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Optical Properties of Manufactured Mirrors Using DC Plasma Magnetron Sputtering Technique

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Abstract

This paper defines a method for sputtering high strength, extremely conductive silver mirrors on glass substrates at temperatures ranging from 20^o to 22^o C. The silver coated layer thicknesses in this work ranges from 7.5 to 16.1 nm using sputtering time from 10 to 30 min at power 25 W, 13.7 to 29.2 nm for time 10 to 30 min at 50 W, 15.7 to 26.4 nm for time 10 to 30 min at 75 W and 13.8 to 31.1 nm for time 10 to 30 min at 100 W. The optimum values of pressure and electrode gape for plasma sputtering system are 0.1 mbar and 5 cm respectively. The effect of DC sputtering power, sputtering duration or (sputtering time), and thickness on optical properties was investigated using an ultraviolet-visible spectrophotometer. The ultraviolet absorption of all coated layers was high, while the visible absorption was low. The transmittance is decrease with increase sputtering time and sputtering power. Highest values of reflection in visible region at 100 W and 20, 25 and 30 min are 46% to 97%. High value of band gap at 100 and 30 min while lower value at 25 W and 10 min.

Keywords: Mirrors, Optical Properties, Ultraviolet-Visible Spectrophotometer, Thickness and DC Sputtering Plasma.

الخواص البصرية للمرايا المصنعة باستخدام تقانة بلازما التيار المستمر للترذيذ الماكنتروني

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الخلاصه

تقدم هذه الدراسة تقنية لترذيذ مرايا فضية عالية القوة وعالية التوصيل على ركائز زجاجية في 20 الى 22 درجة سيليزية في هذا العمل ، يبلغ سمك الطبقات المطلية بالفضة (7.5 إلى 16.1) نانومتر باستخدام زمن الترذيذ (10 إلى 30 دقيقة) وبقدرة ترذيذ 25 واط ، (13.7 إلى 29.2) نانومتر للزمن (10 إلى 30 دقيقة) عند 50 واط ، (15.7 إلى 26.4) نانومتر للزمن (10 إلى 30 دقيقة) عند 75 واط و (13.8 إلى 31.1) نانومتر للزمن (10 إلى 30 دقيقة) عند 100 واط. القيم المثلى للضغط والمسافة بين الكاثود والانود لمنظومة البلازما هي 0.1 ملي بار و 5 سم على التوالي. تم التحقيق في تأثير قدرة الترذيذ وزمن الترذيذ وتأثير السمك على الخصائص البصرية باستعمال مقياس الطيف المرئي فوق البنفسجي. كان امتصاص الأشعة فوق البنفسجية لجميع الطبقات المطلية مرتفعًا ، بينما كان الامتصاص المرئي منخفضًا. تنخفض النفاذية مع زيادة زمن الترذيذ وقدرة الترذيذ. أعلى قيم انعكاس في المنطقة المرئية عند قدره وزمن تردد 100

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واط و(20 و 25 و 30 دقيقة) هي 46٪ إلى 97٪. قيمة عالية لفجوة الطاقة عند 100 واط و 30 دقيقة بينما تكون القيمة أقل عند 25 واط و 10 دقائق. تم التحقيق في تأثير قدرة الترذيذ وزمن الترذيذ وتأثير السمك على الخصائص البصرية باستعمال مقياس الطيف المرئي فوق البنفسجي. كان امتصاص الأشعة فوق البنفسجية لجميع الطبقات المطلية مرتفعًا ، بينما كان الامتصاص المرئي منخفضًا.

1. Introduction

Mirror coatings play an important role in a wide range for applications of optics. It is a necessary component for optical structures or apparatus which include surfaces that reflect radiation. The primary ingredient for this research is pure silver [1]. Whereas, silver coating layers have been of great interest for years due to their superior efficiency in optical applications when compared to other metal coating layers: is an excellent metal for visible and IR wavelength spectrum in front surface mirrors. In the visible wavelength region, silver has the maximum reflectivity, the lowest emission spectra, and the lowest absorption, and the lowest polarization splitting of any known metal in this range [2]. Furthermore, silver has a higher electro migration resistance than other metals [3]. Vacuum evaporation, cathode sputtering, and electron beam physical vapor deposition are three techniques commonly used to create metal layers on a dielectric substrate [4]. Although vacuum evaporation technology produces better results in terms of maximum reflectance, Magnetron sputtering is commonly utilized to manufacture silvery coating layers for advanced tech requirements and is often chosen for other purposes. The sputtering magnetron system's improved scalability to nearly any mirror Diameter, improved increased density with no holes, and increased silver coverage at the layer system's edge all of these factors lead to a more effective protection impact [1]. Magnetron sputtering was used to successfully deposit silver layers onto thin thermally fragile Mylar sheets [5]. Reactive sputtering is known as the sputtering of metallic targets in the midst of chemically reactive gases whose mass interact with both the target surface and the ejected target material [6]. The deposition conditions (deposition rate, vacuum pressure, substrate type, and temperature) govern grain aggregation during the deposition of thin metal layers. The size of the crystalline grains that make up metal coatings has an effect on the electrical and optical properties of the metal layers [7]. According to some studies, the optical properties of the silver film may be influenced by film thickness [8]. Much research has been performed on silver layers [9-10]. Limited experiments have been conducted to investigate the relationship between the thickness of silver layers coating on glasses (with changing power and sputtering time) and the optical properties using magnetron sputtering. The current work investigates manufacture of mirrors with high reflectivity used in the manufacture of telescopes and optical devices using DC planer magnetron sputtering and study optical properties for this mirrors effected with the silver layer thickness coated on the glasses.

2. Optical Properties

The Ultraviolet-Visible spectrophotometer is a spectrophotometer that measures visible and ultraviolet spectrums utilizing a deuterium lamp and a tungsten lamp. Light beam in this spectrophotometer is incident on a mirror, which reflects light, and then passes through a slit. Slit's purpose is to only allow monochromatic light to pass through it. And strikes a diffraction grating, which separates and disperses a light beam into its primary components (or component wavelengths) and can also rotate to obtain a specific wavelength. To exclude unnecessary higher orders of diffraction, a filter is used. Only one of the beams is permitted to pass through the sample cuvette. Meanwhile, another beam is permitted to pass through the reference cuvette. After that, the intensities of the light beam are computed. As a consequence, absorption near the band gap increases dramatically, resulting in a reflection threshold in the Ultraviolet-Visible region of the absorbance spectrum. The following relationships can be used to calculate Thickness (t), Wavelength (λ), Absorbance (A) values and other optical parameters [11]:

$$T = \frac{1}{\exp(2.303 * A)} \quad (1)$$

And the absorption coefficient

$$R = 1 - (A + T) \quad (2)$$

$$\alpha = 2.303 \frac{A}{t} \quad (3)$$

$$k = \frac{\alpha \lambda}{4\pi} \quad (4)$$

$$n = \sqrt[2]{\left(\frac{4R}{(R-1)^2}\right)} - \frac{(R+1)}{(R-1)} - K \quad (5)$$

Where T =Transmittance; R =Reflectance; α =Absorption coefficient; k= Extinction coefficient and n =Refractive index.

The optical band gap of the materials can be calculated utilizing the UV–Vis spectroscopy results. The Kubelka-Munk model can be utilized to measure the optical band gap, while a plot of $(hv)^2$ versus photon energy (hv) can be utilized to estimate the direct band gap energies [12]. This method has been obtained from the Tauc relation, which is given by [13].

$$\alpha = \left(\frac{A}{h\nu}\right)\sqrt{h\nu - E_g} \quad (6)$$

Where

Eg =semiconductor's band gap energy, the line intercept calculated by plotting $(\alpha hv)^2$ vs. (hv) hv incident photon energy, B = is inversely proportional to amorphousness in non-direct band gap semiconductors [11].

$$\alpha h\nu = B(h\nu - E_g)^2 \quad (7)$$

3. Experimental Approaches

The silver was sputtered as layers on a glass substrate using a direct current plasma planar magnetron sputtering technique for the production of mirrors.

System Instruments:

- Vacuum Chamber (Pyrex glass): its length 30 *cm*, thickness 5 *mm* and diameter 2 *cm*.
- Rotary Vacuum Double Stage Pump: It's Pressure up about to 2×10^{-2} *mbar*.
- Power Supply DC High voltage.
- Wire, Pipe, Glass Substrate, Holder, Ar Gas Tube, Magnetron, Ag Target.
- Stainless Steel cathode and anode.

Work Stages:

Initially, the substrates are cleaned with an ultrasound system and heated to remove any remaining water. Figure 1 depicts how we set up the system. Where the standard deposition process begins with a spray chamber that is vacuumed to a high vacuum using a two-stage rotary pump to reach a pressure of 2×10^{-2} mbar to remove the partial pressure of gases as well as contaminants from the chamber. Argon gas is flowed at a constant rate of 100 sccm after we reached the required pressure. For silver sputtering, a high voltage is applied between the cathode and the anode at a rate of 5 kV DC and current 500 mA in this plasma sputtering system.

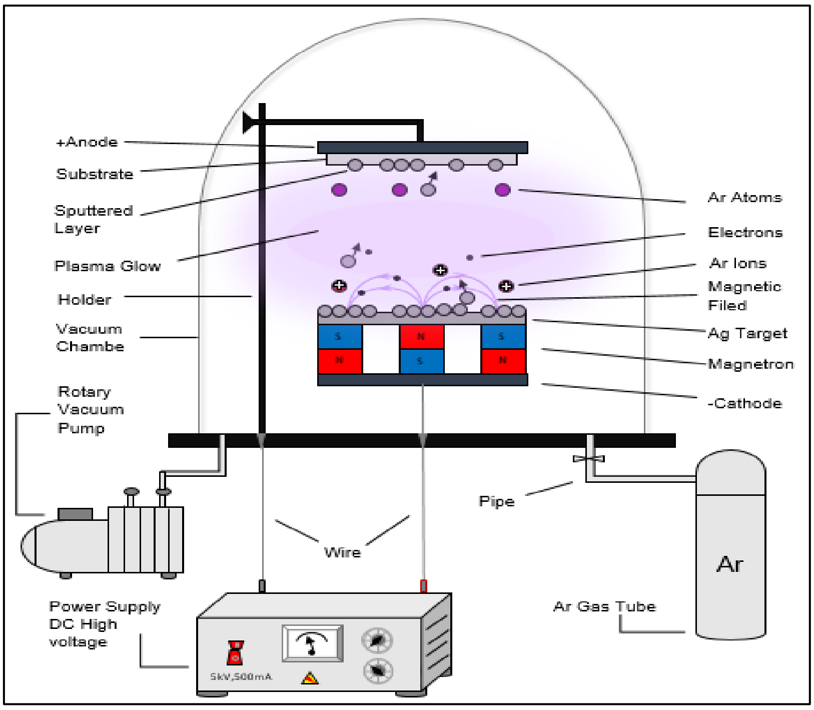

Figure 1 - Schematic diagram of the DC plasma sputtering magnetron experimental setup.

The sputtering parameters were varied in two ways sputtering power and puttering time, where resulting in 20 samples and listed in Table 1. These samples are illustrated in Figure 2.

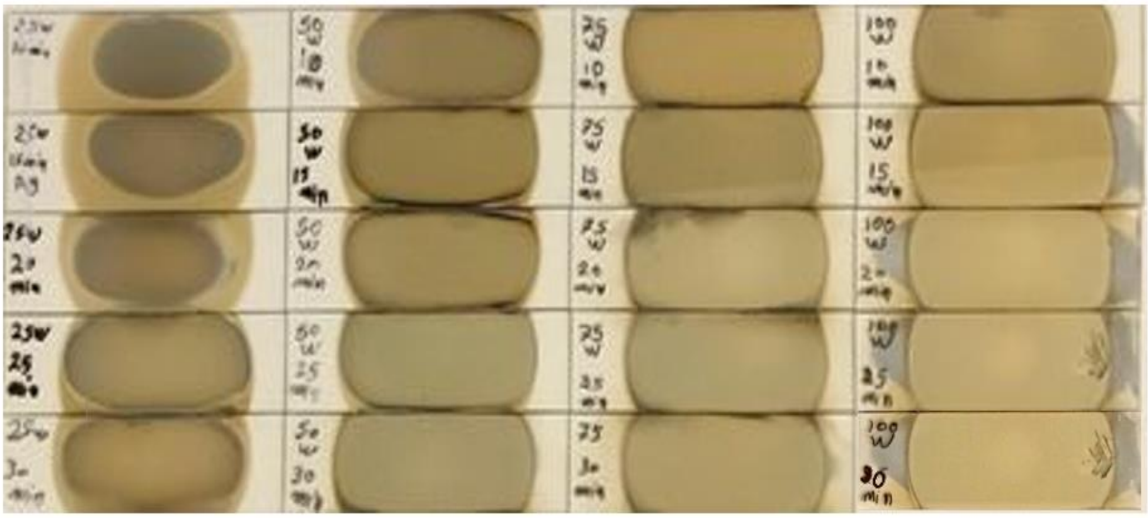

Figure -2 Silver coated layers with deposition parameters (sputtering power and sputtering time).

A PerkinElmer Lambda 950 spectrophotometer was used to measure the sample's transmittance (T), absorbance (A) and reflectance (R) in the UV-VIS-NIR spectral range.

Table 1-20 Silver samples' key deposition parameters.

	Time of Sputtering (*min*)					
Power Of Sputtering (*Watt*)	**#**	**10**	**15**	**20**	**25**	**30**
	25	**G.S.(1)**	**G.S.(2)**	**G.S.(3)**	**G.S.(4)**	**G.S.(5)**
	50	**G.S.(6)**	**G.S.(7)**	**G.S.(8)**	**G.S.(9)**	**G.S.(10)**
	75	**G.S.(11)**	**G.S.(12)**	**G.S.(13)**	**G.S.(14)**	**G.S.(15)**
	100	**G.S.(16)**	**G.S.(17)**	**G.S.(18)**	**G.S.(19)**	**G.S.(20)**

4. Results and Discussion

Preceding research has shown that time and power of sputtering the most significant parameters for the growth of sputtered silver coated layers. We examined impact of these two parameters on our silver coated layers since they specify the essential thickness of the coated layers, which influences the optical properties.

Figure 3 shows curves of thickness against sputtering time for various sputtering power. When the power is equal to 25 W, the silver layer is deposited with a thickness of 7.5 nm for time 10 min, and the thickness of the silver layer increases by increasing the time to become 16.1 nm for time 30 min, when the power is increased to 50 W, thickness of silver layer is 13.7 nm for 10 min to a maximum value of 29.2 nm at for 30 min, when equal 75 W, the layer thickness is 15.7 nm for 10 min to 26.4 nm for 30 min and when equal 100 W, the layer thickness is 13.8 nm for 10 min to 31.1 nm for 30 min.

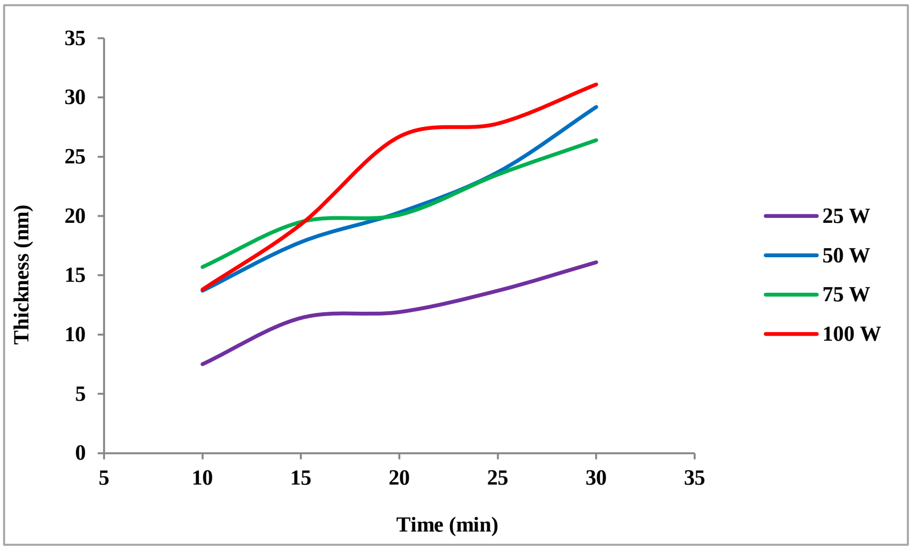

Figure 3- Thickness of Ag thin films against sputtering time for various sputtering power.

The behavior thickness remains nearly constant between 10 – 30 min of sputtering time with approximation high value for high power, these results agree with Ezeobele [14].

The silver coated layers obtained DC plasma sputtering magnetron with deposition rate 0.637, 1.0986, 1.139 and 1.278 nm/min, at sputtering power 25, 50, 75 and 100 W respectively are shown Figure 4.

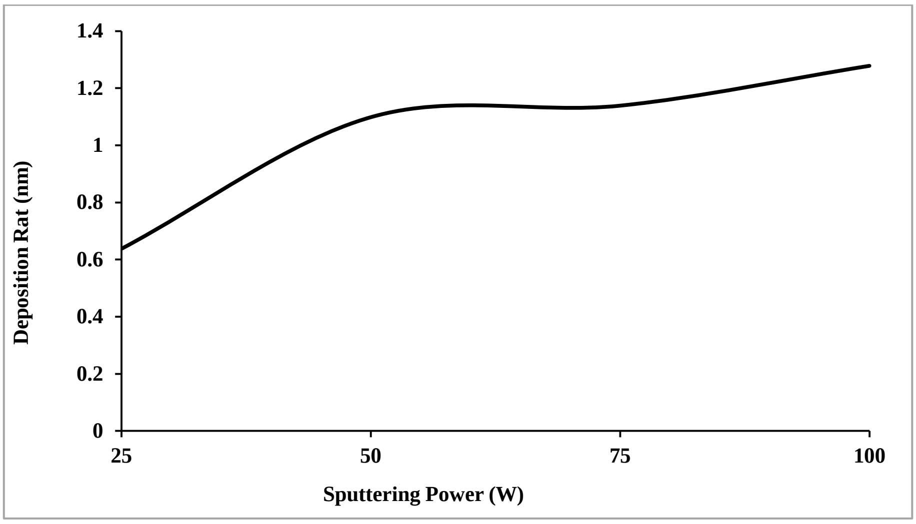

Figure 4- Deposition rate against sputtering power.

From the Ultraviolet-Visible Spectrophotometer can be obtained the absorbance curve as a function of wavelengths, as shown in Figure 5. Where equations (1) and (2) were used to calculate the reflectance and transmittance while assuming negligible scattering. Measurements have been carried 0^o angle of incidence using VN accessories for absolute measurements [1].

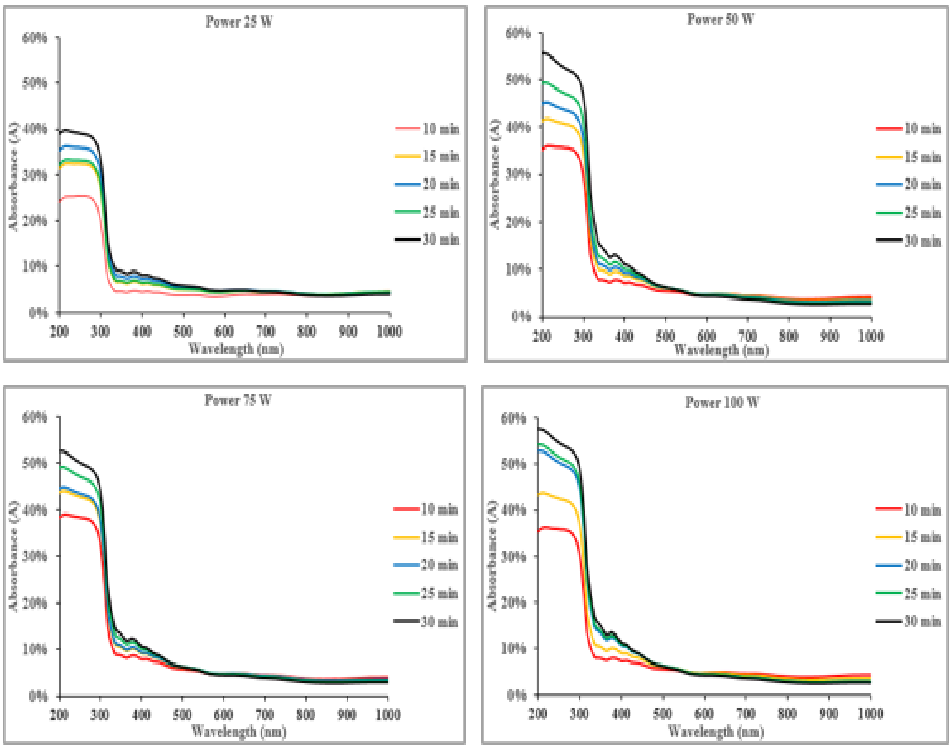

Figure 5-The absorbance spectra of deposited silver coated layers at different sputtering time on glass substrates.

The coated layers all demonstrated substantial absorption in the ultraviolet portion of the electromagnetic spectrum while exhibiting minimal absorption in the visible range.

We found that the rise in absorption was directly proportional to the incremental increase in sputtering time from 10 min, 15 min to 30 min. As seen in Figures 6 and 7, this may be due to a significant decrease in transmittance, which causes a significant increase in reflectance from the silver coated layers with an increase in sputtering time from 10 min to 30 min which is consistent with A. C. Nwanya et al. [15].

The transmittance of the silver coated layer prepared at different sputtering power and sputtering time, in the wavelengths range of 200–1000 nm are shown in Figure 6. The transmittance of silver coated layers decreases with increase sputtering time because of increase thickness of coated layers. Also at sputtering power is increase. And the thicker coated layers are denser, then having more flaws reduces the transparency of the layers. The transmittance peak of silver layers is wavelength of 327 nm for all layers and increase with decrease time and has minimum value in power 100 W at time 30 min, this results agree with F. Hajakbari and M. Ensandoust [16].

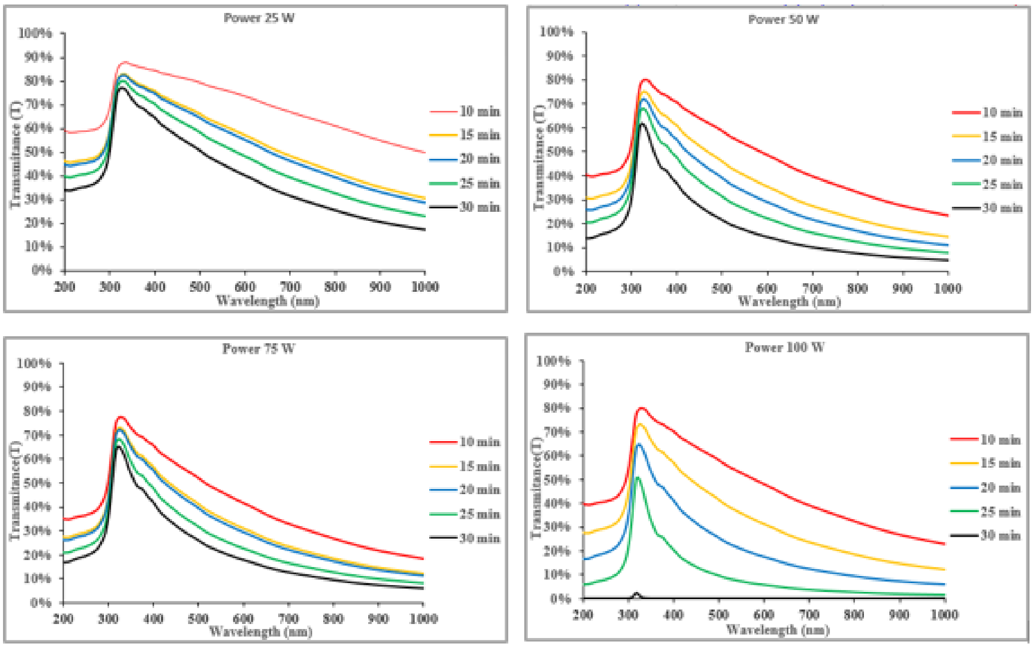

Figure 6- The transmittance spectra of deposited silver coated layers at different sputtering time on glass substrates.

Light absorption induced by inter-band electronic transitions has an effect on transmittance in the short wavelength region. As the silver coating layer deposition time is increased, the silver coating layer thickness increases, resulting in more electrons usable for inter-band transitions and more light absorption. The transmittance is influenced by silver layer reflection in the long-wavelength area, resulting in lower transmittance; these findings are consistent with S. Among those who have contributed to this work are Jalili et al. [17].

Figure 7 illustrated the reflectance of silver layers where increase with wavelength 309–1000 for all values of sputtering time and it has minimum values at 309 nm. And from this figure can be note the reflectance increased with increase sputtering time for all values of sputtering power. The highest values for reflection were obtained at 100 W and 20, 25 and 30 min 46% to 97% in the wavelength region of 365–845 nm. The best mirror can be getting at 100 W 30 min.

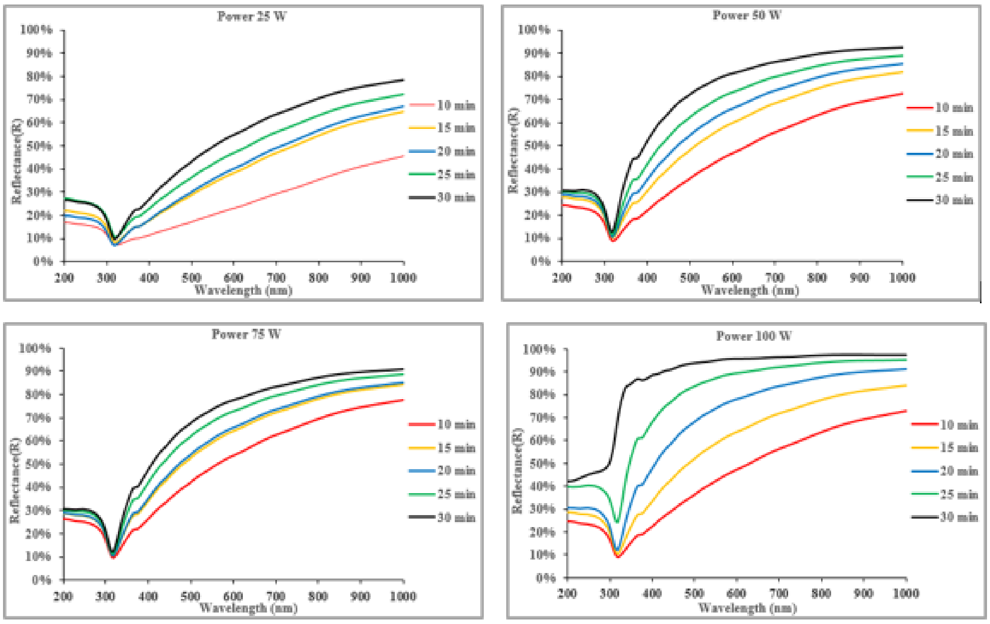

Figure 7-The reflection plot as a function of wavelengths

Figure 8 depicts the plot of $(\alpha h\nu)^2$ vs. $(h\nu)$ of silver coated layers prepared at various silver sputtering times and powers. Table 2 illustrates the direct optical band gaps.

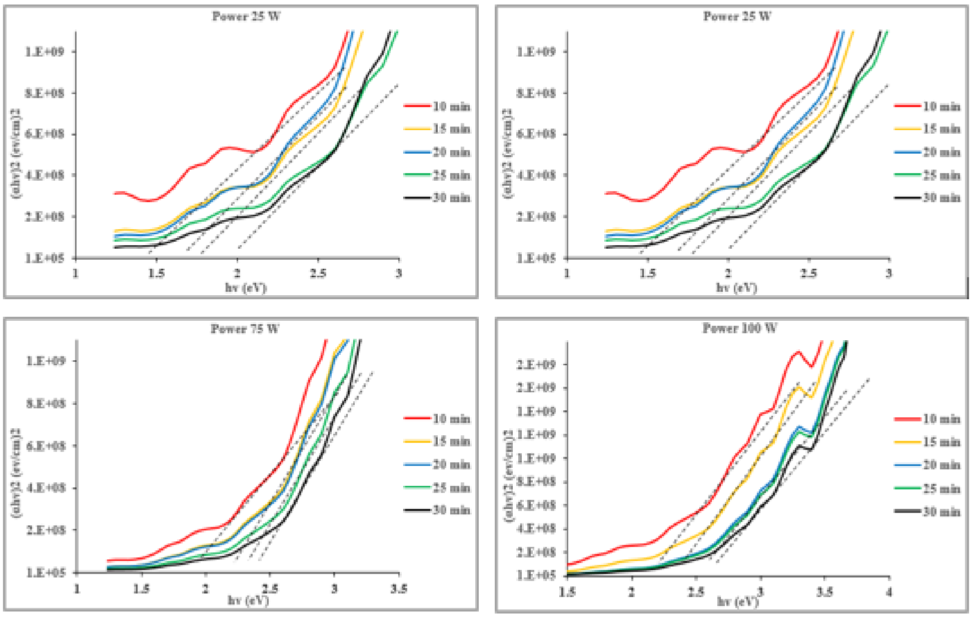

Figure 8- $(\alpha h\nu)^2$ versus $(h\nu)$ plot of silver coated layers deposited on glass substrates

Table 2-Optical band gaps for all samples of silver coated layer.

	Time of Sputtering (*min*)					
Power Of Sputtering (*Watt*)	**#**	**10**	**15**	**20**	**25**	**30**
	25	**1.3**	**1.8**	**1.85**	**2.1**	**2.1**
	50	**2.3**	**2.35**	**2.4**	**2.5**	**2.6**
	75	**1.95**	**2.2**	**2.2**	**2.3**	**2.4**
	100	**2.2**	**2.4**	**2.6**	**2.6**	**2.66**

In addition, for these results, the band gap value increases with increasing sputtering time and sputtering power due to increase in coated thickness with reason increase in grain size. These results agree. Figure 9 illustrated variation of energy gap with sputtering power.
The silver coated layers at time 10 *min* located in conducting region but at 30 *min* located in semiconducting region.

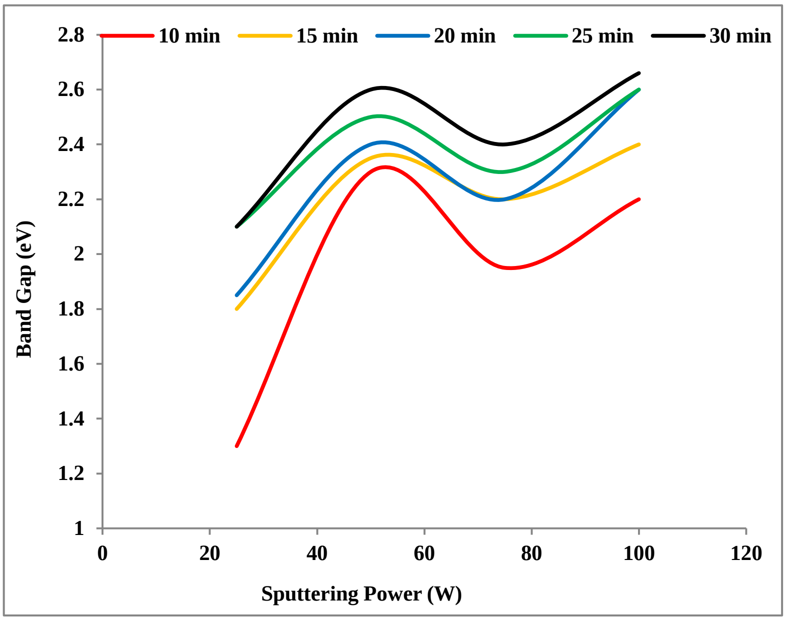

Figure 9- Band gap versus sputtering power of silver coated layers.

5. Conclusions

In this work it is analyzed the impact of the sputtering power and sputtering time on thickness and optical properties of manufactured mirrors.
Deposition rates ranging from 0.637 to 1.278 nm/min by applied sputtering powers ranging from 25 W to 100 W.
From results, high value of absorption in the UV range and low value in the visible range and at 100 W powers, 30 min times can be obtaining high values for all wavelength of spectrum. The minimum value of transmittance can be getting in power 100 W at time 30 min. High values reflectance of manufactured mirrors (97%) at values of power and time 100 W and 30 min respectively.
The silver coated layers located in conducting region at time 10 min and in semiconducting region at 30 min.
From these results, mirrors with high reflectivity can be manufactured with working conditions as follows: metal target silver, pressure 0.1 mbar, electrode gap 5 cm, sputtering power 100 W and sputtering time 30 min.

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