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MICROSTRUCTURAL CHARACTERISTICS AND ELECTRICAL CONDUCTIVITY OF CUO 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

Copper oxide (CuO) thin films have attracted considerable scientific interest due to their unique semiconductor properties, narrow band gap, high optical absorption coefficient, and potential applications in optoelectronics, photovoltaics, gas sensors, and energy storage devices. The structural and electrical characteristics of CuO thin films strongly depend on deposition technology, substrate properties, and growth conditions.

The present study investigates the microstructural characteristics and electrical conductivity of CuO thin films deposited on dielectric substrates using ion-plasma deposition technology. Particular attention was devoted to the influence of structural parameters on electrical transport mechanisms and conductivity behavior of the obtained films.

Structural investigations revealed formation of polycrystalline CuO thin films with monoclinic crystal structure and relatively uniform grain distribution. Variations in deposition conditions significantly affected crystallite size, surface morphology, and defect concentration within the films.

Electrical measurements demonstrated that conductivity characteristics of CuO thin films are closely related to their microstructural organization. Improved crystallinity and reduced structural defects contributed to enhanced charge transport and lower electrical resistance.

The obtained results indicate that ion-plasma deposition technology enables controlled fabrication of CuO thin films with stable structural and electrophysical properties suitable for application in semiconductor and optoelectronic devices.

Keywords: CuO thin films, ion-plasma deposition, microstructure, electrical conductivity, semiconductor materials, dielectric substrate, crystal structure, electrophysical properties.

Introduction

Copper oxide (CuO) is one of the most important p-type semiconductor materials widely investigated for modern electronic and energy-related applications. Due to its narrow band gap, high optical absorption coefficient, chemical stability, and relatively low production cost, CuO thin films are considered promising materials for photovoltaic systems, gas sensors, photodetectors, lithium-ion batteries, and optoelectronic devices.

The physical properties of CuO thin films strongly depend on synthesis conditions, deposition technology, substrate characteristics, and structural organization of the material. Control over microstructural parameters plays a crucial role in determining electrical conductivity, carrier transport mechanisms, optical behavior, and overall functional performance of semiconductor thin films.

Among various thin-film fabrication techniques, ion-plasma deposition has attracted significant attention because of its ability to provide controlled film growth, improved adhesion, uniform surface morphology, and precise regulation of deposition parameters. During ion-plasma synthesis, energetic ions and plasma particles influence nucleation processes, crystallization dynamics, and formation of structural defects within the growing films.

CuO commonly crystallizes in a monoclinic crystal structure characterized by anisotropic electrical and optical properties. Grain size, crystallographic orientation, surface roughness, and defect concentration significantly affect charge carrier mobility and conductivity mechanisms in CuO thin films.

Microstructural characteristics of semiconductor films are closely associated with electrical transport behavior. Structural imperfections such as grain boundaries, oxygen vacancies, lattice distortions, and dislocations may influence carrier scattering processes and electrical resistance. Therefore, investigation of the relationship between microstructure and conductivity remains an important scientific problem in semiconductor physics.

Recent advances in nanotechnology and thin-film engineering have increased interest in developing CuO semiconductor layers with controlled structural properties for highly efficient electronic and optoelectronic systems. Optimization of deposition conditions may significantly improve electrical stability and functional performance of CuO-based devices.

Despite extensive research on copper oxide semiconductors, many aspects related to microstructural evolution and electrophysical behavior of ion-plasma-deposited CuO thin films remain insufficiently studied. Understanding these processes is essential for further development of advanced semiconductor technologies.

Therefore, the aim of the present study is to investigate the microstructural characteristics and electrical conductivity of CuO thin films deposited on dielectric substrates and to evaluate the influence of structural parameters on electrophysical properties of the obtained films.

Materials and Methods

CuO thin films were deposited on dielectric glass substrates using the ion-plasma deposition method under controlled vacuum conditions. Before the deposition process, the substrates were subjected to mechanical and chemical cleaning procedures to eliminate surface contamination and improve adhesion between the substrate and the deposited layer.

High-purity copper target material was used as the source for thin-film synthesis. Oxygen was introduced into the working chamber during deposition in order to promote formation of copper oxide phases. The deposition process was carried out in a plasma environment generated under controlled discharge conditions.

The technological parameters of the deposition process, including chamber pressure, plasma discharge power, substrate temperature, oxygen concentration, and deposition duration, were systematically controlled throughout the experiment. These parameters were varied to investigate their influence on microstructural organization and electrical conductivity of the deposited CuO thin films.

Structural characterization of the films was performed using X-ray diffraction analysis. Diffraction patterns were recorded to determine crystal structure, phase composition, and preferential crystallographic orientation of the deposited layers. The average crystallite size was estimated using the Scherrer relation:

$$D = \frac{K\lambda}{\beta\cos\,\theta}$$

where:

- Drepresents crystallite size;
- $K$is the shape coefficient;
- $\lambda$is the X-ray wavelength;
- $\beta$is the peak broadening value;
- $\theta$is the diffraction angle.

Electrical conductivity measurements were performed at room temperature using standard electrical characterization techniques. Electrical resistivity of the CuO thin films was determined according to the expression:

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

where:

- $\rho$is electrical resistivity;
- $R$is measured electrical resistance;
- $A$is the cross-sectional area of the sample;

- l is the distance between electrical contacts.

Surface morphology and grain distribution were additionally analyzed to evaluate structural homogeneity and microstructural features of the deposited films. Particular attention was paid to grain boundaries, defect formation, and structural compactness of the CuO layers.

The obtained experimental data were comparatively analyzed to determine the relationship between deposition parameters, microstructural evolution, and electrical conductivity behavior of CuO thin films synthesized by ion-plasma technology.

Results

X-ray diffraction analysis confirmed successful formation of CuO thin films with a polycrystalline monoclinic crystal structure. The diffraction peaks observed in the obtained patterns corresponded to the characteristic crystallographic planes of copper oxide, indicating formation of structurally stable semiconductor layers without significant impurity phases.

The intensity and sharpness of diffraction peaks varied depending on deposition conditions, demonstrating the influence of plasma parameters and oxygen concentration on crystallization processes. Films deposited under optimized technological conditions exhibited stronger diffraction maxima and improved structural ordering.

The calculated crystallite size increased with substrate temperature and deposition duration, indicating enhanced grain growth and improved crystallinity of the CuO layers. Increased crystallite size was accompanied by reduction of structural disorder and improved compactness of the film surface.

Microstructural analysis demonstrated relatively homogeneous grain distribution across the dielectric substrate surface. However, variations in plasma discharge conditions affected surface morphology and defect concentration within the deposited films. Samples synthesized under unstable plasma conditions exhibited increased structural irregularities and grain boundary defects.

Electrical measurements revealed that conductivity characteristics of CuO thin films strongly depended on their microstructural organization. Films with improved crystallinity and lower defect density demonstrated reduced electrical resistivity and enhanced charge transport behavior.

The obtained results indicate that grain boundaries and oxygen-related defects significantly influence electrical conductivity mechanisms in CuO semiconductor films. Increased structural homogeneity contributed to more stable electrical performance and lower carrier scattering effects.

Table 1. Structural and Electrical Characteristics of CuO Thin Films

Parameter	**Observed Characteristics**
Crystal structure	Monoclinic CuO
Structural phase purity	High
Crystallinity	Improved under optimized conditions
Crystallite size	Increased with temperature
Surface morphology	Relatively homogeneous
Electrical resistivity	Decreased with improved structure
Grain boundary defects	Reduced in optimized films

Note. Structural and electrophysical parameters obtained from CuO thin films deposited by ion-plasma technology.

The dependence of electrical conductivity on microstructural characteristics may be explained by carrier transport mechanisms associated with grain interfaces and intrinsic structural defects. Improved crystal ordering reduces electron scattering and facilitates more effective charge transfer within the semiconductor structure.

The obtained experimental results demonstrate that ion-plasma deposition technology provides favorable conditions for controlled synthesis of CuO thin films with stable microstructural and electrophysical properties suitable for semiconductor and optoelectronic applications.

Electrical Transport Characteristics

Electrical conductivity behavior of CuO thin films may be associated with thermally activated carrier transport mechanisms typical for p-type semiconductor materials. Structural defects, oxygen vacancies, and grain boundaries play an important role in determining carrier mobility and overall conductivity characteristics.

The relationship between crystallite size and electrical resistivity observed in the present study indicates that optimization of microstructural parameters is essential for improving functional properties of CuO semiconductor films.

Discussion

The results obtained in the present study demonstrate that ion-plasma deposition technology enables controlled synthesis of CuO thin films with stable microstructural organization and favorable electrical conductivity characteristics. Structural investigations confirmed formation of polycrystalline monoclinic CuO layers with relatively homogeneous grain distribution and improved crystallinity under optimized deposition conditions.

One of the most significant findings of the study was the strong dependence of electrical conductivity on microstructural parameters of the films. Samples characterized by larger crystallite size and reduced structural disorder exhibited lower electrical resistivity and more stable charge transport behavior. This relationship indicates the important role of grain boundaries and structural defects in determining carrier mobility within CuO semiconductor layers.

The observed improvement in crystallinity with increasing substrate temperature may be explained by enhanced mobility of adsorbed particles during film growth. Increased surface diffusion promotes formation of larger grains and reduces concentration of lattice imperfections. Improved crystal ordering consequently facilitates more efficient electrical transport through the semiconductor structure.

The influence of oxygen concentration during deposition was also found to be highly significant. Oxygen availability affects stoichiometric composition and defect formation processes in CuO films. Variations in oxygen content may lead to changes in carrier concentration, conductivity type, and electrical stability of the deposited layers.

The obtained results are consistent with theoretical models describing charge transport mechanisms in polycrystalline semiconductor thin films. Structural defects such as grain boundaries, dislocations, and oxygen vacancies act as carrier scattering centers that influence conductivity and electrical

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resistance. Reduction of these defects contributes to enhanced electrophysical performance.

Another important aspect of the study is the technological advantage of ion-plasma deposition for fabrication of semiconductor oxide thin films. The method provides precise control over deposition parameters, uniform film growth, and improved adhesion to dielectric substrates. These features are important for development of stable and reproducible semiconductor devices.

The investigated CuO thin films demonstrate promising potential for application in optoelectronic systems, photovoltaic technologies, gas sensing devices, and energy conversion systems. Their favorable electrical behavior and structural stability make them suitable for integration into modern semiconductor technologies.

Despite the positive experimental results, additional investigations are required for deeper understanding of transport mechanisms and defect-related phenomena in CuO thin films. Future studies involving Hall-effect measurements, optical characterization, and temperature-dependent conductivity analysis may provide more detailed information about charge carrier dynamics in ion-plasma-grown CuO structures.

In conclusion, the present study confirms that optimization of ion-plasma deposition parameters plays a crucial role in controlling microstructural evolution and electrical conductivity of CuO thin films. Improved understanding of these relationships may contribute to further advancement of semiconductor oxide technologies and expansion of their practical applications in electronic and photonic systems.

Conclusion

The present study demonstrated that CuO thin films deposited on dielectric substrates by ion-plasma technology possess stable microstructural organization and favorable electrical conductivity characteristics. Structural analysis confirmed formation of polycrystalline monoclinic CuO phases with relatively uniform grain distribution and improved crystallinity under optimized deposition conditions.

It was established that deposition parameters significantly influence crystallite growth, structural ordering, defect concentration, and electrical behavior of the films. Improved crystal quality and reduced grain boundary defects contributed to enhanced charge transport and lower electrical resistivity.

The obtained results indicate that ion-plasma deposition provides effective control over structural and electrophysical properties of CuO semiconductor thin films. Optimization of plasma conditions, oxygen concentration, and substrate temperature enables fabrication of homogeneous films with stable conductivity characteristics.

The investigated CuO thin films demonstrate promising potential for application in semiconductor electronics, optoelectronic devices, gas sensors, photovoltaic systems, and energy-related technologies. Their stable electrical performance and controlled microstructure make them suitable for modern thin-film electronic applications.

Further investigations involving optical characterization, Hall-effect measurements, and temperature-dependent transport analysis may contribute to deeper understanding of charge carrier mechanisms and defect-related phenomena in CuO semiconductor structures.

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