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Photonic Integrated Circuit

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Lecture No. 07

Photonic Integrated Circuit Components 1

Hello everyone, so let us look at a brief introduction about various photonic integrated circuit components. So, anyway we will be discussing all these components in detail in the course but then we should have an understanding of what are all the components one need to have in order to realize various functionalities we will go through this discrete components briefly in this lecture and then in the following lectures we will look at each component in detail looking at their physics, looking at their operation and how you can realize those components in a circuit. Let us move on.

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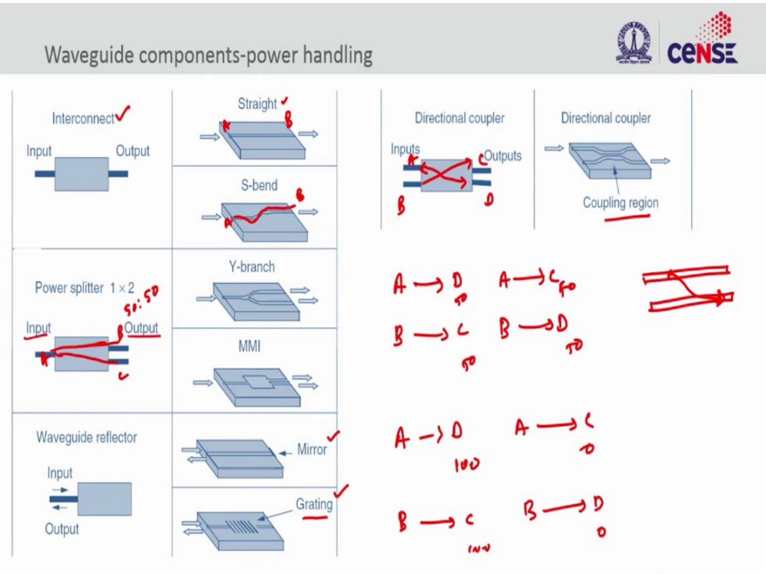


So, there are 3 type of functionalities that that one can do in a circuit, one is power handling which is again a passive operation, the other is polarization handling, and then finally active interaction between electric magnetic fields with optical field. So, let us start with power handling. So, how do we handle a light propagation inside a circuit? So, there are very simple operations we will start with, so one is, a very simple interconnect so that means you want to transport light from point a to point b.

So and you can realize that by using a straight waveguide so this is a planar implementation of a the functionality here, so you want to go from point a to point b in a straight line, but you can also use bends for that, so instead of going straight you can take a bend here and you can still reach point a to point b, unlike a free space guided wave optics allows you to bend the waveguide provided the bending radius are within the limit and we should be able to transport light from point a to point b without any loss. So, this is a very simple configuration is just the basic configuration of waveguide.

So, the next thing is I want to send signal to two different places, so I have one input and then two outputs. So, I want to split the light now. So, I want to split it from point a to point b and also point a to point c, and not just that I want to put a condition that I want to split this in equal ratio 50:50, so how do we do that? So, in a in a conventional optics what we will do is, a beam splitter, so you use a simple beam splitter.

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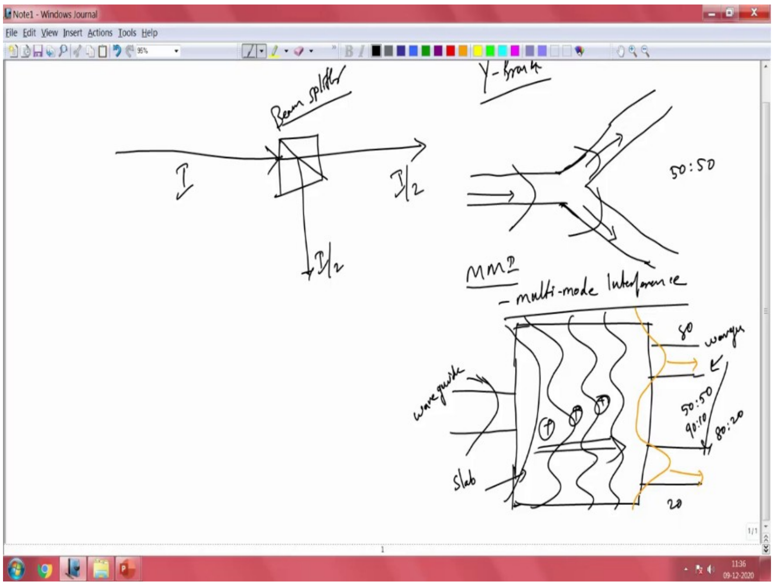


Let me open the journal here, so if you want to split the light so you will use a very simple beam splitter and that so that beam splitter is going to transport one part of the light there, and the another part here. So, if you are going to send in intensity I, it will be I/2, and I/2. So the half of light is getting splitted. So, this is a very simple beam splitter configuration but you need a very large element called a beam splitter when it comes to bulk optics.

But in a in a guided wave optics you can use two kind of implementation one is Y-branch, you branch the waveguide like Y structure and the other one is multi-mode interference. So, Y-branch looks similar to the beam splitter, so, so we take a waveguide and then just split it up as simple as that. So, the this is just a single line so how do you see it in reality it is like a splitter, in a in a road. So, there is a junction so light comes in through here, and it can take this path, and this path.

So, now the light can be divided in equal ratios, so you can see here there is a, there is a section that allows the light to split into two propagating modes here, and this is Y-branch implementation and the other type of splitting here is by using MMI which is called Multi-Mode Interference. So, what is this Multi-Mode Interference? So, again the concept is same, I come in with a single waveguide that has the power that I want to split but I wanted two different places 50:50.

So, instead of having this Y-branch, I can have a a slab here. This is a slab wave section, so this is a waveguide, and this is again a waveguide. These two, then this is a slab, almost like a one-dimensional waveguide structure. But then what the slab waveguide does is, it allows light to interfere with each other. So, you take a configuration like this so when you put it into the waveguide, it generates multiple solutions inside. These are all different solutions inside this section what we call the slab section but they all interfere with each other.

So, when they interfere with each other they result in a final structure like this, let me pick up a different color, so it generates a final resultant interference pattern or image like this and this allows you to couple or split the light into two. We will look at how this actually happens, all the nitty-gritties and the equations involved in splitting and so on, but conceptually this is what happens when you want to use multi-mode interference mechanism to split light between two different waveguides and here again you can have 50:50 splitting.

So, is it only 50:50, can I get any arbitrary splitting? The answer to that is, yes, so you can choose to get 90:10, or you can do 80:20, it depends on your design. So, you can put 80 percentage of light in one arm and 20 percentage in the other or 90 in one and 10 in the other. So, you can also input, so it depends on how you construct this interference between these different propagating mode. So, this is how we split light so this is a power splitter and we can also combine light using this.

So, instead of putting, defining this as the input and these two are outputs, we can switch the direction I can switch this direction, so it becomes a power combiner, so splitter combiner is a reciprocal device so we can we do not have to worry about how do I combine light, so you just change the direction of energy flow, then you get a a combiner. So, Y-splitters, Y-combiners, MMI splitters, MMI combiners. These are just same device and now you might have a question, I want to split more than two, so I have one input and two outputs how about 1 input and 4 outputs, is it possible? To realize that and of course the answer to that is going to be yes, because nothing is impossible.

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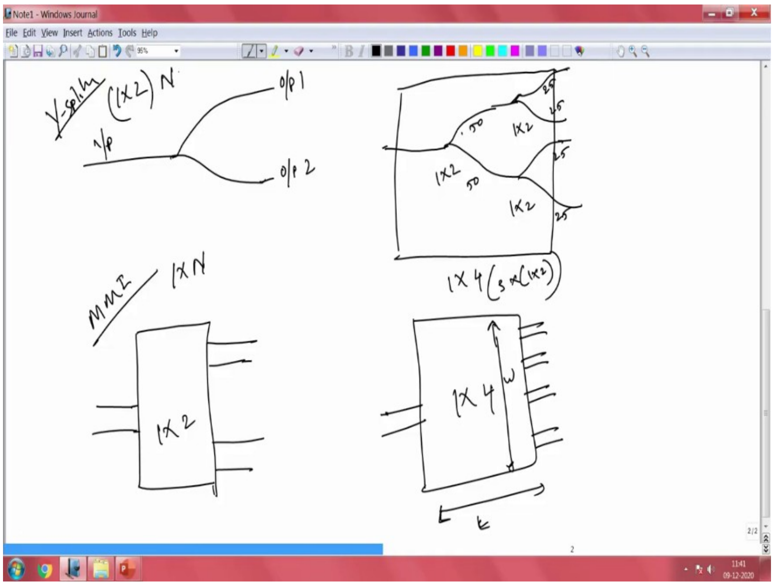


So, in a Y-junction that is you had something like this, so you had input and then you had output 1 and then you had output 2. So, how do I make this 4 outputs? So, it is a bit of a challenge when you use Y-junction, so if you want to make it at 4, you have to do 2 stage splitting, so you have first stage and then you have the second stage. So you have 1/2, 1/2, and 1/2, when you add when you add, take this whole block now you have 1/4, so you have 1 input and 4 outputs, so that means you need to have 2 times 1/2, rather 3 times 1/2, in order to realize 1/4 splitter.

So, splitters need to be added sequentially in order to increase the number of output ports. So, when you do that, so this is 50:50 and now you will have 25:25:25:25, so now you have realized 1/4 splitter equal powers. When you look at MMI, you start with this, so this is a 1/2 power splitter or power combiner, in this case we want to split it let us say, is a very easy way to imagine this similar to Y junction.

So, if you want to do 1/4 the interesting fact here is, you do not have to go for another stage in what you can do is you can actually make 1/2 directly, of course the length and width between the 1/2 and 1/2 are going to be slightly different, however it is not as rudimentary as the Y splitter where you just keep on adding 1/2 splitters stage by stage, here you can have a new design that will give you direct power splitting from 1 input to a 4 outputs with a single device.

So, MMI devices are are scalable, when it comes to output, so it will be 1 by n, you can easily do. However, Y splitters are limited by 1/2 and how much ever you want you just have to add number of stages, so you need to have more number of such splitters in order to realize different splitting ratios and outputs. So, that is power splitting and power combining, now we can propagate light from one place to the other, you can even bend the waveguides if you if you want, and then we know how to split the light and combine the light and we can do it with any number of splitting and arbitrary splitting ratios as well through Y-branch and MMI.

The next question now is, can I reflect the light? All you are looking at is a mirror like function, so I want to send back the light in the same direction it came from, it is a reflector so how do we do that? In in conventional optics, we use a mirror so if you put a mirror, orthogonal to the incoming beam then the beam will be reflected back, so you can send back, we can use same strategy here as well. So, you can take a waveguide and put a mirror here, so when you put a mirror, then the light will be sent back the same waveguide, so this is one way of reflection. The other way to do that is by using grating. So, some of you might have learned about greetings in introduction to photonics course.

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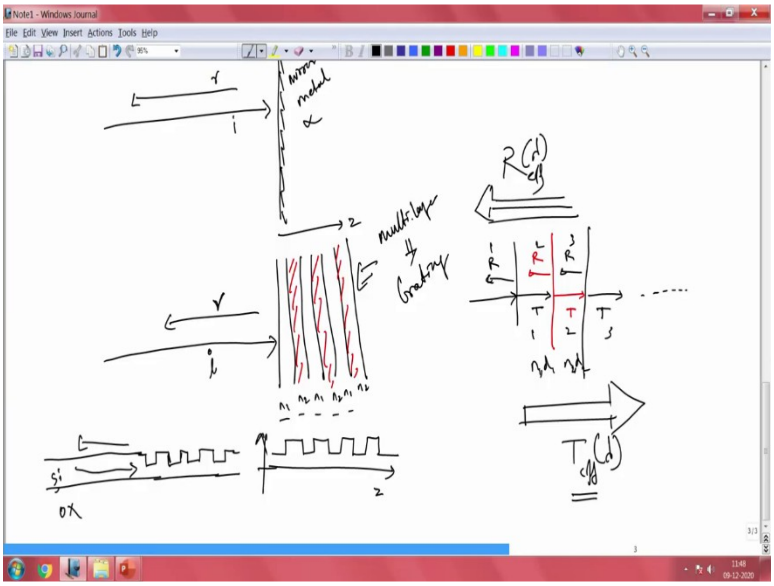


So, we will also understand this gratings in this course, but just to give you an idea it uses multiple layers of let us say alternating layers or sections of refractive index, so there are two ways to reflect light, so you have an incoming light, so if you want to send it back, so this is incident light and this is reflected light by using a mirror, very simple mirror wase most of the time we use metal, so metal has very high absorption, so because of that you will get very strong reflection when it is orthogonal.

So, now the next question is, can we do it any different in a guided wave system? We can use multiple layers of alternating refractive indices, so I had different refractive index now so I can have $n_1$, $n_2$, $n_1$, $n_2$, $n_1$, $n_2$. So, what this gives me is a change in the refractive index along x direction, let us say this is z direction, so along the propagation direction z, I see change in the refractive index. So, this is one way of creating a mirror, so when an incoming light goes tries to go through, it will encounter this multiple layers.

So, we know from our basic understanding of light interacting with surface you will, have with the surface when it comes in you will have transmission, you will have reflection. So, this is what we learned. But, then what if I if I put another surface here, so let me pick up a different color, so what happens when I put another surface here, here again there will be transmission and there will be reflection, and now again I put another here so again there will be transmission and there will be reflection and this goes on. So, now you can see there is successive transmission, so 1, 2, 3 let us say, and then successive reflection again 1, 2, 3.

So, all of this reflected light should constructively interfere in order to create effective reflection and then the light that is passing through transmission should all combine with each other to create an effective transmission. So, this depends on the refractive index that we have and also the thickness that we have, between these two layers so $n_1$ and $n_2$, $d_1$ and $d_2$. So, we look at the physics later on, but this is how it works. So, there is a effective reflection in effective transmission, and because of this reflection you can send the light back and there will be some transmission that is happening, but this reflection and transmission is a function of wavelength.

And for certain wavelengths you can make sure that all the light is reflected back by this is the structure is called a multi-layer structure is called a grating. And, one can put multi-layer structure or you can create a refractive index difference that is all we are looking for, and that can be realized by taking a waveguide, I take a very simple waveguide, so this is let us say silicon and this is oxide and then I can change the thickness of this material, if I change the thickness of silicon actually the refractive index changes because we know the refractive index for the effective index of the material is a function of thickness.

So, this is another way of realizing a grating, because of this when light comes in here it will get reflected back. So, this is another way of realizing a reflector. So, either we use a mirror at the end, or we use a grating structure, so the grating structure can also act as a reflector. So now, you can reflect the power, so you have realized the mirror and the next power handling that we are going to do is what we call directional coupler, this is similar to from the functionality looks like a power splitter or MMI based power splitter or power combiner but it can, it can have a really interesting features.

Let us look at this very simple directional coupler. The reason why it is called directional coupler is, it is it couples light from one waveguide to the other waveguide only in one direction. Let us say in, so the light from here could be coupled to the to the other without coupling anything to this it is possible to realize such configuration and that is the reason why we call it is highly directional, you can make it in one direction. But anyway, this is anyway recent reciprocal device itself. So, when I say directional, you should not think can I do a isolator with this, since this device is going to be reciprocal then you would not be able to realize an isolator.

But let us come back to the directional coupler discussion here, so instead of having 1 input and 2 outputs, we have 2 inputs and 2 outputs. So here, the idea is let us say I want to send light from let us say this is A B and this is C D, so you want to send light from A to D and then you want to send light from B to C, so with single device you can realize this. And let us say you do not want to send all the light to D, you can also couple from A to D, A to C, some fraction of light as well, and you can also take light to B to D, it is also possible to have some fraction.

So, this can be 100 percentage and or you can say I want to just put 50:50 here, or in in other cases you can say A to D is 100 and A to C is 0, similarly B to C is 100 and B to D is 0. So, I can also realize this kind of configuration. So, how do we do this? So, this this can be realized by using two waveguides very close to each other, so which is called coupling region here. So, when you have two waveguides close to each other, so there will be a crosstalk between these two and we use this crosstalk to achieve a power transmission between these two waveguides. So, let us let us quickly look how this cross crosstalk is going to help us.

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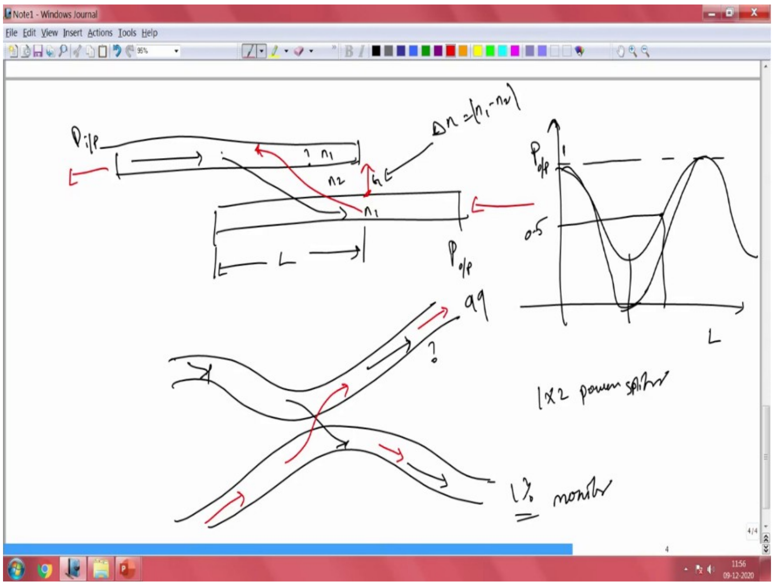


So, I have a waveguide here, and then if I have another waveguide coming close to this this is where I could have crossing of power between these two waveguides, because they are very close to each other. Similarly, when I come from this side, I can couple light from here to here, so by putting waveguides closer to each other one could couple light between these two. How close, it depends on the refractive index that you have between let us say and $n_1$ $n_2$ and let us say this is $n_1$, so the difference between $n_1$ and $n_2$ gives you what the gap should be, we will see that little later when we talk about discrete components and a couple more theory, how one can couple light between these two?

So, conceptually speaking, you can take two waveguides and then bring them closer to each other you will see power coupling, and you might also notice there is a length associated with this. So, whether all the light will couple in there, not necessary, that depends on the length. So, when there is a change in length the coupling, let us say power, let us say this is input and this is output, so the input to output is what you have here. So, as a function of length, you will have a cosine like function, at some point you will have very little or no light going through the waveguide and in the other case you will have maximum coupling of one, let us say.

So, you will have all the light coupled to this waveguide from one to the other in some cases at some lengths where you will not have much coupling in some cases if you design it properly you can make it really 0. So, where you do not have any coupling at all. So, by doing this you can couple light from one waveguide to the other and here again if you design it, a waveguide like this, what you can do is I can put some light here and because of the cross coupling you will see light through this.

So, what I can do is, I can pick a center point or operating point here where it is 0.5 coupling, so now I have 0.5 here and 0.5 here, so half of the light would show up here and half of the light show up here and essentially what I have made is a 1/2 power splitter. So, this is one way of using the directional coupler concept in order to realize a power splitting functionality here, so where do we use this? We use this for proximity coupling, later on we will see we want to split the light a little bit of light in order to create a cavity, in order to detect what is happening here.

So, you want to take that little amount of light and if that is the case, then you want to just take 1 percentage of light, let us say, so we can take 1 percentage of light and watch monitor, what is happening in the circuit because like electrical signal you cannot tap out that easily without disturbing the functionality of your device. So, directional couplers helps us to tap out a very small amount of power in order to monitor what is happening inside this device. So, you can have this way and as I mentioned you can also have something like this as well, all these functionalities one can do by using directional coupler. So, directional coupler is another way of handling power.

So far what we have done is to review various power coupling schemes, so how do you take light from 1 single point and distribute with 2 or more than 2 outputs. So, and also take power from 2 or 3 inputs and combine and put it into a single waveguide. So this is all basic functionalities of power handling or power splitting and combining and also we saw a simple waveguide, so you take light from point A to point B or in a straight line or you want to go through a certain bending and go around some objects that you have in the circuit, so then you need a bend, so a straight waveguide and a simple bend S or completely curved bends, one can use to navigate through the to through your through your structures that you have in the circuit.

So, these are all simple waveguide components or devices that you want to call it as a device or you want to call it as a component, it does not really matter the functionalities that you can use for various power handling. So, with that we will summarize this section of lecture in the next one we will look at polarization. So, how one could handle polarization of light and also how one can interact with electric and acousto-optic processes. Thank you very much.