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Tuning low frequency dielectric properties of flexible ternary polymer blend film reinforced with bio- ionic liquid for the application in green electronics

ABSTRACT

Biofriendly conducting polymeric blends and composites exhibiting high dielectric constant and dielectric loss are promising for applications as sensors, actuators, microwave absorbing materials, fuel cells and biomedical applications. A great deal of work is reported on using fillers such as conductive nanomaterials, bio ceramics, carbon nanotubes, graphene etc in blends of Polyvinylchloride, Polyvinylpyrrolidone, Polymethylmethacrylate, Polyvinyl alcohol with conducting polymer Polypyrrole, Polyaniline for enhancing their conductivities, tailoring dielectric and electrical, thermal and surface properties of such polymeric materials. However, appropriate dispersion of such fillers in polymeric matrices remains technically challenging. In this regard, bio-ionic liquids have emerged as a novel class of materials and their combination with specific polymer blends opens the possibility to develop smart novel materials with different morphologies. Present work aims to explore the low frequency dielectric properties exhibited by free standing, flexible, biofriendly/biodegradable ternary polymer blend film of Polyvinylchloride-Polyvinylpyrrolidone-Polypyrrole reinforced with choline acetate. The detailed analysis of low frequency dielectric properties authenticates that addition of choline acetate result in modifying the dielectric properties of ternary polymer blend film.. The harmlessness of these films was confirmed from disk diffusion test indicating their benign nature towards (Escherichia coli) (CFT073) and (Bacillus subtilis). Therefore, the developed films can potentially be used for various scale multifunctional dielectric and electrical applications working in close contact with living matter, green electronics and various health monitoring systems.

Keywords: *Bio ionic liquid, choline acetate, polyvinylchloride, polyvinylpyrrolidone, polypyrrol*

1. INTRODUCTION

The emergence of the green soft organic electronics has directed to the search of methods that combine the electrical properties of the materials with flexibility, bio-friendliness and bio-degradability [1-5]. Such soft biocompatible polymeric materials (blends and composites) have many advantageous properties and find a great deal of application in food packaging, textile, tissue engineering applications, sensors, actuators, electromagnetic shielding, biomedical implants and other biomedical and electronic applications [5-9].

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The "soft" nature of polymeric materials enables better mechanical compatibility with human body than other traditional electronic materials and opens up options to design them to be used as mechanically flexible substrates often required for thin film electronics and medical implants. However, the hindrance is that polymeric materials usually have very low conductivity compared with inorganic counterparts. In this regard, the use of conducting polymers in areas of electronics and biomedical sciences is also of immense interest. In addition, biofriendly polymeric materials (blends and composites) exhibiting high dielectric constant and dielectric loss are promising for applications as sensors, actuators, microwave absorbing materials and many more [10]. Researchers working in the field of polymers have blended a variety of bio-compatible polymers such as *Polyvinylchloride (PVC), Polyvinylpyrrolidone (PVP), Polymethylmethacrylate (PMMA), Polyvinyl* *alcohol (PVA)* [11-15] and doped such blends with conducting polymer (ppy, pani) for enhancing conductivities, tailoring their dielectric, electrical, optical, thermal and surface properties, [6,16,17]. In addition fillers such as conductive nanomaterials, bioceramics, carbon nanotubes, graphene etc are incorporated in such blends of insulating and conducting polymers for enhancing their dielectric properties, but appropriate dispersion of such fillers in polymeric matrices remains technically challenging [15,18-20]. Therefore, there is an unmet need for the development of biofriendly, biodegradable polymer materials with highly tunable dielectric, electrical and physical properties. In this regard employment of bio ionic liquids in the fabrication of polymer composites is a favourable approach as they exhibit enhanced biocompatibility and low toxicity profiles [21,22]. Reinforcing bio- ionic liquid in polymeric matrix serves as promising alternative in the field of electronics due to their high thermal stability, ionic conductivity and solubility and miscibility with many compounds such as organic, inorganic, and polymeric materials and can provide an advantage because of their responsive chemical structure, which has both large cations and anions that are weakly coordinated. These ions can interact with organic or inorganic fillers and biocompatible polymers. The existence of intermolecular interactions can have synergistic effect on polymer, and consequently improve the interfacial link between the filler and the polymer matrix [10].The combination of bio-ionic liquids with specific polymer blends opens the possibility to develop novel materials with different morphologies such as films, gels, membranes, fibers, with tailored functionality [23].

Having known this, not much of work is reported on preparing and studying bio-ionic liquid reinforced polymer blend film. Present work aims to bridge this gap and explore the properties exhibited by free standing, flexible, bio-friendly/bio-degradable bio-ionic liquid reinforced ternary polymer blend film. In our previous work we have reported optical and electrical properties of ternary polymer blend film of PVC- PVP (taken in ratio 1:1) doped with different weight percentage concentration(10%, 30%, and 50%) of conducting polymer Polypyrrole (PPy). The results indicate that PPy doped PVC-PVP blend films with tuneable optical, electrical and dielectric properties can be potential material for use in photonic biosensors, solar cell and optoelectronics field [24]. Present work aims at understanding and investigating the effect of reinforcing choline acetate (two different concentrations 0.5 gm and 1.5 gm) in PVC-PVP-50%PPy on low frequency dielectric properties of base matrix and how the dielectric properties can be tuned by such reinforcement. Despite all the constituents of the prepared polymer films are individually established as harmless materials but when combined the whole film has to be tested for biological effects as well. Therefore to confirm the biofriendliness and harmlessness of the prepared bio-ionic liquid reinforced ternary polymer blend film, we exclusively carried out the disk diffusion test [2,21,25].

Over all analysis of the studies carried out shows that the presence of bio-ionic liquid choline acetate resulted in enhancement of dielectric constant and ac conductivity in low frequency region. The disk diffusion test shows that the polymer blend film of PVC-PVP-50%PPy exhibited almost negligible development of inhibition ring where as the blend film of PVC-PVP-50%PPy reinforced with choline acetate showed no ring of inhibition indicating their benign nature towards Gram-negative bacteria (*Escherichia coli*) (CFT073) and gram positive bacteria (*Bacillus subtilis*). Therefore the developed flexible biofriendly ternary polymer blend film of PVC-PVP-50%PPy reinforced with appropriate amount of bio-ionic liquid choline acetate with high dielectric constant, low loss factor and high ac conductivity can potentially be used for various scale multifunctional dielectric and electrical applications working in close contact with living matter, green electronics and various health monitoring systems in biomedical field.

2. MATERIALS AND METHODS

2.1. Materials

Conducting polymer, polypyrrole (PPy) has numerous applications in a variety of different fields [26-28]. Polyvinylpyrrolidone (PVP), a water-soluble polar polymer, is known to have a growing pharmaceutical and biomedical importance [29]. However, films made of PVP alone are not practically so useful as they become quite brittle on aging resulting into their poor processability. To make PVP films amenable, here it is proposed to blend it with Polyvinyl Chloride (PVC) which has good resistance to weathering, offers good biocompatibility and possess excellent mechanical strength [17,30,31]. In present work, PVP supplied by Loba Chemie having an average molecular weight of 40,000 gm/mol was blended with PVC.

Polyvinyl Chloride (PVC) with average molecular weight 62,000 gm/mol) supplied by Sigma Aldrich was used as an insulating matrix. Pyrrole monomer supplied by Spectrochem, India, was used as received. Tetrahydrofuran purchased from HPLC was used as solvent and anhydrous ferric chloride purchased from Otto Chemicals, was used as oxidant for polymerization of pyrrole monomer. Choline-based ionic liquids have gained much interest due to their enhanced biocompatibility [32,33]. Choline bio-ionic liquids have shown a potential in applications where low environmental and biological impact is critical [21]. It is also important to note when considering the biodegradability of materials, that choline based ionic liquids can be decomposed by microorganisms [2]. In present work, choline acetate with molecular formula $C_7H_{17}NO_3$ and molecular weight of 163.21 procured from Sigma Aldrich was used.

2.2. Methods

Free standing films of ternary blend film was prepared by solution cast technique. The solution containing PVC-PVP in ratio 1:1 with 50% weight concentration of pyrrole monomer and 0.5 gm of choline acetate was carefully poured in petri dish and allowed to dry for 48 hours in dark place under normal temperature and pressure, so that the solvent evaporates slowly. The films were then gently pulled from the petri dish. The oxidative polymerization of the Py monomer in matrix was carried out by technique called mixing oxidative polymerization [34,35]. Similarly, PVC-PVP-50% PPy film with 1.5gm of choline acetate was prepared. The films were kept in a desiccator until use.

2.3. Characterization

Polymer morphology is a microscale property that is largely dictated by the amorphous or crystalline portions of the polymer chains and their influence on each other. The morphology of PVC-PVP-50%PPy films reinforced with different weight percentage concentrations of choline acetate were examined using Scanning Electron Microscope (SEM) (ZEISS) (Model: Merlin VP Compact) supplied by Carl Zeiss. Low frequency dielectric data were obtained using Agilent precision LCR meter E4980A with solid test fixture (Model No: 16451B) having electrodes of 0.5cm in diameter 0.5cm. The parallel capacitance and parallel resistance were measured in the frequency range of 20Hz to 2MHz at room temperature. The dielectric constant (ε′) and dielectric loss (ε″) and ac conductivity were evaluated. In order to assess the harmlessness of ternary polymer blend films of PVC-PVP-50% PPy with and without choline acetate, the disk diffusion method [2,21] was carried out. The assessment was done towards an uropathogenic strain of Gram-negative bacteria (*Escherichia coli*) (CFT073) and gram-positive bacteria (*Bacillus subtilis*). For this Lysogeny broth agar served as the substrate for bacterial growth and the bacterial suspension was smeared on its surface. The films were cut into 5x5mm size and were placed on the surface of the inoculated agar with sterilized forceps. The plates were incubated at 37^0C. The plates were observed after 48 hrs and 72 hrs and each time they were photographed to assess the development of inhibition rings.

3. RESULTS AND DISCUSSION

3.1. Morphological analysis

The information on microstructural evolution of PPy in PVC-PVP film and morphology of PVC-PVP-50%PPy blend films was obtained from SEM measurements. The micrograph for ternary polymer blend film of PVC-PVP-50%PPy is shown in Figure 1.

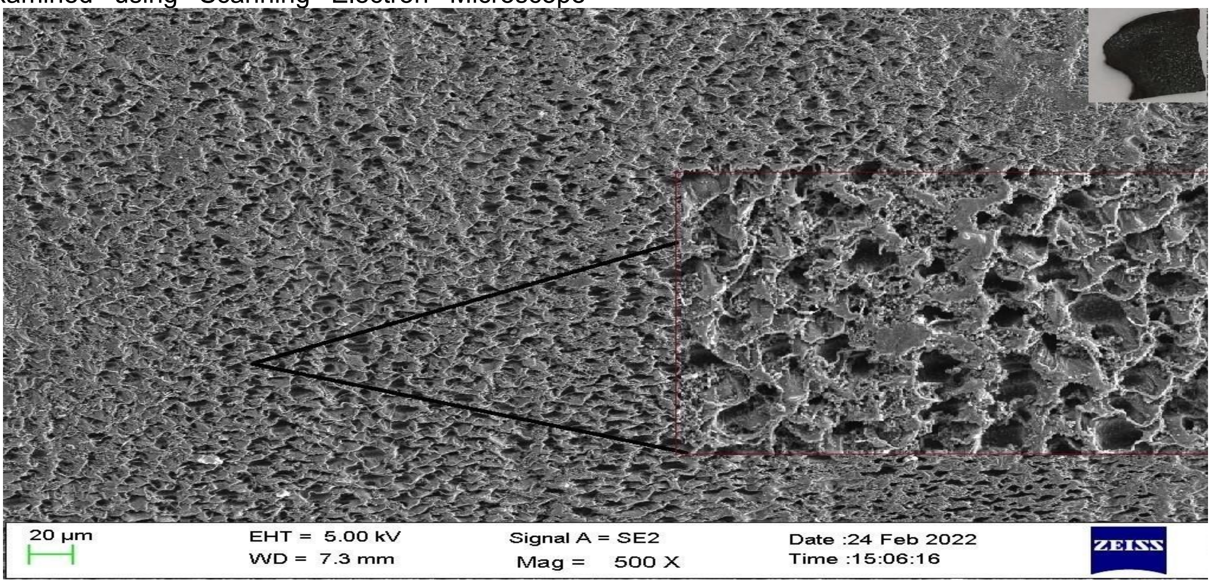


Figure 1. SEM image of PVC-PVP-PPy ternary blend film with 50% weight concentration of PPy (inset shows magnified view). (a)Photographic image of film

Slika 1. SEM slika PVC-PVP-PPi ternarnog mešanog filma sa koncentracijom od 50% težine PPi (umetak prikazuje uvećan prikaz). (a) Fotografska slika filma

The micrograph (Fig. 1) displayed macro granular structure formed by aggregation of small globular structures which are typical cauliflower type confirming the presence of PPy in ternary blend film of PVC-PVP-50%PPy. The SEM image of PVC-PVP-50%PPy ternary blend film shows dense porous network structure. The presence of this porous network indicated that if these ternary polymer blend films are reinforced with some filler, then it could result in enhancing a conducting network thereby modifying its dielectric and electrical properties.

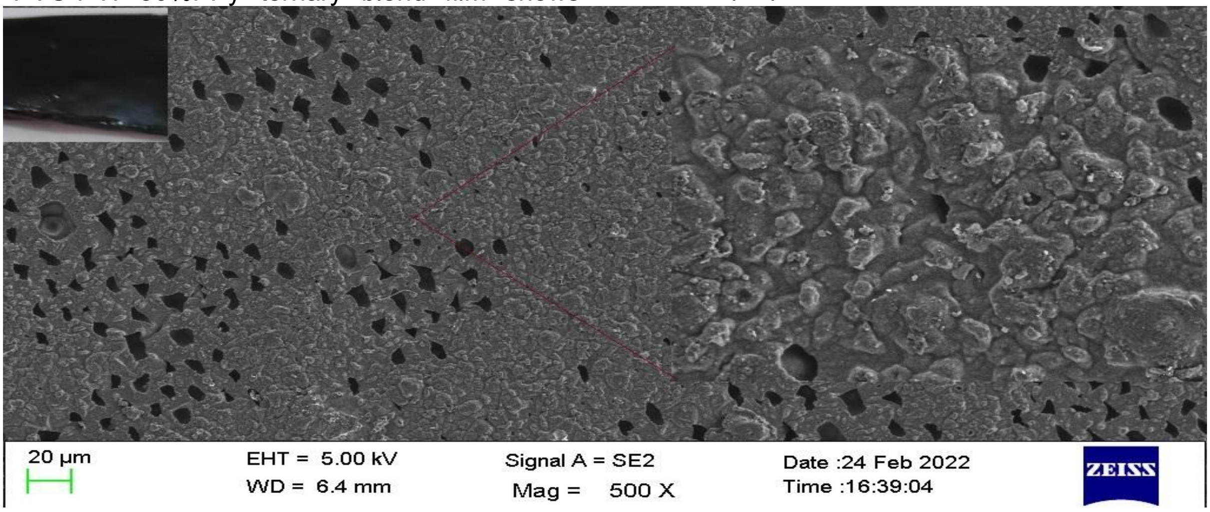


Figure 2. SEM image of Choline acetate (0.5gm) reinforced PVC-PVP-50%PPy Film (inset shows the magnified view) (b)Photographic image of film

Slika 2. SEM slika holin acetatom (0,5 g) ojačanog PVC-PVP-50%PPi filma (umetak prikazuje uvećani prikaz) (b) Fotografska slika filma

By reinforcing the ternary polymer blend with lower concentration (0.5gm) of choline acetate, the microstructure of pristine ternary polymer blend films shows a significant change. The SEM image shows (Fig. 2) clear formation of micropores of different sizes.. which serve as high energy sites and as a consequence, the enhancement in interconnecting network is formed leading to an increase in conductivity. The micrograph also shows expanded regions of globular morphology. The photographic image of this film exhibited smooth surface (Fig.2 (b)) as compared to that of pristine ternary polymer blend film [36].

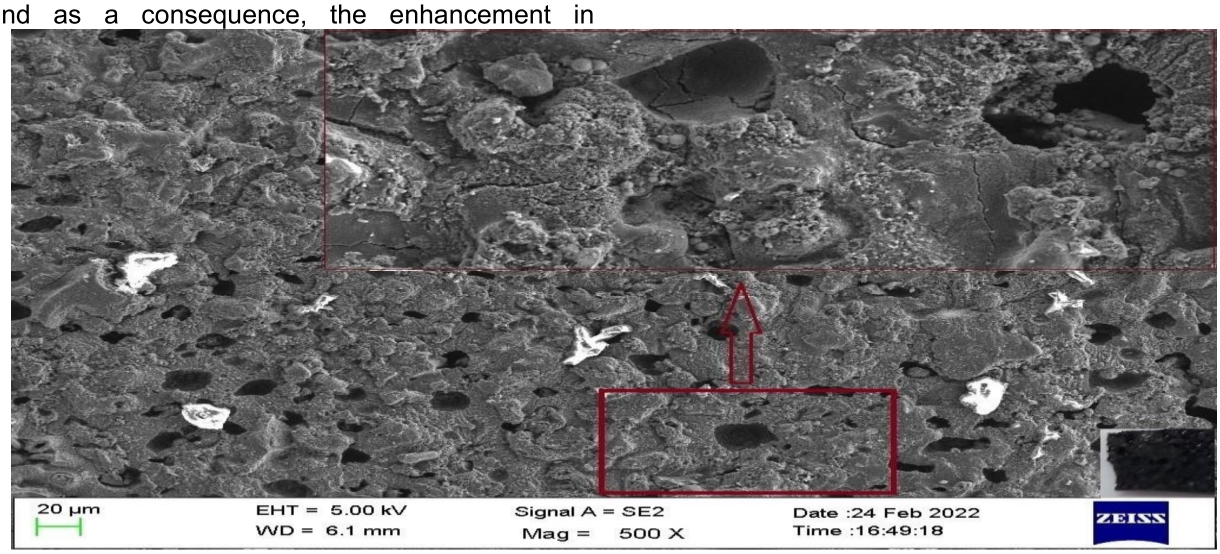


Figure 3. SEM image of Choline acetate (1.5gm) reinforced PVC-PVP-50%PPy Film (inset shows the magnified view) (c)Photographic image of film

Slika 3. SEM slika holin acetatom (1,5 g) ojačanog PVC-PVP-50%PPi filma (umetak prikazuje uvećani prikaz) (c) Fotografska slika filma

However, in the case of reinforcing higher concentration (1.5 gm) of choline acetate in ternary polymer blend, the morphology of the hybrid sample totally changed. The photographic image (Fig. 3 (c)) and the SEM micrograph exhibited rough surface.

Moreover, the surface cracks (encircled in SEM image) and bumps were also observed in the SEM image of ternary polymer blend film with higher concentration of choline acetate. The microgranular aggregations can be seen to be formed but they were not uniformly distributed [37]. It was noteworthy that ternary polymer blend film with lower concentration (0.5 gm) of choline acetate was more efficiently inserted in the film than higher concentration (1.5 gm) and resulted in to a film formation with smooth surface, dominant presence of amorphous content and enhanced flexibility of the films, which may play an important role in the electrical conductivity exhibited by this film [38].

3.2. Dielectric analysis

In order to acquire information on the characteristics of ionic and molecular interaction in polymeric materials, dielectric analysis can be used. In present work, the dielectric properties of PVC-PVP-50%PPy ternary polymer blend film is investigated in low frequency (100 Hz to 2 MHz) region. In addition the effect of reinforcing PVC-PVP-50%PPy ternary polymer blend film with two various concentrations of bio-ionic liquid choline acetate on its dielectric properties is also investigated.

Complex Permittivity Spectra

Frequency dependent variation in dielectric constant (ε′), for ternary polymer blend film of PVC-PVP-50%PPy with different concentration (0.5 gm and 1.5 gm) of Choline acetate is shown in Fig. 4. The large change in ε′ of choline acetate reinforced ternary polymer blend films as opposed to pristine ternary polymer blend film is ascribed to the presence of additional ions as charge carriers and thus the polarizability of the films with choline acetate reinforced shoot up [39]. The diminution in ε′ values in the high frequency region is attributed to the fact that if the rotational motion of the dipoles is not sufficiently faster so as to attain equilibrium with rapidly changing fields, then relaxation of dipoles occur resulting in decrease in ε′ values. As observed the ε' values for choline acetate reinforced PVC-PVP-50%PPy ternary blend film were quite high in the low frequency region which is owing to the dominant contribution of electrode polarization effect over bulk material properties. This effect is observed due to accumulation of ions near electrode surfaces and contributes to the formation of electric double layers when the duration of reversal of applied alternating electric field is slow [40].The appreciable increase in ε' values of these biofriendly choline acetate reinforced ternary polymer blend film suggests that they possible can be used as controllable dielectric material in the design and fabrication of simple functional circuits used in several biodegradable electronic devices in biomedical field as demonstrated in the literature [15]. Therefore, the studied biofriendly films can be dielectrically tuned as per required range for various electrical applications by varying the frequency of exciting field [14].

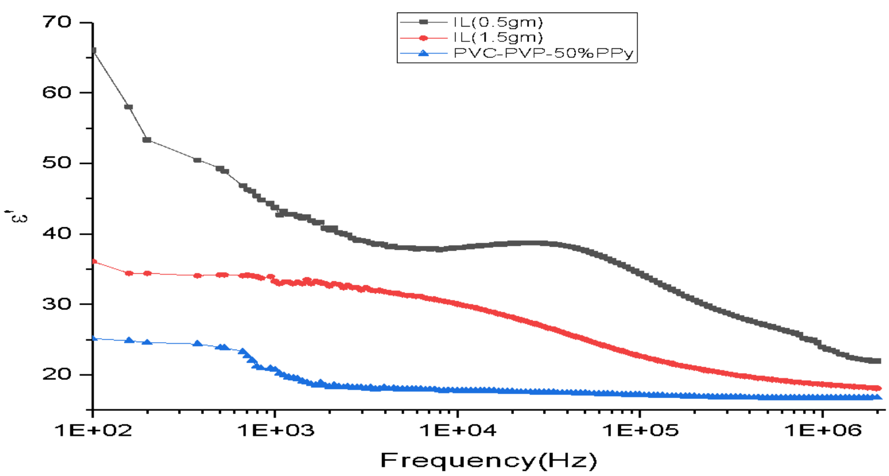


Figure 4. Variation in ε' with frequency for ternary blend films

Slika 4. Varijacija u ε' sa frekvencijom za filmove sa ternarnom mešavinom

Loss tangent

Dissipation factor or loss tangent (tan δ) is the measure of applied energy converted into heat and gets dissipated from the material. Frequency dependent variation of loss tangent (tanδ) for all the films is shown in Figure 5. It can be easily observed that the loss factor of ternary polymer blend film has increased after reinforcing choline acetate in the films. The loss tangent spectra of choline acetate reinforced ternary polymer blend films exhibited well defined relaxation peaks which are attributed to the higher flexibility of polymer chains.

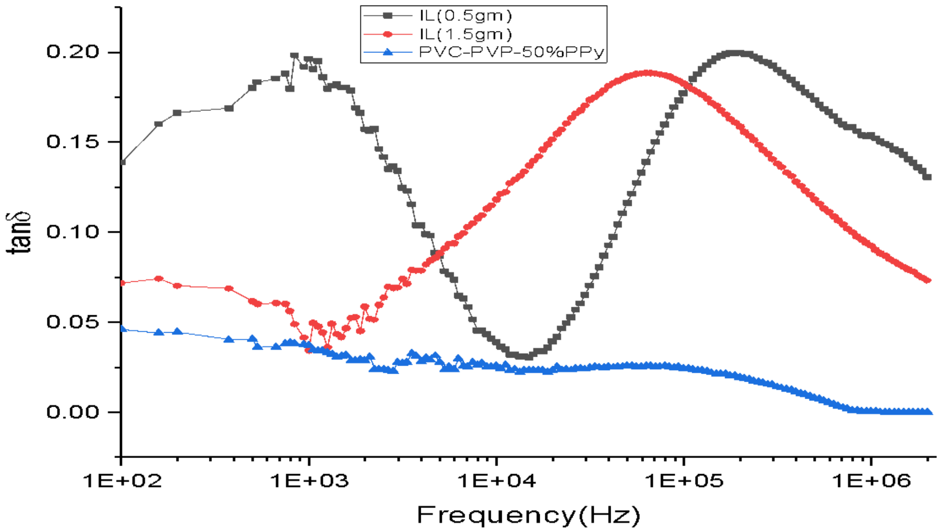


Figure 5. Variation in tand with frequency for Choline Acetate reinforced PVC-PVP-50%PPy film

Slika 5. Varijacija u tand sa frekvencijom za PVC-PVP-50%PPi film ojačan holin acetatom

The loss tangent spectra of choline acetate reinforced ternary polymer blend film exhibited peaks which is the consequence of dielectric relaxation process associated with the presence of heterogeneities in the samples [36]. Appearance of relaxation peak in higher frequency region observed for low concentration of choline acetate reinforced film can be attributed to the fast segmental motion coupled with mobile ions. Relaxation peak appearing in the intermediate frequency region for high concentration of choline acetate reinforced film is the consequence of dipolar and interfacial polarization effects [36]. Thus, the addition of an appropriate amount of bio-ionic liquid, choline acetate may slacken the segmental packing in the chains, thereby increasing free volume for dipolar relaxation to occur. Here, the tan δ values for all the ternary polymer blend films were reported to be less than 0.2, which is desirable for a material to avoid energy loss due to power dissipation.

AC conductivity analysis

The electrical conductivity measurement is a well rooted technique in analysing the properties of charge accumulation at the electrode-polymer interface and ion transport in polymer films. The dielectric conductivity sums overall dissipative effects, which may represent the conductivity caused by migrating charge carriers and related to an energy loss associated with a frequency dependence. For a dielectric, conductivity is a complex quantity which is given as

$$\sigma * = \sigma' + \sigma''$$

Where

σ' is the real part of conductivity

σ'' the imaginary part

The variation of real part of complex conductivity also known as the AC conductivity (σ′) of pristine and choline acetate reinforced PVC-PVP-50%PPy ternary blend films with frequency is shown in Fig. 6. For all the ternary polymer blend films the σ′ values increase by about four orders of magnitude when the frequency changes by four orders (i.e., from 10^2Hz to 10^6 Hz) as can be noted from this figure.

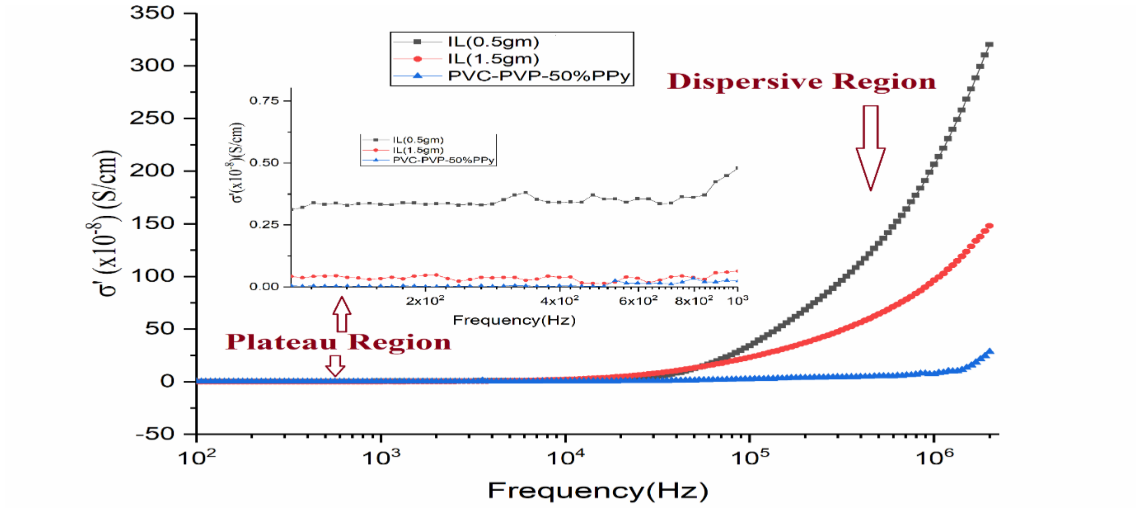


Figure 6. Variation in σ′ with frequency for ternary polymer blend film with and without choline acetate

Slika 6. Varijacija u σ′ sa frekvencijom za film mešavine ternarnog polimera sa i bez holin acetate

A close look at the σ′ spectra for all the films show two distinct regions (i) a low frequency plateau region *i.e.* frequency independent behaviour (ii) dispersion in higher frequency region *i.e.* frequency dependent behaviour. The transition from frequency in-dependent σ′ values to the frequency dependent values observed in these films signals the onset of conductivity relaxation phenomenon [41,42]. In low frequency region, more and more charge accumulation occurs at the electrode-polymer interfaces which lead to decrease in number of mobile ions and eventually result in low values of conductivity (Fig. 3- inset) [43].The high frequency dispersive region points towards a bulk relaxation phenomenon taking place which provides information about the migration of trapped ions related with AC conductivity [44]. Herein, the conductivity is high owing to the increased mobility of charge carriers. Additionally, these σ′ plots of the investigated bio-ionic liquid reinforced ternary polymer blend films validate that their σ′ values at 100 Hz are of the order of 10^{-10} S/cm which is enhanced to 10^{-6} S/cm at 2MHz. Bio-ionic liquid choline acetate produces a slight plasticizing effect leading to chain motion and high ion conductivity [45]. However, the enhancement is much more pronounced for lower concentration (0.5gm) of choline acetate in PVC-PVP-50%PPy in the entire measured frequency window.

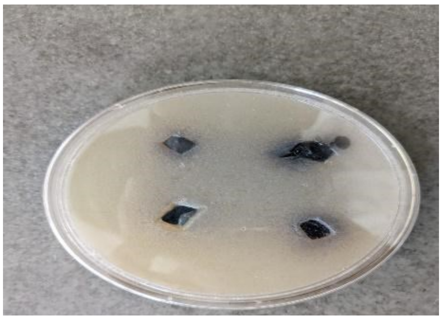
The ternary polymer blend film with higher concentration (1.5 gm) of choline acetate exhibited σ′ values less than that for low concentration in the entire experimental frequency range which could be due to the influence of ion pairs, ion triplets and the ion aggregations formed which reduces the overall mobility and the number of effective charge carriers [36,45].This variation makes it evident that these biofriendly choline acetate reinforced ternary polymer blend films are materials of appreciable electrical conductivity over the four orders of magnitude broad frequency window, and therefore, they can serve as flexible-type biofriendly material in developing the biofriendly electronic devices in the biomedical and green electronics fields.

3.3. Assessment of harmlessness of bio-ionic liquid reinforced film

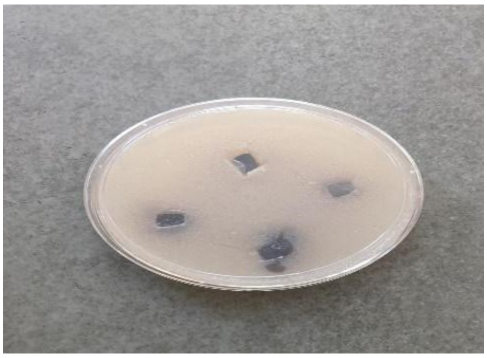
For the prepared choline acetate reinforced polymer films to be used as flexible biofriendly harmless [21] polymeric material in the biomedical and green electronics field, microorganisms are excellent candidates, because of their environmental and industrial impact, and the robustness of the toxicity assays.

Ternary polymer blend film without choline acetate did not exhibit any inhibition zone (Fig. 7). However, the films with choline acetate reinforced also did not exhibit any inhibition zone. What draws our attention is that the ternary films reinforced with choline acetate show a rapid growth of bacteria (Fig. 7 (a) and (b)) on the film as compared to pristine ternary polymer blend film. The benign nature of choline acetate reinforced polymer films towards *E.coli* bacteria have been reported in literature [21] which supports our observations. In present case, the ternary polymer blend film with higher concentration (1.5 gm) of choline acetate exhibited maximum bacterial growth. To sum up, we can say that as such ternary polymer blend film with and without choline acetate are benign towards *E. coli* and *Bacillus*

Subtilis, however ternary polymer blend film with higher concentration of choline acetate is more benign towards these bacteria which shows that the films under study are harmless and can be used as biofriendly polymer film in the field of green electronics and biomedical industry [46].



(a)



(b)

Figure 7. Results for disk diffusion test of E. coli and Bacillus Subtilis assay for ternary polymer blend films. (a) observation after 22 hours and (b) observation after 72 hours. Positions: 1-PVC-PVP-PPy, 2- PVC-PVP-PPy-IL(0.5gm), 3- PVC-PVP-PPy-IL(1.5gm)

Slika 7. Rezultati testa disk difuzije E. coli i Bacillus Subtilis testa za ternarne filmove mešavine polimera. (a) posmatranje posle 22 sata i (b) posmatranje posle 72 sata. Pozicije: 1-PVC-PVP-PPi, 2- PVC-PVP-PPi-IL(0,5gm), 3- PVC-PVP-PPi-IL(1,5gm)

4. CONCLUSIONS

Morphological characterization, low frequency dielectric properties, biological impact of ternary polymer blend film of PVC-PVP-50%PPy reinforced with two different (0.5gm and 1.5gm) concentrations are thoroughly investigated and described herein.The morphological study i.e. SEM images show that, the microstructure of pristine ternary polymer blend films shows a significant change on reinforcing it with various concentrations of choline acetate. Strong physical interactions and networking between choline acetate and matrix of ternary polymer blend resulted in enhancement in flexibility of the blend film which is favorable feature for the flexible green electronics and biomedical applications.

The dielectric study revealed that there is significant improvement of ion-dipolar interaction and ion-dipolar ordering in the film with addition of bio-ionic liquid. The increase in ε' values for choline acetate (0.5gm) reinforced PVC-PVP-50% PPy ternary blend film is about 16% at 100Hz and 4% at 2MHz. Choline acetate reinforced ternary polymer blend film with high values of ε' and low values of loss factor suggest that they possibly can be used as controllable dielectric material in the design and fabrication of simple functional circuits used in several biodegradable electronic devices in the biomedical field. The study of biological impact of ternary polymer blend film with and without choline acetate reveal their benign nature towards E. coli and Bacillus Subtilis, however ternary polymer blend film with higher concentration of choline acetate is more benign towards these bacteria.

To summarize, PVC-PVP-50%PPy ternary polymer blend film reinforced with appropriate amount of bio-ionic liquid choline acetate hold much promising modifications in structural, morphological, mechanical, and dielectric properties. More importantly the benign nature exhibited by these films towards E.coli and Bacillus Subtilis suggest that they can potentially be used for various scale multifunctional dielectric and electrical applications working in close contact with living matter, green electronics and various health monitoring systems in biomedical field.

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IZVOD

PODEŠAVANJE NISKOFREKVENTNIH DIELEKTRIČNIH SVOJSTAVA FLEKSIBILNOG TERNARNOG FILMA MEŠAVINE POLIMERA OJAČANOG BIOJONSKOM TEČNOŠĆU ZA PRIMENU U ZELENOJ ELEKTRONICI

Bioprijateljske polimerne mešavine i kompoziti koji pokazuju visoku dielektričnu konstantu i dielektrične gubitke obećavaju za primene kao senzori, materijali koji apsorbuju mikrotalase, gorivne ćelije i biomedicinske aplikacije. Izveštava se o korišćenju punila kao što su provodljivi nanomaterijali, biokeramika, ugljenične nanocevi, grafen itd. u mešavinama polivinilhlorida, polivinilpirolidona, polimetilmetakrilata, polivinil alkohola sa provodljivim polimerom polipirol polianilin za poboljšanje njihove tanilo-električne provodljivosti, dielektrične provodljivosti, i svojstva površine takvih polimernih materijala. Međutim, odgovarajuća disperzija takvih punila u polimernim matricama ostaje tehnički izazov. U tom smislu, bio-jonske tečnosti su se pojavile kao nova klasa materijala i njihova kombinacija sa specifičnim mešavinama polimera otvara mogućnost za razvoj pametnih novih materijala sa različitim morfologijama. Ovaj rad ima za cilj da istraži niskofrekventne dielektrične osobine koje pokazuje slobodno stojeći, fleksibilni, bioprijateljski/biorazgradivi ternarni polimerni film mešavine polivinilhlorid-polivinilpirolidon-polipirol ojačan holin acetatom. Detaljna analiza niskofrekventnih dielektričnih svojstava potvrđuje da dodavanje holin acetata rezultira modifikacijom dielektričnih svojstava ternarnog filma mešavine polimera. Bezopasnost ovih filmova potvrđena je testom difuzije diska koji ukazuje na njihovu benignu prirodu prema (Escherichia coli) (CFT073) i (Bacillus subtilis). Stoga se razvijeni filmovi potencijalno mogu koristiti za različite multifunkcionalne dielektrične i električne aplikacije koje rade u bliskom kontaktu sa živom materijom, zelenom elektronikom i raznim sistemima za praćenje zdravlja.

Ključne reči: *Biojonska tečnost, holin acetat, polivinilhlorid, polivinilpirolidon, polipirol*

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