Introduction to Photonics
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Light Manipulation-Faraday Rotation

Okay Welcome to intro to photonics last week we had been looking at ways of manipulating light and with respect to that we started with how does light propagate through a medium and then went on to look at the using light polarization manipulating light polarization can we let us say for example change the intensity of light and so that what looking at last week and we said we can change the intensity we can actually change the polarization of light using anisotropic medium and while talking about those.

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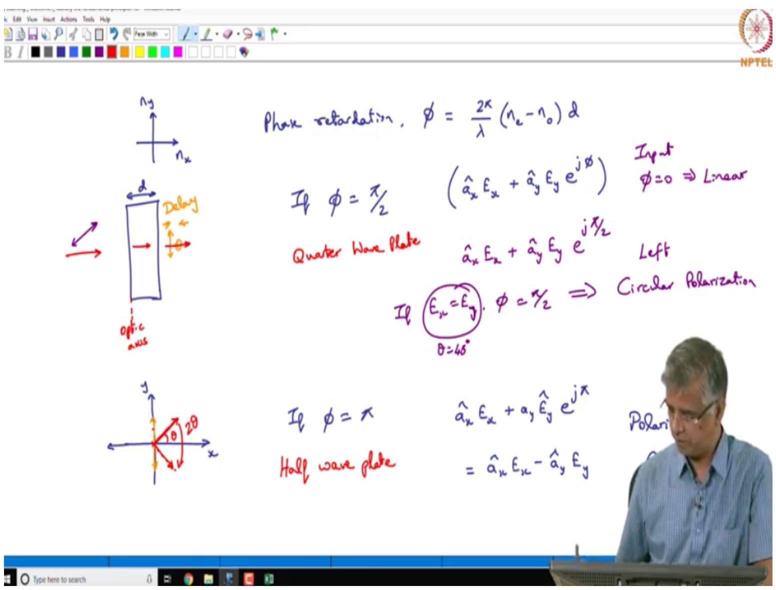

we came up with this specific thing about quarter wave plates and half wave plates and I made a mistake hear I just pointed out by the TA at the end of the last session, so I said we are actually going to go through a rotation this way but what will happen here is you know we talked about the incident polarization being like this into on and half-way plate by theta but while propagating that through the half way plate we said the EY component is getting flipped.

So the EY component will you know show up once it is flipped that the actual polarization will show up here and this is basically 2 theta, so that is what we wanted to convey but you know I did the mistake there in the in the last session, so far we have been looking at either extinguishing a polarization using a polarizer or rotating the polarization or changing the polarization state using a half wave plate or a quarter wave plate there is actually one more important application that I want to touch upon before.

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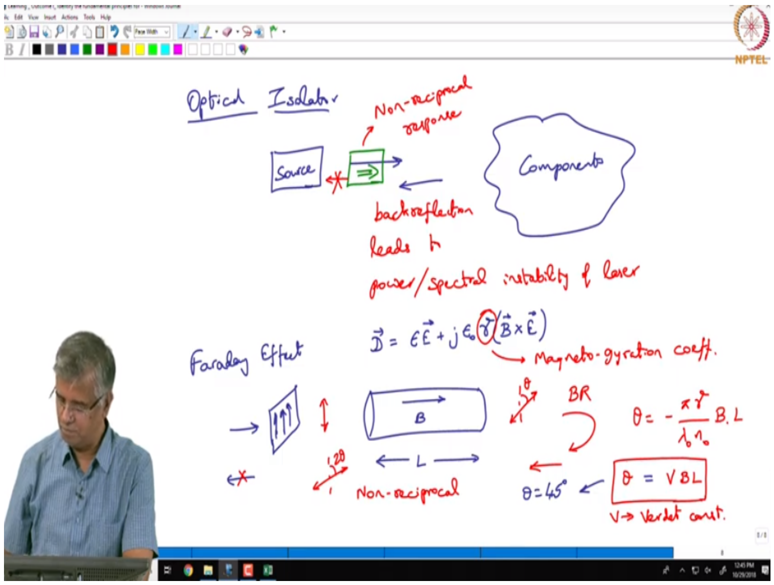

We move forward and that application is what is called optical isolator, so question is when you send light from a source let us say laser you send this light and it gets into some other components over here okay but some of that light could actually get reflected by those components and that reflected light can potentially go into the source, so now we have a cavity a laser cavity let us say that is based on two mirrors and light is going out of that cavity it hits some component and then the reflection is coming back and it gets coupled into the laser again.

So this is like an external cavity that is getting developed, so now the properties of the laser is only dependent on this cavity but also what is happening you know outside based on this reflection and that can change a lot of things that can changes of course the power that is emitted that can fluctuate but it can also mean that there is fluctuation in the wavelength at which light is emitted, so this back reflection is back reflection typically leads to power as well as spectral instability of the laser.

So you need to essentially introduce a component the output of your source such that it allows light to get transmitted in one direction but it should not allow light to comeback so whatever component here it should block whatever component coming back you know it should block that, so that essentially means that this component which will call as an isolator will need to exhibit a non-reciprocal response, so before we talk about on-reciprocal response.

Let us just understand what reciprocity means reciprocity means that you go from left to right you have a certain response from this component and that response should be the same if you go from right to left the opposite direction that is you are flipping the input and output right flipping the input and output if the responses is the same then you say that component is reciprocal but that is not what we want, we want to go from left to right but we should not have light going from right to left, so we need a non-reciprocal response.

So how can you achieve a non-reciprocal response one way of achieving that is through what is called the Faraday effect clearly it is named after Michael Faraday who has a lot of you know brilliant observations this is one of those observations where in what he observed is that when you look at response of certain medium we try to characterize the response of the medium based on your permittivity that is what we are looking at last week in the last weeks lecture but it so happens that there is also a response in terms of changing the polarization of light in the existence of external magnetic field that response is given by J epsilon naught gamma B cross E, where B corresponds to the magnetic field this case represented by the magnetic flux density along the axis of the material.

So through this magneto gyration coefficient this gamma is called the magneto gyration coefficient you have a gyration of the light polarization in other word if you have light polarization let us say linear and going through this material that polarization will be rotated by an angle corresponding to theta and where theta is given by minus pi times gamma over lambda not N not B times L where B corresponds to the magnitude of your magnetic flux density along the axis of this material and L corresponds to the length of this material itself.

So in the presence essentially what we are saying in the presence of an external magnetic field your light polarization which corresponds to the electric field of your wave that polarization is going to get rotated and how much it rotates depends on the strength of the magnetic field or the extent of the interaction length, now this factor over here is denoted by what is called the verdict constant, so it is theta is just given by V multiplied by B multiplied by L where we corresponds to the verdict constant yes, so yeah so what is the significance of this being imaginary thing it is basically saying it is phase shift involved.

So that corresponds to E power J pi sort of factor yeah, so this is in this case we are assuming that the B is constant, so you can assume or you can actually this would be a good idea if B is not constant then you are talking about possibly modulating that polarization coming out of this material, so by modulating B you can achieve modulation of the polarization state I and it is also dependent on the sine if B, so if the B is the opposite direction the rotation will be in the opposite direction so the question is can this be correspond to another electromagnetic wave possibly you can say I mean this just says that B cross.

So that other B can correspond to another electromagnetic wave however the rate at which this change happens the response of the medium would tend to be much muted right, so the we are not talking about the response time it is highly unlikely that this will respond to another electromagnetic wave at optical frequencies that is was your question whether it can respond to that and basically sorry, so we are not actually quantifying the response time corresponding to gamma, so that actually is medium dependent, so I do not know of existence of a material that responses optical frequencies that does not mean that there is an end but you know as far as I know it does not sorry and I do not understand the question.

So the question is whether this can happen in vacuum and answer is no this is actually based on interaction with a material and that material having a magnetic addition coefficient corresponding to gamma and gamma is different for different material jus the same way as your relative permittivity is different for different material gamma is different for different material and a suspect gamma is also dependent on frequency but the point I want to make is that you could achieve this now if this material was a black box you could when you say your polarization is getting rotated what could be in that black box what else can you imagine can give you a rotation of your polarization half wave plate.

A half wave plate could do that rotation but in a half wave plate if you had done this rotation and you flip which is the input and output or rather you come back with this polarization as the input you come in with this polarization angle theta as input from the right side it would have gone back to this linear polarization in other word the half wave plate would have been completely reciprocal in nature nut this faraday effect is not reciprocal why because the sine depends on which way the rotation happens depends on B cross E in one case B is oriented along the direction of propagation the other case of B is oriented at you know against the direction of propagation.

So the rotation would have been in the other direction then what happening in there, so in this case for faraday effect in the this magnetic gyration effect you would have gone out if you came in with that polarization you would have gone out with two theta as your polarization of light that is going in this toward the left direction, so this is actually the because of the non-reciprocal nature of this faraday effect yes that is a question sorry if we put right-right that direction is, so the question is if we had another rod like this after this output after it is rotated by theta it would have gone to theta again.

So that is right so it is going two theta in this case we are looking at it from a perspective of building an isolator, so the question is can we use this we are not talking about just getting rotation if you want to get just rotation theta to theta whatever you would have young usually just used a half wave plate and achieve that rotation orientation of the magnetic field with respect to the electric field yes so if I had another crystal after this and in that crystal let us say the B is in the opposite direction and of the same magnitude both the crystal are you know the same material in the same length then it would have gone back to the original polarization exactly but now we are talking about the reflected light.

So reflected light going from right to left that reflected light would have gone to two theta because of this non-reciprocal nature if it was a reciprocal deice it would have gone back to the original polarization itself, so how would you build an isolator based on this effect that is simple right so you can basically put a polarizer which allows only this polarization, so that is how you got this output polarization like this but that polarizer if the theta, so if this theta is 45 degrees so you have rotated you r polarization by 45 degrees going from left to right but coming back it would have rotated 90 degrees, 90 degrees with respect to the original polarization and then when that goes into the polarizer what happens that would have been absorbed.

So you would not have any light going in this direction, so you had light going this way go through that you material go through theta equals to 45 degrees and go through any back reflection but that back reflection while going back would have been rotated such that two theta is 90 degrees and then it is going across this polarizer which would polarizer would have blocked that orthogonal polarizer, so this entire device now consisting of a polarizer followed by this faraday material or a material which has this gamma the magnetic gyration that would have together work like an isolator.

So the question is yes the would this would work only if theta is 45 degree yes to get maximum isolation you need to have theta set at 45 degree and there is there is something very important about this we go back and look at the verdict constant, the verdict constant is inversely proportional to lambda the wavelength of the light that is going through, so the faraday isolator this that is what this device would be called faraday isolator for a one wavelength will not provide the same isolation at some other wavelength because for some wavelength theta would not be 45 degrees and you would have to go through Malice law essentially to determine how much light is actually going through.

So it would not work as perfect isolator now this isolator typically provides you isolation of up to 25 30 DB with the typical number meaning only 0.1 percent of the light that is going in the forward direction is going back into the going back in the reverse direction that is good for most cases but if you have a high power source let us say you know 100 watt source under what source 0.1 percent of it still 100 milliwatts, so 100 milliwatts may be lot of power to you know handle at your original source so certain application require you to have 50 or 60 DB isolation.

So what would you do you can cascade to two of these things and of course when you cascaded you have to be careful that the polarization alignment is taken care of the second polarizer is alignment at 45 degrees it is a question there yeah, so the reflection that is true the assumption here is that the reflection is not changing the polarization state right but normally it does not but yeah if you have some anisotropic response on the other side then this will not work however in those sort of conditions I did not mean to talk about this very much but since there is a question I will just mention this.

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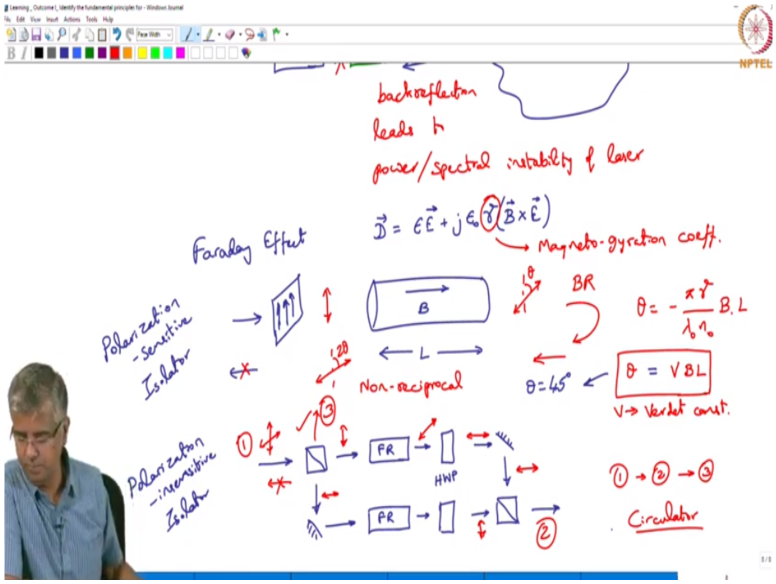

So this a principle for what is called a polarization sensitive isolator it is called polarization sensitive also because of the fact that only if you have polarize light you have maximum throughput right only a polarize light matching the input polarizer then you have maximum throughput if you put circular polarization for example coming in that polarizer right up front would have taken out one of the polarization components, so half the power would be lost right at the polarizer the front end itself.

So then that sort of thing would be lossy so what you would need in that case is a polarization insensitive isolator I did not actually expects so many questions in this topic I am glad I am getting those many question because that means that you guys are really getting into this topic of showing interest in this talk so keep them coming, so you could have a polarization insensitive isolator which basically says okay I will spit my polarization such that my vertical polarization goes that way my horizontal polarization goes this way and then I would have a mirror here and then go through this then I go through my faraday rotation material and then I go through.

So this is my FR material which is rotating this polarization by 45 degrees and then I would go through a half way plate the half way plate would rotate the input polarization it set such that rotating the input polarization by further 90 degrees why that is needed is because of this particular configuration that we have, so you put another polarization splitter here so the polarization splitter what it does is it any horizontal polarization it reflects any vertical polarization it transmits, so both these polarization will go together the same.

So here my input can be any arbitrary polarization consisting of booth X and Y components that polarization will be preserved as it propagates through this structure and similarly any arbitrary polarization coming back is going to go through this polarization you know this what is called the polarization diversity configuration because it separate out the two orthogonal polarization the part for the two orthogonal polarization but it effectively will end up blocking the wave just as we talked about.

So in this case you could have some other arbitrary polarization coming in as well but you know you could find a way of you know extinguishing that providing isolation for that so that is a polarization insensitive isolator, so just to give you a clearer picture here so this is 45 degrees but after going through the half wave plate it would have been this horizontal polarization so vertical is becoming horizontal and when you trace your way back this horizontal would have gone back to 45 but after going through the faraday rotation it would have been 90 degree at 90 degrees this polarization beam splitter will reflect we get the beam splitter is such that it is reflecting horizontal polarization.

So when coming back it would have been 90 degrees and that would have been reflected over there, so it is not going back to the source, so some of you may not be following this polarization insensitive scheme and I can questions on that separately but it is okay if you do not follow that if you understand this polarization sensitive isolator that is all I wanted to convey to you today that is right, so it is actually so look at it this way normally if it is a reciprocal device it would have gone back to the original polarization and in this case it is non-reciprocal that means it is going in the opposite direction because of the orientation of the magnetic field with respect to the incoming polarization.

The magnetic field is reversed yes okay do not go so much into the orientation yes but just think about it as this way right so in one case if it was reciprocal it would have actually given you the original polarization itself and in this case because the magnetic field is opposite because my electric field are the incoming wave is in this direction but magnetic field is in this direction because of that it is going in the opposite direction the polarization is that is essentially the non-reciprocal effect there is a very fine point over here when we talk about a polarization insensitive isolator we are talking about light not going back towards the source.

So we are blocking this light but we are actually having light go into that other direction, so there is an opportunity to pick up that light and use it also or in other words maybe your intention is to go from port 1 to port 2 but anything from port 2 you actually want to extract from port 3 does that remind you of something that you have come across that is the functionality of a circulator, so a polarization insensitive isolator can actually be modified to provide you the circulator functionality as well so you can extract a light coming back from the other direction so you can do one to two but anything coming from two goes into three.

So already out of time I actually wanted to go into different topic but that is fine we can meet on Wednesday and then we will talk about, so where we are going with this so far all this is still very much linear response from the material but what we will deal with in the next lecture is what if the material responds in a nonlinear fashion one key point there is as long as you have linear response whatever your incoming frequency is the same frequency will go out okay for any linear respond material whatever is the excitation frequency the output frequency will be the same but when we go to nonlinear response you have an opportunity of changing that frequency so the outgoing frequency may not be the same as incoming frequency, so those aspects we will discuss in more detail in the next lecture.