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Silver thin film electrodes for supercapacitor application

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Abstract

The potential of a radio frequency (RF) reactive magnetron sputtered silver (Ag) thin film electrodes, for electrochemical energy storage application is presented in this paper. Scanning electron microscope (SEM) was used to reveal the information on the morphology and growth mode of the deposited silver thin film samples. The stoichiometry of the RF sputtered silver thin films was evaluated using X-ray diffraction (XRD), while the elemental constituents of the deposited thin films were confirmed using energy dispersive X-ray spectroscopy (EDX). The surface area, wettability and surface energy of silver thin film electrodes were determined, using Brunauer-Emmett-Teller (BET) and contact angle measurements. Furthermore, the ion diffusion, Faradaic redox reactions and the specific capacitance of the produced Ag thin film electrodes in ionic liquid (1-Ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide) were probed using electrochemical impedance spectroscopy (EIS) and cyclic voltammetry (CV). XRD result reveals that the sputtered silver thin films are crystalline, with metallic silver been the predominant element found on the EDX spectra. The specific capacitance of 431 F/g at 2mV/s scan rate was achieved for Ag thin film electrode produced at 350W forward power, demonstrating its promising potential as an active electrode for supercapacitor application.

Keywords: Silver, BET, contact angle, surface energy, EIS, supercapacitor

1. Introduction

Energy which is the ability to do work is required in all aspects of our daily lives, with the daily demand for it placing enormous strain on the supply systems. This strain can be reduced by using efficient storage technologies like supercapacitor, which can store and release energy at various demand timescales, thereby improving the efficiency of the supply system. Electrochemical capacitors (ECs), also known as supercapacitors are energy storage devices that store and release charges electrostatically and Faradaically [1-2]. The capacitor was first invented in the 18th century and its principle of operation known as static electricity was studied by Von Kleist [3]. Becker first patented a capacitor based on high surface area carbon material known as an electric double layer capacitor (EDLC) in 1957 [4]. In the 1970's Conway et al. [5], noticed that some materials do exhibit redox reaction near their surfaces, with their electrochemical property very close to that of an EDLC supercapacitor, giving rise to pseudocapacitance. These materials that exhibit near surface redox reaction produces a much bigger charge storage level due to their redox ability. Carbon materials in various forms have been used to fabricate EDLC type of supercapacitor due to their (i) low cost (ii) high surface area (iii) availability and (iv) ease of processing techniques. Niu et al. [6], reported a specific capacitance of 102 F/g and a specific power density of 8 KW/Kg for multi-walled carbon nanotubes. The specific capacitance of 180 F/g, energy density 20 W/kg and power density of 7 KW/kg was reported by An et al. [7] for single-walled carbon nanotubes. Specific surface area (SSA) and pore size distribution in EDLC are some of the parameters that determine its electrochemical performance [8-9]. The excessive activation of the pore size distribution leads to large pore volume, which reduces the conductivity and material density. This leads to loss of power capability and low energy density. Furthermore, the inability to withstand high-temperature application is another drawback that carbon-based electrode materials present [10]. Transition metal oxide-based electrode materials such as Iron oxide, nickel oxide, cobalt oxide and ruthenium oxide [11-15], can be used to solve the drawbacks that carbon-based electrodes for supercapacitor application presents. Ruthenium oxide is one of the most promising transition metal oxide materials for pseudocapacitor application. Wang et al. reported a specific capacitance of 1099 F/g for a supported ultrafine ruthenium oxide [16]. The electrochemical performance of RuO₂ is influenced by crystallinity, amount of combined water, annealing temperature and particle size, with smaller particle size offering shorter diffusion and transport pathways for electrolyte ions. This also improves the charge-discharge capability because of the effective utilization of the

high surface area presented by the RuO_2 material [17-18]. Despite the ruthenium oxide excellent electrochemical performance, its toxicity to the environment and its high cost hinders its wider commercialization as an electrode material for supercapacitors. Therefore, the need to source for transition metal electrode material that is very conductive, non-toxic to the environment and exhibits Faradaic redox reaction (oxidation-reduction) for supercapacitor application is the sole objective of this research. A radio frequency (RF) magnetron sputtered silver nanostructure electrode is proposed, as an alternative active electrode material for supercapacitor processing. A lot of work has been done on silver/graphene composite supercapacitors yielding specific capacitance of 110 F/g at 0.5 A/g [19], 147 F/g at 5mV/s [20] and 243 F/g at 5mV/s [21]. Studies from Devarayan et al. [22] reported a specific capacitance of 237 F/g for a silver nano-dendrites processed supercapacitor. application due to their large surface area and good conductivity. Yuksel et al. [23] reported a specific capacitance of 1165.2 F/g for a silver nanowire nickel hydroxide-based supercapacitor. Good conductivity, low flammability, reasonable surface area and reasonable wettability are some of the characteristics which Devarayan et al, Yuksel et al. and Oje et al. [22-24], attributed to silver thin films making it a good electroactive material for a pseudocapacitor application. Therefore, the main objective of this present work is to prepare Ag thin film electrodes using RF magnetron sputtering and to probe their capacitance behaviour in an ionic liquid for energy storage application.

2. Experimental setup

2.1 Thin film deposition

The silver thin films deposition was carried out with a Consolidated Vacuum Corp (CVC) AST-304 radio frequency magnetron-sputtering unit. A 99.9% pure solid silver target from PI-KEM limited, was used as the base material in conjunction with high purity argon as the sputtering gas. The silver target to substrate distance was 24 cm and the RF sputtering unit chamber volume was $21,505.42 \text{ cm}^3$. The substrate materials were microscope glass slides and 304 medical grade stainless steel of dimensions 25.4mm*76.2 mm and 80mm* 80mm respectively. Each of the microscope glass slides and stainless-steel substrates was used for surface characterization, morphological analysis and electrochemical investigation. Prior to the deposition of silver on the microscope glass slides and 304 stainless steel substrates, all the substrates were cleaned in an ultrasonic bath machine, using isopropanol and deionized water to remove any impurities on the surface. To ensure high-quality silver was produced,

the deposition chamber was first evacuated to a pressure of 8 μ Torr and the deposition process carried out under a vacuum condition, to conserve high ion energies and to avoid too many atoms from gas colliding. Furthermore, the deposition chamber was pre-sputtered before starting each deposition process to avoid any contamination on the deposited silver thin films. To ensure uniformly sputtered silver thin films, the substrates were rotated gradually at a speed of 5 rpm for each deposition power of 250W, 300W and 350W. Finally, during the RF sputtering of the silver thin films, argon flow rate and deposition time of 60sccm and 20 minutes were deployed respectively.

2.2 Microstructural characterization.

Siemens D5000 X-ray diffractometer with DIFFRAC plus BASIC software was used to perform the X-ray diffraction studies on the prepared silver thin films, at applied voltage and current of 40KV and 20mA respectively. A scan speed of 0.5sec/step was used during the analysis, at a diffraction angle of 5 $^{\circ}$ to 155 $^{\circ}$ for 0.02 increment.

Hitachi S-4100 model scanning electron microscope equipped with EDX facility was used to probe the morphology and the elemental constituents of the prepared films. SEM images and EDX were conducted using 20keV accelerating voltage, for sample working distance of 10mm and 20mm respectively.

CAM 200 goniometer was used for static contact angle analysis, while dynamic contact angle measurements were done using Wilhelmy balance tensiometry techniques. A computer controlled KSV sigma 700 tensiometer with standard 5mm/min speed up and down movement was used. An immersion depth of 5mm, a return position of 4mm, with a detection range of 2mN/m and a sample interval of 5 was used for the dynamic contact angle measurements. The balance was calibrated within the standard weight range of 2000g, thereby accounting for local variation in the force of gravity.

Tri-Star adsorption analyser by Micromeritics was used to characterize the BET surface area of the deposited samples at 77K. The samples were evacuated in a vacuum oven at 80 $^{\circ}$ C at 5 mbar for 24 h [25].

2.3 Electrochemical characterization.

The electrochemical characterization of silver thin film electrodes was carried out using electrochemical impedance spectroscopy (EIS), cyclic voltammetry (CV) and chronopotentiometry measurements to investigate ion diffusion, specific capacitance and the

charge-discharge ability of the prepared electrodes. These analyses were performed using a VoltaLab 40 PGZ301 manufactured by Radiometer analytical, with a typical electrochemical cell setup of the reference electrode, electrolyte, a counter electrode and the working electrode. The silver thin film electrodes were exposed to ionic liquid to carry out EIS measurement, at the frequency range 0.1 Hz to 10 KHz, and alternating sine wave amplitude of 10mV. The charge-discharge test was conducted using chronopotentiometry technique for 5000 cycles, for a voltage window of 1V. Furthermore, the specific capacitance analysis was conducted using cyclic voltammetry at voltage range -1000mV to 1000 mV and at a scan rate of 2 mV/s for better ion diffusion.

3. Results and discussion

3.1 XRD and EDX

The silver thin films deposited on microscope glass slides diffraction peaks were identified using the standard international centre for diffraction data card number (ICDD Card number: 004-0783 International Centre for Diffraction Data). The Braggs peaks on the three silver thin films deposited at 250W, 300W and 350W, show that the deposited silver thin films are crystalline. Figure 1 shows the X-ray diffraction spectra of silver thin films deposited at 250W, 300W and 350W, with diffraction peaks centered at a 2θ angles of 38.11° and 44.25° . These characteristic peak angle positions belong to a face-centered cubic (FCC) structure of silver [26-30]. The 2θ angle for the three silver thin films corresponds to (111) and (200) crystal plane, with the highest peak intensity on the (200) crystal plane. This implies that the crystal grain orientation is towards the (200) crystal plane and that as the deposition power increases, the crystallinity of the deposited silver thin films increases as well [26,28] on the (200) crystal plane, in agreement with Faria et al. [31] report. A typical silver FCC structure has a close packing arrangement of the octahedral hole at the (111) and (200) crystal planes. The octahedral holes on these crystal planes of the silver thin films reveal the interstitial site for ion diffusion and penetration. The octahedral interstitial site paves the way for redox reactions to take place resulting in pseudocapacitance.

Figure 1: XRD spectra of silver thin films

The energy dispersive X-ray (EDX) spectra evidenced the presence of metallic silver in all the deposited samples as shown in Figure 2 (a, b and c). The positions of the peaks on the silver thin films deposited at 250W, 300W and 350W were observed at 0.13keV, 0.46keV, 3.0keV and 3.5 keV. These peak positions are consistent with literature reports on silver EDX spectra [32-34], confirming the presence of metallic silver on the deposited samples. The EDX peak intensities (counts) at 0.13keV on the silver thin films increased as the deposition power increases as depicted in Figure 2 (a, b and c). Dimitrijević et al. [26] and Agasti et al. [35], attributed this change in peak intensity to ions been more energetic as sputtering power increases from 250W to 350W. This results in more silver particles dislodged from the RF magnetron target onto the microscope glass slides, increasing the count of metallic silver as deposition power increases from 250W to 350W.

Figure 2: EDX spectra of silver thin films deposited at (a) 250W (b) 300W and (c) 350W

3.2 SEM and BET

SEM micrograph top view of the silver thin films in Figure 3 reveals aggregation of silver crystals as shown on silver thin films prepared at 250W. As deposition power increase, segregation can be seen on the top view micrographs on silver thin films prepared at 300W and 350W [36]. Zavala et al. [37], reported that the change in the surface morphology of the silver as deposition power increases, facilitates the formation of nanocrystalline silver films at 250W, 300W and 350W, which is in agreement with reports in the literature [38-39]. There is an increase in the grain size as the deposition power increases, which Wei et al. [40], attributed to the coalescence effect. The coalescence effect leads to the formation of island films in Figure 3 (a and b), with interconnected clusters beginning to appear. The island formation and segregation of silver atoms lead to void creations, which paves the way for ion diffusion and penetration for electrochemical performance. The prepared silver thin films at the argon flow rate of 60sccm and sputtering power (250W, 300W and 350W) exhibited layer

by layer growth mode from the cross-sectional view in Figure 3. The thickness of the prepared silver thin films increases as the deposition power increases from 250W to 350W. This is due to the increase in the number of ions present during deposition, causing more silver atoms to be dislodged from the target increasing the thickness of the film as the deposition power increases. Marechal et al. [41], attributed this to the intense bombardment of the target by high energy particles during radio frequency magnetron sputtering. This eventually leads to thicker films produced at higher deposition power and an increase in the silver thin film growth rate, further supporting the EDX findings.

Figure 3: SEM images of silver thin films deposited at 60sccm showing top and cross-sectional view (a) 250W (b) 300W and (c) 350W

BET analysis was used to evaluate the surface area of the deposited Ag thin film electrodes and the results presented in Table 1. The BET surface area analysis reveals that an increase in deposition power leads to an increase in the BET surface area of the silver thin films. Zhou et al. [42], reported a BET surface area of 23.81 m²/g for silver nanoparticles prepared by an

arc plasma method. BET surface area of 34.5 m²/g was reported by Wani et al. [43], for silver nanoparticles produced via the solvothermal method. It can be seen from Table 1, that the BET surface area and pore size increased as sputtering power increases, which Dimitrijević et al. [26] and Agasti et al. [35], attributed to ions been more energetic as sputtering power increases from 250W to 350W. This results in more silver particles dislodged from the RF magnetron target onto the microscope glass slides. The pore size values in Table 1 indicate that the sputtered silver thin film electrodes are mesoporous (from 2nm to 50nm) in agreement with Wani et al. [43] findings. There is an increase in pore size with deposition power, with Ag thin film sputtered at 350W having the biggest pore size compared to the other two Ag thin film electrodes prepared for this research. Arjomandi et al. [44], proposed that a bigger surface area and pore size allow faster transport through the electrolyte ions, thereby improving the active electrode performance [45].

Table 1: BET surface area of silver thin films

Deposition Power (W)	BET surface area (m ² /g)	Pore Size (nm)
250	25.21	9.03
300	28.02	10.85
350	34.14	12.31

3.3 Wettability and surface energy measurement.

Contact angle measurements reveal the wetting of the sputtered silver thin film electrodes by the electrolyte, with contact angle values less than 90° an indication of a good wettability (hydrophilicity) [46]. Figure 4a shows the static contact angle measurement for Ag thin film sputtered at a constant argon flow rate of 60sccm, and varying RF power of 250W, 300W and 350W. It can be observed from Figure 4a, that as the deposition power increases, the static contact angle decreases. This is due to the greater force of adhesion between the Ag thin film electrodes and the probing liquids, causing the two polar and one non-polar liquid to spread across the surface of the Ag thin films. Wojcieszak et al. [47] attributed the decrease in contact angle, to the increase in the surface roughness and free electron pair on the surface of the prepared silver thin film electrodes. This observation is supported by the SEM results in Figure 3, where the topographical view of the produced samples show an increase in Ag thin film roughness as deposition power increases. Silver thin film sputtered at 350W,

produced the lowest static contact angle, an indication of its stronger adhesive bond with molecules from the polar and non-polar liquid (deionized water, ethylene glycol and diiodomethane respectively [25,48]. Furthermore, some levels of electrolyte penetration are required for charge transfer process between the electrode/electrolyte and this was confirmed using the dynamic contact angle characterization technique. Figure 4b shows dynamic contact angle values less than 90° (advancing and receding), for all the deposited silver thin film. This shows that the prepared Ag thin films are hydrophilic [25], with Ag prepared at 350W having the smallest dynamic contact angle value. The smaller dynamic contact angle for Ag 350W is due to its bigger surface area and rougher microstructure which are available for electrolyte penetration, spreading, interaction as depicted in SEM micrographs and BET results in Figure 3 and Table 1.

Figure 4: Contact angle graphs of Ag thin films (a) static, (b) dynamic

Moreover, the wetting of the Ag thin films is driven by the polar and non-polar components of the probing liquids, which was demonstrated using surface energy analysis as shown in Figure 5a, Figure 5b and Table 2. The surface energy measurement for the Ag thin films was performed using Fowkes, Wu and acid-base approach as shown in Figure 5a, Figure 5b and Table 2. Furthermore, the polar component γ^p contribution to the total surface energy (γ^{total}), defines the degree of wettability offered by each of the prepared Ag thin films. The

higher the polar component contribution to the total surface energy of the prepared Ag thin films, the more favourable is wetting [49]. Silver thin film electrode produced at 350W show higher polar component contribution compared to the Ag prepared at 250W and 300W. This is an indication of Ag thin film produced at 350W exhibiting better electrode/electrolyte interaction, paving the way for lower contact angle value and better wettability. The level of polar components from the Fowkes, Wu and acid-base analysis in Figure 5a, Figure 5b and Table 2, highlights the superior wettability of Ag thin film sputtered at 350W.

Figure 5: Ag thin films Surface Energy using (a) Fowkes and (b) Wu approach

Table 2: Silver thin films surface energy

Power (W)	Surface Energy (mN/m)								
	Fowkes			Wu			Acid-Base		
	γ^d	γ^p	γ^{total}	γ^d	γ^p	γ^{total}	γ^{lw}	γ^{AB}	γ^{total}
250	39.86	10.38	50.24	41.92	14.04	55.96	42.22	-3.16	39.06
300	42.06	10.88	52.94	43.97	14.89	58.85	46.51	-2.62	43.89
350	41.51	15.24	56.75	43.44	19.15	62.60	47.5	-1.46	46.04

3.4 Electrochemical impedance spectroscopy

Electrochemical impedance spectroscopy technique was deployed to investigate the ion diffusion, charge transfer and capacitance performance at the electrode/electrolyte interface, using Nyquist and Bode plots. It is evident in Figure 6a, that for 0.1 Hz to 10 KHz frequency at 10mV amplitude, the silver thin films deposited at 250W, 300W and 350W displayed its capacitive attributes. The intermediate frequency region line 45° , depicts ion diffusion into the electrodes, which is an ion intercalation process and an expression of the pseudocapacitive property demonstrated by the deposited Ag thin films electrodes [50-53]. It can be observed from the Nyquist plots in Figure 6a, the absence of semicircle at a higher frequency, which Usman et al. [54] and Yuksel et al. [55] linked to the high conductivity of Ag thin films at high frequency. An indication of considerable low equivalent series resistance, with the perpendicular line (Warburg diffusion line 45°) at the low-frequency region, an attribute of Ag thin film electrodes exhibiting pseudocapacitor behaviour [54-57]. The Nyquist plots in Figure 6a further reveal that silver thin films deposited at 350W possesses lower impedance, compared to other two silver thin film electrodes prepared for this research. This also emphasizes, that Ag thin film produced at 350W exhibits preferable electron charge transfer, which boosts capacitance performance. The Bode plots in Figure 6b support the Nyquist plots findings, with silver thin film sputtered at 350W exhibiting lower impedance compared to Ag 250W and Ag 300W. The approximate circuit model of the deposited Ag thin films was evaluated using Z-view software and inserted in Figure 6a [58-61]. Silver thin films deposited at 250W, 300W and 350W yielded resistance values of 17Ω , 12Ω and 8Ω respectively. The reduced resistance offered by silver thin film processed at 350W indicates better ionic electrolyte transport via the electrolyte/electrode interface. Pawar et al. [62], reported that the lower impedance of silver thin film sputtered at 350W (8Ω) is an indication of its high conductivity and the ability to offer more sites for ion diffusion for better electrochemical supercapacitor performance [63], which agrees with earlier SEM, BET and contact angle results.

Figure 6: EIS spectra of silver thin films (a) Nyquist plots with equivalent circuit insert and (b) Bode plots

3.5 Charge-discharge

The charge-discharge curves in Figure 7 depict fast pseudocapacitive redox reactions that occur on the sputtered silver electrodes. It can be observed from Figure 7, that oxidation (charging) and reduction (dis-charging) curves are symmetrical at current density of 10mA/g. An indication that the capacitance behaviour is due to Faradaic reaction [64], which is in agreement with Seok et al. [65] finding. Silver thin film sputtered at 250W showed lower voltage window utilization followed by Ag 300W thin film. Bai et al. [66], associated this behaviour to limited ion absorption/desorption taking place at the electrode/electrolyte interface, limiting the charge transfer process of the silver thin films deposited at 250W and 300W respectively. The more surface area offered by Ag 350W presents more sites for electrolyte/electrode interaction, further improving its charge storage ability. Furthermore, an important factor that determines the performance of a supercapacitor is its cycling stability as shown in Figure 7. Excellent cycling stability was observed for the three silver thin film electrodes during the 5000 cycles test, with very a little drop in voltage between the first 10 cycles and the final 10 cycles of the entire 5000 cycles. An indication of approximately 99% capacitance maintained for 5000 cycles, which is promising as an active electrode material for supercapacitor application [65]. Similarly, silver thin films charge-discharge responses at

different current densities 10mA/g, 5mA/g, 2mA/g were carried out and the results depicted in Figure 8. The charge-discharge curves are symmetrical at the various current densities, an indication of rapid current-voltage responses, with good capacitive behaviour and great electrochemical reversibility. Furthermore, as the current densities decreased, a potential plateau starts to appear due to Faradaic reaction.

Figure 7: Ag thin films first and final 10 cycles charge-discharge for 5000 cycles at (a) 250W (b) 300W (c) 350W respectively

Figure 8: Charge-discharge at different current density at (a) 250W (b) 300W (c) 350W

3.6 Cyclic Voltammetry

Figure 9 shows the cyclic voltammetry of silver thin films in 1-Ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide ionic solution with two redox peaks. The anodic and cathodic peaks are due to the oxidation and reduction of silver thin films by the $[\text{N}(\text{Tf})_2]^-$ anion and $[\text{EMIM}]^+$ cation of the ionic liquid (1-Ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide [67-68]. It can be seen from Figure 9 that there are redox peaks at -0.2V and 0.2V versus standard electrode potential. These redox peaks at this potential is an indication of the charge transfer process taking place at the anodic and cathodic side of the silver thin film electrodes. The silver thin film deposited at 350W yields higher peak current compared to silver thin film electrodes sputtered at 250W and 350W

respectively. Literature report on Electrodeposition of nanocrystalline silver films, from 1-ethyl-3-methylimidazolium trifluoromethylsulfonate by Abedin et al. [69], attributed this increase in peak current to the oxidation of the [EMIM]⁺ cation, a reduction reaction product. This implies that the capacitance associated with silver thin films electrodes are pseudocapacitive in nature. The higher peak current from Ag 350W can also be linked to the polarization resistance of the Ag 350W been less resistant to electron charge transfer, thereby improving its pseudocapacitance performance. The silver thin film deposited at 350W seems to have higher peak current density compared to silver thin films sputtered at 250W and 300W respectively. An indication that silver thin film deposited at 350W exhibit better wettability, offers more surface area for electrolyte/electrode interaction, which improves its capacitance performance. Doronin et al. [70], reported similar findings on cyclic voltammetry of silver on gold, where thicker silver thin films offered a bigger surface area for increased redox peak current. The specific capacitance of Ag thin films can be determined using equation 1 [71],

$$C_s = \frac{1}{mv(V_c - V_a)} \int_{V_a}^{V_c} I(V) dV \quad (1)$$

Where v is the potential scan rate (mV/s), $(V_a - V_c)$ is the potential range, I stands for the responses and m the weight of the electrode. Using equation 2, the specific capacitance of silver prepared at 250W, 300W, 350W at 2mV/s are 410 F/g, 419 F/g, and 431 F/g respectively. The non-linearity between the surface area and specific capacitance, Chae et al. and Roberts et al. [72-73], attributed to the pore size and ion size (cation and anion) playing a vital role in the Faradaic redox reaction. Therefore, specific capacitance is not only connected to the silver thin films surface area, but to pore sizes and ion size. It can be seen from Table 1, that the sputtered silver thin film electrodes are mesoporous, with the pore size values close to each other. However, Ag 350W offers more surface area/pore size for electrode/electrolyte interaction and lesser resistance to electron charge transfer process, thereby improving its electrochemical performance.

Figure 9: Cyclic voltammetry of silver thin films at 2mV/s (250W, 300W and 350W)

4 Conclusion

In this research, nanostructured silver thin film electrodes were prepared successfully using radio frequency magnetron sputtering. The XRD and EDX reveal that the prepared thin film materials were crystalline, with metallic silver been the predominant element. The morphology of the produced silver thin films reveal microstructural arrangement that enhances electrode/electrolyte interaction as deposition power increases, which is very important for electrode wetting, electrolyte spreading and penetration.

The specific capacitance of 431 F/g offered by Ag 350W in (1-Ethyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide can be linked to its bigger surface area, better wettability and reduced charge transfer resistance for an oxidation-reduction reaction. This result is an indication that silver thin film sputtered at 350W can be used as an active electrode to process a supercapacitor. Furthermore, applications that require fast energy recovery time namely memory protection circuits, flashlight circuits, requires a supercapacitor to perform this operation. Silver thin film could be used to process active electrode for such energy storage applications.

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ACCEPTED MANUSCRIPT

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HIGHLIGHTS

- Film roughness depends on sputtering power
- Deposition power influences BET surface area
- Wettability depends on the polar component of the total surface energy
- Ag CV is due to redox reaction by $[\text{N}(\text{Tf})_2]^-$ anion and $[\text{EMIM}]^+$ cation