after this objective lens this is called condenser lens this is your mask and this is your objective lens it will finally fall onto your wafer that particular area here what happens is this your photoresist name itself as photo.

So, it has a material or it has thing which is sensitive to a particular light. So, when your light falls onto the certain region, some chemical processes happen either that region gets (sou) (sou) that region will be soluble or it either it will be etched up or removed that region or the other way around the region which is not exposed will get etched up.

So, all this thing will be considered and then this is how overall little process exposure process works further what happens is as I mentioned this is like a mask and this is objective lens further. Then it will be this as like a prebake here it is characterized by two things, one is temperature and one is duration. At what temperature for how much period of time this particular photo is deposited or coated photoresist should be pre baked. Same thing goes for here also temperature and duration.

Now, again, this temperature and duration is a function of your PR, based on different PR you can read or go through the data sheets of PR and identify that how much time you have to prepare for post bake how would be the width would be affected or overall picture further you can develop it and then this metrology is nothing but characterization. So, this is an overall idea of how photolithography technique works.

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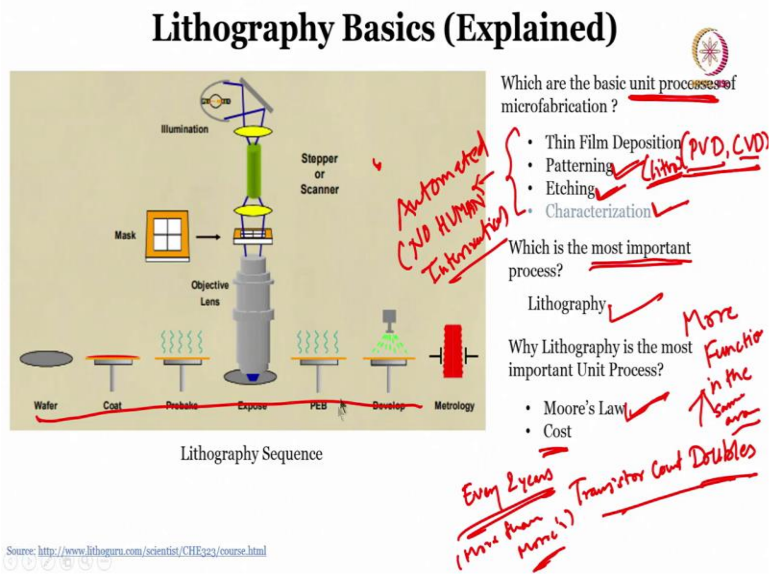

So, there are before moving into the details some quick look at the things what have been already covered there are basic unit process, very important point what are the unit processes in micro fabrication. So, it has been already taught, if you are aware about that, that is fine. Otherwise, I would like you to pause the video and try to remember or recollect what are this plus.

So, there are different processes one is Thin Film Deposition, I already covered I informed you in the beginning of this class, it can be PVD or CVD based on the type of operation whether it is as I mentioned, E-beam sputtering, then it can be a PVD or if it is LPCVD or PCVD is a different type of CVD, where to use PVD where to use CVD already been covered, next thing is patterning, patterning is nothing but lith only we generally mostly used optical lithography or photolithography then after pattern it needs to be etched out and finally characterization.

So, these are like four standard unit process or characterization can be considered as a technique to validate the develop microstructure. So, that is like, second thing, next question is I asked you to pause here to know what is which is the most important process. So, can anybody like, you can think about that and let me know, that what should be the most important process.

Now, here lithography now, why lithography is the most important process, is it because, we are teaching this lithography in this TA class no, no, no. So, that is the reason behind lithography being the most important process. So, what what can be that thing. So, there are basically two reasons why this particular thing is most important. One is Moore’s law.

Now, Gordon Moore, founder of Intel, co founder of Intel has come up with this law every two years for the same region, your transistor counts doubles how it doubles. So, there are some techniques, what are the techniques, it is keep on evolving mostly, then, after some point of time, let us say if it saturates or something, there is something called more than Moore, more than Moore.

So, that you can check it, it is a thing of interested people can check that particular thing, but how this particular thing will help a transistor number get double, which means you can have more functionality more functionality in the same area. Now, how this will be helpful. So, when little bit of history when computer your first computational device was invented, it is almost like a big size of a big room, where currently you can see in one particular mobile, you can achieve all this computational facility and everything.

So, it is all due to this Moore's Law. And second thing is cost, how this cost would be important. So, like half of your fabrication cost goes in the lithography or optical lithography. So, this entire thing all over is like a sequence of lithographic and this is how it will be pattern, but because of this to particular region, there is a cost of lithographic also, I would like you to just emphasize this particular point, of course, that sometimes there is a recall, in fabrication industry or foundries, and there are examples that due to recall one particular company that is completely, vanished or gone at least 10 to 15 years back.

So, that shows the importance of that even if one thing fails, how critical it would be for one particular company or foundry. Second thing if you get a chance, or if you see the videos in YouTube to see the foundries and all not only this particular thing, even your all this process, all this process would be completely automated no human intervention yes, if some fault and some issue (hap) happens, definitely there will be a technician or person researchers who is handling that particular system.

But otherwise, if you go into the Fab Lab or foundries there will be a completely automated or robotic way operation would be happening to just get the desired microstructure. So, main thing is lithography one of the most important phenomena or reason to get the overall evolution in electric design, and why it is more important, again, Moore's slow, and the overall cost of the developed system.

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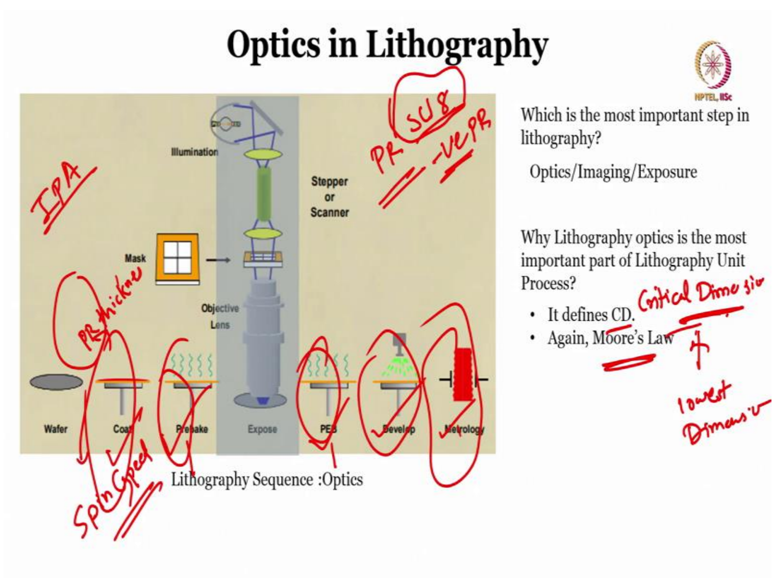

So, now, we will see the next point, lithography as we seen is very important till lithography you can see these are the several steps, coating prebake post bake exposure development and finally characterization so, which is more important out of all this. So, again, I would like you to pause the thing and think about that and think that which one of them is better and why. So, let us see which one of them is more important or which one has in other words, more scope of improvement.

So, it is nothing but this optics which you can see in the shaded region here, why optics is more important. Next question so, same thing, why lithography optic is the most important part in litho unit process, fabrication litho is important, why it is important already told in litho optics or imaging is important.

Again, it is not because this TA class is only through optics, there are some certain reasons for that. So, what are the reasons? So, depends CD, what is CD CD is nothing but critical dimension. Critical dimension is the lowest dimension. Lowest dimension of your micro-structured device, entire process can be evaluated using your CD.

So, and again, Moore’s law also coating now this when I say about coating, each of this thing we will see quickly, development and all and characterization, this coating, it depends on spin speed. It is basically a spin coater using spin spin speed. So, how fast you run it so you can get a width so that there is a relation between PR thickness, this coated PR thickness and spin speed.

And for one particular PR it is identified and optimize, pre bake and post bake, I told duration and temperature for a PR or for several PRs, it is identified one more thing when I say PR there are several companies who make the PR, let us say SU8 is a negative photoresist, negative photoresist. Now, this SU8 is one name of the photoresist like you get a proper let us say IPA.

So, you know the formula of isopropyl alcohol or IPA or ethanol same way there will not be any fixed defined formula for this this SU8 is a combination of several chemicals and known to a particular company who has made this particular thing generally they do not reveal everything in a particular datasheet but they will tell you that okay for this particular temperature this much time prebake is fine post bake is fine.

So, this basically the point of telling this about this coating pre bake post bake or development or even further characterization is that this thing is more or less optimized and saturated in terms of research. Whereas this thing still there is a huge scope of improvement and people are keep on trigging it into the more and more detail and try to identify that what can be further improved to get the better resolution and enhance the resolution. So, this is like a overall idea in fabrication, why litho is important in litho why optics is important.

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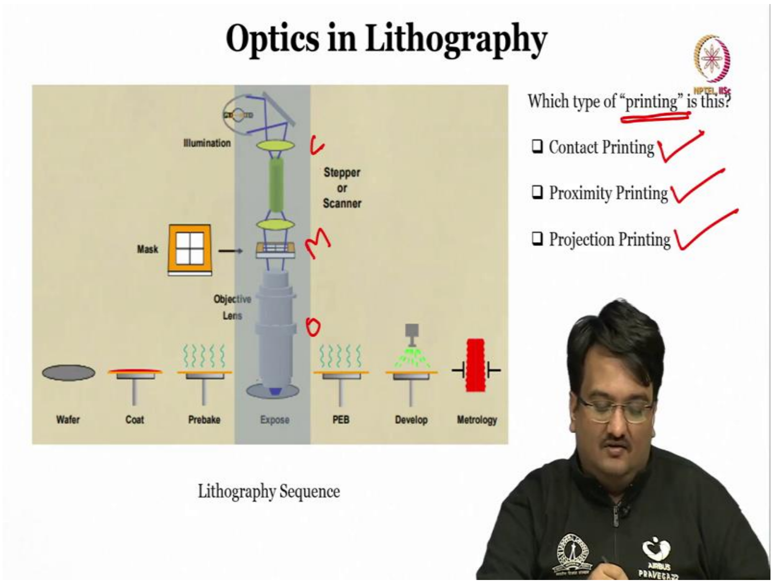

So, in optics also when you are printing using lithography there are different types of printing. So, which is this kind of printing, so, there are three types of printing which is being generally used in litho. So, this is like contact printing, proximity printing and projection printing I told you I will try to make this interactive so far I have asked that several questions asked you to pause the video now we have come to a one like MCQ kind of question.

So, this which type of printing is this. So, initially contact printing would be used when your mask or your desire structure will put in the contact of substrate and you will get a final design then proximity printing would be used and projection printing. So, this is basically as you can see source elimination is that in some form of light and against contention lens mask and objective lens finally, it projected on this particular your wafer which has PR coated.

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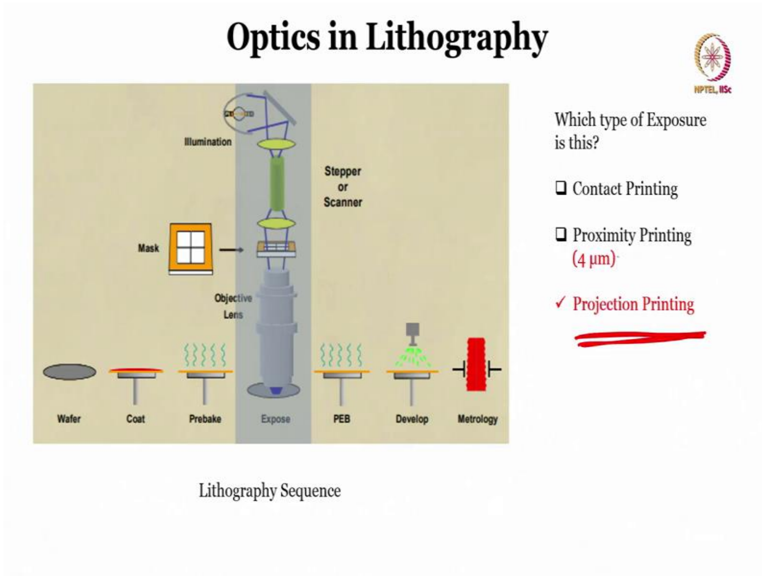

So, this is again it is like projection printing, proximity printing has its own limitations of four micrometer. So, I hope you can see this projection printing here and this is 4 micrometer here. So, this is like overall idea.

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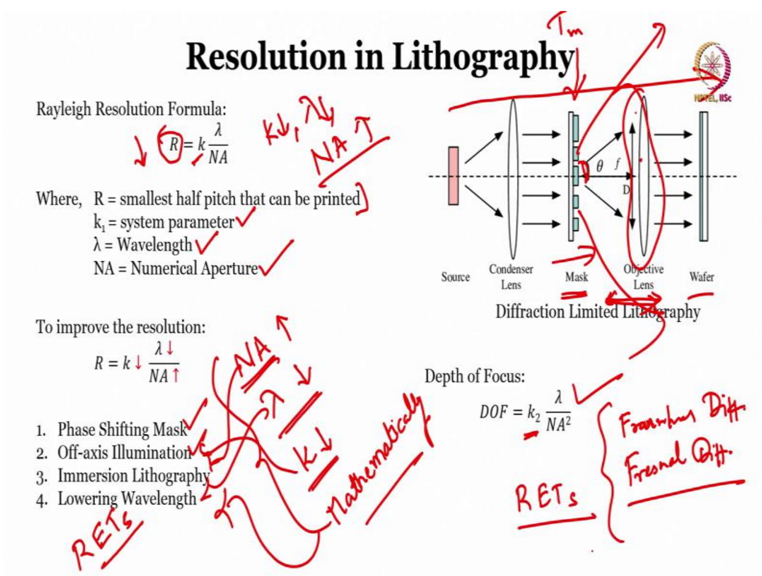

Now, the main thing your entire game of fabrication or getting any microstructure depends on this particular aspect that is nothing but a resolution, how finer or how better how finer structures you can get it faithfully or reproduce on the substrate of wafer faithfully, it is measured by (resol) resolution. Now, this resolution is again, the formula of the resolution has an empirical formula that has been called Rayleigh resolution formula, r is the smallest half pitch distance between two particular let us say if I talk about ID than two particular electrodes.

If I am talking about to any other micro heaters or something that two consecutive channels or two consecutive interconnects how finer it can be that is decided by this thing again, it is a function of your wavelength wavelength of the illumination or the source you saw this particular source illumination. So, wavelength wavelength of that particular source and numerical aperture, what is numerical aperture that I will see in the coming slides it is basically the ability to gather the different diffracted lights now it is slightly difficult to understand.

So, we will see the help of the images and all k is a system parameter depends on several things that how you are giving the light whether the light is normal to the particular wafer or whether it is oblique to the wafer based on that your parameter changes. Now, if you want a lower resolution, what are the parameters which you can change, so, you want this guy this particular parameter to get low.

So, what you can do either you can lower the k or you can lower the lambda wavelength or you can increase the aperture aperture is a property of a particular medium. So, these are like some of the techniques to mathematically thinking how we can do that. This is again the same thing what we have shown here this thing from top to bottom what you are seeing here same thing it is showing here from optical in a simplistic manner from optical source, condenser mask, condenser lens mask, objective lens and finally the wafer, how much you can move this particular objective lens.

Again this is all imaging so, your everything should be precisely placed. And this as I mentioned simplistic image, so, only one lens is shown there will be many lenses because each lens will affect or guide your light into particular direction.

So, there will be a let us say if in one particular system you want higher gain use multiple amplifiers to get the desired gain same analogy if you want to guide your light precisely you need to use multiple lenses, but for the sake of simplicity we have shown only one same goes with objective lens also, however mask will be exactly the same whichever is shown here.

And as I mentioned the light travels through diffraction and all so, then it depends on where exactly you are placing your objective lens needs to be very precise. So, this degree of variability or tolerance your this lens can go here and there. See, even a slight movement can result in a defocused imaging. Defocused imaging means this structure will not appear here, some other structure will appear here.

So, which will spoil the purpose of getting a desired micro structure so, that is why what we can use this we can exactly place this particular objective lens where you want to place it and then you can pattern it in your thing. So, even there that also slight amount of tolerance is allowed that is called depth of focus.

So, there are two parameters one is resolution one is depth of focus resolution is what is the smallest aptitude you can be printed on your particular wafer or on your particular substrate, whereas depth of focus is what is the amount of width you can put on amount of movement you can allow your objective lens to do in order to get the desired fateful report reproduction of the light.

So, moving ahead, this is the formula for depth of focus again like this is empirical formula k2 is different than k. It is again a system parameter, as we already discussed, if you want to improve the resolution, you need to decrease the k you need to increase the NA, NA is the property or the ability to acquire the different certain diffraction order out of all diffractive.

Here if you see, some of the light will pass through, but when your structure is there, it will get diffracted. Now, if it gets diffracted like this or if it get diffracted like this, it will not be acquired by this objective lens. So, this ability is nothing but your NA it depends on this angle higher the angle, if the angle is even more and more than it would be difficult to get everything in the objective lens.

So, and then that diffracter order will be missed and we might not get that much high fidelity or high quality image production on the wafer. So, these are the you can increase the NA by adding more refraction order it has a physical interpretation also, it has formality called mathematical evidence also, you can also change the lambda, but there is a limit on this you can also change the system parameter k as I mentioned, this also depends on how you are giving the light and all this thing.

Now, all this thing what we are discussing mathematically this all is the idea to improve your resolution mathematically same thing you can use by this method, these are some very well known RETs resolution enhancement techniques. So, one of them is phase shifting mask one of them is off axis illumination which is more or less related to this one of them is immersion which is more related to this lowering wavelength this is related to this.

So, this is like overall idea or when we see in the next class different RETs and how exactly this lithography and lithography related to optics and it has a basis in Fraunhofer and fresnel diffraction, I hope you can remember what is that Fraunhofer diffraction and fresnel diffraction, when Fraunhofer diffraction should be used when fresnel diffraction should be used, we need to consider what parameters and how this particular light is being diffracted here.

So, we will there will be based on this mask function based on this mask design there will be something called mask function, how that light will travel to here and then how diffracted pattern will look like all these things we will see in the next class. So, but before moving that I just want to give you a brief idea that I mentioned this things have helped.

So, which parameter has helped immensely or out of which which parameter do we need to work on see we are going top down. First we discussed in fabrication what we can improve lithography patterning in lithography what we can improve optics in lithography optics what we can improve resolution in lithography optic resolution what we can improve that we will see in this slide.

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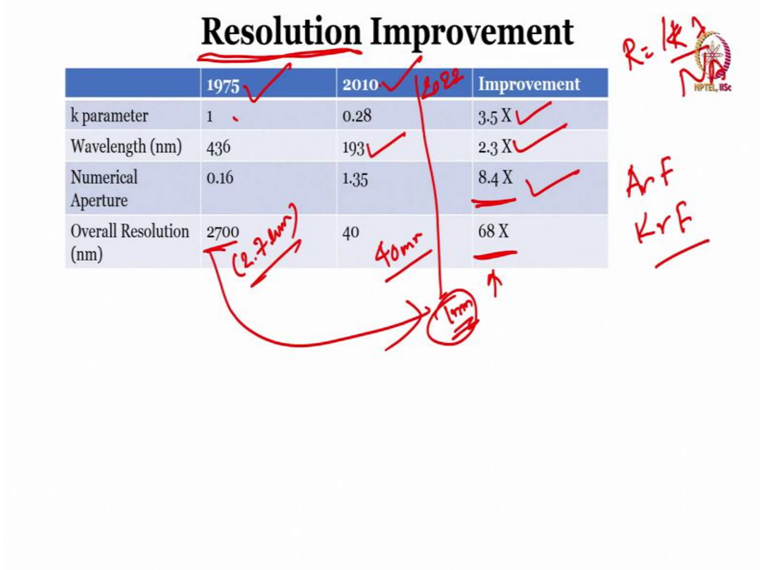

So, these are the different parameters I told you again this resolution is the main hero of the fabrication process. So, resolution is nothing but k lambda by NA. So, over the course over the course of time, which parameter has affect how much improvement. So, this is k in 1975. So, we are almost talking about 50 years back this is before 10 years.

So, what parameter has improved immensely, so, K parameter has gone from 1 to 0 point 5 we need as less k as possible. It has gone down by the multiple of 3 point 5 wavelength earlier 436 now, we are getting 193. You can I think argon fluoride and krypton fluoride are the lasers used which corresponds to this wavelength you can check it if you have a batter sources with lowered wavelength you can use it.

But there is a certain limitation when you go from certain wavelength to lower wavelength, it increases the frequency and when you keep on lowering your wavelength it increases the frequency higher it increases the energy of a particular all these things are electromagnetic waves so, then increasing your optical illumination energy further results in several other unintended reproduction of energy so, it has lightly less resolution.

Here in 1975 overall resolution was like let us say 2 point 7 micrometer. So, in other words 2700 nanometer whereas, in 2010 we have reached to 40 nanometer so, 68 x improvement has happened and here it is not there but if I talk about 2022, it is almost 1 nanometer. So, I think Intel or someone has already announced the production within 1 nanometer.

So, the thing is see how much difference we already reached or achieved, but that if you talk about 1975 to 2010 numerical aperture, has the most significant contribution compared to other two parameter. So, this is just to give you an idea that how people are scientist or researchers in lithography optical lithography are tuning the parameters to get the desired thing.

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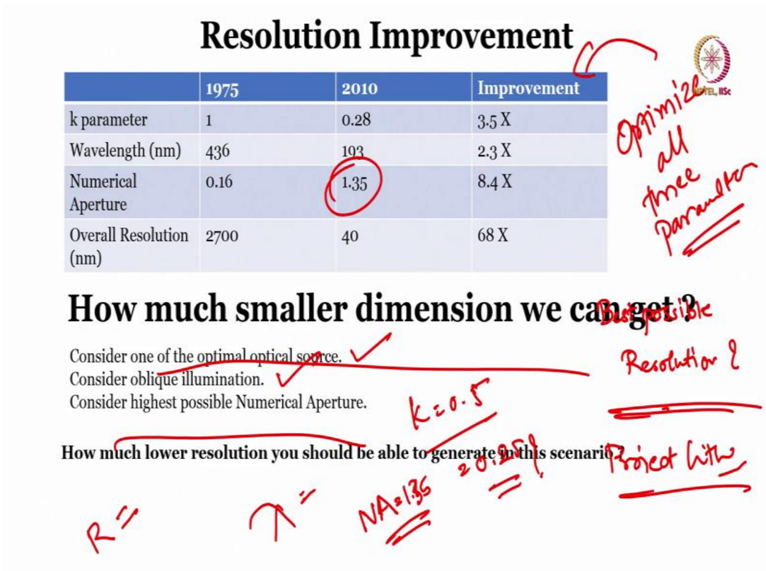

So, another point is I want you people to inform or tell me that with this parameter optimize all three parameters. And what is the best possible resolution we can obtain with this setting, use this table you can also use some other parameters if you already aware, but with this projection based litho what are the best possible resolution you can obtain?

So, how much smaller dimension we can get this in other words, the same thing, what is the best possible resolution you can get? So, consider one of the optical source consider oblique elimination, which will make your k 0 point 5 you can check it if you can even go 0 point 25 or not and then you can also check the highest aperture let us keep only this much which is available here NA.

However, in literature this I have read somewhere it is 1 point 4 or something you for now, consider 1 point 35 put this values, take lambda, if you can go beyond 193 completely okay try to go put this parameter and let me know next linked TA class, we will see how much we can get the resolution using this. And then does it make sense to have even micrometer or nanometers structure with this particular setup?

So, that is like an overall idea. So, for now, it is like homework to check what is the smallest dimension you can get with this current settings with all these parameters, you can search and if you have any other more improved or optimized parameter you can use that also and try to learn this particular thing and identify that in that particular scenario, how much lower your resolution you can get.

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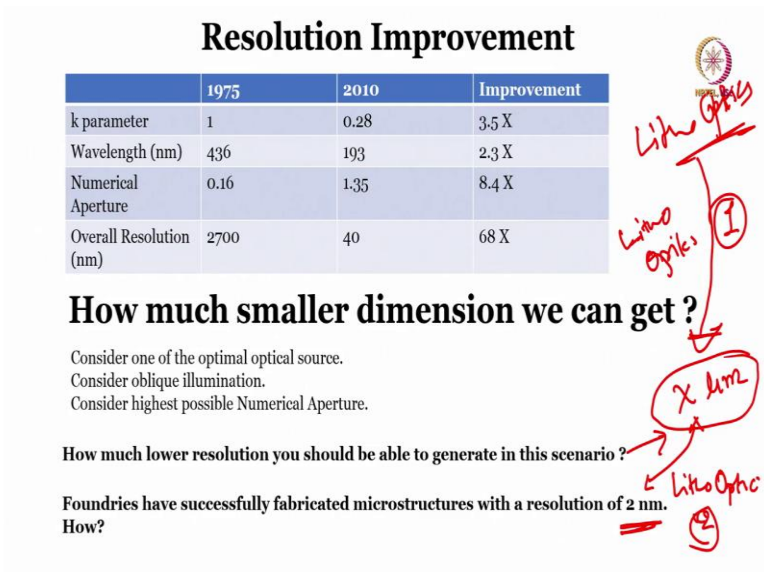

Now, when I say best resolution is obviously a lower resolution, because you are getting micro and nano structures on your substrate. So, as much finer as possible again, the same story applies here, the smaller the dimension, the more functionality can be accommodated in the one space one constant chip area, which will give more functionality in smaller space, smaller devices and that will help in getting more thing.

Again with that also you have to consider low power and all these things, that is a different ballgame altogether I will not go into the detail for that sub threshold current and all this. But for now, try to identify how much lower resolution you should be able to generate in this scenario and with that, try to compare this thing foundries a successfully fabricated 2 micrometers, 2 nanometers rather sorry, then how we can get that.

Here it will give you some number, let us say it is x and let me give you a hint also x micrometer, then from x micrometer to this journey, so far what we have understood how litho optic is important and how it is characterized, it is very important aspect. And the same thing will apply for any kind of micro electrode array you make it for any kind of neural engineering research?

So, this little optics will give you some resolution that is your main that is a main parameter in the litho optics main parameter there is there a few micrometers. Now, from few micrometer to nanometer journey, this we have seen in this class litho optics, one. This journey, we will see in the next class litho optics.

It is equally important for neural science, it is equally important for all the micro engineering devices, because litho remains common for all the applications specifically important for this thing as well neural engineering or developing micro electrode array. So, with that, I will see you in the next class to know how we can or how the technology has transversed from few micrometers to nanometers, we will see in the next class.

If you have any doubts anything feel free to write us in the forum. We will see you in the next class. Bye take care.