Global Conference on Multidisciplinary Research and Innovation
Hosted Online from Berlin, Germany
Date: 2nd May, 2026
Website: https://econferencia.com

EVALUATION OF OPTICAL AND ELECTROPHYSICAL PARAMETERS OF OXIDE THIN FILMS DEPOSITED ON DIELECTRIC SUBSTRATES

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Abstract

Oxide semiconductor thin films have become highly important materials in modern electronics, optoelectronics, and renewable energy technologies due to their unique optical and electrophysical properties. ZnO, CuO, and Cu_2O thin films exhibit considerable potential for application in photovoltaic systems, transparent conductive coatings, photodetectors, and sensor devices. The functional characteristics of these materials strongly depend on their structural organization, optical behavior, and electrical transport properties.

The present study investigates the optical and electrophysical parameters of oxide semiconductor thin films deposited on dielectric substrates using ion-plasma technology. Particular attention was devoted to the relationship between structural characteristics, optical absorption behavior, and electrical conductivity of the synthesized films.

The obtained results demonstrated that deposition conditions significantly influence optical transparency, absorption coefficient, electrical resistivity, and charge transport characteristics of oxide semiconductor layers. ZnO thin films exhibited high optical transparency and stable conductivity, while CuO and Cu_2O films demonstrated strong optical absorption within the visible spectral region.

The investigated oxide thin films showed favorable electrophysical and optical characteristics suitable for application in optoelectronic systems and renewable energy technologies. The obtained results confirm that ion-plasma deposition provides effective control over the functional parameters of semiconductor oxide films.

Keywords. Oxide thin films, optical properties, electrophysical characteristics, ZnO, CuO, Cu_2O, ion-plasma deposition, semiconductor materials.

Introduction

Oxide semiconductor thin films have attracted significant scientific and technological interest due to their wide range of applications in modern electronic, optoelectronic, and renewable energy systems. Materials such as zinc oxide (ZnO),

copper(II) oxide (CuO), and copper(I) oxide (Cu_2O) possess unique optical and electrophysical characteristics that make them promising candidates for photovoltaic devices, transparent conductive coatings, gas sensors, photodetectors, and semiconductor energy technologies.

The optical and electrical behavior of oxide semiconductor films strongly depends on crystal structure, phase composition, defect concentration, and synthesis conditions. Parameters such as optical transparency, absorption coefficient, electrical conductivity, carrier mobility, and resistivity are closely related to the microstructural organization of the deposited films.

ZnO is a wide-band-gap semiconductor characterized by high transparency in the visible spectral region and stable electrical conductivity. In contrast, CuO and Cu_2O possess relatively narrow band gaps and high absorption coefficients, making them highly suitable for solar energy conversion and optoelectronic applications.

The growing demand for high-performance semiconductor materials has increased interest in controlling optical and electrophysical parameters of oxide thin films through advanced deposition technologies. Among various fabrication methods, ion-plasma deposition is considered an effective technique due to its ability to provide controlled growth conditions, high film uniformity, improved adhesion, and precise regulation of structural properties.

During ion-plasma synthesis, energetic plasma particles interact with the substrate surface and influence nucleation processes, crystallization mechanisms, defect formation, and charge transport behavior. Variations in deposition parameters such as plasma discharge power, oxygen concentration, substrate temperature, and deposition duration may significantly affect optical and electrical characteristics of the obtained films.

Optical properties of semiconductor thin films are usually associated with photon absorption processes, electronic band structure, and defect-related energy states.

Electrophysical behavior is determined by carrier concentration, mobility, grain boundary effects, and structural imperfections within the semiconductor material.
Recent advances in nanotechnology and semiconductor engineering have intensified research on multifunctional oxide thin films with optimized optical and electrical performance. Understanding the relationship between structural organization and functional characteristics is essential for development of highly efficient optoelectronic and energy-related devices.
Despite extensive investigations of oxide semiconductor materials, many aspects related to simultaneous evaluation of optical and electrophysical parameters of ion-plasma-deposited thin films remain insufficiently studied. Comparative analysis of these properties may provide deeper understanding of structure–property relationships in semiconductor oxide systems.
Therefore, the aim of the present study is to evaluate the optical and electrophysical parameters of oxide thin films deposited on dielectric substrates and to investigate the influence of deposition conditions on their functional characteristics.

Materials and Methods

ZnO, CuO, and Cu_2O oxide thin films were deposited on dielectric glass substrates using ion-plasma deposition technology under controlled vacuum conditions. Before deposition, the substrates were mechanically polished and chemically cleaned to remove contaminants and improve adhesion between the substrate surface and the deposited semiconductor layers.
High-purity zinc and copper targets were used as source materials for thin-film growth. Oxygen gas was introduced into the deposition chamber during synthesis 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 technological parameters of deposition, including plasma discharge power, oxygen partial pressure, chamber pressure, substrate temperature, and deposition duration, were systematically controlled during film growth. Variations in these parameters allowed investigation of their influence on optical and electrophysical characteristics of the deposited films.

Structural and optical investigations were performed using spectroscopic and diffraction analysis techniques. Optical transmission and absorption behavior of the films were evaluated within the visible spectral region. 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 of the semiconductor films was estimated using the Tauc relation:

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

where:

- $\alpha$is the absorption coefficient;
- hnuis the photon energy;
- $E_g$is the optical band gap energy;
- $A$is a proportionality constant;
- $n$depends on the type of electronic transition.

Electrophysical properties of the deposited films were evaluated through electrical conductivity and resistivity measurements performed at room temperature. Electrical resistivity was calculated using the expression:

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

where:

- ρis electrical resistivity;
- Ris electrical resistance;
- Ais the cross-sectional area of the sample;
- lis the distance between electrical contacts.

Comparative analysis of ZnO, CuO, and Cu_2O thin films was carried out to determine the relationship between structural organization, optical absorption behavior, and electrical transport properties of the investigated semiconductor oxide materials.

Results

Optical investigations demonstrated that the deposited ZnO, CuO, and Cu_2O thin films possess distinct absorption and transmission characteristics associated with their semiconductor band structures and crystal organization. The obtained results confirmed that deposition conditions strongly influence optical transparency, absorption behavior, and electrophysical performance of oxide semiconductor films.

ZnO thin films exhibited high optical transparency within the visible spectral region and relatively low absorption intensity. The films demonstrated stable optical behavior associated with the wide band gap nature of ZnO semiconductor material. Increased crystallinity and improved structural homogeneity contributed to enhanced optical transmission and reduced scattering losses.

In contrast, CuO and Cu_2O thin films demonstrated significantly stronger optical absorption within the visible region of the electromagnetic spectrum. The narrower band gap energies of copper oxide semiconductors promoted more efficient photon absorption and increased interaction between incident radiation and the semiconductor structure.

The calculated optical band gap values varied depending on film composition and deposition parameters. ZnO films exhibited larger band gap energies compared with CuO and Cu_2O semiconductor layers. Variations in oxygen concentration and plasma conditions influenced defect formation and consequently affected optical absorption behavior of the films.

Electrical measurements revealed that electrophysical properties strongly depended on structural ordering and defect concentration within the deposited layers. ZnO films demonstrated relatively stable conductivity and lower electrical resistivity due to improved crystal orientation and reduced grain boundary scattering.

CuO and Cu_2O thin films exhibited p-type semiconductor behavior characterized by conductivity strongly influenced by oxygen vacancies, grain interfaces, and structural defects. Films with improved crystallinity and higher structural homogeneity demonstrated enhanced electrical transport properties and lower resistive losses.

Table 1. Optical and Electrophysical Parameters of Oxide Thin Films

Thin Film Material	**Optical Transparency**	**Optical Absorption**	**Band Gap Characteristics**	**Electrical Conductivity**
ZnO	High	Moderate	Wide band gap	Stable
CuO	Moderate	High	Narrow band gap	p-type conductivity
Cu_2O	Moderate–High	High	Direct band gap	Stable p-type behavior

Note. Comparative optical and electrophysical characteristics of oxide semiconductor thin films synthesized by ion-plasma deposition.

The obtained results indicate that structural quality and phase composition significantly influence optical and electrical properties of semiconductor oxide films. Improved crystallinity reduced defect-related scattering processes and enhanced both optical transmission and electrical transport characteristics.

The comparative analysis additionally demonstrated that ZnO thin films are more suitable for transparent conductive applications, whereas CuO and Cu_2O films possess stronger absorption properties favorable for photovoltaic and optoelectronic systems.

Optical Absorption Behavior

The optical absorption characteristics of oxide thin films are associated with electronic transitions occurring between the valence and conduction bands of semiconductor materials. The absorption process may be described by the relation:

$$h\nu \geq E_g$$

where:

- hnuis the photon energy;
- $E_g$is the optical band gap energy.

Photon absorption occurs when incident photon energy exceeds the semiconductor band gap, resulting in generation of electron–hole pairs and activation of electrical transport processes within the films.

Discussion

The results obtained in the present study demonstrate that ion-plasma deposition technology enables controlled fabrication of oxide semiconductor thin films with stable optical and electrophysical characteristics. Comparative analysis of ZnO, CuO, and Cu_2O films revealed substantial differences in optical transparency, absorption behavior, and electrical transport mechanisms associated with their crystal structures and electronic properties.

One of the most significant findings of the study was the high optical transparency exhibited by ZnO thin films within the visible spectral region. This behavior is directly related to the wide band gap nature of ZnO and its relatively low absorption coefficient. Improved crystallinity and preferential orientation along the c-axis contributed to reduced optical scattering and enhanced transmission characteristics.

In contrast, CuO and Cu_2O films demonstrated stronger optical absorption due to their narrower band gap energies. The enhanced absorption capability of copper oxide semiconductors makes these materials highly promising for photovoltaic applications and light-harvesting technologies. Efficient interaction between incident photons and semiconductor layers promotes increased generation of charge carriers within the films.

The obtained results additionally confirmed the close relationship between structural ordering and electrophysical behavior of oxide semiconductor films. Improved crystallinity and reduced defect concentration contributed to lower electrical resistivity and enhanced conductivity characteristics. Grain boundaries and structural imperfections were found to significantly influence charge transport mechanisms within the deposited layers.

The electrical behavior of CuO and Cu_2O films corresponds to typical p-type semiconductor conductivity associated with copper vacancies and oxygen-related defects. In ZnO films, conductivity behavior was largely influenced by intrinsic donor defects such as oxygen vacancies and zinc interstitial atoms.

The observed dependence of optical and electrical parameters on deposition conditions indicates that plasma discharge characteristics and oxygen concentration play a decisive role in controlling semiconductor properties of oxide thin films. Proper regulation of deposition parameters enables optimization of optical transparency, absorption intensity, and electrical conductivity according to technological requirements.

Another important aspect of the study is the multifunctional potential of oxide semiconductor films for modern optoelectronic and renewable energy applications. ZnO thin films are highly suitable for transparent electrodes and ultraviolet photodetectors, while CuO and Cu_2O films demonstrate favorable properties for photovoltaic systems and photoactive semiconductor devices.

The comparative analysis also demonstrated that ion-plasma deposition technology provides substantial advantages for fabrication of structurally homogeneous oxide semiconductor films with stable functional properties. The method allows precise control over crystallization processes, phase formation, and microstructural evolution during thin-film growth.

Despite the favorable experimental results, further investigations remain necessary for deeper understanding of optical transition mechanisms, carrier dynamics, and defect-related phenomena in oxide semiconductor systems. Additional studies involving photoluminescence spectroscopy, Hall-effect measurements, and temperature-dependent conductivity analysis may provide more comprehensive information regarding the physical behavior of the investigated materials.

In conclusion, the present study confirms that optimization of ion-plasma deposition parameters plays a critical role in controlling optical and electrophysical characteristics of ZnO, CuO, and Cu_2O thin films. Improved understanding of structure–property relationships may contribute to further advancement of semiconductor oxide technologies and expansion of their practical applications in modern electronic, photonic, and renewable energy systems.

Conclusion

The present study demonstrated that oxide semiconductor thin films deposited on dielectric substrates by ion-plasma technology possess favorable optical and electrophysical characteristics suitable for modern semiconductor and optoelectronic applications. Comparative analysis of ZnO, CuO, and Cu_2O films confirmed that deposition conditions significantly influence structural organization, optical absorption behavior, and electrical transport properties of the investigated materials.

ZnO thin films exhibited high optical transparency and stable electrical conductivity associated with their wide band gap and improved crystallinity. CuO and Cu_2O films demonstrated enhanced optical absorption within the visible spectral region and favorable p-type semiconductor behavior, making them promising materials for photovoltaic and photoactive applications.

The obtained results revealed that optimization of plasma discharge parameters, oxygen concentration, and substrate temperature contributes to improved crystallinity, reduced defect concentration, and enhanced electrophysical performance of oxide semiconductor films. Structural homogeneity and phase stability were found to play an important role in determining optical and electrical characteristics of the deposited layers.

The study confirmed that ion-plasma deposition technology provides effective control over growth mechanisms and functional properties of semiconductor oxide thin films. The investigated materials demonstrate substantial potential for application in transparent conductive coatings, solar energy systems, gas sensors, optoelectronic devices, and semiconductor electronics.

Further investigations involving photoluminescence spectroscopy, Hall-effect measurements, and detailed analysis of defect-related electronic states may contribute to deeper understanding of optical transitions and charge transport mechanisms in oxide semiconductor thin films synthesized by ion-plasma technology.

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