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# Multi-Wall Carbon Nanotubes with NiO and pt as Counter Electrodes for DSSC applications

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***Abstract*—NiO-MWCNT was synthesized using the hydrothermal method and used as a low-cost, platinum-free counter electrode for Dye-sensitized solar cells DSSCs. The DSSC based on NiO-MWCNT as a counter electrode achieves a high-power conversion efficiency of 8.53% under a simulated solar illumination of 100 mW cm-2 (AM 1.5). This efficiency is comparable to 7.9% for a DSSC equipped with a Pt counter electrode. Good charge conduction characteristics of the NiO-MWCNT electrode decreases charge loss and boosts the effectiveness of converting light into electrical current. The NiO-MWCNT electrode also increases light absorption and increases the efficiency of converting light energy into electrical energy by enhancing light dispersion within the solar cell. Other advantages of NiO-MWCNT electrodes are low cost and great sustainability. Comparing it to platinum, rare and expensive material, the use of NiO-MWCNT reduces the cost of the solar cell and contributes to environmental sustainability. In addition, the NiO-MWCNT electrode has a high chemical stability, making it more resistant to corrosion and damage in dye solar cell environments. This enhances the lifespan of the cell and ensures its long-term sustainability.**

***Keywords: DSSCs, MWCNT, NiO, Platinum.***

## I. INTRODUCTION

Carbon is the sixth element on the periodic table and one of the most prevalent elements in nature, the human body, and on Earth. The forms of this element can bind to other elements and molecules as well as itself, and that have attracted the interest of scientists in recent years. The existence of carbon in many forms is known as allotropy, a beneficial property that is harnessed by academic and industrial disciplines for different of applications [1]. Despite being the foundation of several industrial applications, the two naturally occurring carbon allotropes, graphite and diamond, are still the focus of extensive research[2]. Carbon nanomaterials, including Amorphous, Porous, Fullerene, Carbon nanotubes (CNTs), Graphene, Activated, Carbon black (Cb), Carbon fiber (Cf), Carbon Rods, Carbon sphere (Cs), Graphite, and other carbon materials have attracted broad interests in the energy community due to the promising advantages of mechanical flexibility, high conductivity, long-term stability, and adjustable energy levels[3][4]. These advantages and high performances of carbon make them an important and good material for making solar cells as counter electrodes, charge transport materials, or photoanode electrodes[5,6].

Dye-sensitized solar cells (DSSCs) are third-generation photovoltaic devices that directly transform the energy of light into electricity through the photovoltaic effect, chemical and physical phenomenon. Solar cells, also known as photovoltaic cells, are electrical devices that do this[7]. DSSCs are a good contender to replace traditional silicon solar cells due to their acceptable energy conversion efficiency, low cost, and simple manufacture[8].

A DSSC based on traditional platinum (Pt) counter electrode (CE) recently obtained the highest power conversion efficiency of 12%. Even so, the expensive noble metal Pt might be converted in the electrolyte into a redox pair. Therefore, it is crucial to find affordable substitutes that might take the place of pricey Pt as counter electrodes[9,10]. Many materials, including these based on carbon, have been tried in the pursuit of Pt as counter electrodes [11,12].

The Multi-Wall Carbon Nanotube (MWCNT) material is regarded as a viable substitute counter electrode due to its significant specific surface area, exceptional electronic conductivity, strong chemical stability, and great mechanical strength [13].


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The two significant elements that influence the performance of DSSCs are the electrical conductivity and the electrocatalytic activity of Pt as the counter electrode. There is a reason to think that MWCNTs decorated with NiO particles (NiO-MWCNT) can boost electrical conductivity and electrocatalytic activity in light of the aforementioned studies. In this study, NiO nanoparticle adorned MWCNTs were successfully created. The DSSC demonstrated greater photoelectric conversion efficiency than that based on standard Pt as a counter electrode because it demonstrated outstanding electrical conductivity and electrocatalytic activity when using the NiO-MWCNT film as the counter electrode.

## II. EXPERIMENTAL SECTION

### A. *Synthesis of NiO-MWCNT paste*

To prepare NiO-MWCNT paste, 0.05 g of nickel nitrate (Ni(NO3)2) was weighed and placed in a suitable glass container. Then, sodium hydroxide (NaOH) solution was added gradually to the glass container containing nickel nitrate. It caused a chemical reaction that led to the formation of a NiO precipitate. After that, the mixture was filtered using a filter paper to separate the precipitate from the solution. The resulting precipitate was washed well with distilled water three times to remove impurities and other substances. The washed sediment was transferred to a convection oven to dry it at a temperature of 50°C to remove residual moisture. Then, a weight of 1 gram of MWCNT was put in a clean glass container containing 0.03 of NiO and 10 ml of ethanol, and finally put the whole mixture in the mixing device for 48 hours. Then, the resulted material that was formed was NiO-MWCNT paste.

### B. *Preparation of Thin Films as Counter Electrodes*

To fabricate a thin film of NiO-MWCNT on FTO glass was the Doctor Blade method was used. After preparing the NiO-MWCNT paste, an amount of NiO-MWCNT paste was placed on the FTO glass near the front end of the blade and slowly pulled it across the FTO glass to evenly distributing the paste and forming the thin film with an effective area of 1 $cm^2$. After applying the thin layer, it was left to dry at 50°C for half an hour. The film was then transferred to an oven for annealing at a temperature of 450 °C for one hour to obtain a stable and cohesive thin film، as shown in Figure 1.

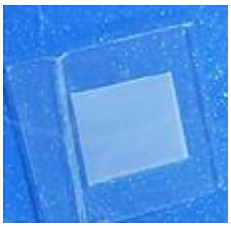

**Figure (1):** NiO-MWCNT film deposited on FTO glass.

To fabricate a thin film of platinum on FTO glass, the vacuum thermal evaporation method (TEV) was used before starting the evaporation process; the glass surface was cleaned well to remove any impurities or deposits using ethanol and then rinsed with distilled water and dried well. The FTO glass was mounted on a suitable holder inside the evaporation chamber. The evaporation chamber was heated gradually until it reached a temperature of 2000 °C to evaporate the platinum. The temperature should be determined according to the specific conditions of thin film manufacturing. Platinum vapor was formed and deposited on the surface of the FTO glass in the evaporation chamber. After the evaporation process completed, the FTO glass with the thin film deposited on it were left to cool down to the room temperature.

### C. *Preparation of Photoanode Electrode*

$TiO_2$/NiO-RGO thin film was prepared as photoelectrode by mixing 1 g Titanium dioxide ($TiO_2$) (Aldrich, >97.0%), 0.5 g RGO (graphene-oxide), and 0.02 g NiO in 50 mL ethanol (99.9%). The solution (mixture) was stirred for 30 min by a magnetic stirrer at room temperature. For greater homogeneity and consistency between the components, the solution was stirred for 2 h with an ultrasonic homogenizer. Then, the suspended material was separated by centrifuge and allowed to dry at room temperature. To obtain a paste of $TiO_2$/NiO-RGO, 1 g of nanopowder was placed in 20 ml of ethanol in a magnetic stirrer at room temperature for 48 hours. Then, the $TiO_2$/NiO-RGO paste was deposited by spin coating on the FTO glass with an effective area of 1$cm^2$. Therefore, the substrates were subsequently annealed for 2 h at 450 °C. The hot films were then cooled to room temperature.

### D. *Fabrication of DSSC Devices*

The $TiO_2$/NiO-RGO optical thin film was dipped in a ruthenium dye solution (N719) at ambient temperature for 24 h without exposure to light after being recovered from a DSSC with an active area of 1 $cm^2$. Following a pure ethanol wash, the $TiO_2$/NiO-RGO sensitive electrode was left to dry in dry and moisture-free air. I2 (0.3 g), LiI (0.3 g), C9H13N (0.15 g), DMPII (0.4 g), CH6N3 (0.33 g), and CH3OCH2CH2CN (2 ml) make up the electrolyte. The dye-impregnated photoelectrode was placed on the pt film counter electrode, and an electrolyte drop was placed between the two electrodes to collect DSSCs. So, it has the first gadget (H1).

The second device (H2) was made in the same way that the first device H1 was made, except by substituting a thin layer of NiO-MWCNT with pt film. To stop electrolyte solution leakage, the electrodes are grouped together with the photoelectrode isolated from the counter electrode by the

use of an insulating material such as glue (see Figure 2).

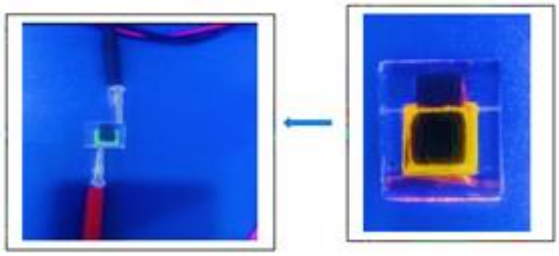

**Figure (2):** The DSSC device it made for this study.

## III. Results and Discussion

### A. *Characteristic Analysis*

Figure 3 shows XRD patterns for NiO-MWCNT. It saw three different peaks that are brought on by NiO production at about (2) 38°, 44°, and 64° (111), (200), and (220), respectively. It saw peaks at around (2°) 26° (002) in the MWCNT XRD spectra. In the case of the NiO-MWCNT nanocomposites, in addition to the broad MWCNT XRD peak, it also detected three exceptionally sharp NiO peaks at about (2) 38°, 44°, and 64°. These peaks provide unequivocal evidence of the MWCNT's successful incorporation into NiO (NPs). The three different NiO peaks are accompanied by the conventional MWCNT peaks. This demonstrates that MWCNT and NiO have been incorporated into the nanocomposite.

Figure 4 (b) showed the results of a TEM examination that was performed to further observe the microstructure of NiO-MWCNT. Notably, MWCNTs have had NiO nanoparticles affixed to their surface. These TEM findings attest to the efficacy of the NiO nanoparticle decoration of the MWCNT surface.

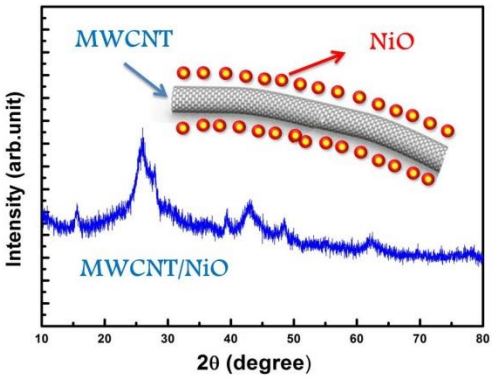


**Figure (3):** X-ray image of the NiO-MWCNT nanocomposite.

The shape of the NiO (NPs) was found to be uniform as shown in Figure 4 (a). It was observed that MWCNT has a tubular shape, and the composite particles were formed with essentially homogeneous sizes. It observed that the width of MWCNT was improved more than the pure MWCNT shown in the same NiO-MWCNT image. This demonstrates that NiO (NPs) was expanded on the surfaces of the MWCNT.

Figure 4b shows the TEM images of the nanocomposites. Additionally, it was noted that the shape and residue of the compound NiO (NPs) were essentially homogeneous. It demonstrates that NiO-MWCNT nanocomposites were formed. It observed that NiO (NPs) are evenly and homogeneously grown on surface MWCNT The MWCNT is obtained with thicknesses of 20 nm.

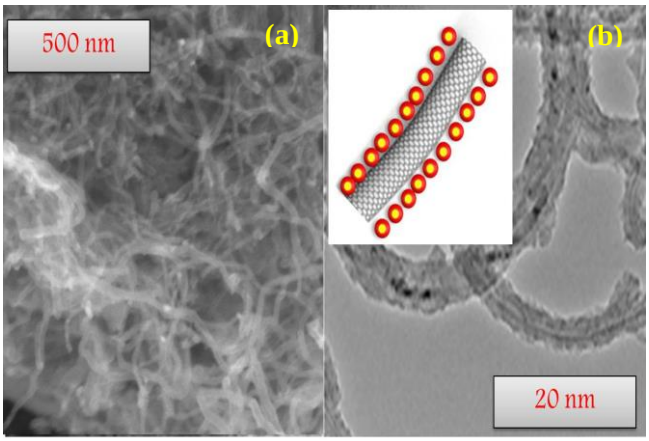


**Figure (4):** (a) SEM of the NiO-MWCNT nanocomposite and (b) TEM of the same material.

### B. *Performance of Pt and NiO-MWCNT as counter electrodes in DSSCs.*

The photovoltage density (JV) curve shows the values of Voc, Jsc, FF, and PCE (see Fig. 5 and Table 1) under similar conditions to sunlight (AM1.5, $p_{in}$ 100 mW $cm^{-2}$). The photovoltaic performance of device H2 is higher than that of H1 under the same conditions. Replacing Pt electrode with the NiO-MWCNT electrode in dye solar cells led to an increase in the efficiency of the solar cell because NiO acts as a semiconductor material and contributes to facilitating the movement of charge between the MWCNT. As a result, the charge loss reduces and increases the efficiency of using light to generate electrical current. The NiO-MWCNT electrode improved light distribution properties because it increases light absorption and thus increases the efficiency of converting light energy into electrical energy in H2.

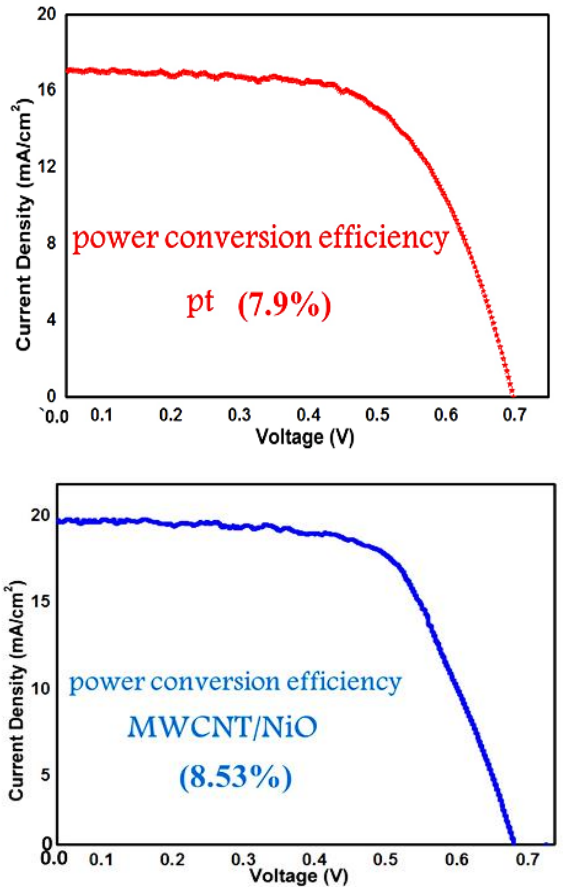


**Figure (5):** J-V curves for DSSCs with counter electrodes made of Pt and NiO-MWCNT.

**Table (1)**: Performance characteristics of H1 and H2, based on pt and NiO-MWCNT as counter electrodes, respectively.

| Cell | H1 | H2 |
|---|---|---|
| CE | Pt | NiO-MWCNT |
| Dye | N719 | N719 |
| $J_{sc}$ (mA/cm$^2$) | 17.09 | 19.03 |
| $V_{oc}$ (V) | 0.69 | 0.68 |
| FF | 0.67 | 0.65 |
| Efficiency % | 7.9 | 8.53 |

## IV. Conclusion

Replacing the platinum electrode with NiO-MWCNT electrode promotes the trend towards cost reduction and increased sustainability in solar cells. Platinum is a precious and rare material and expensive, while NiO and MWCNT have lower costs and more abundant material availability. NiO-MWCNT electrode has better chemical stability than platinum in various environments. Platinum is subject to corrosion or damage due to its chemical reactions in dye solar cells, while NiO-MWCNT has a higher resistance to these reactions, resulting in long-term solar cell stability. In general, replacing the platinum electrode with a NiO-MWCNT electrode provides multiple benefits such as good charge conduction, better light distribution, low cost, and high sustainability and stability of solar cell. These factors contribute to increase the efficiency of the dye solar cell.

## Conflict of Interest

Authors declare that they have no conflict of interest.

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