CHAPTER 5

STUDIES OF GEL POLYMER ELECTROLYTE

\[(100-x) \text{(BPE-I): } x\text{EC (x=10,20,30 and 40 in mol%)\]}\]

In the present work, free standing gel polymer electrolyte (GPE) based on PVA:PVdF:LiCF$_3$SO$_3$:EC have been prepared by solution casting technique. Appropriate quantities of each constituent were individually dissolved in DMF. The dissolved polymers, salt and plasticizer solutions were mixed together and stirred continuously at 60°C until homogeneous solutions were obtained. The obtained solutions were cast onto the petri dishes and dried for 24 hours. The resulting films were flexible and free standing. Thickness of the films has been found to be in the range of 100µm.

The following four different compositions of gel polymer electrolytes have been prepared:

- 90 (80mol% PVA:20mol% PVdF:15 mol% LiCF$_3$SO$_3$): 10mol%EC
- 80 (80mol% PVA:20mol% PVdF:15 mol% LiCF$_3$SO$_3$): 20mol%EC
- 70 (80mol% PVA:20mol% PVdF:15 mol% LiCF$_3$SO$_3$): 30mol%EC
- 60 (80mol% PVA:20mol% PVdF:15 mol% LiCF$_3$SO$_3$): 40mol%EC

Effect of plasticizer in BPE-I blend polymer electrolyte have been analyzed using XRD, FTIR, AC impedance spectroscopy, TG-DTA, stress-strain curve, LSV and CV technique.
5.1 XRD ANALYSIS

XRD pattern is the useful tool to analyze the structure and degree of crystallinity of polymer electrolytes. Figure 5.1a shows the XRD pattern for BPE-I and figure 5.1b depicts XRD pattern for different mol% (10, 20, 30 and 40) of EC incorporated in BPE-I polymer electrolyte.

Figure 5.1 XRD pattern of (a) BPE-I and (b) different mol% of EC incorporated in BPE-I gel polymer electrolyte

The major two diffraction peaks has been observed one at 20° corresponding to amorphous nature of BPE and another at 41° corresponding to overlapping of BPE and EC. It confirms the complete miscibility of polymer host and EC in all GPE systems. Incorporation of EC decreased the diffraction peak intensity and increased the peak broadness compared to BPE-I (un-plasticized system). This is may be due to the addition of EC that makes the polymer chains more flexible and thereby enhances the segmental motion (Ramesh et al. 2011). It supports the greater disorder in its arrangement leading to the increase of amorphous content in all GPE systems. Increasing the amount of EC in BPE-I decreases the degree of crystallinity up to 30 mol%. Hence, the least intense peak has been observed for 30 mol% EC doped system. Above the saturation level (30 mol%), degree of crystallinity increases which may be due to the high viscosity of the system that restricts the formation of amorphous phase.
5.2  FTIR ANALYSIS

FTIR spectroscopy is used to observe the bond vibration in the host polymer and the interactions that occur in the polymer - salt complexes. FTIR is carried out to confirm the complex formation in polymer electrolytes. Figure 5.2 shows the FTIR spectra of BPE-I and different concentration of EC (x=10,20,30 and 40 mol%) incorporated in BPE-I polymer electrolyte system.

![FTIR Spectra](image)

Figure 5.2  (a) FTIR spectra of BPE-I and different mol% of EC incorporated in BPE-I (b) magnified region (3200-400 cm\(^{-1}\))

The observed changes in the vibrational peaks in BPE-1 by the addition of EC have been listed in table 5.1. A broad band appears at 3500cm\(^{-1}\) in all composition is due to O–H bending alcohols in PVA. The minor peak obtained at 1031 cm\(^{-1}\) in all systems show SO\(_3\) symmetric vibrations of CF\(_3\)SO\(_3^-\) anion (Bishop et al. 1996). It specifies the more number of interactions of the lithium salt with the host polymer matrix by the dissociation process. The ring breathing mode of EC (746 cm\(^{-1}\)) has been shifted in all the plasticized systems (Bishop et al. 1996). This may be due to the interaction of lithium ions with the oxygen of EC.
Table 5.1 FTIR vibrational peak assignments of different mol% of EC incorporated gel polymer electrolytes

<table>
<thead>
<tr>
<th>Peak assignments</th>
<th>Absorption peak of (100-x)(BPE-I): xEC in cm⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BPE-I</td>
</tr>
<tr>
<td>C-H (stretching)</td>
<td>2921</td>
</tr>
<tr>
<td>C-H (asymmetric stretching)</td>
<td>-</td>
</tr>
<tr>
<td>CH₂ (symmetric stretching)</td>
<td>2315</td>
</tr>
<tr>
<td>C=O (stretching)</td>
<td>-</td>
</tr>
<tr>
<td>C-O (bending)</td>
<td>-</td>
</tr>
<tr>
<td>CF₂ (stretching)</td>
<td>-</td>
</tr>
<tr>
<td>SO₃ (symmetric)</td>
<td>1031</td>
</tr>
<tr>
<td>-CF₂ (symmetric stretching)</td>
<td>-</td>
</tr>
<tr>
<td>ring breathing mode</td>
<td>-</td>
</tr>
<tr>
<td>-CF₂ (bending)</td>
<td>578</td>
</tr>
</tbody>
</table>

The peak shift, disappearance and presence of new peaks in FTIR spectra confirm the complex formation between the polymer blend, lithium salt and the plasticizer (Song et al. 1999) and it is represented in figure 5.3. The scheme shows the interaction of Li⁺ ions with 88% hydrolyzed PVA, PVdF and EC.
Figure 5.3 Interaction of lithium ions (from LiCF$_3$SO$_3$) with (a) 88% hydrolyzed PVA, (b) PVdF and (c) EC

5.3 AC IMPEDANCE SPECTROSCOPY ANALYSIS

5.3.1 Conductance Plot Analysis

The impedance spectroscopy is an effective and an excellent tool for studying the ionic conductivity of the polymer electrolytes. Figure 5.4a depicts the conductance plot of BPE-I and figure 5.4b shows the conductance plot of different mol% EC (10, 20, 30 and 40) incorporated in BPE-I at 303 K.

Figure 5.4 Conductance plot of (a) BPE-I at 303 K and (b) different mol% of EC incorporated in BPE-I at 303 K
Conductance plot shows two well defined regions: frequency independent plateau region and low frequency dispersion region (space charge polarization). Extrapolation of plateau region to the y-axis gives the dc conductivity value.

**Figure 5.5** Variation of ionic conductivity with different mol% of EC at 303 K

Figure 5.5 shows plot of variation of ionic conductivity with different mol% of EC at 303 K. Initially, the addition of 10mol% EC decreases the ionic conductivity compared to BPE-I (region-I) which may be due to the formation of ion pairs. Further increasing the concentration of EC, ionic conductivity of GPE system increases (region-II) upto 30mol%. For 30mol% EC added system mobile ions are expected to travel long distance in the amorphous region thus leading to the enhanced ionic conductivity. Beyond 30mol% of EC, ionic conductivity (region-III) decreases which may be due to increase in viscosity of polymer matrices that impedes the movement of charge carriers. The obtained result is well in agreement with XRD pattern.

The highest ionic conductivity obtained for EC added system (30mol% EC possess highest ionic conductivity of $7.6 \times 10^{-4}$ Scm$^{-1}$) at 303 K is
low compared to BPE-I which may be due to the increase in viscosity that hinders the motion of free ions. Hence, 30mol% EC incorporated system is designated as GPE-I in the forthcoming sections.

**Figure 5.6 Conductance plot of GPE-I at different temperature**

Figure 5.6 depicts the conductance plot of GPE-I at different temperature. The calculated values are listed in table 5.2. As the temperature increases, the plateau region shifts towards higher frequency region (figure 5.6). This may be due to the electrode polarization effects. The charge that has been build-up at the electrodes decreases the effective applied field across the polymer electrolyte thereby enhances the ionic conductivity. Because the increase of temperature leads to flexibility of the polymer backbone, through which charge carriers can moves easily in the plasticizer rich phase leading to an enhanced ionic conductivity.
Table 5.2 Ionic conductivity values of BPE-I and different concentration of EC incorporated in BPE-I at different temperature

<table>
<thead>
<tr>
<th>Temperature (K)</th>
<th>Ionic Conductivity of different composition of (100-x)(BPE-I):x(EC) polymer electrolyte</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BPE-I x10^-3 (Scm^-1)</td>
</tr>
<tr>
<td>303</td>
<td>2.7</td>
</tr>
<tr>
<td>313</td>
<td>3.5</td>
</tr>
<tr>
<td>323</td>
<td>4.3</td>
</tr>
<tr>
<td>333</td>
<td>6.0</td>
</tr>
<tr>
<td>343</td>
<td>6.2</td>
</tr>
<tr>
<td>353</td>
<td>7.2</td>
</tr>
</tbody>
</table>

5.3.2 Complex Impedance Plot Analysis

Figure 5.7 Complex impedance plot of a) BPE-I at 303 K and (b) different mol% of EC incorporated in BPE-I at 303 K

The conductivity (σ) of the all the prepared gel polymer electrolytes was calculated from the impedance plot by using measured bulk resistance (R_b) for the known area (A) and thickness of the film (l) using the relation (4.2).
The bulk resistance was obtained from the intercept of high frequency semicircle or low frequency spike with the real-axis.

Figure 5.7a shows the complex impedance plot of BPE-I at 303 K and figure 5.7b depicts the complex impedance plot of different mol% of EC incorporated in BPE-I at 303 K. On the addition of 10mol% EC, the semicircle followed by spike has been observed (inserted plot in figure 5.7b) which may due to the combination of resistance and capacitance at the electrode and electrolyte interface. However, the semicircle disappears for the electrolytes beyond 10mol% of EC indicating that the migration of ions through the amorphous phase of polymer matrix. The appeared spike in the low frequency region is due to the electrode polarization phenomenon (Polu & Rhee 2015).

On increasing the addition of EC, the spike has been shifted towards left side upto 30mol% which reveals that decrease in bulk resistance at 303 K. Compared to all GPE systems, the least bulk resistance has been observed for GPE-I leading to higher ionic conductivity. This is because, increasing the addition of plasticizer provides liquid like medium thereby increases amorphous content of polymer electrolytes which leading to enhancement in conductivity upto GPE-I composition and it is well correlated with XRD.

However, the addition of EC above GPE-I the ionic conductivity decreases which may be due to the increase of viscosity that restricts the mobility of the lithium ions. However, compared with BPE-I, bulk resistance increases for all GPE systems which may be due to the restriction for the mobility of charge carriers in gel polymer electrolyte systems (Song et al. 2000). The conductivity value obtained from complex impedance plot is well in accordance with conductance plot.
Figure 5.8 Complex impedance plot of GPE-I at different temperature

Figure 5.8 shows the complex impedance plot of GPE-I at different temperature. The spike appeared at all temperature is due to the double layer capacitance at the blocking electrodes. As the temperature increases, resistance of gel polymer electrolyte decreases which may be due to the enhancement of flexibility of polymer chains. It favors fast mobility of Li$^+$ ions through the plasticizer rich phase at higher temperature.

5.3.3 Temperature Dependence Ionic Conductivity

Figure 5.9 Temperature dependence ionic conductivity of (a) BPE-I and (b) different concentration of EC incorporated GPE
Ionic conductivity of the BPE-I and different mol% of EC incorporated in BPE-I as a function of temperature have been shown in figure 5.9a and figure 5.9b respectively.

The temperature dependence ionic conductivity of BPE-I obeys Arrhenius relation [already been explained in the chapter 4 (section2)] whereas GPE systems has been found to obey VTF relation since the ion transport is associated with segmental motion. Vogel-Tamman-Fulcher relation (5.1) is expressed by:

$$\sigma = \sigma_0 T^{-1/2} \exp \left(- \frac{E_a}{k(T-T_0)} \right)$$

(5.1)

where $\sigma_0$ is pre-exponential factor, $E_a$ is the activation energy, $k$ is Boltzmann constant, $T$ is temperature, $T_0$ quasi-equilibrium is glass transition temperature.

The amorphous content of the polymer matrix increase at higher temperature which enhances the segmental motion and also lowers the glass transition temperature (Abraham & Alamgir 1990 and Bohnke et al. 1993). The higher amorphous nature also delivers a more free volume in the polymer electrolyte system upon increasing the temperature in all GPE systems. This, in turn favors fast ion movements which describes the transport properties in a viscous matrix. It supports the idea that the ion moves through the plasticizer-rich phase and accordingly the conductivity of the polymer electrolyte becomes high (Subba Reddy et al. 2003). Whereas, in BPE-I ion transport follows the hopping mechanism in the amorphous region of polymer matrix.

5.3.4 Dielectric Studies

A broad frequency range of dielectric relaxation spectroscopy is a very useful tool to study the relaxation of dipoles in polymer electrolytes.

Figure 5.10a depicts the real part of dielectric permittivity for BPE-I at 303 K and figure 5.10b depicts the real part of dielectric permittivity for
different mol% of EC (10, 20, 30 and 40) incorporated in BPE-I gel polymer electrolyte at 303 K.

![Image](image1.png)

Figure 5.10 Real part of dielectric permittivity for (a) BPE-I at 303 K and (b) different mol% of EC incorporated in BPE-I at 303 K

High dielectric constant has been obtained at lower frequency region in both BPE-I and GPE systems. This high dielectric constant is corresponds to the presence of space charge effects. It is due to the free charge that builds up at the interface between the polymer electrolyte and the electrodes. However $\varepsilon'$ has been found to be decreases at higher frequency. When the frequency is increased, the dipoles find themselves unable to keep in pace with the fast changing field, so that the dielectric constant decreases with increasing frequency. At higher frequencies, $\varepsilon'$ decreases and then reaches saturated state.

Compared to four compositions (figure 5.10b), GPE-I possess high dielectric constant at 303 K. However the obtained dielectric constant is slightly lower than the BPE-I which may be due to the increase of viscosity, resulting immobilization of polymer segments in GPE systems that impede the free ion motion. The obtained result is good agreement with conductivity studies.
Figure 5.11 Real part of dielectric permittivity for 30mol% EC incorporated BPE-I at different temperature

Figure 5.11 shows the real part of dielectric constant for GPE-I at different temperature. From the plot, $\varepsilon'$ increases with increasing temperature. This is the typical behavior expected in polar dielectrics, in which dipoles orientation occurs easily. At higher temperature, the influence of EC provides liquid like medium which increases mobility of free ions leads to higher dielectric constant.

Figure 5.12 Imaginary part of dielectric permittivity for (a) BPE-I and (b) different composition gel polymer electrolyte at 303 K
Dielectric loss factor ($\varepsilon''$) is a direct measure of energy dissipated and it is generally composed of the contributions of the ionic transport and the polarization of the charge or dipole. Figure 5.12a depicts the imaginary part of dielectric permittivity ($\varepsilon''$) for BPE-I and figure 5.12b shows the imaginary part of dielectric permittivity ($\varepsilon''$) for different concentration of EC incorporated in BPE-I at 303 K. At lower frequencies, very large of $\varepsilon''$ in both BPE-I and GPE systems are due to free charge motion within the material (Sheha et al. 2012). From the figure 5.12b it is clear that, higher dielectric loss has been observed for 30mol% EC doped BPE-I compared to other composition of GPE systems which may due to the more number of charge carriers within the material. However compared to BPE-I, $\varepsilon''$ has been found to be lower for GPE-I which may be due to the increase of viscosity in GPE-I that restricts the Li$^+$ ion transport.

Figure 5.13 Imaginary part of dielectric permittivity for GPE-I at different temperature

Figure 5.13 depicts the imaginary part of the dielectric permittivity ($\varepsilon''$) at different temperature for GPE-I. It is clear that, imaginary part of the dielectric permittivity increases with increasing temperature at all frequency. This phenomenon leads to conductivity Relaxation. Dielectric relaxation peak has been obtained in GPE-I system is caused by the local movement of the side
group dipoles which is so called β- relaxation. Dielectric relaxation has been obtained from the dielectric loss peak as a function varying frequency.

5.3.5 Modulus Analysis

Electric modulus represents the dielectric relaxation process. Frequency dependence of real part of modulus spectra for different mol% of EC incorporated in BPE-I at 303 K have been shown in figure 5.14.

Figure 5.14 Frequency dependence of $M'$ plot for different concentration of EC incorporated in BPE-I at 303 K

At lower frequency, $M'$ value approaches zero indicating the negligible contribution of electrode polarization. The spectra of $M'$ versus log $\omega$ in both BPE-I and GPE systems shows that the $M'$ values increases with increasing frequency which is due to conductivity relaxation phenomenon which indicates prepared polymer electrolyte systems are ionic conductors and this is attributed to the bulk of the material. Since there is particular time for charges to build up at the interfaces before the field changes the direction in $M''$. The obtained maximum of rising curve in BPE-I has been shifted to low frequency region by the incorporation of EC upto 30mol%. Lower value of $M'$ has been obtained for BPE-I compared to GPE-I which may be due to fast mobility of
charge carriers. Figure 5.15 shows the M' plot of GPE-I at different temperature. It is clear that, M' decreases with increasing temperature at all frequency.

Figure 5.15 Real part of modulus (M') plot for 30mol% of EC incorporated BPE-I at different temperature

Figure 5.16 Frequency dependence of M'' plot for (a) BPE-I at 303 K and (b) different concentration of EC incorporated in BPE-I at 303 K

Frequency dependence of M'' plot for BPE-I and different concentration of EC incorporated in BPE-I at 303 K is shown in figure 5.16a and figure 5.16b respectively. It exhibited long and flat tail at low frequency region for both BPE-I and GPE systems. This is attributed to the large capacitance
associated with electrodes. As the frequency increases M" value has been increased and reached the maximum at higher frequency region which may be due to the bulk effect of the material. It indicates the short range mobility of ion carriers. 30mol% of EC incorporated system possesses lowest M" compared to other GPE systems. M" peak has been found to be absent at 303 K for all composition is due to the experimental frequency limitation.

Temperature dependence M" plot of GPE-I has been shown in figure 5.17. Increasing the temperature, the M" shifted to lower value at all frequency. It indicates dielectric relaxation in GPE-I which confirms the mobility of charge carriers. It leads to higher ionic conductivity as evidenced from conductance plot.

![Figure 5.17 Imaginary part of modulus (M'') plot for 30mol% EC incorporated BPE-I at different temperature](image)

5.3.6 Ionic Transference Number Measurement

Transference number is used to find the ionic contribution to the total charge transport by measuring the residual electronic current passing through the electrolytes. Ionic transference number (t_ion) of gel polymer electrolyte was measured by Wagner’s polarization technique.
A fixed dc potential applied across the blocking electrodes and the corresponding current has been measured for one hour for highest conducting GPE-I. Figure 5.18 shows the current vs time plot of GPE-I. Transference number was calculated using the relation in equation 4.7 by using the initial current [sum of ionic (I_i) and electronic (I_e) current] and final current [electronic current]. Transference number for 30mol% EC incorporated system (GPE-I) is found to be 0.98. Also t_{ion} for all GPE systems has been found to be close to unity. It confirms that charge transport in the gel polymer electrolytes is predominantly due to ions & very negligible contribution by the electrons.

5.4 DSC ANALYSIS

DSC analysis has been examined to correlate the glass transition temperature (T_g) and melting temperature (T_m) with the amorphousness and the ionic conductivity of the polymer electrolytes. Figure 5.19a shows the DSC curve of BPE-I and figure 5.19b shows DSC curves of different concentration of EC incorporated in BPE-I.
The glass transition temperature and melting temperature of BPE-I and gel polymer electrolytes calculated from DSC thermogram have been listed in table 5.3. Both the glass transition temperature and the melting temperature have been decreased with increasing the addition of EC, up to 30mol%. This may be due to the softening effect and complex formation (scheme in figure 5.3) by the addition of plasticizer. It is clear that, GPE-I show the lowest $T_g$ (90.7°C) and $T_m$ (166.6°C) compared to other GPE systems. This may due to the addition of plasticizer that makes more flexible in the polymer backbone leading to high amorphous nature thereby enhanced ionic conductivity (as confirmed in conductance plot). However, for greater concentrations of plasticizer (above 30mol% EC), $T_g$ and $T_m$ has been found to increase which may be due to the increase in viscosity of polymer matrix at higher concentrations which increases the degree of crystallinity. The result is well in accordance with XRD analysis. However, $T_m$ of all the GPE systems has been found to be higher compared to BPE-I which may be due to the higher degree of crystallinity by the influence of EC.
Table 5.3 Glass transition and melting temperature of different mol% of EC incorporated BPE-I

<table>
<thead>
<tr>
<th>(100-x)(BPE-I):xE</th>
<th>Glass transition temperature (°C)</th>
<th>Melting temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPE-I</td>
<td>- (below the measured temperature range)</td>
<td>158</td>
</tr>
<tr>
<td>x=10</td>
<td>101.1</td>
<td>174.5</td>
</tr>
<tr>
<td>x=20</td>
<td>99.9</td>
<td>169.1</td>
</tr>
<tr>
<td>x=30</td>
<td>90.7</td>
<td>166.6</td>
</tr>
<tr>
<td>X=40</td>
<td>99.1</td>
<td>168.8</td>
</tr>
</tbody>
</table>

5.5 THERMO GRAVIMETRIC ANALYSIS

Thermal stability of the prepared polymer electrolytes have been studied using TGA curve.

Figure 5.20 TG-DTA curve of (a) BPE-I and (b) GPE-I

Figure 5.20a and figure 5.20b shows the TG-DTA curve of BPE-I and GPE-I respectively. TGA curve of GPE-I exhibit the three step weight loss region. There is no distinct weight loss observed upto 144°C indicating the slight enhancement in thermal stability compared to BPE-I (130°C). Initially, slight weight loss (5%) occurred in first step between 144°C-275°C corresponding to
removal of absorbed moisture during sample loading and trace amount of plasticizer during sample preparation. In general, polymer blend exhibits two step degradation reflects the decomposition of host polymers. The second step degradation has been appeared in the range of 275°C-390°C with 20% weight loss is due to the decomposition of polymer chain in PVA (Chun-Chen Yang et al. 2011). Third step degradation after 400°C reveals the complete decomposition of host polymer PVdF with the weight loss of 39%. In this region, C-C and C-H bonds in host polymer breaks and releases the gaseous compounds. As a result, major weight loss occurs.

After 600°C, the residual content of 20.2% has been found in GPE-I which is higher than the BPE-I (figure 5.20a). This may be due to the influence of plasticizer that enhances the flexibility of polymer backbone thereby slightly reduced the decomposition of polymer backbones (Huili Xie et al. 2014).

DTG (figure 5.20b) shows three degradation peaks. The first trivial peak observed at 145°C, in GPE-I corresponds to the removal of moisture or residual plasticizer. The consequent peaks at 300°C and 440°C have been associated with the decomposition of PVA and PVdF respectively and it has been slightly shifted to higher temperature revealing the increase of stability.

5.6 MECHANICAL STRENGTH ANALYSIS

Mechanical properties of the highest ionic conducting polymer electrolyte have been studied using stress-strain relationship. Figure 5.21 shows the stress strain curve of BPE-I and GPE-I. Tensile strength and % elongation of polymer film decides the mechanical properties of the materials.
The measured value of the tensile strength and % elongation at break for prepared GPE-I is 8.6 MPa and 146% respectively. The tensile strength of GPE-I is decreased compared to BPE-I (for BPE-I, tensile strength -10.5 MPa and %elongation at break - 98%). The decrease in the tensile strength in gel polymer electrolyte indicates the reduction of rigidity in the polymer matrix due to the addition of plasticizer (Weili Li et al. 2015). At the same time, increase of %elongation at break suggests the increase in the flexibility of the films and hence the toughness (Ting maa et al. 2013 and Arfat Anis & Al-Zahrani 2012). Enhancement of the elongation by incorporation of EC may be due to the low viscosity plasticizer that support for enhancing the flexibility of the polymer chains and lowering T_g (Sornakumar et al. 2014-2015). In the present study, 30mol% EC incorporated system (GPE-I) possesses higher % elongation and less tensile strength compared to BPE-I.

5.7 LINEAR SWEEP VOLTAMMETRY ANALYSIS

Electrochemical stability of the polymer electrolyte is the essential parameter for the application of lithium ion battery. Electrochemical stability of the polymer electrolytes was measured using LSV. Figure 5.22a shows LSV curve of BPE-I and figure 5.22b depicts LSV curve of GPE-I.
Figure 5.22 Linear sweep voltammetry curve GPE-I vs Li$^+$/Li

The curve represents the electrochemical stability of the GPE-I is 5.6V versus Li$^+$/Li with current density of 0.03 mA/cm$^2$. It is clear from the figure 5.22b, there is no significant decomposition observed below 5V similar to the result of BPE-I. There is no anodic peak observed within the measured potential range confirming the purity of the prepared polymer electrolyte. It has been found that, lower current density (0.06 mA/cm$^2$) has been observed for GPE-I upto 7V which makes it attractive as electrolyte in lithium ion battery. The higher stability of GPE-I is may be due to the major contribution of plasticizer which supports easy mobility of lithium ions.

5.8 CYCLIC VOLTAMMETRY ANALYSIS

Electrochemical stability window of polymer electrolytes has also been investigated for highest ionic conducting GPE-I using CV technique. Cyclic voltammetry of GPE-I is examined by sandwiching the optimized gel polymer electrolyte (GPE-I) between the stainless steel blocking electrodes for 10 cycles and it has been depicted in figure 5.23.
It is clear from figure 5.23, the optimized gel polymer electrolyte (GPE-I) has good cyclicability and reversibility. Decomposition voltage reflects the electrochemical stability window of the polymer electrolyte. The obtained stability window of GPE-I is found to be -2.8 V to 2.8 V vs SS (5.6 V) for GPE-I. This value is higher than the earlier reports on some other polymer electrolyte using SS electrodes reported by Lyungyu Lee et al is 4.7V, Siva kumar et al is 2 V and Ait Albrimi et al is 4.8V (Lyungyu Lee et al. 2013, Siva kumar et al. 2006 & Ait Albrimi et al. 2011). After the stability region, the slight rise has been observed which may due to formation of interfacial layer. The wide electrochemical stability window (~5.6 V) of the GPE-I will be well suitable for lithium ion batteries.