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Comprehensive Study of Morphological, Optical, and Electrical Properties of PCz-PS/Al_2O_3 Electrospun Nanofibers

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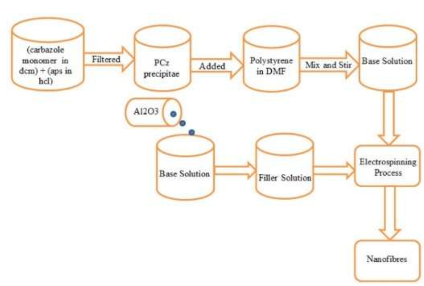
***Abstract*— At present times, nanofibers are one of the most interesting and dynamically developing areas of investigation capable of bringing about revolutionary changes in multidisciplinary areas. In this study, nanofibers were fabricated by electrospinning method by utilizing hybrid polymers Polycarbazole (PCz) and Polystyrene (PS) mixed with Al2O_3 filler. In this paper, characterization and analysis of obtained PCz-PS/ Al_2O_3 hybrid nanofibers have been discussed. Obtained results showed that all samples demonstrated hydrophobic behavior based on measured contact angles. Nevertheless, the higher was filler content in samples, the smaller value of contact angle occurred, which means that hydrophobic character was decreased. The morphological studies of obtained nanofibers were carried out by using Scanning Electron Microscopy (SEM), Energy Dispersive X-ray (EDX), X-ray Diffraction (XRD), Fourier Transform Infrared Spectroscopy (FTIR), and Ultraviolet-Visible (UV-Vis) spectroscopy. Moreover, by means of electrochemical impedance spectroscopy (EIS), it was found that nanofibers have good ionic conductivity and charge transfer resistance. In addition, charge transfer resistance was even lower for samples containing filler (10% and 20%). According to Mott-Schottky analysis, nanofibers samples are able to be classified as p-type semiconductors. As for Photoelectrochemical (PEC) investigation, P2 sample has proven its superiority among others in terms of higher photocurrent stability.**

***Keywords*— Electrospun Nanofibers; Polycarbazole-Based Composites; Photoelectrochemical Performance; Surface Hydrophobicity; Functional Nanomaterials.**

***Graphical Abstract*—**



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I. INTRODUCTION

PCz is a conducting polymer with good electrical properties, making it useful for electronic and sensing applications. It exhibits good resistance to oxidation and environmental degradation. Due to its rigid backbone and poor solubility, blending PCz with other polymers like PS is common to improve fibers formation. PS provides structural support in composite nanofibers and easily dissolved and electrospun into nanofibers with smooth morphology. PS nanofibers can be blended with PCz to improve electrical properties while maintaining mechanical flexibility. Al_2O_3 acts as a reinforcing agent, increasing the tensile strength and elastic modulus of nanofibers.

It prevents fibers breakage and improves fibers uniformity. Pure PCz has moderate electrical conductivity, but adding Al_2O_3 nanoparticles can alter its electrical behavior. Al_2O_3 has a high melting point (~2072°C) and thermal stability, preventing polymer degradation at high temperatures. The produced hybrid nanofibers are used dielectric layers in transistors. It can also be used in flexible electronics as conductive coatings and sensors. Al_2O_3 provides insulation while PCz enhances charge transport. PVDF-polycarbazole nanofiber membranes have a higher level of performance with regard to piezoelectric behavior than PVDF or PVDF-polyaniline nanofiber membranes for the purpose of wearable technology [1]. A number of limb movements by humans can be harnessed to generate electrical voltage, even enough voltage to light up fifteen LED lamps. Therefore, polycarbazole is a suitable polymer that could be used together with PVDF to make it a highly reactive piezoelectric material for cyborg tissue engineering and medical equipment. PANI chain segments have adopted a rod-like structure in the composite material, offering more surface area to react with metal ions present in the aqueous solution [2].

Chemical and electrochemical deposition methods were used to produce polycarbazole (PCz), polycarbazole/ nanoclay, and polycarbazole/ zinc nanocomposites on stainless steel (SS304) electrodes. Grade 304 stainless steel is among the most extensively used grades of austenitic stainless steel. The welding of stainless steel 304 can take place using PCz, PCz/ nanoclay, and PCz/ nanoZn coatings, which have been chemically deposited on SS304 electrodes and have shown higher corrosion inhibition performance than those prepared via the electrochemical technique [3]. Under various conditions of the electrospinning process and varying ratios of PS to Al2O3 nanoparticle concentrations, PS/ Al2O3 nanocomposite coatings had several morphologies of microfibers and beaded fibers. As revealed by the research, the highly porous superhydrophobic nanocomposite coatings (SHCs) demonstrate three orders of magnitude higher corrosion resistance than the uncoated aluminum alloy [4]. Two different approaches, namely, sol-gel and electrospinning, were applied to produce alumina nanofibers. For the synthesis of the electrospun coating, aluminum isopropoxide (AIP) and polyvinylpyrolidone (PVP) were blended with ethanol in the presence of an acid catalyst. As was demonstrated by characterization results, alumina nanofibers with diameters from 102 to 378 nm were successfully developed. It has been seen from the kinetic analysis that the kinetics of the pseudo-second-order is suitable for MO adsorption on alumina nanofibers when compared to the pseudo-first-order kinetics. Methyl orange is a negatively charged anionic dye in aqueous solutions [5].

Electrospinning was carried out to successfully form blend webs using polyvinylcarbazole and polystyrene (PVCz/PS). This technique is adopted to solve the spinnability problem and reduce the high cost of the pure PVCz. The blend ratio of the PVCz and PS solution, voltage, and Thermal Conductivity Detector (TCD) have significantly influenced the morphology of the PVCz/PS blend webs. With the increase in the amount of PS in the solution used for spinning, spinnability will increase along with a decrease in the diameter of the electrospun web at various PVCz/PS blend ratios. An increase in the applied voltage and TCD will also cause the fiber diameter of PVCz/PS blends to be decreased [6]. Significant strides have been taken over the last two decades in the research and development of electrospinning technologies, optimization, and especially fiber collection for the production of stable nanofiber yarns. High performance nano textiles can be revolutionized entirely to overcome existing problems in mechanical stability and scalability, thereby making the new technology more commercially viable and accessible [7]. Fe3O4 nanoparticles are electrospun into fibers using polyvinylidenefluoride (PVDF). It is even more notable that the PTSCS shows improved results in determining the temperature and roughness of the surface of objects. Applications of the flexible PTSCS include material classification and intelligent soft robotics [8]. Though there was a period when polycarbazole and its derivatives fell out of favor, they have been extensively used for the past thirty years [9]. Considering all these factors, this study on electrospinning PCz-PS/Al2O3 nanofibers has investigated the developed hybrid polymer composite thoroughly. In this study, the polymer composite PCz-PS/Al2O3 electrospinning nanofibers have been developed and evaluated for the first time.

II. MATERIALS AND METHOD

The materials were used for this study without further purification; these include carbazole powder ($C_{12}H_9N$, MW=167.21), polystyrene beads, ammonium peroxodisulfate ($(NH_4)_2S_2O_8$, MW=228.19 g•mol−1), dichloromethane (CH_2Cl_2, MW = 84.93 g•mol−1), and hydrochloric acid which was obtained from Ottokemi.
Synthesis of Polycarbazole (PCz): PCz is the chemical name of the polymer produced from carbazole monomer. Carbazole is dissolved in 250 ml of DCM in 60mM concentration, while 1.2M APS dissolves in 0.5M Hcl. The solution of carbazole is slowly added to HCL solution. For 24 hours, the mixture is kept in room temperature. The green precipitate was filtered using a Whatman filter paper. The precipitate is dried. Again, the precipitate was washed using DCM and type
Base Solution (P0): Synthesized PCz compound was dissolved in polystyrene which is in turn dissolved in DMF solution. The solution was stirred for 2 hours and then subjected to Electrospinning technique.
Filler Solution: Carbazole is conductive polymer and polystyrene is the insulating polymer containing filler of Aluminium Oxide. Different concentrations of 10 wt% and 20 wt% of filler solutions are used and denoted as P1 and P2 respectively. The nanofibers samples with their name is shown in Table 1.
Preparation of Nanofibers through Electrospinning Process: Electrospinning is one of the most commonly employed methods of producing ultrathin nanofibers having diameter between nanometer scale to micrometer scale. Electrospinning of the prepared base solution of PCz and PS was done first with the flow rate of 2 mL/h, applied voltage of 15-20 kV, and a collector at a distance of 10 cm from the tip of the needle. In a similar way, electrospinning of the filler solution of PCz, PS with Al_2O_3 was done using different concentrations of 10 wt% and 20 wt%.

TABLE I: NANOFIBERS SAMPLES WITH NAME

Sl. No	Nanofibers Sample	Name
1	Polycarbazole	PCZ
2	Polystyrene	PS
3	Aluminum Oxide	Al_2O_3
4	Polycarbazole + Polystyrene	P0
5	P0+Al_2O_3: 10wt%	P1
6	P0+Al_2O_3: 20wt%	P2

Scanning Electron Microscopy: SEM was used for fiber morphology study by using S-3400, and images were acquired at an acceleration voltage of 15 kV after being coated with a thin film of gold.
Energy Dispersive X-ray (EDX): Energy-dispersive X-ray analysis is an analytical procedure which allows the identification and quantification of the elements making up a material. This is usually done using an SEM as the source of characteristic X-rays, which are detected by detectors installed close to the sample. The energy of each X-ray corresponds to an element within the sample.
Fourier Transform Infrared Spectroscopy (FTIR): FTIR is an advanced technique widely used for studying the functional groups, molecular interactions, and chemical composition of a material, especially for polymer composite and electrospun nanofibers. The principle of FTIR involves detecting the interaction of a material with infrared radiation, where the amount of radiation absorbed by the sample is measured as a function of wavelength. The results of FTIR measurement are expressed as a wavenumber (cm^{-1}) ranging from 4000 to 400 cm^{-1}.
X-ray Diffraction (XRD): XRD is an efficient technique used in determining the crystal structure of any material by analyzing the scattering pattern of x-rays. The X-ray generated by D/teX.
Contact Angle: The measurements of the contact angles were carried out using water on a contact angle tensiometer based on the sessile drop method.
The contact angle measurement of the nanofibers is referred to as the contact angle of the point at which the liquid usually water meets the surface of the nanofibers material. It is an important measure used to estimate the wettability and hydrophobicity/hydrophilicity. A higher contact angle greater than 90° means the surface is hydrophobic while less than 90° means it is hydrophilic.
UV-(Ultraviolet-Visible)-Spectroscopy: UV-Vis spectrometry is very useful when measuring the optical properties and electronic transitions of a polymer composite. The band gap (Eg) of a material can be measured through its UV-Vis spectrum through Tauc's plot. Convert Absorbance (A) to Absorption Coefficient (α) using:

$$\alpha = \frac{2.303\ A}{d} \qquad (1)$$

Where d is the film thickness Plot $(\alpha h\nu)^n$ vs. $h\nu$ (Tauc's Plot). Extrapolate the linear portion of the curve to $(\alpha h\nu)^n = 0$. The x-intercept gives E_g (optical band gap).
I-V characteristics: An I-V curve for nanofibers, or current-voltage characteristic curve, is a graph showing the relationship between the voltage applied across a device made of nanofibers and the current flowing through it. This type of curve is used to characterize the electrical behavior of the nanofiber device, which can be used in various applications like sensors, energy storage, and electronics.
Electrochemical impedance spectroscopy (EIS): Electrochemical impedance spectroscopy (EIS) frequency response analysis (FRA) was employed to evaluate the ionic conductivity of the electrospun nanofiber. The ionic conductivity of the samples was determined using EIS. The following equation was used to estimate the ionic conductivity of the nanofiber membrane according to charge transfer resistance (Rct) in the fibers:

$$\sigma = \frac{L}{R_{ct} * A} \qquad (2)$$

Where A is the symmetrical electrode's contact area in cm^2 (0.1257 cm^2), L is the fiber mat's thickness in cm (= 0.005 cm), Rct is the charge transfer resistance in ohm (Ω), and σ is the nanofiber mem brane's ionic conductivity (S/cm).
Photoelectrochemical measurements: Photoelectrochemical tests were conducted on the selected samples by means of a Metrohm Autolab (PGSTAT302N) electrochemical workstation. The Ag/AgCl reference electrode was combined with a platinum counter electrode and sodium sulfate with the FTO substrate as the electrolyte, while copper wires were utilized for connections. Mott Schottky (M-S) curves were recorded in the potential range of 70–120 mV against Ag/AgCl in order to analyze the semiconductor behavior of the electrode surface. Due to its high stability, ease of use, and reproducibility, the Ag/AgCl reference electrode is commonly employed in electrochemical studies.

III. RESULTS AND DISCUSSION

Scanning Electron Microscopy: Morphology studies were carried out on samples of nanofibers and the diameter of the fiber was determined via SEM analysis. As seen from Figure 1, uniform beads-free morphology for the samples P0, P1, and P2 was studied. According to the results, PCz has granular particles with a nodular structure. PS nanofibers have diameter 2-5µm. The Al2O3 has porous structure with highly agglomerated structure. Nanofibers of the sample P0 have diameter 1.32 µm. Fibers with the diameter ranging from 900 nm to 1.4 µm were synthesized from sample P1 while 331 nm – 754 nm from the sample P2.

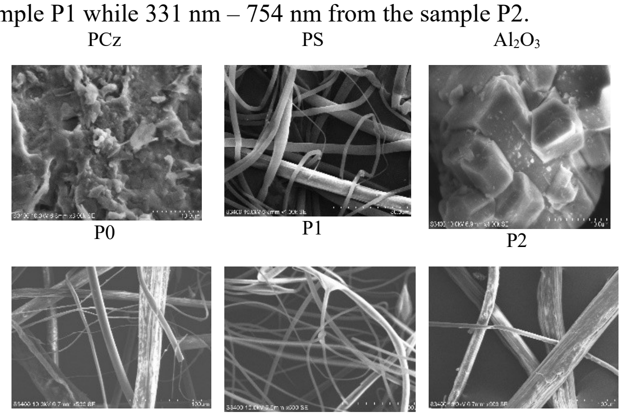


Figure 1: Scanning Electron Micrographs of PCz, PS, Al2O3, P0, P1 and P2 nanofibers samples.

Energy Dispersive X-ray (EDX): Analysis of nanofibers through EDX (Energy Dispersive X-ray Spectroscopy), usually in combination with SEM-EDX. EDX identifies the elemental makeup of nanofibers, which is essential for verifying material purity and composition. It ensures that the nanofibers have the intended chemical composition, particularly for functionalized or composite nanofibers and detects unwanted elements or impurities in nanofibers that might affect performance. Also EDX is a valuable tool in nanofiber research as it enables elemental analysis and mapping, confirming the presence and distribution of functional additives (e.g., metals, metal oxides, dopants) within or on the surface of nanofibers. Figure 2 shows the analysis of EDX for the electrospun nanofibers of PCz, PS, Al2O3, P0, P1 and P2 samples. Analysis confirms the materials composition of the nanofibers. The elements C, H, N, O, Cl confirms synthesized Carbazole monomer as Polycarbazole. C, O elements confirms the material polystyrene. Al and O elements confirms the Aluminum oxide particles. C, N, O, Al elements confirms the composite of polymer and filler for nanofibers samples of P0, P1 and P2.

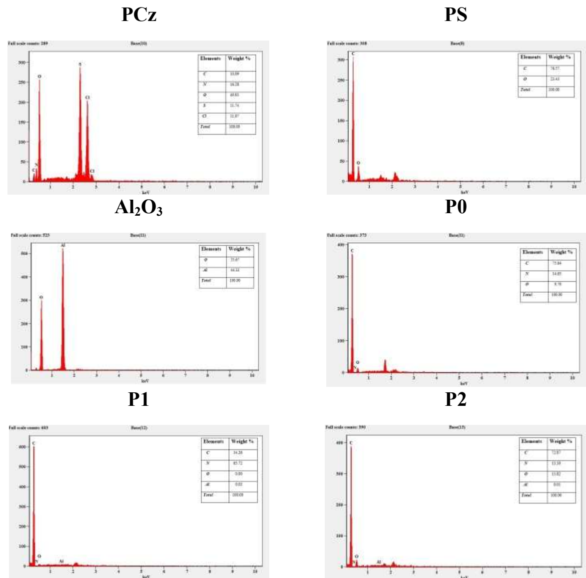


Figure 2: EDX analysis of nanofiber samples PCz, PS, Al2O3, P0, P1 and P2.

Fourier Transform Infrared Spectroscopy (FTIR): To determine the various functional groups that have formed in the composites as a result of constituent interaction, the FTIR has been examined for PCz, PS, Al2O3, P0, P1, and P2 samples. Figure 3 displays the spectra of the current nanocomposites. The di- and tri-substituted benzene rings of PCz exhibit C-H deformation, which is the cause of the infrared bands at 869 cm-1, 747 cm-1, and 647 cm-1. The N-H bond in PCz is stretched, as indicated by a sharp band at about 3219 cm−1. It is possible that the stretching vibration of the carbazole's ring causes the sharp peak at 1438 cm-1. It is known that the stretching vibration of aromatic alkene causes the peaks observed at 1638 cm-1 [10]. The peak at 3126 cm-1 was caused by the stretching vibration of C-H bonds on the benzene ring. The peak at 2892 cm-1was caused by the stretching vibration of C-H bonds on methylene. The peak at 1481 cm-1 was formed by the vibration of deformation of the benzene ring [11]. The strong absorption bands at 655 cm-1, 605 cm-1 were caused by the vibration of stretching of the Al-O bond, proving the existence of Al2O3 particles. The wide absorption band at 3697 cm-1 might be caused by the vibration of O-H bonds on water [12]. In the same manner, the analysis of the nanofiber composite P0, P1 and P2 obtained was done based on the peaks observed along with the corresponding functional groups.

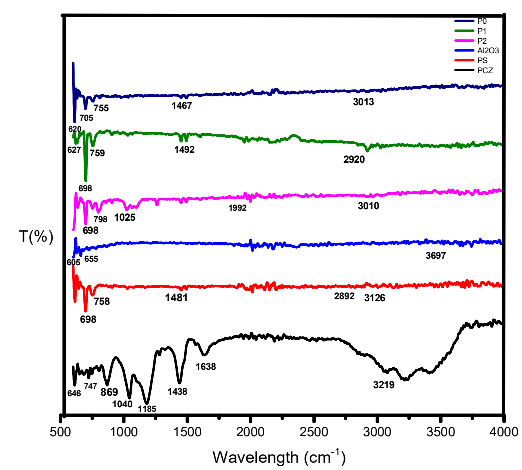


Figure 3: FTIR spectra of Samples PCz, PS, Al2O3, P0, P1 and P2

X-ray Diffraction (XRD): The crystalline structure of pure PCz, PS, Al2O3 samples and composites PCz and PS with Al2O3 were analyzed through the XRD patterns. The XRD pattern for P0, P1 and P2 samples can be seen from Figure 4 below. Some diffraction peaks corresponding to some crystalline/ amorphous planes can be seen.

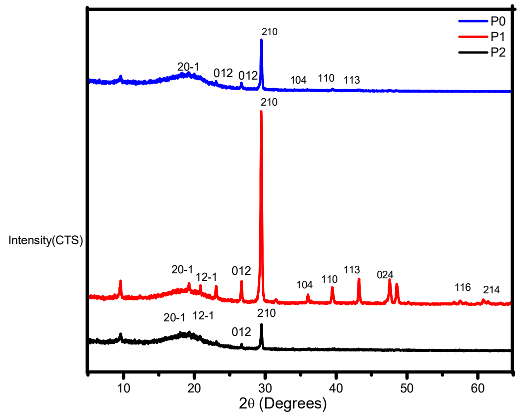


Figure 4: XRD pattern of the samples P0, P1 and P2.

The XRD pattern of pure Polycarbazole and poly styrene composite with Al2O3 was analyzed. The peaks at 19.18°, 20.86°, 26.8° and 29.4° match the (2 0 -1), (1 2 -1), (0 1 2) and (2 1 0) plane of pure PCz respectively [10]. Peaks in the XRD pattern of the synthesized PS samples reveal a very low level of crystallization of the absorbent which reflects a good chemical stability of the latter [11]. It was determined that the peaks 2θ- 43.29°, 36°, 56.9°, 26.69, 39.7°, and 61.5° formed. These are associated with 113, 104, 116, 012 planes of Al2O3 samples [13].

Contact Angle: However, the results from measuring the contact angles of nanofibers P0, P1, and P2 samples indicate similar surface hydrophobicity. Sample P0 had a contact angle of 115°, whereas the contact angles for samples P1 and P2 were 112° and 108°, respectively, as illustrated in Figure 5 below. This shows that the contact angle decreased with an increase in the concentration of the filler.

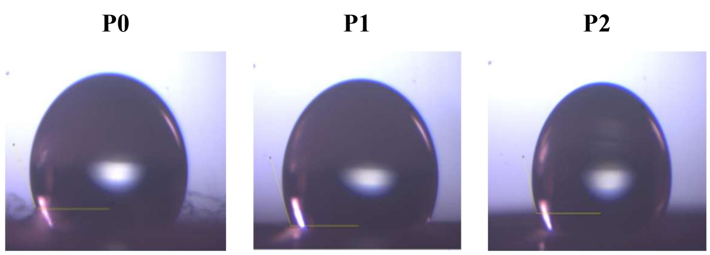


Figure 5: Contact angle of nanofiber samples P0, P1 and P2

The findings reveal that there is no much variation between the samples as far as their wettability characteristics are concerned. Table 2 presents contact angle values of each sample.

TABLE II: THE CONTACT ANGLE FOR SAMPLES P0, P1 AND P2

Sl. No	Samples	Contact Angle
1	P0	115.38
2	P1	112.03
3	P2	108.56

A. UV-Vis Analysis

The UV-Vis absorbance spectra of the samples are determined at ambient temperature with wavelength from 200 nm to 600 nm. The UV-Vis absorbance spectra of nanofibers P0, P1, and P2 with peak values at 266 nm, 257 nm, and 253 nm are presented in Figure 6. The absorption peak shows short wavelengths and also changes in absorbance with various weight percentages of Al2O3. The absorption edge and intensity of samples are tabulated in Table 3.

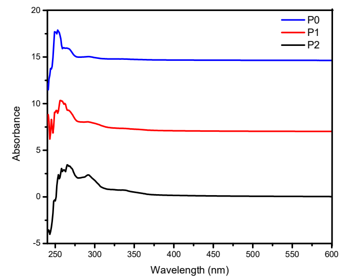


Figure 6: The UV–Vis absorption spectra of nanofibers P0, P1 and P2.

In order to understand the optical band gap, the energy gap of polycarbazole and the nanocomposite is calculated with the help of Tauc's equation. The graphs shown in figure 7(a) and (b) represent the Tauc plot of the samples P0, P1, and P2, respectively.

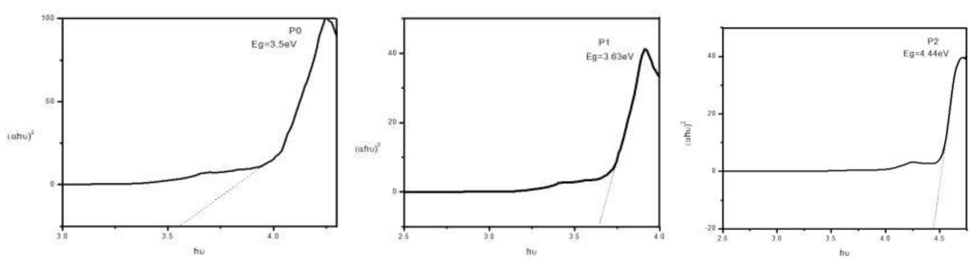
TABLE III: THE ABSORPTION EDGE AND INTENSITY OF SAMPLES P0, P1 AND P2.

Nanofiber Samples	Wavelength (nm)	Absorbance
P0	266.46	3.43
P1	257.41	3.29
P2	253.49	3.16

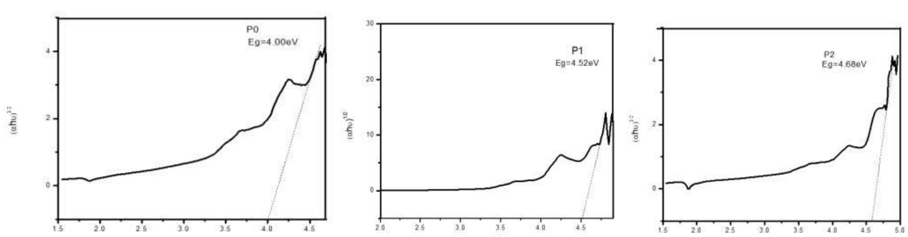
Estimated values of direct and indirect band gaps have been given in Table 4 below. Estimated value of the direct band gap is 3.39 eV for P0 sample and that for P1 and P2 samples is found to be 3.5 eV and 4.24 eV respectively. The estimated value of the indirect band gap is 3.40 eV for P0 sample and that for P1 and P2 are found to be 4.00 eV, 4.52 eV and 4.68 eV, respectively. As can be seen, band gap energy keeps on increasing with the increase in wt% of fillers. There is a gradual blue shift in the absorption spectra with the increasing filler concentration as depicted in Figure 7 below. Values of band gaps greater than 3eV are termed as those of wide band gap semiconductors or insulators.

TABLE IV: DIRECT AND INDIRECT BAND GAP OF SAMPLES P0, P1 AND P2.

Nanofiber Samples	Direct band gap Eg (eV)	Indirect band gap Eg (eV)
P0	3.5	4.00
P1	3.63	4.52
P2	4.44	4.68



(a) Direct band gap



(b) Indirect band gap

Figure 7: Tauc plots for the samples

Ionic Conductivity analysis of electrospun PCz-PS/Al2O3 nanofibers: Figure 8 depicts the EIS analysis of the specimens using the Nyquist plot. The Nyquist plot reveals that the arc radius of the semicircle corresponds to the resistance of the charge transport of the photo-induced charges. P0 had the smallest arc radius, making it the specimen with the least charge transfer resistance. Table 5 displays the results for the charge transfer resistance and ionic conductivity of the electrospun nanofibers P0, P1, and P2.

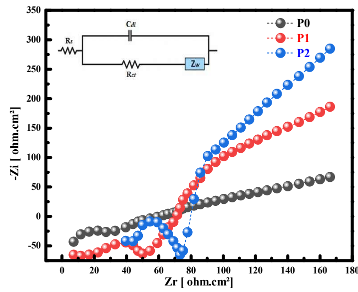


Figure 8: The electrochemical impedance spectroscopy (EIS) of the samples.

The ionic conductivity of the samples P0, P1 and P2 nanofiber was estimated using the charge transfer resistance (Rct) values according to Eq. 2. From Fig. 8 it can be seen that as the value of charge transfer resistance increases, the ionic conductivity of the electrospun fiber samples decreases due to addition of filler. As mentioned above, Fig. 8 shows an equivalent circuit used in obtaining the EIS graph shown above. In this equivalent circuit, Rs is the solution resistance (which is also referred to as uncompensated resistance). It accounts for resistance due to electrolyte and leads, among others. It is the intercept of the high frequency region in the real axis (Z'). Rct denotes the charge transfer resistance in the electrode-electrolyte interface. It depends on the kinetics of the electrochemical reactions, as well as the size of the semicircle. Cdl corresponds to double layer capacitance which comes about due to the charge separation at the electrode-electrolyte interface. It is associated with Rct to make up the RC circuit, resulting in the semicircle shape. Finally, Zw denotes the Warburg impedance which depicts mass transfer diffusion effect.

TABLE V: THE CHARGE TRANSFER RESISTANCE AND IONIC CONDUCTIVITY OF THE P0, P1 AND P2 ELECTROSPUN NANOFIBERS.

Sl. No	Samples	Charge Transfer Resistance (Rct) Ω	Ionic Conductivity (S/cm)
1	P0	29.71	2.22x 10-2
2	P1	33.27	2.00x10-2
3	P2	36.04	1.84x10-2

Photoelectrochemical measurements: Photoelectrochemical (PEC) measurements are used to study how materials behave under light and electrical bias. They involve studying the interaction between light, electrochemical reactions, and semiconductor materials [14]. These measurements typically track how efficiently a material can absorb light and generate charge carriers that drive redox reactions at the electrode–electrolyte interface. In Figure 9, transient photocurrent responses for all samples were depicted. Current rises when light is ON and drops when light is OFF. Repeatable behavior indicates good photostability and switching performance. The material responds quickly and reversibly to light, which is crucial for sensors or phototransistors. The sample P2 shows that highest photocurrent and high stability.

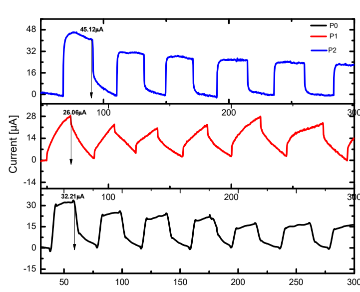


Figure 9: Transient photocurrent response for samples P0,P1 and P2.

Mott-Schottky: As depicted in Figure 10 below, this is a Mott-Schottky (M-S) plot of samples P0, P1, and P2. All three samples had negative slopes; hence, all were p-type semiconductors. It is possible to calculate the flatband potential value (EFB) from the intersection of the linear line of M-S plot on the x-axis. The values of EFB for samples P0, P1, and P2 are +0.105 V, 0.135 V, and +0.095 V, respectively. In the accumulation mode, the sample is negatively biased. Consequently, holes move towards the semiconductor/electrolyte interface. The potential of the flat band is referred to as the potential at which the bands (valence and conduction) of a semiconductor are flattened in the presence of an electrolyte.

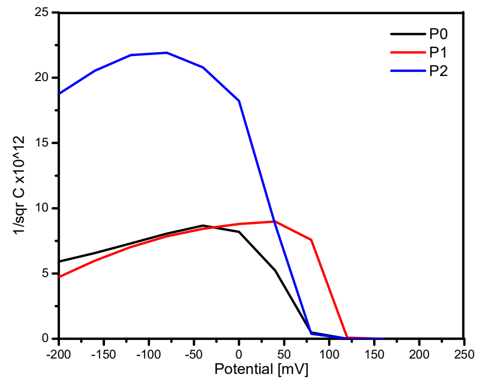


Figure 10: Mott–Schottky plot of P0, P1 and P2

From the results, it can be seen that, the flat band potential obtained from the slope calculation is close to 0V. Flat band potentials were listed in Table 6. Flat band potential is nearer to the valence band edge.

TABLE VI: FLAT BAND POTENTIAL FOR SAMPLES P0, P1 AND P2.

Sl.No	Samples	Flat band potential (V)
1	P0	0.105
2	P1	0.135
3	P2	0.095

I-V Curves: The graphs depicting the relationship between the current (I) and voltage (V) for samples P0, P1, and P2 are provided in Figure 11. As evident from Figure 11, sample P0 displays linearity of the graph denoting ohmic behaviour, while P1 and P2 have exhibited non-linearity of graphs denoting the behaviour of diodes. In all cases, initially no current flows until a certain critical voltage level (approximately 0.2-0.3 Volts) is reached. The critical point for each of these samples is same, implying almost similar activation conditions in all of them. However, the rise in the current-voltage ratio is steepest in P0, thereby depicting highest conductance. While P2 shows lowest conductance, implying highest resistance. Slope of the graph in an I-V curve indicates conductance, P0 > P1 > P2, in order of increasing conductance.

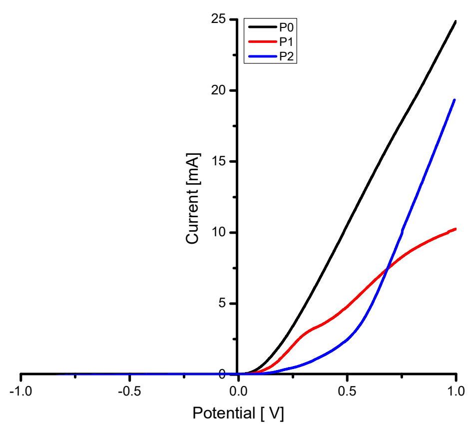


Figure 11: The I−V curves of the samples P0, P1 and P2

IV. Conclusion

Polycarbazole has been prepared by precipitation technique. The nanofiber specimens have been synthesized by electrospinning technique. It is the first time that PCz and PS along with the filler Al2O3 have been examined for their morphology, structure, and optical properties. The characterization of the samples was carried out using SEM, EDX, XRD, FTIR, and UV-Visible spectroscopy. The results clearly show the presence of PS, PCZ, and Al2O3 substances. XRD and FTIR analyses confirm the crystallinity and strong interactions of the compounds with the filler, respectively. The observed UV absorption bands indicate the presence of UVC region which contains maximum energy. Band gaps for direct and indirect transition have been determined from the Mott-Davis-Tauc relation and reveal that the material is an insulating type. With an increase in concentration, there will be a slight increase in the band gap. With the Electrochemical test conducted on the samples of nanofibers, it is revealed that it is a p-type material. It has high ionic conductivity but low charge transfer resistance. From the IV characteristics, it has been identified that the P0 sample exhibits ohmic properties. P0 is better performing electrically when compared with P1 and P2. P1 and P2 exhibit poor electrical performance because of high concentrations of fillers. From PEC tests, it is found that P2 sample shows high photo current.

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