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Ultrathin Si Based Ag Thin Films: Prepared By DC Magnetron Sputtering

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Abstract: *Ultrathin Ag and Ag/Si films deposited on glass substrates by direct current magnetron sputtering and studied the morphological, optical and electrical properties using scanning electron microscopy, atomic force microscopy, UV-Vis-NIR spectroscopy and four-point probe method. By introducing the Si interlayer between glass and Ag shows the smooth and dense whereas, the Ag films deposited on glass shows agglomerated nanocrystals and relatively thick boundaries. The Ag(10nm)/Si(4nm)/glass films showed lowest sheet resistance of 4.7 Ω/□ and thermal emissivity of 0.059.*

KEYWORDS*- Ultrathin films, Silver, Sputtering, Low-emissivity*

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I. Introduction

In energy efficient coatings, solar control and Low-emissivity coatings are the most popular products for large area glazing systems [1].Glass is widely used in commercial and residential buildings and automobiles but, 91% of the solar energy is absorbed and emitted from the glass. In order to replace this conventional normal glass with the energy efficient glazing systems, the Low-emissivity (Low-e) coatings are best choice, due to its high transmittance in the visible region and high reflection in the near infrared region[2-3]. Ultrathin Nobel metal films such as Ag, Cu, Au and Al are transparent in the visible region, high reflectance in infrared region and show good electrical conduction. Silver (Ag) is the best choice in the metal films, because it has high infrared reflectivity and low absorption in the visible region [4]. However, the ultrathin Ag films exhibited poor emissivity properties due to high Ag/glass interfacial energy [5]. This canbe modified by introducingan interlayer (Al, Ni-Cr, Ti, Si, Ta, Nb) between the Ag thin film and glass substrate.Among these interlayer materials, Silicon (Si) has strong binding energy against Ag and could lead to a negative surface energy change in the Ag/glass. In the present work, Si was deposited with different thickness on the glass substrate as the interlayer and investigated the effect of Si interlayer on the electrical and optical properties of the Ag based films.

II. Experimental

Ag/Si/glass films were deposited onto the glass substrates by direct current magnetron sputtering with high purity silicon (3 inch) and silver (3 inch) targets. The substrates were cleaned ultrasonically in acetone, ethanol and deionized water in sequence and finally dried at 100^0C for 1 h in an oven. The target to substrate distance was 70mm and before deposition the vacuum chamber was evacuated until the base pressure was set to $5x10^{-6}$ mbar and pre-sputtered for few minutes to remove the adhesive impurities from the target surface and chamber walls. The sputtering power was 40 W and 30 W for the Si and Ag targets respectively.

The resulting microstructure and Morphological studies were performed by scanning electron microscopy (SEM) and atomic microscopy (AFM). The electrical properties of the films were measured using standard four-probe method. The optical transmittance of the films was measured by UV-Vis-NIR double beam spectrophotometry in the range of 300-2500nm.

III. Results And Discussion

3.1. microstructure and surface morphological studies

Figure 1 shows the SEM microphotographs of the ultrathin Si(2, 4 and 8nm) films. The Si(2 and 4nm) films exhibits smooth and dense surface with no visible agglomeration. With increase of Si thickness to 8nm, some patches were observed on the surface of the films.

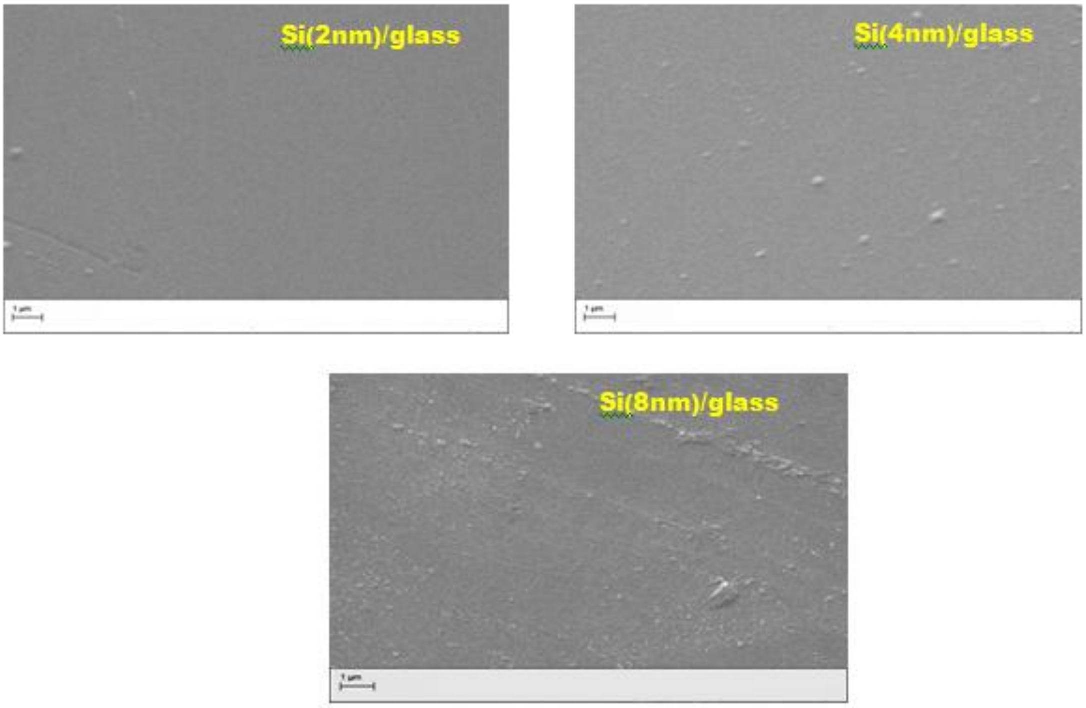

Figure 1: SEM images of ultrathin Si films at different thickness.

Figure 2shows SEM images of Ag films at different thickness. The as-deposited Ag(10nm)/glass showed aggregates of crystals with significant amount of voids leading to the rough surface. With increase the Ag film thickness to 20nm the Ag films exhibited agglomerated nanocrystals with thick boundaries.

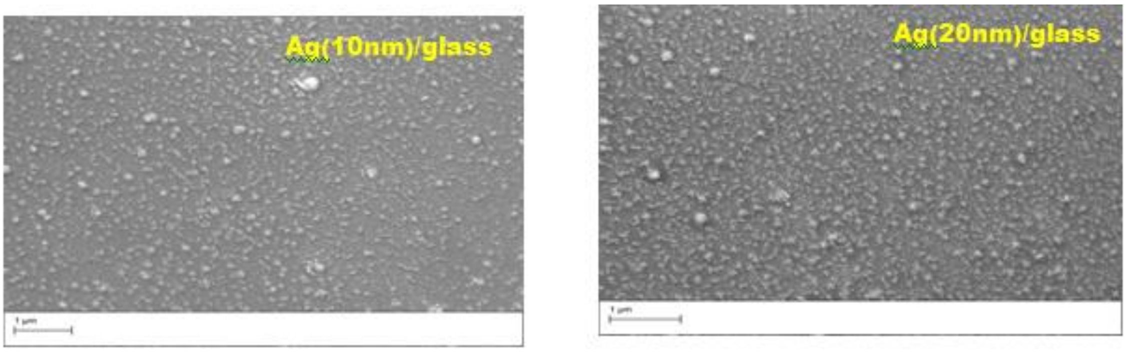

Figure 2: SEM images of ultrathin Ag films at different thickness.

Figure 3 shows the SEM image of Ag/Si/glass with various Si interlayer thickness. The agglomeration of Ag was reduced but irregular shape grains was appeared in Ag(10nm)/Si(2nm)/glass films. With increase of Si thickness to 4nm, the Ag(10nm)/Si(4nm)/glass films exhibited extremely dense and smooth surface morphology without agglomeration. The grain size increased and few clusters are appeared in Ag(10nm)/Si(8nm)/glass films. By introducing the Si interlayer between glass and Ag shows smooth and dense whereas, the Ag films deposited on glass showsagglomerated nanocrystals and relatively thick boundaries. Agglomeration is generally driven by the relatively high Ag/glass interfacial energy [5], and which is changed by Si interlayer, consequently the Ag films deposited on Si interlayer exhibited dense microstructure.

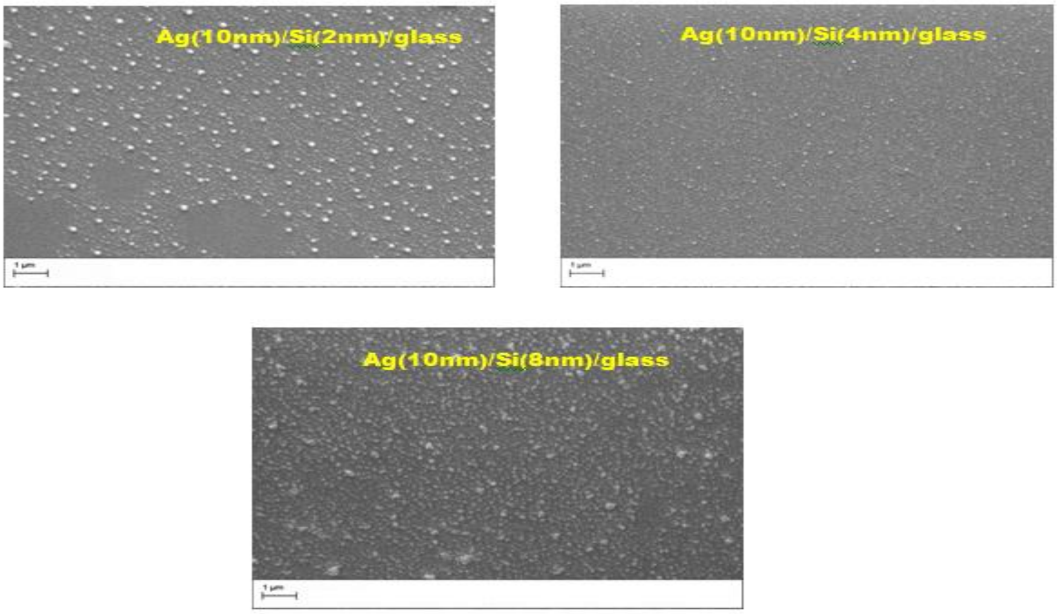

Figure 3: SEM images of ultrathin Ag(10nm)/Si/glass films at different Si interlayer thickness.

Surface topography of the films was examined by atomic force microscopy and shown in Fig. 4. The as deposited Ag/glass films shows rough surface with rms roughness of 1.3nm, whereas, the Ag films deposited on the Si interlayer exhibited smooth surface. The rms roughness of Ag/Si/glass films decreases with increase of Si interlayer thickness.The obtained rms roughness value of Ag(10nm)/Si(2nm)/glass, Ag(10nm)/Si(4nm)/glassfilms, and Ag 10(nm)/Si(8nm)/glass films are 0.7, 0.43 and 0.66nm, respectively. The surface morphology of the films confirms a noticeable transformation with increase of Si thickness.The obtained AFM results are in good agreement with the present SEM results.

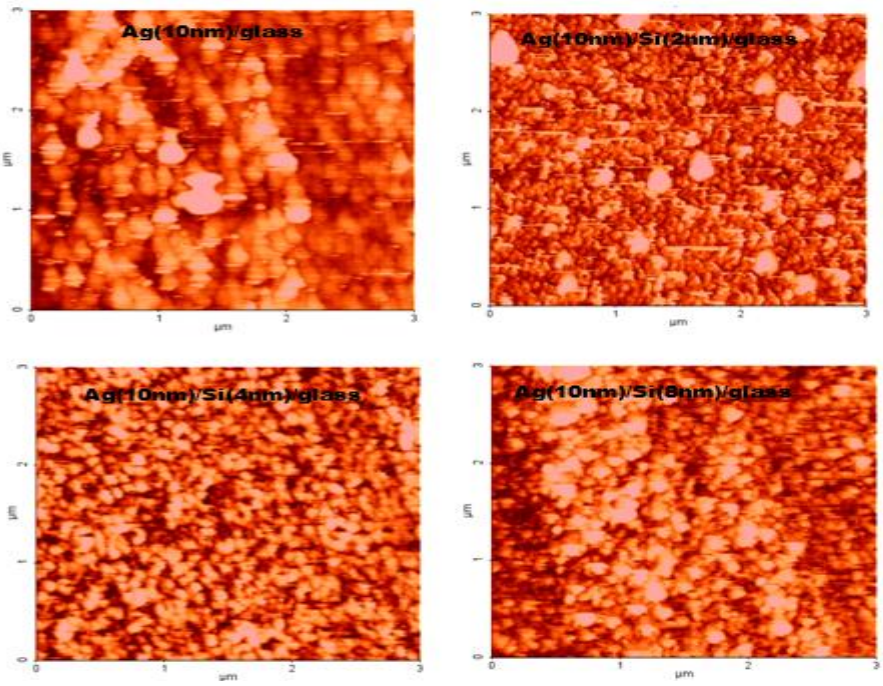

Figure 4: AFM images of ultrathin Ag/glass and Ag/Si/glass films.

3.2. Electrical and optical properties

The transmittance spectra of bare glass, Si, Ag and Ag/Si films were shown in Fig. 5. The transmittance of bare glass was around 93% at wavelength range of 550nm. The transmittance of Si(4nm) film in the visible range at wavelength of 550nm was 92%. The Ag(10nm), Ag(10nm)/Si(2nm) and Ag (10nm)/Si(4nm) films shows optical transmittance of 42, 47 and 60% respectively, in the visible range at wavelength of 550nm. With increase of Si interlayer thickness the transmittance was increased in the visible region, which was attributed the formation of a dense Ag film by the Si interlayer. The application of low emissivity required higher transmittance in the visible region and lower transmittance in the near infrared region [6].

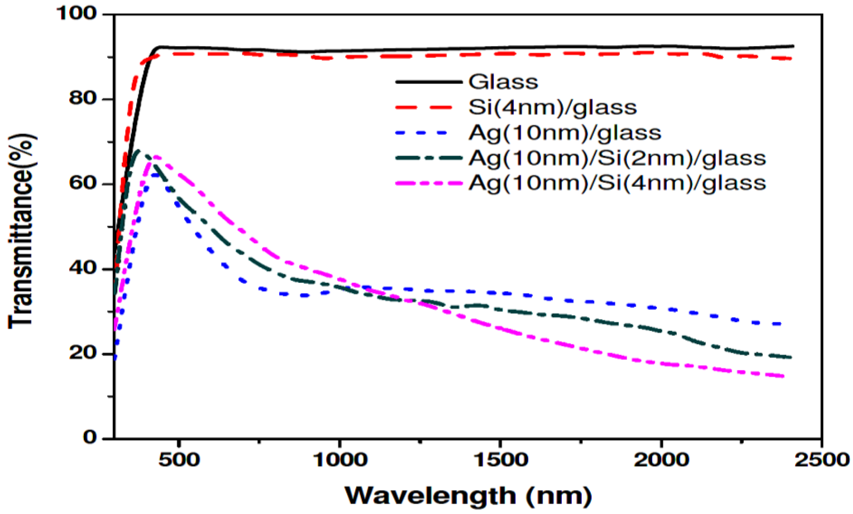

Figure 5: Optical transmittance spectra of ultrathin Ag/glass and Ag/Si/glass films.

The sheet resistance of the ultrathin Si films was above the immeasurable range. The Ag(10nm)/glass films shows the sheet resistance of 15.8Ω/□. The sheet resistance of Ag(10nm)/Si(2nm) and Ag(10nm)/Si(4nm) was 6.6 and 4.7Ω/□, respectively. With increase of Si interlayer thickness, the sheet resistance was reduced. The emissivity of the block body is 1 and a perfect reflector has 0. The emissivity depends of the resistance (R□)of the interlayer and can be calculated using the following equation [7],

$$\varepsilon = 0.0129.\ R_{\square} - 6.7\text{X}10^{-5} R^2_{\square}$$

The obtained emissivity value of Ag(10nm)/glass was 0.187, after introducing the Si interlayer the emissivity was reduced to 0.059. The emissivity of Ag(10nm)/Si(2nm) and Ag(10nm)/Si(4nm) was 0.082, 0.059, respectively. The Si interlayer influenced on the emissivity as well as the resistance at initial stage of thin film growth. Therefore, Si interlayer changed the nanostructure of the film and reduce the resistance and emissivity.

IV. Conclusions

The ultrathin Si/glass, Ag/glass and Ag/Si/glass films were prepared by direct current magnetron sputtering on glass substrates at room temperature. The results revealed that Si interlayer effectively reduced the Ag agglomeration and surface roughness. The optical transmittance of Ag(10nm), Ag(10nm)/Si(2nm) and Ag (10nm)/Si(4nm) was 42, 47 and 60% respectively. With increase of Si interlayer thickness the sheet resistance and thermal emissivity was effectively reduced. The Ag(10nm)/Si(4nm) films exhibited low thermal emissivity of 0.059and high transmittance in the visible region compared to Ag/glass films.

Acknowledgments

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