Semiconductor Optoelectronics
Prof. M.R. Shenoy
Department of Physics
Indian Institute of Technology-Delhi

Lecture-1
Context, Scope and Contents of the Course

Ok so we start welcome to this course on semiconductor optoelectronics and let us start quite a way with the question of what is the subject matter of this course. Thus as you can see the semiconductor optoelectronics. Semiconductors all of us know what is a semiconductor are doing, will see you know what is a semiconductor is a semiconductor optoelectronics. Optoelectronics, optoelectronics to be are overflew of encounter that term earlier optoelectronic basically refers to phenomena and devices.

Study of phenomena and devices which involve interaction of vertical process with electronic process, the other words basically this deals with electronic devices which involve interaction of radiation optical radiation with electrons, that is electronic devices which involve emission or absorption of photons. In simple terms if you look at an LED light emitting diode, it is basically an electronic diode, it is a pn junction diode.

But it involves emission of light and light normal rectifier diode it involves emission of light exactly like that if you take photodetector of photodiode it involves absorption of photons, absorption of light who generate photocurrent. So we basically deal with electronic devices involved interactions of photons with the device. Photos with electronic process. There are others terms some synonyms which looks very similar.

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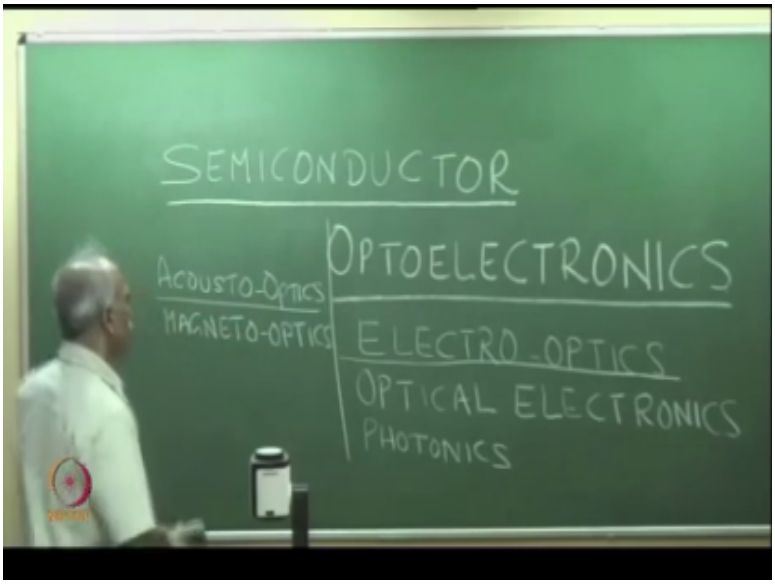

For example there is also a term which is electro optics in a terms equal beam in the same electro optics. There are also other terms like optical electronics, there are books on optical electronics. So let me just try to emphasize on the circle difference optical electronics. There is also photonics optoelectronics electro optics I mentioned that optoelectronics refers to basically the study of electronic devices which involve emission and/or absorption of photons.

In electro optics we finally deal with optical devices and optical systems that the properties of propagation, properties of light or propagation in the medium is affected by an applied electric filed. Electro optics refers to optical systems and optical device. Optoelectronics refers to electronics devices and electronic systems. So these refers to optical systems and devices where the propagation properties of light are the medium is affected by an applied electric pieces.

There are small hints are similar terms for example you may have heard of acousto optics, there is also magneto optics, exactly as I did find electro-optic, this acousto optics they also deal with optical systems or optical devices where the propagation properties of light is affected by an applied acoustics field an applied acoustics and in magneto optics, electrical properties are affected by an applied magnetic field.

There are many important effects those who are from M. Tech optoelectronics, you will have a whole course which will cover acousto optics, magneto optics and electro optics. So magneto optics know the important effects of in magneto optics is a faraday effect where the

polarization stay plane polarized light. The polarization state rotates due to an applied magnetic field.

There are many application of faraday effect, similarly in acousto optics there are 2 important subdivisions are raman-nath diffraction and Bragg diffraction and large number of applications. We will not be electro optics is also very important, there are electro optic modulators which are used for high-speed modulation. So we will not be discussing these, but I brought these just to bring about the differences are similarities between among these various titles.

So our concern will be primarily electro optoelectronic. So we will discuss optoelectronic, there is also couple of other terms which had written. So let me write it again erase it, optical electronics. I also would like to write another subject that is quantum electronics, there are full courses on quantum electronics. Quantum electronics here quantum electronics deals with devices where interaction of radiation with matter is discussed.

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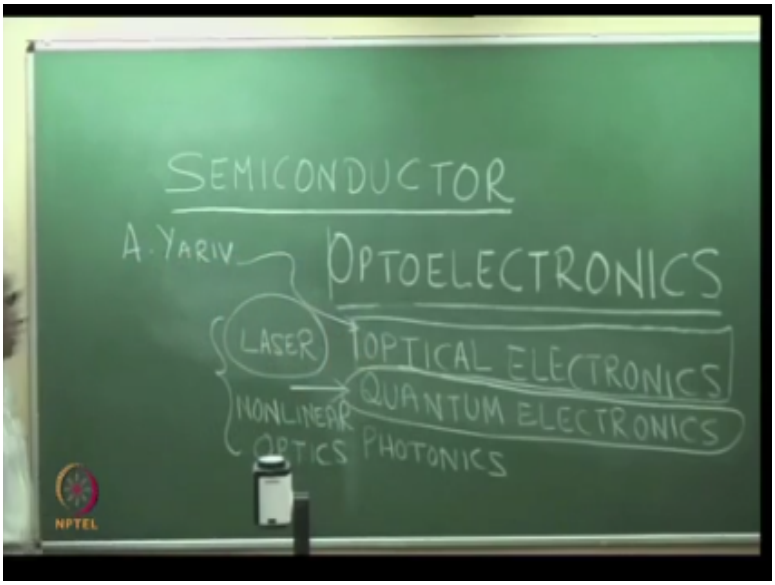

They are quantum electronics is concerned with effects, phenomena and devices which involve interaction of radiation with matter. That important device of quantum electronics is the laser. The laser principle of working of laser is explained from the theory of interaction of radiation matter. Quantum electronics also includes nonlinear optics, laser and nonlinear optics combined together to encompass quantum electronics.

What is optical electronics. In the 1970s all these branches magneto optic, electro-optics, acousto-optic, nonlinear optics and quantum electronics that together called that subject is discussed all these effects together was termed optical electrons. There was a very famous book by A. Yariv, the same title optical electronics. Optical electronics included lasers, nonlinear optics, electro-optics, magneto optics.

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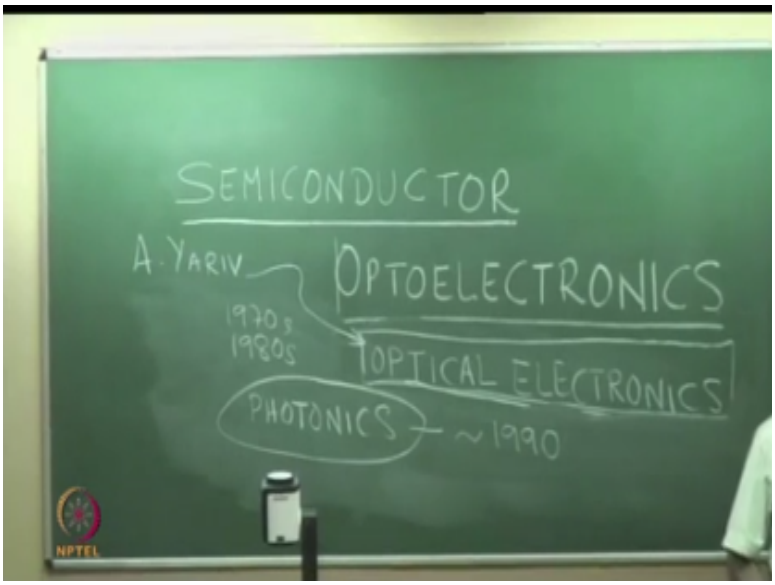

And most of the optical properties, optical electronics. Then comes photonic, in the 1970s and 1980s in the developments in the optical electronics or developments in optoelectronics and optical communication was so rapid that there was a whole branch which emerge and including optical signal processing and the entire branch which discussed all the technologies which included all the technologies involving light.

All light wave technologies where together called photonics. So photonics is a word which is popular in 1970. So this was in 1970s and 80s it was called optical electronics, but from 1990 onwards. These are now all these technologies together are called protonics. So photonics encompasses all technologies which generation, modulation, transmission, detection of electromagnetic waves whose quantum unit is the photon.

Hence the name photonics. I come back to semiconductor of optoelectronics. I would like to discuss the scope and contents and context of this course as you know that this is a core course for the program optoelectronic and optical communication. So in this talk, in this first lecture I would like to discuss the scope and context of this course.

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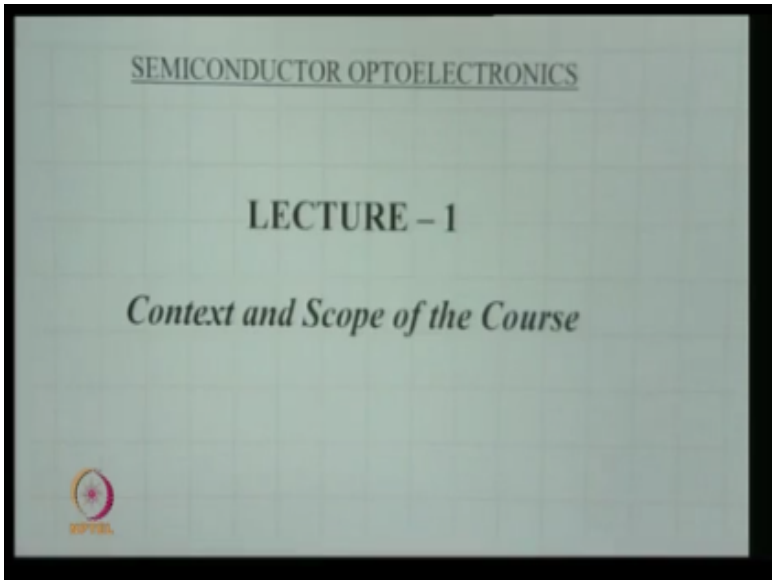

So this is the first lecture in which we will discuss the context and scope of this course, semiconductor optoelectronics. Why do we need to optoelectronic semiconductor. semiconductor optoelectronics came as a complete course and in the 19th in 1995 there were full books which came I will show you a list of books shortly and you will see that there are entire full books with the titles semiconductor optoelectronics.

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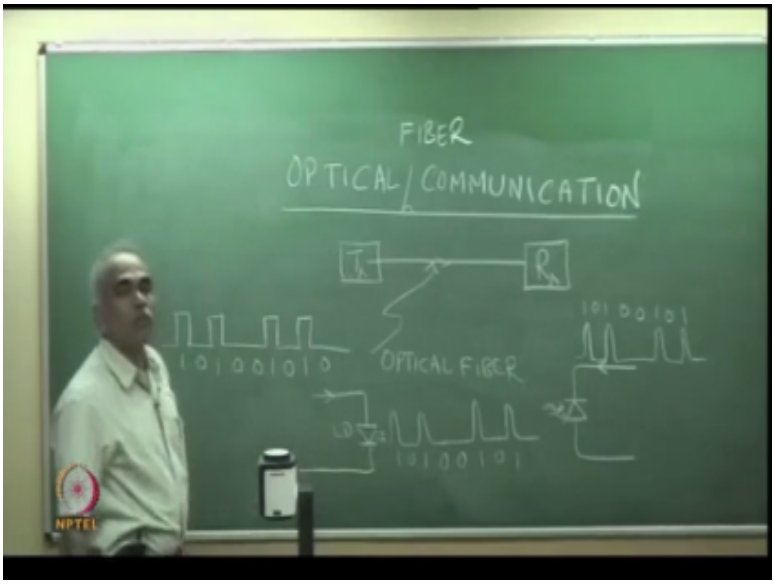

Why study semiconductor optoelectronics, if you consider let me first take an example and illustrate. So if we consider a simple optical communication means optical communication, if you take a simple optical communication which means there is a transmitter here which is link to the receiver to medial. If I consider optical fiber communication. So this is optical communication, but if I consider optical fiber communication by infuse the here word fiber optical fibre communication.

Then you have a transmitter and the medium here, so the medium is an optical fibre, why do we need the medium, we will not go into those details now. But let me if you consider a simple optical fibre communication link, so it has a transmitter and optical fibre and a receiver. The transmitter has all the electronics and finally there is digital beta stream, digital stream of bits of 1s and 0s.

So 1, 0, 1, 0, 0, 1, 0, 1, 0, 1 and so on it is a communication link. So if you are cross meeting a voice signal voice is first digitized, voice is a signal which is digitized and then the digitized are the coded signal is transmitted through the optical fibre. Now the digital signal drives a laser diode usually it drive laser diode. So this digitized signal is fed to a laser diode, this is a laser diode LD which lies output, if this is 1, 0, 1. So it will give the same way 1, 0.

This is 1, 0, 1, 0, 0, no output and then again 1, 0, 1, 0, 1, 0, 1. So the laser diode is giving optical electronic, you have given electronic pulses, the current is modulated by the digital stream which modulates the laser output which means the laser output the laser output the laser diode gives out light, no light. It is getting modulated. The output here is fed to an optical fiber.

The light coming out from the laser diode, so there is a there is light coming out from the laser diode is coupled into an optical fiber and at the receiving end you have a photo detector, the incident light on to the photo detector the incident light generates the photo current. So it generates a photo current, it is a reverse current IP and you retrieve back the current signal the same 1, 0, 1.

So we have the same 1, 0, 1, 0, 0, 1, 0, 1. So what is the point, the point is the last component in this transmitter is a laser diode, has electronics, has modulators, at the last component is a laser diode which is an optoelectronic device. So the laser diode is here and the first component in the receiver is a photo detector which is an optoelectronic device. So you have in between the fibres, laser diode, photodetector, the fiber and the entire communication electronics here at the receiver signal processing.

And at the receiver and at the transmitter. So this course primarily discusses primarily these will get the physics, the structure, design of device and device characteristics of laser diodes

and photo detectors. So this is the relevant in optical fiber communication. But if you ca look at optoelectronics is not important only for optical fiber communication because you know that laser diodes and photodetector are now used in large number of consumer electronics.

And the day today devices which we are using all the laser printer, laser pointer, laptops, LED, LED TVs, LCD TVs everything gives optoelectronics devices. So optoelectronics devices are not semiconductor optoelectronics is not restricted only through optical fibre communication, but also through the whole technology which involve optoelectronic devices. So I have illustrated this with the example of an optical fibre communication leading.

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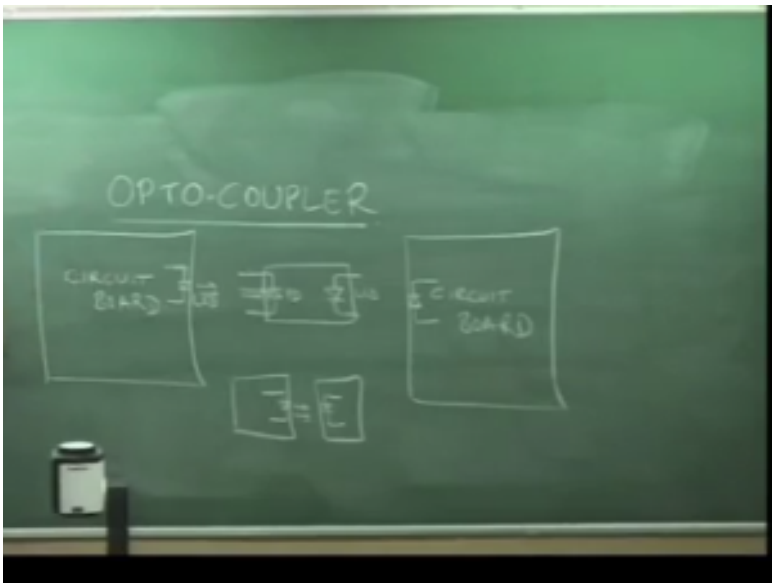

The earliest one of the earliest optoelectronic devices, one of the earliest optoelectronic devices means the optocoupler I do not know how many of you have heard about this optocoupler. Optocoupler (()) (19:55) optocoupler is a device basically is a devices at a detector here and an LED at the other end, inside small devices which is comprised of a photo detector and a light emitting diode.

You have an entire electronic circuitry or a circuit board, so here is a circuit board which wsa doing some signal processing operation, there is another circuit board here, you want to link these but with electrical isolation complete electrical isolation, so how to do that you just need an LED here, this is the signal processing board, this is a signal processing board you would the 2 to be linked but you want complete electrical isolation between these.

One of the easiest way was whatever the final output that was coming from here was fed to the light emitting diode those days we should take only light emitting diode that used for LED. This LED light which comes out from here is incident on a photo detector, so this is a photo detector and this is an LED. There is a second photo detector on this circuit, this is just for historic reasons, but it has now come up again in a very big way for high density optical interconnects to connect chips which are dealing with gigabytes of data.

So this was the early use of an optocoupler which had 1 photodetector and a light emitting diode. So the signal emitted from this LED is detected by a photodetector and that current the current generated by the photo detector modulates another LED which would then couple to this. This is a optocoupler, but you see from here we do not need this at all, you could as well have the 2 chips here and the component here.

The LED is here and the photo detector. So the LED end out signals come here and photo detectors detecting it, what is the advantage, the advantage is they are completely electrically as well., A communication from this to this are the connectivity from this to this is only free space of it, that is free space communication would against with this was in the early 70s and today again the free space optical communication has become very important and optocoupler have come in a big way for high density optical interconnects.

High density of optical detectors, and you have a computer communication when computers have to handle really huge amount of data and data has to be communicated between two signal processing unit then optocoupler is very useful interface, but it is not in this simple form, today what are called as weak cells are used. We will discuss about this later, Vcsel. This stands for vertical cavity surface emitting laser.

We will study in the course vertical cavity surface emitting laser, you can have very large number of these lasers on a single chip monolithically integrate. But this earliest configuration. For today there are large number of large number of applications that I mentioned of large number of consumer electronics goods which used the laser diodes and photo detectors, the barcode scanner which are widely used in marketplace with user laser diode and the photo detector.

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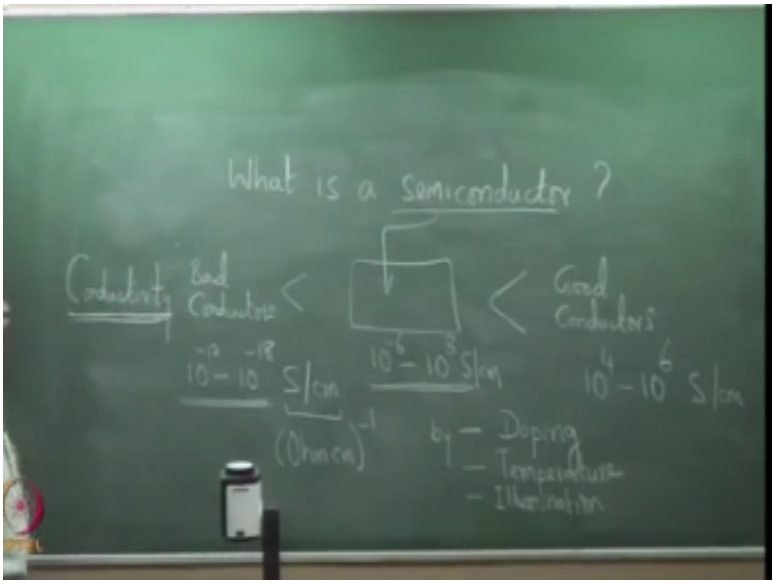

You read the barcode, so let me start, so the first question that is what is semiconductor, we all know it, but let me just recall what is as the semiconductor, as the name indicates semiconductor which means it first a glass of materials which have conductivity between those of good conductors and bad conductors, may be elementary good conductor and bad conductor or insulator.

So semiconductors are those who have which has conductivity in this range, what is the conductivity, so we are talking of conductivity, what kind of number, this is a course for engineers, conductive. So you have to be familiar with number which is necessary large small reasons, you know what kind of numbers, what is the magnitude that are talking of, so bad conductors typical conductivity is 10 power minus 12, 10 power minus 18 S/cm.

So this is the same as you know conductivity is immerse of resistivity and this is basically Ohm cm inverse -1. So Ohm cm inverse S/cm. So bad conductors are insulators typically have conductivity to this range. And what is the conductivity of good conductors typically 10 power 4 10 power 6 is the conductivity of good conductors metals. So semiconductor is other most of the practical semiconductors which we use our connectivity between 10 power -6 and 10 power 3 S/cm.

Depending on the doping concentration as we will see that the conductivity and which so conductors generally we have conductivity in this range. This is sufficient for a material to have conductivity between those of insulators and good conductors and qualify to be a

semiconductor that we know that would not have been that was the case such materials would not have had any practical use.

Why semiconductors have become so important and so many practical applications are possible because the conductivity can be changed by orders of magnitude by, the conductivity of semiconductors can be changed by orders of magnitude by doping temperature changing the temperature, we change the temperature, the carrier concentration and hence the conductivity can be changed by orders of magnitude.

And also by illuminate these light by illuminate impact the photo detection is illumination of semiconductor because of this these reasons the semiconductor has the very important because you can change its conductivity by anyone of one these or by injection career is medium suddenly changed the conductivities and these can lead to switching mechanisms. So a semiconductor is a material whose conductivity lies between those of good conductor and bad conductors.

And whose conductivity can be placed by orders of magnitude by doping or by temperature or by illumination. There are large number of semiconductors, the most widely used semiconductor, the electronics or silicon and germanium are most widely used in electronic, but as we will see when we discussed in greater detail.

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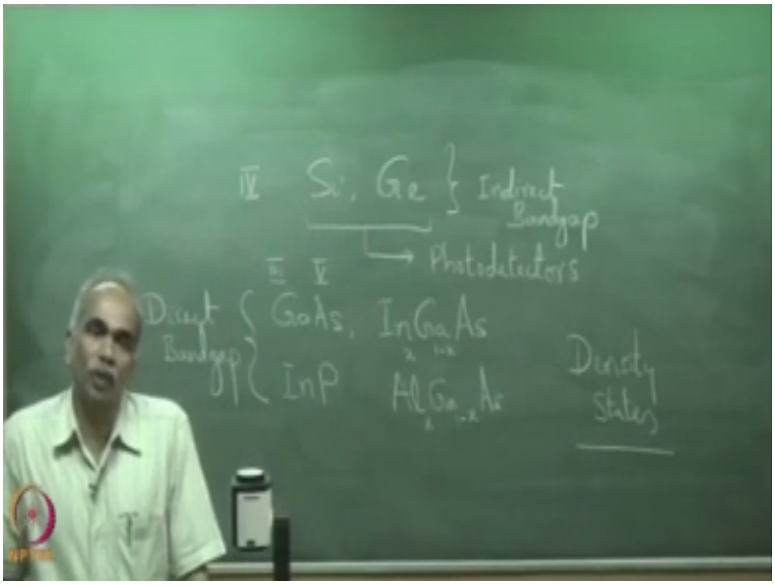

So silicon and germanium are widely used in electronics. They are also used in optoelectronics to realise photo detectors. So these are used to realise photo detectors, but as

we will see later that the materials used to realise light emitting diodes and laser diode are direct band gap semiconductors such as gallium arsenite and the component of gallium such as Indium gallium arsenite.

Indium gallium arsenite which means in this a X component of gallium is replaced by Indium making it a ternary compound Indium gallium arsenite or Alluminum gallium arsenite alluminum gallium arsenite, indium gallium arsenide most widely used succinate in optoelectronics are gallium arsenite and indium gallium arsenide and these are binary compounds or binary semiconductors.

These are also as you can see this is group 4 we will discuss more about this when we discuss semiconductor material, this is from group 3 and this is from group 5 and therefore these binary compounds are also called as 3-5 semiconductors. So 3-5 semiconductors. We will discuss more of this in the next class in the next lecture. We will discuss about energy bands and solids and the E-k diagram and took a indirect band gap and direct band gap.

Silicon and germanium are indirect band gap materials, and gallium arsenite and indium gallium arsenide are direct band gap as we proceed further we will see that normally realise a semiconductor source which emits light you need to use direct band gaps semiconductors whereas indirect band gaps semiconductors can be used to realise photo detectors. We will review basically review the semiconductor device physics to know the density of states.

It is a very important parameters which determine the performance or characteristics of the device is the density of stare. So in the next class we will discuss about density of states, the very important parameter and we will see electron and then we study the devices that we will see that the characteristic are determined by the density of states, ok, so thank you, will stop here.