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Photonic Integrated Circuit

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Lecture No. 05

Photonic Integrated Circuit - an introduction

Hello all, so let us look at what is photogenic integrated circuits. In this lecture we are going to get a brief background of how this photonic integrated circuit as of as an area developed.

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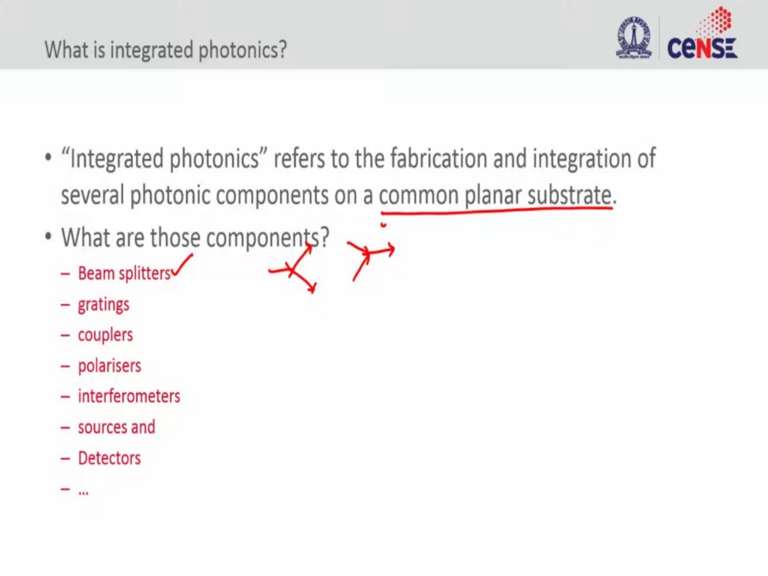

For that we should start with understanding what this integrated photonics is, so in a broader sense integrated photonics refers to the fabrication and integration of several photonic components, on a common planar substrate which is very important. So, we talk about circuits on a planar substrate; so this is most important difference with the regular optics that we talk about. And what are these components, so that there are multiple functionalities that constitute in these components; so, you can you can use beam splitter.

So, this component that is something that you have on the on the planar substrate could be a beam splitter. So, it splits the beam let us say, so you have a single beam and you want to have two beams split out of that; or power splitting let us say. So, this is that is in one direction; so you could also have combiners. This so it is a reciprocal device let us say, so beam splitting combining functionality.

Gratings so gratings are devices that we use for filtering light, and also use for some of the diffraction experiments. So, gratings are another type of components that you can consider integrating. Couplers: How to couple light between two different components let say; so that is also constitutes an integrated component. Polarisers, so you want to change the polarization of light or you want to filter a certain polarization of light out of a scrambled or unpolarized light. So, if you want to do polarization manipulation, so that kind of device could be integrated as well.

Interferometers, so what we saw in the earlier four of these, there are discrete elements; so interferometers is already some sort of circuit. So, you have to divide the light into two and then you know you have a propagating path; and then you can put them together, so this creates interference. So, you have two beams you want to split and combine let say; so, that is an interferometers.

Light sources, so you could have light sources integrated on chip that is generating photons. And when you have photons that are generated, you want to detect those photons. So that is reason why you need detectors as a component on chip. And there are many more of these functionalities one can integrate. So, in a broader sense integrated photonics is a platform of several optical devices that you have; that are integrated or put or realized on a single substrate.

So, that is that is a main concept behind integrated photonic circuits; so integration of photonic components. And what are these photonic components? Each component are going to have its own functionality. So, as I mentioned they can combine light, they could split light; so that becomes functionality that you want to put into it. So, let us look at a historic perspective of what this photonic integration is.

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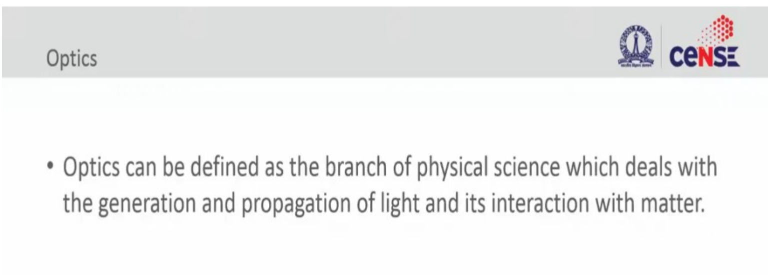

So, we all studied optics at some point in your academic career; we all encountered optics. So, what is optics? So, optics can be defined as the branch of physical science, which deals with the generation and propagation of light and its interaction with matter; so these are all three important constituents that we studied. It is a basically study of light or it is a light science. So, you want to understand how one can generate light, and how the light can propagate through a medium; and also the interaction of light with the medium. So, this is what we understood so through optics. So, all the lens systems that we use in order to control the propagation of light. So, when the light diverges, you want to collimate the light; so that is where we use this optical component called lens.

And then we use crystals let us say any kind of optical material, particularly linear/non-linear crystals. Then the light actually interacts differently. When you have an isotropic medium, light will not see any difference in the medium it will nicely travel through it. But, then when you have an isotropic medium, so that means the the light will see difference in the material. So, the propagation of light through this medium is going to be different; and how do we study that, how do we understand that. So, those are all the things that we did when in the broader sense of optics.

So, optics can be classified as studying light or light science in a broader sense. So, that is that is what we did with optics. But, then photonics is a little bit beyond that; let us look at how it all evolved. So, for that we need to have some historic perspective.

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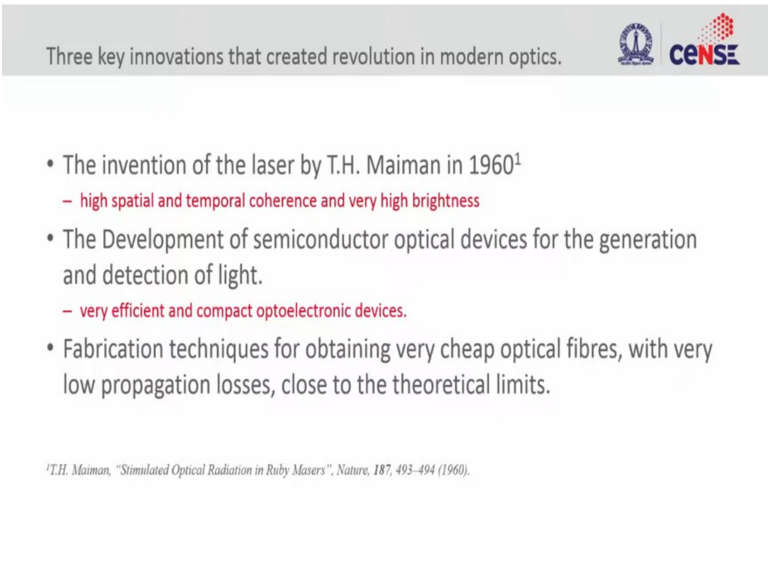

So, there are 3 key innovation that created this revolution in in the modern optics; the first invention is very important. So, the invention of lasers it was created a lot of interest in the optics community. Not just the property of the light that was generated was highly spatially and temporarily coherent; and it has also very high brightness. It is not just because of this; there are a lot of interesting things that happened, when you have high coherence and high brightness, we were starting to do optical signal processing and also we were understanding materials completely in a new platform then available to us before the invent of of the laser. So, that is a very key step towards the modern optics and the current revolution that we see.

The second important development that happened was semiconductor optical devices. So, laser was purely on a different platform. And when the light was generated, everybody was excited, but then over time the semiconductor as a material caught on. And there are lot of interesting things were going on, on the semiconductor front; particularly, in the microelectronics field and also looking at compound semiconductors from the material sciences. So, when the semiconductor devices were found to be really interesting optical properties, then the semiconductor optical devices actually started to evolve.

And evolve for what? So, we were using semiconductor optical material for generating and detecting light. Because we have already studied earlier in in different courses that when you look at semiconductors, there are two type of semiconductors, one is a direct band gap semiconductors and then indirect band gap semiconductors, so these two semiconductors got their own interesting properties. So, the one that we are very interested in, when it comes to photonics is direct band gap materials.

So, there when the direct band gap materials where you could have the transition very efficiently. At the same time you could generate photons; so you can detect photons and then you can generate photons very efficiently, unlike indirect band gap material. So, indirect band gap material you can still use it as a as a detector, but not as an efficient light generator. So, this whole school of material, so you have indirect/direct and then even indirect semiconductors, you could have different material with various composition. So, this composition also allowed people to explore and exploit the band gap. So, the generation of new frequencies were available by engineering the material.

So, from the material science perspective it was very rich, and everyone was excited. At the same time from the application perspective, we were able to generate new frequencies or new wavelengths that one was unable to do it in the absence of such compound material. So, by using these semiconductor optical devices, we were able to generate very efficient and compact optoelectronic devices. So, here we introduced the term optoelectronic; so there is a light and there is also electronics involved in this because you have to put electrons into the system.

And finally, a very key innovation that happened was a fabrication technique for obtaining very cheap optical fibers. So, optical fiber today we we do not even appreciate optical fibers to the level that that should be. But, optical fiber invention was a real revolution. At the same time not just the invention of it but the fabrication of this optical fibers with very low loss. So, if you are going to transport light from point a to point b, you do not want to lose light along the the propagation length.

So, in order to achieve very high transport efficiencies, you want the loss to be very low. So, the fabrication technology here was very key in achieving a very big milestone. So, right now we have propagation loss of optical fibers close to theoretical limit; while they are only limited by material property that we are using. So, these 3` key innovation has created revolution in modern optics, and it has led to many-many application spring up.

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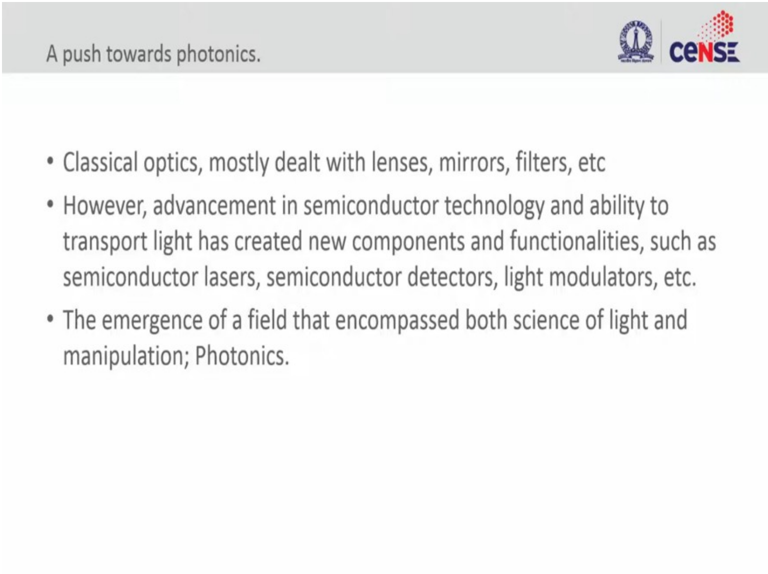

So, what pushed optics towards photonics? So, that is something that we should also understand. A classical optics, mostly dealt with lenses, mirrors, filters as we saw earlier; so these are all the functionalities. However, advancement in semiconductor technology and ability to transport light, so advancement in transport semiconductor technology was brought in by all our lasers and light detectors by using up to electronic devices, and then the ability to transport light. So, this is where optical fiber technology was really thriving and this has created new components and functionalities.

So, such as semiconductor lasers, detectors, modulators primarily for transporting information. So, this was again pushing the conventional optics or just study of light into the application space. And and then came the emergence of field that has both signs of light, where you call the optics and manipulation of it as well. So, you have understanding of light, at the same time you want to manipulate light; so, this whole study of both led to this new field of photonics.

So, photonics today is used in a broader sense; we do not use optics quite a lot these days, we call everything as photonics. So, the reason for that is photonics has just grown out of this very narrow definition of just manipulating photons or interaction of photons with electrons; so, it has really grown out of us. So, now we use photo photonics for even general optical functionalities or optical experiments. So, photonics has a multi phases as I mentioned it has grown out; so what are all the things that this photonics encompasses. Let us have a look at that one by one.

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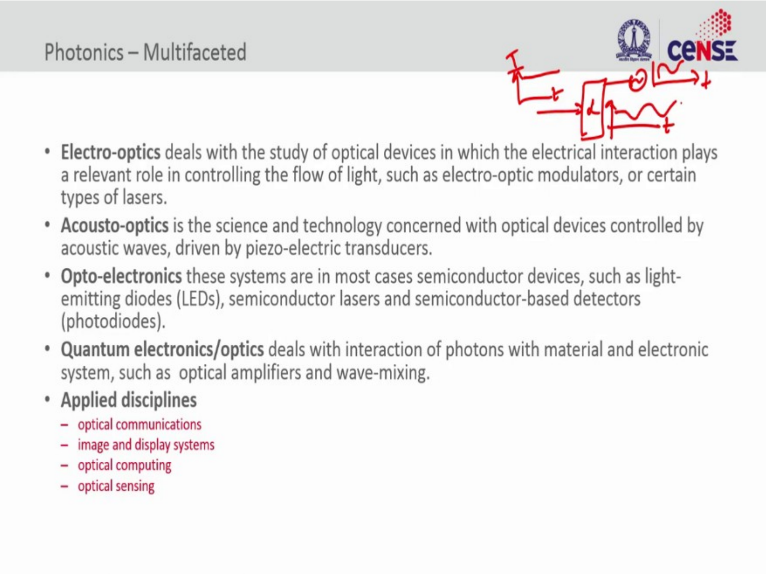

So, one is electro-optics, so electro-optics from the name itself you can deduce that it is the interaction of electrons or electric field to and optics. So, it is a study of optical devices in which electrical and flow of light is controlled, through this electrical interaction. So, one such device is modulated; so you can use electric field in order to control the flow. For example, if I want to make the intensity modulation, so I have a continuous wave and I want to change the intensity of light of this continuous wave. So, one way to do that is by changing the current that is given to a laser like let say. So, that is one way of changing the intensity of light through this electro-optic effect.

The other electro-optic effect is through intensity change to electro absorption for example let us say. So, I can use a material where I give an electrical signal, and this is the continuous wave intensity. So, I have a intensity of light going in, but I have a an electrical signal or electrical pulse; which has a certain function. But, then because the absorption of this material is related to the the electric current or field that I am going to apply; the output intensity will also follow the electric field or electric current that we have. So, this is a very simple example of electro-optic effect. So, I can change the property of light by using electric field or charge in the system. And if I can use that to do electro-optic, I can do similar things through acousto-optics.

So, acousto-optics are nothing but changing the flow of light by changing the acoustic waves. So, I can create acoustic waves by using piezo-electric transducer for example. So, I can use a piezo-electric material in order to control the flow of light. There is also an interesting way to look at is this this acoustic waves that you create is through the phonons that you have in the system. You can have optical phonons for example so, which comes under the class of nonlinear effects; but that is again acoustic phonons. So that one can use that is again still an acoustic wave, but they are generated by a different mean not piezo-electric generated.

So, at the end of the day they are acousto-optic effect; so interaction of acoustic waves with light waves. So, there is again another area under photonics. Opto-electronics, so there is a little bit of debate here, whether opto-electronics is electronics or photonics. So, this is a very good example of this field, the merger of two different fields. So, opto-electronics primarily handles electrons, how electrons could be handled inside the system. But, at the end your effect of those electron manipulation results in the effect of photon.

So, you could have some electronic process happen in the system, but they at the end it will result in photon generation let say. But, you could have some electron process initiated because there is a photon that was put inside this the system. So, there is an initiation of this whole electronic process because of photons involved in this. So, this this whole idea of having both electrons and photons involved in this system has resulted in this opto-electronics. So, primarily the process happens in electronic domain, but it results in either photon generation or detection of photons, so that is what we primarily do.

So, for opto-electronics are the systems that most cases like happens in semiconductor devices, such as LEDs. It could be semiconductor based lasers and semiconductor based detectors as well; so, that is opto-electronics so now it is also part of photonics. So, now the emerging area of quantum electronics and quantum optics, so this is an emerging area, where we are looking at quantum optics. So, we are moving away from our conventional a large number of photons like that we call photon flux; and we do not really take care of in the properties of individual photons into account.

However, when you go to quantum optics, you are trying to understand and also manipulate single photons. So, how do we generate single photon outside the system and how do we manipulate the polarization of the single photon and then how do we detect this photon. Is it possible to interfere these two photons of two different states? How do we decode this? So, all this understanding is captured under this field of quantum optics or photon optics. So, there it is there are a lot of interesting experiments currently being done in this area, to look at the use of photons for key distribution to secure key distribution. And then we have it for optical computing, so can be use these photons to compute?

And then we are also using this for single photons, for imaging, sensing; so there is a lot of other application that comes along with this photon optics. So, this area primarily deals with photons, interaction of photons with material and electronic system. So, for example optical amplifiers are actually quantum devices. So, primarily photonics is the whole area itself is confined by this quantum processes, so any process you use can be easily explained by quantum mechanics. So, these are all some of the primary areas within photonics that we considered.

But, there are some application disciplines that evolved through this photonics, so one is optical communication. So, communication of information so data communication short distance, long distance; they were all enabled through this photonics and that is also part of study of photonics.

And then imaging and display technology, optical computing and then optical sensing; these are all the application domains that are that developed. Because of the modern advancement that we saw both in terms of generating light, transporting light and manipulating light. So, they all eventually end up in a very interesting application of light. So, finally let us look at what is integrated optics or integrated photonics; so that is what we want to understand.

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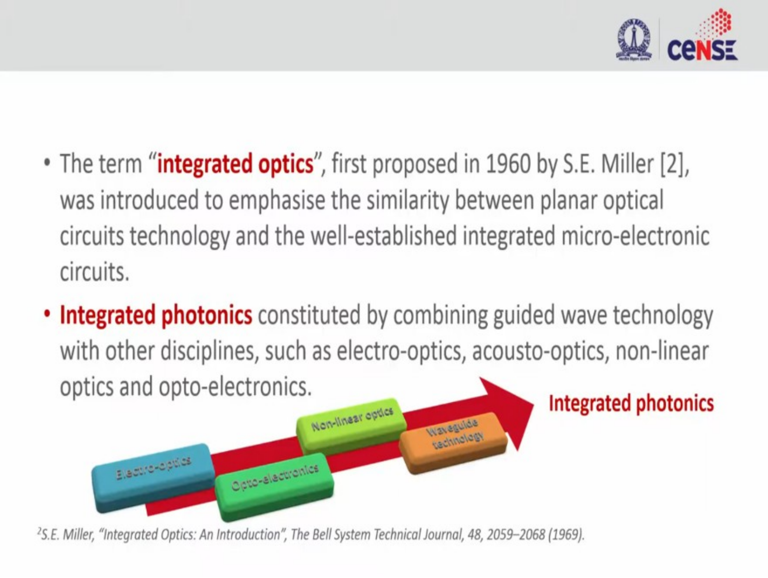

So, let us look at what is integrated photonics? The term integrated photonics it is not new; so this was proposed in 1960. So, the whole idea of this was to emphasize the similarity between the planar circuit technology and the well established integrated microelectronic circuit. So, there was a planar circuitry that was proposed and then seriously thought about in the 60s to start with. And later on it took a completely different structure on its own post 1980s. But, then the concept of integrating various component onto a single substrate was already well established. The concept was already there, but then why do not we mimic such an integration for optical circuits.

So, optical circuit meaning people are putting all these optical components on large optical tables. And the proposal there was this also looks like a circuit; why do not we integrate all of this and make it on a planar technology or planar substrate similar to microelectronics so, that was the initial proposal. And now what we understand is integrated photonics combines a guided wave system; so the various components that we had on optical table. There was no wave guide let us say or there was no guiding mechanism, this is all free space. So, light was travelling in a free space since we were using coherent light sources; so there was no divergence and you were able to manage it, so there were no wave guides.

So, in case of putting a circuit on, you need to have a guiding mechanism. So, in an integrated photonics, so you combine guided wave technology with all associated disciplines that we just discussed. So, you are bringing in electro-optics; you bring in acousto-optics. You have non-linear optics on substrate and you also have opto-electronics functionalities on this. So, putting all of this combined onto a single platform is what constitutes an integrated photonics. So, so integrated photonics in essence is bringing in various disciplines or various functionalities and philosophies onto a single substrate; and what we say is a single substrate alone.

We are not saying it should be of a certain material system; so philosophy of bringing various components and various functionalities onto a substrate, through a guided wave mechanism. So, you have to connect all these functionality and you have to guide light through these different components. So, that is the backbone of this integrated photonics; so that constitutes integrated photonics.

So, with this broad outline, I think most of you must have gotten a clear picture of what this integrated photonics is and what are all the things that we call integrated photonics and what are all the things that should be integrated into the circuit, in order to call it as an as an integrated photonics. So, with that we end this particular lecture; in the following lecture we will look at the historic perspective of various components; and how they evolved before diving into the real physics. Thank you.