Structure of Materials
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Lecture - 1
Overview

Welcome to the NPTEL course on Structure of Materials. My name is Anand Subramanyam and along with me professor Sandeep Sangal will be instructing this course, which will be dealing with the various kinds of materials and there structure. We are both faculty at the Indian Institute of Technology, Kanpur much of the material, which I will be covering, in this course in the slide form will be available at my website and the website of professor Sangal. So, you can consult our website which is http home iitk dot ac dot in slash till day Anandh and give us whatever feedback, so us to improve these course material. So, all the slides and much more of in-depth material will be available, at this website for your future consultation.

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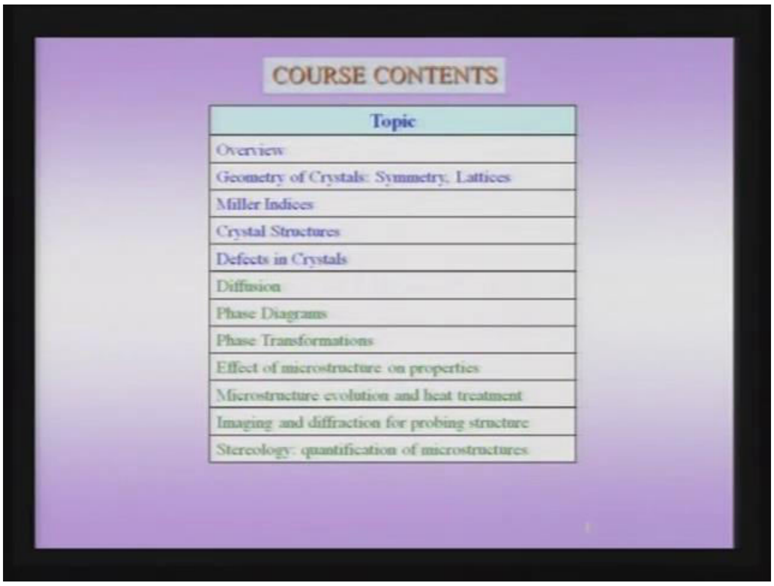

The contents of this course are briefly outlined here, so in the first lecture we can start with the overview, and followed by geometry of crystals, miller indices, crystal structures and defects in crystals. The part in green will be handled by professor Sangal, which will involve diffusion, phase diagrams, phase transformations, and the concepts of microstructures and it is effects on properties, the microstructure evolution on heat treatment, imaging and diffraction for proving structure, and finally Stereology.

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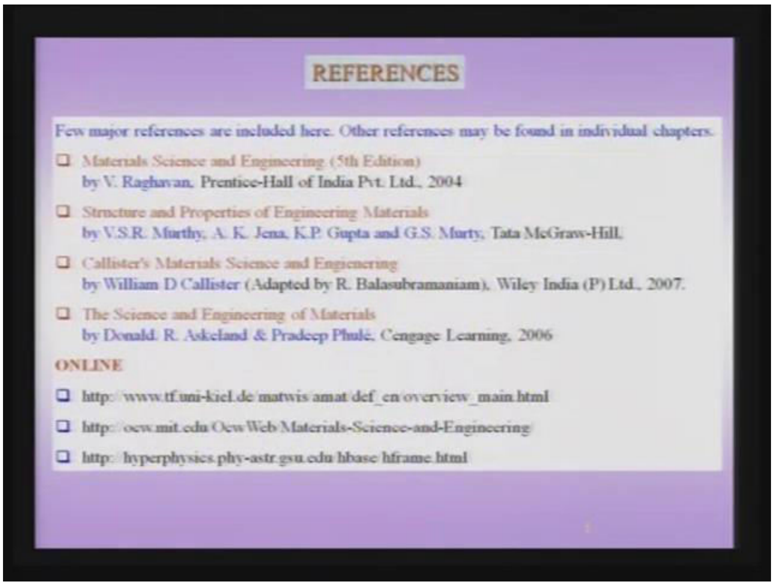

This course is expected to be complete in itself and with the added material which I told you is available in our websites, but additionally students may want to refer to certain standards texts, on various aspects of structures and materials and also material science. The good text which you can refer to for example, are the materials science and engineering by V Raghavan, the structure and properties of materials by professor Murthy Jena Gupta and professor G S Murthy.

'The Callister's materials science and engineering' book, and 'The Science and Engineering of Material's' by Askeland and Phulic. There is quite a bit of a good online content available, which can supplement this course and some of them are listed here, and you may wish to refer to these website for further information not only on structure of materials, but also on various other aspects of materials science and engineering.

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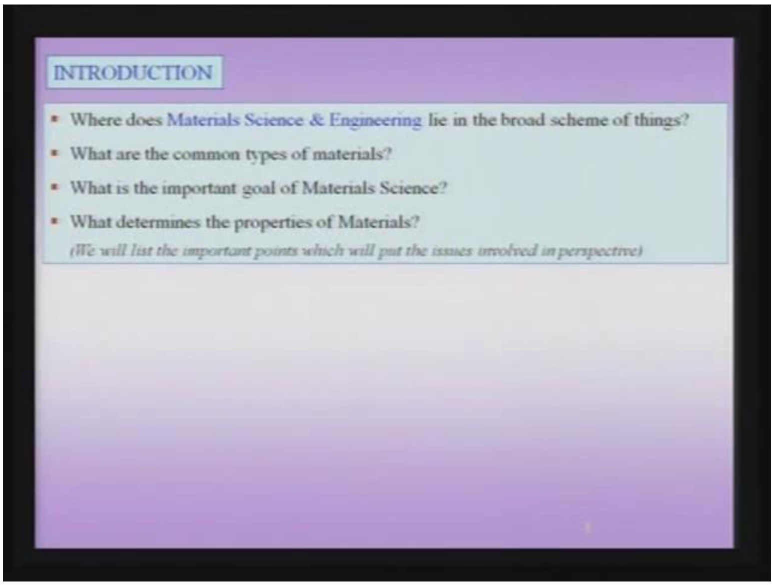

So, in this lecture which is an introduction, we will look and have a broad look at material science and engineering, and where does it fall in even broader scheme of things. We will look at what common type of materials we encountered in our normal life, and how does this structure of these materials finally, influences properties. We will look at t the important goals of materials science, and we will have a look at what exactly are those things, which will go on to determine the properties of materials, and which will put some of the issues involved in good prospective.

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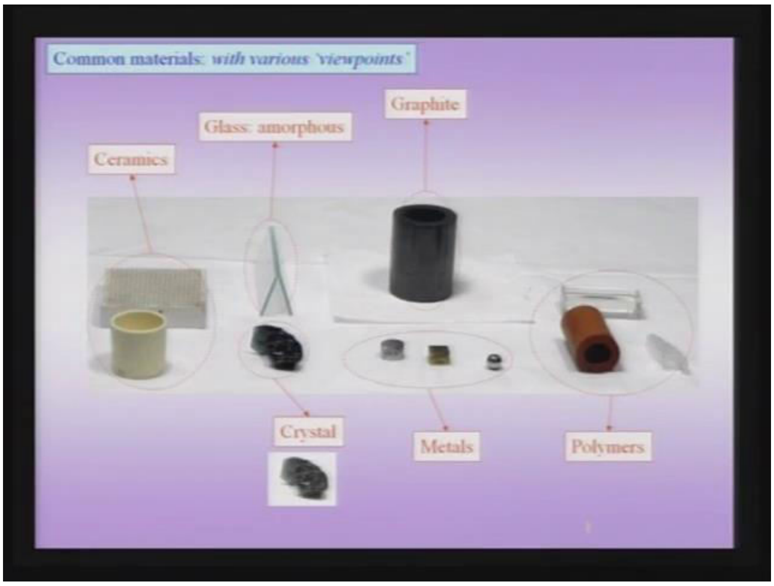

So, let us start with a common set of materials which we normally encounter in our everyday life, and here is a small collection of these kind of materials, you can see on the left hand side of this diagram that there are ceramics. The one in the front is a alumina crucible, there is a ceramic honeycomb, there is a common glass like which is amorphous, there is also a crystal in front which you can see here, there are certain other materials like metals graphite and polymers, so what I should do now is to actually take up some of these materials, in real life and actually explains more points about them.

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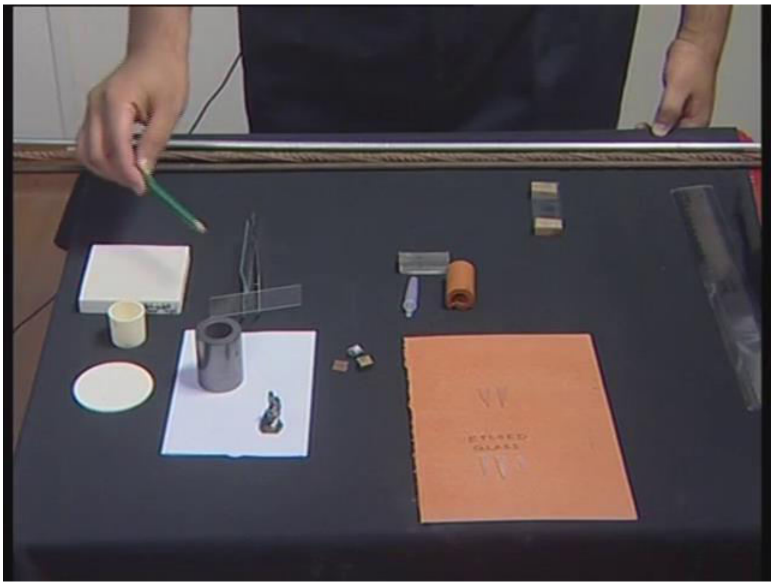

So, here I have in front of me Some ceramics, this is a ceramic disc, this is a ceramic crucible and this is a ceramic honeycomb, this is a graphite crucible, which is typically used for melting materials like metals. We have a glass slide here and another glass slide here, there is you can see which is the crystal which has form here? And if you we will later focus on this crystal to see that actually there is a nice outline hexagonal outline, which is forming here, when this crystal is growing.

So, you can clearly see in this view that there actually a nice outline forming, and later on in the course, we will see that how the structure of the material at the atomic level is responsible for such an beautiful shape when its grow. We are also accustomed to beautiful shape of growth of, for instance ice crystals or the ice snowflakes here, you have certain metals which are kept here for me this is copper this is aluminum. And these matters also have a certain underlying structure, which is responsible for some other properties which we observe on this side of the figure we have certain polymers.

And you can see that this is the common pen cap this is a polymorph, for instance which can actually be bent a little bit it is available to deformation, but as you know certain other kind of polymers may not be available to deformation. This polymer for instance is transparent, while this one is OPHEC, in addition to these matters and ceramics and glasses, which I have got here, I have got certain other specimens here.

For instance I have bought an aluminum rod out here, I have got another broad, which is typically as you might have seen is used in reinforced cement concrete, is used for construction purposes of building and additionally there is an another steel rod which is kept here. So, I shall take one of these rod first the aluminum rod and I will try to bend the rod using some force, bending force. Now, if I tried to bend is aluminum rod by using a bending moment you can see that I can easily bend this rod, of course, it take a little effort, but it is not that difficult to bend this rod. Now, let me take this iron rod which is kept here and try to bend this rod, you can see that I need apply considerable amount of force before, I can bend this rod it is still possible that I can bend this rod, but with considerably additional force.

Now, this rod am not going to attempt to bend the, because this is meant for construction purposes, and actually it will be very difficult to bend this rod under the normal bending moments, which I am applying using my hands. Therefore, you can see that even among these three metals there is a considerable difference in a simple property like the plastic deformation or the permanent deformation. Now, let us try to contrast this three metals with another material, which we have now encountered which is glass slide, and let us see how it behaves when I try to deform it. So, I have a glass slide here, which I will tried to deform by bending, so let us see what happen when I try to bend this glass slide, you can see that this glass slide, actually breaks up.

Another actually in the process of breaking up you can see that it breaks up into a lot of short which are very, very small, and I will keep some of those pieces here for a close up inspection later, but as you can see that clearly see that this glass slide does not undergo any kind of deformation or very little deformation before it fractures. So, let us look at some of the pieces of these glass slide, which are kept here and there are two kinds of glass slide the one, which I just broke now which is actually etched glass. In other words it is a glass slide which has been etched with hydrofluoric acid and if you did the same experiment with an un etched glass there are samples of unetched glass also which have been broken in bending which have been kept here you can see here in the top.

So, these are the samples of un etched glass which have been broken in bending, and these are samples of hydrofluoric acid etched glass which is broken in bending, you can see if you look at detail and see this in a closer view, let us take a closer view and you can see that the glass here has lots of cracks, you can see that, now this kind of a glass breaking of glass might remind, you of the breaking of windshield of cars, so this glass is lot of these cracks while a comparative sample, which is the un etched t glass does not have so many cracks.

When, it fractures and the reason of this is related to something, which we will correlate later, during the course and to just have a prolute towards, that this is actually the effect of surface cracks, which is been etched away, which is leading such a fracture behavior. So, let us revise some of the experiment, we have just now seen we saw that there are different kinds of material, which can be classified based on various parameters which will be soon considered in this lecture important point to note was that.

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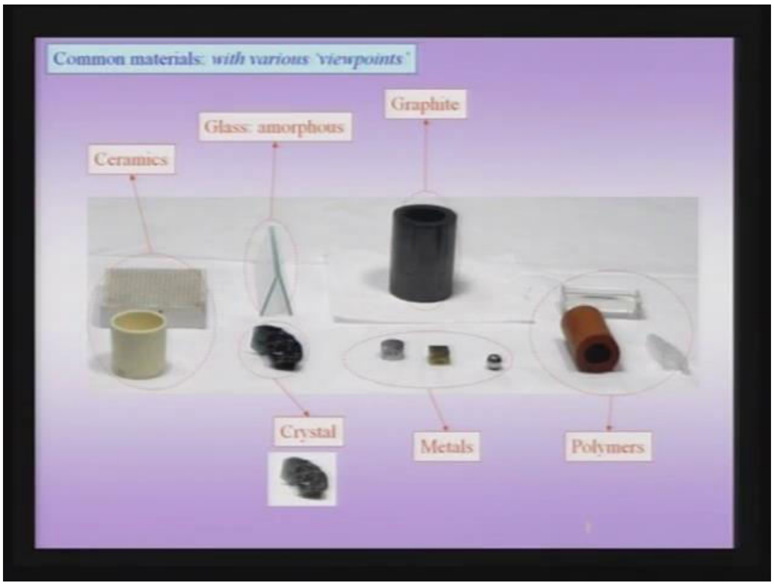

Actually, when you have a crystal for instance it can have an external shape, which is pretty well-defined, you can have metallic object which can be deform. The amount of the deformation which you can give also depends on the kind of material; that means, amount of force, you need to want bending moment. Like an example consider we could easily bend aluminum, while we found it very difficult to bend the reinforcement bar.

On the other hand we saw that the glass slide breaks easily, when we try to deform not only that, we saw that the glass slide the kind of fracture surface created and the amount of force, actually we need to apply to break a glass slide depends quite a bit on the processing conditions. In this case one was an etched glass slide where in we saw that there were numerous cracks in the material, which was fractured on and the other was un etched glass side, where the facture was mainly a few racks propagating and breaking the material.

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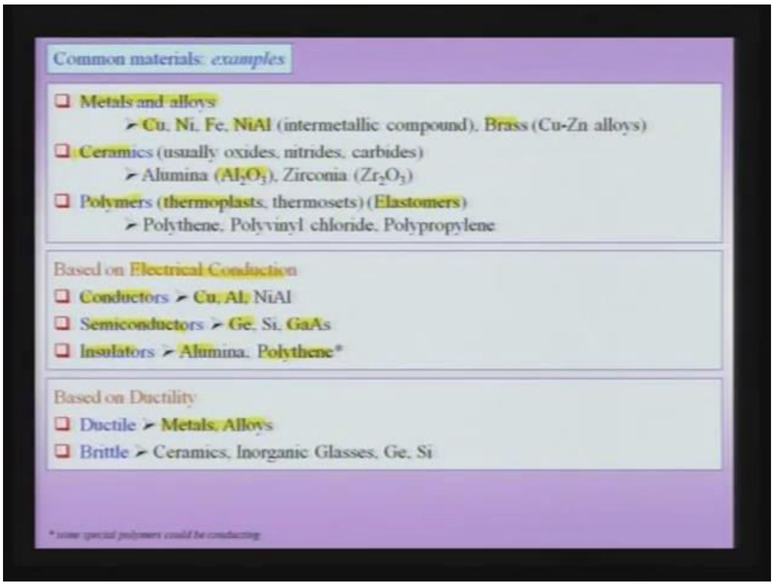

So, let us consider the common materials some of the examples, we have already seen some metals and alloys, we have seen ceramics for instance then was alumina crucible in the samples collected. We have seen there are polymers and polymers as you know can be thermo plastsor, thermo sets, they can be elastomers, which are available to long elastic deformations, and this is what we call the common terminology.

Even among metals and alloys you can have pure metal like copper, nickel, iron, there can be inter metallic conforms and they can also be alloys like brass, which is a copper, zinc alloy, not only can we have these common classifications like based on metals or ceramics or polymers.

We also classify materials based on electrical conduction and we often talk about conductors, semiconductors, and insulators, some examples of conductors would be copper, aluminum. And semiconductors would be germanium, silicon or gallium, arsenide, and insulator as we have seen can be alumina or certain polymeric material like polyethylene.

Of course, some special polymers could also be conducting, we also often talk about materials based on ductility we also say some material are ductile and some materials are brittle. And we also know from our common experience that some material which are ductile and certain conditions, become brittle under certain other condition. One nice example would be rubber band a rubber band can be stretched easily at room temperature, suppose you cool it down to crisenic temperature, it becomes very brittle and it breaks. Typically, it note that metals and alloys are ductile, and ceramics and glasses are brittle.

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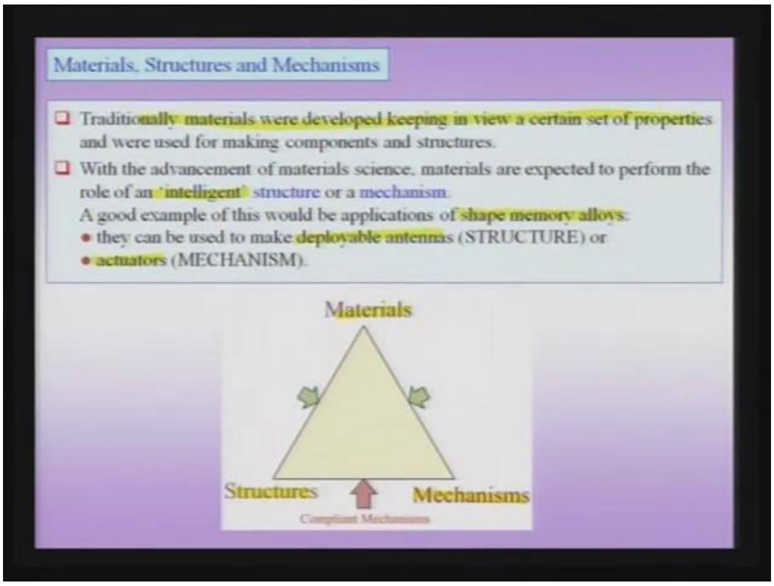

Now, the conventional classification of materials we consider them as usually a certain kind and we consider the structure and mechanism are usually made of materials. So, we have a triangle in which you have materials, you have structures, and you have mechanisms. There are often materials which can perform the function of a structure or material which can perform the function of a mechanism, and this becomes a very interesting topic of study.

In other words we are coming across an intelligent material or an intelligent structure, a good example of this would be shape memory alloys, for instance a shape memory alloy can be used to make a deployable antenna which is for instance under a certain condition is compressed due to a small volume and then heated. It actually expands and deploys the antenna, it can also perform the mechanism the material itself, like in the form of an actuator therefore, you can have material which perform the role of a structure, material which perform the role of a mechanism, and underline all this is our understanding of the structure of the material. And we have to know that traditionally materials were developed keeping into certain properties, and for making components and structures now with the advent of these intelligent materials or materials which can perform multiple roles like mechanisms and structures, the scope of materials has improved considerably.

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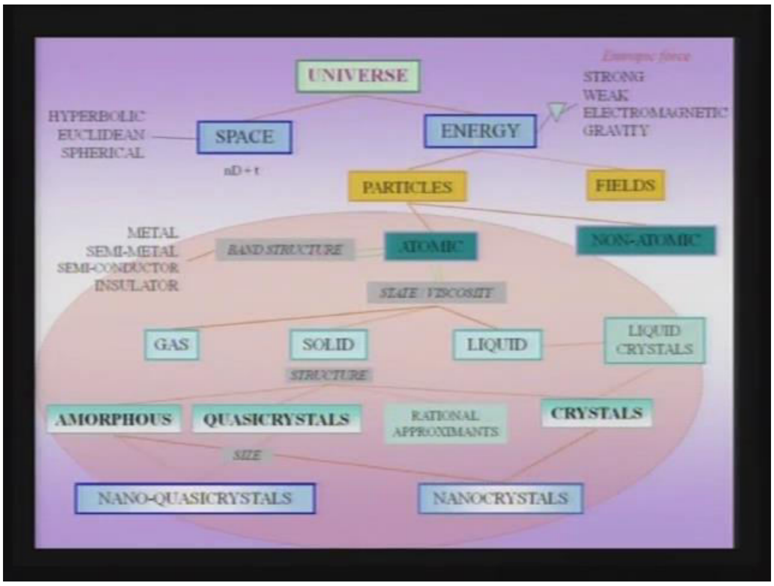

This slide the next slide is actually what you may call a very busy slide, and it in turn compasses virtually everything, it starts from the universe and talk about particles fields and forces. But, what we need to focus on this course point of view is the area enclosed by this ellipse and this is the domain of what you may call material science, so let us focus on this domain of material science wherein we talk about atomic structure of matter.

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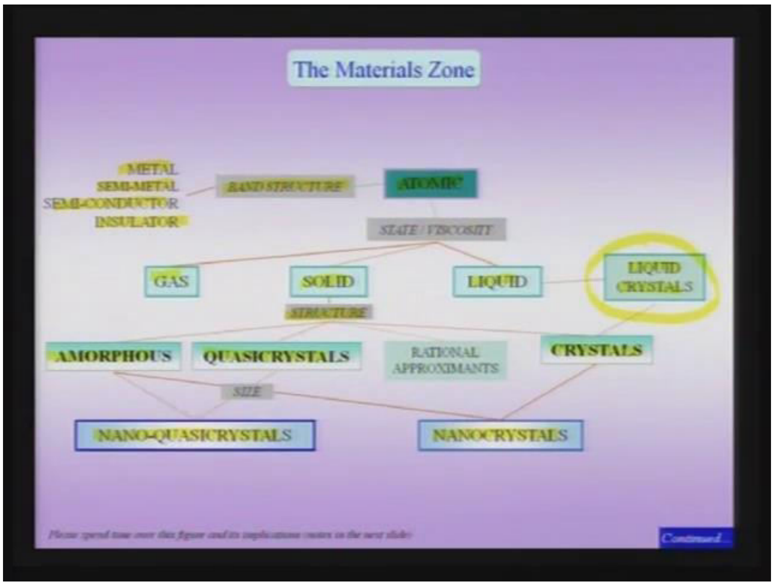

And how this atomic structure of matter can be classified in various ways and how we can understand this material zone, especially from a structure point of view. The atomic structure can be classified based on either the state of viscosity as gases liquids and solids, which we know pretty well. And solids based on the structure can further be classified as amorphous material, quasi crystalline materials or crystalline materials, on the other hand we can think of classification of atomic structure based on the band or the electronic structure.

And in this context we come across terminologies like metals, semi metals, semi conductors and insulators, so in this course we shall primarily focus, on the classification of atomic solid based on the structure, which is the atomic structure. In other courses in the NPTEL you will also be learning about how we understand the electronic properties, and how we classify materials as metal, semi metals, and insulators.

Further you can see in this classification scheme, that we can have materials based whose classification is based on size and based on this classification, you can have material which can be classified as nano crystals, and nano quasi crystals, and nano crystals. And in some sense nano crystals can be thought of as in between something which is amorphous and crystalline.

Additionally students must have come across terminologies likely liquid crystals, which were in between a liquid and a crystal, so this is been intensively studied and as you may be knowing some of the display material are actually liquid crystals, but this course shall not go in regarding the structure of liquid crystals. So, when we are talking about the material zone, I need to worry about the atomic structure and I also need to worry about the band structure. But, primarily when I am talking about the atomic structure I can think about them as amorphous quasi crystalline and crystalline materials.

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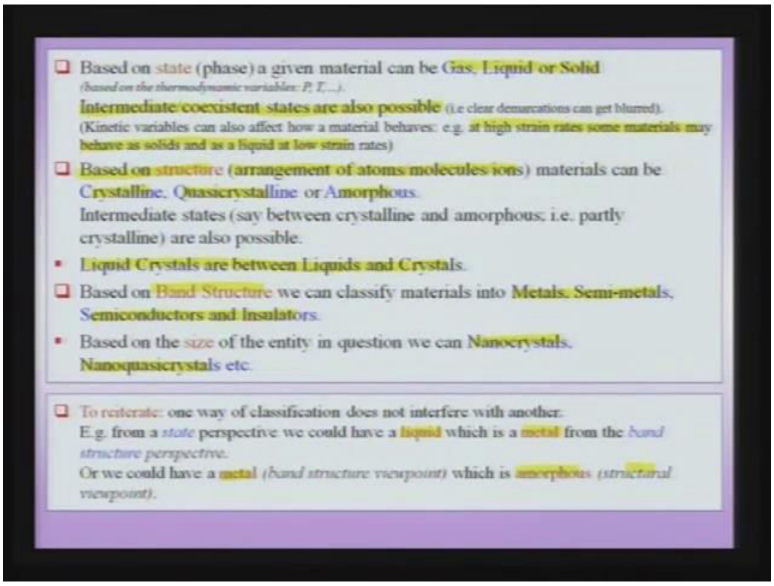

Now, let me summarize what we saw in the next slide in words, based on phase a given liquid can be a gas liquid or solid intermediate states are also possible. And sometimes the clear demarcation between a solid and a liquid or a liquid and a gas can be blurred, for instance how a material behaves can be dependent on a strain rate, at very high strain rate some material may behave like solids and liquids at very low strain rate.

So, at very low strain rate they may flow and at a very high strain rat they may be solids, and as I pointed out based on structure materials can be thought of as crystalline quasi crystalline and amorphous. And this structure we are talking about is the arrangement of atoms molecules or ions which are the constituent particles which go on to make the structure of the material.

And we also seen the intermediate state between crystalline or amorphous are also possible which we can call partially crystalline states, liquid crystals are between liquids and crystals, and as you are well aware these have very important applications as display materials. The other important classification which we considered in the previous view graph was based on the band structure, wherein we had classified materials into metals semi metals semi conductors and insulator.

And finally, based on size we could conceive the classification of materials into nano crystals, nanoqeasic crystals etcetera, and the important thing we have to learn from looking at that classification is the one way of classifying is not to clash with the alternate way of classification. That is from the state perspective we could have a liquid and from the band structure perspective we could have a metal, for instance we know the gallium at room temperature is a molten metal.

So, it is a liquid, but it is also a metal similarly we could have a metal from the band structure view point, which is amorphous from the structural view point. So, we have many examples from these kind of materials like amorphous materials and amorphous metals which can be rapidly solidified or some very special composition, which can be slowly cooled get an atomic structure, which is random. In other words it is an amorphous, but from a band structure view point it is actually a metal therefore, we have to clearly understand, that when you are making such a classification.

That one kind of classification which is based on for instance the band structure, it is not clashed with an alternate way of classification which is based on for instance the state or the viscosity, which is does not clash from a structural view point based on atomic order. Now, let us start with a common perspective like the common perspective of engineering materials, that what kind of materials have we got from which actually, we can go on to make certain components.

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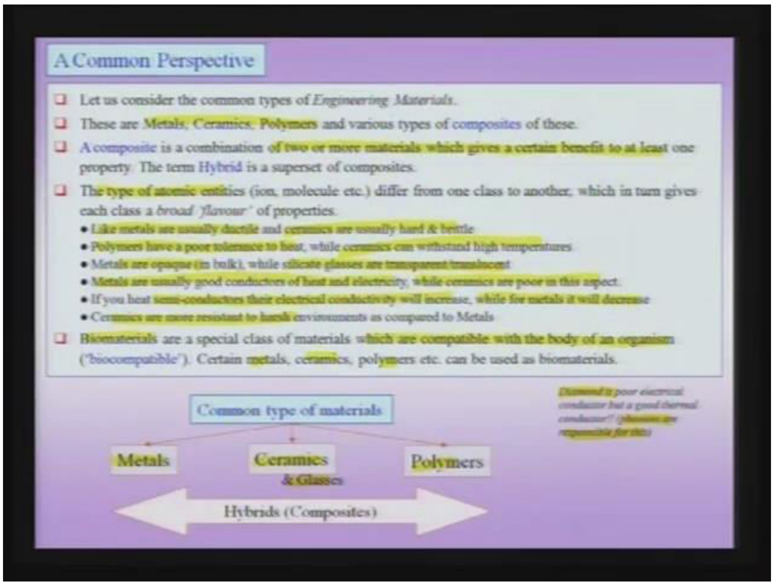

As you have seen we have metals, ceramics, polymers, and more importantly we can make composites out of these, in fact, the composite is a combination of one or more material, two or more materials, which gives a certain benefits. In at least one property and often you will find that a composite can give you a benefit in many properties, and in this context the term hybrid is more useful, which is a superset of composites which we can see in an upcoming slide.

The type of atomic entities like for the since we are about ions molecules etcetera, differ from one class to another which in turn gives each class a broad flavor of property. Now, suppose for instance we consider metals in metals typically you have ion cores which resides in the sea of electron, when you are talking about ceramics typically they are ions sitting in a certain crystalline array. So, what are the broad flavor of properties we are talking about, like we know that metals for instance are typically ductile and ceramics are usually hard and bristle. So, when you are talking about this engineering materials, and engineering way of looking at things and which is the common perspective, which every student has like metals ceramics polymers.

We have to remember that this broad classes also come with a certain baggage of property polymers typically have a poor tolerance to heat some of them even be flammable at high temperature. In fact, fire when you expose to flame while ceramics are highly tolerant to heat in fact, the 4 lines linings are melting hours typically made of ceramics metals. Typically, when they are in bulk or opaque while on their hand celicate glasses at transparent like we have seen in the example our glass light which we broke slide was transparent.

While, the metals their rods were opaque, typically also it is that metals are usually good conductors that to heat and electricity and that is why you make copper wires while ceramics are poor conductors of both heat and an electricity. And that is why we actually use ceramics for insulation, if you talking about not only the conductivity, but change in conductivity temperature due to notice that semiconductors, their electrical conductivity will increase.

In other words if you heat a metal its electrical conductivity will decrease when you heat a semiconductor you notice that its electrical conductivity would increase. So, they are opposite in the sense of electric conductivity ceramics are more resistant to harsh environments as compared to metals, metals as you know for since even iron and steel are very prone corrosion. While, ceramics which are in the typically could be oxides or sulphides are more tolerant to very many different kinds of environment including oxidization.

So, then I have a common perspective of metals polymers and ceramics I can also understand the underlined properties, which can usually be associated with these classification of materials and the one of the goals of this course is how the underlined structure can lead to the these kind of a properties which we are talking about here. Finally, you can also talk about the special class of materials either which are called as biomaterials, which are compatible with the human body or a body of an living being and you very many different kind of materials can perform biomaterials.

Like metals ceramics and polymers have been tested to be biomaterials, like for an instance that hard walls which are made out of polymers you are said implants which made out of platinum and so forth. So, but important criteria for these class of materials is that they are compatible with the human body, that the human body does not reject them they are for instance they machine with the remaining body of the human body system, and they are no way toxic to the human system.

Some time when we talking about such topics if it is like we discuss about the conductivity of the electrical conductivity of a metallic material, if you also assume that the thermal conductivity is also very good.

But, there are some examples were in some instance diamond where in you find that diamond has, actually a very good thermal conductivity, but a very poor electrical conductivity. And this comes from the fact that it is not electron that which are responsible for the thermal conductivity, in the material it is actually phonons which are responsible for this. So, to summarize the common way of living material some have metals we have ceramics and glasses, and we have polymers and we have hybrids which are combination of this three set of materials with per apps additional components.

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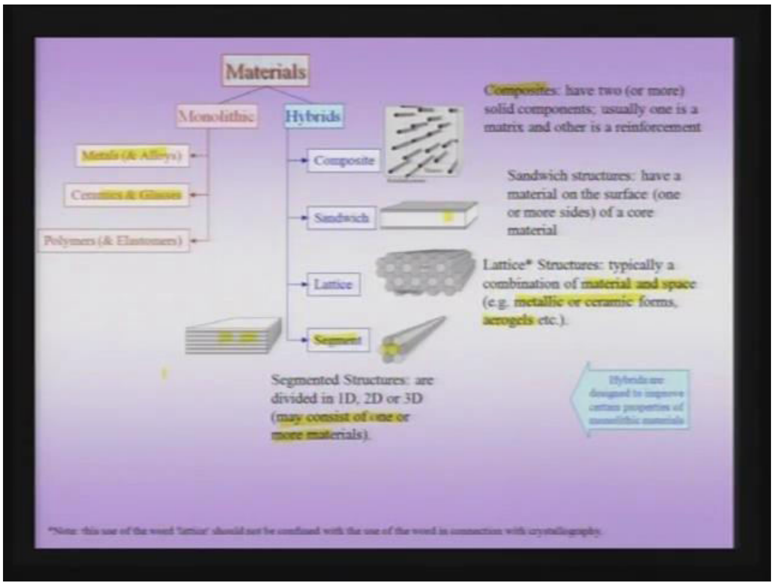

As we will se in the next slide, so we can have monolithic materials and hybrid materials, monolithic materials are single materials and there for there not more than one material present in the same block. So, metals analyze ceramic glasses and polymers all can constitute hemolytic materials, in examples of hybrid could be composites sandwich structures, lattice structures and segmental structures.

Composites typically have two or more solid components, one of them is the matrix typically and one of them is re enforcement, and as I pointed out you want to from hybrid composite to improve certain properties in the material which are not available in any one of the two monolithic material. That is the combination has those properties, while an individual component does not have, a sandwich structure as I shown in this figure has typically one material on the surface, and one material on interior.

Lattice structures are a combination of material and space and typically you have lattice structures like metallic or ceramic phones or even aero gels, where in you want to produce a light weight material. There for the way to produce light weight material is to have a very little material possible, and have more of air as part of the system, which can give you a considerable weight reduction. In this context of course, which has to be noted that the lattice we are talking about is not that the slow graphic slot later on during the course.

We will extensively deal with concept of lattice constant in depth context of crystal structure, but this lattice is considerably different in the definition and the lattice we will b considering in the concept of crystal. Finally, segmented structure is as shown in the figure can be as shown here two dimensional that can be one directional and may consist of more materials. There for to summarize this slide typically we can have monolithic material or hybrids and there is a more than one material available in a hybrid.

In the combination of this structure and the mixture of these materials give right to certain properties, which are pretty unique and which are very beneficial I context. Of course, when you talking about monolithic material, we will have to talk about the property of the material, but in the case of hybrid not only hybrid when we talk about materials terms it also interface good green materials not information in the hybrid.

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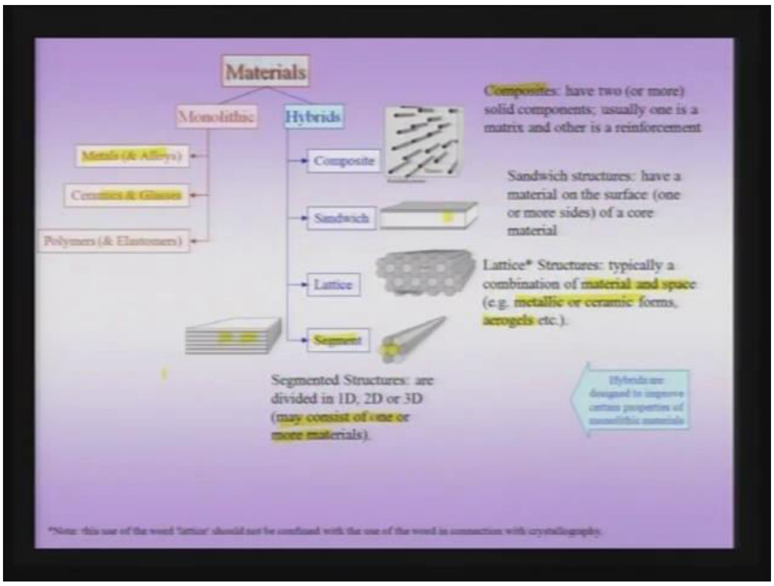

Let us considered next an important concept which is called materials tetrahedron, the material tetrahedron is formed by 4 parameters the performance, the structure the properties and the processing this course as you were aware deals with the structure in detail. As a material scientist we have to understand this material tetrahedron and will, will have to engineer this material tetrahedron, so that we have a desire performance in a component when a certain performance is expected from the component.

And then we play certain material properties as the parameters gauzing that performance, like for instance suppose I want a material to have a certain life. Then I will say that how much of a heat tolerance material used o have how much of corrosion that materials needs to have for a certain performance as a component which could be for and since a reel on which a train runs. Then further I need to form this components somewhere, and I could use very many processing routes like I could use casting warming welding powder metallurgy etcetera.

And this processing rules I can actually manufacture the component, but the important thing is that when I am actually manufacturing the component by a certain processing roads, this also dictate the kind of structure that I am going to update. And as usual see using set of this slides and during this course then this structure word is a very loaded word it has lot of very deep meaning and one has to actually travels across lens scales to understand.

How we can understand the structure of the material? And in this context we are not only talking about atomic structure we also talking about a more involved word which is called micro structure, which we will come soon across soon will deal with in this structure. As you might have noticed during the course of this structure that we are having a broad overview of very many concepts, which are actually going to dealt with much later in the course.

So, this is just the broad overview student should remember that these terms which are start with in this lecture, will be actually expanded in detail drawn. And there for it s just giving you a broad flavor of what are the factors involved in understanding material science engineering, especially from structures point of view. The structure in turn determines the properties and will dictate the performance of the component, there for all these concepts like performance structure properties and processing are intertwined in the tetrahedron, and it goal of the material engineer to actually engineer this tetrahedron to understand the relationship between structure and property between properties and performance. And finally, how to how to design processes which can actually give you all the requirement performance of the component.

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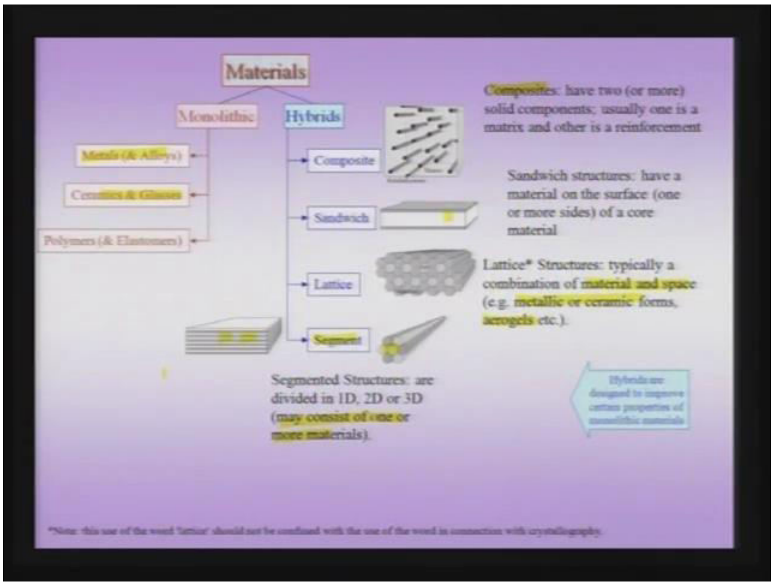

Now, when you talking about properties and materials, electronic interaction at the fundamental level you know its responsible for most of the properties, except for of few where in actually you are dealing of nuclear interaction. But, usually it is an electronic interaction which is responsible for most of the material properties, which we are going to be dealing with, but from the understanding perspective, we can break down this what you might call this these electronic interactions which finally, lead to a terminology like bonding and structure.

So, we talk we can break down this more, what you might have call the abstract concept of electronic interaction into a more acceptable concept which is bonding and the atomic structure. And this will help us understand that how somehow the material properties were talking about involving from bonding and structure, so this course will del in detail with the structure of materials.

So, from the bonding perspective we can think of two kinds of bonds the strong ones and the weak ones, the strong one can be covalent bonding, equivalent bonding, ionic bonding, and metallic bonding and some other examples of weak bonding are the hydrogen bond.

And the Van Der Waals bond as you might be aware that hydrogen bond is responsible for some other very interesting properties, which are water displays, and assume at be aware that for instance diamond is very, very hard. This is coming from the covalent bond which is very directional, and very strong which is giving diamond in extreme hardness. For instance sodium chloride our compound salt is an ironically bonded solid, common metallic materials are metallically bonded, now the others wing of this electronic interaction, which is what the course all about is the structure.

And we shall go in details this course of understanding structure at various lens scales starting from the atomic structure, but when you looking for the bonding perspective it is not necessary that a bond has to be a pure form. That means, a material may be have I mean pure metallic bond or it could have, have a vector between metallic and covalent bond or a mixed character between ionic or covalent bond.

So, in general the bonding characteristic could lie somewhere in the triangle which is shown here, so just revise this slide a common way of understanding the properties of materials is to look at the bonding and also to look at the structures. And when I have an understanding of the bonding and structure, then I have under understanding of the properties of materials and how the property of the material can be change various parameters, which include foresys temperature etcetera.

We had previously configured that how certain broad flavor of property these can be associated with the common kind of materials, like that we said for the ceramic typically bridle. But, now we can associate this broad flavor of materials with the kind of bonding of the material, which are basically coming from the electronic interactions as hard quite out of the material.

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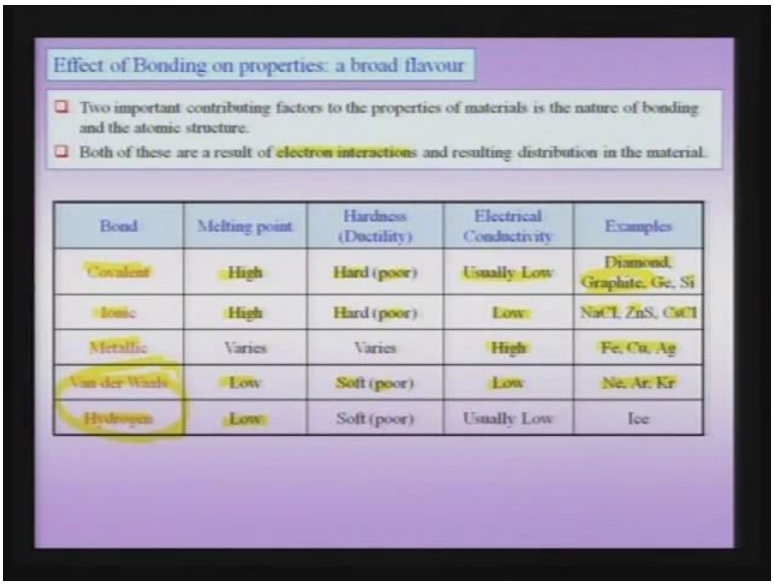

This electronic interaction finally, boils down also to a certain electrons distribution or electron density in the material and if I am looking at for instance a covalent bond, I could realize that typically covalently bonded material have high melting point. And if I am comparing it with a material which is hydrogen bonded like ice for instance then low melting point, a covalently bonded material is typically expected to be hard and it will have a poor ductility. This electrical res conductivity is typically low and some examples is you have already seen diamond graphite germanium and silicon.

Germanium as your diamond as you know it is poor conductor, but graphite is a good electrical conductor, that is why term usually have been used here, ionic materials have a high melting point and typically, they are also hard and with the poor ductility, and their electrical conductivity is typically small. Examples of that are the compound salt, see the ((Refer Time: 33:09)) zinc sulphide metallic materials have a variable melting point like gallium melts at very low temperature lead comparatively melts at low temperature.

But, you could have, have refractory metals like tungsten very high temperature, the hardness again it is a variable. And we had seen in an in experiment which we conducted today in the today's lecture that typically even conductivity varies of course, what sort in today's lecture was a the eel strength that actually it requires a that variable amount of strength or the stress which we need to apply to deform a metal.

And inductile matrix in metal which could be very strong function of the temperature, certain materials certain metals for instance which are very ductile at room temperature, at very low temperature can become pertain brutal. The electrical conductivity typically of metals is very high examples, we are already seen can be pure metals they can be metallic compounds or they can be this ordered alloys Van Der Waals bonded materials.

Typically have low melting point, they are typically soft, they have very poor ductility typically their electrical conductivity is low and you can have actually crystallized forming from neon, argon, krypton which is which are vendor walls bonded. Again hydrogen bonded materials behave very similar to the vendor wall bonded materials because these two as you have seen now weak interaction, they do not have strong interaction.

And later on in the course will see certain materials, where in the molecules formed by covalent bonding, but the molecules are arranged in a crystalline array due to these weak interactions. In another words the force is responsible for the crystallization could be these weak interactions, and there for some of these crystal in solid melt at a low temperature is been one of those example full rain is an another example will consider later in the course.

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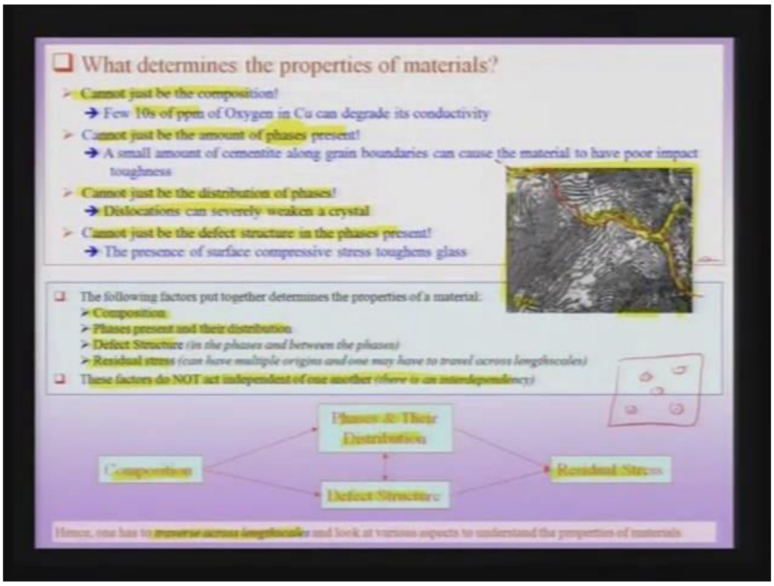

So, we have talked little bit about the properties of the material and the sort of broad flavor of what determines their properties, but let us go into the little more in detail. And this slide actually contains a little bit of detail, what you may call as information which we will actually deal with later in this course or parallel course where in there are certain aspects are considered in far more detail. So, let us ask few questions to ourselves that what determines the property of the materials, it is just cannot be the composition, because if you take for instance copper and you add a few tens of ppm of oxygen in it. It is conductivity degrades consistently, in fact the copper wire which is used as a wire in an electrical appliances for carrying current, is actually what is call OHFC or oxygen OHFC oxygen high free conductivity copper and it has very small amount of oxygen.

So, it is not I just cannot say that something is present in a very small amount, it is influence on the property is going to be small, later on we will be exposed to a term called phases, in more considerable detail, but it is just cannot be the amount of phases present. Because, for instance if you add a structure and this is the structure which is shown here and this is typically called what you call as microstructure or microgram, and in the microgram you will see that it is a small amount it is called as the cymentile which is present in the green boundary.

And this actually pairs the impact properties of this material consistently, so this is what we call as hypertext utility which we consider in detail later, but it is clear that even the phases which formed out of these compositions cannot be account for the properties. It is I need to worry about something more which are distribution of phases, it is just cannot be the distribution of phase alone for instance when I go a level below dislocations can severally can be a crystal.

In fact, if you make a theoretical calculations, which we shall do later during the course you will find that crystals are expected to be very strong in share. But, when you have dislocations they can severely we can see a crystal and that is why, we could see that we could actually bend that aluminum rod, so easily of course, of the motion of dislocation at the atomic level.

It just cannot be the different structure alone, like for instance we have noticed that when you can you there is a concept of toughest glass, and when you introduce residual compressive stresses on the surface of glass. And typically you do this by actually blowing cold air on the surface of the glass while solidifying, then you can actually produce a glass which is very tough. There for what is that which is going to determine the properties of my material it is definitely going to be composition is going to play a role; that means, I need to know.

What are the elements in what fraction atomic fraction can weight fraction they are present in the material, I need to know the phases and their distribution. For example, in the example of the microstructure shown, here if the cementite phase were not present along with the ground boundary, but if they were present in the micro structure which I shall draw here. Suppose, this cementite was present in microstructure in which they were in the form of a small globules, and not as a continuous path on the green boundary.

Then such a material so this is my cementite here such a material would actually show much higher toughness than the material shown in the microgram. This is because in this material cracks can actually propagates all along the green boundary, when loaded in high strain or impact and this can cost failure of the material. Therefore, I need to know what phases are present in what fraction of those phases are presence geometrically they are distributed, in fact in the later end of the course will actually we dealing with the topic, which is called as stediology, in which we shall actually can deal with some more these very aspects in 3D. We need to know about the defect structure, and this defect structure within the phases we are talking about for a certain I have certain phase the alp of phase of copper.

Then I need to know the defects within this phase of copper, and I also need to know the defects which are present at the interface that is we will we could deal later with these concepts on grains. So, I need to know what is the structure of the grain bond what are the defects present in the grain boundary, there for I need to know the different structure in the material. And we will go on formally find the terms of the structures essentially what we are talking about I need to know how defects are distributed in the phase and in between the phases the phases.

Last, but not the least I cannot ignore a residues I have seen that a glass can be very brittle under normal conditions, but suppose I introduce residual compressive spaces on the surface, then the same glass behaves as a tough end fashion. Of course, these factors are intimate of one another, they act in conjunction often, and there is certain inter depth dependency which you see which we need to consider, when we are actually dealing with the properties arising from these aspects.

So, to summarize this slide we need to worry about composition, phases in their distribution the defect structure and residues stress, when I am talking about how a property of a material coming about. An important point to note here is that one at actually travels along lens scales to actual look at the various aspects, which can give rise to the properties of the material. That is we have to look at the atomic scale, we have to look at a scale which for instance tens of nanometer, but we often have to look at which are much larger scale and above. There to understand how that certain property this could be simple property like how are able to bend an aluminum rod, but have to look at all these lens scale if you have to understand such a property.

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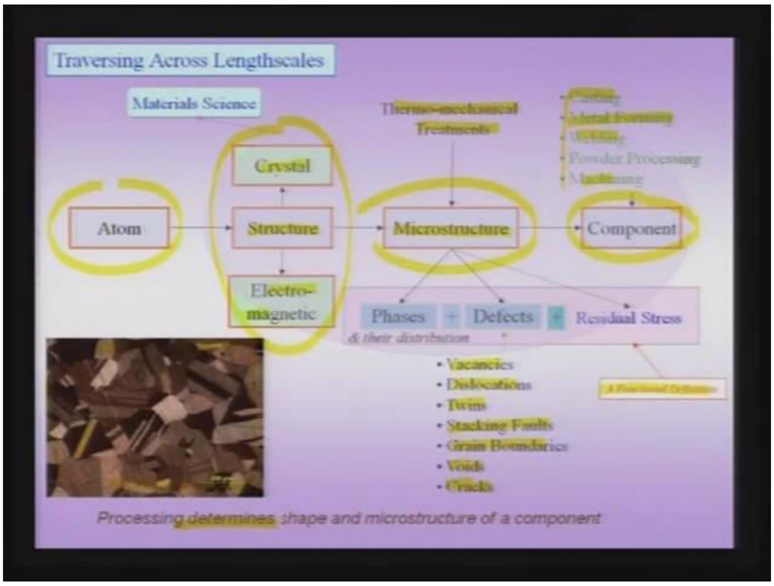

So, what are the lens scale we are talking about which we need to traverse and what are the some of the implication of traversing across, such a lens scale what shown in the slide. We have an atomic scale for an instance and we have an atom in the nucleus etcetera, but this is typically as I pointed out the zone of physics and in the material zone we actually talk about the structure from an the structure point of view or an atomic point of view the structure point of view all the electromagnetic point of view.

The next scale is the scale of the micro structure, so this typically would be a scale or of the order of Armstrong's the micro structure is a scale which starts as we will actually formally define a micro structure also very soon, but this scale is not a fixed scale, but its start from the scale above the crystal structure and extends all the way up to the component. Which, is the next scale which we are talking about, and we are leading with no instance which component is actually manufactured using certain methods of manufacture like casting, metal forming, welding or for instance machining.

And this very processing is in fact, going to affect our micro structure say in other words the processing root is actually going to affect our micro structure, and quite a bit what kind of a crystal structure which is going to form. For instance, suppose I do a casting, if the casting is involving slow cooling rates I would actually obtain a poly crystalline material say for this is I am cooling an alloy, it could so happen if I do the same alloy by every fast cooling rate. By for instance throwing the melt onto a fast rotating copper wheel, then actually I could get an amorphous structure.

So, the structure is not independent of the processing as we had seen in the material structure of heating in few slides back, and this micro structured actually can be tailored by what you may call thermal treatments or mechanical treatment or a combination, which we can call the thermo mechanical treatments. We now go on to what you might call a functional definition of the micro structure typical text book definitions tell you a micro structure is a structure, which is viewed under high magnifications. Like for in the sense you can see a micro graph on the left hand side which is nothing but an cold worked un yield copper which shows recoslide greens and it also shows certain details in the structure for instance this is the twin which is shown here.

So, what is the functional definition of a micro structure, we just nearly goes beyond the definitions beyond based on the scale, this definition of a microstructure which is arising from the need which we have put forth in the previous slide the need the fact that. We need to consider the composition phase distribution the defect structure, and residual stress when I need to worry about the properties. So, the function definition of microstructure would be involved phases and the distribution, the defect structure and the residual stresses.

As later in the courses we will see when we talking about defects there can be many different kinds of defects we are talking about there could be vacancies, dislocations, twins, stocking faults, grin boundaries, voids cracks. In fact, in the example of the breaking glass it was the cracks on the surface, which were playing a dominant role in the breaking of the glass. And when I etched away the cracks on the surface, if we actually measure the strength of that glass the etched glass in bending you would observe that its actually have got a higher strength.

And this is coming from the fact that cracks are being sort of etched away and the length has been reduced, therefore, all these defects would play a role or will go towards the definition of the microstructure, which would be a functional definition of the microstructure. One such example of a photo of a what we call in usual language of the microstructure is shown on the left hand side, so processing not only determines the shape of the component, but also dictates the microstructure, which we are going to produce.

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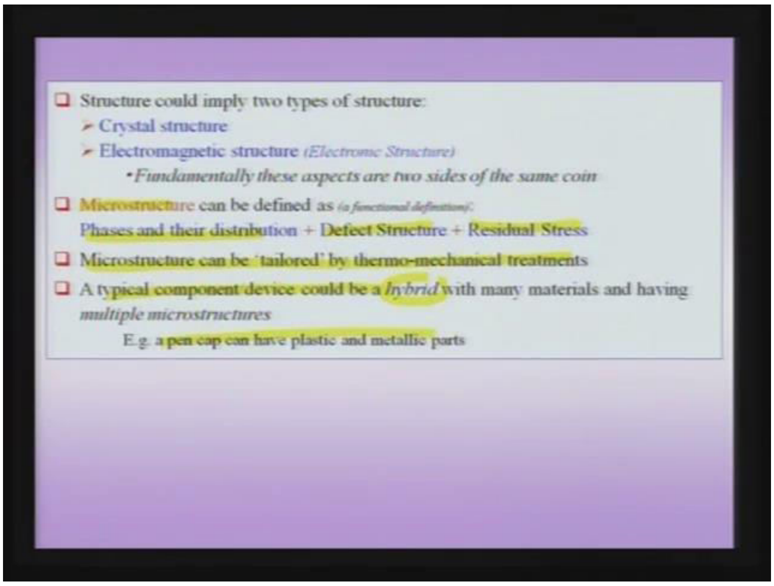

And just to revise we had already discussed these aspects the structure, we should always know is two kinds of structure the crystal structure or the electronic or the electromagnetic structure. And at the more fundamental level we have already seen that these are nothing but two sides of the same coin, we had further gone on to define the micro structure in the previous view graph. Where, as the phases and the distribution the defect structure and the residual stress in the material, and as we have seen the residual stress can be beneficial as in the case of the tough end glass.

But, instead in other circumstances this residual stress could actually be very devious, it can lead to stress corrosion cracking and many other war page of components etcetera, so residual stress could be beneficial or devious. Microstructure can be tailored by thermo mechanical treatments as we saw in the previous view graph, and a typical componential device could be a hybrid of very many materials having, and therefore, a combination of multiple micro structures. Even if you take a simple example of a pen cap for instance often you would see that it has got metallic and polymeric parts.

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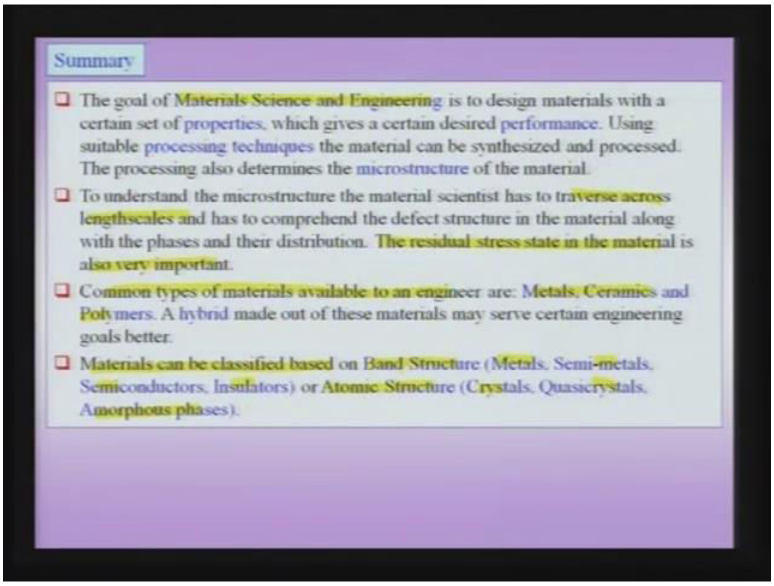

So, to summarize this broad introduction to structure of materials and to materials engineering, the goal of materials science and engineering is to design materials with a certain set of properties, which gives certain desired performance under certain conditions. Using suitable processing techniques like for instance we have seen forging, rolling, casting, etcetera, the material a material can be synthesized or a component can be synthesized. And this very synthetic method actually determines the microstructure in a material, to understand the microstructure the material scientist has to traverse across length scales. Because, if you go back to the previous slide one of the previous slides, we can see our atomic level defects, while other hand void could be large macroscopic defects which are even observed to the visual unneeded eye.

Therefore, even when we are talking about the defects, we are actually traversing across length scales. And of course, therefore, if I want to understand the microstructure or the properties arising out at the microstructure, I have to traverse across multiple length scales which go from the atomic length scales to scale of the component which could be on the order of centimeters or more. The residual stress state in the material is a very important variable, which will not be forgotten, and later on we will see what is the origin of residual stress and how they can affect the properties.

Common type of material which are available to an engineer include metals ceramics and polymers, and often we would make hybrid sort of these common materials, so as to achieve certain properties which can be helpful in certain applications. Materials can be classified based on band structure, into metals, semi metals, semiconductors and insulators, and based on atomic structure into crystals, quasi crystals, amorphous phases. In this course we will primarily deal with crystals with the little ah part of the course, being diverted to amorphous material phases, but it is good to remember that there are other forms of matter like quasicrystals, where which are also rightful in from the scientific interest, and their role in some important applications.