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# Optical and anti-reflecting behavior of CuO and NiO deposited at $Co_3O_4$ solar absorber coating

**A graduation project submitted to the Department of Physics, College of Science in partial fulfillment of the requirements for the Degree of Bachelor of Science in physics**

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# Abstract

This research investigates the optical and anti-reflective properties of Copper Oxide (CuO) and Nickel Oxide (NiO) when deposited on Cobalt Oxide ($Co_3O_4$), a widely used solar absorber coating. The reflectance, transmittance, and absorbance of single and double-layer coatings were analyzed using spectrophotometric technique.

Results indicate that NiO effectively reduces reflectance and enhances thermal absorption more efficiently than CuO, making it a superior anti-reflective material when combined with $Co_3O_4$. These findings contribute to improving the efficiency of solar cells and thermal energy systems.



# Arabic Abstract

**في هذا البحث تم دراسة الخواص الضوئية وخاصية منع الانعكاس لكل الطبقات من اكسيد النيكل والنحاس عند ترسيبهم على اكسيد الكوبالت كممتص اساسي للإشعاع الشمسي حيث تم الترسيب بطريقة الغمس في المحاليل والتسخين لدرجة التفكك الكيميائي. تم دراسة الانعكاسية والامتصاصية والنفاذية لكل العينات وكذلك درجة حرارة السطح تحت الاشعاع الشمسي والذي اظهر زيادة كبيرة في درجة حرارة اكسيد الكوبالت الذي تم ترسيب اكسيد النيكل عليه أفضل من النحاس وايضا بدون طبقة مانعة للانعكاس مما يدل على تغطية الممتص الاساسي بطبقة رقيقة من اكسيد النيكل تزيد من فعالية الممتص الشمسي**

## 1. Introduction

Metal oxides such as NiO, $Co_3O_4$ and CuO  are considered good solar absorber in the UV-VIS-IR solar spectrum. They possess high optical absorbance in the VIS region close to 90% while very low emittance in compared with black body (100 % absorbance and (0) emittance at the same temperature ). Several attempts have been performed in order to increase their absorbance and reduce their emittance. It is difficult to re-engineer the optical material to perform a new property that serve in solar absorption. The preparation of those oxides as a selective coating is governed by the method of preparation, adherence, lifetime and phase stability. The modified dip coating is one of the preparation processes in which thin layers of the material can be prepared with the desired thickness by several dip cycles. Research shows that $Co_3O_4$ possess four main absorption edges in comparison with other materials due to transition from several ionic states of oxygen and cobalt in the other hand this makes a high reflectance within those bands. Other additional metallic oxides can be used as an antireflecting coatings especially CuO and NiO [1-3]. In this work, the use of CuO and NiO anti reflecting coatings will be compared in the view of optical reflectance and absorbance besides the application of these two antireflecting coatings on the main absorber layer ($Co_3O_4$). In this study, the previous data of film deposition and characterization will be considered and the main study will be the optical and thermal characteristics of the deposited interfaces.

# 2. Experimental Techniques

## 2.1 Thin Films preparation technique

The modified dip coating is based on decreasing the solution from the deposition container and the substrate gradually instead of pulling out the substrate. This avoids the fast-drying process of the solvent from the substrate which homogenizes the thickness of the deposited film within the ambient alcohol atmosphere. Several types of films were deposited such that $Co_3O4$, CuO, NiO, besides multilayers of $Co_3O_4$/CuO and $Co_3O_4$/NiO as absorber-antireflective layer structure.

Figure (2.1) represents the deposition apparatus used for films deposition.

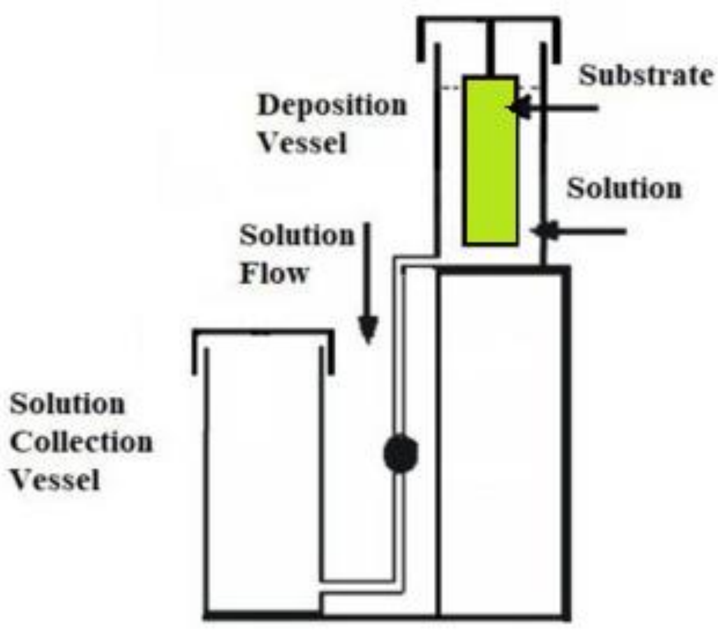


Figure (2.1) : Modified dip coating technique

## 2.2 Cobalt, Copper and Nickel oxides deposition process

A 0.3 M of cobalt nitrate is dissolved in 100 mL ethanol is used as the precursor and stirred for 10 min thin poured in the deposition container with well cleaned substrate. The precursor level starts to decrease and flows to the second container and kept for one minute in order to remove the excess drops at the substrate and thickness homogenization. The substrates are then taken out to be dried and the back side is cleaned in order to obtain one sided film. The substrate is then heated under 250 $^oC$ for 10 minutes and this deposition cycle is repeated 10 times in order to increase the thickness of the film. in the case of the copper and nickel nitrate precursors, the concentration was chosen to be 0.1M because the higher concentration produced powdered films. Also, the reaction temperature for copper nitrate were kept at 300 $^oC$ and for nickel nitrate at 350 $^oC$. The number of deposited cycles for $Co_3O_4$ is 10 layers while for CuO and NiO is only 3 cycles as antireflecting layers. Furthermore, both CuO and NiO films of 10 cycles were deposited in order to study the optical transmittance and reflectance.

The deposited $Co_3O_4$, CuO and NiO single layers different films have been utilized in order to determine the optical transmittance, reflectance and absorbance for each phase. Other double layers consist of $Co_3O_4$/CuO and $Co_3O_4$/NiO have been deposited in order to study the antireflecting phenomena for CuO and NiO on the main absorber layer of $Co_3O_4$ whose reflectivity is much higher. The preparation and structural characterization of those films have been studied in our lab before [3]. We used the same procedure for the preparation of those layers. We focused only on the optical behavior of the double layers especially the comparison between the NiO and CuO antireflecting coating. The samples structure are classified as follows:-

Table (3.1): Composition of different sample structures with deposition cycles and thickness measurements.

| Sample name | Structure |
|---|---|
| $Co_3O_4$ | 10 deposition cycles of total thickness about 400 nm ( from the calibration report of the material deposition |
| CuO | 10 deposition cycles of total thickness about 300 nm ( from the calibration report of the material deposition |
| NiO | 10 deposition cycles of total thickness about 300 nm ( from the calibration report of the material deposition |
| $Co_3O_4$/CuO | 3 deposition cycles of CuO with thickness about 90 nm deposited on $Co_3O_4$ with thickness about 400 nm |
| $Co_3O_4$/NiO | 3 deposition cycles of NiO with thickness about 90 nm deposited on $Co_3O_4$ with thickness about 400 nm |

## 2.3. Investigation of the deposited layers.

All the deposited layers have been previously investigated structurally and optically. The focus in this study was the deposition of NiO and CuO films to compare the effect of sunlight on optical properties and surface temperature.

## 3. Results and Discussions

### 3.1 Optical Reflectance of Single and Double Layers

The optical reflectance of $Co_3O_4$, CuO and NiO single layers as well as of $Co_3O_4$/NiO and $Co_3O_4$/CuO double layers are represented in figure 3.1 . It was observed that the relationship between the optical reflectance dependence on the wavelength is high for $Co_3O_4$ About (25 %), NiO (about 15 %) and for CuO (about 12 %) while in the double layer cases, the $Co_3O_4$/NiO has an optical reflectance lower than for $Co_3O_4$ single layer. In the case of CuO top layer, the optical reflectance was observed to be higher than those in NiO top layer (near to 600-1200 nm). This means that NiO is considered as good antireflecting coating better than CuO for the $Co_3O_4$ main absorber layer at this wavelength range (thermal radiation 300 – 2000 nm).

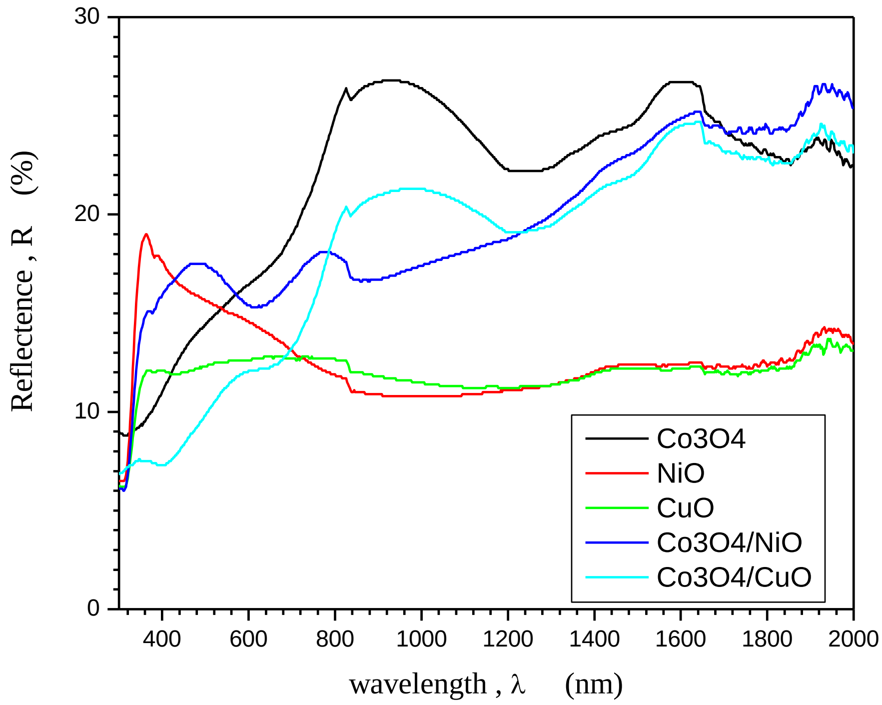


Figure 3.1: The optical reflectance of the $Co_3O_4$, CuO, NiO single layers $Co_3O_4$/NiO and $Co_3O_4$/CuO double layers as antireflecting coatings

## 3.2 Optical Transmittance of Single and Double Layers

The optical transmittance of $Co_3O_4$, CuO, NiO single layers as well as $Co_3O_4$/NiO and $Co_3O_4$/CuO double layers are represented in figure 3.2. It was observed that the optical transmittance of is about 40 % for $Co_3O_4$, about 70 % for NiO and about 90 % for CuO for single layers near visible. The optical transmittance is about 35 % for $Co_3O_4$/NiO while it reaches 50 % for $Co_3O_4$/CuO double layers. This means that NiO antireflecting coating is preferable than CuO for the main absorber layer of $Co_3O_4$ according to its lower reflecting behavior. It is important to discuss how those anti reflecting layer affect on the optical absorbance in which the extraction yield of solar radiation is occur. This requires to calculate the optical absorbance from the reflected and transmitted light.

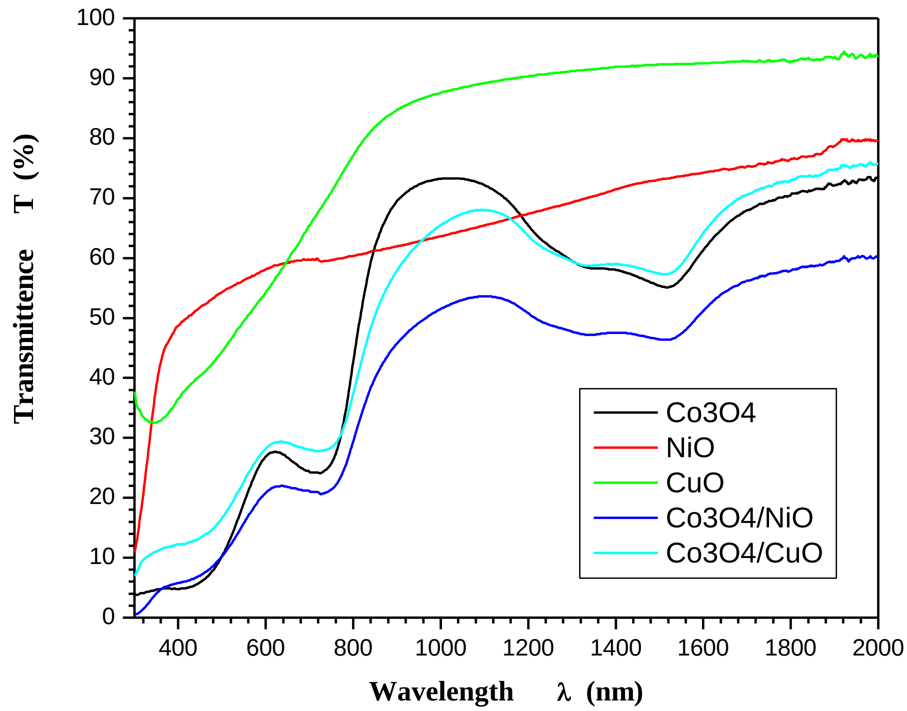


Figure 3.2: The optical transmittance of the $Co_3O_4$, CuO, NiO single layers and $Co_3O_4$/NiO and $Co_3O_4$/CuO double layers as antireflecting coatings.

## 3.3 Optical absorbance of Single and Double Layers

The optical absorbance (A(λ)) of $Co_3O_4$, CuO and NiO single layers as well as $Co_3O_4$/NiO and $Co_3O_4$/CuO double layers were calculated from the optical transmittance (T(λ)) and reflectance (R(λ)) by the following equation:

$$A(\lambda) = 100 - T(\lambda) - R(\lambda) \qquad (\%)$$

The calculated optical absorbances are represented in figure 3.3. It was observed that the higher optical absorbance of the studied single and double layers can be sorted descending from $Co_3O_4$/NiO, $Co_3O_4$/CuO, $Co_3O_4$ , NiO and CuO layers. This means that NiO antireflecting coating is preferable than CuO for the main absorber layer of $Co_3O_4$ according to its lower reflectance and considerable higher absorbance. The problem of high reflectance of $Co_3O_4$ can be then treated using NiO better than CuO which was studied before [3]. This enhancement of absorption properties should be reflected on the solar radiation collection by the solar absorber.

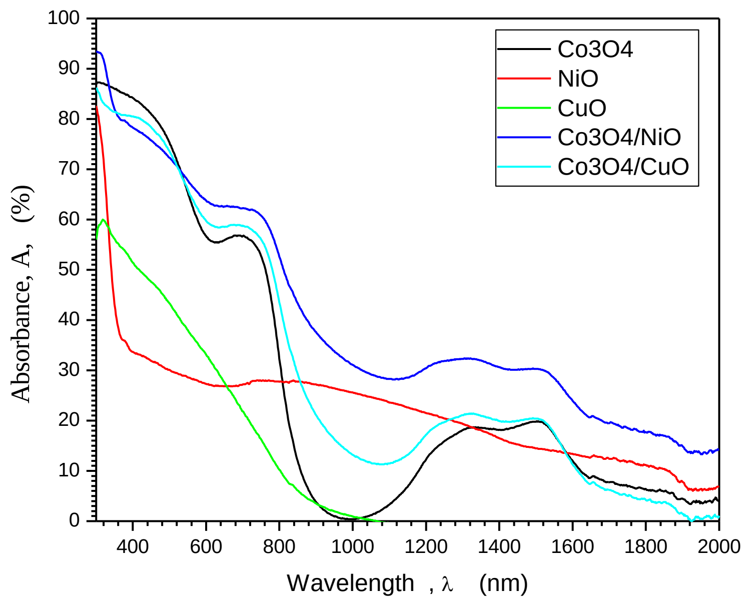


Figure 3: The optical absorbance of the $Co_3O_4$, CuO, NiO single layers $Co_3O_4$/NiO and $Co_3O_4$/CuO double layers as antireflecting coatings

## 3.4 Surface Temperature Test of Single and Double Layers

Surface temperature under direct sun irradiation has been measured using infrared sensor in ambient temperature of 20 $^{o}$C. Surface temperature for each sample have been measured seven times then averaged at noon and they are measured within each cycle in order to compare their surface temperature performance under the same conditions. The results were summarized in Table 2. The amount of heat energy absorber depends on the area under the absorption curve as an integral of the absorbance which is normalized relative to the area under the main absorber curves of (**$Co_3O_4$**). The NiO relative absorbance was found to be higher than in CuO so that it is expected that NiO occurs in two mechanisms. One of them is reducing the reflection and the other is increase the absorption in addition to those for the absorber layer **($Co_3O_4$)**. Although CuO layer has lower reflectance and expected to be a good anti reflecting layer but their optical absorbance is observed to be lower.

Table 3.1: Absorption and surface area, temperature performance of the multi-layer deposited films

| Sample | Area under the absorption curve $\lambda^2$ | Relative area compered to $Co_3O_4$ | Surface temperature |
|---|---|---|---|
| $Co_3O_4$ | 45767 | 100 | 47.5 ± 0.9 |
| NiO | 37640 | 82 | 45.3 ± 1.0 |
| CuO | 15670 | 34 | 41.7 ± 0.8 |
| $Co_3O_4$/NiO | 67816 | 150 | 51.2 ± 1.4 |
| $Co_3O_4$/CuO | 50608 | 111 | 48.8 ± 1.5 |

## Summary

1. This study examines the optical and anti-reflective behavior of Copper Oxide (CuO) and Nickel Oxide (NiO) deposited on Cobalt Oxide ($Co_3O_4$) main absorbing layer that are commonly used as solar absorber material.
2. $CuO/Co_3O_4$ and $NiO/Co_3O_4$ antireflecting coating/ main absorber layers film structures have been examined under optical absorbance as well as surface temperature under solar radiation
3. Optical reflectance of the main absorber $Co_3O_4$ has been redueced using the anti-reflecting layers
4. Thin films of the structures $CuO/Co_3O_4$ and $NiO/Co_3O_4$ as well as the individual films of $Co_3O_4$, CuO and NiO were usefully deposited using the modified dip coating technique
5. Both antireflecting layers plays good antireflecting behavior and the NiO is the best because it give an additional absorption more than in CuO. The results indicate that $NiO/Co_3O_4$ coatings exhibit lower reflectance and higher absorption compared to $CuO/Co_3O_4$, making NiO a more effective anti-reflective material for solar applications.
6. These findings suggest that NiO can significantly enhance solar energy harvesting by improving absorption and minimizing light loss, making it a promising material for solar thermal applications.

**References**


1. **M. Abdel Rafea, A. Eid, Nazir Mustapha, Materials Science and Engineering B 290 (2023) 116294, https://doi.org/10.1016/j.mseb.2023.116294**
2. **M. Abdel Rafea, N. Roushdy and . M Farag, Journal of Alloys and Compounds 621 (2015) 434–440.https://doi.org/10.1016/j.jallcom.2014.09.091**
3. **optical proeprties of NiO thin films deposited by Dip coating , Osamh solaiman Alsoweilim, FYP, 2024, supervisor Mohamed Abdel Rafea konsow**