Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-37
Surface Modification Techniques: Ion implantation and Ion Plating

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering and you know that we are talking about the various surface modification techniques and among the various surface modification techniques especially we are talking about the techniques which are associated with the modification of the composition of the surface and near surface layers.

So that required improvement in surface properties can be achieved for improving the tribological behaviour of the functional surfaces. So under this category now we are talking about the 2 processes 1 is ion implantation and second is the ion plating. So I will be taking up first of all the ion implantation. So the technique which is used to modify the surface properties by modifying the chemical composition is ion implantation.

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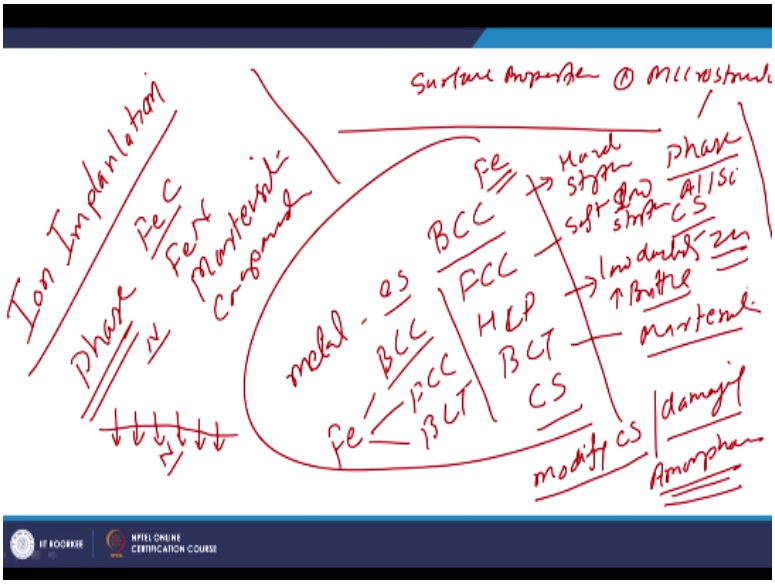

Initially we will talk about the basic principle are related with this process. So you know that the surface properties are affected by the microstructure of the material which includes the kind of the phases which are there and the crystal structure of the material itself. So we know that most of the metals have the crystalline structure and this crystalline structure may be like the BCC or FCC, HCP or like BCT type or like simple cubicle structure.

So and according to these structures the various metals are the different category of the properties different types of the properties. For example the metals and HCP crystal structure of for the low ductile and higher brittleness. On the other hand BCC offers the high hardness and strength. SCC metals are completely soft they are of the low strength. So like iron is having the BCC crystal structure, aluminium, silver etc have the FCC structure zinc is having HCP structure.

BCT structure is found body-centred internal structure is found in the like martensite is a typical phase which is found in the steels. So according to for a given composition of or for a given metal if they can be very is crystal structures special in case of the allotropic material, like iron we can have in form of BCC crystal structure or FCC crystal structure or even BCT also.

So according to the crystal structure properties are significantly influenced. So in this approach what 1 thing which is used to alter the surface property is to modify the crystal structure and this modification basically is in form of completely damaging the crystal structure and making the crystal structure completely amorphous. So there is no systematic of the various items like in typical crystal materials.

So this is 1 aspect that the crystal structure of the material is damaged and it is made the amorphous and another aspect related with the surface properties is the kind of phases which are there like there can be a like iron carbide or iron nitride, there can be like a the martensite or various other kind of the intermetallic compounds which can be present at the surface.

So in this approach in this technique the another thing which is it is achieved is the formation of the typical compounds and phrases which will help to improve the properties with the help of ions of the suitable elements. So like if the nitrogen ions are used the nitrogen will be getting produced at the surface of the metal and this will be reacting with the metal to form the corresponding nitride and which will help to improve the properties.

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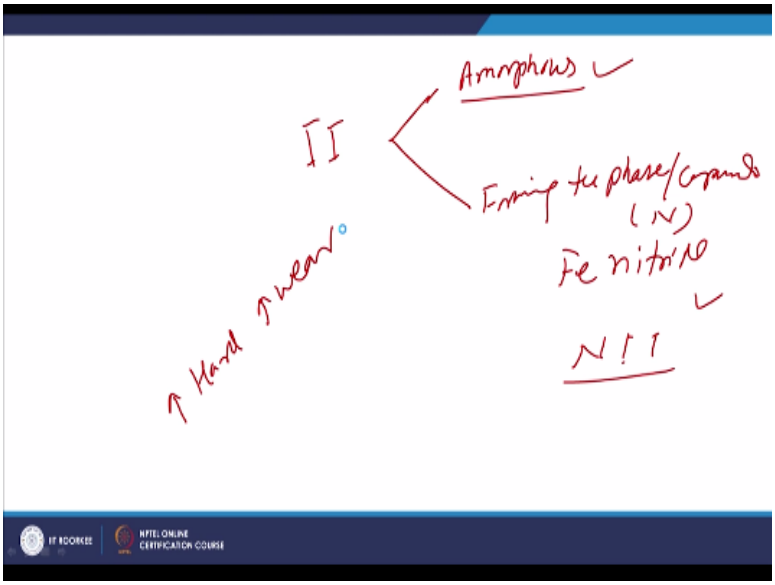

So in ion implantation basically there are ion implantation basically there are 2 mechanism exploited to improve the properties, 1 is making the crystal structure amorphous or forming the required phases and compounds by intruding the suitable elements like nitrogen. So formation of the iron nitride is typically achieved when the nitrogen ion implantation is performed.

And the damaging the crystal structure is it helps in achieving the amorphous structure at the surface and these are basically 2 main lines or 2 main mechanisms which help in improving the hardness, so improving the wear resistance. So how it is realised basically we use the high energy ions or ion beam which is directed on to the surface of the material which is to be modified.

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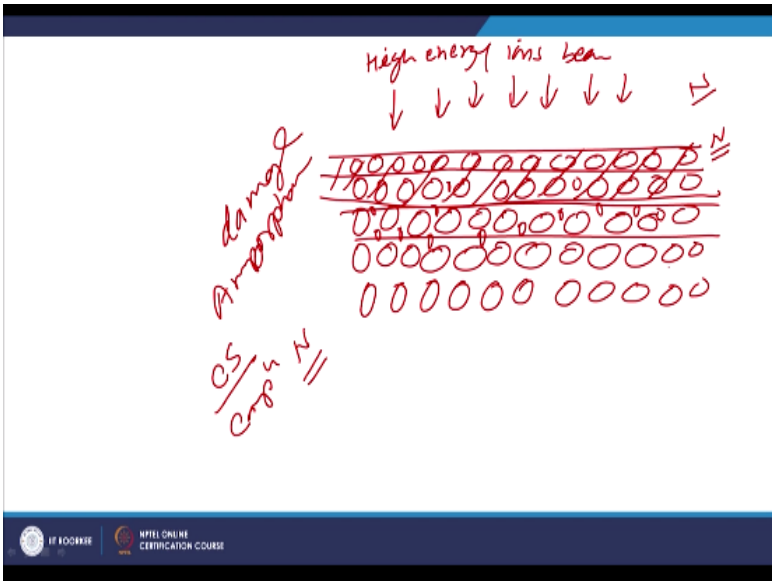

So the impact of these high energy ions with the surface will be modifying or damaging the crystal structure of the metal especially the near at the near surface layers. So there will be various zones which will be formed like say this is the typical arrangement of the atoms in any metal. So up to certain depth we will see that the atomic arrangement has been completely displaced damaged.

And this will be leading to the and this damage happens primary due to the impact of these high energy ions with the substrate and this damage will be leading to the production of the amorphous structure, at the same time these ions of ventricular element like nitrogen when they get introduced in the metal these will be interacting with the substrate material to form their respective compounds.

So now we will see in this situation that obviously the concentration of that particular element ions of the particular element will be more near the surface layer and that concentration will keep on decreasing and for significant depth from the surface there would not be any change in the crystal structure as well as any change in the chemical composition. So this is how will be modifying the surface.

And near surface layers characteristics by changing or damaging the crystal structure and by changing composition by introducing elements or particular element, nitrogen is one of the compound used for reducing, the nitrogen ions in the metal which of the reaction with the ion especially for nitrates to improve the surface properties. So the sequence of this process works in like this impact of the high energy ions with substrate.

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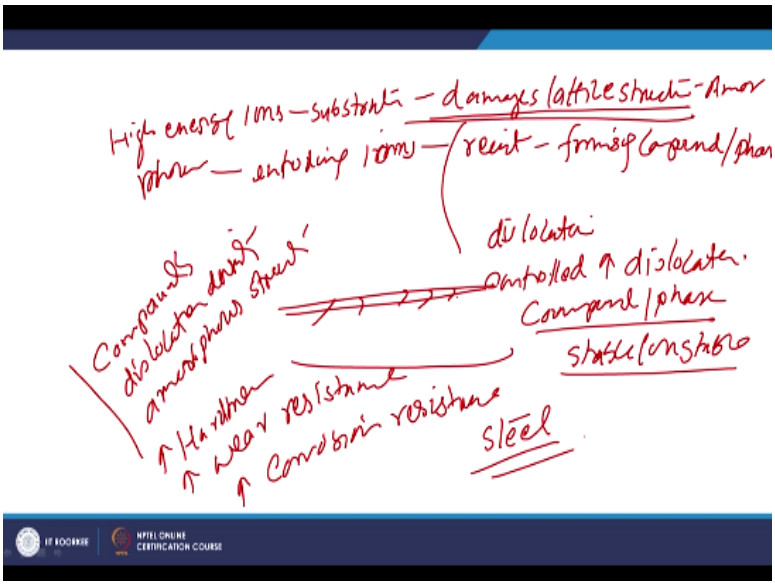

This substrate damages the lattice structure leading to the formation of the amorphous structure, at the same time introducing the ions of particular element which react with the substrate to form the forming the compounds and the phases and this formation of these compounds and phrases will be leading to the improvement in properties. There is 1 specific thing which is to mention is that this damaging the lattice structure leads to the formation of the dislocation.

So dislocation density is increased in very controlled way through the impact of these high energy ions basically development of the damage lattice structure coupled with the controlled increased in the dislocation density formation of the compounds or the phases which will help to improve the properties. These phrases can be stable type or non stable type means which will be modifying their characteristics and nature as a function of time.

And with the change of the conditions which for which will be exposed and when these changes in terms of the formation of the compounds dislocation density and the formation of the amorphous structure. This combination of these 3 changes especially at the near surface layers leads to the significant improvement in properties with regard to the hardness, increase in hardness increases the wear resistance.

And this increased in wear resistance is also coupled with the increase of corrosion resistance. So mostly this kind of the improvement is achieved in case of the steel

components. Now what are the conditions which are required for improving the properties and how do we get this.

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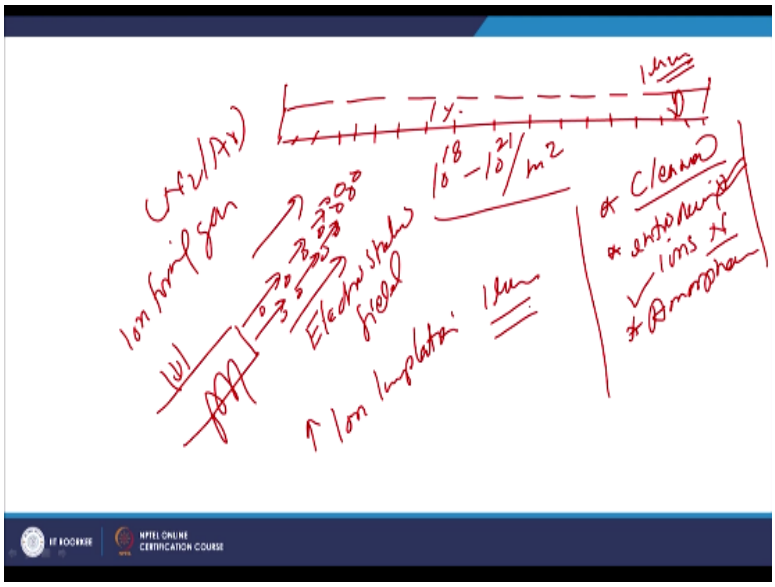

So say there is a setup for producing the ion beam, so like ion forming gas mostly it is nitrogen or argon it can be it is introduced and this will be leading to the formation of the ions which will be directed at high speed towards the surface of the component which is to be modified. So when these are ions impact with the surface these will be leading to the various favourable effects like impurities present at the surface are cleaned automatically during the processing.

And apart from cleaning this will be leading to the introducing the ions of that particular element like nitrogen for nitrogen ion implantation it will be damaging the lattice structure and forming the amorphous structure at the near-surface layers and these ions which are formed these are accelerated towards the substrate using a suitable electrostatic filed. So that they can achieve the required energy for damaging the crystal structure.

And introducing the ions at the surface as far as typical values are concerned for achieving this kind of effects about 1% of the ions are needed to modify the surface properties where in the ion density 10 to the power 18 to 10 to the power 21 number of ions forming about 1% up to the depth where up to which the property improvement is required and these like 10 to the power 18 to 10 to the power 20.

And one number of ions per metre square is required and approximate 1% of ions will be needed to have these favourable changes at the surface layers, but the capability of the process to either the crystal structure and to achieve the required dislocation density as well as forming the required phases and compound. This depth is very limited up to the 1 micrometre means this process ion implantation can be used to improve the surface properties up to the depth of 1 micrometre.

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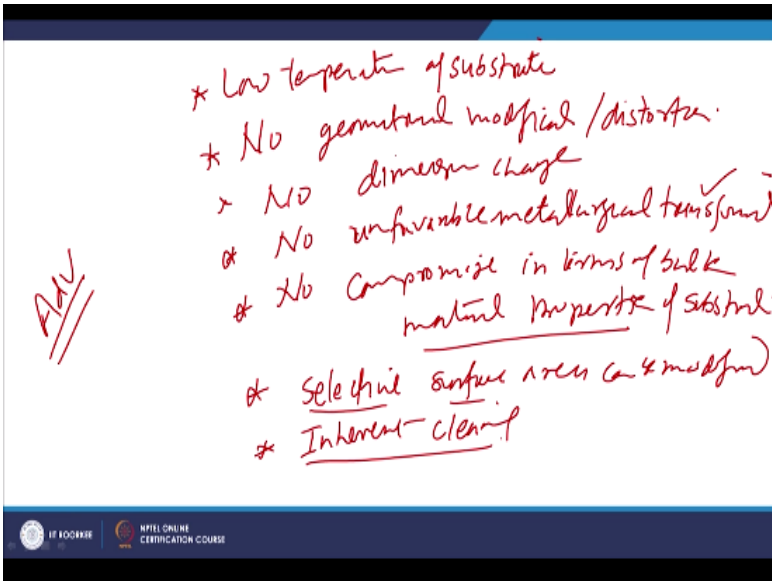

So the depth which can be modified by this process is very limited, as far as advantages of this process is concerned, this process results in very low means the ion implantation is performed the temperature of the substrate is very low. So the low temperature of the substrate are the workpiece. So there are number of benefits associated with this like very less or no geometrical modification which means there is no distortion.

There is no dimensional change because there is no major rise in temperature of the work piece. So the no dimensional change and also due to the limited temperature rise there is no unfavourable metallurgical transformation. There is no unfavourable metallurgical transformation and therefore no compromise in terms of the bulk material properties of the substrate or of the component.

So we have seen that those high temperature processes like carburizing or cyaniding where 2 high temperatures are used to be experience lot of undesirable effects in terms of the distortion or the dimensional changes and favourable metallurgical transformation in the base

metal leading into the compromise with regard to the mechanical properties of the component. At the same time now this process also can be applied very selectively.

So very selective surface areas can be modified, so whatever the small or the large functional areas are there which can be modified those can be modified very effectively in very selective manner and the another important aspect that the inherent cleaning is involved. So inherent cleaning of the surface and so even the cleaning of the surface is not very crucial or critical in this case.

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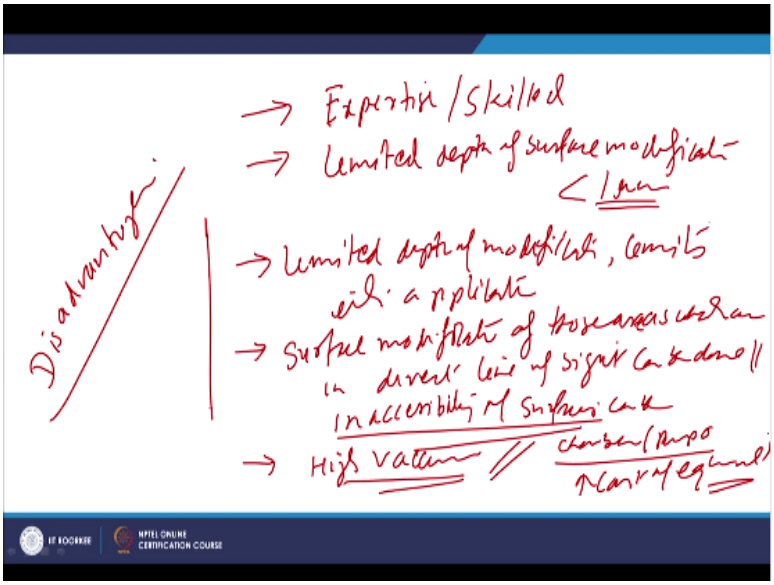

Because bombardment of the ions at the surface performs automatic cleaning of the surface. So these are some of the benefits of the ion implantation only limitations their number of limitations are the disadvantages associated with this process and those disadvantages are like we need really very expertise to handle to design the surface modifications.

So skilled worker or expertise is needed to implement the ion implantation in order to realise the surface properties as per requirement. Another aspect is the limited depth of surface modification as we have seen that normally the process is limited up to the 1 micrometre. Those applications where we need really need very thick modified surface layers and hard surface of greater thickness. There this process cannot be used.

So limited depth of modification limits its applications because all those applications were very high will be acting where limited depth of the modification may not be good enough for improving the performance of the component for longer time and those conditions the ion

implantation technique may not be good. Then the surface modification can be done only those areas which are in direct line of sight of the beam to surface modification of those areas which are in direct line of sight can be done.

These all those areas having the inaccessibility is used and not in direct line of sight of the point beam source those cannot be modified using this process. So in accessibility of the surfaces can be issued or the 1 limitation as far as the areas which can be modified using this process and 1 more disadvantages associated with this is that we need really high vacuum. So whenever vacuum is there we need to perform extra work to modify we need to perform extra work to achieve the requirement vacuum.

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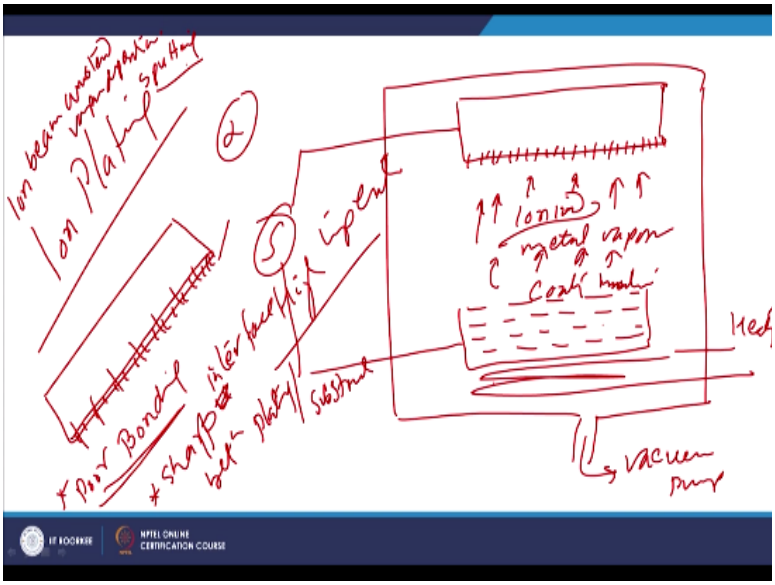

And this in turn requires the vacuum chamber, vacuum pumps and this internal increasing the cost of the equipment as a whole. So these are some of the undesirable sites related to the ion implantation. Now we will be talking about the iron plating, in case of the iron plating ion plating is very simple process. In this case we use chamber with the vacuum pump to clear the vacuum in the chamber like this.

And one side we have the crucible for evaporating the metal to be deposited like this. So heating is done using suitable heating source and this is the coating material which is melted and then it will be coming out in form of the metal vapours. These metal vapours are ionized using suitable electromagnetic fields or developing the suitable conditions, so ionized metal vapours are used.

And these ionized metal vapours will be directed towards the surface of the substrate where they will get deposited on the surface of the substrate. So here this high energy ions of the metals deposited on the surface of the substrate but to give the enough energy to these ions of the metal vapours basically the high temperature conditions are used and which are unfavourable especially with regard to the substrate performance or from the substrate properties.

So in this case ionization of the metal vapours from the required coating material and this ionized metal vapours are accelerated towards substrate using the suitable potential difference, also suitable heat, a suitable source of the potential difference is established between the 2. So that the ionized metal vapours can be accelerated towards the substrate with a sufficient energy.

And they are impact with the substrate will be leading to the deposition of these kinds of the metal vapours with the substrate. So this is how it is very simple one but there are some of the issues like there can be metallurgical issues with regard to this kind of the deposition or plating where ions are plated or deposited on the surface of the substrate. So if there is a large difference in the thermal expansion coefficient of the substrate.

And the material which is being plated then you can lead to the peeling or spelling kind of the situation from the substrate material. So this causes the poor bonding situation between the plating or the plate or the coating which is been applied on the substrate and this is 1 issue related with this process and this also leads to the very sharp interface between the plating layer and the substrate.

So that the sharp interface if being formed due to the metallurgical incompatibility it will be leading to the problem of the poor bonding and the elimination or the peeling of kind of a situation will be leading to the easy removal of the material which is being applied on the substrate. So this is a negative side as far as the iron plating is concerned.

So there are other modifications related with this process if they are applied then the bonding can be improved and in that category basically we have ion beam assisted vapour deposition or ion beam assisted sputtering. These are the 2 other techniques where again the required

element at the surface is deposited and then the required bonding is ensured through the bombardment of the ion beams at the material which is deposited.

So that it forms very good metallurgical bond with the substrate and the bond strength is improved at the same time very good intermixing with the substrate is also facilitated. So now I summarise this presentation, in this presentation basically I have talked about the ion implantation and the ion plating kind of the techniques and we have seen that in case of the ion implantation it is the damaging crystal structure developing the required dislocation density.

And forming the required phases at the surface helps to improve the hardness and the wear resistance using the ions of the nitrogen of the argon where in case of the ion plating metal vapours are ionised and those are deposited on to the substrate. However in this case the bonding between the plating or the coating which is applied and bonding between the coating and the substrate is poor.

Because of the sharp interface which is formed and it can lead to the metallurgical incompatibility especially when the 2 metals are completely different in terms of the metallurgical properties or in terms of the thermal expansion coefficient. So if the properties at 2 different expansion, coefficient is 2 different then it will be leading to the spelling or peeling off or delamination of the coating during the surface because of the poor bonding, thank you for your attention.