Characterization of nanostructure black nickel coatings for solar collectors

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Abstract: In this research, black nickel coatings have been deposited on brass, copper and steel substrates by electrodeposition method. The physical properties of solar absorber black nickel coatings on different metallic surfaces have been investigated. The effect of different metallic substrates including brass, copper and steel with presence of bright nickel middle layer and without its presence on optical and structural properties of deposited layers have been studied. These coatings characterized by scanning electron microscopy (SEM), X-ray diffraction (XRD) and energy-dispersive X-ray analysis (EDAX). For investigation of optical properties of deposited layers, UV-VIS-NIR spectrophotometer was used.

Keywords: *Electroplating, Black nickel, Bright nickel*

1. Introduction

The use of selective coatings has been widely established as an industrial application which used to absorb solar thermal energy. Demands for design and construction of solar absorber plates to achieve reduced energy consumption and its applications in the areas of electrical energy, heating and cooling systems lead to the development of growing of black nickel coatings [1]. Fundamental properties of black nickel coatings are currently excessively studied because of their potential application in numerous fields such as electronic devices, opto-electronic, optics, biotechnology, human medicine, solar energy conversion and etc [2]. Black nickel is one of the most commonly used solar selective coatings in solar collector systems for the efficient conversion of solar energy into thermal energy [3]. Such coatings are identified by high solar absorptance (α>95%) and low thermal emittance (ε<40%). Considering all studied cases selected for selective solar absorber coating, black nickel plates due to lower consumption of requirement electrical energy also electroplating in large scale for production and development in the industry are considered as one of the most appropriate coatings [4]. There are different methods for the deposition of black nickel coatings, including Chemical vapor deposition (CVD), sputtering, spray pyrolysis[5], electroless[6], pulse plating[7] and electrodeposition [8,9]. Among these methods, because of simple setup, low cost process of coating in industrial scale, easy control of production processes and high speed production, the electroplating method attracted special attention.

Electroplating of metallic films is one of the appropriate techniques to obtaining absorber coatings with selective optical properties for solar collectors. Electrical current and reclamation agents that are used in this process are cheap and this good economic sense to develop this approach. By using this method, optical coatings with suitable properties for solar absorber plate's applications with large scale are provided.

Electroplating is a process in which by using electrical current, a thin layer of metal is deposited on the surface of another metal. Figure 1 shows the schematic of electroplating system in hull cell. The presence of the bright nickel middle layer causes changes in the optical properties, including absorptance and emittance, of the films.

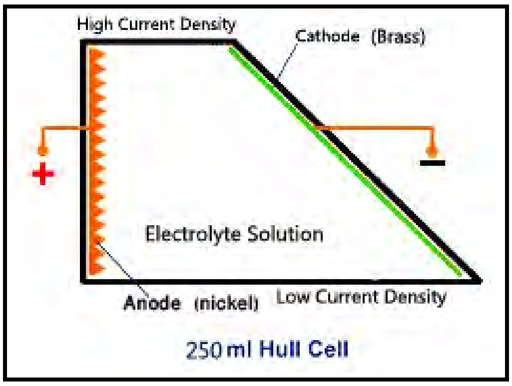

Fig. 1. The schematic of electroplating system in hull cell

2. Methodology

Black nickel coatings have been deposited on three different substrates namely brass, copper and stainless steel by electroplating method. Before deposition at First, the desired metal plates in dimensions of 7 × 1 0 cm perfectly polished and then thoroughly washed with distilled water. After that all substrates were degreased with a hot commercial alkaline solution followed by rinsing in distilled water. Finally they are placed in the chloride electrolyte solution for black nickel plating. All the coating process is carried out in hull cell. The Quality of black nickel coatings depend on the electrolyte solution composition and its concentration, electrodes, solution pH, bath temperature, current density and (deposition) duration (time). Therefore to obtain optimum optical properties for black nickel coatings, deposition parameters have to be optimized. In this type of coating, the soluble nickel metal used as a anode with 99% purity. Direct current passes between two electrodes in a conducting solution of nickel salts. The chemical bath for black nickel deposition consisted of a mixture of distilled water, nickel, zinc, tin and ammonium chloride with potassium thiociyanate. By flowing the current through the electrolyte, one of the electrodes (anode) is dissolved in the solution and the other electrode (cathode) is covered by a black nickel layer. In the electrolyte solution Ni positive ions (Ni^{++}) present so as the electrical current flows through the electrolyte, positive ions by absorbing two electrons on the surface of cathode are converted to nickel metal and deposited on the cathode surface. Reverse reaction occurs at the anode. So with the consumption of nickel in the cathode, the nickel ions are provided by anode. The concentrations of additives were varied to improve the optical performance. After numerous tests the best conditions for strongly adherent and durable black nickel coating, as mentioned in table 1, were obtained as follow: solution with pH 4.2, electrolyte bath temperature 65°C, plating time 10 min and current density 0.1 A/dm^2.

The effect of different substrate metals including brass, copper and stainless steel without the presence of the middle bright nickel layer and with the presence of it, on the optical and structural properties of the black nickel coatings have been investigated. Changes in the physical as well as optical properties of black nickel coatings are measured. SEM and XRD analysis are carried out by Philips PW3710 and Philips XL 30; the absorption spectra of coatings and emittance spectra are measured by carry 500 and Jasco FTIR respectively.

Table 1: Optimum conditions of coating

Current density	**Temperature**	**pH**	**anode**	**cathode**	**Deposition time**
0.1 A/dm^2	65℃	4.2	Nickel metal	Brass plate	10 minute

3. Results

3.1. Evaluation of optical properties, absorption analysis

Absorption spectrum curves of the black nickel coatings for various wavelengths depending on the metal substrate; including brass, copper and steel with and without bright nickel middle layer are presented in Fig.1-a and Fig.1-b. As can be seen from the graphs below, the black nickel coating has high absorption coefficient. The results from Graphs show that by changing the substrate, the absorption spectrum will change. The highest absorption is related to the coating layer on brass substrate without bright nickel and lowest absorption is belonged to the coating layer on stainless steel substrate with present of bright nickel.

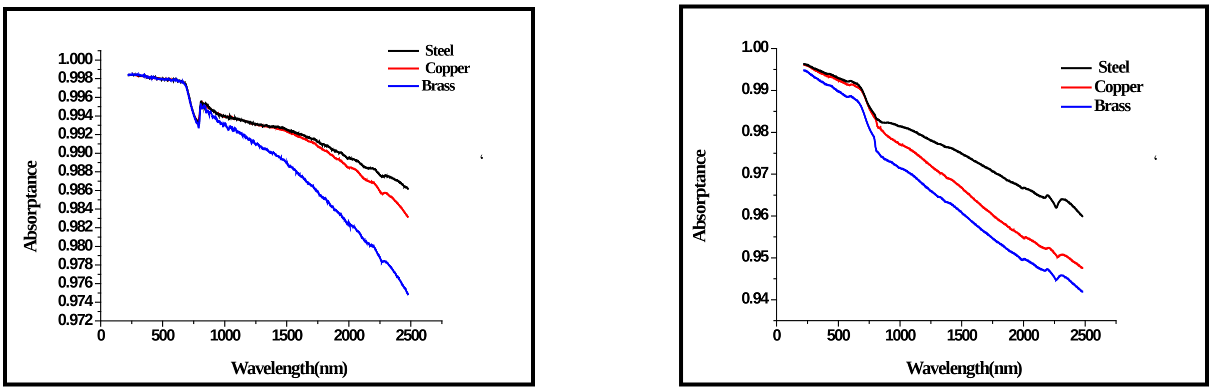

Figure (1 – a) absorption spectrum of black nickel on brass, copper and steel substrates without bright nickel, as a function of wavelength. Figure (1 – b) absorption spectrum of black nickel coating on copper, brass and steel substrates with bright nickel as a function of wavelength.

3.2. Emittance analysis

Below figure shows the result of emittance. By comparing the results the lowest emittance is belonged to the brass substrate and highest emittance is belonged to the steel substrate.

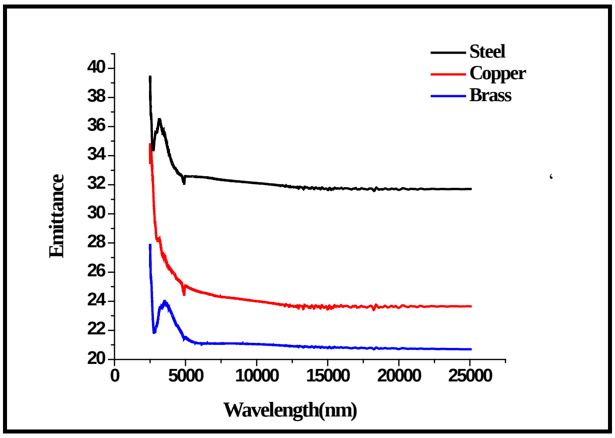

Figure (2) emittance spectrum of black nickel on brass, copper and steel substrates without bright nickel, as a function of wavelength.

3.3. SEM analysis

Scanning Electron Microscopy (SEM) Images of nano black nickel coatings prepared from nickel chloride bath with and without the presence of bright nickel middle layer. fig 3-a and 3-b shows the image of black nickel coating on brass substrate without and with bright nickel middle layer respectively.

By comparing the images of SEM it can be distinguished that layers with bright nickel have larger grains in comparison with layers without bright nickel. Since layers without bright nickel have a higher absorptance spectra so as result when grain size increase absorbtance spectra decrees.

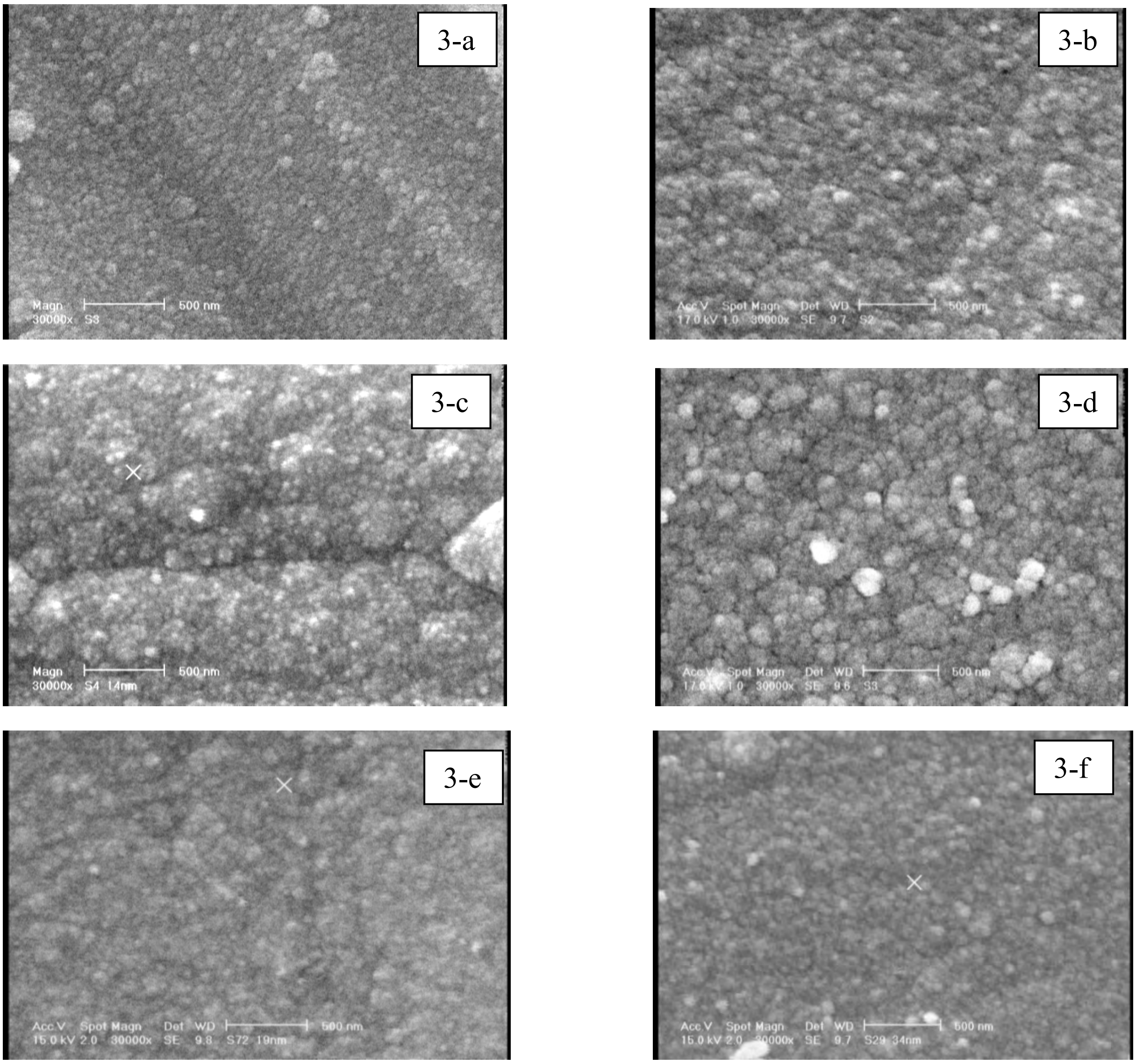

Figure 3: (SEM) Images of the black nickel coating
a) SEM image of a black nickel coating without bright nickel layer on the brass substrate b) SEM image of a black nickel coating on the brass substrate with bright nickel layer c) SEM image of a black nickel coating without nickel layer on the steel substrate d) SEM image of a black nickel coating With the bight nickel layer on stainless steel e) SEM image of a black nickel coating on copper without the bright nickel layer f) SEM image of a black nickel coating on copper with bright nickel layer

3.4. Results of X-ray diffraction and elemental analysis(EDAX)

Figure 4-a and 4-c show X-ray diffraction pattern of electrodeposited black nickel coatings on brass substrate. Two different structures clearly can be seen with and without the presence of bright nickel. Without presence of bright nickel there was no peak related to crystalline nickel and only the peaks belong to brass substrate have grown. While with regard to the 4-b, the presence of Ni element in the deposited films is provided by elemental analysis EDAX. The major difference between two structures can be recognized in fig 4-c. In XRD analysis of layer deposited in the presence of bright nickel the preferred orientations (111), (200) and (220) belong to nickel can be seen.

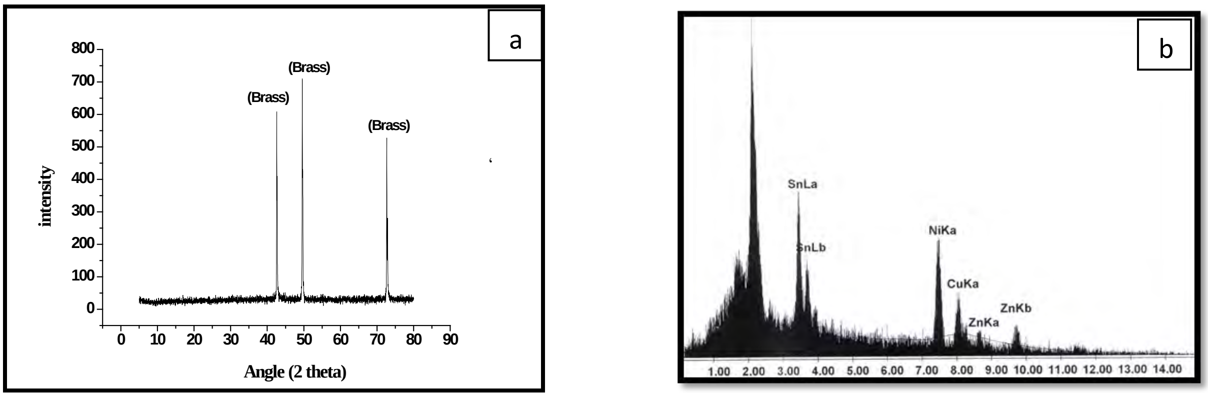

Figure 4– a, b X-ray diffraction pattern and elemental analysis black nickel coating without bright nickel

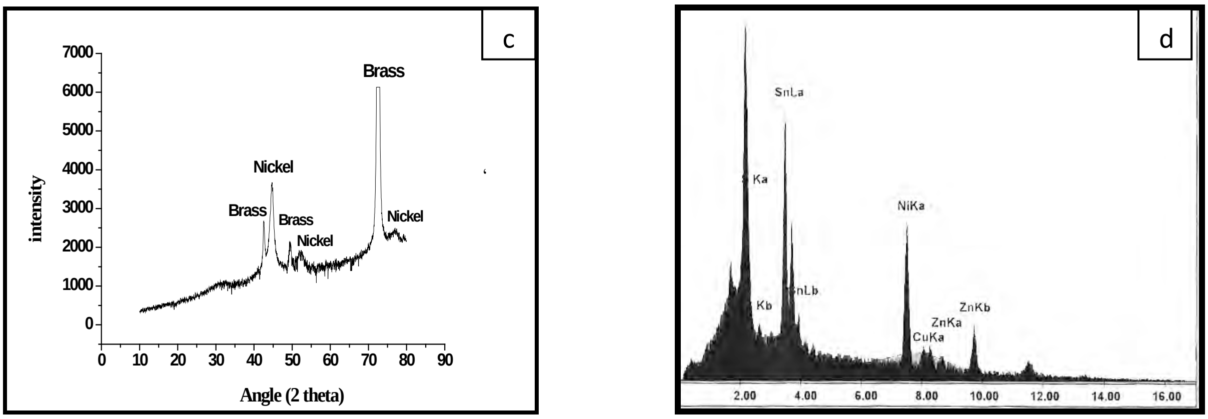

Figure 4–c, d X-ray diffraction pattern and elemental analysis black nickel coating with bright nickel

In order to identify the predominant nickel phase in the deposited films, it is necessary to investigate the coatings using X-ray diffractometer. Fig. shows the typical XRD pattern for the bright nickel substrate coated with black nickel films. This result is in good agreement with result of EDAX analysis.

4. Conclusion

The black nickel coatings with high absorption coefficient are suitable for solar applications. The coatings are very adhesive and have good thermal stability, with high absorption coefficient. SEM images show the relationship between absorption spectra with fine diameter of spherical particles, so that the layer of black nickel deposited on brass substrate without bright nickel coating have very small spherical particles and consequently optical properties of selected increases. Conversely, with the presence of bright nickel layer the particle size increases and absorption spectrum decreases. The highest absorption is for layer deposited on brass without bright nickel and low absorption spectrum associated with the nickel coating on steel with bright nickel middle layer. EDAX analysis indicates presence of nickel on formed films. X-ray diffraction analyses show that electrodeposited films have polycrystalline structure and black nickel films were mainly consisting of metallic nickel. This result is matched with result of EDAX analysis. The presence of bright nickel middle layer cues the growth of nickel structure in orientation of (111), (200) and (220).

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