**Photonic Integrated Circuit**
**Professor. Shankar Kumar Selvaraja**
**Centre of Nano Science and Engineering**
**Indian Institute of Science, Bengaluru**
**Lecture No. 08**
**Photonic Integrated Circuit Components 2**

Hello everyone, in the last lecture we looked at power handling devices or components in photonic integrated circuit. So, now let us look at how one can manipulate and handle polarization in a photonic integrated circuit. Let us look at those devices.

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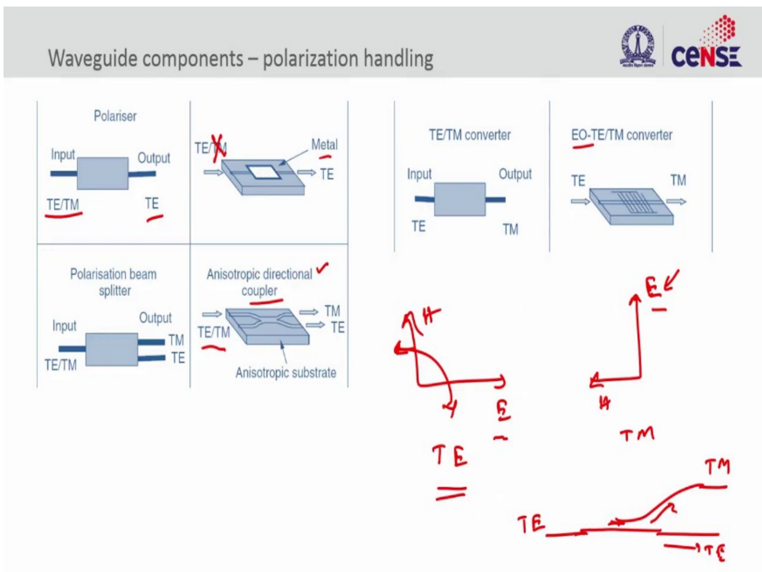


So, light polarization is a (int) interesting property that we have in a photonic in photonics. So, you have electric and magnetic field that are orthogonal to each other, so you could have this configuration or the other configuration where you have electric and magnetic field, so you can you can have one of these configurations. So, when you have these configuration, so whether light is going into the slide here or coming out.

So, the electric field can take transverse, or the magnetic field can have transverse component. So, these are two different solutions on its own so they are orthogonal solutions and they do not talk to each other, because they are isolated solution, they are eigen solutions in the system, but then more often you want to manipulate or you want to filter out these polarization, sometimes you could have unpolarized light but you want only TE polarized light or only TM pola rized light in the circuit, this is all for having a clean circuit. So, you want a single polarization to handle all the circuit functionalities let us say.

So, if that is the case, we should be able to filter out polarization and that is what we call polarizers. So, we use polarizers to filter out only one kind of polarization out of randomly polarized or unpolarized light let us say, if that is the case, then if the inputs TE or TM both are combined then you want to only take out TE, what kind of functionality can I do? So, one easy way to do that is by using a very simple metal on top of the waveguide, so this is transverse electric and transverse magnetic.

So, the magnetic in the TM waveguide, so in TM configuration the electric field is vertical, I only want TE, I do not want TM passing through my waveguide. So, one way to handle this is by creating a high loss for this TM waveguide.

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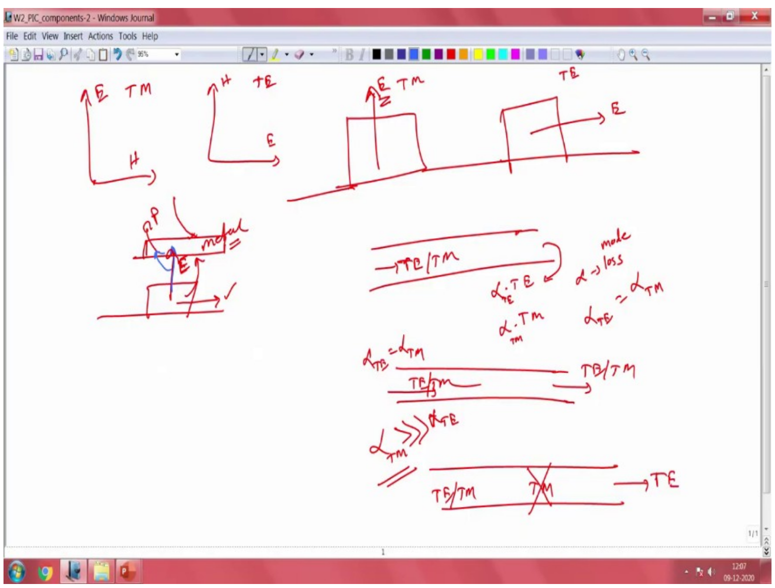


So, just to conceptually look at this let us take this is TM configuration and let us say this is TE configuration. So, when the when light is propagating through a waveguide, so this is a very simple waveguide let us say, you could have electric field this way or you could have electric field this way this is TM and this is TE. So, they are propagating through this waveguide, so you have TE and you have TM going through, but there will be an associated loss when it propagates through the system.

So, let us say you have αTE is what you get at the output and then you have αTM is what you get at the TM. If the loss that you have so α is loss let us say, it is mode loss for this, so if you make this loss specific to the polarization, so this is αTE and alpha for TM, so if α for TE equals to αfor TM, then you will get both the polarization out. So, in case of α TE equals to αTM, input is TE TM and the output is TE and TM. So, this is what you would get.

But then if I take a scenario where α of TM is much greater than α for TE, then my input is TE and TM but only TE would survive, so TM would be lost inside, so this is what polarization or polarizers do, so they just kill one of the polarization, by creating a higher loss for one of the polarization and how do we achieve this? So, this is the concept so you increase the polarize loss for one of the polarization, so how do we achieve this? So, we need to have high loss for this TE mode, so TM mode here, so this electric field should be absorbed.

So, we know from the basics, so if I put a metal, metal has very high refractive index, and your E field should interact with this metal, so when it interacts with this metal, it can create surface plasmons here, so there is a plasmon mode that can be created here. So, because of interaction with this metal, and creating a plasma mode you will actually generate a propagating mode inside the metal, and basically the light from this would leak into the metal for the electric field that is pointing vertical.

But for light polarization where the electric field is horizontal that is the TE polarization light, it will not interact with this metal, when it does not interact with this metal it will just propagate through the medium without any loss. But then for the light that is having interaction with so with the metal this light will be lost into the metal for to create solution into the metal and then they will leak or absorbed in the metal.

So, this is how you create a preferential loss between the two polarization. So, using a metal is one example, so metal acts as an absorber for TE TM polarized light so because the TM polarized side, the electric field is vertical and for TE polarized light it is horizontal, so because it is vertical ,when you put a metal on top, it is going to absorb this vertical field. So, there is a phase matching condition, so those are all details that I am just leaving conceptually to understand this so the vertical E field will absorbed by this vertical metal on top.

But then for the horizontal E field it will not interact with the metal because the metal is too far for the field to interact. So, this is how you can design your structure to create preferential loss for one of the polarization. For example, if I want to absorb light that is with TE polarize, I can put absorbers on the side, so light is sitting here and then I can put a metal the side, so then there will be an interaction of the field and it can couple out to the metal, similarly what happens for the top metal.

So, you can create preferential loss for TE and TM that would result in polarizers, so that is the first kind of polarization, so you are killing one of the polarization so you do not want one and the next kind of device is how do we split the polarization? Because when we say we are going to kill one of the polarization that means that the whatever energy that is present there is lost we are not making use of that.

When you have information both in TE and TM polarized light, you want to capture both this polarization in order to understand all the information that we have there. But then by removing one of the polarization, you only get half of the information provided that the both TE and TM carry 50 percentage of the information let us say, so you are losing that 50 percentage of intensity that that we had. But the information that we you get from TE is the same information that is T present in TM as well, but then the power that was carried by TM wave waves are lost, that is not very efficient way of doing it.

So, in order to capture both the light sources, we can have polarization splitting and then you can capture it. So, that is what polarization beam splitters do, this is the functionality that exists in the bulk optics as well. So, when you have two polarizations here the device or the component would split the polarization, so TE in one and TM in the other. So, this can be easily understood from our anisotropic material concepts, because you have the fast axis, slow axis, and one polarization is sees a different refraction compared to the other, so that you can split these two polarization in space and then you can collect them.

In guided wave optics as well, you could use a directional coupler-based approach by using an anisotropic substrate or some sophisticated directional couplers, which we will see later on, how one can split the polarization between two different sources. So, this is also something that we can do. So, now we can completely take out one polarization and we can actually take information from both the polarization by splitting them, so there is no mixture here, so you are splitting them and the next concept is to convert the polarization, can I convert a light that is TE polarized to a TM polarized or TM polarized light to TE polarized?

So, all you are trying to do, whether I can rotate these polarization, the way that we want in order to achieve a different orientation of electric field. It is indeed doable, the way that we do is by using polarization rotators in a passive form or you can also use electro-optic converter, so you can use electro-optic material something like lithium niobate in order to convert this polarization, by using periodic arrangement of these electrodes that will allow rotation of this field or creating alternate refractive indexes that will allow this phase matching between TE and TM. So, that is another way of handling polarization conversion.

You can also do it through passive means, similar to what we saw here so you could have TE come in and then you can rotate the polarization but not in a single waveguide perhaps you can have some structuring along this that will rotate this polarization, which is something doable or you can do directional couplers as well so you can you can take in a directional coupler configuration where you put TE light here, and then you get TM light in this case.

So, when you when it is transitioning from the bottom waveguide to the top waveguide, you see it is becoming TM and why while the through port will have TE polarized light, so this is another way of realizing polarization conversion in a pure passive nature. So, this is all about phase matching your TE with TM and these concepts we will see later, once you once we go into the details of this device.

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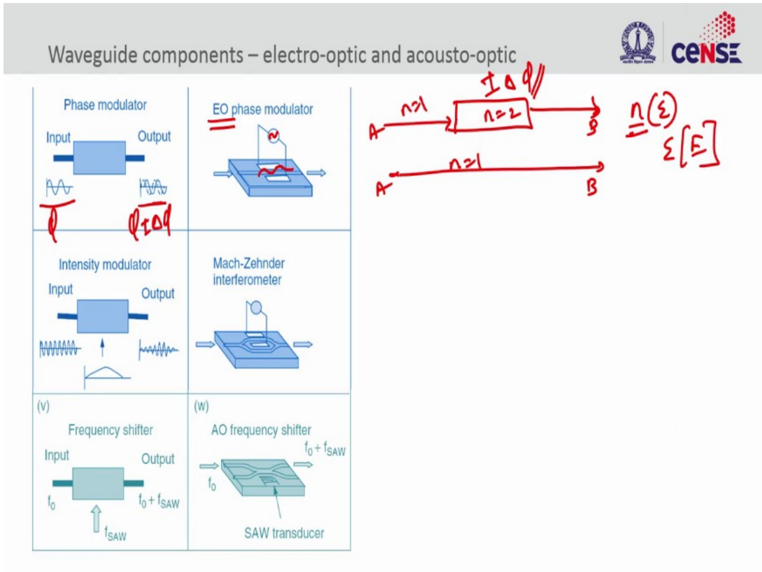


And, finally let us look at waveguide components that interact with other form of energy so electric field and acoustic fields. So, what can we do by using this, a primary thing that we use for many many application is phase manipulation. So, when you have a light wave of a certain phase come into this device you want to change the phase of it, so you want to have a slight phase difference that you add to this device, so add to this wave that is propagating through this device, so how can we do this?

It is basically changing the material property, so I take a bulk of a material and if I transmit a wave through it, because of the refractive index change, if this is n = 1 and let us say n = 2. So, when it is passing through this medium, it is slowed down so that means it will accumulate a certain phase and when it is going through just n = 1 let us say free space, there is no phase difference from point A to point B, and when you when you have a medium in between it changes.

But now the question is, can I dynamically change this phase difference, now it is static? it is indeed possible to do it, by using electro optic effect, so the refractive index that we see here is a function of electric permittivity. So, we all know permittivity is a function of electric field for isotropic and anisotropic materials or electro optic material. So, when you apply a certain electric field, the refractive index would change when the refractive index changes the phase would change. So, this is how you can make a phase change to a light that is propagating through this device which is called a phase modulator.

So, you can change, you can apply a dc, or you can apply an alternating current. So, by applying an alternating field, you can change the phase oscillate between two $\Delta\phi$, so if you want a constant change you can apply a dc. So, when you apply a dc, you should be able to change this phase only in one direction. So, what are all the other things that we can do by using this electro-optic or phase change?

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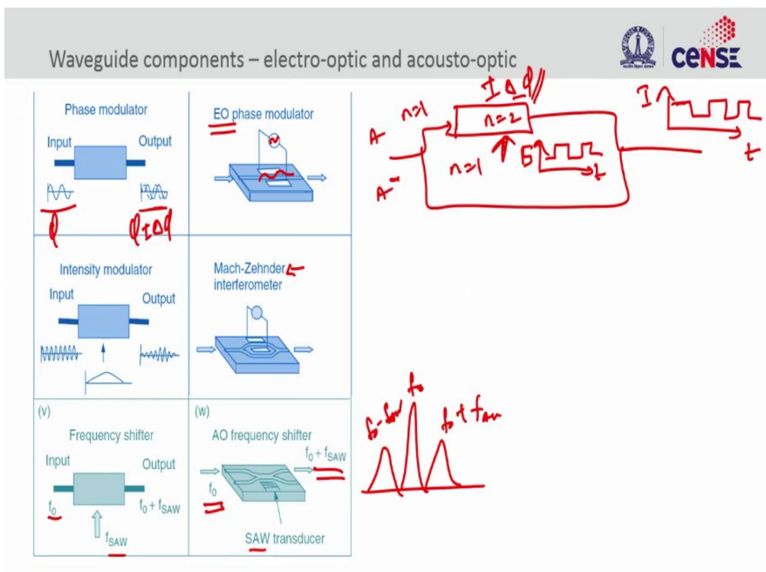


So, by just taking the same configuration I can take this and combine these two. So, by doing this you can create an interferometer and now this interferometer again is static, so but when I apply an electric field here my phase is also changing dynamically, so because of this dynamic change in the phase, I can change my intensity here as well. As a function of time, when my electric field is changing as a function of time, I can change my optical intensity change as a function of time because you are changing your phase as a function of time, so that is what we do in order to realize a intensity modulator.

So, you want to change the intensity of light passing through this device by an external stimuli, so the external stimulus here is an electric field. So, by applying an electric field in this interferometer is called a Mach–Zehnder interferometer, you can change the light intensity that is coming out.

And finally, you can also use Acousto-optic interaction which is used to create frequency shifts, so you can take a certain frequency coming from an acoustic transducer a sum of Piezoelectric materials let us say, and you create this field and this field is going to interact with an incoming frequency, a modulated light or an unmodulated light you are going to interact with this, so with the frequency coming from the surface acoustic wave here, the surface acoustic waves are going to interact with the incoming optical waves and they will mix and this is basically frequency mixing and this will generate frequency sidebands, that are placed $\Delta f$ apart, so this is $f_o$ and this is $f_o + f_{saw}$ and $f_o - f_{saw}$.

So, this is these are all the side bands one can generate from this frequent acousto-optics model it is, you can create new frequencies coming out of this. So, you can have an unmodulated one or this this whole input could signal could also be already a modulated signal. So, there are interesting optical or Rf signal processing that you can do by exploiting the optical on-chip, optical signal processing here. So, with this device there are lot of material aspect involved here as well, but there are interesting signal processing strategies one can do at very high frequencies that that sometimes are impossible to do it with traditional microelectronic based circuits.

So, with that we have come to a summary of end of summary of this components, so integrated photonic components that we can use for realizing various functionalities. So, this is not a comprehensive list, so what I given you is some of the important concept devices. So, you can build on top of this devices for example we have not discussed cavities, so you can create optical cavities by using waveguide. So, that is again a very important component but then that component could be realized by putting some of these components together.

For example, a simple cavity could be realized by the grating reflector, so we talked about reflectors in the last class, so you can put two reflectors and give a gap between this a cavity between the two mirrors that will give you a very nice cavity that you can use it for realizing a laser, for example, we can also use this for polarization manipulation. So, you want to capture all the light that is coming to you, so how do we do that by using this cavity by using this polarization splitters and you can use power combiners later on, in order to capture this.

So, combining this fundamental blocks you can create more complex functionalities, and this is not a comprehensive list. There are much more discrete functionalities people are coming up with by combining material aspects with light matter interaction as well. So, with that we have a comprehensive understanding now with different type of device or components that we have seen so far we had power handling, we had polarization handling, and we had some active interaction with electric field, acoustic fields by combining material aspect as well, to realize a certain functionality.

Going forward we will look at each and every component that we just discussed into their physics and how it actually works. Thank you very much.