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A Review On Semiconductor Chalcogenide Thin Films: Properties, Fabrication, And Applications

J. A. Borse
Department of Physics, Late Pushpadevi Patil Arts & Science College Risod. Washim- 444506

Abstract

Chalcogenide semiconductor thin films, comprising elements from Group VI (S, Se, Te) and Groups IV–VI metals (e.g., Cd, Pb, Sn, In, Cu, Ga), have gained immense attention for their versatile optical and electrical properties. These materials exhibit a tunable band gap, high absorption coefficients, and cost-effective fabrication, making them suitable for diverse applications, including photovoltaics, photo detectors, thermoelectric, and phase-change memory devices. This review provides a comprehensive summary of the synthesis techniques, structural and optoelectronic properties, and emerging applications of key chalcogenide thin films such as CdSe, CdTe, SnS, $CuInSe_2$, and GeTe. Emphasis is placed on how doping, nanostructuring, and fabrication processes influence film characteristics and performance. The review concludes with current challenges and future prospects in this rapidly evolving field.

Keywords

Chalcogenide thin films, semiconductor, CdSe, SnS, $CuInSe_2$, photovoltaics, thermoelectric, doping, chemical synthesis, band gap engineering

1. Introduction

Chalcogenide semiconductors are compounds formed between chalcogenide elements (S, Se, Te) and metals from groups II–VI, III–VI, or IV–VI. These materials have unique photoelectric and thermoelectric properties, which make them promising candidates for next-generation energy and electronic devices. The thin film form of these materials is especially attractive due to its scalability, cost-effectiveness, and the ability to tune material properties via deposition parameters or doping. Among the most extensively studied chalcogenide thin films are cadmium selenide (CdSe), cadmium telluride (CdTe), copper indium diselenide ($CuInSe_2$), tin sulfide (SnS), and germanium telluride (GeTe). These films find broad applications in solar cells, IR detectors, sensors, and non-volatile memory due to their direct bandgap, high optical absorption, and compatibility with flexible substrates.

2. Types of Semiconductor Chalcogenide Thin Films

2.1 Cadmium Selenide (CdSe)

CdSe is a II–VI semiconductor with a direct band gap (~1.7 eV). Its high absorption coefficient and good electron mobility make it suitable for solar cells and photodetectors. CdSe thin films can be deposited using methods such as chemical bath deposition (CBD), electrodeposition, and spray pyrolysis.

2.2 Tin Sulfide (SnS)

SnS is a promising IV–VI chalcogenide with a band gap around 1.3–1.5 eV and high absorption ($>10^4$ cm^{-1}). Due to its earth-abundant, non-toxic nature, SnS is being explored as an alternative absorber layer in photovoltaics. The anisotropic crystal structure also makes it of interest for thermoelectric applications.

2.3 Copper Indium Diselenide ($CuInSe_2$, CIS)

CIS belongs to the chalcopyrite family and has a direct band gap of ~1.0 eV. It shows superior photovoltaic performance when alloyed with Ga (forming CIGS). Films are typically prepared by sputtering or co-evaporation and require high-temperature post-annealing for crystallization.

2.4 Cadmium Telluride (CdTe)

CdTe is one of the most successful thin-film PV materials with an optimal band gap (~1.45 eV). CdTe-based solar panels have achieved commercial success due to low production cost and high efficiency. However, toxicity and cadmium regulation remain challenges.

2.5 Germanium Telluride (GeTe)

GeTe is a narrow-gap semiconductor (~0.6 eV) that is widely studied for its phase-change memory properties. It switches between amorphous and crystalline states under thermal stress, making it ideal for data storage applications.

3. Fabrication Techniques

Chalcogenide thin films can be deposited using both **physical** and **chemical** techniques:

- **Chemical methods**: Chemical Bath Deposition (CBD), Successive Ionic Layer Adsorption and Reaction (SILAR), spray pyrolysis
- **Physical methods**: Thermal evaporation, Pulsed Laser Deposition (PLD), sputtering, Molecular Beam Epitaxy (MBE)

Parameters such as precursor concentration, substrate temperature, pH, and annealing significantly affect the film's microstructure, crystallinity, and electronic properties.

4. Properties of Chalcogenide Thin Films

Material	Band Gap (eV)	Optical Absorption	Electrical Conductivity	Notable Features
CdSe	~1.7	High	Moderate	Photodetector, solar cell
SnS	1.3–1.5	Very High	p-type	Non-toxic, absorber
$CuInSe_2$	~1.0	High	High (p-type)	PV absorber layer
CdTe	~1.45	High	Moderate	Commercial PV material
GeTe	~0.6	Moderate	Phase-change	Memory devices

Structural Properties: Crystallinity, grain size, and orientation affect carrier mobility and recombination.

Optical Properties: Band gap tuning can be achieved through doping or quantum confinement in nanostructured films.

Electrical Properties: Controlled by doping concentration, intrinsic defects (e.g., vacancies), and post-deposition annealing.

5. Doping and Alloying Effects

Doping is a key strategy to improve performance. Examples include:

- **Cu or In doping in CdSe**: Enhances conductivity and modifies band structure.
- **Al or Ag doping in SnS**: Increases carrier concentration and reduces resistivity.
- **Ga addition in $CuInSe_2$**: Improves efficiency and stability (forming CIGS).
- **Sb or Bi doping in GeTe**: Enhances phase-change speed and data retention.

These dopants introduce localized energy levels or modify crystallinity, enhancing device performance.

6. Applications

- **Photovoltaics**: CdTe, $CuInSe_2$, and SnS thin films are used in commercial and experimental solar cells.
- **Photodetectors**: CdSe and SnS films are responsive in the visible and near-IR range.
- **Phase-Change Memory**: GeTe and its alloys are widely used in non-volatile memory devices.
- **Thermoelectrics**: SnSe and Sb_2Te_3-based chalcogenide show high thermoelectric efficiency due to low thermal conductivity.

7. Challenges and Future Directions

- **Toxicity** of Cd and Te poses environmental and health concerns.
- **Stability** under long-term exposure (UV, humidity) needs improvement.
- **Scalability** and uniform deposition over large areas require advanced process control.
- **Bandgap Engineering** through nanostructuring and heterostructures is a key research area.

Future research is focusing on **eco-friendly alternatives**, **2D chalcogenide**, **hybrid perovskite-chalcogenide systems**, and **integration with flexible electronics**.

8. Conclusion

Semiconductor chalcogenide thin films represent a diverse and promising class of materials with significant potential across electronics, energy, and sensing technologies. Their unique combination of tunable optoelectronic properties and compatibility with low-cost fabrication techniques makes them key candidates for future innovation. Continued research into their physical properties, doping behavior, and device integration will be crucial to unlocking their full potential.

References

1. Mitzi, D. B. et al., "Chalcogenide semiconductors for thin-film solar cells", *Nature Materials*, 2020.
2. Chopra, K. L., "Thin Film Solar Cells", *Springer*, 2010.
3. Liu, X. et al., "A critical review of chalcogenide thin films for PV applications", *Solar Energy Materials & Solar Cells*, 2017.
4. Tiwari, A. N., "CIGS Thin Film Solar Cells", *Progress in Photovoltaics*, 2012.
5. Kolobov, A. V., "Phase-Change Chalcogenide Thin Films", *Springer Series in Materials Science*, 2018.
6. Alireza Goudarzi, Ghaffar Motedayen Aval, Reza Sahraei, Hiva Ahmadpoor, **2008**. Ammonia-free chemical bath deposition of nanocrystalline ZnS thin film buffer layer for solar cells. *Thin Solid Films*, 516, P-4953-4957. https://doi.org/10.1016/j.tsf.2007.09.051
7. Naglaa Fathy, Masaya Ichimura, **2005**. Photoelectrical properties of ZnS thin films deposited from aqueous solution using pulsed electrochemical deposition, *Solar Energy Materials and Solar Cells*. 87, P-747-756. https://doi.org/10.1016/j.solmat.2004.07.048
8. H.M.M.N. Hennayaka, Ho Seong Lee, **2013**. Structural and optical properties of ZnS thin film grown by pulsed electrodeposition, ***Thin Solid Films***, **548**, P-86-90. **https://doi.org/10.1016/j.tsf.2013.09.011**
9. Poulomi Roy, Jyoti R.Ota, Suneel Kumar Srivastava, **2006**. Crystalline ZnS thin films by chemical bath deposition method and its characterization, *Thin Solid Films*, 515, P- 1912-1917. https://doi.org/10.1016/j.tsf.2006.07.035
10. J.Wang,T.Li, Q.Wang,W.Wang, R.Shi, N.Wang, A.Amini, C.Cheng, **2020**.Controlled growth of atomically thin transition metal dichalcogenides via chemical vapor deposition method, Material todays advances, 8, P-100098. https://doi.org/10.1016/j.mtadv.2020.100098
11. J.M.Blackmore, A.G.Cullis, **1991**.The structure of ZnS thin films deposited by r.f. sputtering, *Thin Solid Films*,199, P-321-334 https://doi.org/10.1016/0040-6090(91)90014-O
12. EdwinJose, M.C.Santhosh Kumar, **2017**.Room temperature deposition of highly crystalline Cu-Zn-S thin films for solar cell applications using SILAR method, *Journal of Alloys and Compounds*, 712, P-649-656. https://doi.org/10.1016/j.jallcom.2017.04.097
13. Tayfur Kucukomeroglu, Emin Bacaksiz, CabirTerzioglu, AhmetVarilci, **2008**.Influence of fluorine doping on structural, electrical and optical properties of spray pyrolysis ZnS films, *Thin Solid Films*,516, P-2913-2916 https://doi.org/10.1016/j.tsf.2007.05.075
14. G Contreras-Puente, OVigil, MOrtega-López, AMorales-Acevedo, JVidal, M.LAlbor-Aguilera, **2000**.New window materials used as heterojunction partners on CdTe solar cells, *Thin Solid Films*,361–362, P- 378-382. https://doi.org/10.1016/S0040-6090(99)00806-8
15. Hyun JooLee, Soo IlLee, **2007**.Deposition and optical properties of nanocrystalline ZnS thin films by a chemical method, *Current Applied Physics*, 7, P-193-197. https://doi.org/10.1016/j.cap.2006.03.005
16. M. Muthusamy, S. Muthukumaran, (2015) Effect of Cu-doping on structural, optical and photoluminescence properties of CdS thin films. Opt. Int. J. Light Electron. Opt. 126(24), 5200–5206.
17. A. AbdolahzadehZiabari, F.E. Ghodsi, (2013) Influence of Cu doping and post-heat treatment on the microstructure, optical properties and photoluminescence features of sol-gel derived nanostructure CdS thin films. J. Lumin. 141, 121–129.

18. P. Kumar, N. Saxena, A. Agarwal, V. Gupta, (2015) Influence of Ag doping concentration on structural and optical properties of CdS thin film. AIP Conf. Proc. 1661, 080017.
19. T. Gaewdang, N. Wongcharoen, T. Wongcharoen, (2012) Characterisation of CdS/CdTe heterojunction solar cells by current-voltage measurements at various temperatures under illumination. Energy Procedia 15(2011), 299–304.
20. R. Ochoa-Landín, J. Sastre-Hernández, O. Vigil-Galan, R.Ramírez-Bon,(2010) Chemically deposited CdS by an ammonia-free process for solar cells window layers. Sol. Energy 84(2), 208–214.
21. S.A. Mirsagatov, R.R. Kabulov, M.A. Makhmudov, (2013) Injection photodiode based on an n-CdS/p-CdTe heterostructure. Semiconductors 47(6), 825–830.
22. T.T. Xuan, J.Q. Liu, R.J. Xie, H.L. Li, Z. Sun, (2015)Microwave-assisted synthesis of CdS/ZnS: Cu quantum dots for white light-emitting diodes with high color rendition. Chem. Mater. **27**(4), 1187–1193.
23. T Abe, J. Sato, S. Ohashi, M. Watanabe, Y. Kashiwaba,(2002) Light emission of a CdS(Cu)/CdS thin-film diode. Phys. Status Solidi Basic Res. **229**(2), 1015–1018.
24. S.R. Ferrá-González et al.,(2014) Optical and structural properties of CdS thin films grown by chemical bath deposition doped with Ag by ion exchange. Opt. Int. J. Light Electron. Opt. 125(4), 1533–1536.