Study Optical Properties of Copper and Silver for Astronomical Solar Filters Prepared by DC Sputtering Plasma

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Abstract. This study presented a technique to sputter high strength, highly conductive copper and silver astronomical solar filter on glass substrates at room temperature. In this work, the thicknesses of copper are (110 and 230) nm and for silver are (230 and 400) nm using power 25 and 50 W respectively have been sputtered on glass substrate by DC sputtering plasma technique at room temperature. The base pressure of the plasma sputtering system found that it is very good at 0.1 mbar. The thickness and DC power sputter effect on the optical properties were studied by using UV-Visible spectrophotometer. The transmittance for all coated layers is increases rapidly as the wavelength increases in the range of (350-750) nm. The absorbance decreases rapidly at short wavelengths corresponding to the energy gap of the layer and the range of optical band gap values between (2 and 2.6) eV,

Keywords. Astronomical solar filter, optical properties UV-Visible spectrophotometer, DC sputtering plasma.

1. Introduction

Solar filters are very important for observing the Sun safely with your telescope. A filter can greatly enhance the human eye's perception of small details on solar system and deep sky objects. Correct use of photo-visual filters can greatly enhance an observing. Filters work by blocking a specific part of the color spectrum, thus significantly enhancing the remaining wavelengths. Colored filters work by absorption/transmission, and immediately telling which part of the spectrum they are reflecting, and therefore transmitting. The so-called light-pollution reduction and nebulae filters are very selective in the wavelengths they transmit. [1]. Pure metals like copper, silver and aluminum are very conductive and very soft. The coating layer for these metals become stronger by various approaches like grain size reduction, solid solution strengthening, cold working leads to high strengths but low electrical conductivity. For instance, Copper, which has been reinforced two times or three times, has been lost conductivity by 50 to 60 percent in comparison with pure copper. There are three different types coating processes:

1- vapor phase, which includes physical vapor deposition (PVD) (a) Thermal evaporation (b) Electron beam-PVD (c) plasma Sputtering (PS).
2- Chemical vapor deposition (CVD) (a) Low pressure CVD (b) Plasma enhanced CVD (c) Photochemical and laser-CVD.
3- Liquid phase, which includes painting, dipping, and electroplating.
4- Solid phase, which includes (a) plasma spry processes (b) laser cladding [2].

After deposition the different deposition methods (PVD, CVD and PS) different parameters and annealing are lead to different coating layer properties like texture, grain size and grain boundary misorientation [3].
Physical sputtering is a process in which atoms are ejected from a source material due to impinging energetic particles. Sputter deposition takes place in a chamber at a reduced pressure. Low background pressure is realized by a tightly sealed system consisting of a vacuum chamber, gas supply lines and vacuum pumps [4]. DC or Direct Current Sputtering is a coating layer Physical Vapor Deposition (PVD) Coating technique where a target material to be used as the coating is bombarded with ionized gas molecules causing atoms to be “Sputtered” off into the plasma. These vaporized atoms are then deposited when they condense as a coating layer on the substrate to be coated. DC Sputtering is the most basic and inexpensive type of sputtering for PVD metal deposition and electrically conductive target coating materials. Two major advantages of DC as a power source for this process is that it is easy to control and is a low cost option if you are doing metal deposition for coating [5]. The growth of coating layer copper and silver coating layer on glass is a subject of great interest, as many optical filters, low emissivity coatings, and sun protection coatings are made of coating layer metallic and dielectric layer [6]. In general, one speaks about solar coatings when the optical layer properties are adapted to the solar spectrum. The considered solar range may vary with application. A weak or near-zero absorptance is a requisite if only interference effects should occur inside the layer. Interference coating layer consist of alternating high- and low-refractive index materials [7]. Optical experiments provide a good way of examining the properties of coating layers. Especially measuring the absorption coefficient for various energies gives information about the band gaps of the material. Knowledge of these band gaps is very important for understanding the electrical properties of a semiconductor, and is therefore of great practical interest [8]. The UV-Visible spectrophotometer uses two light sources, a deuterium (D2) lamp for ultraviolet light and a tungsten (W) lamp for visible light. After bouncing off a mirror, the light beam passes through a slit and hits a diffraction grating which can be rotated allowing a specific wavelength to be selected. At any specific orientation of the grating, only monochromatic light successfully passes through a slit. A filter is used to remove unwanted higher orders of diffraction. The light beam hits a second mirror before it gets split by a half mirror. One of the beams is allowed to pass through a reference cuvette (which contains the solvent), the other passes through the sample cuvette. The intensities of the light beams are then measured. As a result, there is a sharp increase in absorption at energies close to the band gap energy that manifests itself as an absorption edge or reflection threshold in the UV-V region is absorbance spectrum. Having the values of Absorbance (A), wavelength (\(\lambda\)), and Thickness (t). Other optical parameters can be calculated using the following relationships [9]:

\[
T = \frac{1}{\exp(2.303 A)}
\]

(1)

where \(T\) is Transmittance \(A\) is absorption

\[
R = 1 - (A + T)
\]

(2)

where \(R\) is Reflectance

\[
\alpha = 2.303 \frac{A}{t}
\]

(3)

where \(\alpha\) is Absorption coefficient

\[
k = \frac{\alpha\lambda}{4\pi}
\]

(4)

Where \(k\) is Extinction coefficient
\[ n = \left( \frac{4R}{(R-1)^2} - K^2 \right)^{1/2} - \frac{(R+1)}{(R-1)} \]  
\hspace{1cm} (5)

where \( n \) is Refractive index.

The band structure of coating layers can be probed directly by measuring their absorption spectrum.

For direct band gap [9]:
\[ \alpha h\nu \propto \sqrt{h\nu - E_g} \]  
\hspace{1cm} (6)

where \( \alpha \) is the absorption coefficient, \( h\nu \) is the energy of incident photons and \( E_g \) is the band gap energy of the coating layers, \( E_g \) is the intercept of the straight line obtained by plotting \((\alpha h\nu)^2\) vs. \( h\nu \). For indirect band gap semiconductors [9]:
\[ \alpha h\nu = B(h\nu - E_g)^2 \]  
\hspace{1cm} (7)

where \( B \) is inversely proportional to amorphousity.

2. Experimental Setup

DC plasma sputtering technique has been used to sputter the Copper and silver as layers on glass substrate. The glass substrate were used for copper deposition and washed in ultrasonic device and dry in air. Plasma sputtering system apparatus was used at a rate of 10kV DC and current 500 mA for copper and silver sputter. Plasma chamber was made from Pyrex glass. The length, thickness, and diameter of the cylinder chamber are 30cm, 5mm, and 20cm respectively. Two plane-parallel stainless steel electrodes were used as electrode. Copper and silver are used as a target for sputtering system. The photography picture for plasma chamber is illustrated in Figure (1). The discharge was fed with argon at variable flow rate (100-600) sccm.

![Figure (1): DC plasma sputtering system.](image)

The base pressure of the plasma sputtering system was better at 0.1 mbar. The thickness for coated layer was measured by using Spectroscopic Reflectometer SR300 systems. The optical properties were measured using UV-Visible spectrophotometer. The images of copper and silver astronomical solar filter illustrated in Figure (2)
3. Results and Discussion

The treatment was performed for different time intervals. After this treatment of the class samples copper and silver was deposited stepwise on the sample by DC sputtering from a pure copper and silver target with argon as processing gas. The total pressure during the copper and silver deposition was 0.1 mbar. The deposition rate of the silver was controlled by time. Determine of the thickness of coated layer using Spectroscopic Reflectometer. The thickness for copper and silver was measured for each sputtering power as shown in Table (1). The optical properties of copper and silver astronomical solar filter is grown on glass substrate which involve the transmission, refractive index, absorption coefficient and the optical energy gap (Eg).

3.1 Transmittance

The spectral dependence of the transmittance (T) for copper and silver astronomical solar filter deposit at conditions (d = 5cm, power = (25 and 50) W, sputtering time = 30 minutes and 0.1 mbar pressure). Figure (3) illustrate the transmittance versus wavelength for those prepared astronomical solar filter deposited on glass slides.

![Figure (2): Copper and silver astronomical solar filter.](image)

![Figure (3): Transmittance as a function of wavelength for sputtering process copper and silver astronomical solar filter on glass.](image)
The transmission of astronomical solar filter deposited in the UV-Visible region (300-600 nm) on glass slides has been examined and found that all astronomical solar filter prepared by DC sputtering method has high transmission at longer wavelengths. The transmittance (T) can be calculated using equation (1) shows the relation between transmittance and wavelength for copper and silver layers.

It can be noticed that the transmittance for all coated layers increases rapidly as the wavelength increases in the range of (350-750) nm, and then increases slowly at higher wavelengths. Maximum value in transmission at 0.7232 for 1048 nm of silver 1 solar filter at power 25 W and silver 2 at 0.97 for wavelength 858 nm at power 50 W. Copper 1 at power 25 W a maximum value in transmission at 0.739 for wavelength 930 nm and copper 2 at power 50 W 0.724 for wavelength 802 nm. Optical transmission measurements depend strongly on the power DC sputtering; this result is in agreement with [10].

3.2 Absorbance

Figure (4) demonstrate the optical absorbance as a function of wavelength of copper and silver coated layers. The absorbance decreases rapidly at short wavelengths corresponding to the energy gap of the coated layers. This clear increase of energy is product from the interaction of the material electrons with the incident photons which have enough energy for the occurrence of electron transitions. The increase in energy deposition of silver and copper leads to increased absorption, this result is in agreement with [10].

3.3 Refractive Index (n)

The refractive index (n) calculated from Equation (5). The refractive index of the copper and silver coated layers samples prepared under different conditions (d = 5 cm, applied power (25 and 50) W, sputtering time = 30 mints and 0.1 mbar pressure) as represent in Figure (5). From this figure, the refractive index increases in the visible region in the shorter wavelength at maximum value n= 2.5553 \( \lambda = 649 \) nm for silver1, silver2 maximum value n= 2.537 \( \lambda = 433 \) nm, copper1 n= 2.611 \( \lambda = 478 \) nm and copper2 n= 2.554 \( \lambda = 556 \). This increase goes back to the film densification and improvement in the crystalline of the coated layer, this result is in agreement with [11].
3.4 Absorption coefficient ($\alpha$)

The absorption coefficient is variation with wavelength of power (25 and 50) W for copper and silver astronomical solar filters are shown in Figure (6). This figure shows that in the region of short visible wavelength, absorption coefficient takes high values and then decreases significantly with increasing wavelength and in the long visible wavelength the absorption coefficient takes low values, this is because the absorption coefficient is directly dependent on the absorption and inversely with the thickness according to the equation (3). Copper1 it have maximum value greater than other films where reach $\alpha = 208153.85 \text{ cm}^{-1} \lambda = 329 \text{ nm}$, copper2 $\alpha = 100130.43 \text{ cm}^{-1} \lambda = 354 \text{ nm}$, silver1 $\alpha = 99214.60 \text{ cm}^{-1} \lambda = 312 \text{ nm}$ and silver2 $\alpha = 56562.42 \text{ cm}^{-1} \lambda = 335 \text{ nm}$ these results are consistent with [12].
3.5 Optical Energy Gap (E_g)

Study and estimate the average value of the energy gap is very necessary to understand the optical properties of the astronomical solar filter manufactured by DC sputtering technique. The coated layers structure and arrangement and the distribution of atoms in the crystal lattice are very important for value of energy gap. To calculated the value of band gap (E_g) the graph of \((\alpha h\nu)^{1/2}\) vs. \(h\nu\) has been plotted for different preparation conditions (\(d = 5\) cm, applied power (25 and 50) W, sputtering time = 30 mints and 0.1 mbar pressure) as demonstrated in the Figure (7). To determine the band gap (E_g) of the copper and silver solar filter can be used data point near the absorption edge.

The extrapolating the straight line portion of the graph of the energy axis is use to determined band gap. From energy gap values will notice that the increase in energy deposition leads to increase the thickness and density of formed solar filter, where for copper filter it will notice when sputtering energy 25 W produces energy gap 2.45 eV and energy 50 W the energy gap equal to 2.2 eV. For silver filter at sputtering energy 25 W energy gap equal to 2.6 eV and at energy 50 W energy gap become 2 eV.

Energy gap in the copper and silver solar filter which, is deposited in this work is low value due to from impurities these results are consistent with [12].

4. Conclusions

Copper and silver astronomical solar filters were deposited on glass substrates by DC sputtering technique successfully. The optical properties variation is depending on the amount of sputtering power. Were found to have high absorbance in the ultra violet region and scale down as the wavelength increased. They have high transmittance in the visible / near infra-red region. It has high refractive index. The energy gap for the fabricated copper and silver solar filter was found to be 2, 2.45, 2.2 and 2.6 eV.
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