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Chalcogenide Semiconductor Technology: Present Status and Future Prospects

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ABSTRACT

Today's electronic devices market depends on wide band semiconductors with the members of chalcogenide compounds. They are chemicals which contain group 16 elements led by oxygen and followed by anion elements, like selenium, sulfur, selenium, tellurium, and others. On the other hand, second components include cations, like, zinc, beryllium, copper, and others. At present, chalcogenide compounds are used for infrared optical windows with strong refractive index. They are used in different optical sensors, especially in photodiode, photo sensor, optical transmission. Obtainable in crystal-like, and nano-crystal-like forms, chalcogenides are noted for their superior electronic, optical, and semiconducting properties. We have discussed present utilization and prospects of this semiconductor. It has been observed that chalcogenides with Cu as another cation component are good to use due to their less toxicity. Even though it is in nanocrystal form. Other chalcogenides are comparatively toxic, for example, cadmium and lead. But they are effectively used in biomedical applications. On the other hand, some applications in photovoltaics are supplemented with copper chalcogenides. They are efficient in clean energy transformation as they efficiently work on photocatalytic activity. In this paper we have reviewed evolutionary applications of chalcogenide compounds in different domains.

Keywords: Semiconductor, Chalcogenide, photonics, Thin film, band gap

I. INTRODUCTION

Chalcogenide semiconductor technology refers to the use of compounds containing elements from the chalcogen group (sulfur, selenium, and tellurium) in semiconductor devices. Chalcogenide semiconductors have unique properties that make them attractive for various applications, including memory devices [1-4], photovoltaics [5], and optoelectronics. A few strategies introduced based on structural conversion processes for the fabrication of nanocomposites [6]. It consists of different metal nanoparticles with a controlled structure. A crystal-like concrete state is basically categorized based on the position of member atoms in the crystal. One can characterise glasses based on neighbour environment in a localized way. It indicates that after altering crystal-like state of material or non-crystal-like, the minimum inter atomic distance between neighbour atoms is nearly similar in structure of crystal. It is due to minor alteration that leads to abolishing the Long-Range Order [7]. CGs hold optical and electrical band gaps around 1-3.2eV and therefore considered as amorphous semiconductor material. These are largely used for photonic characteristics.

TABLE I
FEW PROPERTIES OF EXCEPTIONAL GLASSES

Glass Type	Thermal Extension $10^{-7}/^{\circ}C$	Refractive Index	Transmission energy μm	Hardness Kgf.mm -2
Heavy Metal Oxide	130-180	2.65	0.37-6.5	500
Flouride material	140-180	1.52	0.3-6.75	230-250
Chalcogenide	230-250	2.3-2.7	0.45-10.0	100-250

Chalcogenide material suits the applications because of smart properties like high thermal extension, refractive index, large photosensitivity etc as shown in Table I. Thermal characteristics are identified at different temperatures. These represent the significant parameters which can be considered for realizing applications and manufacturing of Chalcogenides. The suitable values of these factors are calculated by differential thermal investigation [8]. Using first principles calculation, the structural, elastic, and thermal properties have been studied for cadmium based dichalcogenides using an ab initio calculation [9] and the structural and lattice- dynamical properties for lead chalcogenides compounds [10]. It is reported in [9] for the ratio of B/G in the series of the dichalcogenides in a very systematic way. It has been observed that the same ratio is well above the critical value of 1.75, which is the criteria for achieving a good ductility property of the compound. The first principles calculations have also been extensively used to study structural [11, 12] and optical properties for cadmium chalcogenide [13]. A study on band gap of the different polymer composites has been studied using scanning electron microscope (SEM) and transmission electron microscopy (TEM) [14]. The same work reported an uneven distribution of the particle size with a great range of variation. On the other hand, a report on TEM study reveals the assemble of the particles exist in the form of chain formation as dispersoid. The reference of [15], showed a review of wide band gap chalcogenide semiconductor in which authors explored the current state of material research in wide band gap chalcogenide semiconductor with band gap $(E_G > 2\,\mathrm{eV})$ and its importance in current and future research. Electronics band structure, techniques for measuring band gap, material fabrication and characterisation, thermoelectric properties have been studied to analysis the band gap of lead chalcogenide alloys [16]. Significance of CdS as a photodiode in an employing photo electrochemical (PEC) cell is emphasized and structural, optical, and electrical properties are studied and correlated to its PEC performance [17]. A systematic study on the effect of variable doping material in the chalcogenides glasses [18]. It reported bandgap variation of $Se_{100-X}In_X$ (X = 0, 5, 10, 15 and 20) chalcogenide glasses at room temperature and normal pressure and found minimum energy band gap in case of $Se_{90}In_{10}$ chalcogenide glass [18]. Fig.1 shows the comparison study of Chalcogenide Glass.

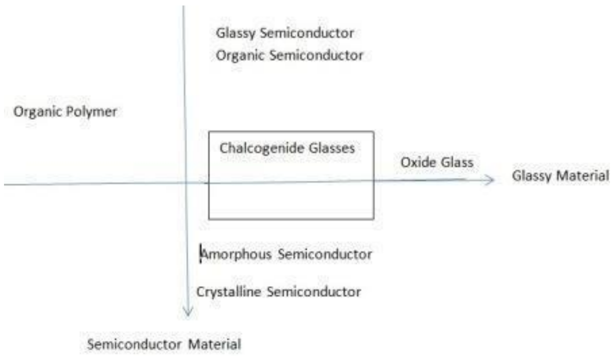

Fig. 1. Classification and comparison of CGs

I. THE HISTORY OF CHALCOGENIDES

Arsenic Sulfide was the first commercially established Chalcogenide Glasses (CGs) during 1950s mainly for Mid Infrared applications. After some years, sulfide along with selenides glasses were produced and utilized for Far Infrared utilization, Utilization of CGs contains the discovery of thermal mistakes, supervision of energy, finding of electronic track faults, recognition of presence of tumor, finding fingerprints of lung cells of human in distinct metabolic situations and continuous monitoring of temperature [19]. Chalcogenide Glasses were established during 1968s to form lively electronic expedient components. Many such applications are found. For example, they are used as primary materials in the process of photocopying. They are also found to be key materials in the process of switching methodology. Some report is worthy to be mentioned as chalcogenide glasses having application to be considered as building block of optical fiber in infrared Communication [20]. In contrast of using silica, they are better option for achieving low attenuation in infrared transmission. The authors in [20] have measured the attenuation in infrared transmission in chalcogenide glasses at 9dB/km. Some report is found on the use of Chalcogenide glasses in the infrared region as sensor application, to decide volatile organic contaminants in ground water [21].

II. THE PRESENT STATUS OF CHALCOGENIDE

Chalcogenide-based memory devices, such as phase-change memory (PCM), have gained significant attention in recent years. PCM utilizes chalcogenide materials that can switch between amorphous and crystalline states, representing the "0" and "1" states of binary data storage. PCM offers advantages such as high-density storage, fast switching speed, and non-volatility. [22] It has the potential to replace traditional memory technologies like flash memory due to its improved performance characteristics. It is worth mentioning for application in non-volatile memory also. It has great commercial value. For instance, crossbar arrays of non-volatile memories are used in an analogue manner [4–7]. Such non-volatile repository includes phase-change memory [29, 30] resistive memory [23–28], and flash memory. On the other hand, another memory device, such as, spin- transfer-torque magneto resistive random-access memory (MRAM) becomes challenging in manufacturing at present. The challenge comes from the fact that the MRAM has low resistance, due to which, crossbar array consumes a large power in the process of multiply– accumulate operations on current summation technique.

Chalcogenide-based photovoltaics have also made progress. At present copper indium gallium selenide (CIGS), a chalcogenide compound, is used as primary material deposited in substrate for solar cell application. CIGS-based solar cells have demonstrated high conversion efficiencies and the ability to be fabricated on flexible substrates, offering potential for low-cost, lightweight solar panels [30].

A great deal of chalcogenides photodiodes is worked on. It includes avalanche photodiode (APD) function. Application of APD can be found in different fields, which includes fiber communications [28,29] biosensing, LiDAR, photonics, quantum information. Even a lot of usage of APD is found in optical communications. It is very useful, as APDs are good for shorter internal response times, having wider optical-to-electrical (O-E) bandwidths.

A low scale power transmission is very effective by using chalcogenide glass fibers for enhanced optical properties and associated dielectric responses. A great deal of such low power transmission applications is engineered in different domains. They include welding, drilling, endoscopy, scanning, microsurgery operation [21]. Effective conversion of light to other forms of energy in chalcogenide glass fibers unlocks an extensive range of applications. By using this property, incorporated optical devices like optical fibers, lenses, multiplexers and demultiplexers, logical essentials of multiple output and optical scanners many more are recognized [22]. CGs are discovered for utilization in optoelectronics area. Changeable optoelectronic expedients founded on chalcogenide glasses have been established. For instance, it is being used for recording and reading data in optical transformed information in memory devices. The present necessities of holographic recording media with short time duration, high precision, and scope of image data collection over large regions are realized to a great satisfactory level with the incorporation of chalcogenide glasses. The photo dissolution of metal properties of chalcogenide is helpful for formation and storage of different image [22]. Some chalcogenides have the property of short time response to cope up the change of phase from amorphous to crystalline alignments, and it is a perfect reversible process. This aspect makes the chalcogenide compound a good choice for high-density memory device manufacturing.

III. THE FUTURE PROSPECT OF HALCOGENIDE

Chalcogenide semiconductor technology holds promise for further advancements and applications. Some of the potential future prospects include:

Memory Technology: Continued research is focused on improving the performance and scalability of chalcogenide-based memory devices. This includes exploring new materials, device architectures, and fabrication techniques to enhance memory density, endurance, and energy efficiency . Chalcogenide-based resistive random-access memory (RRAM) is also an emerging area of interest.

Photovoltaics: Chalcogenide-based solar cells could be optimized to achieve even higher conversion efficiencies and improved stability. Researchers are investigating novel chalcogenide materials and device structures to enhance light absorption, carrier mobility, and charge collection. Integration of chalcogenide materials in tandem solar cells or hybrid systems may also be explored.

Optoelectronics: Chalcogenide semiconductors have unique optical properties, making them suitable for optoelectronic applications. Future prospects include the development of chalcogenide-based photodetectors, light- emitting devices, and lasers. These devices could find applications in telecommunications, sensing, and imaging

.

Energy Storage: Chalcogenide materials, particularly sulfides, have shown potential for energy storage applications. They can be used as electrode materials in batteries and supercapacitors. Research is focused on improving their electrochemical performance, stability, and cyclability.

Emerging Applications: Chalcogenide semiconductors may find applications in emerging technologies such as neuromorphic computing, where their unique properties can be utilized for efficient information processing and pattern recognition .

Overall, the present status of chalcogenide semiconductor technology is promising, with significant progress made in memory devices and photovoltaics. The future prospects of this technology are wide-ranging, spanning memory technology, photovoltaics, optoelectronics, energy storage, and emerging applications. Continued research and development efforts are likely to drive further advancements, leading to the commercialization of chalcogenide-based devices in various fields. Through improving the activity above the present status, the chalcogenide tinny films incorporated with biological surface can open much exposure in using biosensors with great sensitivity.

IV. CONCLUSION

A great deal of research work on the applicability of chalcogenides is highly focused in front of research community. Specially it is emphasized for bright prospect of amorphous chalcogenide semiconductor. Different kinds of research are going on to focus on advanced application of fundamental discoveries. These research inclinations will quicken the progress of the area, which seems, at present, still ridiculous in unexpected discoveries. Seeking methodology for improvements in the response to quick phase change of chalcogenides pays much attention by considering wide band gap-based chalcogenide substances, and their application and engineering on the device's construction. They will be assets for effective sensor, communication, medical application, optoelectronics, high density memory device, energy storage device manufacturing in future.

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