مجلة الدراسات التربوية والعلمية - كلية التربية - الجامعة العراقية
العدد السادس والعشرون - المجلد الأول - علوم الفيزياء - أيلول 2025 م
doi.org/10.52866/esj.2025.01.26.29

Study of The Structural And Optical Properties of Films Prepared By Thermal Evaporation Method at Different Temperatures

Marwa Saadi Mahmoud , Nadeem Khalid Hassan
Tikrit University / College of Education for Pure Sciences / Department of Physics
Email: Ft230080ued@st.tu.edu.iq

Abstract :

Thin films of CuO and CoO are prepared using thermal evaporation technology. The results of X-ray diffraction showed the phase stability of the films, where the diffraction angles were constant, and a decrease in the size of the crystals was observed with increasing temperature, indicating an improvement in the growth of crystals. The results of the atomic microscopy (AFM) also reported a decrease in the average diameter of the crystals and the average roughness, demonstrating improved surface quality. Furthermore, the results showed an increase in absorption as the temperature increased, while the permeability decreased as a result of increased crystalline defects. The energy gap deteriorated, reaching a maximum value of 2.69 eV at 500 °C, while falling to a low value of 2 eV at 700 °C, reflecting changes in electronic properties.

Keywords: thin films, thermal evaporation, temperature, energy gap, absorptivity

دراسة الخصائص التركيبية والبصرية للأغشية المحضرة بطريقة التبخر الحراري عند درجات حرارة مختلفة

مروة سعدي محمود ، نديم خالد حسن
جامعة تكريت / كلية التربية للعلوم الصرفة / قسم الفيزياء
iq.edu.tu.st@Ft230080ued

مستخلص:

تم تحضير أغشية رقيقة من CuO و CoO باستخدام تقنية التبخر الحراري. أظهرت نتائج حيود الأشعة السينية استقرار الطور للأغشية، حيث كانت زوايا الحيود ثابتة، وتم ملاحظة انخفاض في حجم البلورات مع زيادة درجة الحرارة، مما يدل على تحسين في نمو البلورات. كما أفادت نتائج المجهر الذري (AFM) بتقليل متوسط قطر البلورات ومتوسط الخشونة، مما يظهر تحسين جودة السطح. علاوة على ذلك، أظهرت النتائج زيادة في الامتصاص مع ارتفاع درجة الحرارة، بينما انخفضت النفاذية نتيجة لزيادة العيوب البلورية. فجوة الطاقة، حيث بلغت قيمتها القصوى 2.69 eV عند 500 °م، بينما انخفضت إلى قيمة منخفضة قدرها 2 eV عند 700 °م، مما يعكس تغييرات في الخصائص الإلكترونية.

الكلمات المفتاحية : أغشية رقيقة، التبخر الحراري، درجة الحرارة، فجوة الطاقة، الامتصاصية.

1- Introduction

Thin films are extremely thin layers, typically ranging in thickness from nanometers to micrometers, and are used in a wide range of scientific and industrial applications. Their importance stems from their unique properties that make them suitable for a wide range of fields, from electronics to medicine.[1,2].

In electronics, thin films are essential in the manufacture of integrated circuits and sensors. These films are used to reduce the area required for circuits.[3], allowing for increased density of electronic components. For example, indium tin oxide (ITO) films are used in touch screens and solar cells because they have excellent electrical transparency properties. Thin films also play a crucial role in improving the performance of transistors, helping to improve response speed and reduce power consumption[4,5].

In the energy field, thin films are widely used in solar cells. This technology is used to improve conversion efficiency.[6] Ultra-thin solar cells can be manufactured using thin films of silicon or other materials such as cadmium telluride.[7] The use of thin films contributes to reducing production costs, making solar energy more competitive compared to traditional energy sources.[8]

In the medical sector, thin films are used in drug delivery technologies. These films can be designed to be biodegradable.[8] This allows for controlled drug delivery over a period of time, enhancing treatment effectiveness and reducing side effects. For example, thin films are used in the manufacture of medical patches that slowly release medication into the body.[9]

Thin films have unique properties that make them suitable for a variety of applications. These films can be transparent, making them ideal for use in optical applications, such as lenses and other optical devices. Additionally, the physical and chemical properties of the films can be modified by changing the composition or thickness. This flexibility allows researchers and engineers to design films to suit specific needs. [10,11].

2-Materials used

Table(1)Materials used and their specifications

Manufacturer	Purity	Nanoparticle size	The material
Alfa Aesar	99%≤	(nm 50 - 20)	CuO
Sigma-Aldrich	99%≤	(nm 30 - 10)	CoO

3-Practical Method

Vacuum evaporation technology is one of the most common methods in the manufacture of thin films. In this process, the material to be used (such as CuO or CoO) is heated to a high temperature until it turns into steam. This vapor collects on a cool surface, where it is deposited as a thin layer.

CuO was deposited on quartz slices using vacuum evaporation method under pressure of (10 mbar × 2.2), with an electric current of (3.8780 A) and an electric voltage of (49.62 V). Then the samples were oxidized in furnaces at different temperatures ranging between (500 - 700 ° C) with a difference of (50 ° C) for an hour. The next day, the samples were extracted and oxidized again in the same way, with pressure (10 mbar × 2.4), electric current (3.47 A) and voltage (48.72 V).

For CoO, it was also deposited using vacuum evaporation technology under approximately the same conditions. CoO was prepared on quartz strips with the same pressure, current and voltage. The samples were then oxidized in furnaces at temperatures between 500 to 700 °C for an hour, ensuring similar properties with CuO.

4-Results and discussion

4-1X-ray diffraction

Figure (1) shows the results of X-ray diffraction of the prepared films, where the diffraction angles (2Theta) of the different phases (CuO and CoO) remain almost constant with increasing temperature, indicating phase stability and no significant change in crystal structure. However, there is a significant decrease in crystal size (GS) with increasing temperature; the crystal size of CuO in (110) at (500°C) was (93.50

nm), while at (700°C) it decreased to (38.49 nm). This decrease may be attributed to the improvement of the crystal growth process.

In addition, the peak width at half height (The FWHM increased significantly with increasing temperature, reflecting improvements in crystalline regularity. For example, the FWHM of CuO(110) at 500°C was 0.10162, while at 700°C it increased to 0.2462, indicating an improvement in crystalline interaction[14].

The results also indicate that the phase remained constant, as all data indicate that the phase is CuO and CoO both belong to the monoclinic crystal system. The stability of this phase despite changes in size and width shows that the films retain their basic properties.

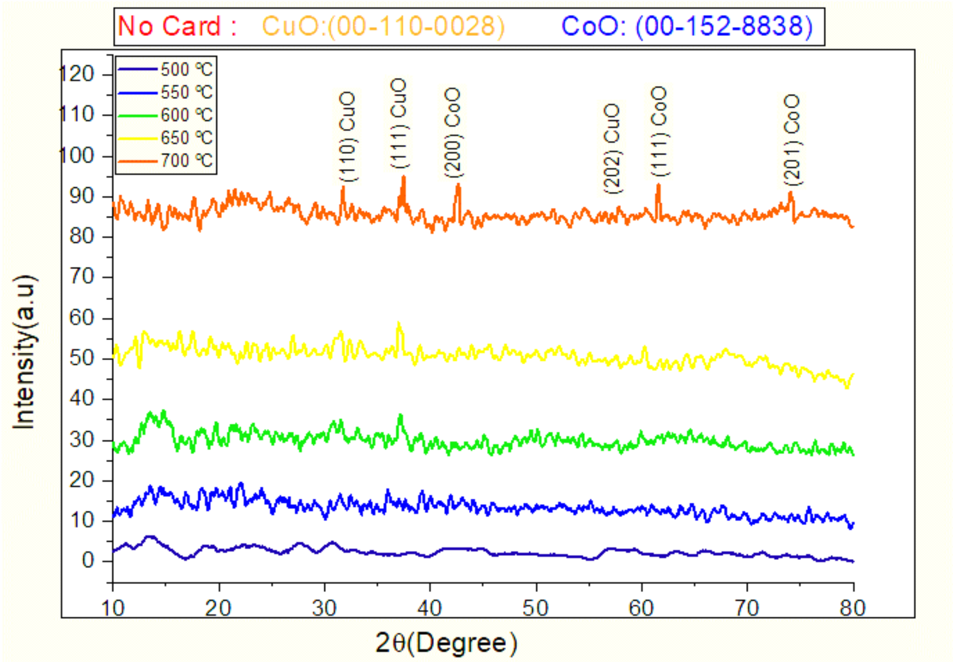


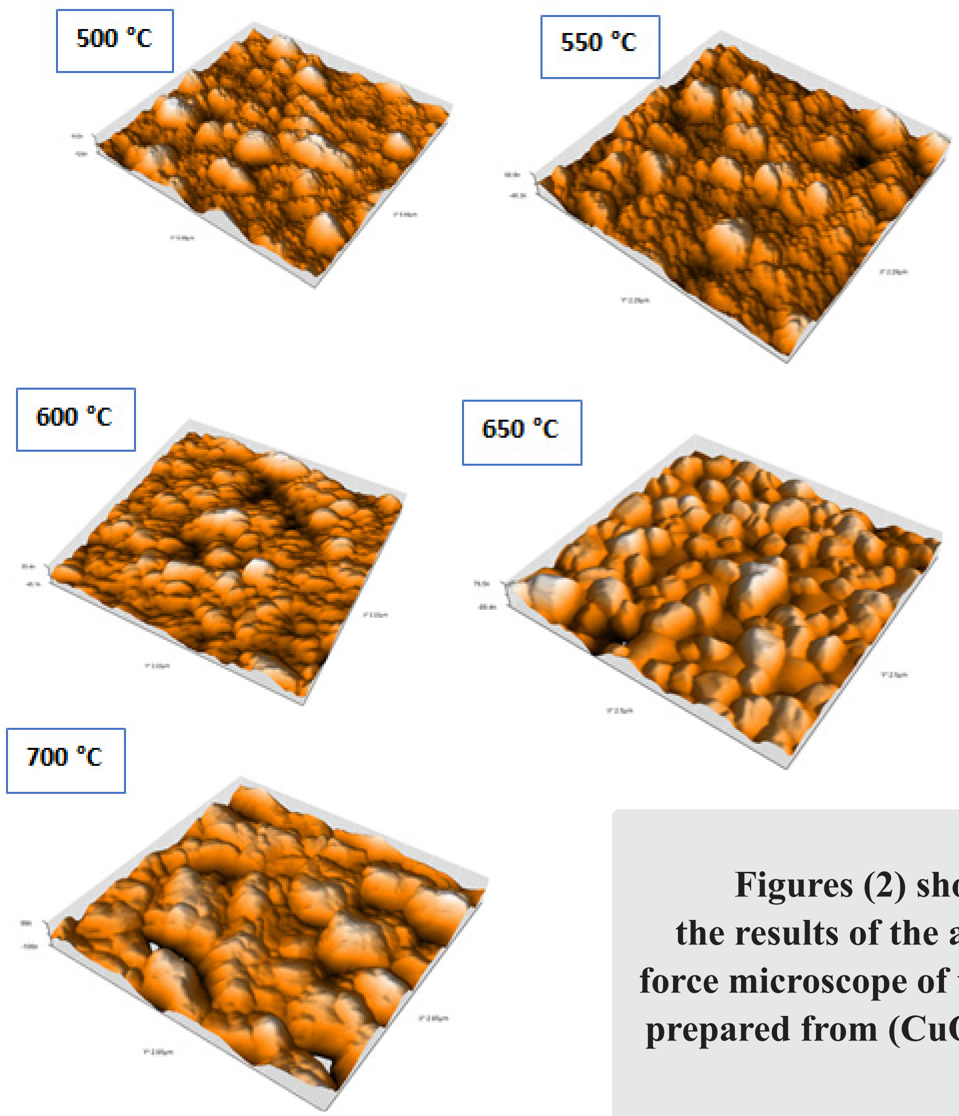
Figure 1 X-ray diffraction of membranes (CuO:CoO)

4-2 Atomic force microscope results

Figures (2) show the results of the atomic force microscope of the films prepared from copper oxide and cobalt oxide. The results indicate a significant decrease in the average diameter with increasing temperature. The average diameter is at (500 ° C) (145.9 nm), while it decreased to (47.44 nm) at (700 ° C). This decrease indicates an improvement in the control of crystal growth, resulting in the creation of smaller, more regular structures.

The root mean square ((rms) showed a clear decrease with increasing temperature, where at 500°C it was 40.62 nm and decreased to 21.12 nm at 700°C. This improvement reflects an increase in surface regularity and a reduction in roughness, which enhances the quality of the films[15].

For the average roughness, the results also showed a decrease with increasing temperature, where at(500°C) (32.07 nm) and decreased to (16.73 nm) at (700°C). This indicates an improvement in the overall surface of the films, which may positively affect their optical and mechanical properties.



Figures (2) show the results of the atomic force microscope of the films prepared from (CuO:CoO).

4-3 Absorption

Figure 3 shows the absorption spectrum where: The experimental results show that absorption increases with increasing temperature. This can be explained by the effects of chemical reactions and the physical properties of (CuO:CoO) films. When films are exposed to high temperatures, the atoms in the crystal lattice are rearranged, which enhances the regularity of the crystal structure and reduces defects, thereby increasing the electron density of the films. The structured crystal structure improves optical properties, which leads to increased absorption. [14].

Furthermore, higher temperatures increase the surface activity of materials, facilitating chemical reactions. These reactions promote the formation of new bonds between atoms, increasing the films' ability to absorb a broader spectrum of light. High temperatures also accelerate chemical reactions, promoting the formation of desired compounds, such asCuO and CoO, which have improved absorption properties.

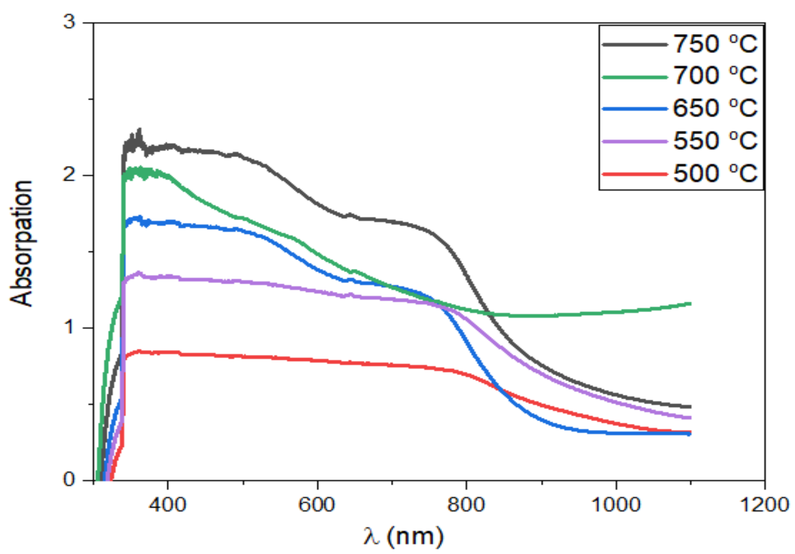


Figure 3: Absorbency spectrum of prepared films (CuO:CoO)

4-4 Transmittance

Figure (4) Permeability spectrum of films prepared from (CuO:CoO) The results showed that the decrease in permeability with increasing temperature can be explained by several interrelated factors. When thin films are deposited at high temperatures, a change in the crystal structure may occur, which leads to an increase in crystalline defects. These defects can hinder the movement of photons within the material, reducing light transmittance.

Furthermore, as temperatures rise, the particle size distribution may change, with larger particles clustering together, reducing the amount of empty space that allows light to pass through. Oxidation and other chemical processes that occur at elevated temperatures may also lead to the formation of new compounds or additional layers that impede light transmission.[15].

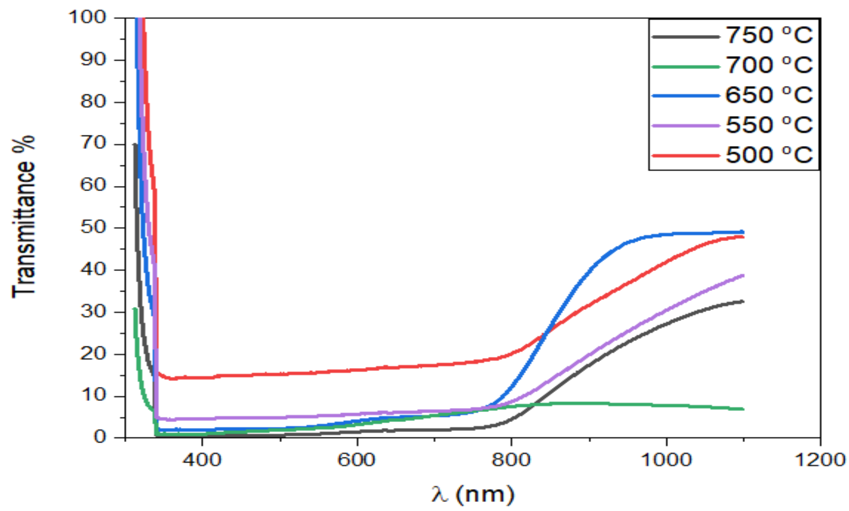


Figure 4 : Film Permeability Spectrum (CuO:CoO)

4-5 Absorption Coefficient

Figure 5 shows the optical absorption coefficient of copper oxide and cobalt oxide films prepared by vacuum thermal evaporation method at temperatures between 500 and 750 °C. The results showed that the absorption coefficient increases with increasing temperature.

The transition in this case is straightforward. Photons are absorbed by electrons that travel directly from the valence band to the conduction band, resulting in increased absorption as the temperature rises. These results illustrate the importance of temperature in improving the optical properties of these materials, contributing to the development of new applications in optical technology.

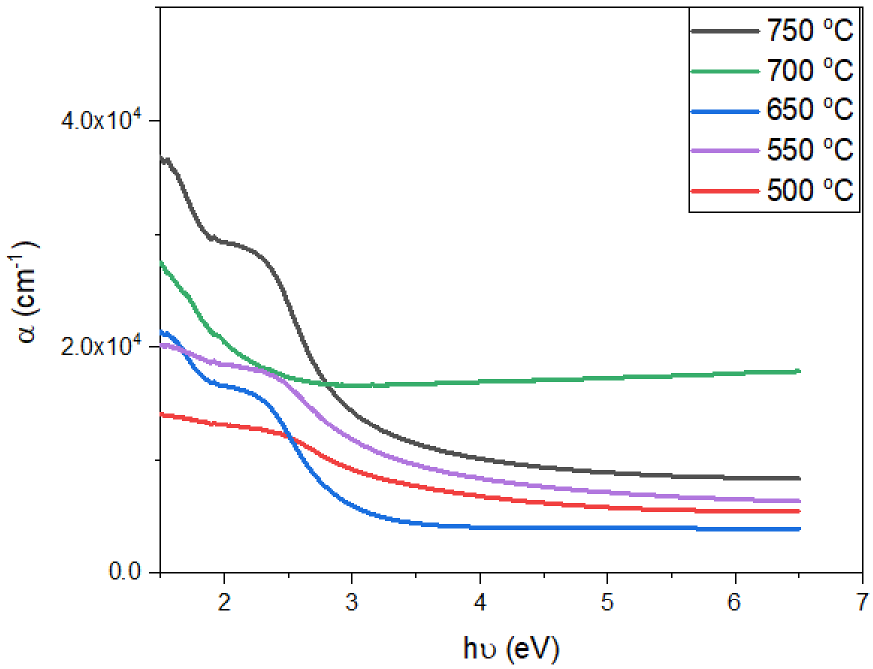


Figure 5 Absorption coefficient of (CuO:CoO) films

4-5 Energy gap

Shape () shows the energy gap whereThe optical energy gap results for thin films deposited at different temperatures show a deterioration in the energy gap with increasing temperature. At a temperature of (500°C), the energy gap was 2.69 eV, while at (550 °C) it decreased to 2.51 eV. As the temperature increased to (600 °C), the gap deteriorated to 2.26 eV, and continued to decrease at (650 °C) to 2.14 eV, until it reached 2.00 eV at (700 °C).

These results can be explained by several factors. First, the effect of temperature on the crystal structure of the films. At higher temperatures, the crystal structure may be improved, leading to a reduction in crystal defects, but new defects may also form, negatively affecting the energy gap. Second, changes in particle size and distribution may play a role, as larger particles may lead to a reduction in the energy gap due to size effects.

Interactions between molecules at high temperatures may also lead to changes in chemical composition and thus changes in the energy gap.[16].

Tible 2: Energy gap of (CuO:CoO) film

T (°C)	Energy Gap (eV)
500	2.69
550	2.51
600	2.26
650	2.14
700	2

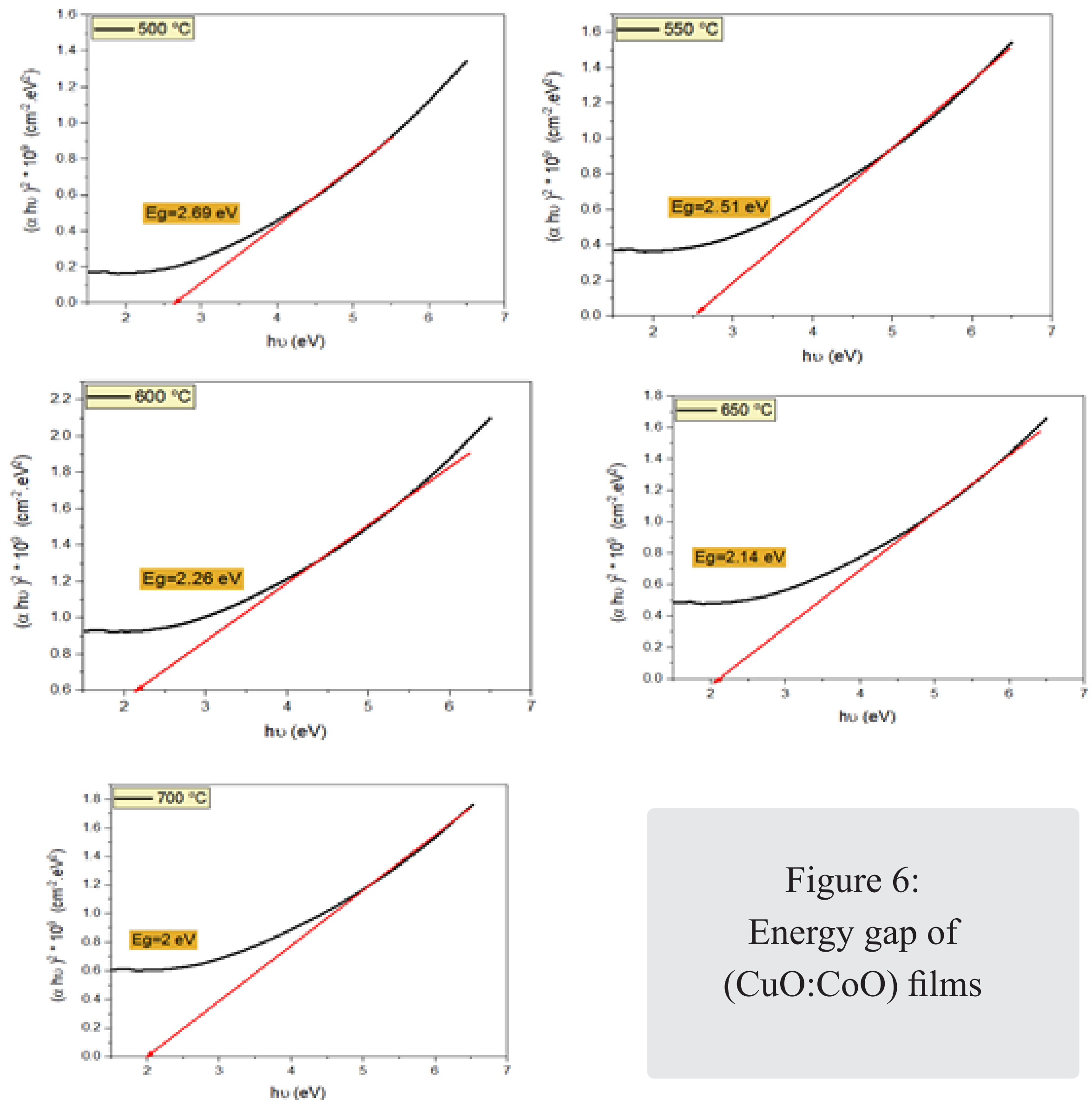


Figure 6:
Energy gap of
(CuO:CoO) films

Conclusions

The results showed that increasing temperature improves the crystalline properties of thin films, increasing surface regularity and reducing defects. An increase in the absorbance of the films was also observed with increasing temperature, reflecting an improvement in the crystal structure. Meanwhile, the energy gap deteriorated with increasing temperature, indicating changes in the electronic properties. The decrease in transmittance also reflects the effect of crystalline defects on the movement of photons. These results underscore the importance of temperature control for improving the properties of thin films in various technical applications.

Reference

1. Ohring, Milton. “Mechanical properties of thin films.” Materials Science of Thin Films (2002): 711-781.

2.Sze, Simon M., Yiming Li, and Kwok K. Ng. Physics of semiconductor devices. John wiley & sons, 2021.

3.Petosa, Adamo R., et al. “Aggregation and deposition of engineered nanomaterials in aquatic environments: role of physicochemical interactions.” Environmental science & technology 44.17 (2010): 6532-6549.

4. Boudiar, Meriem, et al. “Sol–gel derived Zn doped MgO thin films and their waveguides.” Journal of Sol-Gel Science and Technology (2023): 1-11.

5. M. A. Khan, J. W. Park, and E. Y. Lee, “MgO thin films deposited by pulsed laser deposition: structural, optical, and electrical properties,” Thin Solid Films, vol. 496, no. 1-2, pp. 152-156, 2006. https://iopscience.iop.org/article/10.1088/2053-1591/ab1208/meta

6. S. X. Wang, Z. M. Zhang, S. H. Ji, L. P. Liu, C. L. Xu, and Z. G. Liu, “Structural and optical properties of MgO thin films prepared by reactive magnetron sputtering,” Materials Letters, vol. 57, no. 4, pp. 714-717, 2003. https://www.researchgate.net/publication/354889540_Structural_and_Optical_Properties_of_MgO_Thin_Films_Prepared_by_Dip-Coating_Process_Effect_of_Thickness

6. J. F. Pierson, “MgO thin films for electronic applications,” Journal of Vacuum Science and Technology B, vol. 9, no. 4, pp. 2115-2121, 1991.

7. Nagu, A., et al. “Additive-free vapour-phase hydrogenation of benzonitrile over MgO-supported Ni cata-

lysts.” Research on Chemical Intermediates 46 (2020): 2669-2681.

8. lmontasser, A., Parveen, A. Probing the effect of Ni, Co and Fe doping concentrations on the antibacterial behaviors of MgO nanoparticles. Sci Rep 12, 7922 (2022). https://doi.org/10.1038/s41598-022-12081-z.

9. Allaedini, Ghazaleh, Siti Masrinda Tasirin, and Payam Aminayi. “Synthesis of CNTs via chemical vapor deposition of carbon dioxide as a carbon source in the presence of NiMgO.” Journal of Alloys and Compounds 647 (2015): 809-814.

10- Almontasser, A., A. Parveen, and A. Azam. “Synthesis, Characterization and antibacterial activity of Magnesium Oxide (MgO) nanoparticles.” IOP Conference Series: Materials Science and Engineering. Vol. 577. No. 1. IOP Publishing, 2019.

11- Güney, Harun, and Demet İskenderoğlu. “Synthesis of MgO thin films grown by SILAR technique.” Ceramics International 44.7 (2018): 7788-7793.

12- Dolai, S., et al. “Cupric oxide (CuO) thin films prepared by reactive dc magnetron sputtering technique for photovoltaic application.” Journal of Alloys and Compounds 724 (2017): 456-464.

13- Arman, Ali, et al. “Micromorphology characterization of copper thin films by AFM and fractal analysis.” Journal of Materials Science: Materials in Electronics 26 (2015): 9630-9639.

14- Lin, Qingfeng, et al. “Efficient light absorption with integrated nanopillar/nanowell arrays for three-dimensional thin-film photovoltaic applications.” ACS nano 7.3 (2013): 2725-2732.

15- Qasrawi, Atef F., and Alaa A. Hamamdah. “Thickness effects on the dielectric dispersion and optical conductivity parameters of CuO thin films.” Microwave and Optical Technology Letters 62.4 (2020): 1453-1458.

16- Chen, Yue, et al. “Band gap manipulation and physical properties of preferred orientation CuO thin films with nano wheatear array.” Ceramics International 44.1 (2018):441-467.