Energy Conservation and Waste Heat Recovery

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Lecture - 45
Direct Conversion - Thermo - Ionic Generation

Greetings, welcome back to the next lecture of Energy Conservation and Waste Heat Recovery. So, today what we will do is, we will continue our discussion on Direct Conversion Devices.

If you recall direct conversion device is one, where thermal energy can be directly converted to electrical energy. We have seen one example, in the form of thermo electric generators where we saw that how using PN junction which is a solid state device. It was possible to generate electricity using a temperature gradient. If you recall we had one heat source, which allowed us, you know the hot junction, the cold junction was typically will be the ambient, and if we use thermoelectric materials it is if we showed that it is possible to generate electricity, if we have that temperature gradient across a thermoelectric module or thermoelectric generator.

So, today what we will do is, we will look at one more such form of direct conversion device, which is thermo ionic generation. So, what is thermo ionic generation? So, thermo ionic generation, if I just give the definition first, and then we will go into the details. I would say it is a static device that converts. Again remember the word static device. So, we are not talking about rotating parts, we are not talking about turbo machinery or turbines or compressors or pumps here.

It is a static device that can convert thermal energy to electricity, by utilizing the emission or release of electrons. I repeat it utilizes the emission or release of electrons from a hot emitter surface which is maintained at an elevated temperature. And these electrons when they are released from the hot emitter surface, goes and hits another surface which we call the collector and which is at a lower temperature, and where it gives up its energy, and in the process we can generate electricity. So, how is that possible is a question. So, before that, let us write down the definition, and then we will look at how this works.

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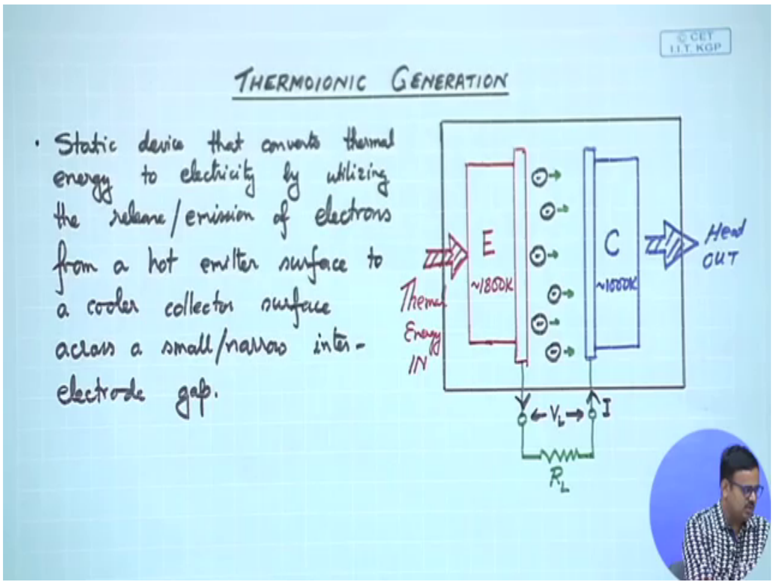

THERMOIONIC GENERATION

- Static device that converts thermal energy to electricity by utilizing the release/emission of electrons from a hot emitter surface to a cooler collector surface across a small/narrow inter-electrode gap.

So, I would say thermo ionic generator, it is a static device that converts thermal energy to electricity by utilizing the release, or let us call it emission also, same thing of electrons, from a hot emitter surface to a cooler collector surface, across a small or narrow inter electrode gap. So, this is our definition, converts thermal energy to electricity by utilizing the release or emission of electrons from a hot emitter surface to a cooler collector surface across a small or narrow inter electrode gap.

So, if I draw schematic, this will look something like this, where I have one surface which I am calling the emitter, which is at an elevated temperature. And I have another surface, which is slightly away. I have exaggerated the gap here, typically it is around 500 microns or less, and I will call that the collector. So, the emitter let us say is around 1800 kelvin, and the collector would be around say 1000 kelvin. So, an appreciable temperature difference I would say.

So, what happens is, right now, let us say if this emitter is above a certain temperature. And how do I get that certain temperature, is by the supply of heat to that emitter electrode. So, I would say thermal energy, which comes from our waste heat in the context of this course. So, what happens is- as the temperature of this surface keeps increasing, it reaches a point where electrons become free from the surface. Electrons are detached from the surface and they start moving.

So, this is from a solid surface. So, what happens therefore? So, let me draw a bunch of electrons here and so on. So, these electrons now have a net momentum. So, it breaks away from the surface and goes towards the colder collector surface. So, there is a net migration of electrons from the emitter to the collector. So, therefore, what happens when the electrons go and hit the collector surface it releases its energy, and that is again we see that that will be dissipated from the other end, again in the form of heat.

So, I would say this is heat out. So, this was thermal energy in. This is also heat out waste whatever, as the electrons give up their momentum after hitting the collector surface, we do get some heat dissipation from the collector, but; however, what happens is, If I now connect the collector and emitter externally, then what happens is, let us say I collect it externally through a resistance or load RL, then what will happen is they will have a net current flow in this direction clear.

So, why, because as there is a movement of electrons from the emitter to the collector, there is a potential difference that is created across this: so you will be able to measure at voltage across. And if I connect a load across this to emitter, across the emitter and collector, we will be able to see. Sorry a flow of current in the externally from the emitter to the collector surface. Why, because as we will see later, the electrons which has migrated from the emitter to the collector, actually comes back to the emitter through the external load, because of certain potential difference, which we are going to study later.

So, again if I look at it as a black box what happens is the following, and let us look at this slide also here.

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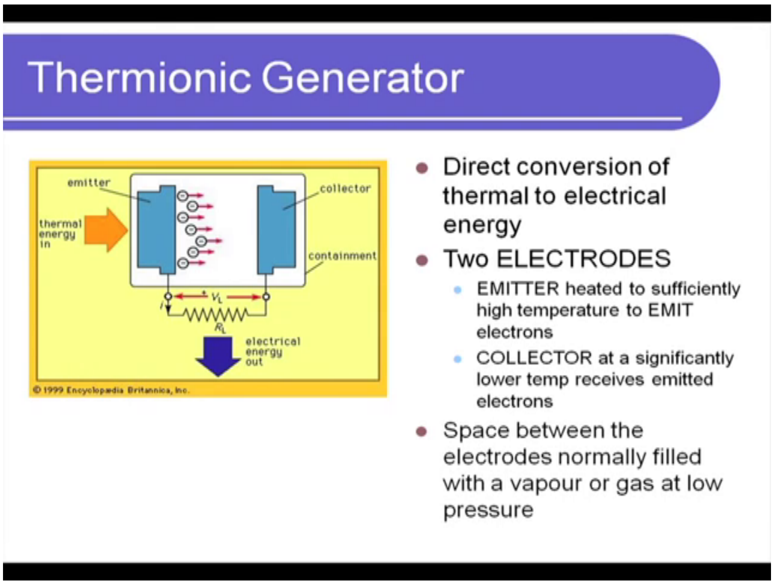

Thermionic Generator

- Direct conversion of thermal to electrical energy
- Two ELECTRODES
  - EMITTER heated to sufficiently high temperature to EMIT electrons
  - COLLECTOR at a significantly lower temp receives emitted electrons
- Space between the electrodes normally filled with a vapour or gas at low pressure

So, which is similar to what I have drawn; so we have a thermal energy in, and then this is inside a container and a small gap which is also exaggerated here. So, there are two electrodes; one is the emitter which is sufficiently emitted, sufficiently heated to a certain temperature, so that it emits electrons. And the collector is at significantly lower temperature, so that it receives the emitter emitted electrons and as the emitter electrons gets collected in the collector surface, it gives up heat, but what happens is, because of the movement of electrons there is a potential difference; that is created between the emitter and collector, and the electrons. If you collect a load across it, the electrons from the collector will now travel back to the emitter through this external load.

How, we will see, as we study in the physics of, what is happening here, but this is how a thermo ionic generator works. If you just see it as a black box. So, all that I will say is, I have the collect emitter plate which I have to maintain at a sufficiently high temperature. So, that it emits electrons, and then what I will have to do is? I will have to collect the external load across the emitter and collector, and I will be able to get electricity. So, this is, overall if I say that what do you get if you have a thermal energy generator. This is what you get, I have to heat one end, I have to keep the collector at a sufficiently lower temperature compared to that of the emitter, and I should be able to get an electric current through an external load. Now the space between the electrodes, is normally filled with a vapour, it can be a vacuum also.

But if it is vacuum then what happens is, the kind of temperatures that you need is very high. So, what we do is, normally we put it is, we filled it with a gas; like a caesium at low pressure, and then what happens is, in that case we are able to get, we are able to get a this emission at a lower at lower temperatures. So, now, that we have come to the. Now that we have understood how this thermoelectric emitter works. Let us talk about that physics of what is happening here. So, what is happening in the physics is the following. So, let me remove this. So, let me talk about what is happening in the emitter and collector.

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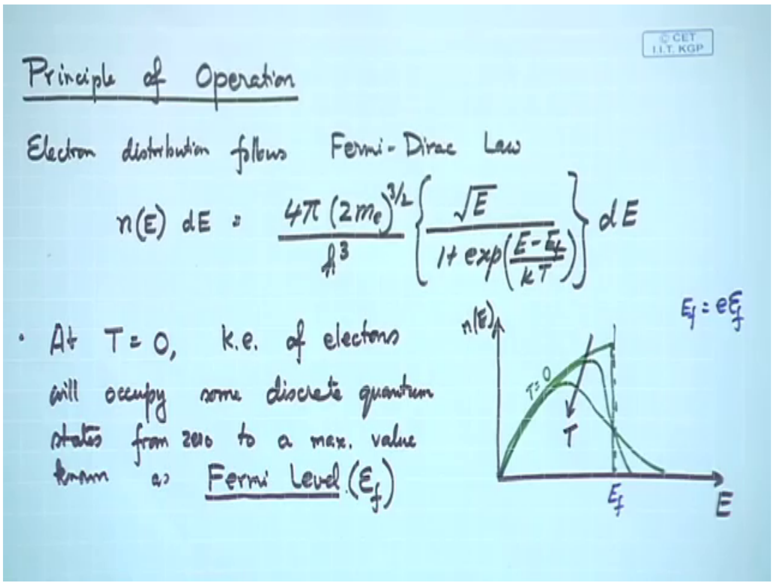

Principle of Operation

Electron distribution follows Fermi-Dirac Law

$$n(E)\,dE = \frac{4\pi (2m_e)^{3/2}}{h^3} \left\{ \frac{\sqrt{E}}{1 + \exp\left(\frac{E - E_f}{kT}\right)} \right\} dE$$

- At T = 0, k.e. of electrons will occupy some discrete quantum states from zero to a max. value known as Fermi Level (E_f)

$E_f = e\xi_f$

So, I will say that you know what has happen, the principle of operation if I may call it; so of thermo ionic generation. See if you take any material or any surface what happens is, we have a distribution of electrons on the surface, and the distribution of electrons actually what it follows, is something called a Fermi Dirac Law. The Fermi Dirac Law states that let me write it down. The electron distribution follows Fermi Dirac Law.

So, if I write it in this manner n E, which is the distribution. This is a complicated expression, but that is ok, we adjust. This is mass of an electron to the power 3 by 2. For some of you it may be familiar from your physics, if you have a physics background. So, this times root over E, which is the energy level 1 plus exponential E minus E f divided by k T.

So, this is the Fermi Dirac Law, where m e is the mass of an electron, k is the Boltzmann constant, h is the plancks constant. So, what happens is, from here you can also find out what is the probability, that an energy state is occupied by an electron, but that is more involved physics, let us not get into that. What I will say is, some of the auxiliary understandings of from this Fermi Dirac distribution is at absolute 0. If I write it as this way at T equal to 0. The kinetic energy of electrons occupy some quantum states, from 0 till a maximum value, which is known as the Fermi level. So, if I consider the absolute 0 temperature. Then the kinetic energy of electrons, will occupy some discrete quantum states from 0 to a maximum value known as Fermi level. It is important to know this, what is the Fermi level.

So, if I have to draw it in this manner. Let us say I right this is n of E, and this is E, this is the axis E. Then what happens is, there is a maximum limit, and let me call it E f . So, that is the Fermi level and. So, that is whatever, that is are actually mult, that is it represents the Fermi level. I will not say that is exactly equal to the Fermi level, why I will talk about that.

So, what happens is if I now plot n E, then the graph that I get looks as following, and there is nothing above the Fermi level. So, this is a maximum energy that an electron can have at absolute 0. So, let me write it as T equal to 0. Now what happens is, as we increase the temperature beyond absolute 0, then what happens is, some of the electrons especially the ones at the outer levels, will tend to vibrate around this Fermi level.

So, before that, let me write here Fermi level is actually we are going to denote it as epsilon f, and this E f is actually E the electron charge times the Fermi level E f. So, this is what happens at absolute 0. Now if I increase a temperature beyond 0, then what happens? If I increase the temperature beyond 0, the electrons have free energy above this Fermi level, and it would tend to vibrate around that. So, if I increase the temperature, then what will happen is, I will start tend to start seeing something like this, it goes like this, and then some of the electrons will be in this manner.

Then I increase it even further, then what happens it goes like this, and so this is how it continues. So, you can see that, there are some electrons, as given by n E which is above the Fermi level. So, as I keep on increasing the temperature. So, this is I would say, that in this direction the T keeps increasing. So, as the absolute temperature goes beyond absolute 0 then what happens is, some of the electrons will have enough energy especially the outer ones, and it will vibrate around the Fermi level. So, some of them will have energies above Fermi level, and most of them will keep vibrating, and this amplitude of vibration keeps increasing as we keep increasing the temperature. Then what happens is the following. If I increase the temperature even further, then what happens? Then what happens is the energy of some of the electrons increases or goes beyond a certain value.

Whereby it can detach itself from the surface and break free. I repeat if the temperatures increased further, some of these electrons will have enough energy to detach itself from the surface and become free .And as it detaches it has a lot of kinetic energy with it. So, what is that threshold temperature beyond which it becomes free; that is called the work function. So, the work function is a function of the material, and it is also a function of if you if you treat the surface, it is also going to depend on the surface properties. So, therefore, let us look at this, at even higher temperatures what happen.

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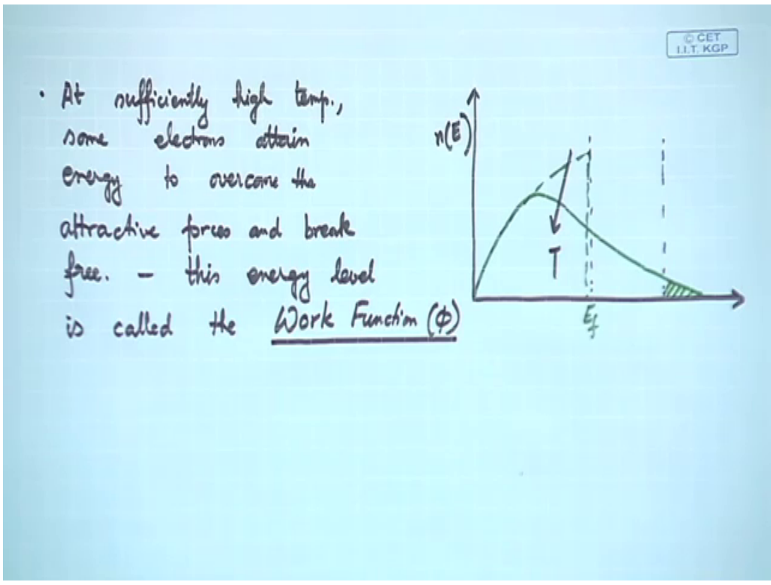

- At sufficiently high temp., some electrons attain energy to overcome the attractive forces and break free. – this energy level is called the <u>Work Function (ϕ)</u>

If I extrapolate that curve further, then I can draw it in this manner. So, I will draw it as n E, this remains my energy axis. So, let me draw the Fermi level over here, and then I will draw one more level. So, what happens? We knew that at the absolute 0 this was my distribution, but beyond a certain temperature what happens is. So, look at this. This was my E f, it remains f, but here I have some temperatures or some electron sorry, at adequately high temperature, where some of the electrons go beyond this level which is known as work function. So, let me write it down, that at sufficiently high temperature some electrons attain enough energy to overcome the attractive forces, and break free. This energy level is called the work function. I will denote it by phi. So, this is what is happening. As I keep increasing the temperature of the emitter surface.

What happens is some of the electrons, will attain energy beyond its walk function, and therefore, it is going to dissociate or detach from the surface, and move towards the collector surface. Now as it reaches the collector surface what happens is it gives up its energy and that though the energy level comes down, to the level of the, to the Fermi level of the collector surface.

So, again I repeat the electrons in the emitter surface of course, it went beyond the Fermi level some of them, and then at sufficiently high temperatures. It attains the energy that is higher than the work function. Therefore; it can dissociate from the surface and go towards collector. As it goes to the collector it gets collected and its energy levels comes down, to that of the Fermi level of the collectors. So, if we have to show it pictorially, this is how I am going to write. So, let me draw this, and probably from here it is most convenient to explain.

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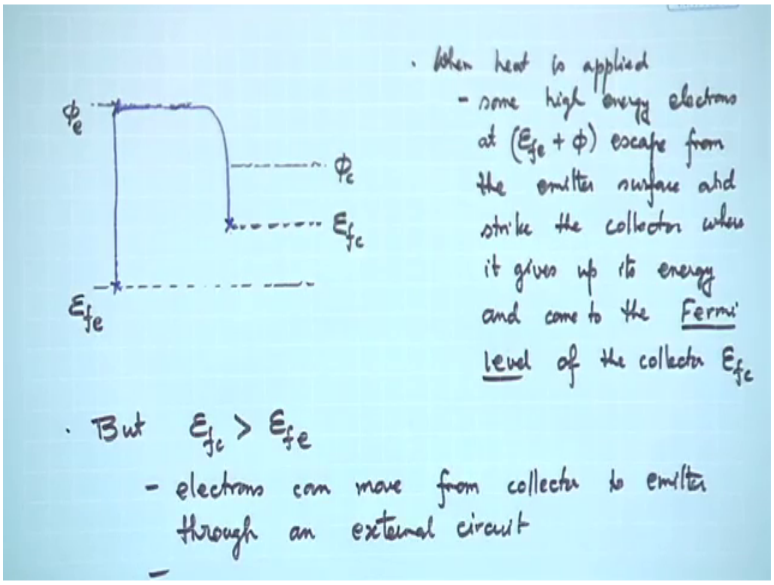

- When heat is applied
  - some high energy electrons at $(\varepsilon_{fe} + \phi)$ escape from the emitter surface and strike the collector when it gives up its energy and come to the Fermi level of the collector ε_{fc}
- But $\varepsilon_{fc} > \varepsilon_{fe}$
  - electrons can move from collector to emitter through an external circuit
  -

So, let me say that this is one level, this is the energy level, and I am calling it the Fermi level of the emitter. Similarly this is one level and I am going to call it the work function of the emitter. So, now, here is the trick, or here is where we have to choose the materials judiciously. Of course, the work function of the collector will be lower than that of the emitter; however, the Fermi level of the collector will be higher than that of the emitter, understand.

So, I repeat, the emitter and collectors surfaces are chosen such that, the Fermi level of the emitter is lower than that of the collector, but the work function of the emitter is higher than that of the collector. So, therefore, what happens, if an electron goes to this level, it will dissociate from the surface and go to the collector, where it will give up the energy, and come down to this level.

So, what I will draw it in this manner. So, it goes up, and then it will come down in this manner. So, that of the, to the Fermi level of the collector surface, but remember this is higher than that of the emitter surface. So, therefore, what happens, if I attach these two points externally, then the electrons will tend to move from the Fermi level of the collector to the Fermi level of the emitter, which is at a lower energy level. So, from E fs of the collector to the Fermi level of the emitter, the electron will tend to move, if we collect it through an external load.

So, this is how the thermo ionic generator works. So, let me quickly summarize it here once more. So, I would say, when heat is applied, some high energy electrons at, I would say epsilon phi f E plus phi escape, from the emitter surface and strike the collector. Where it gives up its energy, and comes to the Fermi level of the collector epsilon fc, but epsilon fc is greater than epsilon f of E. So, therefore, the electrons can move from collector to emitter through an external circuit.

So, this is how we generate electricity clear. So, with this understanding, we will come to the end of this lecture, and we will take off from where we stop today and understand; what are some of the other factors that we need to take into account, to make a thermo ionic generator work.

Thank you very much. And we will continue with this in the next lecture.