Electronic Packaging and Manufacturing
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Lecture – 29
Thermal Management 8: Thermal Technologies

Welcome back and we will continue our discussions on Thermal Management analysis and design which is a very important module of this course on Electronic Packaging and Manufacturing. So, in the last couple of lectures we kind of revisited the concepts of heat transfer and also solved a couple of problems applied to the domain of electronic packaging and cooling for the electronic cooling.

So, today and that was primarily about heat sinks which is probably the most common you know heat cooling solution that is used in electronic products, today we will look at apart from heat sink what are the other thermal technologies, some other thermal technologies that have been used ok. So, that is the concept where that is going to cover today that is going to be covered today thermal technologies ok.

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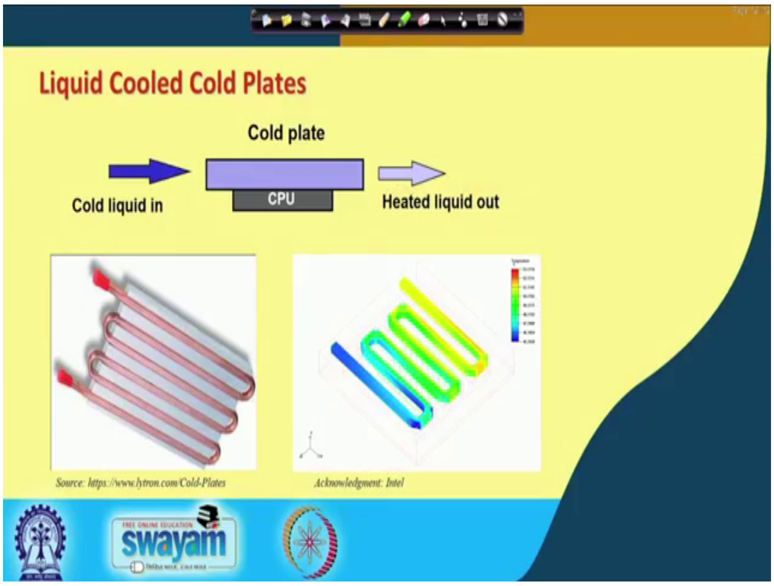

So, let us move on and look into the first one which is called cold plate. So, there is a heat sink through which we is primarily air cooled heat sink is what we talked about, but what is a cold plate cold plate is instead of air if you are having a liquid coming in. So, then the liquid as it flows over the CPU through this cold plate, it picks up the heat and that is generated at the CPU and when it leaves, it leaves as a heated liquid. So, this is a typical picture of a cold plate ok of course, the cover has been made transparent because if you look from outside you would not be able to say that, you will only see an inlet point an outlet point and probably and copper or aluminum block.

But inside you have this serpentine channels ok, serpentine is one configuration you can also have parallel channels right, if I have to draw it here you can have a cold plate with parallel channels like a heat sink and then what is called an inlet and exhaust manifold so the water the liquid comes in and then gets distributed and then again it comes out all right. And on the right hand side what you see is typically a you know simulation which tells you how the temperature of the fluid varies it comes in so, its blue.

So, it comes in as a cold liquid and then as it flows through these different the serpentine path and picks up the heat and in and therefore, gets heated itself it leaves at a higher temperature. So, and that is the change in color gives you that variation alright.

Now, what do I do with this heated liquid in a heat sink the hot air is thrown out in our laptops desktops everywhere in TVs also you will see this in many of these electrical electronic appliances you see this, but liquid I cannot just throw away.

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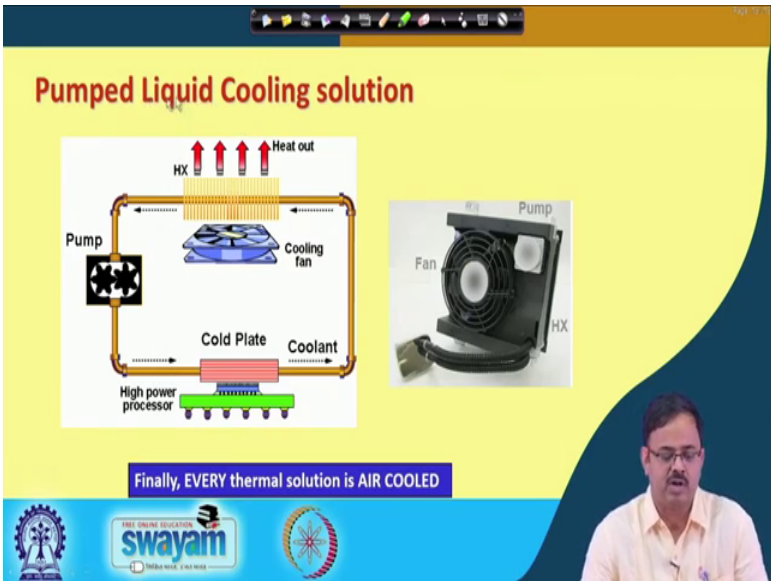

So, therefore, any liquid cooling solution cold plate being one of them what you have is its called a pumped liquid cooling loop. So, definitely like you have a fan for air cooled heat exchanger under force convection you need a pump for liquid cooling. So, if it is water, you need a pump that you know forces the water to flow through this cold plate and then this coolant it comes out in the form of hot liquid as we saw and then what do I have to do.

I have to cool it down using this air cooled radiator type heat sink or heat exchanger. Here so, therefore, this coolant at a higher temperature the liquid at higher temperature flows over and then you have these fins attached to the outer surface of this tube or pipe and you have fan blowing air to extract the heat. So, this is a typical heat exchanger a water air or air water heat exchanger and so, therefore, the liquid gets cooled back and is again ready to be pumped in to the cold plate. So, therefore, the heat that is extracted out of this by the liquid is again dissipated at this heat exchanger and the liquid is cooled down.

So, the next question that you will ask is. So, finally, looks like everything is air cooled right. So, the liquid just helped in dissipating the heat from this point extracting the heat from this place of generation and transferring it to this place, where it was eventually air cooled. So, the question is that why not put this heat exchanger or these heat sink with the fins and the fan right over here why. In fact, this actually adds a little bit whatever; however, tiny that is it adds to the overall thermal resistance because these are in series right.

There is a convection resistance, for the liquid and then there is a convection resistance because of this air cooled heat exchanger if you had put the air cooled heat exchanger directly on the CPU you would have been able to reduce the heat thermal resistance why did we do not do that. That is because look at this is an this is a real sample, look at the size of the heat sink or heat exchanger look at the size of the fan and look at the size of this cold plate which is here with this inlet and exit.

The cold plate is required because I do not have enough space at the place where I need to cool that is why the cold plate is required. And of course, there are other advantages of liquid cooling as well of course, there are disadvantages will this pump reliability its a more complex system, but the advantage is this part the heat exchanger part can be away from these circuits and components. So, all the problems about vibrations because of the fan running at certain or few thousand rpm because of dust etcetera will not be there ok.

So, this is called remote cooling and the liquid all it does is it helps in conducting the transferring the heat that is generated from this in convenient location to this convenient location where it can be air cooled. So, finally, everything is air cooled if somebody says I will replace air cooling by liquid cooling and get a lower thermal resistance the immediate point you will ask is come on you cannot do that because finally, you have an air cool you must have an air cooled heat exchanger.

Unless you are saying that you can dump the heated liquid somewhere, such applications are very very few maybe if you have some underwater electronics maybe during deep sea drilling and all that is possible probably you can have a liquid cooled loop, you have a lot of sea water around and yeah liquid cold water comes in hot water is just dumped into this large volume of the ocean that is one example, but otherwise no ok.

So, otherwise everything is finally, air cooled the other thing I want to point out is both I mean in here as well as in the previous one is a cold liquid in heated liquid out, but there can be situations where the liquid may reach its boiling point and start to boil and therefore, what comes out is liquid plus vapor combination ok.

So, that is also possible that is called two phase cooling the heat transfer coefficients in two phase is very very high, but so, its pressure drop. So, therefore, the pumping power that you need for two phase flow is very very high, but. So, will be the heat transfer coefficient. So, therefore, this part will be very very small ok.

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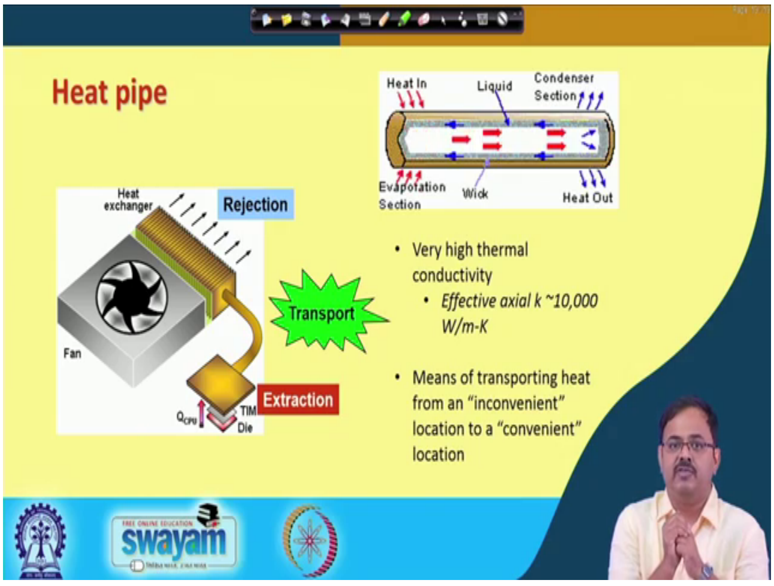

The next one I am going to talk about is something called heat pipe. So, heat pipe is a thermal solutions that is used in laptop computers, I think most almost all laptops have heat pipes and laptops that have fan heat exchanger inside have heat pipes. So, it is very similar to liquid cooled except that you do not have a pump, but before that so, this is a die there is a thermal interface material and there is a cold plate or there is a thermal plate let us say ok.

So, this is where the heat needs to be extracted, but then and finally, rejected to the environment using this fan and heat sink this blower and heat sink parallel plate heat sink, but then the size of this fan and heat sink just like liquid cooling loop that we saw before its too large to be kept at the CPU location. So, what do we do?

So, we put something called a heat pipe from outside it looks like a copper rod, but you know what happens inside its actually a hollow tube with a fibrous material attached to the wall in the annulus which is called the wick. So, what happens is one end of the heat pipe where there is when it is heated the liquid starts to boil ok, as the liquid starts to boil it converts to vapor and flows through this central core to the other end where you have a means of extracting the heat out maybe through a fan heat exchanger like this.

So, where the liquid the vapor or the fluid gets cooled and the vapor condenses back to liquid and then the liquid is pumped back to the evaporator to the hot section because of what is called the capillary reaction inside the wick. Wick remember when we light the diya at our homes what do we do the diya has some oil and then we have this wick its cotton and you light the fire at the wick and what happens therefore, is that the oil percolates through the wick to the tip, where it is lighted because of this capillary action its exactly the same thing here its a fibrous material and which helps in driving the liquid back due to capillary action ok.

So, this is like a liquid cooling two phase order two phase cooling, but you do not need a pump because the pumping action is accomplished through this wick. So, I have a sample over here once again as you can see that the heat pipe is just a method of transporting the thermal energy from this location where it is generated to the point where it is rejected finally, it is air cooled ok.

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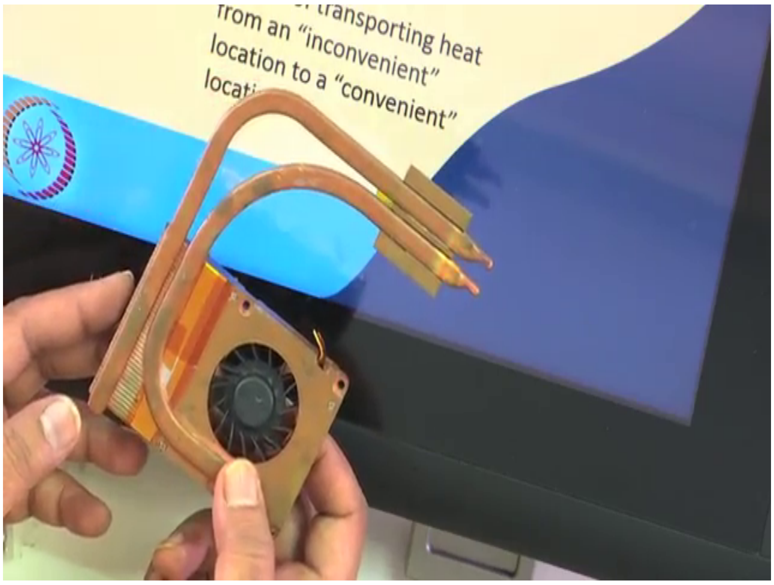

So, I have a sample which I want to show over to you over here. If you can focus on this screen see this is a typical heat pipe heat sink arrangement in a laptop computer ok. So, this is this plate inside which this heat pipe is embedded this is what sits on the CPU ok.

And then this is a fan and this is this parallel plate heat sink I am sorry this has got a little damaged at the ends ok. So, therefore, what happens is the fan blows air through this heat exchanger or through this parallel plate heat sink alright. So, here it shows two heat pipes, but in most cases there can be one, in rather in most cases there is one alright. Again there is no standard design because every layout in the laptop is different.

So, therefore, whether the heat pipe is going to have a bend or whether it will be straight or whether it will be have two bends, but there are there will be two heat pipes whether it will go on the fan casing like this and these are all you know there is a pretty non standard these are from one model to another you will it will vary, but the basic principle of a heat pipe heat sink arrangement is the same.

So, this fan blows air as it is powered on it the fan blows air through this heat sink and that is how the heat is rejected extracted from here transported to here and rejected all right. So, from outside what do we see this looks like a copper copper rod right a flattened copper rod, but actually inside it is hollow alright. So, let us come back to the screen. So, why do we use heat pipe instead of a copper rod because the effective axial thermal conductivity is very very high its like 10000 watts per meter Kelvin copper is

400. So, this is a much more efficient conductor conducted within quotes because its an effective heat conduction actually what is happening inside is a very complex heat and mass transfer phenomenon its two phase flow. Now what do these most of these heat pipes have? What is the liquid that is used its typically water a few drops of water, but the pressure inside is lower than atmosphere.

So, that is why the heat pipe is evacuated and then sealed at the top. So, let us see if I evacuate it to right around 0.3 atmosphere then the water will boil at 70 degrees because otherwise if its atmospheric pressure the water is not going to boil before 100 degree c all right.

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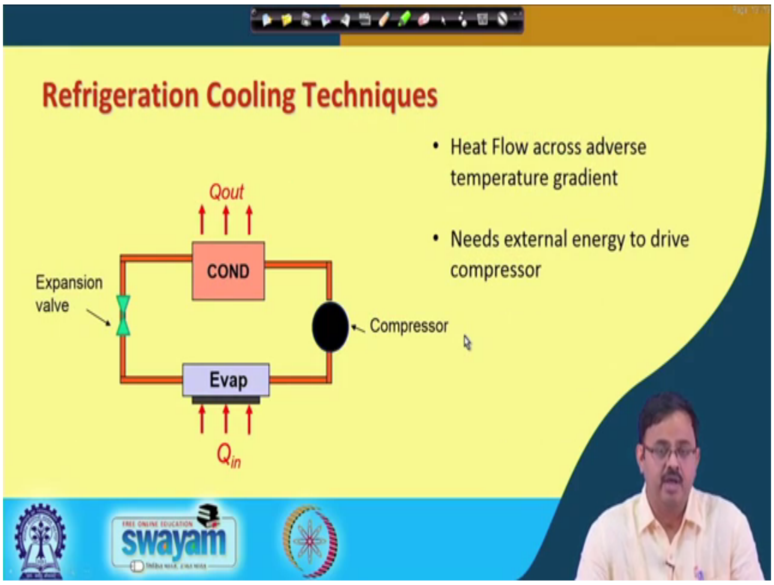

So, that is the heat pipe refrigeration cooling techniques what if I want the temperature of the CPU to be lower than the ambient, can I remove heat from a lower temperature to a higher temperature? The second law of thermodynamics says you can only if you do work on the system if you spend energy. So, that is refrigeration moving heat or heat flow across an adverse temperature gradient from a lower to higher temperature and that is accomplished in our ACs in our refrigerators that is Accomplished by the Compressor which needs external energy ok. So, a refrigeration system has an evaporator which extracts heat.

And in case of electronic cooling from the CPU, in case of a refrigerator from the chamber inside in case of your air conditioner from the room then the refrigerant comes out in the form of vapor it vaporizes actually the refrigerant that flows through this evaporator comes in as a liquid and comes out as vapor and that vapor is compressed.

So, as a result of which the, what comes out to the compressor the refrigerant vapor is at a higher temperature and pressure. And then it is the heat is extra in the condenser which typically is situated outside the main refrigerator chamber or outside in the outside unit of your room air conditioner ok. So, what comes out of the kind of the condenser is therefore, again refrigerant liquid at the high pressure.

And therefore, high temperature as well typically ambient temperature outside ambient or slightly lower or slightly higher and then what we have is something called an expansion valve where it undergoes a certain expansion a large pressure drop and as a result of which the refrigerant vapor cools down and also expands to a lower pressure.

So, what comes out here again is the refrigerant liquid or a mixture of liquid and vapor at a low pressure and temperature and this is how the circle continues extracting heat from the evaporator section rejecting heat out at the condenser section. So, for CPU I am going to place this evaporator on the CPU which is generating the heat all right.

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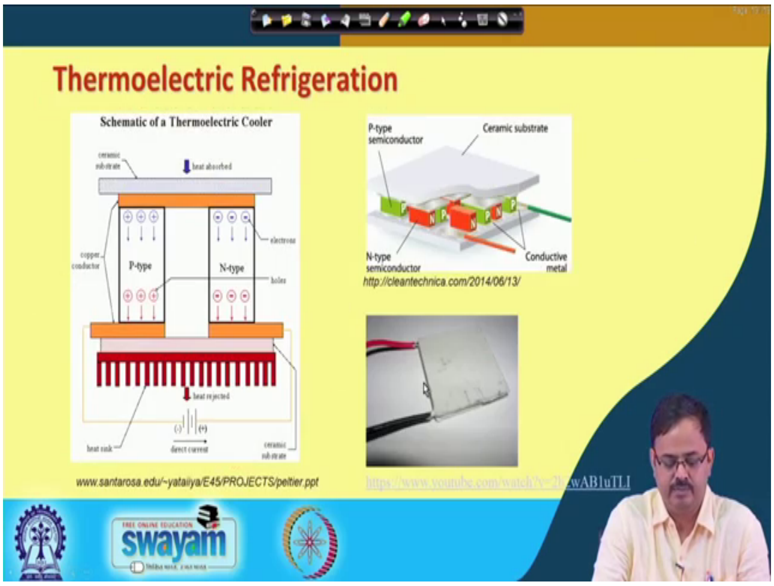

So, similar of another refrigeration technique which is known as a solid state refrigeration is known as thermo electric refrigeration. A thermoelectric cooler or thermoelectric refrigeration by the way thermo electric thermal electricity as the name suggests is thermal and electrical ok, it can work both as a generator of electric power electrical power or given an electrical power it can lead to a temperature difference. Now what we are going to talk about is in the as a cooler where we are going to supply electrical power to this thermoelectric cooler and as a result of which it is going to cool down.

So, a thermoelectric refrigerator or thermoelectric cooler consists of an array of semiconductor devices where you know you have what is called a peltier copper this by the way this effect is also known as peltier effect and peltier cooler is also a term it that is used after the person who first came up with this invented this phenomenon ok.

See back and peltier we owe it to them they are the first who showed us that if two dissimilar materials or conductors are joined at the two ends an electric current passes through and temperature gradient will exist or what peltier said is if you want to keep them the temperatures hold the temperatures at a certain level heat has to be extracted out from one of the ends continuously that was peltier effect. See beck effect on the other hand says that if there is a temperature difference you are going to read and you are going to give its going to give rise to an emf or a potential difference across the two ends ok.

So, seebeck is one which the seebeck effect is used for generation peltier effect is used as cooler, but we can do all those I mean you can read this up separately, but what a peltier cooler has is its it has a pair of a P type and an N type semiconductor P doped and N doped semiconductor the P 1 has more number of holes N 1 has more number of electrons.

These are the free charge carriers. So, now, if we pass an electric current through these the other thing is these are kind of arranged such that they are electrically in series. So, as you can see they are connected at this end by a conductor made of copper or some other conductor and then thermally in parallel in the sense the top surface has a certain temperature bottom surface has a certain temperature. So, if or rather if there is a temperature gradient that exists between the top and bottom there will be heat flow in one direction between through this P as well as N type and they will be treated as parallel heat paths.

So, now what it says is if you actually pass an electric current through this then there will be heat absorbed at one end and in order to keep this at the same temperature, if you reject it you can you have to put a heat sink and so on and dissipate that heat out ok. So, that is my thermoelectric cooler all right. So, now, what we will do is, this is a broken down view because there are lots of these PN junctions and then this is how it actually looks out from outside ok.

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What we will do now is, we will look at a small video which kind of explains how thermoelectric generator works at least in the first part.

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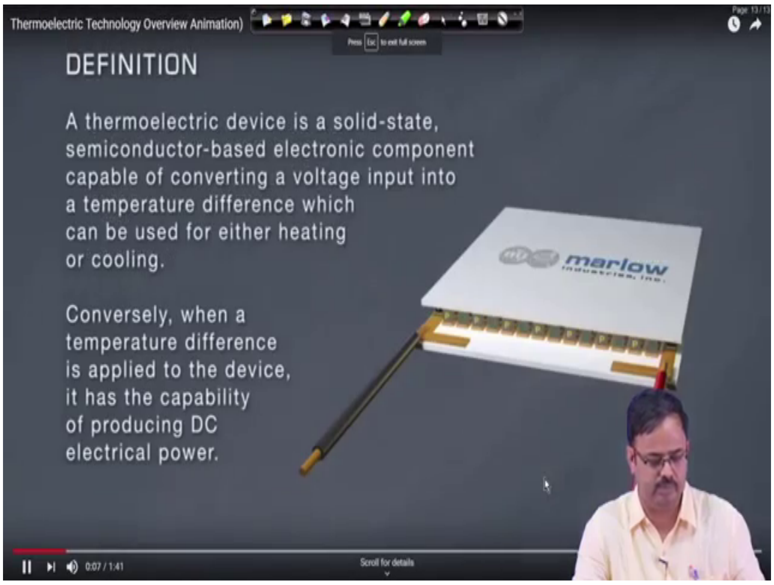

It will talk about both generator and cooler.

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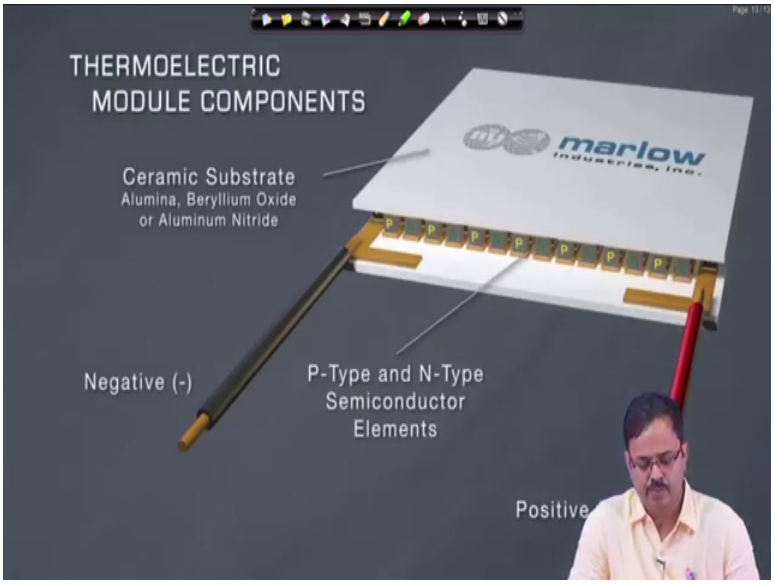

So, this is from a company called Marlow and you see this P and N type next to each other.

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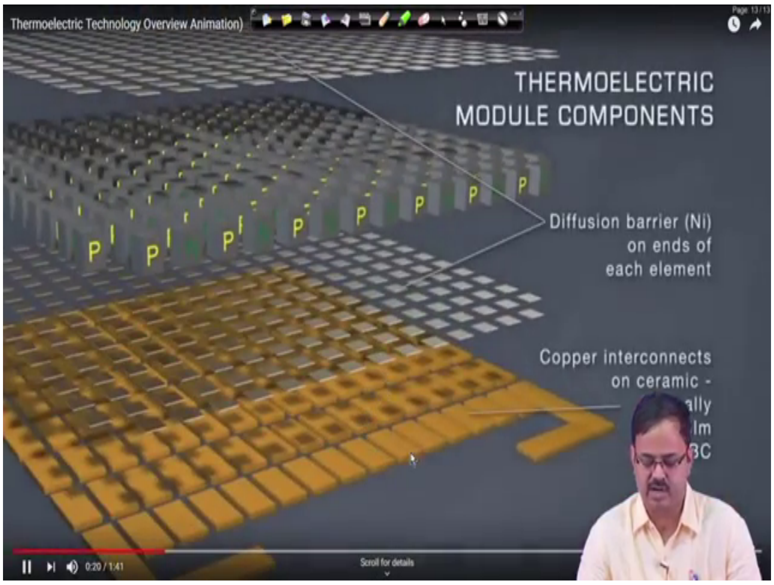

Typically they have a ceramic substrate, but you see this conducting copper interconnects at both ends ok.

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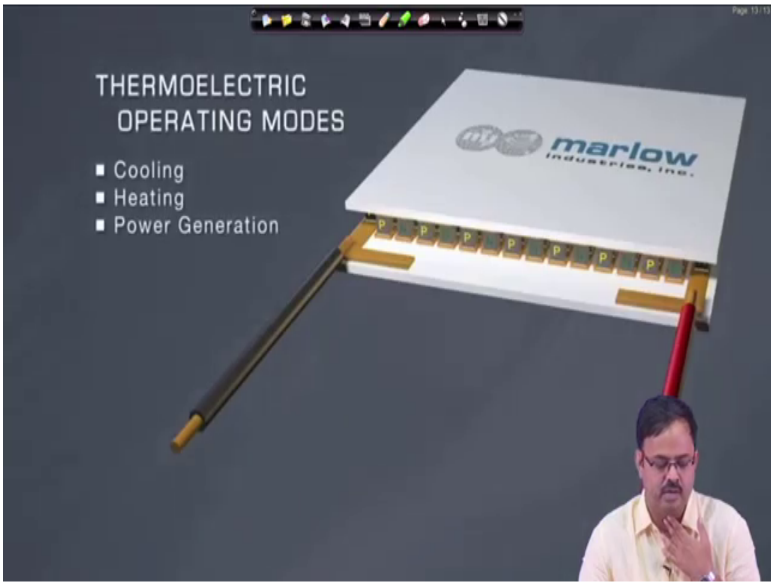

So, this can be used for cooling which is what we were talking about. It can be used for heating as well if you change their direction depending on which end is of interest to you.

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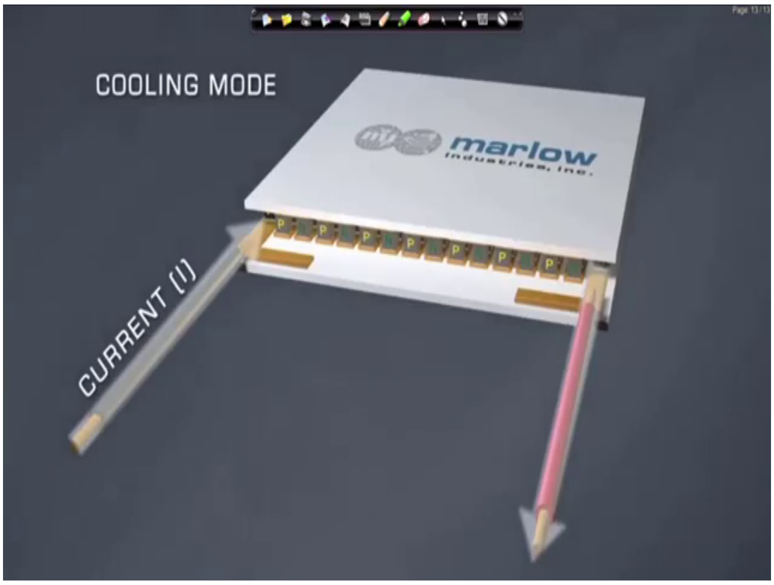

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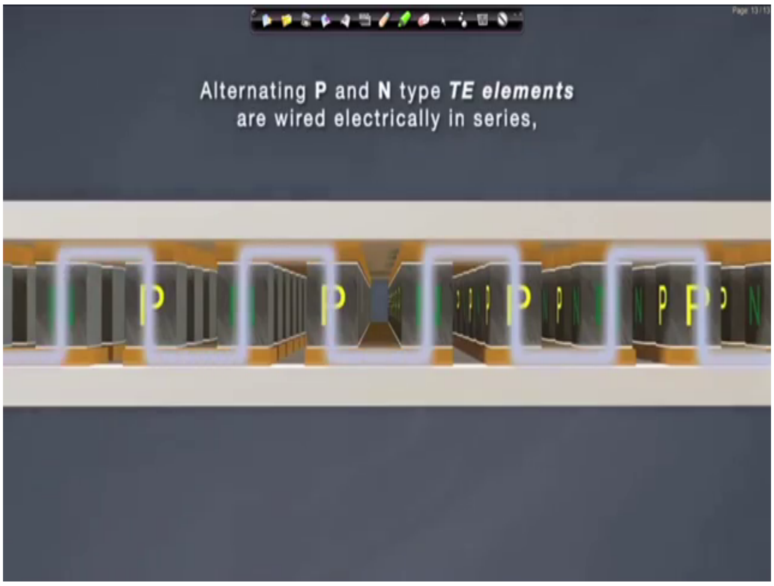

And it can be used for power generation as well. So, you see alternating P and N type next to each other wired electrically in series and then also in series like this.

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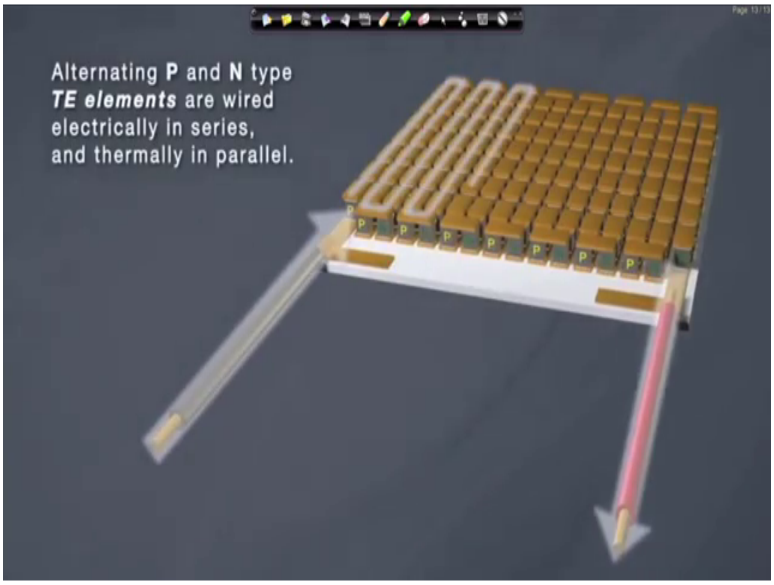

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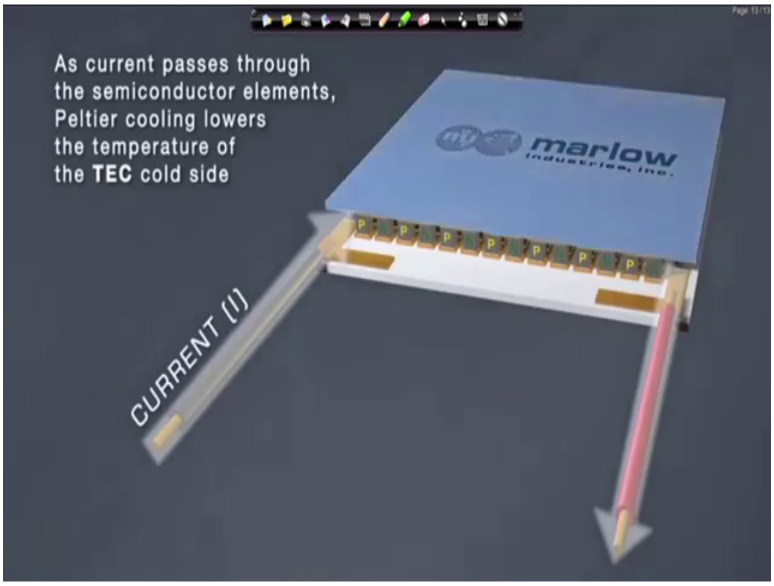

And thermally in parallel assuming that the temperature difference is between the top and bottom surfaces ok.

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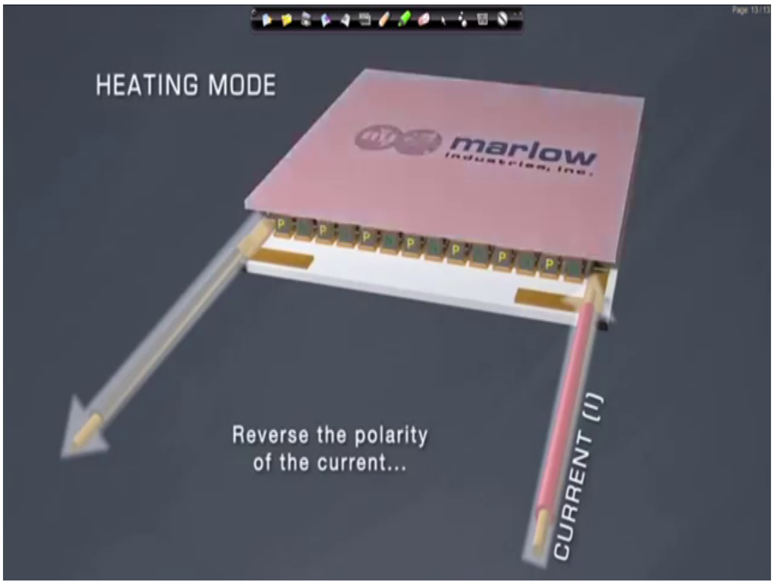

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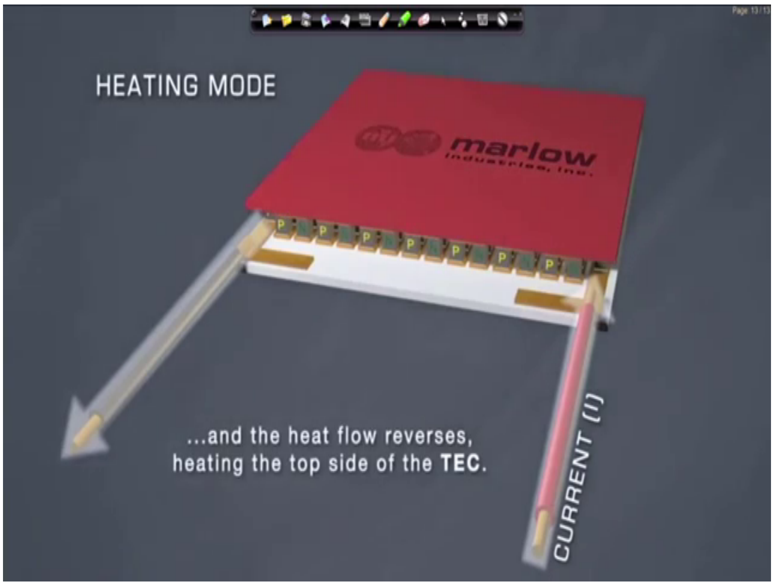

So, depending on which direction the current flows it can be used for cooling the top one or the heating the top surface.

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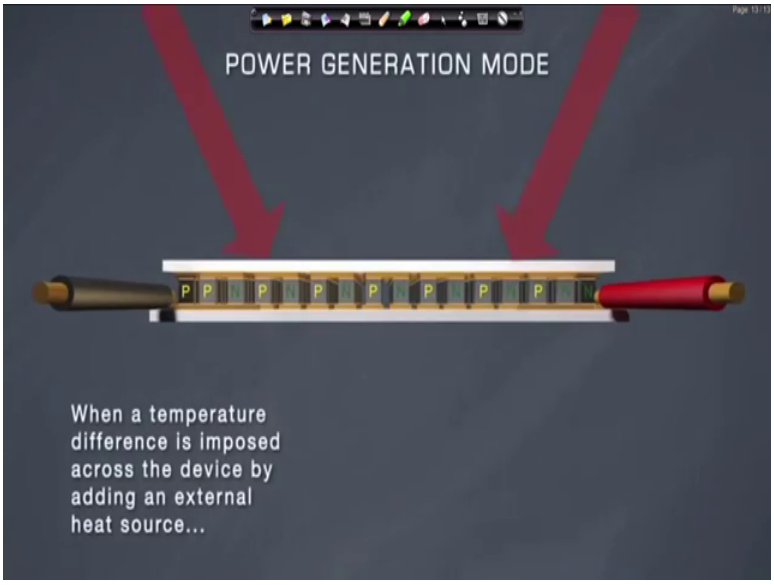

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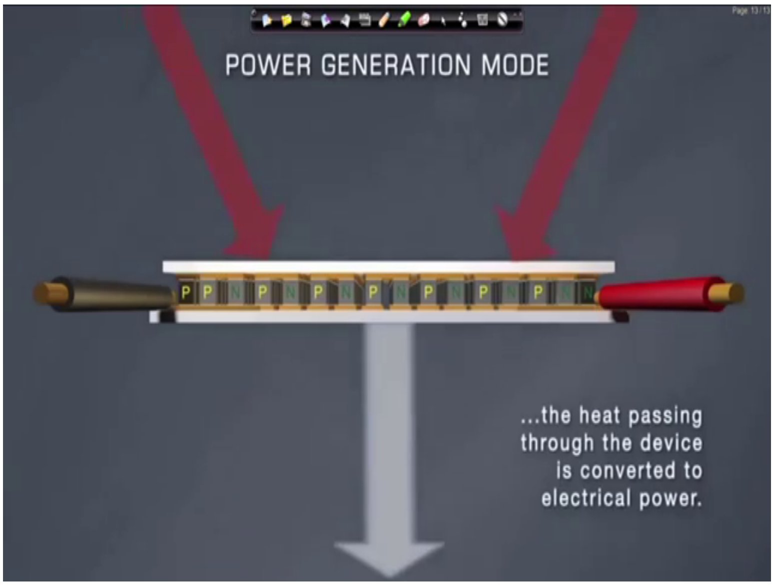

So, if there is a temperature difference that is imposed.

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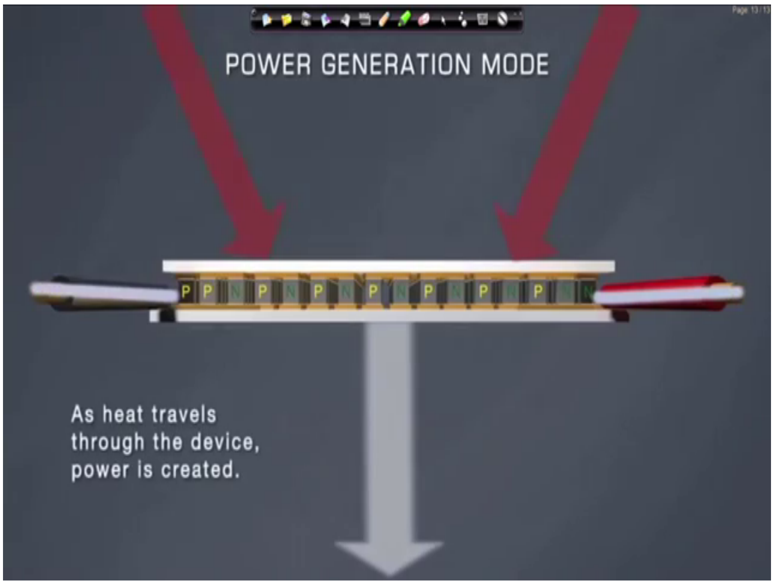

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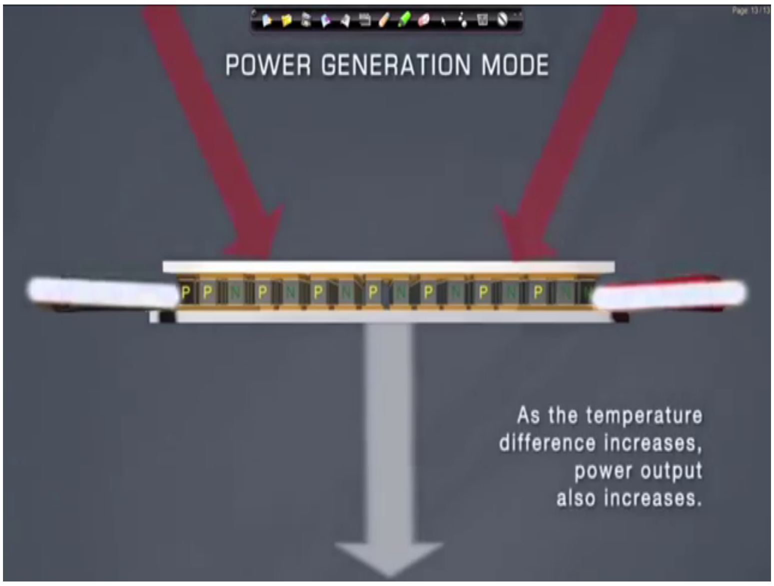

You can also generate electricity. So, its the other way.

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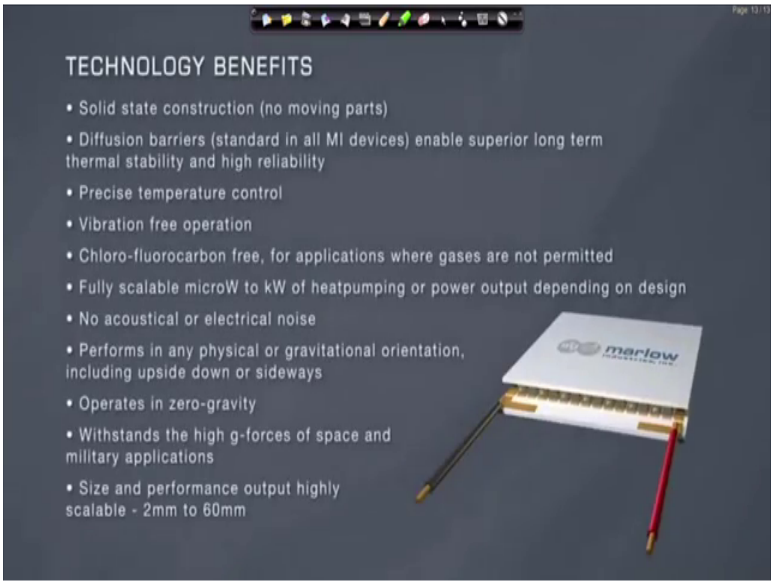

In the first one as a cooler we were actually putting in electric power and we were getting this temperature difference on the other hand in case of a generator.

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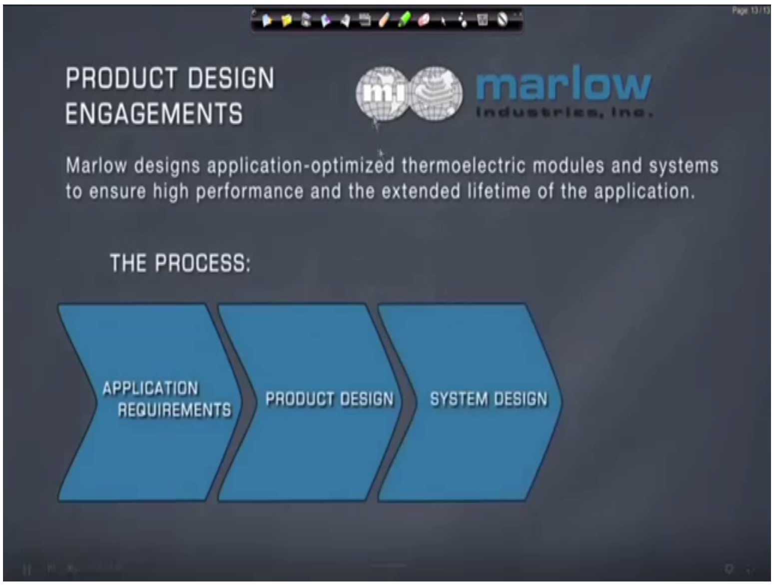

If you actually have a temperature difference you can use a thermoelectric a peltier device like this to generate electricity I think rest of it is fine.

So, generation of electricity for example, if you have waste heat somewhere let us say that you have a lot of steam or a hot surface which otherwise you are just wasting its heated temperature and on the. So, if you can now put it put one of these peltier devices and put a heated heater at the top and the other side is maybe kept on a cold surface you will be able to see that there is an electric flow of electric current through these wires ok. So, thermoelectric generation is often used where you have a lot of waste heat, for example, exhaust of a car battery can you apply put some of these thermoelectric coolers at the exhaust pipe right because in the inside surface through the pipe you have very hot gases at 6, 600 700 degree c coming out, the other side is probably well more than ambient.

But probably within 100 degrees or so, so there is a large temperature difference and that can give rise to electrical. So, that the temperature difference can be leveraged using this thermoelectric effect to generate electric power, but for our case for refrigeration we are looking at it as a cooling device ok. So, once again just to wrap up in this lecture what we discussed is we started with of course, in the people the previous lecture we talked about heat sinks and then at the beginning of this lecture we said heat sink is typically air cooled when you have liquid cooled.

We typically call it a cold plate with shock this we saw a cold plate with this serpentine passages inside, but again the point I wanted to make is a liquid cooled solution will always almost always have to work in a closed loop whereas, the heated liquid that exists the component that is cooled or exists exits from system exists from the cold plate has to be cooled back using a remote heat exchanger and then pumped back into this cold plate.

So, therefore, finally, everything is air cooled it is just that I am unable to put that air cooled solution for some reason most likely for space constraints at the location where the cooling is required or. So, therefore, I have to extract that heat and transport it to the place to the location where it is cooled ok. So, that I s cold plate next we looked at heat pipe which is a similar device used almost its almost ubiquitous lis present in all laptops and we also saw a physical sample of that here the heat pipe is also a mechanism to transfer heat from the location of the CPU to the location where I can put a fan and heat sink.

But the heat pipe from outside it looks like a copper copper tube, but inside there is a lot of complex two phase flow had that is happening there is evaporation or boiling at one end condensation at the other end. And this is a pump less system because of pumping of the condensed fluid back to the hot section which is also called the evaporator section is because of capillary action through this porous or fibrous weak material ok.

Then we talked about refrigeration systems and finally, we talked about thermoelectric refrigeration which is a solid state refrigeration it does not need compressor ok. So, no moving device it comes at a very small it is coming at a very as a very small piece maybe 2 inch by 2 inch. But the problem here is for thermoelectric it is an extremely inefficient device in a refrigeration in a proper refrigerator which is also called vapor compression refrigeration cycle which is what is used in our refrigerators and air conditioners, the amount of the ratio of the amount of energy that you have to spend to run the compressor to the amount of heat that you can extract from the place you want to refrigerate.

That ratio is also called coefficient of performance that coefficient of performance is much higher for a household refrigerator air conditioner or for a conventional vapor compression refrigeration system its very very low for a thermoelectric refrigerator. So, which means that you have to spend a lot of energy the amount of cooling that you will get that you are going to get is going to be a much lower for the same amount of energy that is spent.

So, therefore, you do not have a fridge or a room air conditioner based on thermal electrics, but for localized thing you know where you your space constraint you just want to put something or then this is for localized cooling where the amount of electrical energy to be spent is not a lot even though the amount of cooling that we are going to get is going to be going to be low we use thermal electrics because of its convenience of a reliability.

Because there is no moving parts no noise no vibrations so, that is why it is very very convenient very very nice very very elegant ok. Actually there are some small you know refrigerate small refrigerators that can be used for you know medicinal cabinets in clinics. So, these are these can all be used based on thermoelectrics alright. So, thank you very much that is all I had for this lecture and when we come back in the next lecture we will talk about some of the more you know a little bit of this novelty and some innovative solutions that have come up some not the obvious ones like water cooled, air cooled even refrigeration or thermal electrics which have which are now pretty well known.

But we are going to look at some of these more novel cooling technologies that have been maybe a few of them that have been explored and researched over the last few years ok.

Thank you very much and see you in the next lecture.