1. Introduction

Lithium-ion batteries (LIBs) have nowadays conquered the market of rechargeable batteries for portable electronic devices\(^1\) and electric vehicles (EVs).\(^2,3\) However, commercial LIBs, employing a graphic carbon anode, carbonate-based organic solvent (e.g. ethylene carbonate (EC) and diethyl carbonate (DEC)) and lithiated transition metal oxide cathode,\(^4\) do not offer the high safety required in the EV field. The unsafe events mainly result from flammable gaseous emission by continuous electrolyte decomposition on the electrodes surface. In addition, high flammability and high vapor pressure of the organic carbonates also present serious safety risks. For these reasons, a facile and intuitive approach to solve the safety problems from the electrolyte is to develop a functionalized electrolyte system with low flammability and extremely high thermal stability.\(^5\)

Room temperature ionic liquid has been worldwide used as LIBs electrolyte due to its high electrochemical stability and nonflammable nature.\(^6\) In particular, the electrolyte systems consisting of ionic liquid and organic solvent have attracted much attention.\(^10\)–\(^14\) These electrolyte systems combine the high electrochemical and thermal stability of ionic liquid and low viscosity of organic solvent resulting in better performance without compromising safety.\(^15\)–\(^18\) For example, studies by Yang \textit{et al.}\(^19\) and Theivaprakasam \textit{et al.}\(^20\) reported the combination of organic carbonate solvents and pyrrolidinium-based IL to improve physico-chemical properties of electrolyte systems. Especially, the electrolyte mixtures containing 30–40% of IL with alkyl carbonates improve the thermal stability without compromising electrochemical performances.\(^21\)–\(^24\) However, the common lithium salt LiTFSI or LiPF\(_6\) strongly corrodes the Al current collector around 3.7 V vs. Li/Li\(^+\), which is detrimental to the performances of LIBs.\(^25\)

Lithium difluoro(oxalato)borate (LiODFB), which combines the advantages of lithium bis(oxalato)borate (LiBOB) and lithium fluoro borate (LiBF\(_4\)), is one of the most promising lithium salts.\(^26\)–\(^30\) Compared to LiBOB, LiODFB is more soluble in linear carbonate solvents and the electrical conductivity of LiODFB-based electrolytes is higher.\(^31\) In addition, LiODFB may also protect the Al foil from corrosion of LiTFSI-based electrolytes. Chen \textit{et al.}\(^32\)–\(^34\) introduced lithium difluoro(oxalato)borate (LiODFB) as lithium salt and dimethyl sulfite (DMS) as co-solvent into IL-based electrolyte to enhance the energy density and rate capability of LiFePO\(_4\)/Li half cells. However, their study doesn’t explicate on the improvement mechanism of electrochemical performance explicitly.
In this work, a novel IL N-allyl-N-methylpiperidinium bis(trifluoromethansulfonyl) imide (PP13-TFSI) will be used as electrolyte solvent because of low viscosity and high conductivity at room temperature resulting from the C-C double bond in PP13 cations side chains.31 On the other hand, moderate amount of dimethyl carbonate (DMC, 20 vol%) is introduced in order to increase the solubility of LiODFB in IL PP13-TFSI (80 vol%). The electrolytes with different concentrations of LiODFB were prepared, e.g. 0.3 mol L\(^{-1}\) LiODFB-PP13-TFSI/DMC (8 : 2 v/v), 0.4 mol L\(^{-1}\) LiODFB-PP13-TFSI/DMC (8 : 2 v/v), 0.5 mol L\(^{-1}\) LiODFB-PP13-TFSI/DMC (8 : 2 v/v), 0.6 mol L\(^{-1}\) LiODFB-PP13-TFSI/DMC (8 : 2 v/v). The charge–discharge performances of the cells with the above electrolytes were tested at the 0.05C rate for the first four cycles and 0.1C rate for the subsequent cycles at room temperature (25 °C). The results were depicted in Fig. S1.† It can be seen that cells with LiODFB concentration of 0.4 mol L\(^{-1}\) containing electrolyte present higher cycling capacity than that cycled with the other electrolytes. In order to investigate the role of PP13-TFSI and DMC in electrochemical improvement, the electrolytes 0.1 mol L\(^{-1}\) LiODFB-PP13-TFSI, and 0.4 mol L\(^{-1}\) LiODFB-DMC were prepared for comparison with the electrolyte 0.4 mol L\(^{-1}\) LiODFB-PP13-TFSI/DMC (8 : 2 v/v). The thermal stability performances of these electrolyte systems have been investigated. Furthermore, the electrochemical tests of Li/LiFePO\(_4\) cells using these electrolyte systems were conducted at room temperature (25 °C) or evaluated temperature (60 °C). Meanwhile, the characterization of solid electrolyte interphase (SEI) on the cycled LiFePO\(_4\) electrodes were carried out using surface characterization techniques.

2. Experimental

2.1. Electrolytes and electrodes preparation

High purity dimethyl carbonate (DMC) (99.99%) was purchased from Aldrich Co. N-allyl-N-methylpiperidinium PP13-TFSI ionic liquid (purity > 99.9%) was provided by Shanghai Chengjie Chemical Co. Ltd and used without further purification. Investigated electrolyte formulations 0.1 mol L\(^{-1}\) LiODFB-PP13-TFSI and 0.4 mol L\(^{-1}\) LiODFB-DMC were prepared by dissolving a certain amount of LiODFB salt into PP13-TFSI and DMC solvent, respectively. 0.4 mol L\(^{-1}\) LiODFB-PP13-TFSI/DMC (8 : 2 v/v) electrolytes was also prepared at volume ratio of 8 to 2 between PP13-TFSI and DMC. All the electrolytes were prepared in an argon filled glovebox.

LiFePO\(_4\) electrodes were prepared by depositing a slurry of 80 wt% artificial graphite, 10 wt% super p conductive additive, and 10 wt% poly(vinylidene fluoride) (PVDF) in N-methylpyrrolidone (NMP) on a piece of aluminum foil. After drying at 60 °C for 6 h, the electrode laminate was cut into pellets with 13 mm diameter and thoroughly dried overnight at 120 °C under vacuum.

2.2. Physical properties measurements

Thermal analysis was carried over a temperature range of 303–773 K in Ar atmosphere at a heating rate of 10 K min\(^{-1}\) by a thermal gravimetric analysis (TGA).

2.3. Electrochemical analysis

Galvanostatical charge/discharge measurements were carried out using the cells with LiFePO\(_4\) as positive electrode at room temperature or elevated temperature by using an Arbin BT2000 (Arbin Instrument, Inc., USA) battery tester. LiFePO\(_4\)/Li half-cell cycling experiments were carried out with a constant charge and discharge rate of 0.05C for the first four cycles and 0.1C for the subsequent cycling in the cutoff voltage range from 2.2–3.9 V and 2.2–4.1 V, respectively.

Electrochemical impedance spectroscopy (EIS) was done on a electrochemical workstation in a frequency range of 100 kHz to 10 mHz with a 5 mV perturbation.

2.4. Characterization of electrode surface and separator

The morphology and the chemical element distribution of the surface of the cycled LiFePO\(_4\) electrodes were investigated by scanning electron microscopy (SEM, Hitachi N–2300NII) and X-ray photoelectron spectroscopy (XPS, Bio-RAD-FTS-60 V spectrometer). The development of the SEI on the LiFePO\(_4\) electrodes surface was observed via transmission electron microscopy (TEM, FEI Tecnai G-20). The surface components of the separators from the cycled cells were studied by Energy Dispersive X-ray Analysis (Oxford EDX system).

3. Results and discussion

The thermal stability of the electrolyte is one of the most keys to battery safety. Generally, the ionic liquids with TFSI\(^-\) anion exhibit the highest thermal stability.32–34 As reported, the allylic ion liquid, PP13-TFSI, starts to decompose at 330 °C.34 Li salt, LiODFB, starts to decompose at 200 °C, and the melting point is about 265 °C.35

Fig. 1A presents the thermogravimetric analysis (TGA) curves of all the studied electrolytes. The neat PP13-TFSI electrolyte 0.1 mol L\(^{-1}\) LiODFB-PP13-TFSI remains stable and is essentially no weight loss up to 300 °C. Compared to the pure ionic liquid PP13-TFSI, the decreased thermal stability results from the LiODFB salt. While for the 0.4 mol L\(^{-1}\) LiODFB-PP13-TFSI/DMC (8 : 2 v/v) electrolyte, the thermal stability is decreased slightly because of the addition of DMC. The weight loss (ca. 6 wt%) is observed and can be attributed to evaporation of the volatile solvents DMC at the initial 100 °C, which is far less than the case of 0.4 mol L\(^{-1}\) LiODFB-DMC. As reported by Huifeng et al.,

![Figure 1](image-url)
the presence of ionic liquid can delay the organic solvent evaporation.\textsuperscript{26}

Fig. 1B shows the differential thermal analysis (DTA) of these electrolytes. For the electrolyte 0.4 mol L\textsuperscript{–1} LiODFB-DMC, the endothermic peaks can be attributed to the evaporation of DMC at 50 °C and decomposition of LiODFB at 250 °C. However, the decomposition temperatures of LiODFB and PP\textsubscript{13}-TFSI are delayed to 370 and 445 °C, respectively, for the electrolyte 0.1 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI, which are attributed to the strong interaction between cations and anions. The decomposition temperature of LiODFB and PP\textsubscript{13}-TFSI are decreased slightly when the DMC is used as co-solvent additive, which is ascribed to the weakened interactions among ions in the presence of molecular solvent. However, it can be noted that the peak intensity of PP\textsubscript{13}–TFSI thermal decomposition is lower for 0.4 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI/DMC electrolyte than the case for 0.1 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI electrolyte, indicating that the weight loss is decreased in per unit temperature. Meanwhile, the peak intensity of LiODFB thermal decomposition becomes strong resulting from higher Li salt concentration. These results confirm the thermal stability is improved for the mixture electrolyte 0.4 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI/DMC.

In order to study the electrochemical stability of these electrolytes, the charge–discharge cycles of LiFePO\textsubscript{4}/Li half-cells were conducted at the 0.05C rate for the first four cycles and 0.1C rate for the subsequent cycles in three electrolytes in the potential range of 2.2–4.1 V, as shown in Fig. 2. Apparently, the 0.1 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI electrolyte shows a great potential separation about 0.14 V between the charge and discharge voltage plateau, as shown in Fig. 2A, and the cells with 0.1 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI electrolyte acquire a first discharge capacity of 132 mAh g\textsuperscript{–1} and a coulombic efficiency of 78.81%. In the cases of 0.4 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI/DMC (8 : 2 v/v) and 0.4 mol L\textsuperscript{–1} LiODFB-DMC, the polarization loss between the charge–discharge voltage plateau become smaller to 0.07 V. Obviously, the use of DMC can decrease the cell polarization.\textsuperscript{27,28} This may be attributed to the effective SEI formation leading to the improved Li ion transport in the electrode and electrode/electrolyte interface. In addition, their first discharge capacities are comparable to the theory capacity (170 mAh g\textsuperscript{–1}). The first discharge capacity and coulombic efficiency arise to 170.5 mAh g\textsuperscript{–1} and 90.4% for 0.4 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI/DMC (8 : 2 v/v) electrolyte as well as 165.2 mAh g\textsuperscript{–1} and 97.05% for 0.4 mol L\textsuperscript{–1} LiODFB-DMC electrolyte. However, the cell with the 0.4 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI/DMC (8 : 2 v/v) electrolyte shows the best stable cycling performance for 150 cycles. After 100 cycles, a discharge capacity of 160 mAh g\textsuperscript{–1} is obtained, thus the capacity retention reach up to 94.1%, as shown in Fig. 2B. The excellent electrochemical cycles can be ascribed to the perfect SEI film on the LiFePO\textsubscript{4} electrodes.

Rate performance is also one of the most important characteristics of Li ion transport. Thus, the rate capability of LiFePO\textsubscript{4} electrodes in different electrolytes were investigated from 0.05C to 2C, as shown in Fig. 3. The discharge capacity of the cells with the electrolytes 0.4 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI/DMC and 0.4 mol L\textsuperscript{–1} LiODFB-DMC could reach up to 168 mAh g\textsuperscript{–1} at lower current densities of 0.05C and 0.1C, which is close to the theoretical capacity of 170 mAh g\textsuperscript{–1}. The discharge capacity of the cells with the electrolytes 0.1 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI is only ca. 130 mAh g\textsuperscript{–1} during the initial five cycles, and the discharge capacity is significantly decreased with the increase of current densities. However, a discharge capacity of the cells with the electrolytes 0.4 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI/DMC is similar to that case with 0.4 mol L\textsuperscript{–1} LiODFB-DMC being capable to keep stable to 1C, while the discharge capacity is ca. 147 mAh g\textsuperscript{–1} and 128 mAh g\textsuperscript{–1} at 2C, respectively, which are much higher than the case with the electrolyte 0.1 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI. Compared to the electrolyte 0.4 mol L\textsuperscript{–1} LiODFB-DMC, the small loss capacity at 2C for the electrolyte 0.4 mol L\textsuperscript{–1} LiODFB-PP\textsubscript{13}-TFSI/DMC is resulted from the higher viscosity in the presence of IL PP\textsubscript{13}-TFSI. However, the discharge capacities are not affected by the viscosity at low rate. In summary, it is suggested that the Li ion transport is improved a lot because of the addition of DMC to the IL.

Electrochemical impedance measurements (EIS) of Li/LiFePO\textsubscript{4} cells with the three electrolytes were carried out after 20 cycles. The obtained Nyquist plots, as shown in Fig. 4A, were fitted with equivalent circuits in Fig. 4B. The use of a Constant Phase Element (CPE) Q instead of a capacitor was due to the existence of depressed semicircles in the system.\textsuperscript{29}A CPE represents a resistor when $n = 0$, a capacitor with capacitance of C when $n = 1$, an inductor when $n = -1$, and a Warburg resistance when $n = 0.5$. The simulation results are listed in Table 1. The relative standard error for most parameters obtained from fitting the experimental impedance spectra are within 10%,
Table 1 Equivalent circuit parameters obtained by simulating experimental impedance spectra after 20 cycles

<table>
<thead>
<tr>
<th>Electrolytes</th>
<th>0.1 mol L(^{-1}) LiODFB-PP(_{13})-TFSI</th>
<th>0.4 mol L(^{-1}) LiODFB-PP(_{13})-TFSI/DMC (8 : 2 v/v)</th>
<th>0.4 mol L(^{-1}) LiODFB-DMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>Values</td>
<td>Error (%)</td>
<td>Values</td>
</tr>
<tr>
<td>(R_{el} (\Omega))</td>
<td>39.14</td>
<td>0.741</td>
<td>6.013</td>
</tr>
<tr>
<td>(Q_{1-V_0})</td>
<td>4.772 \times 10(^{-6})</td>
<td>10.4</td>
<td>2.304 \times 10(^{-6})</td>
</tr>
<tr>
<td>(R_{SS} (\Omega))</td>
<td>0.782</td>
<td>1.230</td>
<td>0.8608</td>
</tr>
<tr>
<td>(Q_{2-V_0})</td>
<td>6.562 \times 10(^{-6})</td>
<td>7.746</td>
<td>1.476 \times 10(^{-6})</td>
</tr>
<tr>
<td>(Q_{1-n})</td>
<td>0.873</td>
<td>1.182</td>
<td>0.8444</td>
</tr>
<tr>
<td>(R_{ct} (\Omega))</td>
<td>2305</td>
<td>2.595</td>
<td>387.2</td>
</tr>
<tr>
<td>(Q_{2-V_0})</td>
<td>2.396 \times 10(^{-4})</td>
<td>14.08</td>
<td>2.506 \times 10(^{-4})</td>
</tr>
<tr>
<td>(Q_{1-n})</td>
<td>0.3026</td>
<td>12.73</td>
<td>0.7678</td>
</tr>
<tr>
<td>(O-V_0)</td>
<td>—</td>
<td>—</td>
<td>2.135 \times 10(^{-3})</td>
</tr>
<tr>
<td>(O-B)</td>
<td>—</td>
<td>—</td>
<td>0.8843</td>
</tr>
</tbody>
</table>

Fig. 4 (A) Nyquist plots of the AC impedance spectra and (B) the equivalent circuits of the LiFePO\(_4\)/Li cells with 0.1 mol L\(^{-1}\) LiODFB-PP\(_{13}\)-TFSI (a), 0.4 mol L\(^{-1}\) LiODFB-PP\(_{13}\)-TFSI/DMC (8 : 2 v/v) (b), 0.4 mol L\(^{-1}\) LiODFB-DMC (c).
In the oxidative reaction of LiODFB, (CO$_2$BF$_2$)$_2$ is formed in the SEI film, which is attributed to the oxidative reaction of LiODFB. It is assumed that the presence of oligomeric species in the SEI makes the surface film elastic.

The B1s peak at 192.42 eV is attributed to LiODFB, which is not observed on the LiFePO$_4$ electrode cycled in the electrolyte 0.1 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI. The F1s peak at 685.8 eV shows the presence of LiF, which may be from the oxidative reaction of ODFB$^-$ and TFSI$^-$ anions in electrolyte. In addition, the F1s peak at 688.5 eV along with C-F peak at 291.1 eV of C1s spectra represents the PVDF.

In addition, the main peak of S2p spectra at 169.4 eV is corresponded to sulfur oxidation state +4, which is not observed in the electrolyte 0.4 mol L$^{-1}$ LiODFB/DMC, indicating that the anion TFSI$^-$ decomposed to join in the SEI formation on the LiFePO$_4$ electrodes cycled in the electrolyte 0.1 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI and 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC. Sulfur oxidation state +4 consolidates the SEI layer by...
adherent compounds Li$_2$SO$_4$. Taking the cycling performance into consideration, the cell with the electrolyte 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC has the excellent cycle stability, revealing that the joint of anions TFSI$^{-}$ and ODFB$^{-}$ enhance the SEI forming ability of the electrolyte, and the concentration of ODFB$^{-}$ play an important role in the improvement of the SEI performance.

Finally, high-temperature electrochemical behaviors of the LiFePO$_4$ electrode were studied. The long cycling performance of LiFePO$_4$/Li cells with two different electrolytes were performed at 60 °C. The results are depicted in Fig. 7. It is found that LiFePO$_4$/Li cell with 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC (8 : 2 v/v) electrolyte shows superior cycling performance, delivering first discharge capacity of 158 mAh g$^{-1}$ and first coulombic efficiency of 90.22% and retaining 162.5 mAh g$^{-1}$ at 30$^{th}$ cycles. However, when 0.1 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI electrolyte was used, capacity fading is significantly accelerated as the cycle numbers was increased. The discharge capacity of 62 mAh g$^{-1}$ was retained at 30$^{th}$ cycles.

To get a deeper insight into the reason of perfect cycle performance, cycled LiFePO$_4$/Li half-cells were disassembled, and the LiFePO$_4$ electrodes were carefully harvested and then analyzed by TEM. TEM micrographs of cycled LiFePO$_4$ electrodes in 0.1 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI and 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC electrolies are shown in Fig. 8. The cycled LiFePO$_4$ electrode in 0.1 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI electrolyte is coated with quite thick film layer, which reveals continuous electrolyte oxidation and parasitic electrode/electrolyte reactions and thus leads to fast capacity fading during cycling. However, the cycled LiFePO$_4$ electrode in 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC electrolyte is covered with a thin and uniform film layer, which suppresses continuous electrolyte/electrode reactions and thus leads to excellent electrochemical stability. The difference between the two surface SEI films results from the changes to the surface film species, as shown in Fig. S2.† The peak of B-O (at 191 eV in the B1s spectrum or at 532.2 eV in the O1s spectrum) is observed on the LiFePO$_4$ electrode extracted from the cell with 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC electrolyte suggested the generation of dimmers (CO$_3$BF$_2$)$_2$ in SEI film. Meanwhile, in the Fe2p spectrum, as discussed in Fig. 6, the main peaks of discharged LiFePO$_4$ electrodes are in good agreement with the pristine material, and the peak characteristic of Fe$^{3+}$ is not appear, indicating the good reversibility of the Fe$^{3+}$/Fe$^{2+}$ redox process upon charge/discharge cycles in electrolyte 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC. These cases are not appear in the spectra of LiFePO$_4$ electrode extracted from cell with 0.1 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI electrolyte. Hence it can be suggested that the addition of DMC increases the solubility of LiODFB in the IL and makes the ability of film-formation of LiODFB salt exhibited obviously at high temperature.

The cells cycled at 60 °C after 30 cycles were dismantled in a glove box and the separators were taken out to be studies by EDX, as shown in Fig. 9. The separators exhibited a apparent difference that can be seen by the naked eyes. The separator in the cell with 0.1 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI electrolyte was deep brownish, however, the separator in the cell with 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC electrolyte was deep white, as shown in the inset of Fig. 9. In order to confirm this, EDX analysis of the separators was carried out. It is apparent that the dissolution of Fe element is suppressed largely in the electrolyte 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC, indicating that an effective SEI film was formed on the LiFePO$_4$ electrode to protect the electrode structure. At the same time, the decrease of F and S elements on the separator surface reveals the small decomposition of TFSI$^{-}$ anions, and the formation of the SEI film in the electrolyte 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC is dominated by the oxidation of ODFB$^{-}$ anions. It is the reason why the capacity retention is higher in the electrolyte 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI than that in the electrolyte 0.1 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI.

4. Conclusions

The electrolyte of 0.4 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI/DMC (8 : 2 v/v) was prepared, and DMC is used to enhance the solubility of LiODFB in IL. PP$_{13}$TFSI. For comparison, the electrolytes 0.1 mol L$^{-1}$ LiODFB-PP$_{13}$TFSI and 0.4 mol L$^{-1}$ LiODFB-DMC...
also were prepared. The LiFePO₄/Li cells were operated with the above three electrolytes at room temperature. In addition, considering the poor thermal stability of electrolyte 0.4 mol L⁻¹ LiODFB-DMC, LiFePO₄/Li cells with electrolytes 0.1 mol L⁻¹ LiODFB-PP₁₃-TFSI and 0.4 mol L⁻¹ LiODFB-PP₁₃-TFSI/DMC (8:2 v/v) were operated at 60 °C.

IL PP₁₃-TFSI exhibits low viscosity and high conductivity at room temperature attributing to the C–C double bond in PP₁₃⁺ cations side chains. Therefore the electrolyte 0.4 mol L⁻¹ LiODFB-PP₁₃-TFSI/DMC (8:2 v/v) possesses low viscosity and satisfying thermal stability. LiFePO₄ cathode also exhibits perfect cycling and rate performances in the electrolyte 0.4 mol L⁻¹ LiODFB-PP₁₃-TFSI/DMC (8:2 v/v). These perfect electrochemical performances can be mainly attributed to two reasons: on the one hand, the addition of DMC increases the solubility of LiODFB in the IL PP₁₃⁻ cations side chains. Therefore the electrolyte 0.4 mol L⁻¹ LiODFB-PP₁₃-TFSI/DMC (8:2 v/v) presents a best electrochemical performances. It is worth noting that the decomposition of ODFB⁻ and TFSI⁻ anions prior to the only ODFB⁻ or TFSI⁻ anions decomposition, LiFePO₄/Li cell in electrolyte 0.4 mol L⁻¹ LiODFB-PP₁₃-TFSI/DMC (8:2 v/v) presents a best electrochemical performances. It is worth noting that the decomposition of ODFB⁻ anion is dominant and TFSI⁻ anion is auxiliary during the formation of SEI film on LiFePO₄ electrode.

In summary, IL cations containing C=C in cations side chains can be regarded as a promising electrolyte solvent candidate because of its low viscosity and high conductivity. Li salt LiODFB should be combined with linear solvent to increase its solubility in IL to improve the electrochemical performance of the electrolyte.

Conflicts of interest

There are no conflicts to declare.

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