

Preparation and Characterization of Nano-Composite Electroless Ni/Ag Coating as Solar Absorber Panels

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ABSTRACT: The purpose of this paper is an investigation on nano-silver effect on the optical properties of nickel-phosphorus electroless coatings. Nano-composite Ni/Ag electroless coatings were deposited on aluminium (Al -1100) substrate. The phase analysis carried out by X-ray diffraction (XRD). Dispersion of nano-silver particles and chemical composition of the coatings investigated by field emission scanning electron microscopy (FESEM) and EDS, respectively. The results show that the composite coatings were high phosphorus and their microstructures were amorphous. Optical properties of the samples were obtained by using UV-Visible spectrophotometry (UV-VIS). The optical properties analysis of the obtained coatings revealed an absorption coefficient higher than ~99% in the ultraviolet and visible regions while emission coefficient decreased about 3% in the infrared region by adding nano-silver particles to the coatings. Therefore, nano-composite Ni/Ag electroless coating is a good candidate for using in solar absorber systems.

KEYWORDS: Composite, Coating, Solar cell, Ni(Nickel),Ag (Silver).

I. INTRODUCTION

Nowadays the most widely used industrial solar selective absorbers are metal particles in ceramic structures which are produced by electrochemical or deposition methods [1]. The electrochemical methods have many advantages that can note the simple process and produce the coatings with metallurgical properties suitable. Some well-known examples include electroless black chrome (Cr-Cr₂O₃) and nickel-nickel oxide (Ni-NiOx) that they were as a good absorber [2]. Also, Electroless nickel composite coatings such as Ni-Co, Ni-Cu, Ni-Al₂O₃, NiS-ZnS, Ni-Sn, have been used as a solar absorber in during the last years. So far, much research has been done to improve the absorption of electroless nickel [3-6]. For instance, silver nanoparticles were included in a thin layer of polymer that this layer can be prevented from silver nanoparticles sticking together and also leads to the formation a pattern that increases absorbing sunlight. The results showed that in polymers which did not contain silver particles was generated electricity about 6.2 mA cm square while in samples containing silver nanoparticles this figure is about 7 mA cm square. In total, with this task amount of generated electricity is added 12% [7]. On the other hand, Miango He and et al [8] by adding the silver to absorber coating in the solar thermal system could increase absorption from 0.85 to 0.92 that proves silver improved absorption and this coating can be a good choice for use in thermal solar cells. So, given that silver in most cases increased the absorption efficiency of solar radiation on various materials, silver can be considered as an improvement of absorption in the solar system. The purpose of this paper is precipitation of Ni-P/Ag composite coating and investigation on its absorption properties. It should be noted that this composition as the solar absorber has not been evaluated by other researchers.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 6, June 2016

II. MATERIALS AND TEST PROCEDURE

A. PRODUCTION OF THE COATINGS

The samples of commercially aluminum (Al-1100) sheets were cut into 15*15*1 mm and cleaned them by several steps and procedures for surface preparation and applying the coating. After sanding and create a suitable surface, then chronologically, the samples were placed in aluminum degreasing solution for 4 minutes - caustic soda for 2 minutes - nitric acid for 1 minute - 4 minutes' zincate (After all cleaning, steps were followed by careful rinsing with deionized water). In the following, the samples were coated according to table I:

Table I: Bath composition and electroless plating parameters

Composition parameters	Quantity, g L ⁻¹
Nickel sulfate (NiSO ₄ · 6H ₂ O)	25
Sodium hypophosphite (Na ₂ H ₂ PO ₂ · H ₂ O)	25
Sodium citrate (Na ₃ C ₆ H ₅ O ₇ · 2H ₂ O)	50
Ammonium sulfate ((NH ₄) ₂ SO ₄)	28
Lactic acid (C ₃ H ₆ O ₃)	5
Lead acetate (Pb(C ₂ H ₃ O ₂) ₂)	2
Silver nanoparticles	0.001 to 0.005
Cetyl trimethylammonium bromide	0.05 to 0.25
Temperature	85 ± 2°C
Time	2.5 h

After the coating was applied with 15 μm/h deposition rate, blackening method was accomplished soaking of samples in 4 M nitric acid solution at 25 °C for 10 s.

B. CHARACTERIZATION

Field emission scanning electron microscopy (FESEM, Mira, 3-XMU) was employed for the detailed study of morphology. Additionally, Energy dispersive X-ray spectroscopy (EDS) and elemental mapping analyses were used to investigate the materials composition. X-ray diffraction was carried out using Asenware AW-XDM300 equipped with monochromator at 40 kV, 30 mA and CuKα radiation (λ=1.542 Å). The optical properties of the coatings, comprising absorption and emission were examined by the results of the spectrophotometer (Jasco model: V-670 and 6300). Also, the wavelength range was determined 220–2200 nm for the reflection radiations.

III. TEST RESULTS AND DISCUSSIONS

Figure 1 shows the X-ray diffraction patterns of Ni-P/Ag coatings including various silver nanoparticles (NPs). Since the X-ray diffraction is shown only the wide peak Ni (111), this indicates the presence an amorphous phase and due to low silver content added the peak of silver not be able to see. Ni (111) has the highest intensity peak of the electroless Ni-P coatings deposited in all baths containing sodium hypophosphite as the reducing agent and sodium citrate or glycine as the complexation agent [9].

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 5, Issue 6, June 2016

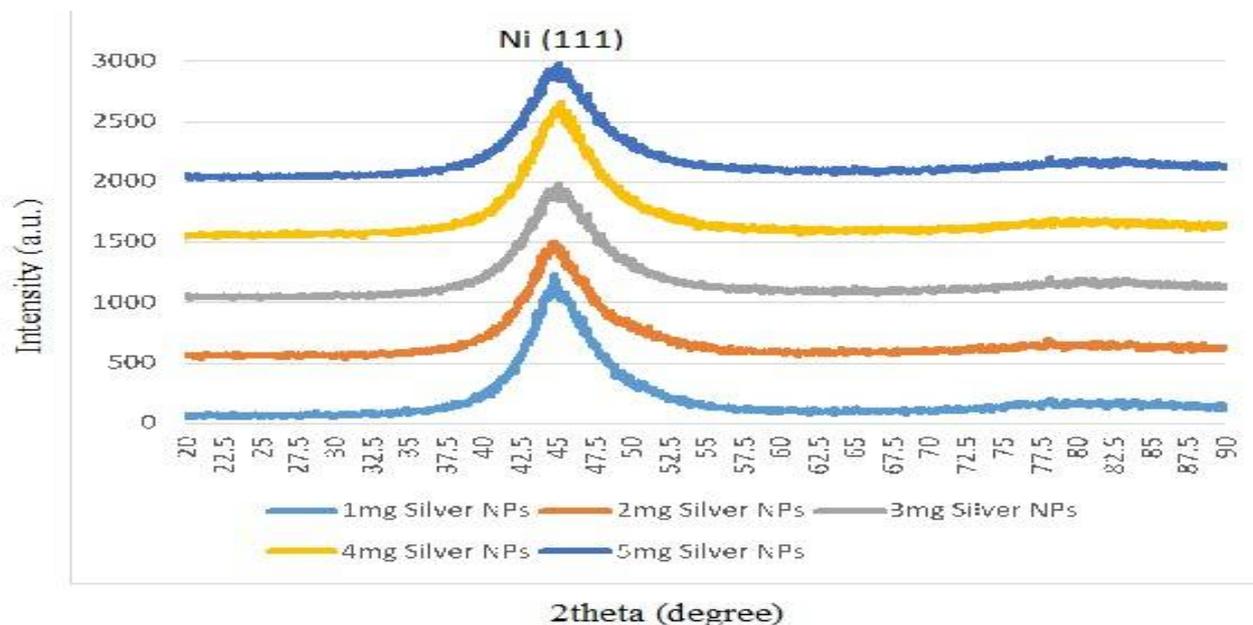


Fig.1: XRD patterns of nanocomposite coatings Ni/Ag.

Figure 2 shows field emission scanning electron microscopy (FESEM) images of Ni-P/Ag coatings that we can find silver NPs visibly different and seen their growth in the matrix with the increasing silver NPs in the bath solution. As shown in Figure 2a-b, the surface morphology of the coatings is similar to cauliflower and orange peel which this structure is common in the electroless nickel coatings [10]. It is able to observe that nickel electroless coating has a smooth surface while with the adding silver NPs surface is rough that helps to the absorption. The electroless nickel coatings have a high absorption since benefit a microscopic condensed array and vertical cone-shaped pores on the surface. The pores including the various diameter and depth and the created spaces between themselves act as the optical traps that can trap any light in the wide spectral range. Accordingly, the pores of electroless coatings are much more and can be reached in better optical properties [11]. In Figure 2, the dispersion of silver NPs in the composite coating can be seen. This is while at the time of coating, nano-silver particles have a strong tendency to agglomeration and for avoiding this problem CTAB was added to the bath. As seen in Figure 3, Ni-P/Ag coating has $\sim 34\mu\text{m}$ thickness. The optimum thickness of electroless nickel is $35\pm 5\mu\text{m}$ and with $\sim 7\%$ phosphorus and also for obtaining the high optical properties, the color of coatings must be black [12]. Moreover, the distribution of the particles in the coating surface is shown in Figure 4 by elemental mapping analysis. Results of microanalysis proved the formation of Ni-P/Ag coatings.

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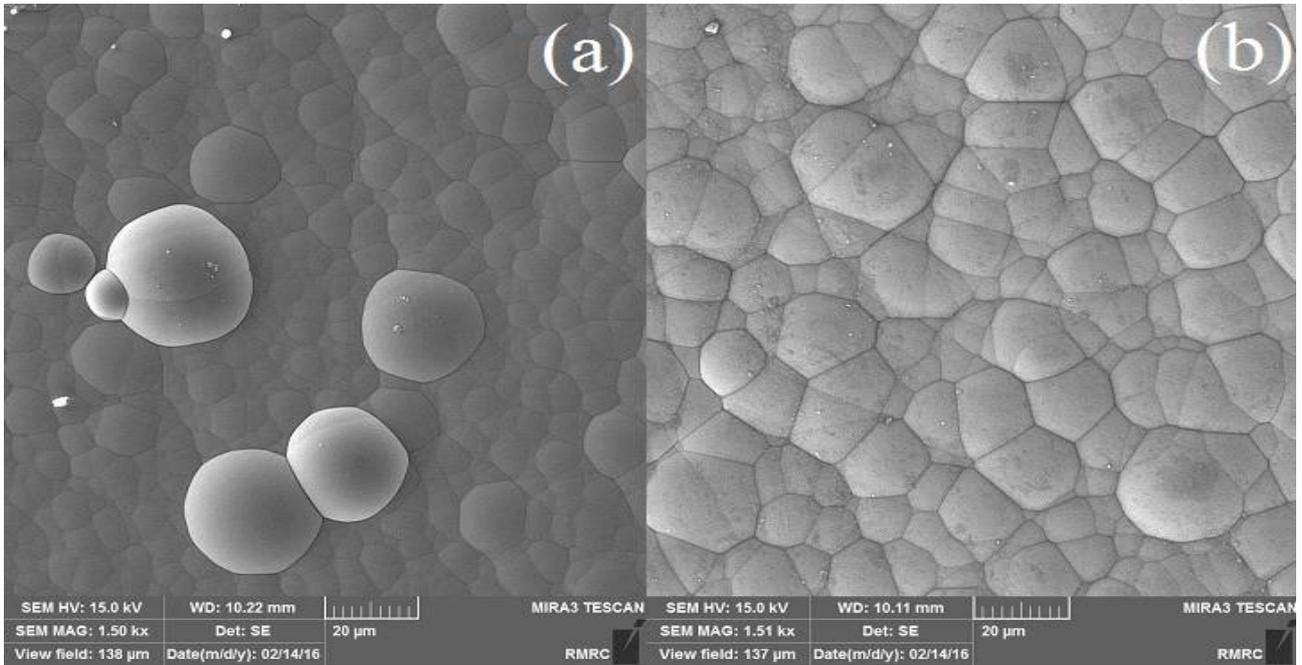


Fig. 2: FESEM micrographs of the Ni/Ag coatings morphology.

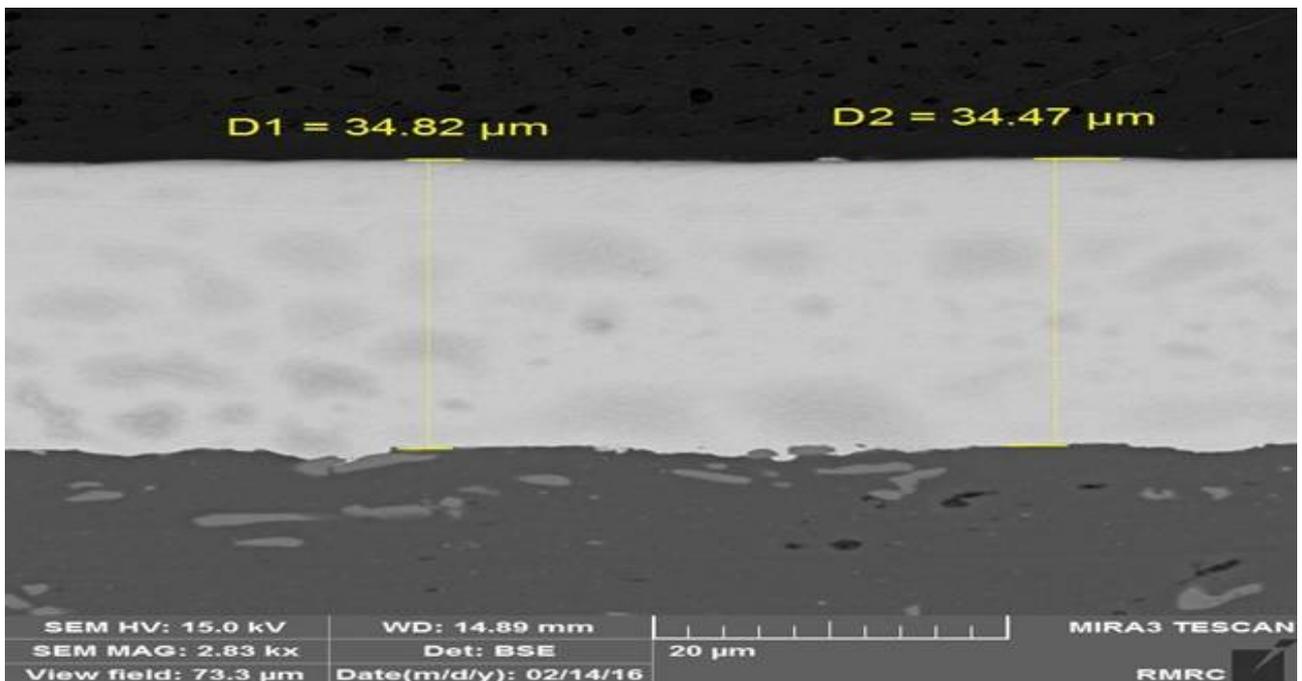


Fig. 3: FESEM micrographs of the Ni/Ag coating.

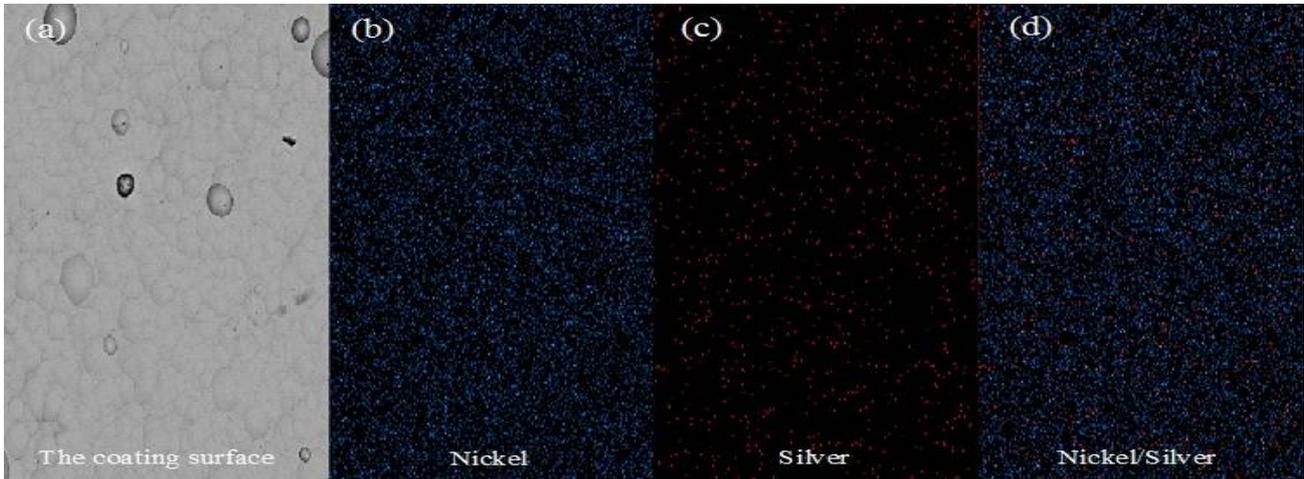


Fig. 4: Elemental mapping analysis of the coating surface.

EDS elemental analysis of Ni/Ag coatings, shown in Figure 2, prove the presence of Ni-P and silver NPs appeared in the spectrum. The low weight of silver NPs in the coatings compared to added silver NPs can be due to the nano-size of particles that causes keeping them far away from the surface and also, for being a part of the added particles on the surface of samples. Basically, electroless coatings bath must be free of any impurities and secondary particles and nanoparticles as the second phase eventuate the bath decomposition since these particles will become the coating places to sit [13].

Absorbance and emittance of a selective solar absorber material are a result of various mechanisms, which depend on the chemical composition and structure of the material. The absorption, transmission and reflection in the absorber material can also be determined by physical effects such as intrinsic properties of the material, interference in a double layer (absorber-substrate), interference effects due to interchanging dielectrics and metals, geometrical trapping by surface roughness, and the size effect of metal particles in insulating matrix [3]. solar selective absorbers must possess a high absorption coefficient in the ultraviolet and visible regions and a low emission coefficient in the infrared region [14]. This leads to the following formal definitions. Solar absorbance (α) is broadly defined as a weighted fraction between absorbed radiation and incoming solar radiation (I_{sol}), while thermal emittance (ϵ) is defined as a weighted fraction between the emitted radiation and the Planck blackbody distribution (I_p), and both can be determined in terms of the surface reflectance ($R(\lambda)$) using the following

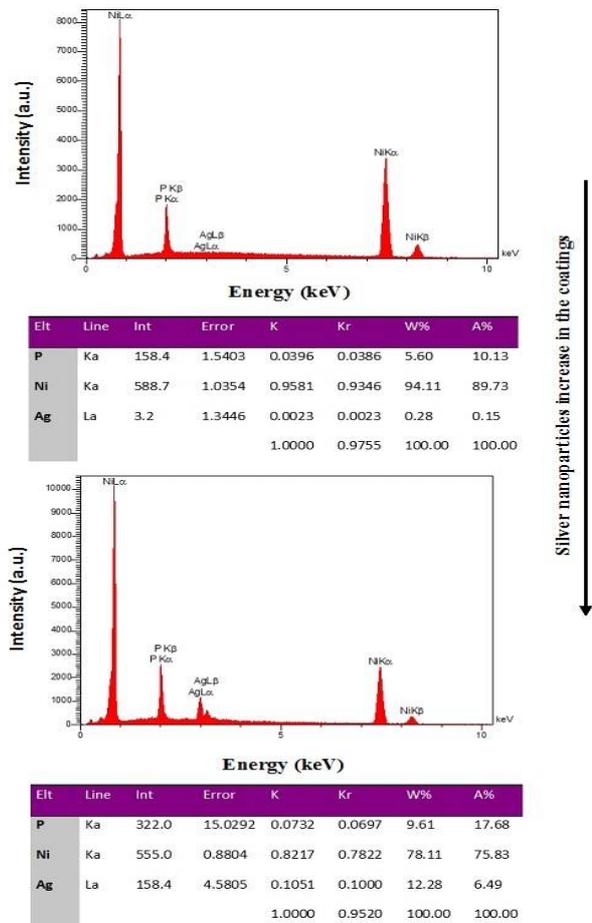


Fig. 5: EDS elemental analysis of Ni/Ag coatings.

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$$\alpha = \int_{0.3}^{2.5} I_{sol}(\lambda)(1 - R(\lambda)) d\lambda / \int_{0.3}^{2.5} I_{sol}(\lambda) d\lambda \quad (1)$$

$$\varepsilon(T) = \int_{2.5}^{20} I_p(\lambda)(1 - R(\lambda)) d\lambda / \int_{2.5}^{20} I_p(\lambda) d\lambda \quad (2)$$

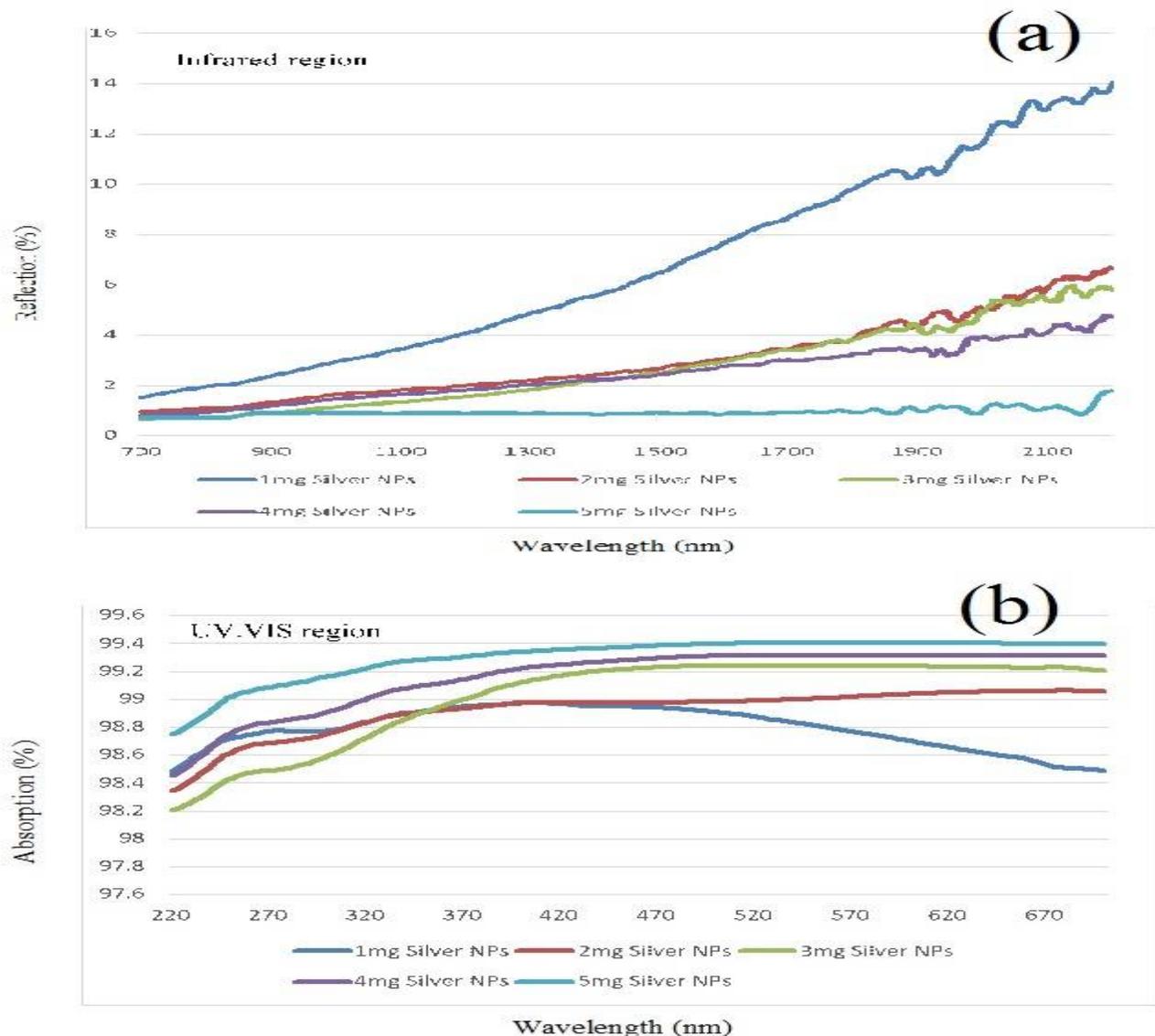


Fig. 6: Reflection in the infrared region (a) and absorption in the ultraviolet and visible region (b) vs. wavelength of the Ni/Ag coatings.

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As shown in Figure 6, by increasing the silver NPs content from 1mg to 5mg, the emission coefficient decreased in the infrared region in order 7.77- 3.80- 3.20- 2.73- 1.22. While the relevant results of absorption coefficient in the UV-Visible region were higher than ~99. The ratio of solar absorbance to thermal emittance (ξ) is the basic parameter to determine a suitable absorber surface [15] that were increased respectively, and in the best condition was achieved 80.99 for the Ni-P/Ag coating with 5mg of the added silver NPs. While in the another investigation conducted by Fatemeh Ebrahimi and et al ξ was in the best sample about 5 [16]. In addition, the various compounds of absorber materials were studied by Aman Amri [17]. The results have been showed that the nickel oxide–alumina on the aluminium substrate with having ξ about 30 was the best solar absorber.

IV. CONCLUSION

1. Uniform distribution of Ag nanoparticles in the Ni-P/Ag coatings has been achieved.
2. With increasing the silver NPs in the solution, the percent of Ag in the coating was increased.
3. The solar absorption coefficient is raised in the ultraviolet and visible region until higher than 99% by adding silver NPs.
4. The solar emission coefficient reduced up to 1% in the infrared region by adding silver NPs to the coatings.
5. Considering the data obtained and related analysis, Ni-P/Ag with 5mg silver NPs introduce as the best candidate for the absorber panels.

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