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Growth and Optical Characteristics of Jordanian Silica Sand Thin Films

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Abstract: High-purity Jordanian silica sand (J-SiO_2) thin films have been grown by RF-reactive magnetron sputtering on crystalline Si (100) and quartz substrates at temperature T < 52^o C. From the X-ray diffraction observations, it was found that all films have an amorphous nature. The chemical states of oxygen and silicon in the SiO_2 thin films were also investigated by energy-dispersive X-ray (EDX) spectroscopy. The EDX analysis revealed that the films have a nearly stoichiometric composition (Si/O, 73.42%/25.83%). The surface morphology of the as-deposited films was studied using field emission scanning electron microscopy. The films are observed to be dense in nature and uniformly distributed over the surface. Using the Bruggeman effective medium theory, the surface roughness layers were found to be 0.0 – 9.74 nm. By modeling the measured ellipsometric spectra with the Cauchy-Urbach dispersion model, the thicknesses and optical constants of the films were obtained in the ultra violet – infrared range. Refractive indices of the films were determined to be in the range 1.46 – 1.59, while the extinction coefficients were found to be in the range 9.6×10^{-6} – 0.076. Also, the films reveal a high transmittance (90%) and very low reflectance (< 7%) at normal incidence. Hence, the obtained accuracy of the optical constants with the transmittance and reflectance values of the J-SiO_2 films for the spectral range 200 - 2200 nm is of great significance for the design of antireflection optical coatings and silicon-based electronic devices.
Keywords: Silica sand; Sputtering; Ellipsometery; Optical constants; Cauchy-Urbach.
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Introduction

White silica is another name for silicon dioxide, SiO_2, and it is applied to quartz sand that conforms to the specifications of which the main composition is SiO_2 > 98%, with very little contaminant contents and heavy minerals of < 0.1% [1, 2]. Impurities are found to be very minor and commonly are clay minerals (e.g. kaolinite and illite), titaniferous minerals, iron oxides and refractory minerals, such as chromites [2].

Silica (SiO_2) thin films, in their various crystalline (c-SiO2; α-quartz) and amorphous (a-SiO_2; ultrahigh-purity fused silica) phases, are attractive because of their excellent physical, chemical and optical characteristics [3 – 5]. Owing to their inherent thermal stability and conductivity in the optical transmission window, many of them have been widely studied and fabricated for their potential applications in various industrial fields, such as beam splitters, waveguides, photonic crystal fibers,

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photolithographic photo-masks, optical fiber telecommunications and fibrous thermal insulation [6]. Also, SiO_2 thin films have been one of the most popular gate insulators for low-temperature (< 400^{o}C) poly-silicon (LTPS) thin-film transistors (TFT) [7]. Moreover, silica thin films are one of the most used oxide materials for the manufacture of interference multilayer coatings. It is also known as a very high laser damage threshold material with good environmental stability [8 - 10]. In addition, modern nanoscale technology requires the production of nanometer-sized SiO_2 thin films, which are of frequent use in silicon-based electronic devices for passivation and electrical insulation [11 and 12].

Several techniques have been applied for thin film depositions of silica, such as plasma-enhanced chemical vapor deposition (PECVD), dual ion beam sputtering (DIBSP), atomic layer deposition (ALD), ion beam assisted deposition (IBAD), electron beam evaporation (EBE), vacuum arc plasma evaporation (VAPE), sol-gel process (S-GP) and radio frequency-magnetron sputtering (RF-MSP) [7 – 10, 13 – 16]. Among these deposition methods, the RF-MSP has become one of the most common, because it allows fabrication of silica thin films having good coating uniformity across the substrate and controlled microstructure at a low deposition rate as well as at low substrate temperature.

The optical properties of silica films have been the subject of numerous studies [6, 7, 17 – 25]. Due to their technological importance, the spectral measurements have been carried out from VUV to far infrared (IR) wavelengths [6, 17, 18] by various experimental techniques, such as prism method [19], interferometric method [18], Kramers-Kronig (KK) analysis of reflectance data with moderate accuracy [6, 21], successive interference fringes method [22] and spectroscopic ellipsometry [6, 7, 23 - 25].

For Jordanian silica sand (J-SiO_2) thin films, however, there is as yet no report on the optical properties, within any range of the electromagnetic (EM) spectrum. On the other hand, there are several reports regarding mineral exploration and on the chemical, mechanical and physical properties of the raw, wet sieved and scrubbed fractions of the Jordanian silica sand [1, 2, 26 - 30]. A study which was conducted by the Jordanian Royal Scientific Society (JRSS) on local materials reported that 40% of Jordan's total area is covered by silica sand [1]. Recently, Jalham *et al.* [1] have investigated the behavior of bakelite matrix material reinforced with Jordanian silica sand. Their study was carried out on relatively fine natural sand of different size distributions. The chemical composition of the Jordanian silica sand was found as follows: SiO_2 (97.65%), Na_2O (0.01 %), K_2O (0.02%), CaO (0.01%), MgO (0.02%), Fe_2O_3 (0.66%) and Al_2O_3 (0.85%) [1]. However, these studies have revealed that Jordanian-silica sand deposits are very promising and could be utilized for a variety of industrial purposes after upgrading beneficiation processes which require high technologies. Thus, there is a need to do original scientific analysis not only on the chemical components of those materials, but also to measure their structural and optical properties. To the best of our knowledge, there is no systematic experimental or theoretical investigation of the structural and optical properties of the J-SiO_2 materials. This type of characterization along with other previously studied properties [1, 26 - 30] could create a good opportunity to produce high quality Jordan-silica sand for different industry applications, such as solar cells, windows (hot and cold), antireflection optical coatings, sensors, glass making and automobile industry

In this work, the fabrication and the optical characteristics of white Jordanian silica sand thin films deposited on crystalline Si (100) and quartz substrates by RF magnetron sputtering at a temperature T < 325 K (52 ^{o}C) have been investigated over a wide wavelength range (200 – 2200 nm). The grown films were characterized by X-ray diffraction (XRD), energy-dispersive X-ray spectroscopy (EDX), spectroscopic ellipsometry (VASE) and UV-VIS-NIR spectrophotometers.

Experimental Details

Jordanian silica sand (J-SiO_2) deposits are found exposed on the surface of Early Ordovician life and Lower Cretaceous sandstone in the southern parts of Jordan [2, 26]. Geological map at a scale of 1:50,000 covering most of the J-SiO_2, outcrops in the following areas: Ras En Naqb, Qa'Ed Disa, Petra-Ein El Biada, Wadi Es Siq-Wadi Rakiya and Wadi Gharandal, which was published by the Jordanian-Natural Resources Authority (J-NRA) (see Fig. 1) [2]. Representative samples, as white fine silica sand, were collected from the huge silica sand resources of the Ras En Naqb escarpment (70 km north of Aqaba, Jordan, as shown in Fig. 1) by the Jordanian Natural Resources Authority (J-NRS) [2]. Further, more detailed descriptions and mineralogical information have been presented elsewhere [2, 26 - 30]. The deposition of the samples as thin films was performed by means of an RF-magnetron sputtering technique of pure white fine silica sand (SiO_2) target of 98% purity in reactive argon plasma with an ultra high purity of 99.999%. Before any deposition, the chamber was evacuated down to 1.0×10^{-7} Torr. The RF-sputtering power during the growth was maintained at 120 W with a reflected power of 4 - 8 W at a working pressure of 12×10^{-3} Torr. The films were deposited on crystalline silicon (100), c-Si (100) and quartz substrates. The substrates were clamped to a thick copper block that limited the temperature during deposition to T < 325 K (52 °C). The substrates were placed parallel to the target, at a distance of 150 mm. The white SiO_2 sand thin films were deposited at a rate of 1 Å /s. The deposition rate and the nominal film thickness were monitored with a quartz crystal thickness monitor.

FIG. 1. Principal silica sand resources in Jordan and location of study area: Ras En Naqb [2].

The structural properties of the white J-SiO_2 sand films were studied using X-ray diffraction (XRD) measurement with Cu Kα (1.54 Å) as the incident radiation (Rigaku Geigerflex, 2000 Watts, x-ray diffractometer) operated at a voltage of 40 kV and a current of 30 mA.

Energy dispersive x-ray spectroscopy (EDX, JEOL JED-2300) attached to the field emission scanning electron microscope (FE-SEM)) was used to identify the elemental composition of as-deposited white J-SiO_2 sand thin films.

For the determination and analysis of the optical constants (the index of refraction, *n* and the extinction coefficient, *κ*), spectroscopic ellipsometry measurements of the white J-SiO_2 sand thin films on c-Si (100) substrates were made using a Variable Angle Spectroscopic Ellipsometr (VASE^{TM}, J.A. Woollam Co.) of the rotating analyzer type over a wide wavelength range of 190 – 2200 nm in the air at room temperature [31]. Further details concerning the VASE measurements and analysis with the use of appropriate optical dispersion models for the amorphous semiconductor materials can be found in previous publications [31].

Spectral normal transmittance T(λ) and near normal reflectance R(λ) of the films on quartz substrates were measured in the wavelength range 200 – 2200 nm in air at room temperature, on a computerized double beam solid-spec 3700DUV Shimadzu spectrophotometer equipped with 198851 Barium Sulphate ($BaSO_4$) integrating sphere. The SolidSpec-3700DUV is the first UV-VIS-NIR spectrophotometer with three detectors: a photomultiplier tube (PMT) detector for the ultraviolet and visible region; InGaAs and PbS detectors for the near-infrared region [32].

Results and Discussion

Fig. 1 illustrates the XRD pattern of the as-deposited Jordanian white silica sand (J-SiO_2) thin films on c-Si (100) substrates. It can be clearly seen from the pattern that the J-SiO_2 thin films showed no diffraction peak at any 2θ diffraction angle (10^o - 100^o), suggesting that the films have an amorphous nature. In addition, no diffraction peaks from impurities, such as Al, Au, Fe and Ca, which are usually found in the silica sand, are detected in the patterns, indicating that the product is of high purity. On the other hand, the XRD patterns of the J-SiO_2 thin films sputtered onto c-Si (100) substrates show two diffraction peaks at $2\theta = 32.85^o$ and 69.57^o with an orientation of (200) and (400), respectively which were due to the crystalline Si (100) substrate. However, amorphous SiO_2 is a key component of metal-oxide semiconductor field–effect transistors, solar cells and optical fibers, all of which are basic elements of modern technology. Practical applications are often limited by various defects that can change the mechanical, electrical and optical properties of the oxide.

The chemical composition of as-deposited white J-SiO_2 thin films was investigated by an energy dispersive X-ray (EDX) analysis. Fig. 3 (a) shows the typical EDX spectrum taken from the white silica sand (SiO_2) thin films sputtered onto c-Si (100) substrate. The chemical analysis of the sputtered films measured by the EDX analysis shows that only features of Si (weight of 73.22 % and atomic of 61.21%) and O (weight of 25.83 % and atomic of 37.93%) signals have been detected, which indicated that the films are indeed made up of Si and O atoms, and quantitative analysis indicates that the atomic ratio of Si to O is about their stoichiometric ratio. The measured atomic % of elements is found nearly in a ratio of 1:3 for O and Si, respectively. Detecting Si and O atoms confirms a high purity of the prepared films, although we cannot exclude the possible presence of some minor Al (0.65 %) and Au (0.2%) impurities which were not detectable in the XRD spectra (see Fig. 2). The EDX result is found to be in good agreement with the result found for the deposition of SiO_2 films on silicon substrates by flame hydrolysis deposition (FHD) system for photonic device application [33] as well as for SiO_2 nanowires grown by annealing SiO particles on Si substrate [34]. Furthermore, the EDX of the J-SiO_2 thin films gave results in agreement with those from the X-ray photoelectron spectroscopy (XPS) for SiO_2 thin films deposited by atomic layer deposition (ALD) technique onto Boron-doped Si (100) wafers [7]. The surface morphology of the deposited films was also studied using field emission scanning electron microscope at 20 kV with magnification of 150 K. Fig. 3 (b) shows the FE-SEM image of the white J-SiO_2 thin films. This image shows the formation of amorphous J-SiO_2 thin film onto the c-Si (100) substrate. Closely packed small regular structures are clearly visible in this image. Thus, the film is observed to be dense in nature and uniformly distributed throughout the surface. This result was expected, since the samples were deposited at a very low deposition rate (1 Å/s).

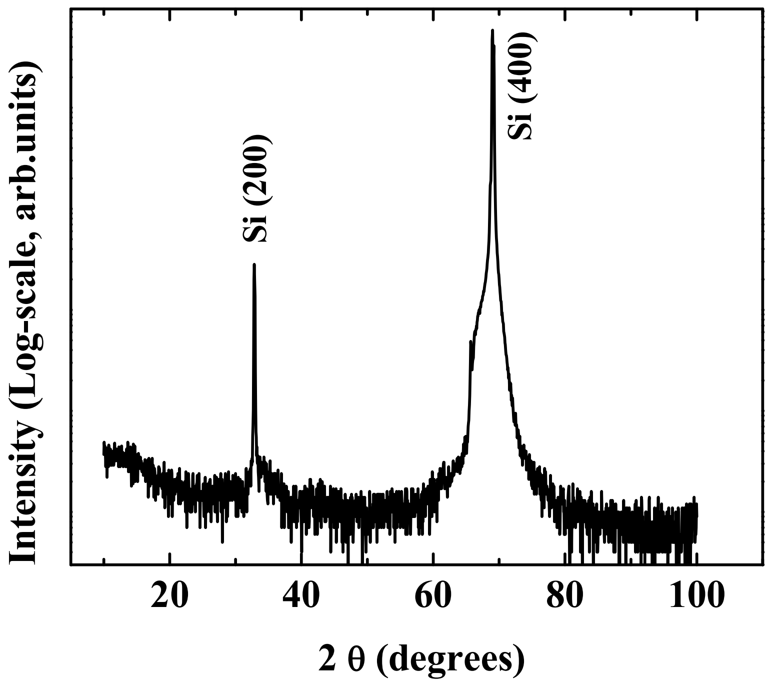

FIG. 2. XRD patterns of amorphous white J-SiO_2 thin films sputtered onto c-Si (100) substrates.

The optical constants (n and κ) of the amorphous white J-SiO_2 thin films are derived from numerical fitting to the experimental data (Ψ and Δ) of the model structure: air / surface roughness / amorphous SiO_2 / c-Si (100). The optical constants of the crystalline silicon substrate were taken from the literature [36] and were not allowed to vary during the fitting process. The surface roughness, SR, layer was chosen as an over layer to obtain accurate thin film optical constants and a good fit to the experimental data. The SR was modeled using Bruggeman effective medium theory [31] and it was found to be in the range 0.0 – 9.74 nm with different thicknesses as shown in Table I. These values are in good agreement with the FE-SEM image (see Fig. 3 (b)). Since amorphous J-SiO_2 thin films were optically transparent in the spectral region of interest (200 – 2200 nm), the Cauchy – Urbach (CU) dispersion model was then applied to model this region and hence calculate their optical constants. The details about using this model for amorphous transparent semiconductor materials have been reported elsewhere [31].

The measured and simulated VASE data, Ψ and Δ, of 240 nm amorphous white J-SiO_2 thin films sputtered onto c-Si (100) over the spectral range 200 – 1350 nm are shown in Fig. 4 (a) and (b). The dashed, dotted and dashed dotted lines represent the experimental data of Ψ and Δ for angles of incidence 65°, 70° and 75°, respectively. The fitted Ψ and Δ spectra simulated with the best-fit CU model parameters are shown by solid lines in the figure. The fitting was thus done by minimizing the mean square error (MSE) automatically through a Levenberg – Marquardt algorithm by the ellipsometer WVASE32™ software [31]. Therefore, the CU dispersion model represents adequately amorphous white J-SiO_2 thin films and provides a very flexible approach to calculating their optical constants over a wide spectral range 200 – 1350 nm. The wavelength dependence of the refractive index and extinction coefficient for the five films is given in the form of the CU parameters in Table I. The table shows that the values for each fitting parameter in the CU model for all samples are close and the values of the 90% confidence limits are minima, confirming the validity of the model used for the amorphous white J-SiO_2 thin films over the entire measured spectral range (200 – 1350 nm). On the other hand, there are very sharp peaks in the dispersion curves of Ψ (λ) within the desired wavelength range (see Fig. 4 (a)) at any angle of incidence, indicating that the imaginary part of the complex refractive index, $n + i\kappa$, is very small. This result is consistent with the fact that a silica (SiO_2) thin film is a typical wide band-gap insulator of approximately 9 eV (137 nm) [36, 37].

TABLE I. Values of different parameters for amorphous J-SiO_2 thin films determined by the VASE in the wavelength range 200 -1350 nm. The 90 % confidence limits are given by (±).

Sample no. / Parameter	1	2	3	4	5
Film thickness (nm)	69.15 ± 0.079	110.66 ± 0.479	130.33 ± 0.341	179.99 ± 0.309	240.22 ± 0.371
SR thickness (nm)	0.00	5.16 ± 0.846	9.60 ± 0.654	9.74 ± 0.624	6.13 ± 0.497
A	1.47 ± 0.001	1.46 ± 0.001	1.47 ± 0.000	1.49 ± 0.000	1.49 ± 0.001
B $(nm)^2$	$0.006 \pm 8.9 \times 10^{-5}$	$0.004 \pm 13.5 \times 10^{-5}$	$0.004 \pm 9.1 \times 10^{-5}$	$0.005 \pm 6.8 \times 10^{-5}$	$0.005 \pm 6.2 \times 10^{-5}$
C $(nm)^4$	0.00	0.00	0.00	0.00	0.00
α	0.093 ± 0.022	0.061 ± 0.008	0.081 ± 0.021	0.133 ± 0.021	0.107 ± 0.012
β (nm)	1.801 ± 0.215	1.053 ± 0.089	1.577 ± 0.429	1.429 ± 0.098	1.140 ± 0.054
γ (nm)	200	200	200	200	200
MSE	0.87	1.53	0.96	1.79	1.35

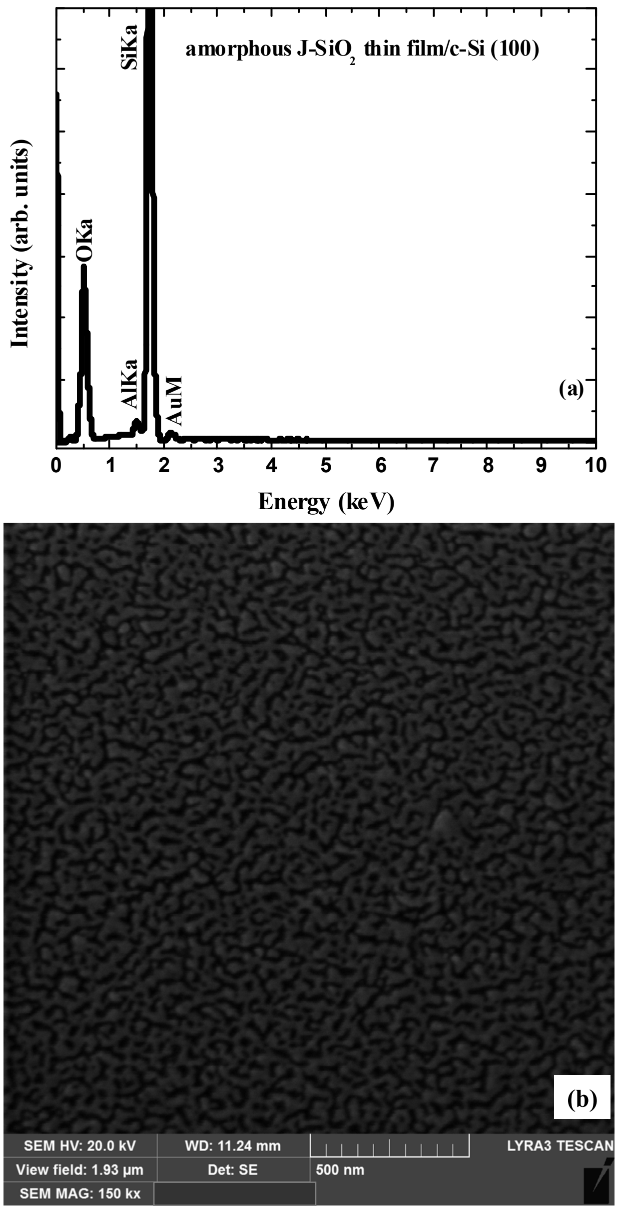

FIG. 3. (a) EDX spectrum of amorphous white J-SiO_2 thin films sputtered onto c-Si (100). (b) Top surface view of the FE-SEM image of the 240 nm amorphous J-SiO_2 thin film sputtered onto c-Si (100) substrate.

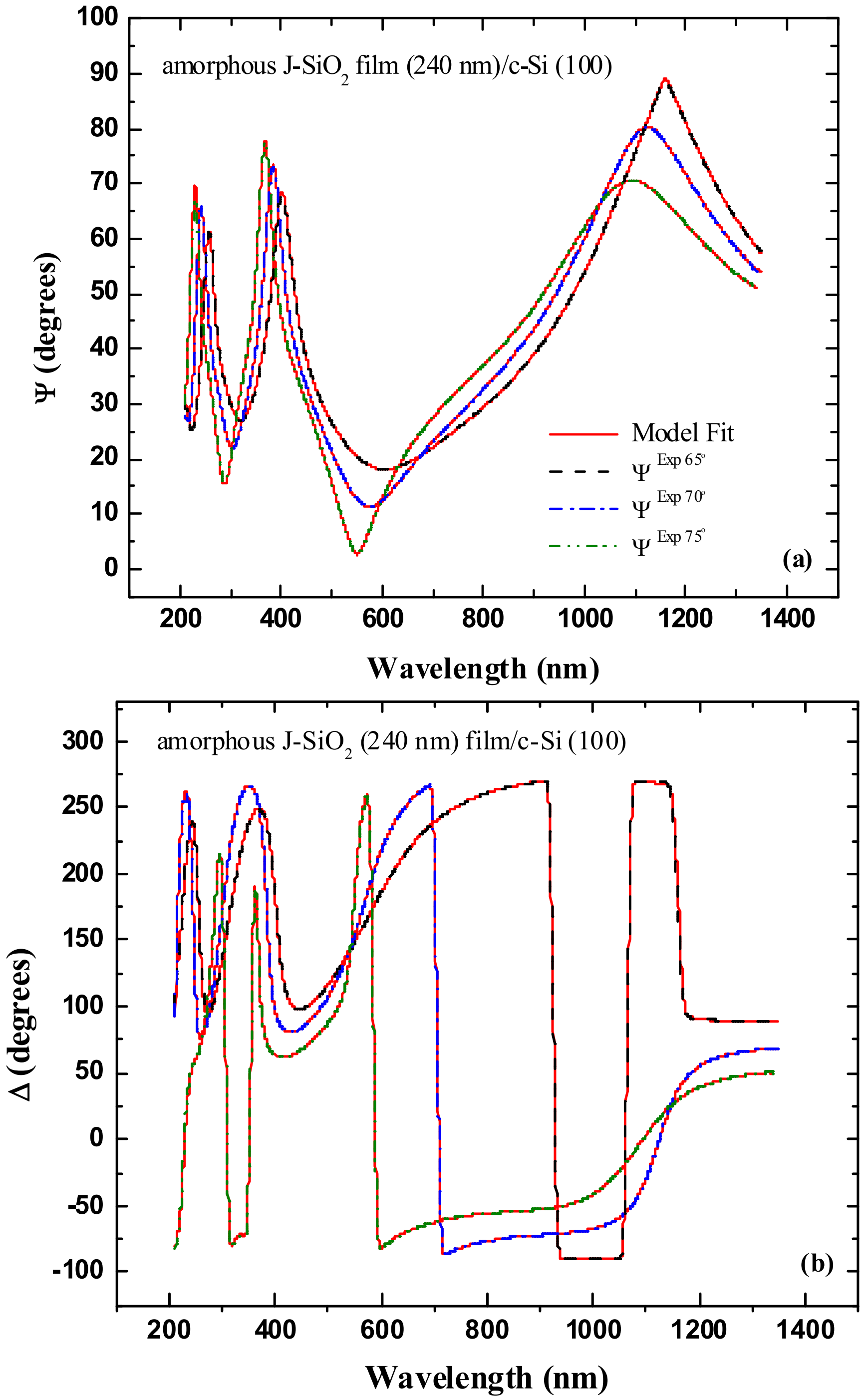

FIG. 4. Experimental and fitted ellipsometric parameters (a) ψ and (b) Δ for amorphous white J-SiO_2 thin film of 240 nm thick sputtered onto c-Si (100). The dashed, dashed dotted and dashed dotted dotted lines represent the experimental data of the ψ and Δ, while the solid line is the model fit for angles of incidence, 65°, 70° and 75°.

Fig. 5 shows the dispersion curves of the optical constants, the refractive index, *n* (λ) and the extinction coefficient κ (λ), obtained from the fitted Cauchy-Urbach model (see Fig.4 (a) and (b)), for the amorphous white silica sand (SiO_2) thin films with different thicknesses deposited onto c-Si (100) substrates in the wavelength range of 200 –1350 nm. The obtained accuracy of the optical constants of the films in the wavelength region from 0.20 µm to 1.4 µm is of great importance for the design of high quality coatings, such as ultra-low loss coating, because they are closely related to the electronic polarizability of ions and the local field inside materials [36]. As can be seen, the refractive index and the extinction coefficient decrease monotonically with increasing the wavelength of the incident light over the desired spectral range. In addition, the extinction coefficient is negligible in the VIS and near-IR regions, indicating that the films are transparent within those regions. Also, the spectral dependence of the extinction coefficient shows a little absorption when the wavelength is smaller than 300 nm (4.13 eV, UV region). Thus, the films could show significant absorption in the VUV region, where the bandgap energy is about 9 eV [36, 37]. The refractive indices and the extinction coefficients of the amorphous white J-SiO_2 thin films were determined to be in the range 1.46 – 1.59 and 9.6×10^{-6} - 0.076, respectively. Moreover, it is clearly seen from the figure that the optical constants show little dependence on the film thickness, and the difference between the values of the refractive indices and the extinction coefficients of the studied samples with different thicknesses becomes smaller at shorter wavelengths; whereas it becomes very obvious with the VIS and near-IR regions (see Fig. 5). However, the variations of the optical constants of the studied films are found to be less than 0.04 for the refractive indices and less than 3.8×10^{-3} for the extinction coefficients. These variations become more significant with decreasing thickness at longer wavelengths. In general, the optical constants of films are assumed to be constant regardless of film thickness in any conventional optical design. However, this assumption is not valid when the film thickness in the optical design becomes very small (ultra-thin film) and it is still applicable for bulk materials [38, 39]. Hence, the variations could be explained by the Bruggman effective medium theory's [38, 39] correlation with the film growth and the structure variation [40]. In addition, the grain's sizes, shape of the islands, long-range order in thicker films, the substrate, the deposition conditions and different void fractions significantly alter the effective optical constants [41]. Also, that variation (< 0.04) in the values of the optical constants could be attributed to the different values of the surface roughness layers, which are in the range of 0.00 – 9.74 nm as shown in Table I.

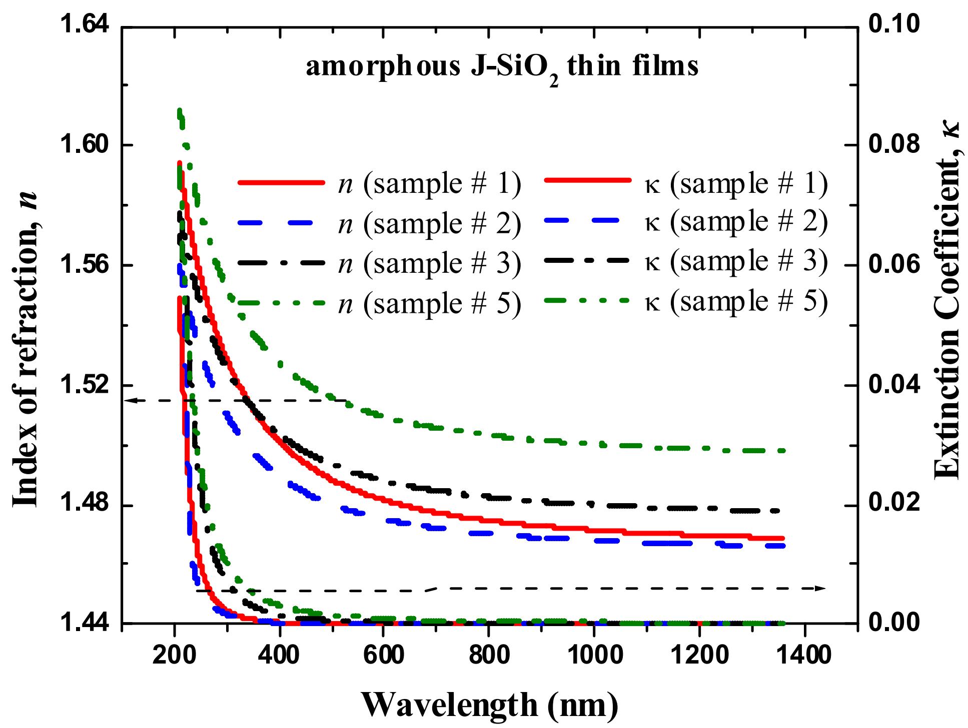

FIG. 5. The fitted spectroscopic dispersion of the optical constants (index of refraction and extinction coefficient) obtained from the CU model for amorphous white J-SiO_2 thin films with different thicknesses sputtered onto c-Si (100) substrates.

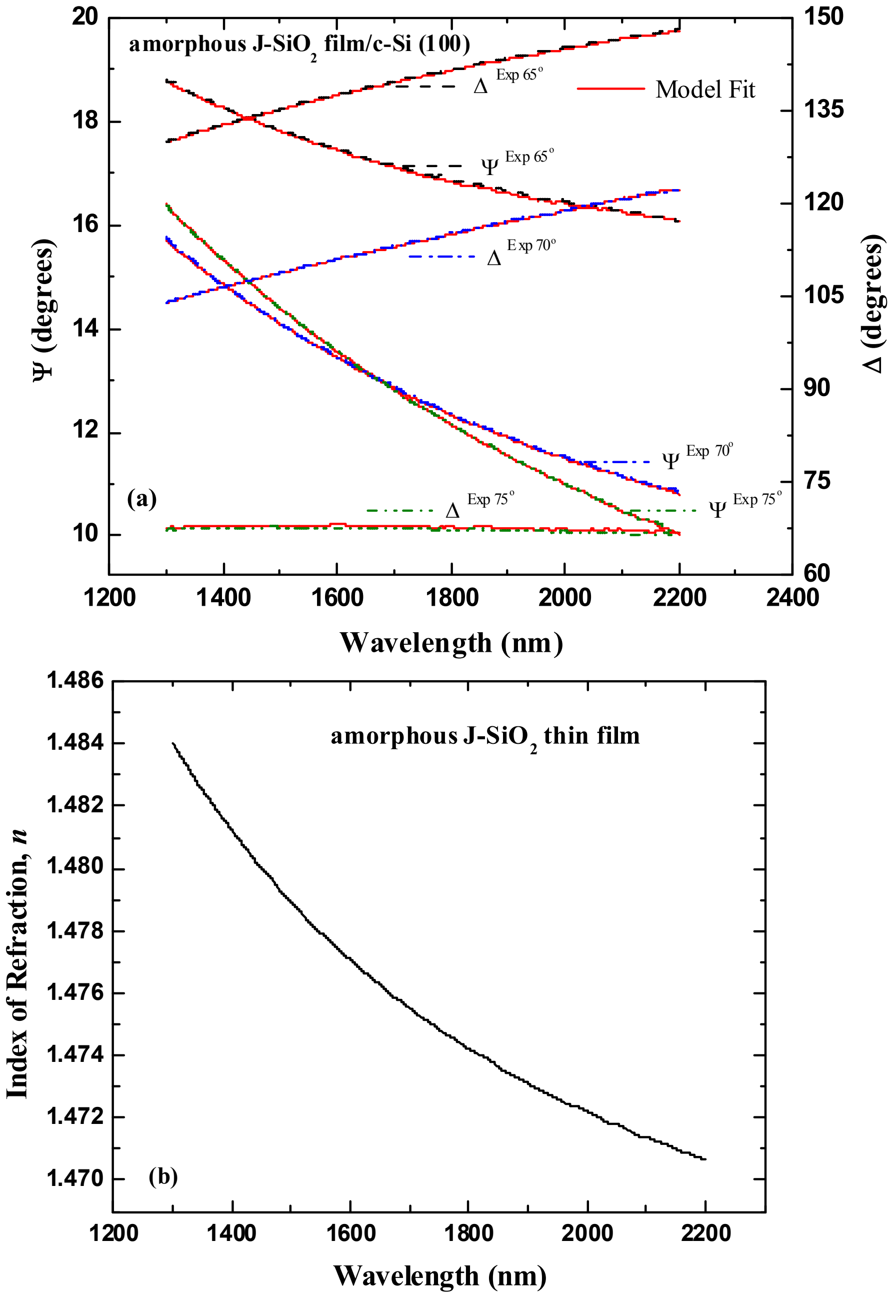

FIG. 6. (a) Experimental and fitted ellipsometric spectra: ψ and Δ of amorphous white J-SiO_2 thin film sputtered onto c-Si(100) for angles of incidence of 65°, 70° and 75° obtained from the Cauchy model. The fitted model parameters: A = 1.464 ± 0.002, B = 0.0347 ± 0.003 and C = 0. The thickness of the film as an extra fitting parameter is 68.31 ± 0.094 nm. The 90 % confidence limits are given by (±). (b) The fitted spectroscopic dispersion of the refractive index of the SiO_2 thin film.

Due to no absorption or little absorption, κ is almost zero, when $\lambda > 900$ nm (see Fig. 5), it is appropriate to apply the Cauchy layer for the calculation of the refractive index of the films over the spectral range 1300 – 2200 nm. The measured and simulated SE data with the best-fit Cauchy model parameters of a 69 nm amorphous white J-SiO_2 thin film sputtered onto c-Si(100) over the spectral range 1300 – 2200 nm for angles of incidence of 65°, 70° and 75° are shown in Fig. 6 (a). Fig. 6 (b) shows the calculated refractive index and the values of the fitting parameters with the 90% confidence limits of a 70 nm amorphous white J-SiO_2 thin film deposited onto c-Si (100). Refractive indices of the films with different thicknesses in this study were found to be in the range 1.470 – 1.484.

As has been mentioned previously, optical constants for silica (SiO_2) sand thin films have been previously reported [6, 10, 17 - 25]. However, to the best of our knowledge, there are currently no systematic reports on the optical constants of amorphous white J-SiO_2 thin films over a wide wavelength range. Hence, it is worth discussing and comparing the refractive indices and extinction coefficients results measured in this work within the context of other available literature on the subject, in order to accurately model, design and analyze the films to be used in optoelectronic devices. The refractive index of the SiO_x films as a function of the growth temperature was investigated by López *et al.* [24]. In their study, a variation in the refractive index from 1.4 to 2.2 was measured when the growth temperature was increased from 1150°C to 1400°C. This variation has been related to a change of the silicon excess in SiO_x films. Also, SiO_2 films were prepared by atomic layer deposition technique at 350°C - 400°C and characterized for being applied as a gate insulate of low-temperature polysilicon thin film transistors by Lee *et al.* [7]. They found that the refractive index increased gradually with increasing growth temperature to reach a maximum value of 1.46 ± 0.01 at 400 °C. Refractive indices for the SiO_2 thin films deposited on Si and glass by e-beam evaporation under different substrate temperatures (25 °C – 250 °C) were measured by the VASE technique over a wavelength range of 300 – 1300 nm [14]. For substrate surface deposition temperatures of room temperature and 150 ° C, they were found to be in the range of 1.44 to 1.48. The refractive index of the SiO_2 was in the range of 1.46 -1.50 at substrate temperatures from 200 °C to 250 °C. The highest refractive index of the films was attributed to the lowest roughness results. An interferometric method was used to determine the refractive index of silica glass (Suprasil 2, ~ 1000 ppm OH-content) in the infrared wavelength range (i.e., 3 to 6.7 μm) by IR spectroscopy [21, 22]. The refractive index was described with a three-term Sellmeier equation and it was found to be in the range 1.15 – 1.43. The optical constants of the bulk Suprasil 1 amorphous silica, which has very high OH content (up to 1200 ppm level), were determined by VUV-spectroscopy and spectroscopic ellipsometry within the photon energy range of 0.7 to 8 eV (i.e., 155 – 1240 nm) [23]. The index of refraction and the extinction coefficient values for Suprasil 1 amorphous SiO_2 were found in the range n = 1.45 – 1.72 and κ = 0.00 – 0.0002. Kitamura *et al.* [6] have reviewed most of the experimental and theoretical determinations of the optical constants of silica glass from extreme ultraviolet to far infrared (30 nm - 1000 μm) at near room temperature. In their critical review, they report that silica glass is effectively opaque for wavelengths shorter than 200 nm and larger than 3.5 – 4.0 μm. Strong absorption bands are observed below 160 nm due to the interaction with electrons, absorption by impurities and the presence of OH groups and point defects. Recently, the optical constants of amorphous SiO_2 films sputtered onto crystalline Si (110) substrates and thermally treated with the annealing temperature of 550◦C were calculated from spectroscopic ellipsometry throughout a graded Cauchy model as the fitting model in the wavelength range 200 – 2500 nm [42]. The refractive index was calculated by reflectance spectra and ellipsometry data fit methods and it was found to be 1.45 - 1.55; whereas the films showed high absorption in the infrared region with the maximum value of the extinction coefficient of 2.6 at 2400 nm. The actual values of the optical constants of the silica thin films can vary considerably due to the degree of crystallinity, preparation conditions such as substrate and substrate temperature and to the presence of impurities, point defects, as well as to the experimental uncertainties and approximations in the retrieval methods [6].

Fig. 7 illustrates the spectral normal transmittance T (λ) and near normal reflectance R (λ) of the amorphous white J-SiO_2 thin film sputtered on quartz substrate in the spectral range 200 - 2200 nm. In Fig. 7, the film exhibits a high transmittance (about 90%) and very low reflectance (< 7%) within the VUV-VIS and NIR regions. Comparison of the reflectance and the transmittance results also shows an excellent agreement with the reported data in the literature [20, 21 and 41]. For example, Tan *et al*. [23] showed that the Suprasil 1 amorphous SiO_2 exhibited very low reflectivity (< 8 %) and good transparency (82% - 92%) over the spectral range of 180 - 1240 nm. Consequently, amorphous white silica sand thin films could be a potential candidate as an optical material for transparent optoelectronic devices, such as antireflection (AR) optical coatings and ultra-low loss coating.

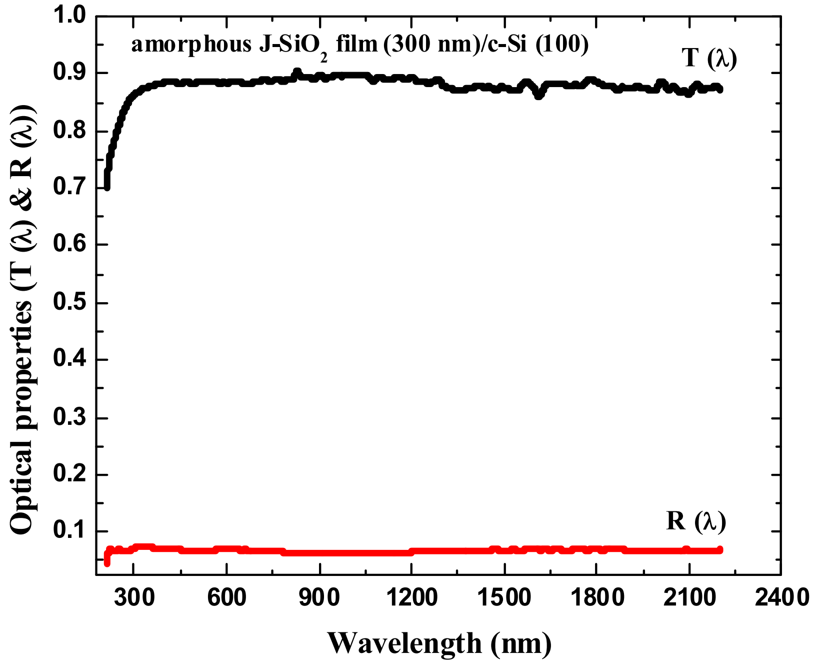

FIG. 7. Normal transmittance *T* (λ) and reflectance *R* (λ) for the amorphous white J-SiO_2 thin film of 300 nm thickness sputtered onto a quartz substrate.

Conclusions

Amorphous J-SiO_2 thin films have been successfully fabricated from white fine silica sand on c-Si (100) and quartz substrates by using the RF-magnetron sputtering technique. The EDX analysis reveals the chemical bonding states of silicon and oxygen in the surface of the films. Using the FE-SEM images, the as-deposited films are homogeneous and continuous with an excellent agreement with the results of the analysis of the surface roughness layers (0.0 – 9.74 nm) throughout the Bruggeman effective medium theory. The optical constants and the thicknesses of the films were simultaneously determined using the VASE via the Cauchy-Urbach model. It has been shown that the CU model represents adequately amorphous J-SiO_2 thin films over a spectral range of 200 – 2200 nm. At normal incidence, the films exhibit a high transmittance (about 90%) and very low reflectance (< 7%) within the VUV-VIS-IR regions. Therefore, the sputtered amorphous J-SiO_2 films could have a profound importance for new applications in the field of optoelectronic devices, such as broadband antireflection optical coatings, ultra-low loss coatings and glass making.

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