**Indian Institute of Science**

**Photonic Integrated Circuits**

**Lecture – 09**
**Integrated optical Systems and Applications**

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**NPTEL Online Certification Course**

In this presentation we will discuss about the systems and applications of integrated optical devices. So I have put up a few points.

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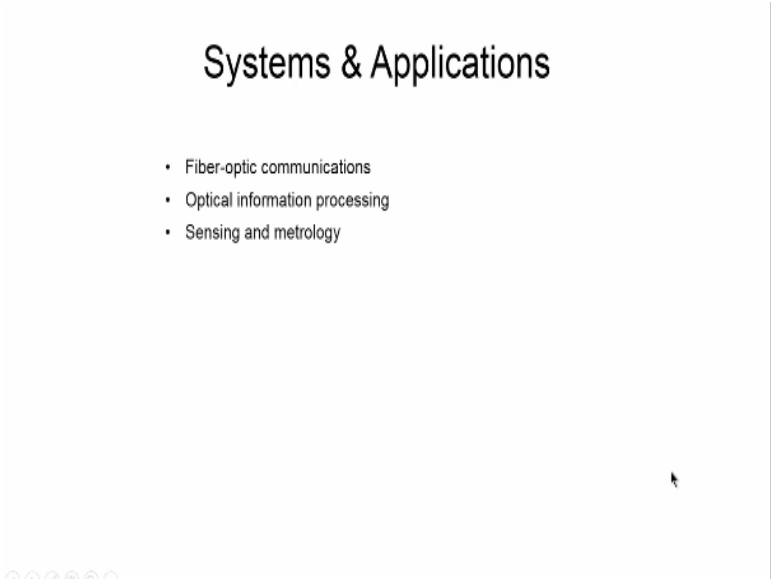


So we will look at fiber optic communication systems, optical information processing systems, sensing, storage these are the various applications that integrated optical devices are required.

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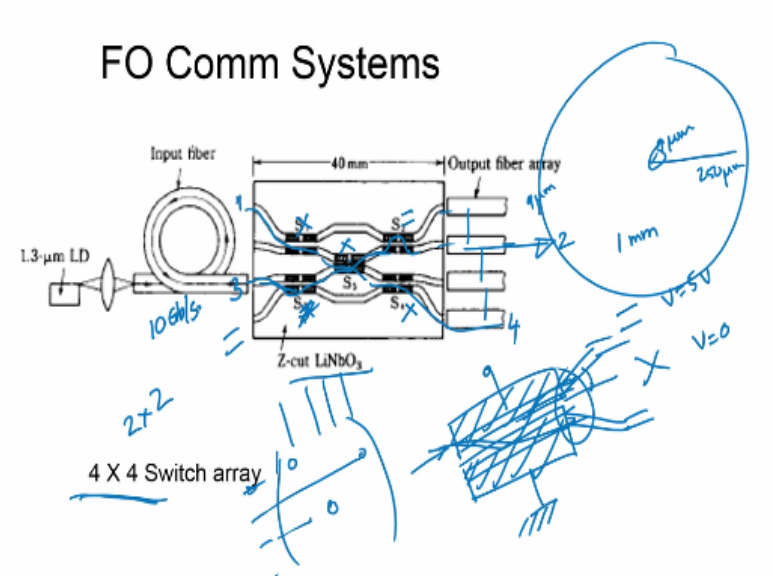


This is the simple example of a fiber optic communication system, in a typical fiber optic system one of the important problems in communications right now is networking not only long distance communication. Fiber optic links have been very, very popular there are no other reality for long distance applications. You can go for high data rid communications of the hours of 10 gay of disperse second.

So in a typical situation there are several users not only a single user, but there are several users information has to exchange across all these people and so on. So if you are using fiber optic communications for such purpose there is also a necessity to switch or communicate between different users and so we have this is an example of a system where you have several say let us say, four users they receive the signals and then the signal from one user has to be communicated to another user on.

So we have four input ports and four output ports and the signal has to be routed or switched from any of the input ports to any of the output ports. In this example I have chosen the directional coupler switches, electro optic switches, we have chose and seen earlier. As we know the electro optic switch has a configuration of any directional coupler just I have taken. Okay, a directional coupler switch has got two waveguide directional couplers and then we have the electrodes over that.

And depending on the voltage that you apply to these electrodes you can switch the signal from the one input port to another output port. We have seen that earlier in the electro optic effect. So

when the voltage that there is no voltage on this you design it such that it is in the, what is called the cross over state and when you apply voltage to this and switch back into the bar state. So cross over state with no voltage and bar state with the voltage of say for example 5 volts or 9 volts.

So this is the functioning of the directional coupler switch and we can configure this to achieve a higher order switching like a 4/4 switching how can it be done is what I am showing here. There is one additional feature or which we did not discussed earlier is that there are tapered region these directional couplers have to be tapered if you want to connect inputs and outputs. Of course there is a taper in between these section which we are ignoring at this moment for conceptual purposes.

But in the practical situation we need to consider the coupling of light between these and then adjust the voltages or the coupling lens according to that so for the time being we will assume that the functioning of these directional couplers which I sees has discussed earlier, so when a signal is input at any particular port or in fact input in fact we have signals at all the ports and we have to be exchanged at all the ports.

We can represent this by a matrix of elements for example say let me say the columns and rows represent in fact input output combinations say for example power coming from the first port to be routed into the first port or power coming from the 3$^{rd}$ port as to be routed to the 3$^{rd}$ port and power coming from the second port, may have to be sent to the 4$^{th}$ port and so what are the combinations needed of course all combinations are not possible.

But let us look in the typical given situation we would like to send the power from the 3$^{rd}$ port to some port let us see so for example I would like to send the signal from the 3$^{rd}$ port to 2rd port so what I do I can but this in the cross over state so that light coming at this will go into this port or may be let me for the time being let me say bar port in bar state 3$^{rd}$ one is the bar state the light goes back and her also I would switch to cross over state that goes into this and will retain this once again in the bar state.

So bar state for this cross over state over this and bar state for this and send the signal to the next port, at the same time I can think of sending the first one to last port for example I will but this in the cross over state this already we cross over state and this also I will but in the cross over state

so what happens the light from this will store into this and once again into this and to this, so we are seen that case where the light from the 3rd port as gone with 2nd one like from the 1st port as gone with the 4th.

And by appropriate combination of these switches we can achieve whatever a particular matrix that is possible of course you can work out with more complicated examples and you can say that not all combinations are possible this way could achieve higher order switching by using 2/2 elemental switches, so when you look at the technology typically this is made on a lithium niobate crystal with electros on top is what is shown here the input is through fibers each of the fibers contain the data signals typically of the orders of 10GBPS.

And they are modulated the signals are modulated to 10GBPS you have typically laser diode transmitters are used in a output you can if you wanted to check the signal directly you can put the photo editors sectors and of course many time most of the at up to 10GBPS you can also use then direct modulation of laser diodes we will assume that the signal is modulated in whatever format you wish.

And typically is dimensions if you look at as you know the wave guides are of the widths are the orders of 4 micros thick and about 2 and half micros depth and the electrode voltage of the orders of a few volts and the overall chip would come to 40 mm, one of the important feature that we know about the conventional integrated optical devices is these angles are very, very small. So these angles are very, very small of the typically of the orders of a few degrees one or two degrees so when a cascade several such electro optics which has a length of the chip is going to be quite large 40mm and as we know the fibers are of the orders of the core diameters of the orders of the few microns and overall cladding size is quite large of the orders of 250 microns, so this is about 9 microns.

So you can observe that if you want to couple the light into the chip you need to have spacing between the fibers of the orders of 250 microns, so this is very large. So as the angles are very small the chip becomes very, very long and across the cross sections you can calculate that if it is 250 micron circles across each of this one two three about four times about a microns about a millimeter is the size or across about 40 mm is the size across this a technological problem.

Which will lead us later on in feature, functionally it is possible by using electro optic effect to achieve a 4 x 4 switch array, just to mention there are many other ways that switching and routing of signals is done in optical communication system without converting the electrical domain for example means we will see in the next one of the classes in future, so I will go to the next application.

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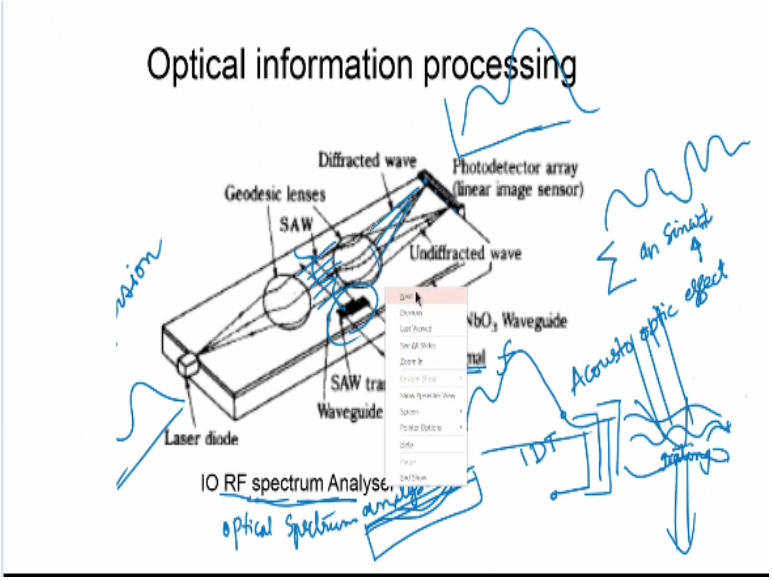


So this application called optical information processing, this is based on the acoustic optic effect we talked about a layer. So just to recall the design IDT pattern acoustic optic cell shown here it is a finger pattern like this or may be already connected in this side and this side in a surface acoustic wave could propagate a strain wave and which can create a grating on the crystal that means the refractive index varies periodically creating a sort of grating.

And we shall seen that the light could be deflected by this grating a light incident say let me say the so the light incident on this could be deflected into some directions so this acoustic optic cell and the surface = wave or the grating is created here these are the lenses you called geodesic lenses we can take a slab waveguide and by proper stress impression we can create a lenses like this we have not discussed lenses in this course.

But you can expect like a conventional lens these lenses also have the same properties like the focal length and so on and in like the conventional lenses you can use them to focus the beam and beam shipping and so and so forth, so the initial the input lens would spread the beam across

this grating and the output beam will help to redirect the various components of the signal on to the appropriate output photo detector array, so this is the configuration I will, we will call it as a application to a spectrum analysis.

So we have seen that the acoustic optic effect is depend on the frequency of the RF signal the pitch of the grating and so on or dependent on the RF signal and let us I show in this example we will use a laser diode input we coupled into these chip of course we have a planar waveguide here on which you have made all these components and the input light is spread across the grating region and its reader into photo detector array and we apply the RF signal to be analyzed into this IDT pattern.

And this is not a simple grating it is a complicated grating some arbitrary shape based on the RF signal, so you say that this is super position of several gratings that mean there are several frequency components RF frequency component in this correspondingly the grating that we create is a super position of all this and you can say that the behavior of this device will depend on the RF signal. So it is possible to work out depending on the various components in which direction the light is deflected by the overall.

So we can expect that the output you can calibrate and we can work out that the deflected signals at each of this photo detector array can correspond to different components of the RF signals so if you have an RF signal something like this you can expect and calibrate the output of current of the photo detectors in signal fashion and we can use it for RF signal analysis. So the cuts of the problem is acoustic optic effect where we create a grating periodic variation of the refractive index and reflect the light into appropriate output ports this is a basic idea of the acoustic optic effect based RF spectrum laser.

Then there is one more application that we can think of using a similar arrangement we can also think of optical spectrum analysis. So we will talk about optical spectrum analyzer, so in this particular waves we fix the RF signal of a constant frequency and we know the what is the pitch of the grating and so on and we give the optical signal to be analyzed here as a modulated on to laser diode or we can also say this a composite optical signal of having different colors or frequency components with need to be analyzed.

Intuitively or conceptually we can think of this optical signal to be various components of the optical signal to deflected by this grating into different output ports. As we know the grating has got a very good dispersive properties, for optical signals and we can use this property of the grating to create what can be called as an optical spectrum laser. So technology wise we have seen that a lithium neuobade is a good candidate for acoustic optic effect and we have used conventional integrate optical elements like the rating lenses and so on to achieve this.

Once again we can note that the chip is quite thin across the dimension and quite long, this is one of the important directions that optical integrated optics has taken the conventional optical elements like lenses, mirrors, gratings extra how been translate through on to an integrate optic form to achieve the conventional and new functions and also modern functions like this spectrum analysis and also we will also try to imitate whatever is in the electrical domain like the electronic switches extra into optical domain.

This is one of the important domains of classical integrated optics, when we go to a future we will see some modern devices which can do functionally different functions in a different way. So completely new ideas could be explored to achieve various functions are required in modern applications, so we will go to a more application.

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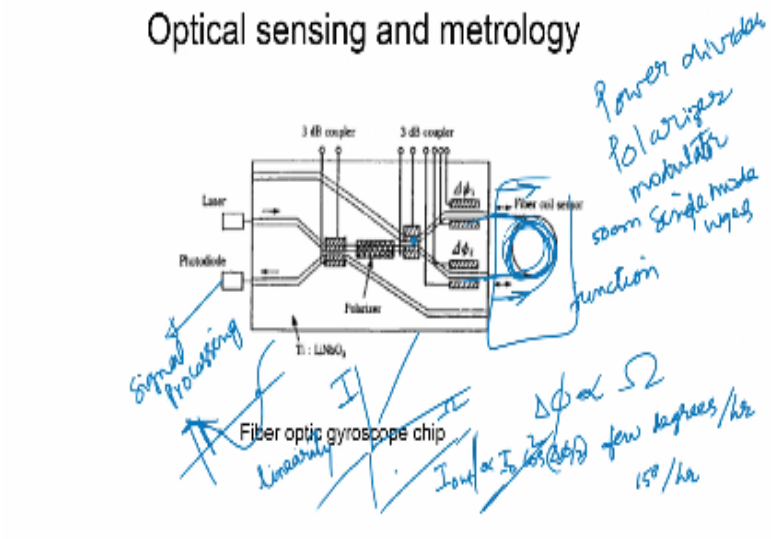


So this actually in this particular example I am using this integrated optical chip for a sensing the application. In fact the chip itself is not a sensor but is a support for sensor just let me give a brief

intro to the sensing applications I will take an example of a gyroscope or I will just take an example of gyroscope or I will just take an example of gyroscope and explain what this sensor is and then how the integrated optical chip is being used for sensing application.

So in a fiber optic gyroscope you have coil of optical fiber several rounds and you launch the light in the clock wise direction and anti clock wise direction so this is typically a 500m length of optical fiber it could we can calculate what is the delay that you can produce and so on and so forth.

I am not going to details of the gyroscope but just to emphasize that the integrate optic chip can be used for gyroscope application I am emphasizing only on the function of this chip as well as the gyroscope. So in typical fiber optic gyroscope you have a optical signal going in a clock wise direction and con clock wise direction and they are super post at this coupler and the phase difference between these two elements Δ5 clock wise and count clock wise beam can be shown to be proportional to the angular velocity of the Ω if this put is on a rotating object suppose this entire device gyroscope is put in a air craft or satellite we can measure what is the rotation rate of this object.

So I am not shoeing you the calculations but we can go of the orders of a few degrees per hour, so to get an idea you know that earth rotates in one day 3600 so the rotation date of the earth is about 150 per hour and now ion the current technology we have fiber optics gyroscopes of the order of few degrees per hour even point fraction of degree per hour also available now. So now I would like to emphasize in this application the role of the integrate optical ship so you absorb the integral chip only thin may bit and in you have a laser diode to launch the light in to the cruel in a photo detector to receive the signal and lot of signal processing will be dine after this electrical signal processing to analyze the signal and extract the information obtain from the gyroscope.

So we have various elements necessary for this operation for example you have to divide the function input laser be in to two output ports example at this point you have power dividers is needed and there is a polarizer here you can assume that there is a wave guide on top of it quarter bacterial which is very sensitive to direction of the electric fields of the light and also you have a modulator here phase modulator here in a typical inter pyrometer applications you know that the output light of inter pyrometer I output is in terms of $\cos 2\Delta 5$ or $\Delta 5 / 2$.

So that if you look at the input output relationship cos2 or so this is not very sensitive at these points so you need to bias the coil or the signal at 450 points that means periodically that is where the linearity you require ion linearity of the input output for example I will put Δ5 on the φ axis or maybe light intensity on the y axis and the phase shift or the Ω on the x axis we need a linear response.

So in order to be achieve a linear response we have to bias the this coil at some point like this so that bias is equal vent to ramping the signal the clock signal so that you get continuously the light is bias till their particular point, so ultimately what I want to say is that need a modulator maybe phase modulator you can call it and also of course all these are single module waveguides and also polarization has to be maintained single polarization.

So there are several components in necessary for a application like this, and they could be put in a small wave for like this, this is an important application similar application similar situation arise in many other application where you would like to process a signal based on some parameters etc, so optical techniques have proved to be very good and if the entire thing is in optical domain we have lot of advantages and like a high sensitive sensor serer could be made using integrate to optical devices. Of course later I will show you one or two examples where the optical signal itself the pitch is in sensor this particular case we have the coil fiber coil sensor were as we can have the devices were in right itself based on the input parameter.

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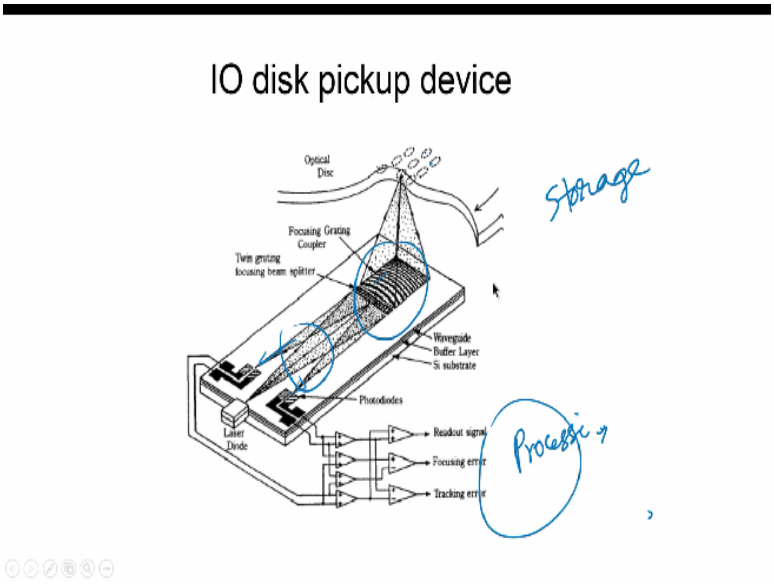


That example we take applied from so finally popular applications some time for the storage so storage is the very important function in engineering particular in electronics in varying we need to store lot of information before you can processing so on so we have many types of storages devices like magnetic disks then now flash on the so on and so far so optical techniques we can provide very high data storage like holography holograms and so on to store lot of information.

This particular example I have briefly to show you a disk pick up application so you have any integrated optical which can be used for reading and writing on it optical disk you have an optical disk here showing and there are several like in conventional electronic memories you have lot of pits or storage locations which are to be return and or read out and they have to be processed.

So you have a laser chip as got a great thing this is crucial events in this were integrating and which can focused on this pits very accurately and it could be designed such that you can have a movement of the disks also could be erased such that pits are accurately aligned with the were the part is focused for this arrangement start with the laser diode source of the light which this focused on the integrating it could be directed by using other events also if necessary can be less here lot of other incident okay

So let me start with this focused on this integrated lighting there is a leaf integrating here which can focus light on to its pits also it also received by this and directly into the output parts so there

could be photodegetic is here to convert the optical signal and electric signal later on we can do lot of processing with this point.

So whatever what I am trying to show here this integrated optical chip for this pick up applications so we will take of more of applications as we will go on these are the applications with conventional integrated optical like the wave lights integrating and so on so on in future will think about components which are made on the optical wave lights thank you very much for this module.