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Development And Performance Analysis Of High Energy Density Thin Film Capacitors With Ag/Pva Nanocomposites As Dielectric Medium

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Abstract:

In recent years, the need for light weight, compact, high energy density capacitor increases rapidly for applications in various household as well as industrial appliances. The previously used monolithic materials are reaching a plateau in terms of energy storage capabilities due to the trade-off between dielectric constant, dielectric loss and voltage breakdown. The metal polymer nanocomposites have the potential to overcome these limitations through a synergistic coupling of high dielectric constant nanoparticles in high dielectric breakdown polymer matrices based on their characteristics like Coulomb Blockade Effect, Interfacial Polarization Effect etc. Here, we present the synthesis and characterization of Ag/PVA nanocomposites and investigate the dielectric properties of these materials in thin film capacitors in terms of energy density, dielectric constant and dielectric loss.

***Keywords**: Nanocomposites, Dielectric, Thin Film Capacitor*

Introduction

In recent years, the metal-polymer nanocomposites have attracted the close scrutiny and considerable interest in both the academia and industry. Ag/PVA nanocomposites are novel invention of nanocomposite materials which indicate a promising field in the frontiers of nanotechnology. These are promising nanocomposite materials for chemical and biological sensing applications [1] as well as high K materials [2]. Ag nanoparticles possess many interesting and unique properties. It is found in various applications, such as catalysis, electronics, non-linear optics, antimicrobial and biomaterial applications [3]. Several methods have been reported for the synthesis of Ag nanoparticles, e.g., photochemical reduction [4, 5], microwave [6], chemical reduction [7, 8], and γ- irradiation [9]. The concept of green Ag nanoparticles preparation was first developed by Raveendran et al. [10], who used β-D-glucose as the reducing agent and starch as a capping agent to prepare Ag nanoparticles. A green method for nanoparticles preparation should be evaluated from three aspects: the solvent, the reducing agent and the stabilizing agent. The use of polyvinyl alcohol (PVA) as the host polymer for Ag nanoparticles is advantageous due to the reducing ability of the secondary alcohol groups, its excellent film forming properties and optical transparency [11-13].

In the present work, the fabrication of homogeneous Ag/PVA nanocomposite thin films with optimized fabricating parameters (40 mmol/L $AgNO_3$, 4% PVA, 130 ^{0}C annealing temperature and 20 minutes annealing time) by thermal annealing process, their characterizations and dielectric characteristics are reported. The performance analysis of the thin film capacitors with Ag/PVA nanocomposite, bulk Ag/PVA composite and only the PVA matrix as dielectric layer is reported in this investigation. The effect of degree of coating on the capacitive properties of the capacitor is an important ingredient in this paper.

Experimental

Synthesis Of Ag/PVA Nanocomposite

In the present work, Ag/PVA nanocomposite with optimized fabricating parameters (40 mmol/L $AgNO_3$, 4% PVA, 130 ^{0}C annealing temperature and 20 minutes annealing time) are fabricated by thermal annealing process. This synthesis process of Ag/PVA nanocomposite is the modified form of the process used by S. Porel. et al.[14]. In their work thermal treatment is used after casting the reaction mixture on the substrate i.e. on the thin films. But in our work, heat treatment is used in the solution stage of the reaction mixture. The main advantage of the nanocomposites in solution form is its flexible applications. This type of nanocomposites can be used as coating on any symmetrical objects and surfaces where direct heat treatment is not possible. The detail fabrication chemistry and the process of optimization for generating homogeneous nanoparticles are reported in our earlier work [15].

Preparation Of Ag/PVA Nanocomposite Thin Film Capacitor

To prepare the capacitor, a piece of glass (cut into 20x15x1.5mm^3 size) is used as substrate. The glass substrate is cleaned chemically followed by ultrasonication at100 C^0 for an hour. The substrate is then kept overnight at 100C^0 to eliminate the contaminants. The bottom aluminum electrode of thickness 500Å and width 5mm is deposited on the substrate at very high vacuum (10^{-6} Torr) by thermal evaporation process. A uniform thin film of the fabricated Ag/PVA nanocomposite is formed over the bottom Al electrode by dip coating method. The top electrode is deposited over the composite thin film by the same thermal evaporation process at the same condition [2].

Characterizations

The generation of Ag/PVA nanocomposite and the size and shape of Ag nanoparticles in PVA matrix are confirmed by characterizing the prepared films by Perkin- Elmer spectrophotometer, Scanning Electron Microscopy (SEM) and Atomic Force Microscope (AFM) (Molecular Imaging PICOSCAN TM 2500 USA). The capacitance and the dissipation factor of the fabricated capacitors in this investigation with parallel plate prototype are measured by LCR 21, multi-Frequency LCR Meter. The measurement is conducted at room temperature and at frequency of 10 kHz. Selection of low frequency (10 kHz) is due to the fact that Coulomb Blockade Effect and Interfacial Polarization Effect of metal polymer nanocomposites are observed at low frequency range. Additionally, the contribution of interfacial loss is more evident in the high frequency range [16]. Thicknesses of the electrodes are measured by Tolansky method (multiple beam interference method) [17].

Results and discussions

UV-VIS Absorption, SEM And AFM Characterization

The UV-VIS spectrum for the fabricated film is shown in fig.1. The recorded spectra show an intense single peak at 413.6 nm. The singular peak reveals spherical shape of the Ag nanoparticles [18]. This spherical nature of the particles is further confirmed by AFM characterization.

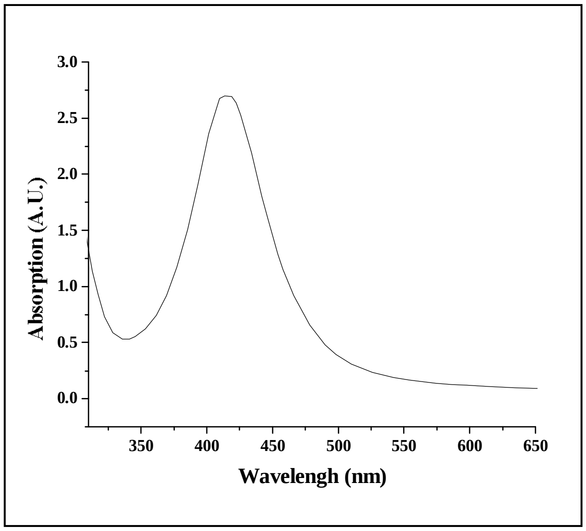

Figure 1: UV-VIS spectra

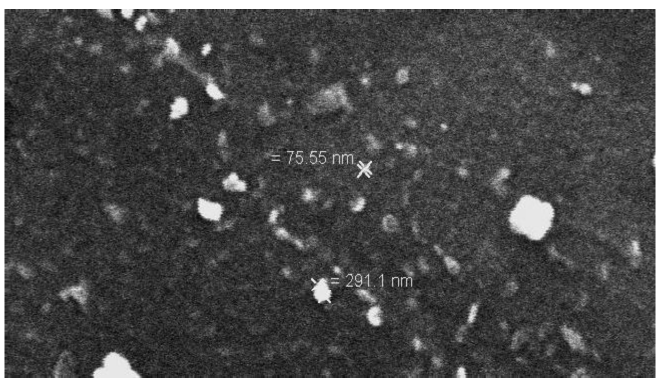

Figure 2: SEM photograph

The surface morphology and the finer details of the particles of the fabricated Ag/PVA nanocomposite thin film are investigated through SEM [fig. 2] and AFM characterization [fig. 3(a) and 3(b)].

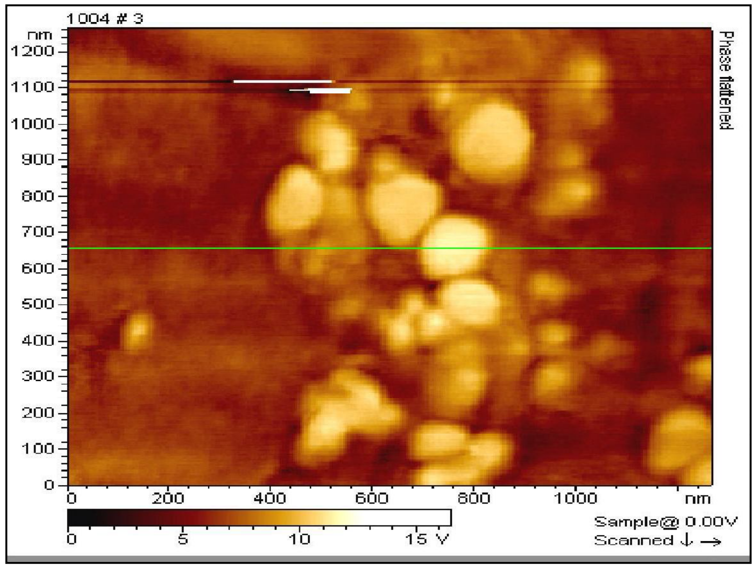

Figure 3a: AFM photograph (surface morphology)

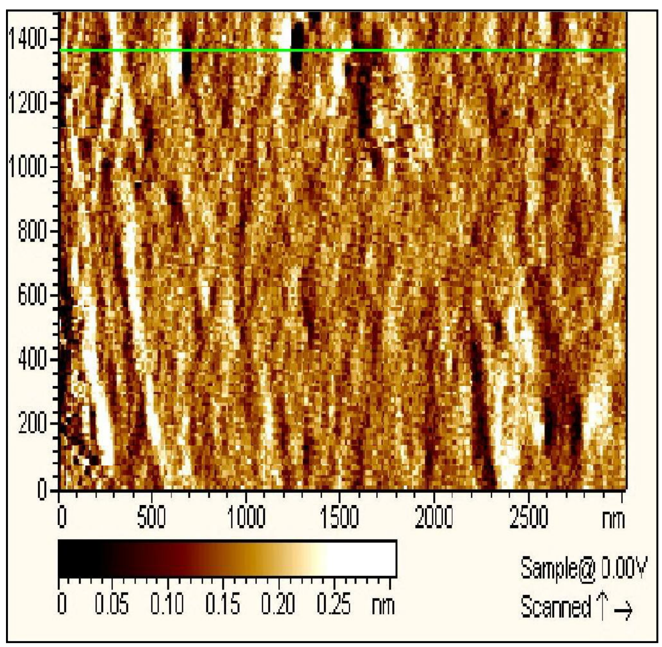

Figure 3b: AFM photograph (particle shape)

Capacitive Properties

The measured capacitance, capacitance density and dissipation factors are given in table1.The fabricated thin film capacitor with Ag/PVA nanocomposite as dielectric layer exhibits high capacitance, high capacitance density and low dielectric loss. The high capacitance density of the nanocomposites is due to the piling of charges at the extended interface of the interfacial polarization-based composites. The reduced dielectric loss might be due to the Coulomb Blockade Effect of the containing Ag nanoparticles, a well-known quantum effect of metal nanoparticles [16]. The capacitor with bulk Ag/PVA composite and only the PVA matrix as dielectric layers shows comparatively low capacitance density and very high dielectric loss (table1) in comparison to the Ag/PVA nanocomposite as dielectric layer, which reveals the non occurrence of Coulomb Blockade Effect and Interfacial Polarization Effect for those materials. The table 2 summarizes the coating effect on the capacitive properties of the capacitors.

The investigation on the fabricated capacitors with 1 to 5 numbers of coatings reveals that the single coating results comparatively good capacitive character in comparison to the multiple coatings.

Dielectric material	**Capacitance (nF)**	**Capacitance density (nF/cm^2)**	**Dissipation factor**
Ag/PVA nanocomposite	290.90	1163	0.1261
Ag/PVA bulk composite	219.73	878.92	2.9690
PVA	55.37	221.48	2.505

Table1: Capacitive properties for the thin film capacitor

Sample No.	**Capacitance(nF)**	**Dissipation Factor (D)**	**Capacitance density (nF/cm^2)**
1(1st Coating)	290.90	0.1261	1163
2(2nd Coating)	266.00	0.3736	1064
3(3rd Coating)	262.33	0.4342	1049.32
4(4th Coating)	232.65	0.6123	930.6
5(5th Coating)	185.11	0.6490	740.44

Table 2: Effect of coating on the capacitive properties of the capacitor

Conclusion

In the current investigation it is found that the composite material thin films exhibit high capacitance as well as capacitance density and low dielectric loss and hence it may be the suitable ingredient for fabricating high capacitance capacitor. The Coulomb Blockade Effect and Interfacial Polarization of Ag nanoparticles in PVA matrix make the composite material suitable as dielectric medium in embedded capacitor. It is practically not feasible on our part to demonstrate Coulomb Blockade Effect experimentally due to the lack of the art of the experiment and instrument.

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