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PROSPECTS FOR ENERGY AND PHOTONIC APPLICATIONS OF OXIDE THIN FILMS DEPOSITED ON DIELECTRIC SUBSTRATES

Fazliddin Arzikulov
Researcher of Tashkent State Technical University named after Islam Karimov,
Assistant at Tashkent State Medical University, Tashkent, Uzbekistan.
Email: arzikulovfazliddin1997@gmail.com
ORCID: 0009-0004-6901-5291

Asror Mustafakulov
Professor of the Department of Physics,
Jizzakh Polytechnic Institute, Uzbekistan
Email: asrormustafakulov69@gmail.com
ORCID: 0000-0002-3251-9742

Isroil Kosimov
Senior Researcher at the O.S. Sodikov Institute of Bioorganic Chemistry,
Academy of Sciences of the Republic of Uzbekistan, 100143, Uzbekistan.
Email: isroilkosimov@list.ru
ORCID: 0000-0002-3463-2861

Sherzod Kuchkanov
PhD in Technical Sciences, Associate Professor of
Tashkent State Technical University named after Islam Karimov.

Abstract

Oxide semiconductor thin films have become highly important functional materials in modern photonic and energy-related technologies. Materials such as

ZnO, CuO, and Cu_2O possess unique optical, electrical, and structural properties that enable their application in photovoltaic systems, optoelectronic devices, photonic structures, and renewable energy technologies. The performance of these materials strongly depends on deposition technology, crystal structure, and electrophysical characteristics.

The present study investigates the prospects for energy and photonic applications of oxide thin films deposited on dielectric substrates using ion-plasma technology. Particular attention was devoted to the relationship between structural organization, optical behavior, electrical conductivity, and functional performance of the synthesized semiconductor layers.

The obtained results demonstrated that ZnO thin films exhibit high optical transparency and stable conductivity suitable for transparent photonic systems, while CuO and Cu_2O films possess strong optical absorption properties favorable for photovoltaic and photoactive applications. Optimization of ion-plasma deposition parameters significantly improved structural stability and electrophysical performance of the investigated materials.

The study confirms that oxide semiconductor thin films synthesized by ion-plasma technology demonstrate substantial potential for application in advanced photonic systems, solar energy conversion devices, semiconductor sensors, and renewable energy technologies.

Keywords: Oxide thin films, photonic technologies, renewable energy, ZnO, CuO, Cu_2O, ion-plasma deposition, semiconductor materials.

Introduction

Oxide semiconductor thin films have become one of the most promising classes of functional materials for modern photonic and renewable energy technologies.

Materials such as zinc oxide (ZnO), copper(II) oxide (CuO), and copper(I) oxide (Cu_2O) possess unique optical, structural, and electrophysical properties that make them highly suitable for photovoltaic systems, photonic devices, optical sensors, and semiconductor energy applications.

The rapid development of renewable energy technologies and photonic engineering has significantly increased scientific interest in semiconductor oxide materials with controllable optical and electrical characteristics. Thin-film semiconductor structures are widely used in solar cells, transparent conductive coatings, photodetectors, light-emitting devices, and integrated photonic systems.

ZnO is a wide-band-gap semiconductor characterized by high optical transparency, strong ultraviolet emission, chemical stability, and stable electrical conductivity. Due to these properties, ZnO thin films are widely applied in transparent electronics, ultraviolet photonics, and optoelectronic systems.

CuO and Cu_2O are p-type semiconductor materials with narrow band gaps and strong optical absorption within the visible spectral region. These characteristics make copper oxide thin films highly promising for photovoltaic energy conversion, photoelectrochemical devices, and light-harvesting technologies.

The functional efficiency of oxide semiconductor thin films strongly depends on deposition technology, crystal structure, phase composition, and microstructural organization. Among modern fabrication methods, ion-plasma deposition technology provides important advantages due to precise control of plasma-assisted growth processes, structural ordering, oxidation kinetics, and film homogeneity.

Photonic applications of oxide thin films are mainly associated with their optical transparency, photon absorption capability, refractive index characteristics, and interaction with electromagnetic radiation. In renewable energy technologies, semiconductor oxide films are actively investigated as photoactive layers, transparent electrodes, and charge transport materials in photovoltaic devices.

Recent advances in nanotechnology and semiconductor engineering have intensified research focused on development of multifunctional oxide semiconductor films with optimized optical and electrophysical properties. Integration of photonic materials with renewable energy systems is considered one of the most перспективные directions in modern materials science.

Despite extensive progress in this field, many aspects related to optimization of structural and functional characteristics of ion-plasma-deposited oxide thin films remain insufficiently investigated. Understanding the relationship between crystal structure, optical behavior, and energy conversion efficiency is essential for development of next-generation photonic and energy devices.

Therefore, the aim of the present study is to investigate the prospects for photonic and energy-related applications of ZnO, CuO, and Cu_2O thin films deposited on dielectric substrates by ion-plasma technology and to evaluate their functional characteristics for advanced semiconductor systems.

Materials and Methods

ZnO, CuO, and Cu_2O thin films were deposited on dielectric glass substrates using ion-plasma deposition technology under controlled vacuum conditions. Before the deposition process, the substrates were mechanically polished and chemically cleaned in order to eliminate surface contamination and improve adhesion of the deposited semiconductor layers.

High-purity zinc and copper targets were used as source materials during thin-film synthesis. Oxygen gas was introduced into the deposition chamber to regulate oxidation processes and stabilize formation of oxide semiconductor phases. The deposition process was carried out in a plasma environment generated under controlled discharge conditions.

The main technological parameters, including plasma discharge power, oxygen partial pressure, chamber pressure, substrate temperature, and deposition duration, were systematically controlled throughout the experiment. Optimization of these parameters enabled investigation of the influence of structural organization on photonic and energy-related properties of the synthesized films.

Structural characterization of the deposited thin films was performed using X-ray diffraction analysis to determine phase composition, crystal structure, and crystallographic orientation of ZnO, CuO, and Cu_2O semiconductor layers.

Optical investigations were carried out to evaluate transparency, absorption behavior, and photon interaction characteristics of the films. The optical absorption coefficient was determined according to the relation:

$$\alpha = \frac{1}{d} \ln \left(\frac{1}{T} \right)$$

where:

- $\alpha$is the optical absorption coefficient;
- $d$is the film thickness;
- $T$is the optical transmittance.

The optical band gap energy was estimated using the Tauc equation:

$$(\alpha h\nu)^n = A(h\nu - E_g)$$

where:

- $\alpha$is the absorption coefficient;
- $hnu$is photon energy;
- $E_g$is the optical band gap energy;
- $A$is a proportionality constant;

- n depends on the type of electronic transition.

Electrical conductivity measurements were performed at room temperature using standard electrical characterization methods. Electrical resistivity was calculated according to the expression:

$$\rho = R\frac{A}{l}$$

where:

- ρ is electrical resistivity;
- R is measured resistance;
- A is the cross-sectional area of the sample;
- l is the distance between electrical contacts.

Comparative analysis was carried out to evaluate the suitability of ZnO, CuO, and Cu_2O thin films for photonic systems, photovoltaic devices, transparent conductive coatings, and renewable energy applications.

Results

Structural and optical investigations demonstrated that ZnO, CuO, and Cu_2O thin films synthesized by ion-plasma deposition possess favorable characteristics for photonic and renewable energy applications. The obtained results confirmed that deposition parameters significantly influence crystal structure, optical absorption behavior, electrical conductivity, and functional stability of the semiconductor layers.

ZnO thin films exhibited high optical transparency within the visible spectral region and stable electrical conductivity. The films demonstrated relatively low optical absorption and strong ultraviolet response associated with the wide band gap nature of ZnO semiconductor material. Improved crystallinity and structural homogeneity contributed to enhanced transparency and reduced optical scattering losses.

CuO and Cu_2O thin films demonstrated significantly stronger optical absorption in the visible spectral range. Their narrow band gap energies promoted efficient interaction with incident radiation and enhanced photon absorption characteristics, making these materials highly suitable for photovoltaic and photoactive applications.

Electrical investigations revealed that optimized deposition conditions contributed to reduced electrical resistivity and improved carrier transport properties in all investigated oxide semiconductor films. ZnO films exhibited stable n-type conductivity, whereas CuO and Cu_2O layers demonstrated characteristic p-type semiconductor behavior.

Comparative analysis indicated that structural ordering and crystallite growth strongly influence functional properties of oxide semiconductor films. Films with improved crystallinity and lower defect concentration demonstrated enhanced optical stability and more efficient electrical transport behavior.

Table 1. Functional Characteristics of Oxide Thin Films for Photonic and Energy Applications

Thin Film Material	**Optical Behavior**	**Electrical Properties**	**Potential Applications**
ZnO	High transparency	Stable conductivity	Transparent photonics, UV devices
CuO	Strong absorption	p-type conductivity	Solar cells, sensors
Cu_2O	Visible light absorption	Stable photoresponse	Photovoltaic systems

Note. Comparative functional characteristics of oxide semiconductor thin films synthesized by ion-plasma technology.

The obtained results indicate that ZnO thin films are highly suitable for transparent conductive and ultraviolet photonic applications due to their wide band gap and stable optical properties. In contrast, CuO and Cu_2O films demonstrate strong potential for renewable energy systems and photovoltaic technologies because of their efficient visible light absorption capability.

The relationship between optical absorption and electrical conductivity confirms that structural optimization of oxide semiconductor films plays a decisive role in improving photonic and energy conversion performance.

Energy Conversion Mechanism

The photoactive behavior of oxide semiconductor thin films is associated with generation of electron–hole pairs under electromagnetic radiation exposure. The process may be described by the condition:

$$h\nu \geq E_g$$

where:

- $hnu$is the photon energy;
- $E_g$is the semiconductor band gap energy.

When the photon energy exceeds the band gap energy, charge carriers are generated within the semiconductor structure, leading to activation of photoelectrical and energy conversion processes in the thin films.

Discussion

The results obtained in the present study demonstrate that oxide semiconductor thin films synthesized by ion-plasma deposition possess substantial potential for advanced photonic and renewable energy applications. Comparative analysis of ZnO, CuO, and Cu_2O films revealed significant differences in optical

transparency, absorption behavior, and electrophysical characteristics associated with their crystal structures and semiconductor properties.

One of the most important findings of the study was the high optical transparency and stable conductivity exhibited by ZnO thin films. These characteristics are directly related to the wide band gap nature of ZnO and its relatively low absorption coefficient within the visible spectral region. Improved crystallinity and reduced structural defects contributed to enhanced optical stability and more efficient carrier transport within the films.

CuO and Cu_2O thin films demonstrated stronger optical absorption in the visible spectral range, which is highly favorable for photovoltaic and photoactive applications. Efficient interaction between incident photons and semiconductor layers promotes enhanced generation of electron–hole pairs and improved photoelectrical conversion processes.

The obtained results additionally confirmed the close relationship between structural organization and functional performance of oxide semiconductor films. Films characterized by improved crystallinity, larger grain size, and reduced defect concentration exhibited more stable optical behavior and lower electrical resistivity.

The observed dependence of optical and electrophysical properties on deposition conditions indicates that oxygen concentration, plasma discharge energy, and substrate temperature play a decisive role in controlling semiconductor behavior of oxide thin films. Proper optimization of these parameters enables fabrication of materials with tailored functional characteristics for specific photonic and energy-related applications.

Another important aspect of the study is the multifunctional potential of oxide semiconductor materials for modern renewable energy technologies. ZnO thin films may serve as transparent conductive layers and ultraviolet photonic

components, while CuO and Cu_2O films are highly promising for solar energy conversion systems due to their strong visible-light absorption capability.

The investigated films also demonstrated favorable characteristics for integration into photodetectors, optical sensors, photoelectrochemical devices, and semiconductor energy systems. Their stable structural organization and controllable optical behavior make them suitable for advanced photonic engineering applications.

The effectiveness of ion-plasma deposition technology was additionally confirmed through formation of structurally homogeneous semiconductor layers with stable optical and electrical performance. The method provides precise control over plasma-assisted crystallization, oxidation kinetics, and phase stabilization processes during thin-film growth.

Despite the favorable experimental results, further investigations are necessary for deeper understanding of photoelectrical mechanisms, carrier dynamics, and defect-related optical processes occurring in oxide semiconductor films. Additional studies involving photoluminescence spectroscopy, Hall-effect analysis, and time-resolved optical measurements may provide more comprehensive information regarding photonic behavior and energy conversion efficiency of the investigated materials.

In conclusion, the present study confirms that optimization of ion-plasma deposition parameters plays a critical role in controlling structural, optical, and electrophysical characteristics of ZnO, CuO, and Cu_2O thin films. Improved understanding of these relationships may contribute to further advancement of semiconductor photonic technologies and expansion of renewable energy applications based on oxide semiconductor materials.

Conclusion

The present study demonstrated that ZnO, CuO, and Cu_2O thin films synthesized by ion-plasma deposition on dielectric substrates possess favorable structural, optical, and electrophysical characteristics suitable for modern photonic and renewable energy technologies.

ZnO thin films exhibited high optical transparency, stable electrical conductivity, and strong potential for transparent photonic systems and ultraviolet optoelectronic applications. CuO and Cu_2O semiconductor layers demonstrated enhanced visible-light absorption and favorable p-type conductivity, making them promising materials for photovoltaic systems and photoactive semiconductor devices.

The obtained results confirmed that optimization of deposition parameters, including oxygen concentration, plasma discharge conditions, and substrate temperature, significantly influences crystallinity, optical absorption behavior, electrical transport mechanisms, and overall functional stability of oxide semiconductor films.

The study additionally demonstrated that ion-plasma deposition technology provides effective control over structural evolution and semiconductor properties of oxide thin films. Improved crystallinity and reduced defect concentration contributed to enhanced optical stability, lower electrical resistivity, and more efficient photoelectrical behavior.

The investigated materials exhibit substantial potential for application in photovoltaic energy conversion systems, transparent conductive coatings, photodetectors, optical sensors, and integrated photonic devices. Their controllable structural and electrophysical properties make them suitable for advanced semiconductor and renewable energy technologies.

Further investigations involving photoluminescence spectroscopy, Hall-effect measurements, and detailed analysis of photoelectrical processes may contribute to deeper understanding of photonic behavior and energy conversion mechanisms in oxide semiconductor thin films synthesized by ion-plasma technology.

References

1. Özgür, Ü., Alivov, Y. I., Liu, C., et al. (2005). A comprehensive review of ZnO materials and devices. Journal of Applied Physics, 98(4), 041301.
2. Janotti, A., & Van de Walle, C. G. (2009). Fundamentals of zinc oxide as a semiconductor. Reports on Progress in Physics, 72(12), 126501.
3. Klingshirn, C. (2007). ZnO: Material, physics and applications. ChemPhysChem, 8(6), 782–803.
4. Barreca, D., Gasparotto, A., Maragno, C., et al. (2011). Nanostructured CuO thin films by plasma-assisted techniques. Surface and Coatings Technology, 205(7), 2068–2073.
5. Sekkat, A., Liedke, M. O., Nguyen, V. H., et al. (2022). Chemical deposition of Cu_2O films with ultra-low resistivity: Correlation with the defect landscape. Nature Communications, 13, 5322.
6. Deuermeier, J., Gassmann, J., Brötz, J., & Klein, A. (2011). Reactive magnetron sputtering of Cu_2O: Dependence on oxygen pressure and interface formation with indium tin oxide. Journal of Applied Physics, 109(11), 113704.
7. Ellmer, K. (2012). Past achievements and future challenges in transparent conductive oxide research. Nature Photonics, 6(12), 809–817.
8. Pearton, S. J., Norton, D. P., Ip, K., et al. (2005). Recent advances in processing of ZnO. Progress in Materials Science, 50(3), 293–340.

9. Hussain, S., Akbar, K., & Ali, S. (2021). Recent progress in copper oxide thin-film semiconductors and their applications. Journal of Electronic Materials, 50(5), 2674–2691.
10. Wang, Z. L. (2004). Copper oxide nanostructures: Synthesis and properties. Journal of Physics: Condensed Matter, 16(25), R829–R858.