All Sciences Proceedings
http://as-proceeding.com/

1st International Conference on Scientific and Innovative Studies

April 18-20, 2023 : Konya, Turkey

https://as-proceeding.com/index.php/icsis

Structural Analysis and Hydrophilic Behavior of Co_3O_4 Thin Film for Enhanced Photocatalytic Activity under Visible Light with Hole Scavengers

Mohammed Althamthami[1*], Hachemi Ben Temam[1], Guettaf Temam EI Hachmi[1], Najran Malfi[2], Gamil Gamal Hasan[3], Hadjer Brakat[1]

[1]Physics Laboratory of Thin Layers and Applications, Biskra University, BP 145 RP, Biskra 07000, Algeria).
[2]University 20 August 1955, Skikda, Algeria.
[3]University of El Oued, N48, 30000 El Oued, Algeria.

*(mohammednasser132@gmail.com) Email of the corresponding author

Abstract – This research presents a cost-effective sol-gel technique to produce a uniform and highly effective Co_3O_4 thin film on glass substrates with a withdrawal speed of 5 m/s. The surface morphology and roughness of the film were analyzed, and it demonstrated a thickness of 177 nm and band gap of 2.0 eV. Under solar irradiation, the thin film exhibited remarkable photocatalytic degradation efficacy, with a high efficiency of 78% for blue methylene (BM). The 3D surface topography scan indicated significant roughness at 54.7 nm. Hole-scavengers such as H_2O_2, EDTA, and Octan-1 were found to enhance BM degradation. The study highlights the potential of the Co_3O_4 thin film for treating various organic contaminants in wastewater from diverse sources under solar irradiation.

Keywords – Dip-coating, Co_3O_4 thin films, H_2O_2, Photocatalysis, Hydrophilic

I. INTRODUCTION

Photocatalytic processes have gained significant attention in environmental treatment by decomposing various pollutants in water, soil, and air. Water pollution is a global problem, and organic pollutants such as dyes, antibiotics, benzene, and phenols have a negative impact on the environment. Classic water treatment systems are not effective in removing all organic pollutants, leading to the need for better alternatives. Semiconductors are considered promising materials for photocatalysis due to their good photocatalytic efficiency, low cost, and non-toxicity. The photocatalytic process involves the promotion of electrons from a low energy level to a higher energy level, resulting in the production of hydroxyl radicals and superoxide, which can oxidize organic contaminants. Sol-gel technology, particularly the dip-coating method, is widely used in thin-film applications such as sensing, solar cells, catalysis, and medical diagnostics. Cobalt oxide is a suitable material for water purification due to its good photocatalytic effect, cheap cost, and abundance. This work aims to prepare cobalt oxide thin films on glass using the dip-coating technique at 5 mm/s. The films were analyzed for structural, and morphological properties using UV-visible spectroscopy, SEM, surface topography analysis, and degradation of blue methylene [2].

II. MATERIALS AND METHOD

A. *Synthesis of Co_3O_4 film*

Sol-gel was prepared by dissolving cobalt chloride hexahydrate in ethylene glycol, adding 1-propanol, and glacial acetic acid. Glass substrates were cleaned, and films were dipped in cobalt oxide solution for 30 seconds at different withdrawing speeds. The procedure was repeated five times, and films were annealed at 500 °C for 90 min.

B. Films Characterization

The cobalt oxide films were analyzed using X-ray diffraction (CuKa radiation), scanning electron microscopy, and UV-vis spectroscopy. Surface topography and roughness were analyzed with a mechanical profilometer.

C. Figures and Tables

.

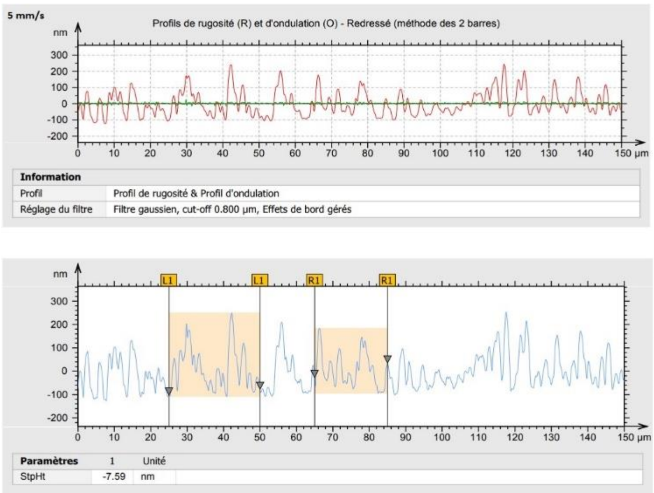

Fig. 1 Topographical features of a thin film of Co_3O_4 at a WS of 5 mm/s.

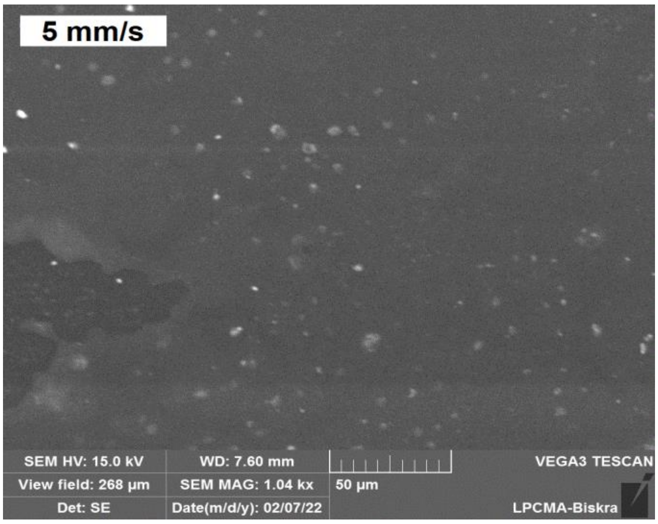

Fig. 2 Investigation of Co_3O_4 thin films using SEM imaging at a speed of 5 mm/s

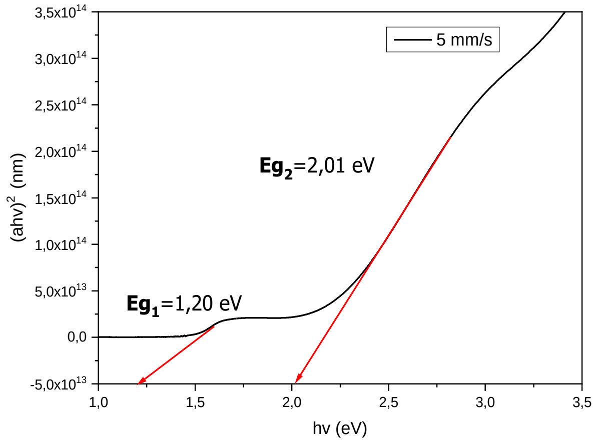

Fig. 3 Analysis of the optical band gap of a film using Tauc or Menth plots.

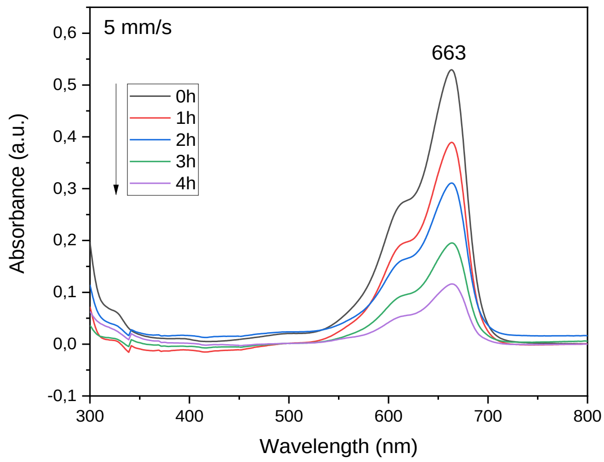

Fig. 4 Evolution of the UV-visible spectrum of BM during photodegradation on Co_3O_4 thin films.

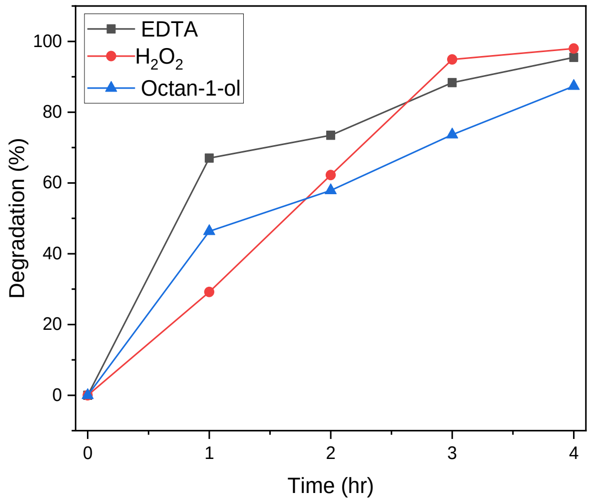

Fig. 5 Graphical representation of photocatalytic efficiency rate as a function of degradation time at 5 mm/s withdrawn speed with the addition of hole-scavengers (EDTA, H_2O_2, Octan-1-ol).

Table 1. Data summary

Parameters	5 mm/s
Surface Roughness (Rq)	55 nm
Film Thickness	178 nm
Band Gap	2.0 eV
Photocatalytic Efficiency	78 %
Photocatalytic EDTA	95 %
Photocatalytic H2O2	98 %
Photocatalytic Octan-1-ol	87 %

III. RESULTS AND DISCUSSION

The 3D surface topography, as presented in Fig. 1 and Table 1, serves as an essential indicator of the Co_3O_4 thin films' surface roughness heights. In addition, the scanning electron microscopy (SEM) image, displayed in Fig. 2, illustrates the compressed and homogenous nature of the films, devoid of any cracks or grain. The unstructured surface of the Co_3O_4 films, resulting from increased roughness, significantly enhances the adsorption of BM, thereby improving the photocatalytic efficacy of the films. The Tauc and Menth Equation (1) was employed to calculate the band gaps of the Co3O4 thin films. This equation, represented as

$$\alpha hv = A(hv - Eg)^{\eta} \quad (1)$$

, involves the absorption coefficient α, Planck's constant h, the frequency of light ν, the optical indirect band gap Eg, and proportionality constant A. Additionally, the variable η, which signifies the nature of the optical transition after photon absorption [1]. Fig. 3 showcases the Tauc and Menth plot for the optical band gap (Eg) at a withdrawn speed of 5 mm/s, providing valuable insights into the Co_3O_4 thin films' properties. To determine the thickness (t) of the thin films, the gravimetric equation (2) was utilized,

$$t = M/(g.A) \quad (2)$$

where t represents the thickness of the film (cm), A denotes the surface area of the films (cm^2), M is the mass of the films (g), and g signifies the density of the film material ($g.cm^{-3}$), as reported in previous studies [2]. In Fig. 4, degradation analysis of BM during the irradiation time of Co_3O_4 thin films is displayed, revealing the remarkable photocatalytic activity of the films. Additionally, Fig. 5 demonstrates the substantial improvement in photocatalytic efficacy under sunlight, achieved by adding hole-scavengers such as EDTA, H_2O_2, and Octan-1-ol, exhibiting large rates of 95.45%, 97.97%, and 87.35%, respectively. The incorporation of hole-scavenger compounds, namely EDTA, H_2O_2, and Octan-1-ol, into the degradation process of BM at the optimal 5 mm/s withdrawn speed has been observed to greatly amplify the photocatalytic activity of Co_3O_4 thin films. The precise addition of these compounds in minute quantities effectively curtails electron-hole recombination, thus leading to a marked acceleration of Photolysis under visible light. These results significantly advance the understanding and utilization of Co_3O_4 thin films in the field of photocatalysis.

IV. CONCLUSION

In this research, the sol-gel method and dip-coating technique were utilized to synthesize cobalt oxide thin films with a compressed and homogenous surface morphology. A 3D surface topography image of a film withdrawn at 5 mm/s revealed a remarkably high surface roughness of 71.1 nm. The band gap of the 5 mm/s film was measured to be 2.0 eV, and its thickness was found to be 177 nm, making it an optimal candidate for photocatalysis. The addition of hole scavengers (H_2O_2, EDTA, and Octan-1-ol) was found to enhance the degradation rate of BM, with H_2O_2 showing the highest rate at 5 mm/s withdrawn speed. Interestingly, the study highlights the critical role of the Co_3O_4 film's high surface roughness in improving photocatalysis efficiency. The findings demonstrate that cobalt oxide can serve as an affordable and effective photocatalyst for removing complex organic pollutants from contaminated water.

ACKNOWLEDGMENT

The authors would like to thank the Algerian Directorate General for Scientific Research and Technological Development-DGRSDT for financial assistance.

REFERENCES

[1] G.G. Hasan, A. Khelef, N. Chaabia, M.L. Tedjani, M. Althamthami, Electrochemical deposition of Ag nanoparticles on ITO-coated glass: effect of different cyclic voltammetry scan rates on Ag deposition, Https://Doi.Org/10.1080/00150193.2022.2149307. 602 (2023) 121–134. https://doi.org/10.1080/00150193.2022.2149307.

[2] M. Althamthami, E. Guettaf Temam, H. ben Temam, G.G. Hasan, N. Malfi, Influence of hole-scavenger and

different withdrawn speeds on photocatalytic activity of Co_3O_4 thin films under sunlight irradiation, Ceram Int. 48 (2022) 31570–31578. https://doi.org/10.1016/J.CERAMINT.2022.07.078.