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Nanostructured Semiconductor Thinfilms and Its Applications: An Overview

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Abstract: Thin films have got an enormous interest among the researchers because of their several applications. The major interest in thin films is due to the significant properties differ from bulk. As the film becomes thinner, the properties are essential in the efficiency of elements such as resistors, transistors, capacitors and solar cells. Thin films are fabricated by the deposition of materials on a substrate. A thin film is defined as a low-dimensional material produced by condensing, one-by-one, atomic or molecular or ionic species of matter. Compared to bulk solids, thin films are having very large surface to volume ratio. The present reviews deals with an overview of the semiconductor compounds and tin films growth mechanisms and also the applications of the thin films.
Key words: Nanotechnology, thin films, semiconductors and solar cells.

1. Introduction

Thin film science and technology plays an important role in hi-tech industries. The demand for the development of smaller devices with higher speed, especially in the new generation of integrated circuits, requires advanced materials and new processing techniques suitable for integration technology. The material cost of thin films is extremely small as compared to the corresponding bulk material and they perform the same function when it comes to surface process. Thus, knowledge and determination of the nature, functions and new properties of thin films can be used for the development of new technologies for future applications. Thin film science has received tremendous attention because of its numerous applications in diverse fields such as electronic industries, military weapon systems, space science, solar energy utilization, optical, superconducting, high memory computing, sensors, and in microelectronic and hybrid circuits. Nanotechnology inclusion into the films indicates extraordinary enhance efficiency and lower total cost. Many nano-structured materials are at the present being investigated for their potential applications in photovoltaics. Nano-structured layers in thin film solar cells offer three important advantages. First, due to multiple reflections, the effective optical path for absorption is greatly larger than the actual film thickness. Second, light generated electrons and holes require traveling over a much shorter path and thus recombination losses are greatly reduced. As a result, the absorber layer thickness in nanostructured solar cells can be as thin as 150 nm as an alternative of several micrometers in the traditional thin film solar cells. Third, the energy band gap of various layers can be tailored to the desired design value by varying the size of nano-particles. This allows for more design flexibility in the absorber and window layers in the solar cells.

Semiconducting thin film materials have recently involved much interest as materials for optoelectronics technology. Semiconductor thin films are extensively used in the photovoltaic applications due to their size dependent optical properties and their tunable spectrum in visible to IR. Among others, II–VI group semiconductor nanoparticles are broadly used in such applications. All photovoltaic devices incorporate a p-n junction in a semiconductor across which the photo voltage is developed [1]. Photovoltaic devices are based on the idea of charge separation at an interface of two materials of different conduction mechanism. The dominance of the photovoltaic field by inorganic solid-state junction devices is now being challenged by the emergence of a third generation of solar cells. These offer the prospective of very low cost fabrication and present attractive features that facilitate market entry. It is now possible to depart completely from the classical solid-state junction device, by replacing the contacting phase to the semiconductor by an electrolyte, liquid, gel or solid, thereby forming a photo-electrochemical cell. The phenomenal progress realized recently in the fabrication and characterization of nanocrystalline materials has opened up vast new opportunities for these systems. Contrary to expectation, devices based on interpenetrating networks of microscopic semiconductors have shown strikingly high conversion efficiencies, which compete with those of conventional devices. The prototype of this family of devices is the dye-sensitized solar cell, which realizes the optical absorption and the charge separation processes by the association of a sensitizer as light-absorbing material with a wide band gap semiconductor of nanocrystalline morphology [2].

Electronic semiconductor devices and optical coatings are the main applications benefiting from thin film construction. Thin film properties are sensitive not only to their structure but also to many other parameters, including their thickness especially in the computer elements, sensors and in microelectronic and hybrid circuits and so on. Electronic semiconductor devices and optical coatings are the main applications benefiting from thin film construction. The analysis on thin films have led to the growth of new kind of active devices and passive components, different types of sensors, solar cells, optical image storing devices, electromechanical devices, gas detecting transducers, interference filters, reflecting and antireflecting coatings and ferroelectrics. Thin films can be defined as thin material layers ranging from nanometer to micrometers thickness [3].Thin film deposition involves deposition of individual atoms or deals with the deposition of particles. Thin films refers to a very thin layer of material, the thickness can be varied range between 50 Å to 1000 Å. At present, thin film technology itself is a separate branch and has evolved into a set of techniques used to fabricate many products [4]. Applications of thin film are very large scale production of integrated circuits, electronic packages, optical sensors and devices [5, 6]. Semiconducting thin films play a very important role in the research to development of solar cells. Thin film devices are much useful in photovoltaic conversion in which the solar energy is directly converted into electric energy [7-9]. The aim of this short review is to describe the highlight and to the potential applications of thin films.

2. Growth Kinetics of Thin Films

Thin films are most usually prepared by the condensation of atoms from the vapour phase of a material. Atomistic condensation takes place at the earliest stage of observation, in the form of a three dimensional nuclei which then grow to form a continuous film by diffusion-controlled processes. This condensation is the net result of equilibrium between the absorption and desorption processes taking place in the district of the substrate surface. Many theoretical models of condensation are proposed by various researchers that are fairly consistent with the experimental observations [10, 11]. The steps involved in thin film growth are schematically represented in Fig.1.

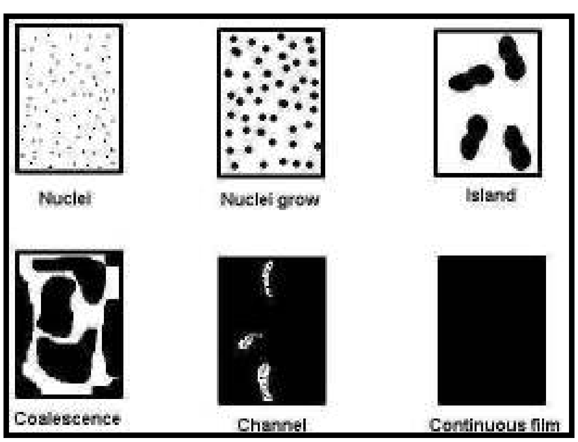

Fig.1 Nucleation and growth kinetics of thin films

The characteristic sequential growth stages in the formation of a continuous film [12] are:

(i) Randomly distributed, three-dimensional nuclei are first formed and fast approach a saturation density with a small amount of deposit. These nuclei then produce to form observable islands whose shapes are determined by interfacial energies and deposition conditions. The growth is diffusion controlled, viz., the clusters diffuse over the substrate surface and are captured by the stable islands. (ii) More deposition increases the size of the islands and these islands approach closer to each other, the large ones appear to grow by coalescence of the smaller ones. Island density decreases at a rate determined by the deposition conditions. (iii) When the island distribution reaches a critical state, a rapid large-scale coalescence of the islands results in a connected network structure and the islands are flattened to increase surface coverage. This process is fast initially and slows down on formation of the network. The network contains a large number of empty channels. (iv) The final step of growth is a slow process of filling the empty channels that requires a considerable amount of deposit. Secondary nucleation takes place in the empty channels and these nuclei grow and coalesce very slowly with further deposition. The above sequence is qualitatively common to all types of vapour deposited films prepared by a variety of techniques. However, the kinetics of each step may vary markedly, depending on the deposition parameters and the deposit-substrate combination.

2.1 Mechanism for Growth of Thin Films

Film development involves deposition of the material, atom-by-atom, molecule-by-molecule and layer-by-layer. It gets enough time intervals for the two successive depositions. In the process of surface diffusion the atoms or molecules interact with themselves and form bigger clusters. These clusters or nuclei are thermodynamically unstable depending on the deposition parameters. After reaching a certain size the clusters become thermodynamically stable and the nucleation barrier is said to have been overcome. The critical nuclei grow in number as well as in size until a saturation nucleation density is reached. The nucleation density and the average nucleus size depend on a number of parameters such as the energy of the impinging species, the rate of impingement, the activation energies of adsorption, desorption, thermal diffusion, temperature and chemical nature of the substrate. A nucleus can grow both parallel to the substrate by surface diffusion of the adsorbed species and perpendicular to it by direct impingement of the incident species. This step involving the formation of stable, critical sized nuclei is called the nucleation stage. Nuclei may increase and gives a certain thickness; the gaps are filled up and form a continuous film. The theory involves film formation over a substrate surface which plays a dominant role in nucleation. If the substrates are different it is called as heterogeneous nucleation. If it is a same substrate then called as homogeneous nucleation. The formation and growth of a film depends upon nucleation, adsorption and cluster formation. In order to explain the nucleation and cluster formation two models namely capillarity model and atomistic or statistical models can be applied.

3. Semiconducting Materials Thin Films

Semiconductor compounds are found in column IV and neighbouring column of periodic table. The column IV semiconductors are called elemental semiconductors because they are composed of single species of atom. In addition to elemental material, compounds of column III and V also can make up compound semiconductors. The elemental semiconductor Ge was widely used in the early days for the development of transistors and diodes. Silicon is now used in majority of transistors, rectifiers and integrated circuits. Compound semiconductors which consist of various elements have a wide range of physical properties, which include bandgap, crystal lattice structures, electron and hole mobility therefore they can be used for many applications. By selecting appropriate compound semiconductors, it becomes possible to realize various devices which cannot be achieved using the main elemental semiconductor material, silicon. It is therefore important to understand the physical properties of compound semiconductors and to know how to select appropriate materials for desired applications. Some of the typical compound semiconductors which consist of more than two elements are shown in Table 1.

Table 1. Various Semiconductor Materials

Elemental	Si, Ge
II-VI compound	CdS, CdSe, CdTe, ZnS, ZnSe, ZnTe, $Hg_{1-x}Cd_xTe$, $Cd_{1-x}Zn_xTe$
III-V compound	GaP, GaAs, GaSb, InP, InAs, InSb
IV-VI compound	PbS, PbSe, PbTe, $Pb_{1-x}Sn_xTe$, $Pb_{1-x}Sn_xSe$
IV-IV compound	SiC, $Si_{1-x}Ge_x$
V-VI compound	Bi_2Te_3
Chalcopyrite	$AgGaS_2$, $AgGaSe_2$, $CuInS_2$, $CuInSe_2$

3.1 Properties of Semiconducting Materials

During the recent decades, semiconductor materials are very essential in the development of broad range electronic and optoelectronic devices for information applications. A significant property of a semiconductor is its temperature dependence of conductivity, i.e., the fact that the conductivity in semiconductors increases with increasing temperature, whereas the conductivity in metals decreases with increasing temperature. One of the essential parameters that often determine the range of applications of a given semiconductor is the essential energy bandgap that splits the conduction from the valence bands, which is typically in the range from 0 to 3 eV for semiconductors [13]. The nanoscale semiconductor particles are with size smaller than 10 nm, this range corresponds to the establishment of quantum confinement. The presence of the particle boundaries and respond to changes in the particle size by adjusting their energy spectra is known as the quantum size effect, where nanoscale particles are often referred to as quantum dots (QDs). As the quantum dot size decreases, the energy gap increases, leading, in particular, to a blue shift of the emission wavelength. In general semiconductors are classified according to the type of bandgap as direct or indirect semiconductors. The bandgap has a major influence on the properties like structural, optical absorption and electrical conductivity of the material. The direct bandgap semiconductors are found to be advantageous over indirect bandgap semiconductors. Most of the II-VI and IV-VI compounds are found to exist as direct bandgap semiconductors and it's dominating the solar cells, IR detectors and optical field for shorter wavelength applications. II-VI and IV-VI semiconducting nanocrystalline thin films have attracted considerable interest of investigators because of their optical, electrical parameters in the optoelectronic, solar cells, IR detectors and photo induced devices. There are several reports available on the deposition of binary thin films in the different substrates. The chalcogenide compounds have been focused on number of investigations because they crystallise in the different crystal systems depending upon the crystal system the applications of the materials also vary.

4. Applications of Thin Film Technology

Thin films are fabricated by the deposition of materials on a substrate by appropriate methods. Thin films with thickness ranging from one to several microns are very important for thermal barrier coatings to protect materials from thermal and atmospheric influences. Thin films have other useful properties of electrical conduction, optical transmittance, reflectivity, absorption and corrosion resistance. Thin films based devices are establish in measuring and controlling the humidity in air and other gases, meteorology, domestic environment, medical equipment, industrial and agricultural processes. Thus, the electronic industries due to the use of thin films in electronic, opto-electronic and other devices have become the greatest beneficiary of thin film technology. The use of thin films in making active and passive electronic components made it possible to produce very large-scale integrated and microcomputer. Due to development of thin film technology, the three dimensional bulk display units became flat. Because of compactness, better performance and reliability and low production cost thin film devices and components are chosen over their bulk counterparts. The thin film technology has applications in diverse field from microelectronics to optics, space science to aircrafts, superconductivity to photovoltaic. One of the most important applications of thin films is in the photovoltaic devices and other solar cells [14]. Studies on thin films have been responsible for the development of active and passive components, different types of sensors [15], solar energy conversion [16], magnetic memory devices [17], superconducting films [18], optical image storing devices [19], electromechanical devices like strain gauge [20], gas detecting transducers [21], interference filters [22] and reflection and antireflection coatings [23].

Majority of semiconductors are used for several applications, bulk crystals as well as thin films state. The II-VI and IV-VI compound chalcogenides cover a broad range of electronic and optical properties due to the wide variations in their direct energy gap efficient emission or absorption of electromagnetic radiation. The II-VI compounds are typically used as n-type and p-type in the devices. The lead chalcogenide materials have narrow energy gaps and high carrier mobility. Most important applications of these compounds are in light emitting devices and detectors in the infrared spectral region. The III-V compounds are significant semiconductors for various device applications. In general, these materials crystallize with a comparatively high degree of stoichiometric and most of them can easily be obtained as n- and p- type. Several of these compounds have direct energy gaps and high carrier mobility. III-V compound semiconductors are used in a variety of optoelectronic devices for both the detection and generation of electromagnetic radiation, and also in high-speed electronic device applications as detectors and diode lasers. The current development is towards new types of devices, monolithic, hybrid circuits, Field Effect Transistors (FET), Metal Oxide Semiconductor Field Effect Transistors (MOSFET), sensors for different applications, switching devices and high-density memory systems for computers. Thin films are used in interference filters, polarized beam splitters, wave guides, couplers, modulators, switches etc. The magnetic film tape would have higher information storage density, main applications in computer memories.

5. Conclusion

Nanometer-sized semiconductor thin films have involved much interest over the past few years because of their novel attractive electrical and optical properties, originating from quantum confinement of charge carriers within the nanoparticles. Due to wide range of applications the nanocrystalline semiconductor thin films gains importance among the researchers. Further progress is estimated in closing the gap between the achieved efficiencies and the theoretically expected ones, with more detailed understanding of the electronic role of interfaces in the layered structure of the devices and with more precisely audited account of photons and excited carriers in the device.

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