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Nano the revolution of 21st century

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Abstract

The emerging world of nanotechnology comes in the wake of major changes in the use of technology. The materials in the bulk form when transfer to nano form which exhibit wonderful properties like the transparency of plastic coated lens when coated with nano particles of zirconia, malleability, ductility of brittle ceramic on conversion to nano form. Further there is considerable increase in strength of copper when converted to nano size. The bandgap engineering of nano semiconductor has also been discussed.

Keywords: Nano material, Bandgap, Malleability, Ductility.

Resumen

El mundo emergente de nanotecnología viene a raíz de importantes cambios en el uso de la tecnología. Los materiales en la mayor parte se forman cuando son transferidos a forma de nano exhibiendo propiedades maravillosas como la transparencia de plástico que le da a las recubiertas cuando están cubiertas con nano partículas de óxido de zirconio, maleabilidad, ductilidad de frágiles de cerámica en la conversión a nano forma. Además hay un aumento considerable en la fuerza de cobre cuando se convierte a nano escala. La reducción del punto de fusión y sintetizando la temperatura de materiales como el óxido de titanio cuando es llevado a nano escala se observa también. La ingeniería de bandgap de semiconductores nano también se ha discutido.

Palabras clave: Nano materiales, Bandgap, Maleabilidad, Ductilidad.

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I. INTRODUCTION

The emerging world of nanotechnology which comes in the wake of major changes in the use of technology, essentially depended on basic materials, has been very slow in the Stone age but picked up a little in the Bronze and Iron ages. In contrast the changes gained momentum from the Chemical age around AD 1900. Subsequent progress was rapid in the Plastic age (1940's), the Material age (1960's), the Silicon age (1970's), the Biotechnology age (1990's) as shown in the figure.

Right from the Middle ages, the urge to probe matter and manipulate it in search of the proverbial gold has been punctuated by philosophical contemplation on the nature of matter and its constituents. Some of the theoretical predictions have been eventually verified with the advent of modern instruments. The ongoing Information age is noted for outstanding advances in the biological science as well. Biologists and information scientists have joined hands in exploring matter at the nano scale and have discovered new features of many materials. An interdisciplinary study with revolutionary implications for the entire world is emerging. The study of nanotechnology and its applications is expected to dominate the 21st century. Hailed as the all-embracing innovation of the 21st century, nanotechnology is expected to impact on almost all aspects of life. Nanotechnology is an enabling technology, as it would impact on almost every area of research.

Research at the nano scale is bringing together chemists, physicists, chemical engineers as well as computer experts biologists and doctors in a truly interdisciplinary manner. The results of this endeavour are likely to affect almost every aspect of our daily life. The impact is expected to be global transport, communications, drugs, disease detection and rediscover our immune system, our genetic make-up, reinvent and reengineer industrial production and rewrite the strategy of war. Nanotechnology is designed to bring out an entirely new generation of products, cleaner, stronger, lighter and environment friendly. On the down side, nanotechnology has become a deadly weapon in the hands of terrorists. Even otherwise, the nano revolution could spell the end of human control over matter.

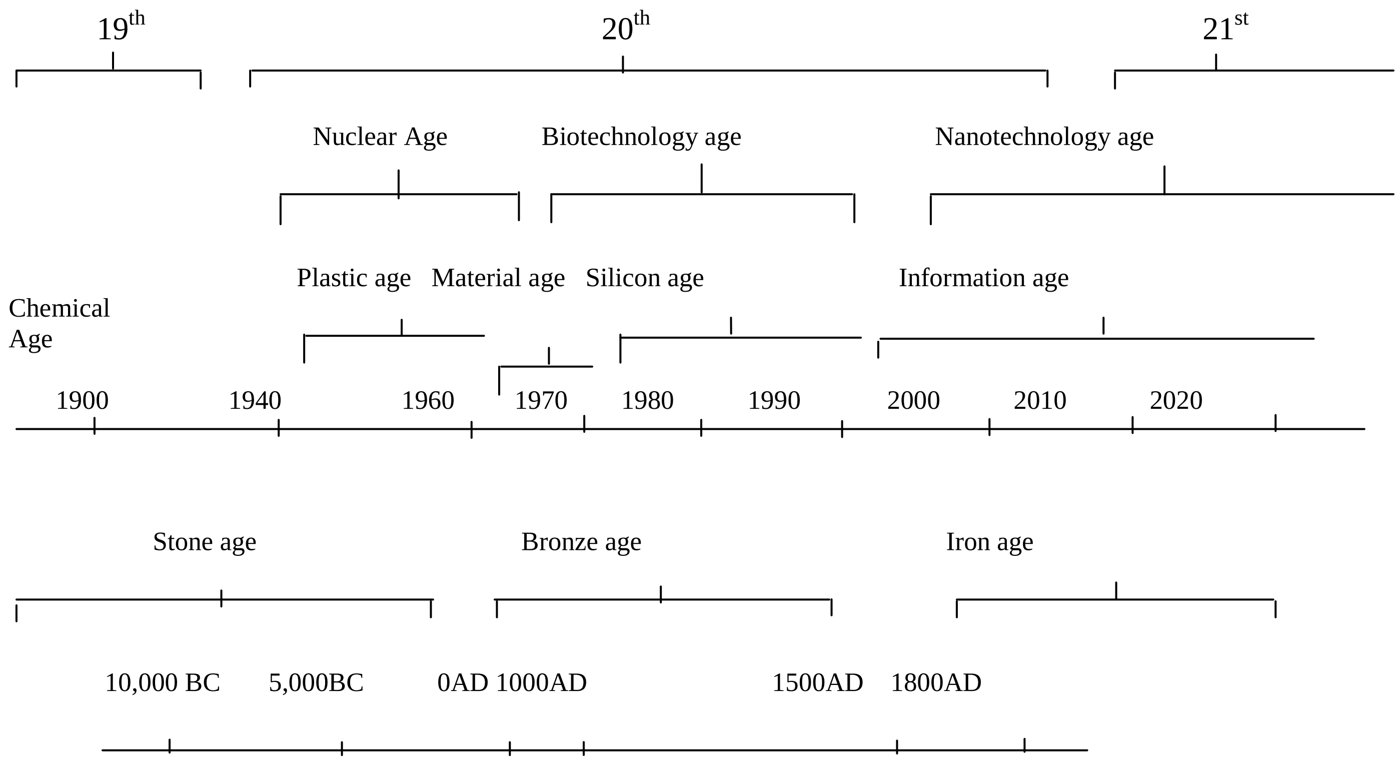

FIGURE 1. From stone age to nano age: Progress of Technology.

In the last two decades path-breaking discoveries and inventions of new microscopes have led to a lot of hype in the media about the ability of nanotechnology. An overview that separates the science from the fiction in this matter is urgently called for. Moreover, a knowledge of the challenges met and the results achieved is essential, if the younger generation in developing countries, such as India were to acquire an interest in the new field of nanotechnology and become motivated to address the challenge of applying it for the benefit of their people. India has taken the initiative to encourage research and application of nanotechnology and selected scientific establishments in the country have done outstanding work on this field.

II. SCIENCE OF NANOMATERIAL

We have seen that nanotechnology is based on some new properties acquired by materials in nano form. When prepared in the nano form bulk particles become transparent and do not scatter visible light; ceramic materials, which are brittle, become malleable and ductile when reduced to nano form, and magnetic nano materials acquired large magnetic moments. Not only these but also that the strength of metals increases many folds, the electrical resistance of some semiconductors become dependent on the applied voltage, the melting and sintering temperatures of some materials decrease drastically; and some ceramics and transition metals show better catalytic properties when prepared in nano form. The question that remains to be answered is "Why does such drastic change in properties occurs? Can we understand it?" If we understand the physics of nano materials, it may be closer to achieving the success of producing tailor-made materials. In order to understand this, we must first review our understanding of the properties of bulk materials, and then see how they change when their sizes are reduced. Keeping in the view of wonderful properties of materials when transfer from bulk to nano form, we have undertaken the discussion.

- Transparency of nano particle-coated plastic lenses.
- The malleability and ductility of ceramic nano particles.
- Strength of materials increases in nano form.
- Melting and sintering temperatures for nano materials.
- Band gap engineering in semiconductors nano materials.

III. TRANSPARENCY OF NANOPARTICLE-COATED PLASTIC LENSES

From our day –to-day experience we know that when a sheet of glass is shattered, its pieces become opaque. So it may appear rather puzzling how a plastic lens coated with nano particles of zirconia becomes transparent. The answer to this puzzle lies in the size of the nano particles itself. Zirconia is a ceramic material-an oxide of zirconium-which is an insulator in its bulk form [1, 2]. Hence it has a large band gap in its electronic energy spectrum, which makes it transparent to visible light. When its size is reduced to nanometer scale, the band gap increases further so the nano particles retain their transparency to visible light. So the light is not absorbed by these tiny particles, but can they be scattered resulting in opaqueness, as it happens in the case of shattered glass! The wavelength of the visible light falls in the range of 360 to 800 nano metres. Whereas the size of nano particles lie anywhere between 1to 50nm. This size being too small compared to the wavelength of light would not scatter the incident light.

This can be explained by considering the simple analogy of a cyclist riding his bicycle on a road full of ditches. If the ditches are too small compared to the diameter of the wheel of the cycle he can ride through them without any problem. But if the size of the ditches are comparable to the wheel diameter and he tries to ride through them then he will simply fall. Thus the cyclist will never reach his destination, and we can say that he was scattered by the ditches on the road. In this analogy the ditches are the nano particles and the diameter of cycle wheel is the wavelength of light.

IV. THE MALLEABILITY AND DUCTILITY OF CERAMIC NANOPARTICLES

How is it that a brittle material like a ceramic becomes malleable and ductile when its size is reduced to nano scale? The property of malleability and ductility of a polycrystalline material depends on the size of the crystalline grains constituting the sample. Usually in bulk samples the grain sizes are of the order of microns (= 10^{-6} m). Hence in polycrystalline bulk samples there are less number of grain boundaries (regions separating a grain from its surrounding grain), because of which it is difficult to move the grains over each other by applying stress. Hence polycrystalline bulk ceramics are brittle [3, 4, 5]. But when prepared in nanometer size the number of grain boundaries increases enormously, which allows the grains to move under applied stress. Hence, when prepared in nano form polycrystalline ceramics acquire malleability and ductility, and can be used to make engines for motor vehicles.

The technicality of grains, grain boundaries, and their movement under stress can be understood in terms of a simple analogy. Consider a heap of broken bricks. If you put your foot on top of the heap and press, it will not go down simple because the broken brick pieces being larger in size the number of boundaries between the pieces are less, and they can resist the pressure of your foot. On the other hand if you perform the same experiment with a heap of sand, your foot will immediately go down. In this case the sizes of the sand grains are small, so the number of grain boundaries is large, which allows the grains to move under the pressure of your foot. In a similar way nano ceramics are malleable and ductile.

V. STRENGTH OF MATERIALS INCREASES IN NANOFORM

The best-known example of this is Copper. On reducing size of a piece of copper to 50nm its strength doubles as compared to the bulk value. When the size is further reduced to 6nm its strength becomes 5 times that of the bulk value. How does this happen? What determines the strength of a materials? The strength of a crystalline material is determined by the ease with which an atomic plane slide over its neighboring plains on application of stress. The easier it is to make the plane slide the lesser is its strength.

Presence of defects in the solid facilitates the sliding of the atomic planes over each other. In particular, an extended defect called a ‘dislocation’, which is intrinsically generated in crystalline lattice, help in the sliding of the atomic planes and thereby are responsible for the reduction of the strength of a material. When a stress is applied the dislocation moves in the direction of the stress, which can result in the fracture of the material. However, in a polycrystalline material these dislocations are generated in the grains, which are surrounded by grain boundaries where the motion of the dislocations get arrested, preventing a fracture.

In this scenario how can we understand the increase in strength of the material when it is produced in the nano form. In the nano material there are large numbers of grain boundaries, which arrest the motion of the dislocations and stop the sliding of the planes before they moved too far to cause a fracture. At first it was thought that it is this arresting of the motion of the dislocations which increases the strength of nano materials compared to their bulk counterparts. But more recently this view has changed; scientists argue that the grains being of nanometer sizes the nano particles cannot even sustain dislocations. As a result, the crystallites being dislocation free their strength would be much larger than their bulk counterparts.

Again the technicality of sliding of atomic planes due to the motion of dislocations under stress can be understood by means of a simple analogy. Consider a carpet spread over the floor in the room. If you want to slide it over the floor by pulling it from one end, you have to apply enormous force to overcome the force of friction opposing the motion. However, before pulling the carpet if you push it from the opposite end so that the carpet gets lifted up in the middle forming a ridge than it becomes easier to pull the carpet, corresponds to the motion of the dissolution by the applied stress. If the carpet is not large it may not be possible to form a ridge by pushing it from the opposite end, because there won’t be enough area of the carpet in contact with the floor to provide the required frictional force to form the ridge. In the later case there is no other alternative but to pull the carpet, which is going to cost lot more energy.

VI. MELTING AND SINTERING TEMPERATURES FOR NANOMATERIALS

Materials in the nanoform have lower melting and sintering temperatures. For example titania (titanium oxide) in the nanoform it sinters at 1400^0C, where as prepared in the nanoform it sinters at the temperature of 600^0C. This clearly shows that there is a large reduction in the sintering temperature [6, 7]. While melting is commonly understood phenomenon, let me explain what is meant by sintering and sintering temperature. To form a polycrystalline sample you take small grains of the material in a die of given shape and apply pressure so that the grains loosely hold together forming a pallet in the shape of the die. To give strength to the pallet it has to be heated to a temperature above a certain characteristic temperature for the material for a given period of time, so that the grains in the pallet bind to form the polycrystalline sample. This process is called sintering and the characteristic temperature for the material is called the sintering temperature.

In order to understand why the melting and sintering temperatures are lowered for nanomaterials, let me remind you that both these phenomena depend on the available surface area. Both these processes are initiated by the motion of the atoms at the surface. While for bulk materials the surface is small, for nanomaterials it is extremely large. Since both melting and sintering start at the surface, availability of large surface area amount to lowering the corresponding temperatures.

VII. BAND GAP ENGINEERING IN SEMICONDUCTORS NANOMATERIALS

It is well known that semiconductors are characterized by a band gap of the order of an electron volt (eV), between the valence band, which is fully occupied with electrons, and the empty conduction band. Hence under some circumstances these can emit radiation of a specific wavelength when electrons are injected into the material. This is called electroluminescence. The same thing can also happen when electrons are promoted from the valence to the conduction band by shining light of appropriate wavelength. Under these conditions, holes will be left behind in the valence band and when the electrons and the holes recombine, radiation with energy equal to the band gap will be emitted. This phenomenon is called photoluminescence.

For either of the abovementioned phenomena to occur the semiconductor must be of 'direct band gap' type, which is a requirement arising from momentum conservation in the process of light emission. Besides, for emission of visible light of different wavelengths the band gap must have energy appropriate to the corresponding wavelength. This in turn requires that it should be possible to tune the band gap of semiconductor. The commonly used semiconductor silicon is an 'indirect band gap' material with the magnitude of the gap rather small compared to the energy of light in visible range. Hence it is not a light emitter. In contrast cadmium sulphide(CdS) and cadmium selenide (CdSe) are "wide band gap' semiconductors [8, 9]. Hence these are more appropriate for light emission provided their band gaps can be tuned for emission of a particular colour of light. CdSe fulfills this requirment when prepared in the nanoform. When CdSe nanoparticles prepared in different sizes are suspended in a liquid and white light is shone on the test tubes containing these suspensions, each test tube emits light of different colour depending on the size of the nano particle suspended in it. This clearly indicates that the band gap of CdSe changes depending on the size nano particle; in fact, the smaller the size the larger is the band gap of the material. As a consequence of these even materials that are not emitters of light in their nanoform. This is often referred to as "band gap engineering" or "quantum size effect" Thus silicon, the base material of electronics technology, can be made to emit light in its nanoform.

For example, if the size of the CdSe nanocrystals is between 2nm to 7nm its fluorescence can be tuned between the visible range of wavelengths of 450 to 650nm; that is from bluish to orange. In contrast to a bulk semiconductor where the energy levels of the electron form a quasi continuum like that for a free particle; in the case of quantum dots the energy levels from a discrete spectrum of localized states. This makes it possible for an indirect band gap semiconductor to have a direct band gap component. Hence a material like silicon in its nanoform can be made to emit visible light. These possibilities are really exciting from the technology point of view.

VIII. CONCLUSION

In this article we have outlined briefly what nano materials are, and how new technologies can evolve using the unusual properties of these materials in their nanometer sizes. Also we attempted to provide qualitative explanations of the origin of these changed properties .In principle, any particle can be reduced to nanometer size, which opens up enormous possibilities for the development of new technologies. This is basically the reason for the continuing emphasis on the study of nano materials at a scientific level. The more we understand these materials the wider would be the potentiality for their use. At the present juncture one of the major problems that engage the efforts of the materials scientists is to evolve some method for the production of nano materials in mono-dispersive form. It is needless to mention that all the methods used produce these with a distribution of sizes, and when one talks about particles of a given size it refers only to the average size. Mono-dispersive nano particles of given material as building blocks are expected to have exotic properties the study of which it is of interest purely from scientific point of view. The only such solid that exists at present is fullerene. We know that fullerides (compounds formed by substituting metal atoms for one or more carbon atoms in the fullerene molecule), which are bad conductors of electricity in their pure form, become conductor when doped with alkali atoms and even become superconductors at comparatively high temperatures. Besides, their electrical and magnetic properties show dramatic changes with the choice and concentration of dopants. Overally the capacity to manipulate such solids increases manifolds resulting in their futuristic use related materials that also exhibit many exotic properties are the carbon nano tubes. Scientists are visualizing their use in making nano electronic devices and in engineering application with such exotic ideas as dent resistant cars to earthquake-resistant buildings.

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