Advanced Materials and Processes
Prof. Jayanta Das
Department of Metallurgical and Materials Science Engineering
Indian Institute of Technology, Kharagpur

Lecture – 05
Introduction (Contd.)

Hello, welcome to NPTEL. I am Prof. Jayanta Das from IIT Kharagpur, Department of Metallurgical and Materials Engineering; and I will be teaching you Advanced Materials and Process. In the last four classes, we have tried to understand what are these advanced materials; what is metastability, what is their connection between the metastability, functional behavior, and advanced materials. So, today we will continue those discussions more. So, let us see what has been discussed so far.

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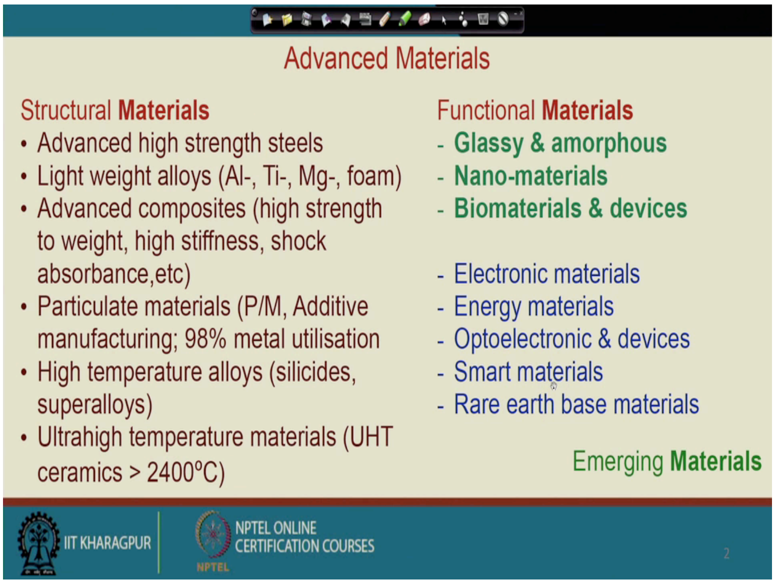

So far we have discussed about the structural materials, different type of structural materials, and also some of the functional materials had been discussed, which has also well known as emerging materials. And today we will continue the discussion along the direction of smart materials, some of the energy storage, electronic materials and so on which are very much relevant, and connected with subject matter.

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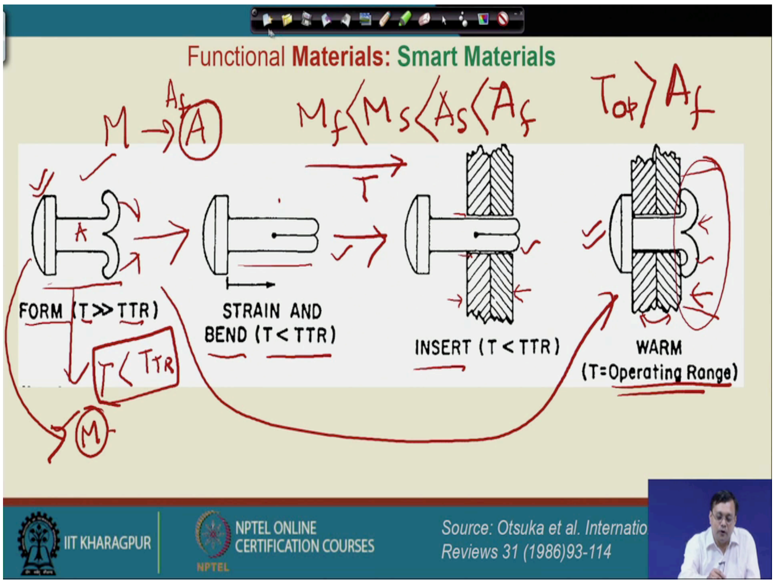

Let us have a look at one of the smart material. In the last class, we have discussed about piezoelectric effect. And today we will be discussing on a smart material, which is a alloy. So, let us assume that we need a rivet, and we have to joint two different material using a rivet. And here in this place, we have no access, so that manually we can hammer this position, and to joint.

So, the smart material as an example like nickel titanium, nitinol. We can take in such a shape of the final one. And we have formed such a shape at a temperature, which is above the transformation temperature. Here, transformation means we are talking about the austenite temperature, which transform from martensite. So, here at temperature austenite finish temperature, all the phases are austenite ok, all the grains they are in austenite phase.

And, now if I take such a shape, and let us say cool it down; cool it down means T, which is less than T_{TR} or transformation temperature. Then, the same shape will be there, the shape will be same. However, the phase will be no longer austenite, but here it will be martensite. And, now in that particular phase, we deform this shape into here, so we straightened this two side in such a way so that we can push it and fit it into this hole, which is been made to in order to joint this two different plate. So, now we are talking about temperature, which is below the transformation temperature.

So, in case of martensite-austenite, or austenite to martensite, this transformation, here, the four temperatures are very important, martensite finish, martensite start, austenite start, and austenite finish. And definitely, this temperature is higher; austenite finish is higher than austenite start, and martensite finish and so on. So, temperature increases along this way. And, now assume that here, we take such a shape after giving some strength, and it becomes straightened and we simply push it through the whole, which has been made here, so we simply insert.

And then the operating temperature is greater than austenite finish temperature means T operating is greater than austenite finish. And you see, we simply take or make without any kind of hammering, and the same shape has been achieved as it was initially. So, this is called remembering the original shape or shape memory behavior.

Now, there are many different scientific explanation behind this, and metallurgical aspect, there are understanding a lot of understanding; lot of research has going on along this direction to understand such behavior, and they are really really very useful material, which I will discuss in a minute. But, try to understand that if we have no such access in a region, where we can deform such a material. However, we can simply get the same shape, as it was initially just simply changing the temperature, and initially bend it below this transformation temperature. Let us have a look, what is the reason behind it, the metallurgical reasons or the science behind it.

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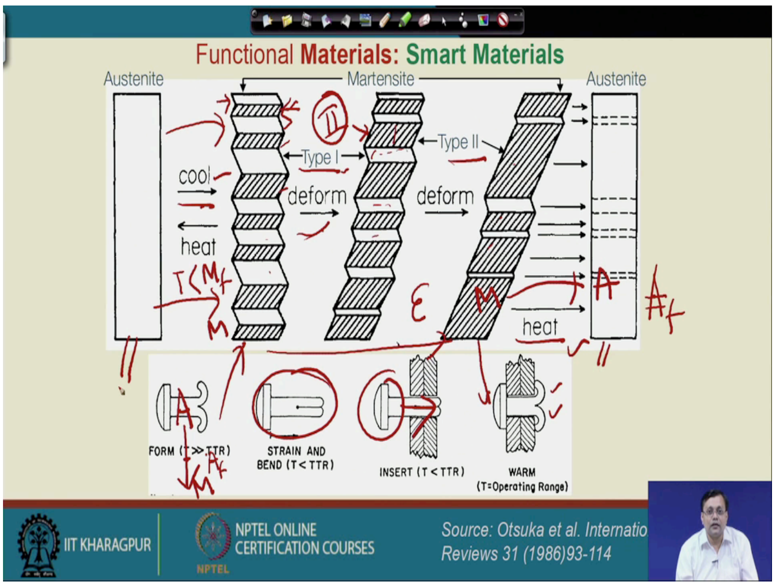

Here, I talked about austenite. Definitely, austenite is a phase, which transform into martensite upon cooling. So, if you cool it down, if we cool it down, then austenite transform into martensite ok. And this temperature definitely, in with the complete martensitic transformation from austenite will occur, when the temperature is less than martensite finish.

And, when martensite transform from austenite, due to the phase transformation and the shape strength, there are twins form. So, twinning in martensite is a very mandatory criteria in order to achieve shape memory behavior. We will discuss all this things in detail in later classes, but at this moment let us understand this matter in this way that austenite transform into martensite upon cooling, and that martensite content twins, many twins.

However, this twins are two different type, which is shown one as an empty; and another one in a hash ok, so these are the two different type of twins. So, I marked here as type I twin or let us say this is type II twin, and then, we deform it. And, so after deformation, we have given some strength. And type II twin has grown, you can see that the region of type I twin is always less than the earlier case. So, type II twin has grown, in expense of type I twin, and which help us to accommodate the given strength. So, at the final stage you see almost, it is only type II twin.

And, now if we heat it, then again all this twin will vanish, and this martensite will transform into austenite, at temperature above, austenite finish temperature. And here, the same thing, here this is, this particular geometry was in austenite, because T is greater than the temperature of austenite finish temperature. And then, we have deformed, we have cooled it down, so we get martensite, which is the same as here.

And then, we took this martensite, and deform it ok, we have given strength in order to achieve such a shape, which has been inserted to through the hole. And finally, when the material is heated, then we get back the same austenite shape, as it was initially. So, this is the mechanism, underline mechanism of shape memory effect, and definitely it is a very smart material or smart metal.

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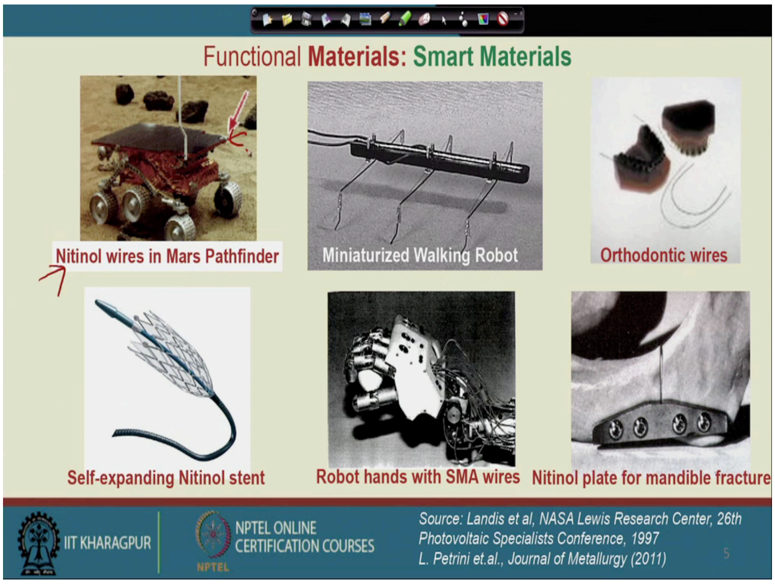

Now, there are huge number of application of such smart metal or shape memory nitinol alloy, there are many alloys has been developed. So, let us have a look, so like the Nitinol wires, which was used in Mars Pathfinder, and for using some antenna, which open and closed due to temperature variation or even you can put some of this antenna in the polar region, where there is temperature gradient or there is a huge thunder storm goes on and so on.

There are also these particular material used as a strength in heart operation ok. So, these are some self-expending material that simply goes inside the vane and simply expand at a given temperature and avoid the blockage, which is one of the major reason for any kind of heart failure.

Also we develop many different kind of Miniaturized Walking Robots, where the moment of this legs are achieved due to the shape memory effect of nitinol. Also there are robotic hands, which definitely need such kind of smart material or shape memory effect. Now, if you want to shape your teeth, then also you need to tighten and to give a proper shape. So, how to do that; you initially make that shape, you deform it then you simply raise the temperature, and then get back the shape of the teeth you want, which will be tight.

And let us say, if you have some broken some of the bones, then we simply screwed this kind of shape memory or smart metal plate; And for tightening purpose, if we heat this material into the temperature of which is operating temperature and definitely the austenite finish temperature should be below that, and it will give some stress, and it will automatically tightened your broken bones. So, these are really really smart material, and definitely, we have to study this as a advanced material, because it does our job.

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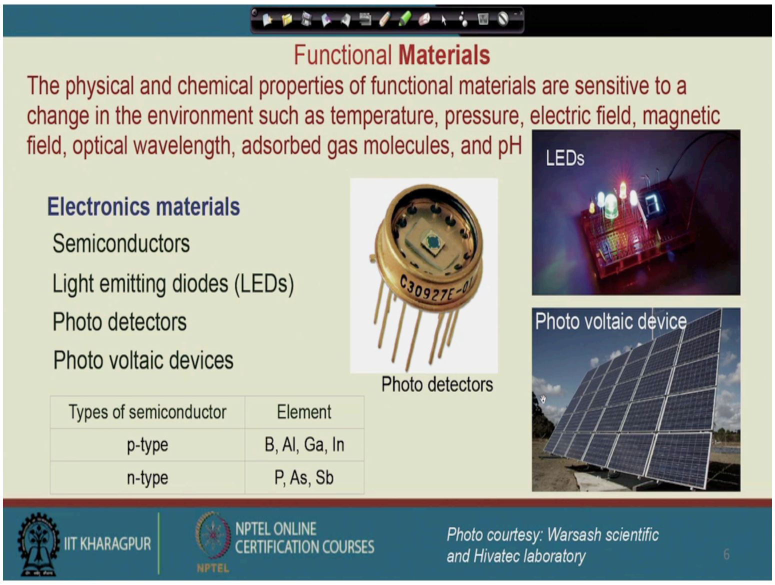

Now, let us have a look to some other kind of material; functional material that I was discussing like a like a like an electronic materials. So, what do you mean by electronic materials; like the physical or chemical properties of this functional materials are very much sensitive to the change of the environments such as temperature, or pressure, or let us say electric field, or magnetic field, or let us say some of the optical wavelength, or let us say some set of absorbed gas, or molecule, or pH. And then, we can change the properties, and we can use this functional materials.

So, one of these such a functional material is like electronic materials; we all know about semiconductor, this is one of the very much useful material like light emitting diode, LEDs, and let us say some of the photo detector, or let us say photo voltaic devices. So, I show you here, a simple image of such a photo detector, you can see how it looks like. But, the type of semiconductor that is used, we all know that there are two major type, one is the n-type; and the p-type.

And the element, which is definitely required in order to prepare those like boron, aluminum, gallium, indium, and let us say phosphorous, and arsenic and so on. And definitely, we need silicon, silicon is the base actually. And we add them in order to achieve a purposely, which kind of hole or n-type of p-type material we need. And definitely, they have a large use in kind of photo voltaic devices or let us say LEDs. So, these are also very much functional materials, and we need a lot of them for our uses.

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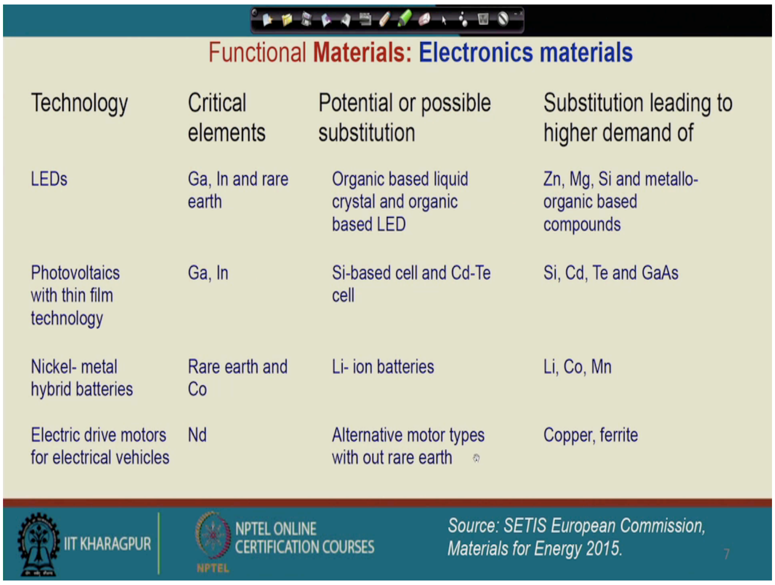

So far, the technology, different technology has been developed for these electronic materials, and like LED or photo voltaic. In case of LED, the element that are commonly used like gallium, or let us say indium, and rare earth. However, we can somehow make some better LED, or let us say let us say, organic based liquid crystals, or organic based LEDs, we can develop.

But, if we have to develop such kind of devices, then the use of zinc, manganese, and sorry magnesium, silicon, or other kind of metallorganic based compounds, that we simply increase, and we have to look at that. At the same time in case of photovoltaics thin film technology, we use this gallium indium as a critical element. However, the silicon based cell or let us say cadmium tellurium, these are often used, and may be they can partially replace some of these.

At the same time for nickel base metal hybrid batteries, which are common technologies known. And we use as a rare earth or cobalt for making those nickel base batteries, this could be replaced by lithium ion batteries, which is also an advanced material. And definitely, the use of these elements will increase like lithium, cobalt or let us say manganese. In case of electric drive motors for electric vehicles, we use permanent magnet and neodymium iron boron is well known as a permanent magnet.

And it is also an energy material, and definitely alternative motor types without rare earth may be also useful. And also, if we need to do that, then the use of copper or ferrite will also increase. So, you can see, that there are plenty of opportunities to conduct research as well as to develop advanced material. And we need to know, thus present state of the earth of all this different kind of material and so on.

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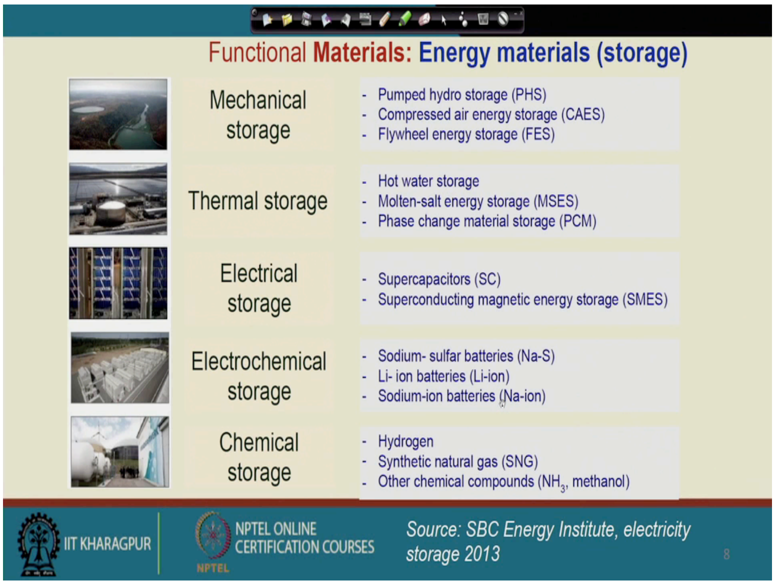

Like for energy storage, like we can store energy, or we can take energy, or you can convert energy from let us say from the sea, or let us say or like a reservoir, let us say some set of pumped hydro storage; or let us say compressed air energy storage; or let us say some set of flywheel energy storage; we can use them ok. So, all the material required for developing those kind of technology is also advance material. Also let us say for the thermal storage like hot water ok, molten-salt energy storage, these are also the energy materials; and let us say the phase change material, that can also be used for storage.

And let us say the electrical storage also we need super capacitors, or let us say super conducting magnet energy storage devices, and these are very advance technology for energy storage. For an electro chemical storage like sodium-sulfur batteries, lithium ion batteries, just I told a few minutes ago; or let us say some set of sodium-ion batteries, they are quite capable of high energy storage. Also we can use some set of chemical reaction for chemical storage like hydrogen, or let us say synthetic natural gas, or other kind of methanol or ammonia.

So, these are all different kind of energy materials, because we call them as an energy material, because we use those material for storing energy. So, so energy storing is one of the important aspect, not only energy harvesting or energy conversion. But, in next couple of slide, I will discuss some of the conversion how we convert energy into other.

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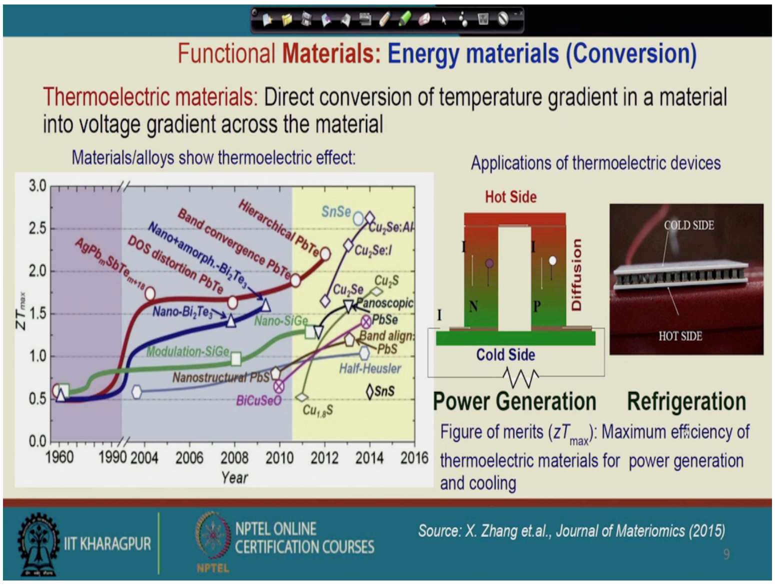

And one of such very important energy conversion material, means like a thermoelectric materials. So, let us say from electrical energy to thermal energy or thermal to electric, we loss lot of energy during energy conversion, because the efficiency is not so high. So, scientist has to develop a good or reliable material that gives you a better efficiency in terms of energy conversion.

So, thermoelectric material is one of such an opportunity or field, where we convert directly the temperature gradient from a from a electrical voltage across the material. So, from 1960s you can see, up to 2016, so many different material has been developed, I just tell you a few names like density of state distortion in lead tellurium, and that basically gives you an energy conversion from voltage to temperature. And let us say some sort of band gap convergence and so on. So, here there is some silicon germanium, lead sulphide, and copper sulphide, tin sulphide, and so on. So, these are so many materials, selenium best material, tin selenium and so on. So, they are all used as thermoelectric material.

And here, we have plotted ZT_{max}, which is basically a figure of merit, which represent the quality of a better energy conversion or the energy conversion become much more better in terms of efficiency when you talk about the maximum efficiency of thermoelectric material for power generation and cooling.

So, if we apply some electrical field, and then we can create a hot side and cold side, so we can use that cold side for refrigeration purpose. So, thermoelectric material are very very useful, even for getting some refrigeration in your car or may be very small refrigerator ok, for portable refrigerator, or let us say lot of devices and so on. So, application of such thermoelectric devices is a huge potential area of research and development. So, we really need to show that how this material or let us say some of the alloys, show such kind of thermoelectric effect. So, these are some of the recent literature that that we have tried to collect.

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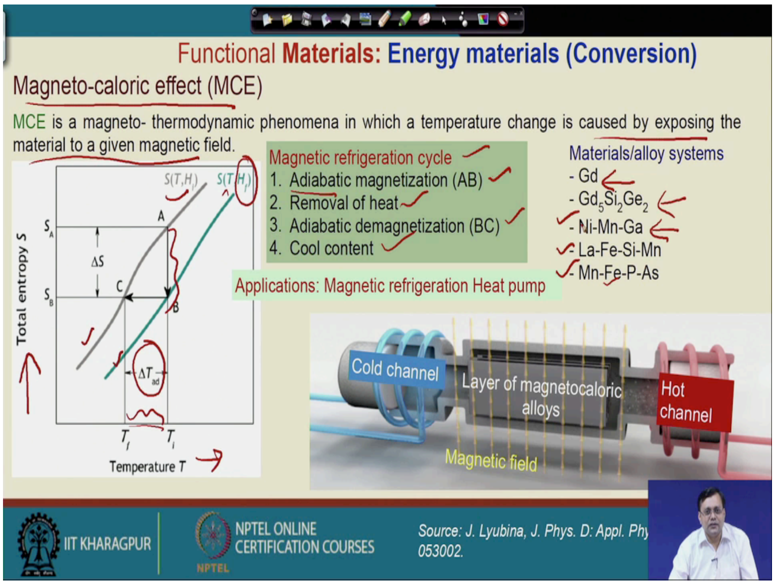

Now, another such important energy conversion came up recently as a magnetocaloric effect. What it is really; it is a phenomenon that is magneto thermodynamic phenomenon, which causes a temperature change due to exposing a material in a given magnetic field. What does it mean; it means that you can keep an alloy or a material in a magnetic field, so under that magnetic field, and temperature, the entropy is fixed. And then, if you change the magnetic field, then definitely there will be certain temperature change, which causes adiabatically ok.

And how to do that; yes, if we plot a entropy, here we are talking about magnetic entropy and temperature, and we keep material into two different magnetic field, immediately we open up a window of entropy change, which causes a temperature change. So, this is an adiabatic temperature change that occur in a material, it depends on whether it is positive or negative. So, this effect is called as magnetocaloric effect or inverse magnetocaloric effect, depending on whether the temperature change is positive or negative vice versa.

So, how we really use such a material for refrigeration purpose, we adiabatically magnetize the material, then we extract the heat, and then we demagnetize the material, and then we can get the cooling. So, this is a cycle goes on. So, the first material that was developed that was a gadolinium or let us say their compounds, and since after that there are lot of development goes on, to develop let us say lanthanum base material or a manganese, or let us say some of these iron base, or let us say some nickel manganese gallium system.

And there are so many alloy system has been developed, and definitely the performance of this material is very high than what we use for a vapor compression, because ultimately all these energy conversion is linked with the Carnot cycle. And the better the coefficient of performance, and Carnot efficiency will increase; and the higher the Carnot efficiency, the higher the energy conversion from a magnetic energy to let us say to a thermal energy and so on.

So, here this is just a schematic we have shown you that if we take a stacking of magnetocaloric alloy plate. And then, we apply some magnetic field here, then we can pass, we can develop some cold junction and hot junction, which is a very common in case of a Carnot cycle. And then we can get a cooling effect or we can get also a heating effect. So, therefore, not only magnetic refrigeration can be exploited from these magnetocaloric materials, but also we can use as a heat pump.

So, this a very great phenomena that scientist has discovered and there are many company this days came up, which developing those kind of magnetic refrigeration technique. At this moment, it may be a more expensive process, but as the technology will develop with time may be after 20 or 30 years, it will give it will give you a much better performance.

So, so far we had definitely discussed different kind of advance materials and so on. And we can we can have a look to the main slide, where we have started with on discussing different structural materials. So, like here, like the advanced high strength steels, or let us say the light weight alloys, advance composite, particulate and so on.

So, in this particular subject from the next class onwards, we will try to start with this glassy or amorphous alloys and their scientific background of this material, how material has been developed; what are the basis of glassy structure and so on. And also, we will discuss chronologically development of nano-materials, development of a smart materials, and their detail discussion on, and definitely we will discuss some of the high strength alloys or let us say advanced alloys, in terms of high strength steels, light weight alloys and so on, or let us say some of the high temperature silicide, where metallurgy has a large opportunity to contribute. And with this I believe that we will discuss all these things in detail in the next classes.

Thank you.