Chapter 4

Investigations on the Electrical and Structural Properties of Polyaniline Doped With Camphor Sulphonic Acid

4.1. Introduction

Ever since the discovery of polyacetylene, the field of conducting polymers became an attractive research topic for chemists, physicists and electrical engineers alike [1]. In recent years much of the attention is devoted to the study of the semiconducting properties of these polymers. Among the various conducting polymers, polyaniline, polypyrrole and polythiophene need special mention owing to their potential applications [2-7] and interesting properties. In that, polyaniline is unique because the electrical properties vary with respect to their oxidation states of the main chain and protonation of the imine nitrogen atoms.

The wide range of electrical, electrochemical and optical properties of polyaniline along with its excellent stability makes it a useful electronic material for various applications. Some of the potential devices based on polyaniline are organic light emitting diodes [8], low power rechargeable plastic batteries, gas sensors, super capacitors, photovoltaic cells [9], liquid crystal displays [10,11] and Schottky devices [12-14]. Bulk polyaniline in its pure form is an insulator and dopants like camphor sulphonic acid, methane sulphonic acid and hydro chloric acid enhance the electrical conductivity of polyaniline [15]. The enhancement of the conductivity in these materials is either by the generation of extended states in doped molecules or by charged defects with electronic structures [16].
Incorporation of dopants also modifies the structural properties of polyaniline. This modification plays an important role in improving the conductivity of the polymer.

Pure polyaniline and polyaniline doped with camphor sulphonlic acid is synthesised in the bulk. The electrical, structural and morphological properties are evaluated. The results are explained based on the crystallinity and morphology of the samples. This chapter deals with the analysis of these results.

4.2. Sample Preparation

Polyaniline is prepared by the direct oxidation of aniline using an appropriate chemical oxidant [17, 18]. The method employed for preparing PANICSA is cited in section 2.6.2 of chapter 2.

4.3. X - Ray Diffractogram

XRD scans for polyaniline emeraldine base (PANI EB) and polyaniline doped with camphor sulphonlic acid (PANICSA) were recorded using a Rigaku D Max C. X - ray diffractometer with Cu Kα radiation (λ=1.5415Å). The samples were scanned at the rate of 1° per minute in the reflection mode over a range of 2θ from 5°-35°.

The X Ray diffractograms obtained for PANIEB and PANICSA are depicted in Fig. 4.1. It has been reported that the crystallinity of the polyaniline sample depends on the conditions set during the synthesis of the polymer [19]. The XRD pattern of polyaniline emeraldine base powder shows distinct peaks at 2θ ≈ 9.80°, 10.75°, 12.10°, and 20.60°. The peak at 2θ = 20.60° indicates that the PANIEB is amorphous. The reported value for this amorphous peak is at 2θ = 19.30° [20].
Fig. 4.1. XRD Scans of Powdered PANIEB and PANICSA

However, in the case of polyaniline doped with camphor sulphonic acid, broad and weak diffraction appeared at $\theta = 13.90^\circ$, $15.40^\circ$, $17.55^\circ$, $21.38^\circ$, $22.84^\circ$, and $24.88^\circ$. In the case of PANIEB the amorphous peak is at $\theta = 20.60^\circ$. But the corresponding peaks for PANICSA were observed at $15.40^\circ$, $17.55^\circ$, and $21.38^\circ$. This is an indication that doping induces certain amount of crystallinity in the samples. However, the appearance of an appreciably sharp crystalline peak at $\theta = 15.40^\circ$ for CSA doped PANI with a weak crystalline peak at $\theta = 24.88^\circ$ may also be due to the change in the crystalline form of the sample. From the X-ray diffractogram, (Intensity versus $2\theta$) the crystallinity index of the sample was calculated by employing a formula put forwarded by Manjunath et al.'s [20]. According to this, the resolution of the peak R is given by
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\[ R = \frac{m_1 + 2m_2 + \ldots + m_{n-1}}{h_1 + h_2 + \ldots + h_n} \]  \hspace{1cm} (4.1)

where \( m_1, m_2, \ldots \) are the heights of minima between two peaks and \( h_1, h_2, \ldots \) are the heights of peaks from the base line.

From the resolution of the peak (R), the lateral order or the index of the crystallinity (1-R) was calculated. The percentage of crystallinity for PANICSA has been estimated by employing the relation (4.1) and it has been found to be 56%.

4.4. Morphology

In order to confirm the crystallinity of polyaniline doped with camphor sulphonatic acid, the SEM of polyaniline emeraldine base and polyaniline doped with camphor sulphonatic acid has been carried out by using JEOL Scanning Electron Microscope and is shown in Fig. 4.2. (a) and (b). In PANIEB, the particles are seen agglomerated without much interparticle spacing.

![Fig. 4.2. A. Scanning electron micrographs of PANIEB](image)
The grain size is ~ 0.6 μm. However, in PANICSA the particles can be seen distinctively. The grain size is ~ 0.8 μm. From SEM and XRD studies, it can be concluded that polyaniline doped with Camphor sulphonic acid is more crystalline than that of polyaniline emeraldine base.

4.5. FTIR Studies

Fig. 4.3. shows the FTIR spectrum polyaniline emeraldine base and polyaniline doped with camphor sulphonic acid.

In the PANICSA Spectrum the peaks at 1475 cm$^{-1}$, 1558 cm$^{-1}$ indicate that the aromatic ring is retained in the polymer. Also it exhibits two distinct peaks at 2926 cm$^{-1}$ and 2960 cm$^{-1}$. These peaks are assigned to the C-H stretching. The peak at 3432 cm$^{-1}$ shows the stretching of NH Group. The peak at 1286 cm$^{-1}$ corresponds to the C-H in plane of deformation [21]. Also the peaks at 792 cm$^{-1}$, 1042 cm$^{-1}$ correspond to the sulphonic acid group. The existence of a peak at 1738 cm$^{-1}$ shows that the ketone group [22] is in tact.
However, in the FTIR Spectrum of PANIEB, there are no peaks corresponding to sulphonic acid group and ketone group. Hence it is concluded that the monomer aniline is getting polymerised and the sulphonic acid group is attached to NH group. Based on FTIR spectra and further analysis a plausible structure of PANICSA is suggested and is as shown in Fig. 4.4.

Fig. 4.3. FTIR Spectra of PANIEB & PANICSA

Fig. 4.4. Structure of PANICSA
4.6. Dielectric and AC conductivity Studies

The powdered polyaniline doped with camphor sulphonic acid samples were pressed in the form of pellets with a diameter 10 mm. Dielectric permittivity studies were carried out on these samples by using a home made four probe dielectric cell and an HP 4285A LCR meter in the frequency range 100KHz to 2MHz in the temperature range 300K to 373K under the dynamic vacuum (10^{-2} Torr).

![Dielectric permittivity vs Temperature](image)

**Fig. 4.5. Variation of Dielectric permittivity with Temperature**

The variation of dielectric permittivity with temperature and frequency is shown in Fig. 4.5. and Fig. 4.6. The value of dielectric permittivity varies from 73 - 136. When temperature increases, the dielectric permittivity also increases and it decreases with frequency. From Figs. 4.5. and 4.6. it is seen that in the lower temperature regime the change in dielectric permittivity is small but it rises thereafter. Also the increase is rapid at higher temperatures.
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Fig. 4.6. Variation of Dielectric permittivity with Frequency

The increment of dielectric permittivity is rapid above 360K. The increase of dielectric permittivity with temperature could be related to the well-known phenomenon that the polarisation increases with temperature, which was found to be valid in a wide range of materials [23]. This is due to the effect of interfacial polarisation caused by space charges and microscopic filed distortion [24]. If the applied field is increased the probability of tunneling of electrons between molecules is also increased which cause high dielectric permittivity and dielectric loss.

The variation of ac conductivity with frequency for different temperatures is shown in Fig. 4.7. When frequency increases the ac conductivity also increases with temperature. The variation of $\sigma_{ac}$ is small at lower temperatures and shows rapid change at higher temperatures. $\sigma_{ac}$ can be written with the help of the following equation [25].

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where $\omega$ is the angular frequency and $n$ is the index which is characteristic of the type of conduction mechanism/relaxation mechanism dominant in amorphous materials. The value of $n$ evaluated from Fig. 4.7. is around 0.045 both at lower and higher temperatures.

![Fig. 4.7. ac Conductivity of PANICS A as a function of frequency](image)

**Fig. 4.7.** ac Conductivity of PANICS A as a function of frequency

Fig. 4.8. shows the characteristics dependence of the ac conductivity with temperature at different frequencies. The activation energy calculated from these plots is 0.069 eV. The activation energy required for hopping process for materials with higher dielectric permittivity is assumed to be quite low. Also because of this low activation energy, a weak temperature dependence of electrical conductivity is expected to appear around room temperature [26].
4.7. DC Conductivity Studies

The current voltage measurements were carried out on these samples and the characteristics are studied. The sample shows ohmic behaviour without any breakdown. The variation of dc conductivity with temperature is plotted and is shown in Fig. 4.9. The conductivity value of PANICSA calculated at room temperature is around 27 S/cm. The temperature dependent of DC conductivity indicates that the observed metallic DC conductivity is due to only a small fraction of delocalised carriers which are primarily localised in metallic islands and that the achievable conductivity for such systems when the entire charge carriers density participates surpasses that of copper [6]. It has also been shown that the relaxation of an electric field in a charge carrier system is attributable to the charge hopping of mobile carriers, which can lead to both short-range $\sigma_{dc}$ and long-range $\sigma_{dc}$. The activation energy is calculated by employing the following relation.
\[ \sigma_{dc} = \sigma_0 \exp \left( - \frac{E_A}{K_B T} \right) \] (4.3)

Where \( \sigma_0 \) is constant. \( E_A \) is the activation energy and \( K_B \) is the Boltzmann Constant. The activation energy calculated is around 0.015 eV. The disagreement between the activation energy value of \( \sigma_{ac} \) and \( \sigma_{dc} \) suggests that the hopping conduction mechanism plays an important role for the conduction process [27].

![Graph](image)

**Fig. 4.9.** DC Conductivity of PANICSA as a function of temperature

### 4.8. Conclusion

From the FTIR spectrum and further analysis it can be concluded that the sulphoninic acid group is attached to the polyaniline chain without altering the aromatic ring. The retention of the aromatic ring in the polymer structure is responsible for the high thermal stability to the material. X Ray diffraction studies indicate that the doping of polyaniline with camphor sulphoninic acid modifies the
structure. The percentage of crystallinity was calculated and found to be increasing. This is in conformity with the findings of electron micrography studies. The dielectric studies on PANICSA proved that the cross-linked polymers possess good dielectric behaviour at higher temperatures. It is known that the dependence of conductivity on frequency and the low activation energies of the carriers are indicative of a hopping conduction mechanism. It can be seen that doped PANICS A is semiconducting.
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Chapter 5

Studies on Polyaniline - Tetrameric Cobalt Phthalocyanine Composites

5.1. Introduction

Organic and metallo organic polymers gained importance because of their electrical, electronic, non-linear optical, electrochemical and photochemical applications [1-4]. In order to make use of these polymer compounds for specific applications they are modified either by co-polymerisation or by making blends with other polymers [5]. The production of blends using organic and metallo organic polymers is an attempt to obtain new polymeric materials by combining properties of the components of the blend [6,7]. The use of blends/composites in various electric and electronic devices attracted attention because of their conductive properties, chemical stability and low price. Among the many conducting polymers, polyaniline seems to be one of the best candidates for preparing conducting polymer composites since it is stable both thermally and environmentally [8-11]. The blends of polyaniline doped with sulphonic acid [12], phosphoric acid in different polymers such as polymethyl methacrylate [13], cellulose [14] and polyurethane [15] have been investigated. Electrical properties of polyaniline blended with other polymers are relatively different from the pure polyaniline. Along with the incorporation of insulating polymers into conducting polymers, introducing polymeric/oligomeric phthalocyanine into polyaniline matrixes are also investigated [7,16]. A conductive composite using polyaniline and polymeric phthalocyanine can be used as a rechargeable batteries [16].

In this chapter optical, electrical and morphological studies on blends of polyaniline - oligomeric cobalt phthalocyanine are discussed. The dielectric and
conductivity measurements of polyaniline at different proportions with oligomeric cobalt phthalocyanine are carried out for different temperatures and the conduction mechanism in these composites is explained based on the Mott's variable range hopping model.

5.2. Preparation of PANICSA - CoPc Composites

Powdered polyaniline doped with camphor sulphonic acid (PANICSA) was blended with tetrameric cobalt phthalocyanine (CoPc) by mixing them homogeneously in an agate mortar for several hours. The method of preparation of both the polymers is explained in section 2.6.3 of chapter 2.

5.3. FTIR Studies

The FTIR Spectrum of tetrameric cobalt phthalocyanine and PANICSA/CoPC composites are as shown in Fig. 5.1. and 5.2. respectively.

![FTIR Spectrum](image)

**Fig. 5.1. FTIR Spectrum of tetrameric cobalt phthalocyanine**

In Fig. 5.1. the peak at 721cm\(^{-1}\) is attributed to non-polar deformation vibrations of the CH bonds of benzene ring [17]. The peaks at 1460cm\(^{-1}\), 1307cm\(^{-1}\)
are indicative of skeletal stretching vibrations of C-C in benzene ring and the characteristic peak for C=N skeletal stretching vibration is also noted at 1517 cm\(^{-1}\) [18]. Metal ligand vibration band is observed at 904 cm\(^{-1}\) for tetrameric cobalt phthalocyanine indicating the stability of the metal phthalocyanine, which is due to the strong bonding between the metal ion and four surrounding nitrogen atoms [19]. The CO stretching and OH deformation confirm the presence of COOH, which is characterised by the band 1696 cm\(^{-1}\). Moskalev and Kirin found an intense band at 1006 cm\(^{-1}\)-1008 cm\(^{-1}\) and Stymne observed at 1539 cm\(^{-1}\) for NH vibration in metal free phthalocyanine [20,21]. The absence of these peaks in Fig. 5.1. suggests that the sample doesn’t have any metal free phthalocyanine.

IR spectra of polyaniline with tetrameric cobalt phthalocyanine blends show peaks at 715-733 cm\(^{-1}\), 904-1038 cm\(^{-1}\), 1081-1100 cm\(^{-1}\) and 1695-1728 cm\(^{-1}\), which are attributed to phthalocyanine skeleton [22-24]. In addition to that the bands at 1460-1479 cm\(^{-1}\), 1578-1597 cm\(^{-1}\), 1234-1299 cm\(^{-1}\) and 1129-1142 cm\(^{-1}\) are corresponds to the polyaniline [25].

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**Fig. 5.2.** FTIR Spectra of Conducting polymer composites

a. PANICSA 90 CoPc 10: b. PANICSA 50 CoPc 50: c. PANICSA 10 CoPc 90
In that the bands at 1234-1299 cm\(^{-1}\) and 1129-1142 cm\(^{-1}\) show that the incorporated polyaniline in composites is camphor sulphonic acid doped polyaniline. Apart from these the peaks at 1695-1728 cm\(^{-1}\) in the blends correspond to \(-\text{COOH}\) group. These data prove that the respective cobalt phthalocyanine tetramer is incorporated into polyaniline matrix.

5.4. Dielectric Studies

5.4.1. Dielectric Permittivity

A typical set of graphs depicting the dielectric behaviour of the conducting polymer composites of polyaniline with tetrameric cobalt phthalocyanine over frequency range 100KHz-5MHz at different temperatures were carried out and is shown in Figs. 5.3 - 5.8.

Fig. 5.3. Variation of dielectric permittivity of CoPc10 PANICSA90 at different temperatures
Fig. 5.4. Variation of dielectric permittivity of CoPc50 PANICSA50 at different temperatures

Fig. 5.5. Plot of frequency vs dielectric permittivity for CoPc90 PANICSA10
Fig. 5.6. Variation of dielectric permittivity of CoPc10 PANICSA90 at different frequencies

Fig. 5.7. Temperature vs dielectric permittivity of CoPc50 PANICSA50
Fig. 5.8. Variation of dielectric permittivity of CoPe90 PANICSA10 at different frequencies

The pattern of variation of dielectric permittivity for all compositions is almost similar and the values at 373 K for 1 MHz are tabulated and are shown in Table 5.1.

Table 5.1.
Value of Dielectric permittivity of cobalt phthalocyanine, polyaniline doped with camphor sulphonlic acid and their composites

<table>
<thead>
<tr>
<th>Sample</th>
<th>Dielectric Permittivity [373K, 1MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoPc</td>
<td>50.78</td>
</tr>
<tr>
<td>CoPe90 PANICSA10</td>
<td>65.71</td>
</tr>
<tr>
<td>CoPe50 PANICSA50</td>
<td>104.99</td>
</tr>
<tr>
<td>CoPe10 PANICSA90</td>
<td>98.86</td>
</tr>
<tr>
<td>PANICSA</td>
<td>105.26</td>
</tr>
</tbody>
</table>
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The value of dielectric permittivity at 1MHz of oligomeric cobalt phthalocyanine at 373K is 50.78 and it increases with increase of polyaniline concentration, till both PANICSA and CoPc are at equal proportions and after that it decreases. However the value of dielectric permittivity of CoPc10 PANICSA90 approaches towards the PANICSA value. This shows that the tetrameric cobalt phthalocyanine doesn’t influence the dielectric permittivity of composites.

The dielectric permittivity increases with increase of temperature and at each temperature it decreases monotonically with increasing frequency. This may be due to the tendency of induced dipoles in macromolecules to orient themselves in the direction of the applied field when the frequency of alternation is low. However at high frequencies the induced dipoles will hardly be able to orient themselves in the direction of the applied field and hence the dielectric permittivity decreases [26]. Frequency dependence of the dielectric permittivity in these composites is more pronounced at lower frequencies. This is because the interfacial polarisation plays an important role in these composites at lower frequencies. This polarisation will arise only when the phases with different conductivities are present [27]. Conducting polymers and its composites show high dielectric permittivity due to the large effective size of metallic islands in these compounds and easy charge transfer through well-ordered chains in disordered regions.

5.4.2. Dielectric Loss

The dielectric loss vs frequency curves for composites are presented in Figs. 5.9. - 5.11. The loss factor decreases with increase of frequency and increases with temperature. This is usually associated with ion drift, dipole polarisation or interfacial polarisation [28]. The increase of dielectric loss with decreasing frequency is very rapid at low frequencies. Also the study of miscibility in blends/composites by dielectric relaxation involves the assessment of one or more loss peaks. In binary blends one or multiple loss peaks will occur [29]. These blends does not exhibit peaks except in the case of CoPc90% PANICSA10% composition. In the case of CoPc90% PANICSA10% mixture there appears a peak in the
dielectric loss curve at higher frequencies. Also the loss peak is shifted towards the higher frequency as the temperature increases. This shift in the loss peak is in accordance with the Debye theory of orientation.

![Graph showing variation of dielectric loss of CoPc90 PANICSAn at different temperatures](image)

Fig. 5.9. Variation of dielectric loss of CoPc90 PANICSAn at different temperatures

This indicates that CoPc90% PANICSAn10% mixture behaves more like CoPc. The appearance of a peak only in this composition is because of the extended conjugated structure of CoPc tetramer, which causes delocalisation of the charge and hence the peak shift towards higher frequency. As polyaniline content increases in the mixture, the mixture exhibits the characteristic of polyaniline itself because of very high conductivity of polyaniline there by leading to loss peak at lower frequency. This dielectric loss behaviour is in accordance with the dielectric permittivity behaviour observed for the same blends.
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Fig. 5.10. Plot of frequency vs Dielectric loss for CoPc50 PANICSA50

Fig. 5.11. Dielectric loss vs frequency curves for CoPc10 PANICSA90
5.5. AC Conductivity

AC conductivity of the composite samples is calculated from the measured dielectric permittivity and dielectric loss. Variation of AC conductivity of conducting polymer composites with frequency for different temperatures is shown in Figs. 5.12 – 5.14.

![Graph showing AC conductivity variation with frequency](image)

**Fig. 5.12.** Variation of AC conductivity of CoPc90 PANICSA10 with frequency at different temperatures

From the curves it is seen that in samples with high concentration of CoPc frequency dependence is predominant whereas in the sample with high concentration of PANICSA show less frequency dependence. This is because the incorporation of phthalocyanine materials in conducting polymers improves the charge storage capacity of the blends. The ac conductivity obeyed the empirical relation of the form [30]

\[ \sigma_{AC}(\omega) = A\omega^s \]  

(5.1)
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Fig. 5.13. Variation of AC conductivity of CoPc50 PANICSA50 with frequency

Fig. 5.14. Variation of AC conductivity of CoPc10 PANICSA90

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The variation of exponent $s$ with temperature gives information about the conduction mechanism involved. The value of $s$ is less than 1 for all samples. An increase in AC conductivity with frequency and weak temperature dependence indicates that there may be charge carriers, which are transported by hopping through the defect sites along the polymer chain [31].

5.6. DC Conductivity

To investigate the charge transport mechanism in composites, the temperature dependence of the electrical conductivity is studied in the temperature range 70K to 300K for all compositions. The temperature dependence of dc conductivity for different volume fractions of polyaniline doped with camphor sulphonate acid is shown in Fig. 5.15.

![Graph](image)

**Fig. 5.15.** Temperature dependence of dc conductivity of composites

In semiconductors, if the main conduction mechanism is due to the carriers excited beyond the mobility edge into non-localised or extended states, the dc conductivity is expressed as [30]
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\[ \sigma_{dk} = \sigma_0 \exp \left( - \frac{E_a}{kT} \right) \]  \hspace{1cm} (5.2)

Where \( \sigma_0 \) is the proportionality constant, \( E_a \) the activation energy, \( k \) the Boltzmann constant and \( T \) is the temperature.

The conductivity increases with increase of temperature for all compositions and it increases with increase of volume fraction of polyaniline doped with camphor sulphonic acid (PANICSA). The activation energy values are evaluated from the graph (Fig. 5.15.) and it is found that this decreases with increase of volume fraction of polyaniline doped with camphor sulphonic acid. The low values of activation energy implies that the conduction is due to the excitation of carriers into mobility edge and/or to the localised states at the band edges which is inadequate to explain the conduction mechanism.

The conductivity data is analysed with the help of Mott’s Variable range hopping. In polymers with non-degenerate ground states, the charge transport is due to polarons and bipolarons \([32,33]\). This mechanism is consistent with the existence of high-density states in the band gap. Charge carrier localisation may give rise to the formation of polarons and the charge transport may be considered due to the variable range hopping. According to Mott’s Theory the conductivity is expressed as

\[ \sigma = \sigma_0 \exp \left[ - \left( \frac{T_0}{T} \right)^N \right] \]  \hspace{1cm} (5.3)

In this equation, if \( N=1/2 \) or \( 1/4 \) corresponds to the variable range hopping conduction in one dimension or in three dimension respectively. Where \( T_0 \) is the Mott’s characteristic temperature and is explained in chapter 3. \( \log \sigma \) vs \( T^{-1} \). \( \log \sigma \) vs \( T^{-1.4} \) are plotted for composites and are shown in Figs 5.16.- 5.18.
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Fig. 5.16. $\ln \sigma_d$ vs $T^{-1.4}$ for CoPc90 PANICSA10

Fig. 5.17. $\ln \sigma_d$ vs $T^{-1.4}$ for CoPc50 PANICSA50
From the plots Mott’s characteristic temperature is evaluated. Based on the obtained $T_0$ and using appropriate relation Mott’s parameters for composites are calculated and are tabulated in Table 5.2.

**Table 5.2.**

Mott’s parameters for composites

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mott Temperature</th>
<th>$N (E_F)$ cm$^{-3}$ eV$^{-1}$</th>
<th>$R_{hop}$ (Å) 100K</th>
<th>$W_{hop}$ (eV) 100K</th>
<th>$E_a$ (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoPc 90 PANICSA 10</td>
<td>$1.7187 \times 10^8$</td>
<td>$1.2225 \times 10^{23}$</td>
<td>1.5626</td>
<td>0.3119</td>
<td>0.095</td>
</tr>
<tr>
<td>CoPc 50 PANICSA 50</td>
<td>$1.1929 \times 10^7$</td>
<td>$1.7614 \times 10^{22}$</td>
<td>3.044</td>
<td>0.16</td>
<td>0.049</td>
</tr>
<tr>
<td>CoPc 10 PANICSA 90</td>
<td>$1.376 \times 10^6$</td>
<td>$1.527 \times 10^{22}$</td>
<td>5.22</td>
<td>0.052</td>
<td>0.029</td>
</tr>
</tbody>
</table>
From Table 5.2, it is seen that depending on the volume fraction of polyaniline, density of states at the Fermi energy, range of hopping, energy for hopping of composites are changed. Not only the Mott’s parameters the conduction mechanism also changes. The available literature indicates that the conduction mechanism of unblended polyaniline is one dimensional variable range hopping. But tetrameric cobalt phthalocyanine follows the three-dimensional hopping conduction. From our observations, it is clearly seen that tetrameric cobalt phthalocyanine and polyaniline composites follows the three-dimensional hopping conduction.

5.7. Morphology

Fig. 5.19 represents the electron micrographs of polyaniline - tetrameric cobalt phthalocyanine composites. From Fig. 5.19, it is seen that the distribution of the polymer depends on the volume fraction of the polymers in composites. This is clearly seen in our conductivity measurements. That is Depending on the volume fraction of the polymer the conductivity value is changed.
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5.8. Conclusion

Blends of polyaniline and tetrameric cobalt phthalocyanine are prepared. The incorporation of tetrameric cobalt phthalocyanine into polyaniline matrix is confirmed with the help of FTIR spectrum. The dielectric studies of these blends are carried out in the frequency range 100KHz – 5MHz and the corresponding dielectric loss are compared. From I-V studies it is clear that variable range hopping conduction is the dominant conduction mechanism in the blends and it
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obeys the 3D type mechanism. The conduction mechanism is explained with the help of Mott's theory and the conduction parameters are determined. Distributions of polymer components in conducting polymer composites are confirmed with the scanning electron micrographs.
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