Nanobiophotonics: Touching Our Daily Life

Professor. Basudev Lahiri
Department of Electronics and Electrical Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture No. 04

Why Photonics? Hello and welcome back. We were discussing about Nanobiophotonics. So, we are going to discuss about the Photonics and to make the argument forward let us in today's topic just try to see why do we go for Photonics yeah this can very well would have been a topic on Nano Bioelectronics or Nano Bioacoustics. So, why go for Photonics at the end of the day the idea here is light based diagnosis or light bad ah therapy. So, Photonics is important or Photonics is the one of the major components in it. So, question might arise that why go for Photonics we have Nano Bioelectronics or Nano electronics right why go for Photonics.

So, let us try to understand in the course of next 25 to 30 minutes that why Photonics have certain advantages over its electronics or acoustic counterparts believe you me those two other topics are also significant also there, but Photonics can provide certain advantages that the other two cannot mind you Photonics have certain disadvantages as well like anything else, but let us try to make an argument on why Photonics have been utilized. Now to just to go little bit forward or as a matter of fact little bit back in the history human beings have always been fascinated by light. As soon as a child opens her or his eye it is the light that you know enters the eye and all the processes starts. So, human beings have been fascinated by light and its manifestation in from time immemorial ancient Egyptians ancient Greeks our very own ancient Indians have their own theories on what light is what is the concept of light what is light made up of the Sankhya philosophy Sankhya darshan of Indian ancient philosophy considered light to be one of the primary elements of nature one of the Tatva primary elements of nature along with air water fire. The Greeks considered light to be some sort of inherent structure that shoots out from eyes of human beings.

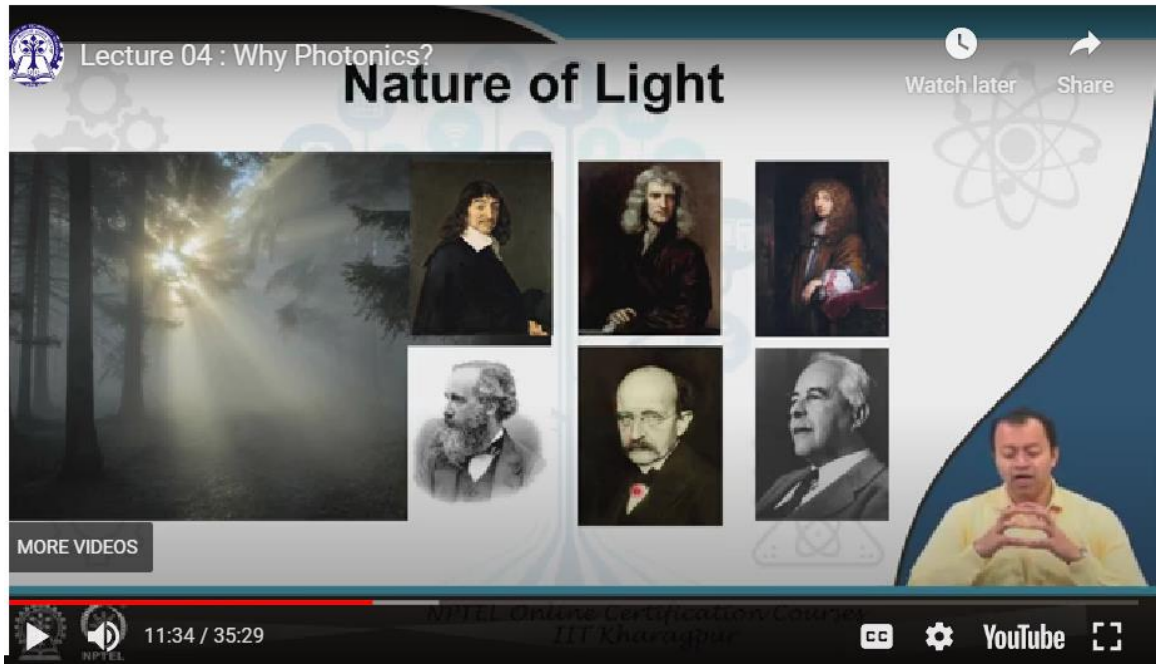
So, like remember they do not have anything you should not be making fun bad of me. So, light is something that comes out of human beings I hit a particular object and then reflect back and then a person is able to see I think it was in 1000 AD when a Persian philosopher Persian scientist Al Hatim I think I think I am pronouncing the name wrong a Persian physicist I think in Baghdad came up with the idea that light could definitely be waves and instead of human being shooting light from their eyes it is the other way round light gets you know reflected or light falls on human beings eyes from an object and that a human being interprets. Cut to the 16th and 17th century these three pioneers have made tremendous contribution towards understanding the nature of light. The first gentleman is obviously, if you do not know Rene Descartes this is the gentleman all mathematics student hate or people who hate mathematics love to hate this person this is the person who gave

rise to three dimensional geometry the Cartesian coordinate system remember (X1-X2) (Y1-Y2)to understand the difference between two points this guy gave this famous x y and z coordinates the Cartesian geometric Cartesian coordinate. Rene Descartes he also was a philosopher at that age people were not just mathematicians or physics physicists or philosophers individually they were all together and there thereby they were able to see the world or nature around them significantly as a whole picture. He also gave the famous philosophical ah term cogito ergo sum if you go to ah you know science festivals you will see this Latin written on t-shirts and people have even tattoos Latin for I think therefore, I am. The question was how do you know that you exist philosophy and this person said that because I think therefore, I exist cogito I think, ergo sum hence I am ah Rene Descartes apart from doing mathematics and philosophy also came up with the idea that lights are indeed pressurized waves they are highly pressurized wave traveling from media to media. This was the one of the first instances and I think he was quite inspired by Al-Hatim the Persian philosopher Persian scientist from few centuries ago. It was quite common during dark ages or medieval ages in Europe to interact well if interact passively with Arabic scholars and Persian scholar middle eastern scholars. So, maybe he was influenced by that, but then came Sir Isaac Newton, Isaac Newton came up with the theory that light are already particles corpuscular theory of light in which these particles travel at an infinitely high speed and goes from rarer to denser medium and gravity has some effect on it.

Now ask yourself this question how many theories of Newton have you studied in any any person who has gone to school have had to study ah Newton's laws of motion, Newton's laws of gravitation, but you never get to study Newton's laws of light, why because it was wrong. He thought it was particle and this particle has an effect on gravity the denser the

medium the light will get more attracted towards it so and so forth. Counter part of Newton few years here and there few decades here and there was Huygens Huygens firmly believed that light is actually waves light are actually waves and just like any other wave it should have wave properties like interference and diffraction. You know interference in which particular wave interfere with another wave and thereby they combine they mix sometime the interference is positive sometime the interference is negative sometimes it is in between and final product comes up. He gave the theory and later Thomas Young, Young's double slit experiment I believe you have done it in your high school physics where a particular light beam is made to pass through two slits and they pass through and then they interfere and then they make this dark fringes and bright fringes this pattern of light dark light dark those those those straight line. So, Thomas Young came up with this beautiful practical experiment and proved that Newton is wrong and Huygens is actually right light is indeed a wave. light is indeed a wave and it shows wavelike properties in which light can interfere with and the resulting interference positive interference very bright light negative interference no light and thereby you get this bright and dark bright and dark fringes you have must have done it in your high school physics experiment ah if not in your undergraduate first year experiments.

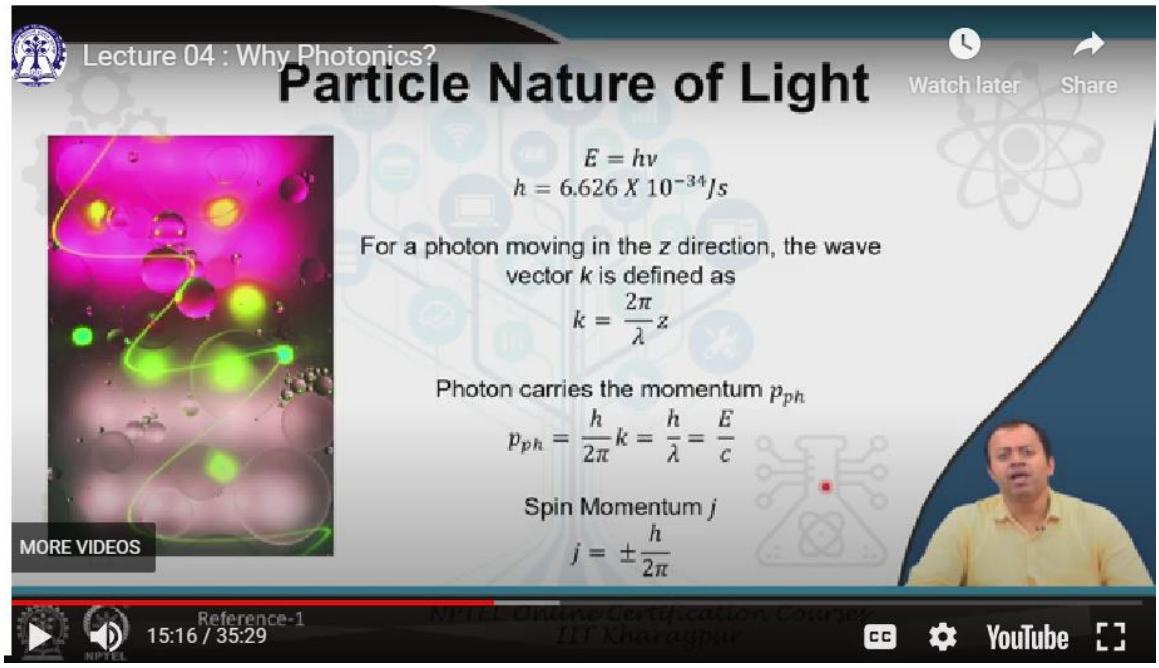
But then came these three pioneering gentleman first was Scottish physicist um Maxwell he knew of electromagnetic waves he proved that light is a type of electromagnetic wave electromagnetic wave where already discovered that. He gave up the theory he gave the theory in which he showed that light is simply a type of electromagnetic wave that our eyes can detect and gave the famous Maxwell's equations all those four formulas that you know physics student I think like an engineering students hate or vice versa it depends on who or where you are and what your inclination is. Though several of these theories several of those equations have previously been done by Gauss and other people, but he utilized them he collected them he modified them he added them and then came up with the idea in which light was firmly captured firmly proved to be wave nature right and it is performing all the functions of light. So, the idea was in 19th century this gentleman Max Planck along with Albert Einstein figured out that wave nature of light is simply cannot be explained or the several phenomena that takes place utilizing light cannot be explained using considering light as a wave number one being photo electricity you shine light onto a particular object and electrons move. Those phenomena cannot be explained using wave nature. So, Max Planck and Einstein came up with the idea that light is not necessarily a wave, but it consists of packets of energy, quantas of energy, quantas of energy and this energy. So, he was actually discussing black body radiation.



So, they came up with the idea that light is indeed not a continuous wave, but discrete packets of energy, they are not technically particle, but packets of energy moving forward at the speed of light right. So, they call it quanta, quanta of light packet of light they are discrete they have a particular frequency and they are one like a train like a train buggy one after another moving forward. It was only in the late 19th century where this chemist this professor Gilbert Lewis from University of California Berkeley, he was a chemist ah gave the term photons to these quanta of light phos from the Greek term phos, phos basically means light you, you use photography or photon which basically means light. So, he came up with this Greek term photon to the quanta of light that previously Max Planck and Einstein have utilized to discuss to prove the particle nature of light when it comes to application of photo electricity. They simply called it remember Max Planck and Einstein did not coin the term photon they simply called it quanta of energy, energy has quantized and it is photon.

This gentleman chemist came up with the term photons and you if you do not know Gilbert Lewis you have used his work almost entirely in your chemistry classes. You know how you describe single bond, double bond, triple bond etcetera you make a dash c dash c this dash means single bond, two dashes means double bond and one dash can be represented as two dots two dots describing two electrons when you try to make a molecular bonding of you know NaCl ionic bond or covalent bond you make this two dots here 7 one dot here, 7 dot there and then combine NaCl or carbon-carbon single bond each dash represent two dots. So, there are triple bond, single bond, double bond etcetera you make this dot and this dash while writing bonds while describing bonds of two different molecules. Yeah guess where it comes from this was the gentleman who actually made this Lewis dots to describe bonds whenever you try to describe a molecular bond between two two two

molecules whatever you do whatever you draw individual dots or individual dashes this gentleman was the one who was the first to logically put it down and it is his theory that anybody who has gone to high school keeps on utilizing . So, as we go on further more and more from quantum mechanics we understand that light is simultaneously both now here understand it what I am talking to you about.



Light is simultaneously a particle as well as a wave it is simultaneously both almost all elementary particle almost all elementary particle like electron is also behaving like that simultaneously acting as a wave simultaneously acting as a particle. Specificity of light being here is light has or photon or the particle nature or the quanta of light is somewhat significantly different from elementary particle such as electron. You ask in which way well I can give you several examples like charge and mass and all of those things if I am feeling funny I will go and talk to you about spin, but understand one single thing the fundamental difference between electron and photon in my opinion is this. Electrons can never be created cannot be destroyed photons can be created can be destroyed ok. How is that? Photons can get absorbed photons get absorbed electrons can absorb photon go from lower level to higher level if you are from electronics background I can say valence band to conduction band and then return back return back to the valence band return back to lower level of energy and simply dissipate heat, heat is not photon heat is not light.

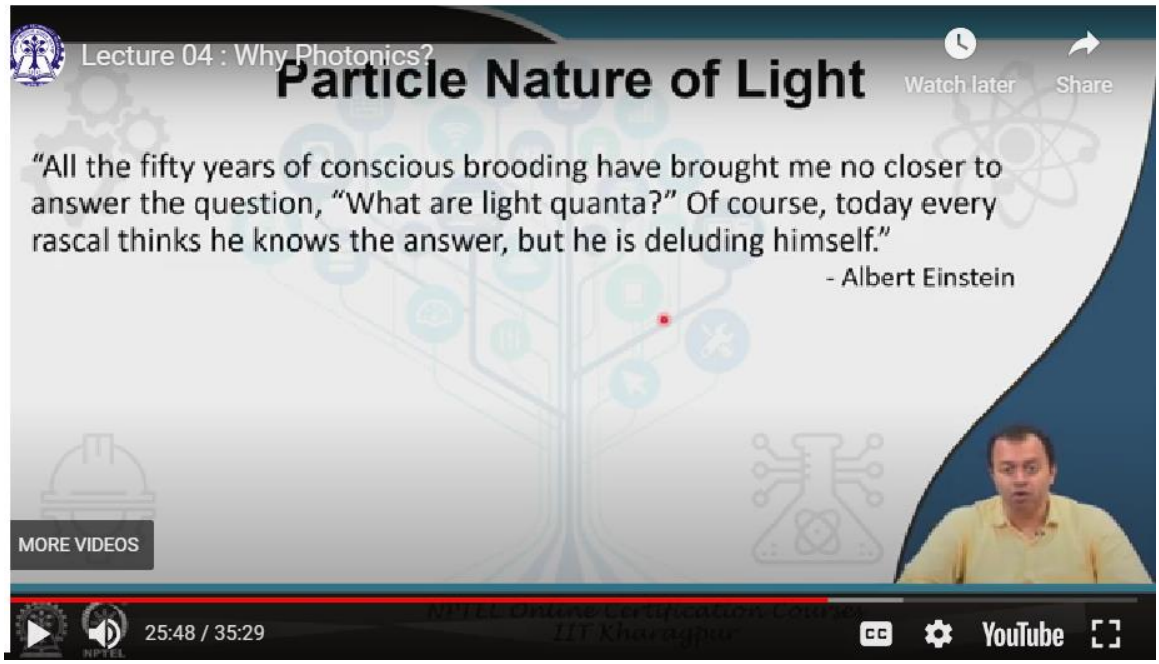
So, what happened to the photon? The photon was absorbed the photon was annihilated the photon was destroyed the photon converted into something else. Photon in itself does not exist understood that granted that energy can never be created never be destroyed you can only change from one form to another, but show me where an electron has converted to anything other than electron. All with an electron you can do is move it from point A to point B and movement of electron gives you electric current. Flow of charge particles is

current electronics engineer will also say hole holes you know electrons and holes both go physics people will say no ions can also flow and goes current, but overall 99 percent of current is flow of electron. So, electrons going from one area to another area point A to point B gives rise to electric current, that is all you are capable of doing moving electrons from point A to point B you can never destroy electron what about creation can you create electron? Electron is already existing every matter every atom consists of electrons you can then use high amount of energy magnetic field these that to extract that electron out or add some amount of electron on to it. I am hinting towards doping electronics engineers perhaps have heard this term I think semiconductor doping where you add extra electron into semiconductor or sometime you add extra hole into the semiconductor, but you are never annihilating you are never destroying the electron photon on the other hand could simply be absorbed could simply be absorbed and converted into heat converted into phonons etcetera can you generate can you create light can you create photon of course, you can of course, you can there are several mechanisms available in which electrons can jump electrons which are at an upper energy level by absorbing energy, energy in the form of heat energy in the form of electric current voltage energy in by some kind of chemical reaction has gone to upper level and then it has returned back to lower level by emitting a specific frequency of photon. We see that in fluorescence all the time we see that in phosphorescence all the time you know the dim light that keeps on you know making your night lamp or making your watch glow at night phosphorus there is a dim light that is glowing. We created that light you can artificially create that radium watches you must have heard previously they used to think we can create light we can create photon of specific energy specific frequency thereby specific color specific wavelength using various different material properties material mechanisms. So, photons can be created can be destroyed electrons cannot be created cannot be destroyed to the best of my knowledge prove me wrong and say come up with a mechanism in which you can create an electron out of nothing or destroy it completely into its energy counterparts thus far this yet to achieve, but creation and annihilation of photon is a regular business that keeps on happening. Obviously, it has these properties we will be discussing about the properties of light or properties of photon in detail in the next chapter, but understand from a point of view that photonics usually utilizes the particle aspect the quanta aspect of light it does not mean that it is not a wave or the wave nature has simply cease to exist make no mistake light is simultaneously wave as well as a particle we can only see one aspect one face of it at a time.

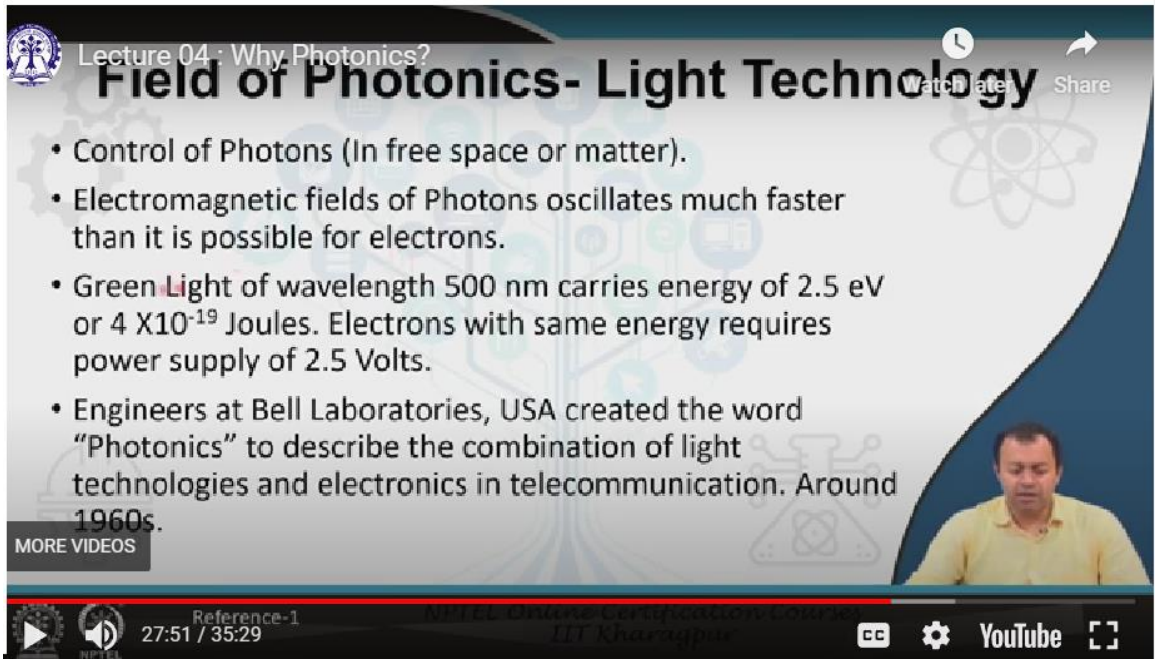
Thus far human brain human technology human civilization have not gone that far have not developed any technology that can show simultaneously together both the wave and the particle nature of photon at the same time, it can only show one aspect at a time certain experiments of light shows that it is particle nature certain experiment shows that it is wave nature both are correct both are correct there is no experiment thus far which shows

wave as well as particle together. So, how do we know we know by theory we know by mathematical calculation we know by quantum mechanics, quantum mechanics is the single most fundamental theory that mankind has come up with which is the most proved theory in the history of mankind and quantum mechanics is proving is telling you mathematically proving you that light is both experimentally we have not developed it yet. Let me try to make you understand this with an analogy now no analogy is perfect all analogy is inaccurate all analogy can be falsified having said that since I have a diverse background of students let me tell you this. So, I have a coin with me right it has head and tail right normal coin any other coin when you suppose you are flipping this coin you are flipping this coin and then it falls onto a flat surface you have a camera on top and it matches or it takes the picture of the front surface either it will take a picture of head or it take a picture of tail. You can only get one face or one type of face in your camera either you will see head or you will see tail you can never get head or tail simultaneously. Does that mean does that mean that the coin only contains head a tail does not exist or vice versa the clever among you might come up with the idea that let us have a high speed camera. .

So, that when the coin flips in the middle we will take some picture a very high speed camera and it will show that it is flipping from head to tail and thereby we can say that it contains both head and tail granted accepted small problem we have not been able to develop such a camera or such a technological breakthrough that can come up with you know imaging a single photon while it is spinning while it is moving we simply do not have the capacity we simply do not have the technology yet. So, that we could see the wave nature and the particle nature together simultaneously. We simply knew it by mathematical calculations. All mathematical calculations points towards that experimentally one at a time which means light is both how can something be particle and wave both well I do not know.



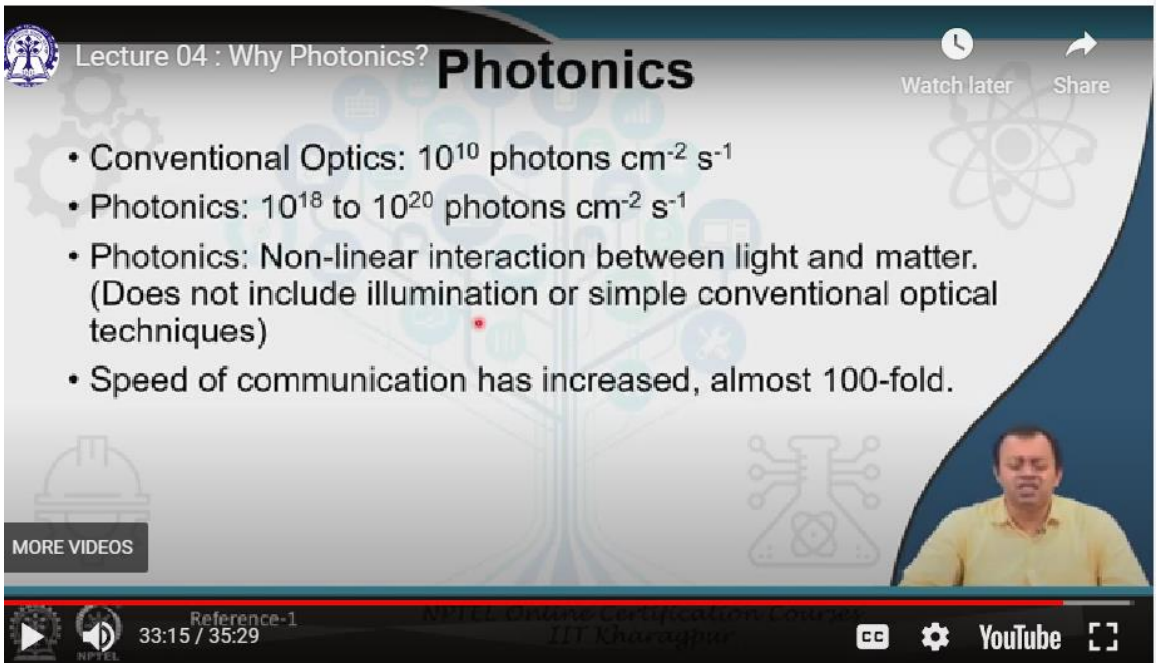
You can ask this person who came up with this with this famous theory all the 50 years of conscious brooding have brought me no closer to answer the question what are light quanta how can something be both wave and particle of course, today every rascal thinks he knows the answer, but he is deluding himself and who said this this gentleman said this this gentleman came up with light quanta and he has himself failed stating that I do not know how can something be both wave as well as particle I am not the right person to answer that if you know somebody who can tell you this let me know I will also seek the answer I do not know it simply exist it simply is there. And then there is going on about the mass of photon and then recently they have come up with mass of photon to be nonzero, but for the time being let us not go this much detail on to it I have given you. So, that those people who are from a physics background can go further and discuss about the mass of photon and spin of photon some part of it will be discussed in the coming chapters do not worry, but remember one thing that the one which I have been telling you that simultaneously light is both. It is never one at a time we only see one face of the coin at a time it does not mean that the coin is only head it is both simultaneously together at the same time head do not exist without tail, tail do not exist without head we can only see one at a time. So, how exactly the field of photonics have gone together or why are we utilizing photonics well simply speaking like electronics is the manipulation of flow of electron photonics is the control or manipulation of the flow of photons either in free space or in matter and why photonics to the answer is that the photons oscillates much faster than it is possible for electrons more oscillation more frequency more frequency more energy equals to you know that oscillation is frequency. So, photons are far far faster than electrons.



So, this is an example green light of a wavelength 500 nanometer carries 2.5 eV or this much number of joules whereas, the electrons with same energy will require 2.5 volts. So, we have a huge energy source at a very high frequency which oscillates at a very high frequency remember the more it vibrates the more frequent higher frequency it is the faster you can transmit data your electrons would not be able to oscillate why oscillation is required well switch on and off. If it toggles from one level to another level the top level you call it on the bottom level you call it off the faster it goes you can faster toggle between on and off. So, what well I do not know maybe you can call off just maybe as 0 and on as 1.

So, the faster this thing toggles perhaps you can send sets of 0s and 1s to great distances with light based communication and perhaps you know that any information in the world could be converted into sets of 0s and 1s.That is exactly what your mobile phone processor or the laptop computer that you are watching this video basically does you know converts everything into digital format 0s and 1s and and and send information. So, you can send information using light which can toggle which can oscillate at a very very high frequency and thereby your rate of data transmission becomes very high more amount of data less amount of time will coded. So, this is exactly what the scientist or engineers at Bell laboratory in New Jersey USA found out and they coined the term photonics they utilize the combination of light technologies and obviously, you require electronics electronics cannot simply be wished away for telecommunication. Data transmission optical fiber came in Narendra Kapani one of the pioneers of electronics fiber optics communication should have received a Nobel Prize did not showed data transmission through optical fibers

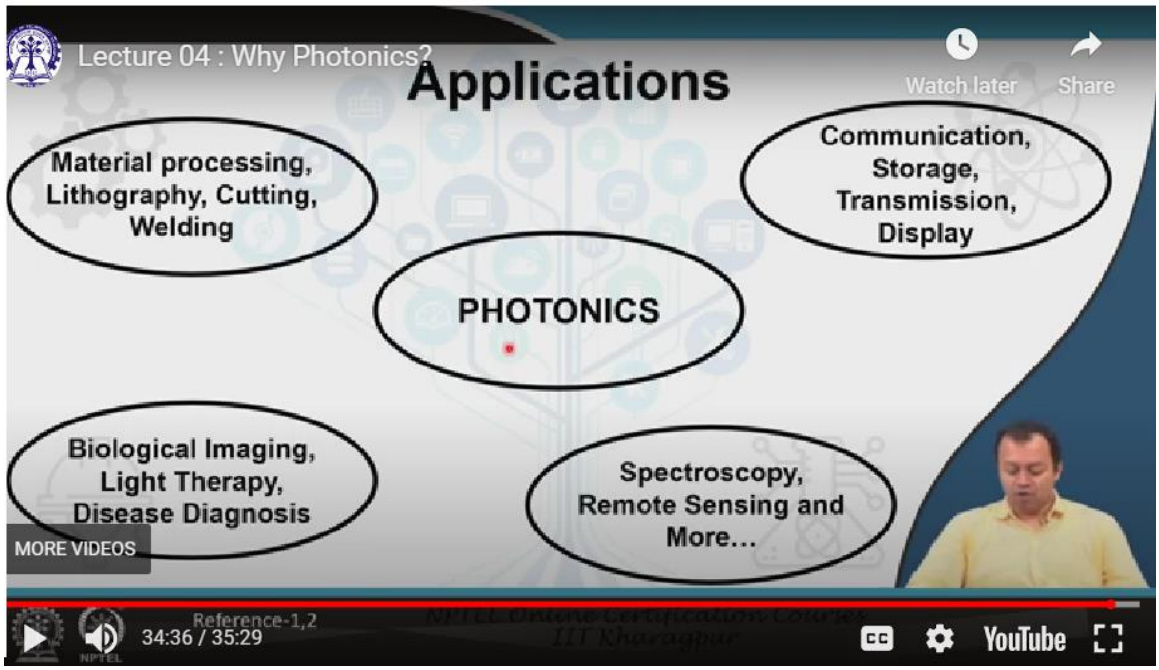
and the overall field of photonics came up. So, why photonics faster perhaps cheaper perhaps because you still need to do it and it is not affected by stray electric or magnetic field noiseless as compared to electrons you can simply stray away an electron by putting high amount of magnetic field high amount of electromagnetic field.



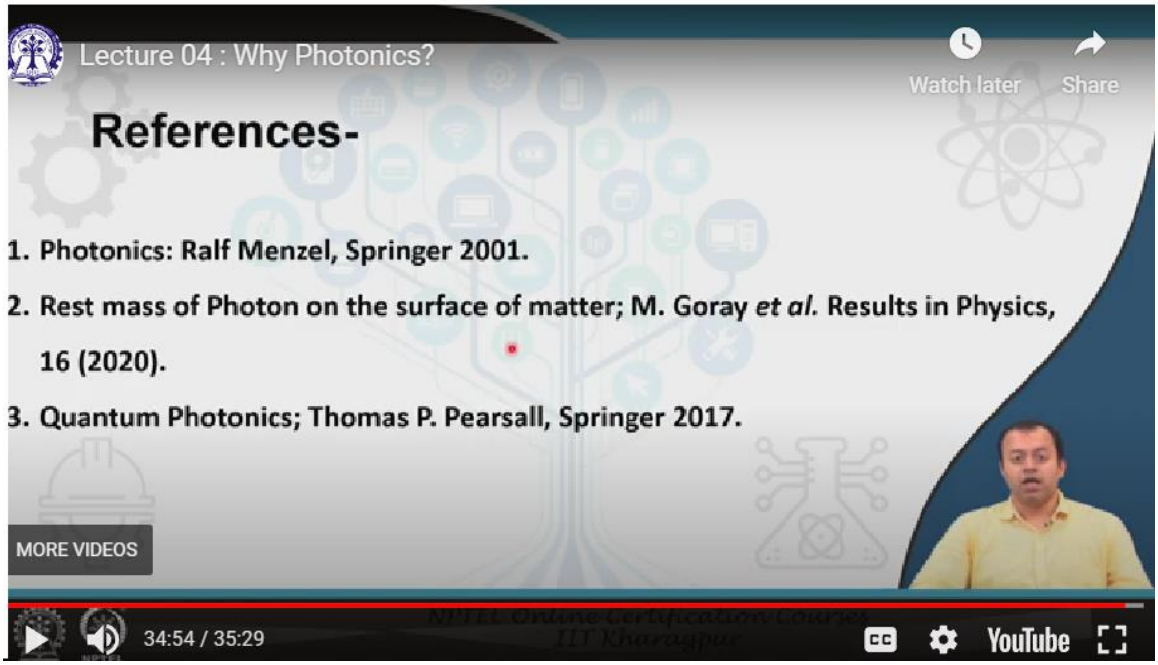
So, what exactly is the difference between photonics and optics now this question should come up why we term photonics we already had optics optical physics or electromagnetism why do why call it photonics well photonics is a technology photonics is a technology whereas, optics is mostly dealing with understanding the nature of light and how it behaves photonics on the other hand utilizes it. Modern physics or semiconductor physics versus electronics that is overall the difference. From a from a very academic viewpoint conventional optics of 10^{10} photons $cm^{-2}s^{-1}$ where photonics utilizes almost the double the number of photons. Photonics also deal with non-linear interaction between light and matter and speed of communication. So, again this is something very academic if somebody asks you what is the difference between optics and photonics you will say that photonics utilizes larger number of photons more number of photons per $cm^{-2}s^{-1}$. However, this demarcation 10 to the power 10^{10} versus 10^{20}no one follows it no one follows it no one will come and say ok you have 10^{15} photons. So, you will no longer be considered photonics you will be considered optics that does not exist these differences are purely academic once it used to exist like the difference between electrical engineering versus electronics engineering the difference is at this present moment non-existent people used to say 2.

5 volt and above is electrical 2.5 volt and below is electronics not correct you have power electronics. The difference used to be electrical engineering deals with generation of electrons whereas, not creation generation whereas, electrons cannot be created whereas,

ah electronics is manipulation of the flow of electrons, but at this present moment there is very little difference between electrical and electronics. Similarly, there is very little difference between photonics or optics. If still somebody insist optics is mostly mirrors lenses whereas, photonics is mostly lasers, LEDs light emitting diodes, fluorescence microscopy these are photonics technologies optical coherence tomography these are photonics.



It deals with non-linear interaction I will discuss non-linearity do not worry about this simply something to do with it and of course, speed of communication has increased the optical fiber that is bringing internet to you to your house to your institute how fast can you now watch movies in high definition, how faster it streams to your mobile phone device you can understand compare it with 5 years ago 10 years ago 15 years ago and we can we can come up with this. There are several advantages of photonics communication storage spectroscopy biological imaging light therapy needless to say we will be focusing more on that then there are cutting it edge. So, photonics has a plethora of application communication photonics based communication is something that you daily use spectroscopy remote sensing etcetera are already there. So, we need to so, photonics has several applications that we can utilize photonics is a technology that is existing that is available that is cheaper perhaps cheaper and it can be utilized in multiple different field.



So, these are my references please go through several of them all of them if possible and try to get a better understanding remembers this is merely the introduction part this merely the introduction part. I am only telling you some of the topics that we will discuss in detail in the coming module in the coming lessons in the coming lectures.

Do not worry if certain topic have not been paid enough attention I will ah see you in the next class where I plan to finish this first chapter of introduction. Thank you very much.