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## Synthesis and Characterization of Novel PVA–Starch–Y<sub>2</sub>O<sub>3</sub> Bionanocomposites for Pressure Sensors

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Synthesis of the polyvinyl alcohol (PVA)–starch (ST)–yttrium oxide (Y<sub>2</sub>O<sub>3</sub>) nanocomposites and studying their structural and dielectric properties are considered for the sake of high-sensitive pressure sensors. The nanocomposites are prepared by casting method. The PVA–ST blend is prepared with following concentrations: 85 wt.% polyvinyl alcohol, 15 wt.% starch. The effect of yttrium-oxide nanoparticles' concentration on the structural and dielectric properties of PVA–ST blend is studied. The dielectric properties of PVA–ST–Y<sub>2</sub>O<sub>3</sub> nanocomposites are examined in frequency range from 100 Hz to 5 MHz. The results show that dielectric constant and dielectric loss of nanocomposites are decreased with increase in frequency of applied electric field. The A.C. electrical conductivity increases with increase in frequency. The dielectric parameters (dielectric constant, dielectric loss, and A.C. electrical conductivity) of PVA–ST blend are increased with increase in yttrium-oxide nanoparticles' concentration. The PVA–ST–Y<sub>2</sub>O<sub>3</sub> nanocomposites are tested for pressure-sensor application. The results show that the electrical resistance of PVA–ST–Y<sub>2</sub>O<sub>3</sub> nanocomposites decreases with increase in pressure.

Синтеза нанокompозитів полівінілового спирту (ПВС)–крохмалю (К)–оксиду йтрію (Y<sub>2</sub>O<sub>3</sub>) та вивчення їхніх структурних і діелектричних властивостей розглядаються заради високочутливих датчиків тиску. Нанокompозити готують методом лиття. Суміш ПВС–К готується з наступними концентраціями: 85 ваг.% полівінілового спирту, 15 ваг.% крохмалю. Досліджено вплив концентрації наночастинок оксиду йтрію на структурні та діелектричні властивості суміші ПВС–К. Діелектричні властивості нанокompозитів ПВС–К–Y<sub>2</sub>O<sub>3</sub> досліджуються в діапазоні частот від 100 Гц до 5 МГц. Результати показують, що діелектрична постійна та діелектричні втрати нанокompозитів зменшуються зі збільшенням частоти прикладеного електричного поля. Електропровідність змінного струму збільшується зі збільшенням частоти. Діелект-

ричні параметри (діелектрична константа, діелектричні втрати та електропровідність змінного струму) суміші ПВС-К збільшуються зі збільшенням концентрації наночастинок оксиду Ітрію. Нанокompозити ПВС-К- $Y_2O_3$  тестуються на застосування датчиків тиску. Результати показують, що електричний опір нанокompозитів ПВС-К- $Y_2O_3$  спадає зі збільшенням тиску.

**Key words:** conductivity, structure,  $Y_2O_3$ , nanocomposite, pressure sensor.

**Ключові слова:** електропровідність, структура,  $Y_2O_3$ , нанокompозит, датчик тиску.

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## 1. INTRODUCTION

Organic-inorganic nanocomposites are extremely promising for applications in light-emitting diodes, photodiodes, photovoltaic cells, smart microelectronic device, and gas sensors among others. The properties of nanocomposites films can be adjusted by varying the composition. Their fabrication shares the same advantages of organic device technology such as low-cost production and the possibility of device fabrication on large area and flexible substrates.

PVA is a potential material having high dielectric strength, good charge storage capacity and dopant-dependent electrical and optical properties. It has carbon chain backbone with hydroxyl groups attached to methane carbons. These OH groups can be a source of hydrogen bonding and hence assist the formation of polymer composite [1].

Starch is the most abundant carbohydrate reserve in plants and is found in leaves, flowers, fruits, seeds, different types of stems and roots. Starch biochemical chain responsible for starch synthesis involves glucose molecules produced in plant cells by photosynthesis. Starch is formed in the chloroplasts of green leaves and amyloplasts, organelles responsible for the starch reserve synthesis of cereals and tubers [2].

Yttrium oxide, as an important member among rare-earth compounds, has been actively studied in the recent years. It is one of the most promising elements for the fabrication of optoelectronics devices and chemical catalysis.  $Y_2O_3$  can be used as high-efficient additives and functional composite materials like yttria-stabilized zirconia films. This material could be synthesized *via* several methods, including cathodic electrodeposition, gas-phase condensation, precipitation, sol-gel, pyrolysis, solvothermal and hydrothermal syntheses [3]. The addition of inorganic nanoparticles to polymers allows the modification of the polymer physical properties as well as the implementation of new features in the polymer matrix [4].

Pressure sensors have a great significance for industrial equipment, and they are widely used for the control and monitoring of thousands of applications such as biomedical, environment, space, and automobiles. Furthermore, piezoresistive pressure sensors have been proposed to detect the strain by applying pressure to change the resistance of test patterns. Materials typically used for piezoresistive pressure sensors are silicon, polysilicon thin films, bonded metal foils, sputtered thin films, and inkjet printing films. Generally, piezoresistive pressure sensors are the most commonly employed technology in the pressure sensor market owing to their advantages of high sensitivity and low cost [5].

The idea of connecting two or more different constituents into one substance gives almost infinite possibilities to create new engineering materials characterized by variety of different properties. Composite materials, because of these diverse properties, are successfully used in almost all areas of industry and science [6–9]. One advantage of nanoparticles as polymer additives appearing to have is that compared to traditional additives, namely, loading requirements are quite low [10].

## 2. THEORETICAL PART

The dielectric constant,  $\varepsilon'$ , of PVA-ST-Y<sub>2</sub>O<sub>3</sub> bionanocomposites is defined by the following equation [11]:

$$\varepsilon' = C_p / C_o, \quad (1)$$

where  $C_p$  is parallel capacitance and  $C_o$  is vacuum capacitance.

The dielectric loss,  $\varepsilon''$ , of PVA-ST-Y<sub>2</sub>O<sub>3</sub> bionanocomposites is written by the equation as follows [12]:

$$\varepsilon'' = \varepsilon' D, \quad (2)$$

where  $D$ —dispersion factor of PVA-ST-Y<sub>2</sub>O<sub>3</sub> nanocomposites.

The A.C. electrical conductivity of PVA-ST-Y<sub>2</sub>O<sub>3</sub> bionanocomposites is determined by the equation [12]:

$$\sigma_{A.C.} = \omega \varepsilon'' \varepsilon_0, \quad (3)$$

where  $\omega$ —the angular frequency.

## 3. EXPERIMENTAL PART

The nanocomposite films are prepared from PVA-ST blend with dif-

ferent of yttrium-oxide nanoparticles' concentrations by casting method. The PVA-ST blend is prepared by dissolving 1 gm of polyvinyl alcohol and starch in 20 ml of distilled water with concentrations: 85 wt.% PVA and 15 wt.% ST by using magnetic stirrer to mix the polymers for 1 hour to obtain solution that is more homogeneous. The  $Y_2O_3$  nanoparticles added to polymers' mixture with different concentrations 1, 2 and 3 wt.%. The samples of PVA-ST- $Y_2O_3$  nanocomposites are casted in the template (Petri dish has diameter of 10 cm). The samples are prepared with thickness range 120–142  $\mu\text{m}$ .

FT-IR spectra (Fig. 1) were tested in wave number range 500–4000  $\text{cm}^{-1}$  by FT-IR (Bruker Company, German origin, type Vertex-70). The nanocomposites' samples are examined by using the optical microscope (supplied from Olympus name (ToupView) type (Nikon-73346)) with magnification ( $\times 10$ ). The dielectric properties of PVA-ST- $Y_2O_3$  nanocomposites' samples are tested within the frequency range from 100 Hz to  $5 \cdot 10^6$  Hz by using LCR meter type (HIOKI 3532-50 LCR HI TESTER). The pressure-sensor application of nanocomposites is investigated by measuring the resistance between two electrodes on the top and bottom of the sample for different pressures' range 80–200 bar.

#### 4. RESULTS AND DISCUSSION

The FT-IR spectra of PVA-ST- $Y_2O_3$  nanocomposites are shown in Fig. 1. As shown in Fig. 1, the broad peak around 3250  $\text{cm}^{-1}$  indicates stretching of hydroxyl groups (O-H). The peak at 1087  $\text{cm}^{-1}$  is due to the C-O stretch of secondary alcoholic groups [13].

Figure 2 shows the dependence of real dielectric constant on the frequency at room temperature. It verifies that value of dielectric constant for PVA-ST- $Y_2O_3$  nanocomposites is high at low frequencies since electric dipoles have enough relaxation time to be supported with the field. Thus, there is a high dielectric constant. However, relaxation time decreases with increase in frequency as dipoles do not get sufficient time to be supported with the field, and the dielectric constant decreases. The values of dielectric constant for PVA-ST- $Y_2O_3$  nanocomposites rise with a dopant concentration of yttrium-oxide nanoparticles.

This rise in dielectric-constant values could be ascribed by Maxwell-Wagner interfacial polarization [14] and increasing number of charge carries as shown in Fig. 3. This figure shows that the  $Y_2O_3$  nanoparticles are aggregated as clusters at low concentrations. When increasing the concentration of  $Y_2O_3$  nanoparticles, the nanoparticles form a paths' network inside the PVA-ST blend.

The variation of dielectric loss for PVA-ST- $Y_2O_3$  nanocomposites

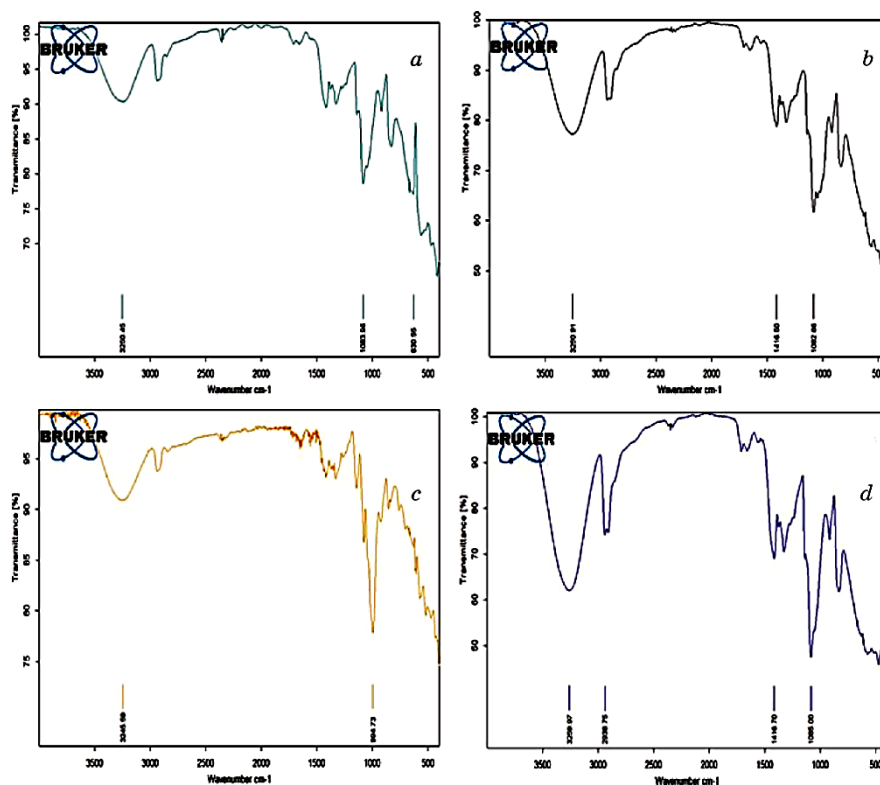


Fig. 1. FT-IR spectra for PVA-ST- $Y_2O_3$  nanocomposites; *a*—pure blend; *b*—1 wt.%  $Y_2O_3$  nanoparticles; *c*—2 wt.%  $Y_2O_3$  nanoparticles; *d*—3 wt.%  $Y_2O_3$  nanoparticles.

with frequency at room temperature with different concentrations of yttrium-oxide nanoparticles is shown in Fig. 4. It is clear from the graph that loss decreases with frequency. The higher value of the dielectric loss for PVA-ST- $Y_2O_3$  nanocomposites at the higher concentration of yttrium-oxide nanoparticles can be understood regarding electrical conductivity, which is related to the dielectric loss. Moreover, polyvinyl alcohol is polar polymer with polar bonds and shows flexible polar groups since the bond rotating having intense dielectric  $\alpha$ -transition [14].

Figure 5 shows the variation of A.C. electrical conductivity for PVA-ST- $Y_2O_3$  nanocomposites with frequency at room temperature. As the yttrium-oxide nanoparticles' concentration is increased, the inorganic filler molecules start bridging the gap separating the two localized states and lowering the potential barrier between them, thereby, facilitating the transfer of charge carriers between two localized states.

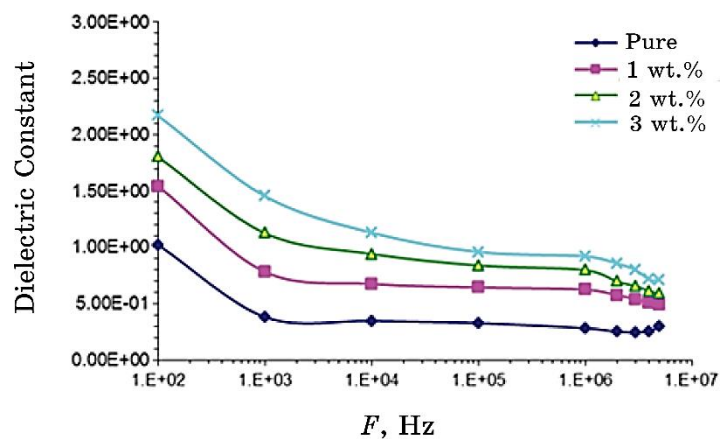


Fig. 2. Variation of dielectric constant for PVA-ST- $Y_2O_3$  nanocomposites with frequency at room temperature.

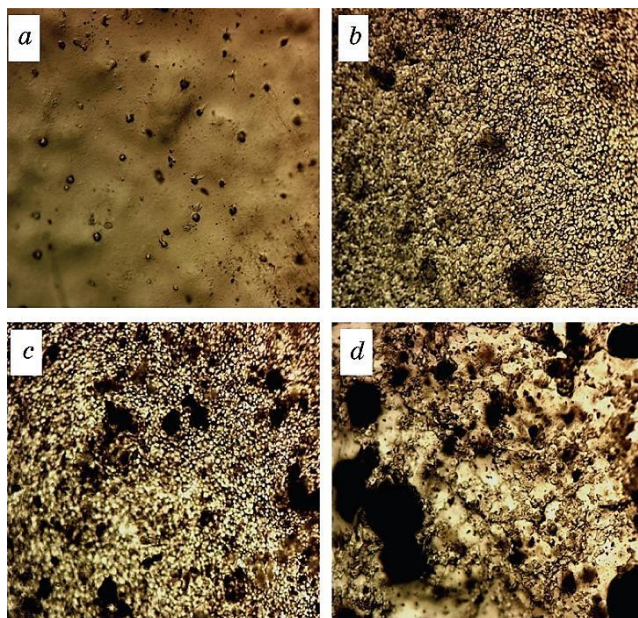


Fig. 3. Photomicrographs ( $\times 10$ ) for PVA-ST- $Y_2O_3$  nanocomposites: (a) for pure blend; (b) for 1 wt.%  $Y_2O_3$  nanoparticles; (c) for 2 wt.%  $Y_2O_3$  nanoparticles; (d) for 3 wt.%  $Y_2O_3$  nanoparticles.

The frequency-dependent conductivity is conditioned by the hopping of charge carriers in the localized state. The term hopping refers to the sudden displacement of charge carriers from one position

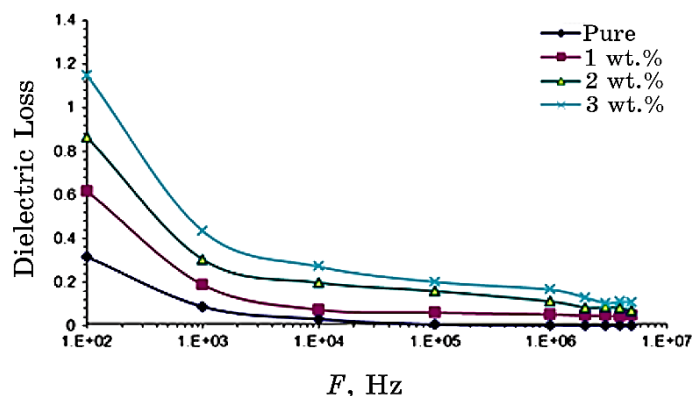


Fig. 4. Variation of dielectric loss for PVA-ST-Y<sub>2</sub>O<sub>3</sub> nanocomposites with frequency at room temperature.

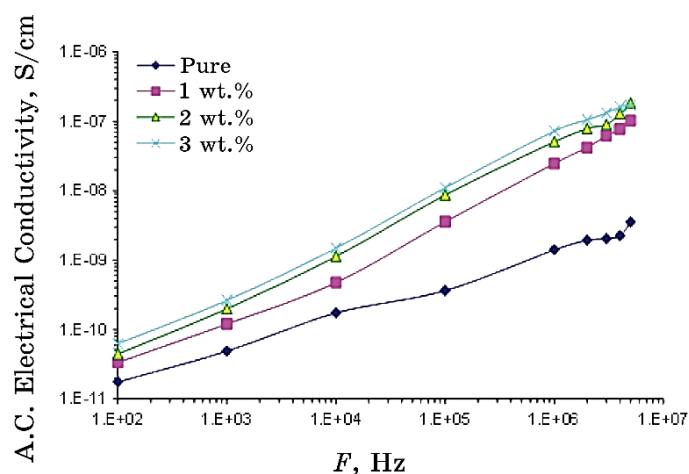
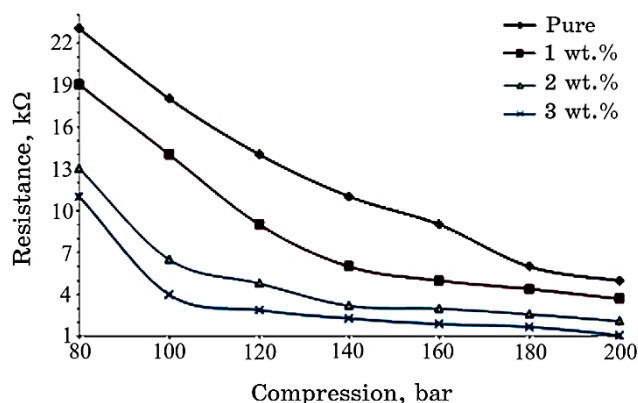


Fig. 5. Variation of A.C. electrical conductivity for PVA-ST-PbO<sub>2</sub> nanocomposites with frequency.

to another neighbouring site and, in general, includes both jumps over a potential barrier and quantum mechanical tunnelling [15].

Figure 6 shows the variation of electrical resistance for PVA-ST-Y<sub>2</sub>O<sub>3</sub> nanocomposites with compression stress. From the figure, the electrical resistance of nanocomposites decreases with increasing the pressure. Typical piezoelectric polymers have a crystalline region that has an internal dipole moment. These dipole moments are randomly oriented without any mechanical or electrical poling process, and the net dipole moment is zero in these conditions. When stress is applied to the stacked polymer chain region, it will change



**Fig. 6.** Variation of electrical resistance for PVA-ST-Y<sub>2</sub>O<sub>3</sub> nanocomposites with compression stress.

the local dipole distributions and induce an electric field in the stack. The induced electric field accumulates the charges at both the top and the bottom of the film [16].

## 5. CONCLUSIONS

The dielectric properties (dielectric constant, dielectric loss, and A.C. electrical conductivity) of PVA-ST-Y<sub>2</sub>O<sub>3</sub> nanocomposites increase with an increase the yttrium-oxide nanoparticles' concentration.

The dielectric constant and dielectric loss of PVA-ST-Y<sub>2</sub>O<sub>3</sub> nanocomposites are decreased with an increase of the frequency, while the A.C. electrical conductivity increases with an increase of the frequency.

The electrical resistance of PVA-ST-Y<sub>2</sub>O<sub>3</sub> nanocomposites decreases with an increase in pressure, and these samples have high sensitive for pressure.

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