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Impact of a Bright Nickel Interlayer on the Performance of Solar Absorber Nano Coatings Deposited by Electroplating on Copper Substrate

Abstract: *In this, work, a layer of bright nickel was deposited on the copper substrate using electroplating technique watts bath, before copper nanoparticles (CuNP) Evaporation via physically vapor deposition. The improvement of the solar absorber using CuNP and CuNP, combined with bright nickel, was found to be well than CuNP singly. Bright nickel improved the thermal stability of the absorber. Also the other optical properties absorption, emissivity slight decrease from (93% to 87%0) in another hand thermal conductivity was evaluated using hot disk analyzer with a good improvement obtain by CuNP(89%) deposited on copper substrate while it decreases with percentage18.8% in the presence of bright nickel combined with CuNP, other Characteristics like structure and phases of coating layers achieve using XRD, topographic was obtained using AFM and SEM.*

Keywords: bright Nickel, Copper Nanoparticles CuNP, PVD, Solar Absorber.

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1. Introduction

Due to the increasing demand for energy, the need for alternative clean energy sources with the least emission of dioxide has increase; sun is one of the main sources of energy at all, In order to convert this thermal energy into useful energy, selective coatings are emerging as an important industrial application [1,2].

A good selective solar absorber coating should have two criteria a high absorption across the solar spectrum wavelength in an ultra violet area visible (UV. Vis) and range and low thermal emittance in the near infrared (NIR). Usually, the optical characteristics are determined using reflectance spectrophotometry, and the reflectance should be lesser than 10% in the UV-Visible range and higher than 90% in the infrared range [3]. In the meantime metals have a relatively low thermal emittance, selective solar absorber coatings are normally prepared on metallic substrates with good corrosion resistance and great thermal conductivity [4,5].

There are many techniques and methods for producing selective coatings including paint, chemical vapor deposition (CVD), Sol-Gel, Spray coating, and physical vapor deposition(PVD), Electroplating is a simple and attractive option due to its reproducibility and excellent control over the morphology and thickness of the coatings also it low cost and short deposition times[3,4,6]

Bright nickel is an attractive, low-cost solar absorber material the coatings got with this electrolyte and similar formulations for chemical conversion baths showed good optical properties [7-9]. Nickel is usually used as an intermediate layer to protect the thin film and prevent the diffusional problem of the nanoparticle to the material substrate, also giving thermal stability [10,11].

Copper is an attractive substrate material for selective coatings related to its good thermal conductivity, stability and its high reflectance (low emittance) in the near IR. Furthermore, copper is very suitable as a substrate for electrodeposition from other side copper

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nanoparticles completely different from bulk, where it characterized by their unique and distinctive properties in the field of thermal and electrical conductivity as well as their use in selective coating [12].

The selective coating based on thin nanofilm multilayer has a deep researcher's interest. In this work, the electroplating of bright nickel working as an interlayer between the copper substrate and copper nanoparticles (CuNP) selective absorber and the effect of this layer on optical and thermal properties have been implemented. This nickel layer coating is slightly lower thermal absorption and emissivity than copper nanoparticles coated onto copper directly. The comparing of the optical and thermal properties of between nanocoatings directly deposited onto the copper substrates and copper nanoparticles coated with the presence of bright nickel have been investigated in this research.

2. Experimental Part

I. Substrate Preparation

Substrates cut like rectangular with dimensional (20mm×200mm×3mm) using band saw machine type Knuth German manufacturing, and to hang the samples in an electroplating bath, it should have a drill about (5mm). Figure 1 shows the geometry of the samples.

Figure 1: Copper substrate alloys Pre-sample cutting

Later Copper substrates post cut carried out with dimensional (20mm×20mm×3mm) as present in Figure 2 in order to employ the samples in a vacuum chamber of thermal evaporation system using knuth wire cutter machine type (Smart DEM) German manufacturing to be the substrates of the copper nanoparticles (Cu NP) as solar selective coatings.

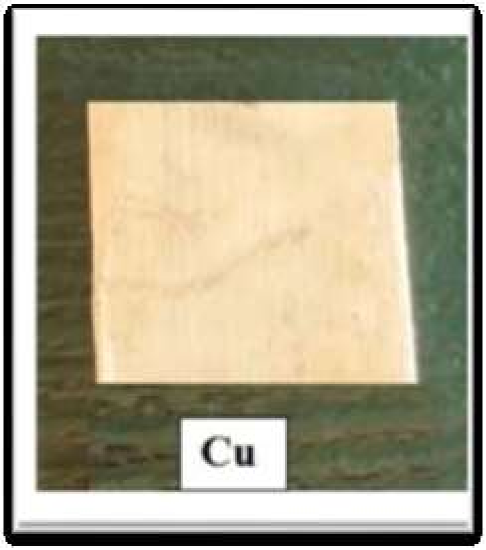

Figure 2: Copper substrate alloys post-sample cutting

II. Chemical Analysis of the Substrate Alloys

The chemical composition of the copper substrate alloy has been analyzed with spectrophotometer at the condition of temperature with 20˚C and the humidity of 62%the chemical analysis was carried out using by using optical emission spectrometer (OES) type (Foundry-Master x pert) S.N 52Q0089 German manufacturing The results of the analysis have been illustrated in Tables 1, which include the actual measured and standers values, while Figure 3 shows the microstructure of copper under an optical microscope.

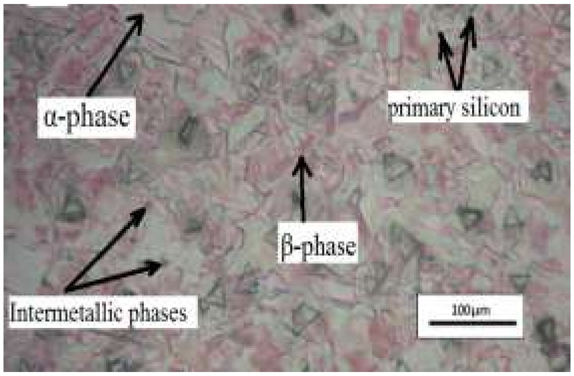

Figure 3: Microscopithe c structure of the Copper substrate

Table 1: The stander and actual chemical compositions of copper [13]

Chemical Composition%	Standers Values	Actual Values
Cu	Man.96	98.910
Fe	Max.2.4	0.141
Si	Max. 0.7	0.494
P	Max.0.005	0.000
Pb	0.001-0.005	0.001
Ag	Max. 0.05	0.019
Mn	0.001-0.005	0.003
Zn	Max.0.5	0.415

On the other hand, copper nanoparticles used, as raw nanomaterial absorber was present with a mean particles size of 24 nm. Table 2 gives the general specifications of CuNP.

Table 2: Specifications of CopperNanoparticles.

Property	The value	Units
Average particle diameter	24	nm
Purity	99.98	%
Bulk Density	0.46	g/cm3
True Density	4.23	kg/m3
Color	Black	-

III. Preparation for Electroplating Process

Before employing the copper substrates pieces into the chemical bath of electroplating system, the Substrates were prepared for coating. You must remove the Impurities, Contaminants, dust, grease, and other stranger particle remains from manufacturing operations. It may sometimes require removed layer in order to achieve free surface like remove the oxides this will lead surface ready for the electroplating process .in this work different techniques carried out to prepare the copper substrate for nickel electroplating (electropolishing, ultrasonic cleaning and alkaline ,acid clearing) cleaned and polishing as illustrative in Figure 4 below.

IV. Bright Nickel Electroplating

Bright nickel deposited on copper substrates as inter layer carried out by electroplating technique The bright nickel layer was achieve using The plating cell rectangular like size (50 liters) containing ($NiSO_4 .6H_2O$ 240 g/l, $NiCl_2.6H_2O$ 20 g/l, H_3BO_3 20 g/land with different concentrations of KNO_3) as electrolyte solution sometimes called Watts bath . While plating bath was made from Polyphenols Chloride (PVC). Nickel sheets with dimensions (25.0 × 25.0) cm were used as the anode while Copper pieces with dimensions 2.0×2.0 cm used as a cathode. Before each run, the nickel-plating Sample Preparation carried out Direct current was supplied by a D.C power supply unit. The cathodic current efficiencies CCE were determined with the help of a coulometer (CCE=89%). However, the conditions of coating applied current density (2.4-2.8) Amp/dcm^2, and coating time (0.5-1) minute the condition of electroplating process is presented in Table 3.

Figure 4: Flow chart shows surface methods achieve in this study

Table 3: Nickel electroplating process conditions [8]

Electroplating Condition	Standard Parameter	Actual parameter
Temperature of electroplating	50 - 60 °C	53 °C
P.H of electrolyte	3.5 - 5	4.8
Size of bath	-	25 liters
Size of sample	-	20 cm x 2cm
Electroplating period	Max. 30 min.	2 min.
Area of anodes to cathode	2 -1	2(25 x25 x3cm)
The cathodic current efficiencies CCE	high	
Type of bath Nickel	Watts bath	Commercial watts bath
Anode and cathode range	Min. 2.5 cm	25 cm

V. Thermal evaporation Preparation Procedure

In order to obtain a thin film using thermal evaporation which a kind of physical vapor deposition system that has been described in detail in Figure 5. Before putting the substrates into the vacuum chamber the Substrates were prepared for coating material into the boat made from Molybdenum, the substrate pieces cleaned and polishing in order to remove the dust, grease, and other stranger particles also the vacuum chamber was pumped down to a base pressure of 2.5×10^{-4} Pa. Starting powder nanomaterials was weight to be contained in Molybdenum boat and placed at the center of the champers. The deposition process used in this work consists of units showing in Figure 5.

Figure 5: Thermal evaporation unit using in the study

3. Results and Discussion

I. XRD Result

XRD spectrum of the Cu with Cu Ka radiation (E=1.0454A°) at a scanning rate of 10 deg. per sec ranging from 20 to 80. Figure 6 shows the X-ray patterns of crystalline structure of copper nanoparticles, from the bottom the black line diagram indicted the strong peaks at angles 43.4029$^{\mathbf{o}}$ and 50.4952$^{\mathbf{o}}$, and 74.1857^{o} corresponding to the copper substrate without coatings [14], while middle lines with red line shows peak refer to the presence of nickel at peak 49.7181 $^{\mathbf{o}}$ with structure (200) regarding to XRD card(pdf#451027), on another side nano copper thin films exhibited a strong peaks at angles, 43.3669$^{\mathbf{o}}$, 50.4378$^{\mathbf{o}}$ and 74.1583$^{\mathbf{o}}$ [14], which indicate the nanostructure of CuNP at angles 43.3669^{o}, 50.4378^{o} and 74.1583^{o} with structure (1 1 1) (2 0 0) and(2 2 0) respectively (pdf#004-0836) [14].

II. SEM

The results pointed to the topography of the films prepared by this method more uniform as compared to the topography that prepared by another method. It's clear from two Figure 7, and Figure 8 shows the images of the scanning electron microscope with a magnification force of 20µm And 1µm analysis for copper thin film prepaid by thermal evaporation The surface of the thin appear as dense layer of small, semi-spherical nanoparticles distributed uniformly over the sample surface area.

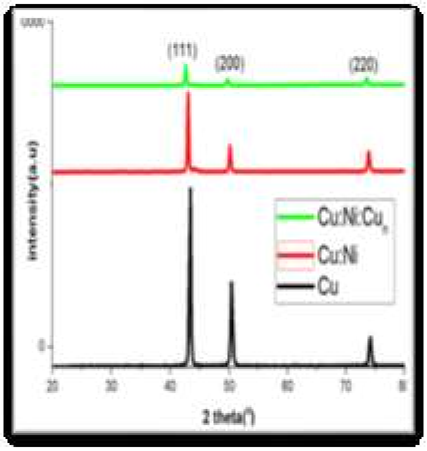

Figure 6: The x-ray diffraction pattern of bright nickel and CuNP deposited on copper from the bottom to the top.

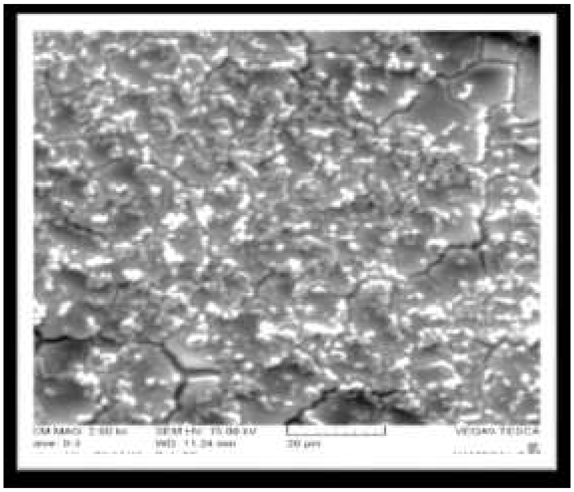

Figure 7: SEM image of surface copper nanoparticles deposited on copper

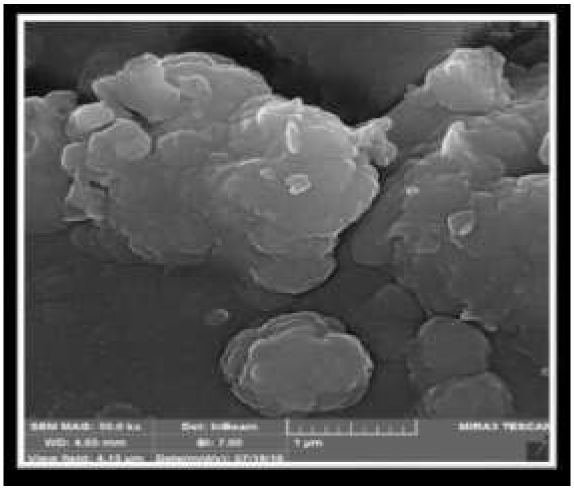

Figure 8: FESEM image of surface copper nanoparticles deposited on the bright nickel-copper substrate.

III. AFM Analysis

The surface roughness and topographies of the prepared thin films were examined by AFM. Figure 9 shows the AFM images of the 3D surface of CuNP thin films that were prepared by thermal. From the topographic results, it can be noted that the substrate preparation and time coating plays an important role affected by both grain size and average surface roughness. It was found that average roughness was 1.94 nm and average grain size distribution obtains 102 nm as present in Figure 10.

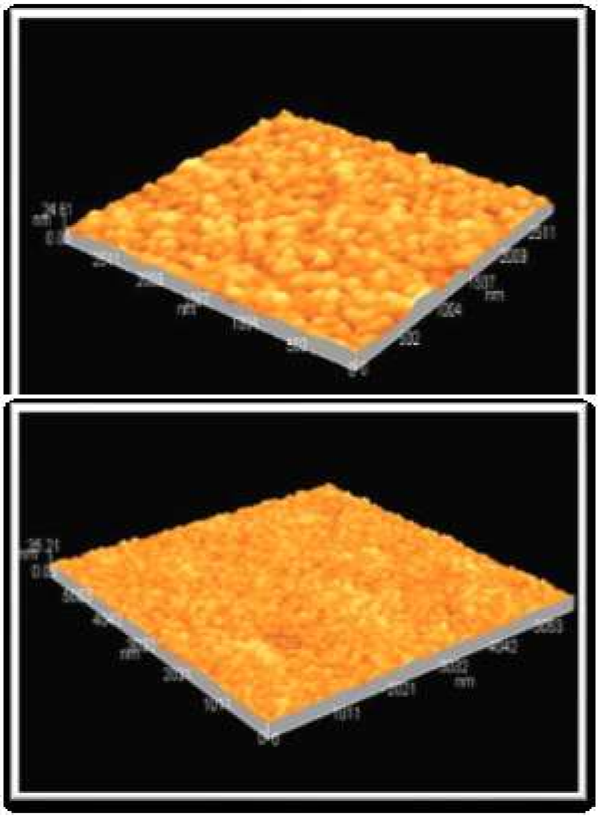

Figure 9: Present the 3D surface topography of copper nanoparticles thin film.

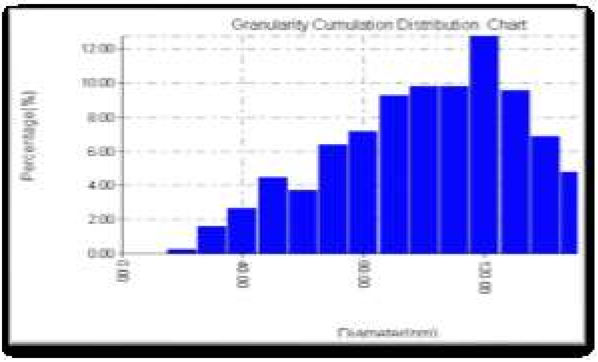

Figure 10: Grains size distribution along thin film surface area examined.

IV. Thermal Conductivity

Using hot disk Equipment (Thermal Constant Analyses) TPS-500 with single side sensor to study and evaluated the thermal conductivity behavior of copper nanoparticles and influencing of bright nickel on thermal properties. It was found that slight decrease with thermal conductivity while thin film of nanoparticles show a good enhancement in thermal conductivity that will lead optical and thermal properties which are lead to a good improvement in absorbent by the data show in Table 4 a good enhancement with presence of copper nanoparticles as compared with copper nanoparticles combined with bright nickel [15, 16].

Table 4: Thermal properties of different samples used in this wok.

Samples	Thermal Conductivity W/m.K	Thermal Diffusivity mm^2/s	Specific Heat $MJ/m^3 \cdot K$
Cu	3.392	0.0083	405.1
Cu- Ni - CuNP	5.213	6.427	0.8111
Cu-Cu NP	6.426	0.9874	6.026

V. Optical Properties

Thermal selectivity coating depends on the optical properties, hence an increase in absorbance in general is a result of increasing in the thickness of thin film, This due to increase the degree of crystallization by increasing the thickness this will lead to increase in the particle size, in another hand this may obtain higher roughness cause efficient absorbance, and this agrees with researchers J. El Nady et al. [16] and M.A. Estrella [17].

The higher the thickness of the thin films, the greater the absorbance as in Figure 11shows a comparison between the behaviors of the absorption spectrum of copper nanoparticles as a function to the presence of the bright nickel layer combined with CuNP deposited on copper. Bright nickel layer caused slight decreases in thermal absorbance. The copper nanoparticles deposited on copper showed a high absorption in the wavelength range from 300 to1100 nm to reach a maximum value of 93.191%, while this value reduced in the presence of bright nickel to 87.73% [18].

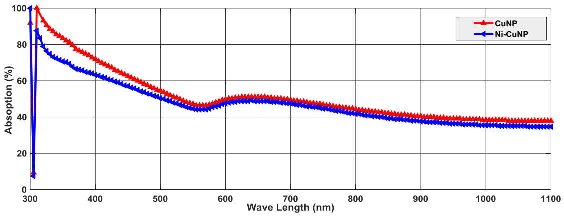

Figure 11.The spectral absorption in the UV-Vis region for copper nanoparticles deposit on (Cu and Ni-Cu).

4. Conclusion

Even though copper nanoparticle has good thermal absorption about (93.191%), while a layer of bright Ni electrodeposited has been implemented to avoid the diffusion of the copper nanoparticles thin film toward the substrate. It slightly decreased the optical performance of the coatings about (87.73%) and decreased the thermal emissivity. It is clear that bright nickel electroplating is a good choice to overcome the problem of the diffusion of thin film nanoparticles, while they are reducing the thermal emission and increases the efficiency of the selective absorber coating, also thermal conductivity have a great improvement with copper nanoparticles about 89.4458% as compared with copper substrate alone, in other hands slightly decrease in thermal conductivity about 18.87644%, in addition, to a good improvement in the thermal stability of the absorber surface has been noted due to bright nickel electroplating .

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