Introduction to Semiconductor Devices
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Lecture - 01
Types of Semiconductors

Hello everyone, my name is Naresh Emani. I am a faculty member in the Department of Electrical Engineering at IIT Hyderabad. Welcome to Introduction to Semiconductor Devices. As we saw in the introduction, semiconductors have evolved quite dramatically in the last 70 years starting with semiconductor devices which are the size of buildings in 1940s and 50s. To today's technology, where we are able to pack more than 1 billion transistors on a single chip of about 1 square inch. This dramatic improvement has been possible because of various technological advances. And in this course, we would like to understand the physics of how these semiconductor devices work. So, today we will begin that journey.

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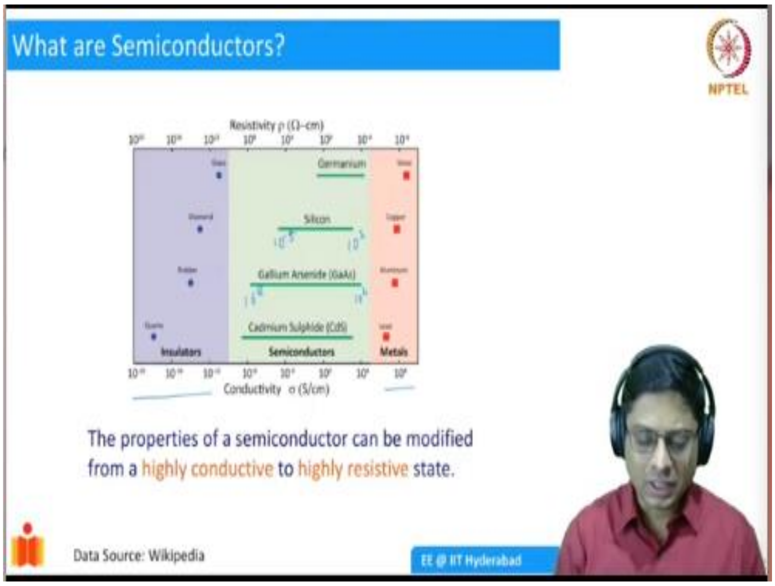

So, the first question we ask ourselves, what are semiconductors? Well, all of us are familiar with metals in our daily life, metals like copper, lead, gold, silver, etcetera. So, if you apply a potential across these metals and then measure the current, you will see that the metals carrying a lot of current, conduct a lot of current. The current carrying capability of metals is given by quantity you know, as conductivity(σ) whose units are Siemens per centimetre (S/cm).

So, in this graph here, I have shown a few metals and their corresponding conductivities. You will see that most of the metals have conductivities in the range of about 10^8 S/cm. So, that is a reasonably large amount of conductivity. On the other extreme, we also have insulators, which are not good conductors of electricity. For example, plastic or diamond or glass, rubber, etcetera, these are all not very good conductors of electricity. And so, we expect that their conductivity is going to be very small (relatively small compared to the metals!). So, we see that the conductivity range of typical insulators is in the range of 10^{-20} to 10^{-12} S/cm. So, we see that there is almost 20 orders of magnitude difference in the conductivity of metals and insulators. These are the extremes.

In between these two extremes, there is a very broad range of materials, which have intermediate conductivity, the conductivity falls in between these two extremes. The most prominent example of a semiconductor is silicon. You see in the graph here that silicon has a conductivity of about 10^3 to 10^{-5} S/cm, showing about 8 orders of magnitude range.

While metals and insulators have a fixed amount of conductivity. The conductivity of silicon can be tuned over 8 orders of magnitude, by changing certain properties as we will see later in this course. The ability to adjust conductivity over a broad range is a very unique property of semiconductors. Also, Gallium Arsenide is another very popular semiconductor which exhibits the conductivity in the range 10^4 to 10^{-8} S/cm. So, in this case, we see that it is about 12 orders of magnitude change in the conductivity. So, semiconductors are those materials whose conductivity can be modified from a highly conductive to highly resistive state. This is one of the simplest definitions of semiconductors. In the graph here, I have also shown resistivity(ρ) on the top. So, resistivity is essentially inverse of conductivity($\rho = 1/\sigma$). So, it has a unit of $Ohm - cm$. And we will use resistivity to denote the properties of semiconductors later in the course. So essentially, whenever the resistivity is high the conductivity is low and vice versa. So, it is quite simple. So, we understand the semiconductors and intermediate conductivity.

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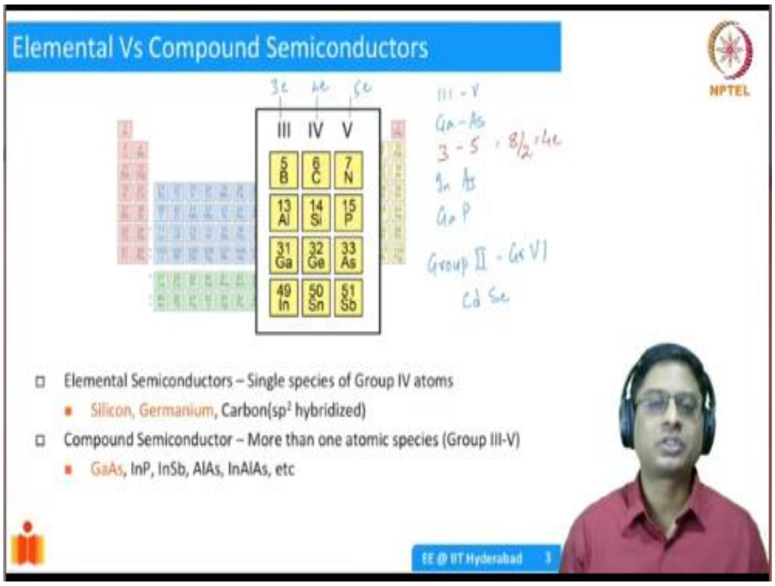

But, how does this come about? What is the origin of this property? To understand that, we will have to look at the periodic table. So, out of more than 100 elements in the periodic table, most of the important semiconductors fall into 3 groups: group III, group IV and group V. As you might have studied, group III elements are those elements which have three electrons in the valence shell, in the outer most shell. Group IV are those which have four electrons in the outer most shell and group 5 are those which have 5 electrons. So, if you look at group IV elements, *e.g.*, Silicon falls in group IV, you see that silicon has an atomic number of 14 and it exhibits semiconducting behaviour. It is a very good semiconductor. Similarly, germanium is another very famous semiconductor. And recently one of the allotropes of carbon called Graphene has been shown to exhibit very interesting properties.

So, these are all called elemental semiconductors which means the semiconductor consists of only one type of atomic species, *e.g.* Silicon, Germanium. In addition, you could also have what are called as III-V semiconductors. So, what I will do is I will take one element from the group III and I will take another element from group V, and form a compound out of it. So, for example, I can take Gallium from group III and Arsenic from group V to form a compound. If I do that, it turns out that even this compound exhibits semiconducting behaviour. The reason for this is, if you look at the periodic table, immediately we see that Gallium has 3 electrons in outer most shell. Arsenic has 5 electrons. So, f you look at the number of electrons in outer most shell per species, here you have two species, Gallium and Arsenic, and a total of 8 electrons in outer most shell. The number of electrons in outer most shell per species is 8 by 2 which turns out to be 4 electrons again. So, even when you have a combination of Gallium and Arsenic, we are having 4 electrons in the outer most shell. And it is not surprising that all the semiconductors have these 4 electrons in the outer most shell. We will see why this is in later lectures. You could also have various other III-V semiconductors. For example, I can form a compound between Indium and Arsenic. I can form a compound between Gallium and Phosphorus and so on. And you can have various compounds which are known as compound semiconductors which basically have more than one atomic species. Some examples are given here.

Out of all these compound semiconductors, Gallium Arsenide is the most famous one. Compound semiconductors are very important for opto-electronic devices, and we will talk more about them in the last 2 weeks of the course. Till then, we will focus on elemental semiconductors, namely Silicon and Germanium. Mostly silicon, germanium is only for comparison purposes.

You might ask, is it possible to go further out like? For example, can I take group II element and a group VI element and form a compound semiconductor? Well, you can do that as well. One of the popular combinations here is Cadmium Selenide which is a good semiconductor. So, you could have various other compound semiconductors this way.