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Review—Room-Temperature Ionic Liquids for Electrochemical Application with Special Focus on Gas Sensors

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Room temperature ionic liquids (RTILs) are the most common electrolyte now a day, which is usually a molten salt comprised of cationic and anionic charge, generate a neutral species having high thermal stability and exceptional chemical property. Due to these unique properties, RTILs had been used for many applications as a solvent/electrolyte for decades. There are many RTILs, which possess good conductivity, as well as an optimum electrochemical window, which is suitable for electrochemical sensor application. Among various electrochemical sensors available in the market, the electrochemical gas sensor is a popular device for environmental monitoring. The use of RTILs to the existing technology leads us to new era of sensing where we can able to address sensitivity, stability, robustness, and ability to do multiplex array along with the fundamental behind the electrochemical gas sensor. This paper is consisted of the electrical and electrochemical properties of some popular RTILs along with its application in electrochemical sensing, with a special focus on the electrochemical gas sensor. This review will help the general audience to fabricate the next-gen electrochemical sensor using RTILs.

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Table I. Conductivity and electrochemical window of highly conducting RTILs.

| RTIL                                      | Conductivity | Electrochemical stability | Viscosity |
|-------------------------------------------|--------------|--------------------------|-----------|
| 1-ethyl-3-methyl imidazolium thiocyanate   | 27 mS/cm     | 2.9 V                    | 24.7 cP   |
| 1-ethyl-3-methyl imidazolium dicyanamide  | 21 mS/cm     | 2.3 V                    | 14.6 cP   |

If the conductivity of these species is compared with conventional inorganic salts like NaCl which possesses higher ionic conductivity than these RTILs but it has obvious disadvantages compared to RTILs that the inorganic salts can be operated in low temperature range due to evaporation of water beyond 100°C. Due to its high conductivity both of these species has been used as electrolyte for supercapacitor applications, SO₂ solvation, separation of azeotropic mixtures, desulpharization etc. These RTILs have good electrical conductivity but less electrochemical stability, which inhibits them to use for electrochemical sensing application. By means of electrochemical stability, we are trying to focus on the electrochemical window the molecule can operate based on reduction or oxidation (redox).

\[
\text{Cation}^+ + e^- \rightarrow \text{neutral species}
\]

\[
\text{Anion}^- \rightarrow \text{neutral species} + e^-
\]

The electrochemical stability of cation generally follows this order:

\[\text{Hal}^- < \text{AlCl}_4^- < \text{PF}_6^- < \text{BF}_4^- < \text{N}^- \left(\text{SO}_2\text{CF}_3\right)_2\]

Combinations of these cations and anions can lead to multiple RTILs.

We have tried to review RTIL for different sensor application with a special attention in electrochemical gas sensor in this paper. We will discuss systematically starting from RTIL used in standard electrochemical application based on their conductivity and electrochemical window.

RTIL for Electrochemical Application

When we talk about electrochemical applications, it includes batteries, fuel cells, sensors, metal depositions, electrochemical synthesis etc. Among the electrochemically most stable materials having comparable small conductivities are found to be with a common anion bis(trifluoromethylsulphonyl)imide. Three different compositions using the same anion fragment are hereby described (see Fig. 2). These RTILs are hugely reported for their diverse electrochemical application as electrolyte in battery, fuel cells, metal depositions and electrochemical synthesis of nanoparticles. Their conductivity and electrochemical window is shown in Table II.

Although there are several reports of bis (trifluoromethylsulphonyl) imide based RTILs for different electrochemical applications, still it has some drawbacks due to low conductivity, which inhibits these RTILs applied in electrochemical sensors and supercapacitor applications. These specific electrochemical applications required combined property of both conductivity and electrochemical window. N-methyl-imidazolium based RTILs with anions of tetra fluoroborate and trifluoromethyl sulphonate both shows good conductivity as well as good electrochemical window, depicted in Fig. 3 and Table III.

Electrochemical Sensor Application

The stability, conductivity and wide electrochemical window of selective RTILs are useful for electrochemical sensor application. Using these RTILs and utilizing electrochemical techniques like voltammetry, chronoamperometry, impedometry, conductometry, there are many electrochemical sensors were fabricated which include chemo sensors, actuators, biosensors, gas sensors etc. There are several electrodes ranging from microelectrode to bulk electrode and different electrode materials were used. Carbon nano tube (single walled, multi walled), gold nanoparticles, metal oxide nano particles were also used with RTILs to enhance surface area as well as electro catalytic activity.

**RTIL application for detection, extraction and estimation.**— Since the discovery of electroanalytical techniques for electrochemical application, voltammetry is found to be an excellent tool for electrochemist to monitor diffusion coefficient and concentration of species present in a solution. The technique is applicable to redox reactions where analyte undergoes oxidation and reduction in a liquid or liq-

![Figure 2.](image-url)
Table II. Conductivity and electrochemical window of electrochemically stable RTILs.

| RTIL                                                   | Conductivity | Electrochemical stability | Viscosity |
|--------------------------------------------------------|--------------|--------------------------|-----------|
| Triethylsulphonium bis(trifluoromethylsulfonyl)imide    | 8.2 mS/cm    | 5.5 V                    | 5.2 cP    |
| N-Methyl-N-trioctylammonium bis(trifluoromethylsulfonyl)imide | 2.2 mS/cm    | 5.7 V                    | 530 cP    |
| N-Butyl-N-methylpyrrolidinium bis(trifluoromethylsulfonyl)imide | 2.1 mS/cm    | 6.6 V                    | 0.002 cP  |

Figure 3. (a) 1-ethyl-3-methylimidazolium tetrafluoroborate \([\text{C}_2\text{mim}][\text{BF}_4]\) (b) 1-ethyl-3-methylimidazolium trifluoromethylsulfonate \([\text{C}_2\text{mim}][\text{F}_3\text{MeS}]\).

Table III. Conductivity and electrochemical window of RTILs with combined property.

| RTIL                                               | Conductivity | Electrochemical stability | Viscosity |
|----------------------------------------------------|--------------|--------------------------|-----------|
| 1-ethyl-3-methylimidazolium tetrafluoroborate       | 12 mS/cm     | 4.3 V                    | 33.8 cP   |
| 1-ethyl-3-methylimidazolium trifluoromethylsulfonate | 8.6 mS/cm    | 4.3 V                    | 39.8 cP   |

uid/liquid interface. The electrolyte plays an utmost role in this kind of sensor. The setup is consist of two/three electrode connected with an electrolyte where the species of interest is diffused to the charged electrode surface through the electrolyte depicted in Figure 4.

Generally, water, non-aqueous solvents with supporting electrolyte were used as an electrolyte previously. Later, RTIL become one of the alternative and had been used extensively as electrolyte. Low volatility, high conductivity, excellent electrochemical window and ability to solvate multiple species, makes the RTILs an alternative electrolyte for various electrochemical application including sensor application.

We will discuss various RTIL based voltammetric sensor and then will proceed to amperometric and impedometric sensor with a special focus on gas sensors later. There are many voltammetric sensor reported which can be broadly classified by the interfacial property. We will first talk about solid/liquid interface and then will talk about liquid/liquid interface. Solid/liquid interface depicts the interaction between solid electrode and the liquid RTIL, which is currently one of the mutual interest of scientific community. Moreover, reaction mechanism as a whole was found almost similar for RTIL compared to conventional electrolyte but there are still differences in mechanism for RTIL.\(^{26}\) Lu et al. fabricated an electrochemical sensor using functionalized task specific ionic liquid to detect heavy metal including \(\text{Cd}^{2+}\), \(\text{Pb}^{2+}\) and \(\text{Cu}^{2+}\) using ITO coated 3-electrode setup. The RTIL used in this report, contained a bis-(trifluoromethanesulphonyl)imide \([\text{NTF}_2^-]\) anion and a tetra-alkyl ammonium cation with a carboxylic acid functionalization. The carboxylic group allows the heavy metal oxides to solubilize into the RTIL. Then a fixed potential of \(-1.1\) V was applied for 120 seconds to deposit all the metal ions at the surface of the RTIL modified electrode and then performed stripping voltammetry to get peak currents for \(\text{Cd}^{2+}\), \(\text{Pb}^{2+}\) and \(\text{Cu}^{2+}\), depicted in Figure 5.

They have achieved a very good sensitivity and a low detection for these heavy metals.\(^{27}\) The report suggests that it is possible to tune the surface property of the electrode suitable for specific application. Huang et al. in the other hand used \(\text{Au}_x\text{Zn}_{1-x}\) mesoporous electrode to detect \(\text{Cu}^{2+}\) using stripping voltammetry. The electrode was fabricated by electrodeposition of zinc on gold surface \((\text{Au}_x\text{Zn}_{1-x})\) where \(\text{ZnCl}_2\) is mixed with 1-ethyl-3-methyl imidazolium chloride \([\text{C}_2\text{mim}]\)[Cl], followed by removal of Zn to achieve nanostructured gold electrode. The surface of the gold electrode was then modified
by 3-mercaptopolysulphonate to achieve a self-assemble monolayer and further used for the detection. The RTIL here is not directly used as a transducer in sensing process but it had been successfully utilized as a solvent, which can endure high temperature for the formation of the alloy.28

Regardless of the solid liquid interface, there are many reports the application of RTILs in liquid/liquid interface. The insolubility of many RTIL with water and other non-aqueous solvent creates a phase difference, which is further utilized by a three-phase boundary condition with solid electrode interface/liquid and RTIL. Samee and kakuichi,29 Opallo and Lesniewski30 put a comprehensive review on this application. Ballantyne et al. reported formation of stable liquid/liquid interface with water and several hydrophobic ionic liquids.31 Silvester and Arrigan studied the transport of common ions between the interface of hydrophobic RTIL and water.32 The amount of RTIL inventory is huge for different applications.

New concepts evolved when people synthesizes biological ionic liquid and applies it for liquid phase extraction of protein and even DNA. Ventura et al. provides a comprehensive review about this approach.33 Mondal et al. synthesized several bio-based RTIL mostly made of cholinium cation and anions derived from plants natural acids, and utilized it for extraction of pure Immunoglobin G.34 In another work, they have used similar bio based RTILs to precipitate high purity agarose from agarophyte extract.35

There are many group who had utilized RTILs as a binder for electrochemical application also. The porosity and adsorption ability of RTIL along with its conductivity and electrochemical window helps to solve many unsolved electrochemical problems. Such as, Kim et al. fabricated multi wall carbon nanotube (MWCNT)/ RTIL modified electrode for successful detection of phenolic compounds in red wine.36 Whereas Sun et al. fabricated an ionic liquid based (1-butyl-3 methyl imidazolium hexafluorophosphate [C4mim][PF6]) carbon ionogel electrode for detection of hydroquinone.37

There is an important role of KCl in fabrication of reference electrode and especially screen printed electrode. There are many groups, who have tried to solve this problem by trying to attach KCl in saturated solution form but most of the time the system get more impractical due to problem arises to hold the liquid KCl in an solid surface. Srivastava et al. put an excellent perspective regarding this issue. A novel ionic liquid based practical reference electrode had been fabricated and utilized for potentiometry and stripping voltammetry analysis.38 [C4mim][PF6] had been mixed with Poly(vinylidine fluoride) PVDF and and mixed with AgCl and coated in the surface of graphite-polymer based electrode, termed as Plastic chip electrode. The fabricated reference electrode (Fig. 6) is termed as Plastic chip reference electrode and compared with standard Ag/AgCl (sat. KCl) reference electrode. The reference electrode shows excellent sensitivity in pH, faradaic redox reaction compared with standard reference electrode.

**RTIL based gas sensor.**—RTILs recently shows considerable promise for gas sensor applications due to its non-volatile nature. Gas diffuses directly toward the surface of the RTILs and create non covalent interaction which eventually generates a change in their dielectric as well as capacitive behavior. RTILs were directly put on the surface of the sensor to detect CO2, O2, SO2, H2S, NO2, Cl2 etc. Moreover, RTILs are more or less an excellent candidate to fabricate environmental sensors. The shelf life due to no volatility and high thermal stability (>300°C) makes themselves useful for desorption of gases from their surface to refresh the sensor surface. Saturation of gases into RTIL can create an issue in the response which can be overcome by simple joule heating from the sensor surface as they have high thermal stability. Amperometric gas sensors are widely popular

**Figure 5.** Electrochemical sensor with a thin layer of task specific RTIL as a soluble medium of metal oxide showing distinctive peak in stripping voltammetry analysis.

**Figure 6.** Thin film composition of [C4mim][PF6] and silver chloride encapsulated in PVDF matrix is coated on the surface of graphite-polymer plastic chip electrode to fabricate practical reference electrode.
as the gas diffusion can be controlled at the RTIL/electrode surface by employing suitable potential. Rogers et al. put an excellent review regarding RTIL based gas sensors. The first successful gas sensors had been designed by Clark in 1956. The sensor was consisted of in-house electrode and electrolyte in an container separated by a porous membrane poly(tetrafluoroethylene) (PTFE, Teflon) or polyethylene, having a thickness ranging from 1–200 μM.\(^\text{40}\) The original arrangement is depicted in Figure 7a.

The design creates a complete overlap of the membrane over diffusion layer of the electrode, readily creates a diffusion gradient across the porous membrane which further results a current change which is directly proportional to the concentration of the gas. The current is governed by the famous Cottrell equation:

\[
    i_0 = \frac{nFAc_0}{\sqrt{\pi t}} \quad [1]
\]

Where \(i_0\) = current, in unit A, \(n\) = number of electrons, \(F\) = Faraday constant, 96485 C/mol, \(A\) = area of the (planar) electrode in cm\(^2\), \(c_0\) = initial concentration of the reducible analyte \(j\) in mol/cm\(^3\); \(D_j\) = diffusion coefficient for species \(j\) in cm/s and \(t\) = time in s.

The equation is modified to calculate the transport-limiting current in a one-dimension model (Figure 7a), depicted in Eq. 2.

\[
i_{lim} = \frac{nF \pi r^2 p_i}{d_f/p_e + d_m/p_m} \quad [2]\]

Where, \(i_{lim}\) is the transport-limited current, \(p_i\) is the partial pressure of oxygen in the sample, \(d_f\) and \(d_m\) are the thicknesses of the electrolyte and membrane layers, and \(p_e\) and \(p_m\) are the permeabilities of oxygen through the electrolyte and membrane.

The Clark’s sensor ruled for about 20 years until in 1978, Jensen et al. proposed a new alternative design. Figure 7b represents the design proposed by Jensen et al.,\(^\text{41}\) where they keep the basic design of Clark’s sensor fixed but miniaturize the dimension of the electrode to micrometer scale. This results a partial overlap of the membrane over the electrode diffusion layer. Two dimension model is used to almost define the steady-state behavior perceived at a micro electrode-membrane interface. (Figure 7b) The model accounts for two different diffusion activity at the interface. Axial diffusion of the analyte occurs through the membrane and radial diffusion occurs through the electrolyte layer, depicted in Eq. 3.

\[
i_{lim} = nF\mu r^2 p_i d_m \left[1 + \frac{2}{X_r} \frac{K_1(X_r)}{K_2(X_r)}\right] \quad [3]
\]

Where, \(K_1\) and \(K_2\) are modified Bessel functions of the zero and first order, respectively, and \(X_r\) is a dimensionless radius, defined as Eq. 4.

\[
    X_r = \sqrt{\left(\frac{p_m}{p_e}\right)} \frac{d_m d_e}{d_f}
\]

Compton et al. provided new solution as an alternative of Clark type sensor, where they have used three electrode, instead of cathode and anode used in Clark’ sensor. There arrangement is depicted in Figure 7c uses a micro electrode of radius 2 μM, which generates a controlled diffusion over the electrode surface which does not overlap with the membrane. The protocol was used to fabricate hydrogen sulfide (H\(_2\)S) gas sensor.\(^\text{42}\) This design helps to think further to get rid of the membrane in gas sensor which ultimately drove the same group to design first membrane free gas sensors. The protocol is depicted in Figure 7d.

The arrangement with the microdisk electrode generates a steady state current, depicted in Eq. 5.

\[
i_{lim} = 4nF\tau D_c f (\tau^*) \quad [5]
\]

Where, \(\tau\) is a dimension less parameter can be defined as Eq. 6.

\[
    \tau^* = \frac{4D_t}{r^2}
\]

Although it’s a long way to go to establish such kind of system for practical applications. Hence there are still large number of membrane based gas sensors are available. They proposed a hydrophobic RTIL (tributyl(tetradecyl)phosphonium tris(pentafluoro-ethyl)trifluorophosphate [F\(_{14+6,6.6}\)][FAP]) thin film coated at the surface of gold recessed microelectrodes to detect O\(_2\) in high sensitivity. The use of microelectrodes helped to decrease the IR drop, generally appeared in bulk macro electrode electro.\(^\text{43}\) The same group also reported selective RTIL (1-butyl-3-methyl imidazolidum acetate [C\(_4\)mim][Ac]) for CO\(_2\) detection as they found an interesting chemical complex formed due to reduction CO\(_2\) to CO\(_2\) when potential applied in the RTIL based Pt microelectrode. The formation of the complex allows to interact with the acetate group present in the RTIL which results an excellent carbon sequestration.\(^\text{44}\) They have also reported H\(_2\)S sensor\(^\text{44}\) using [C\(_2\)mim][NTf\(_2\)] and Cl\(_2\) sensor using several RTILs (1-Ethyl-3-methylimidazolidium bis(trifluoroethyl-sulfonyle)imidide [C\(_4\)mim][NTf\(_2\)], 1-butyl-3-methylimidazolidum bis(trifluoromethylsulfonyle)imidide [C\(_4\)mim][NTf\(_2\)], 1-butyl-3-methyltrimidium bis(trifluoromethylsulfonyl)imidide [C\(_4\)mim][NTf\(_2\)], 1-butyl-3-methylimidazolidum tetrafluoroborate [C\(_4\)mim][BF\(_4\)], 1-butyl-3-methylimidazolidum hexafluorophosphate [C\(_4\)mim][PF\(_6\)], 1-Butyl-3-methylimidazolidum trifluoromethanesulfonate [C\(_4\)mim][OTf], and 1-Hexyl-3-methylimidazolidum chloride [C\(_6\)mim][Cl]).\(^\text{45}\) They observed a significant drop of limiting current with increment of sweep rate in cyclic voltammetry. It was concluded as the reduction of the chlorine gas to chloride occurs at the surface of the RTIL modified Pt microelectrode. In the other hand, Ruth et al. proposed a unique technique regarding measurement of diffusivity of CO\(_2\) gas in RTIL. A transient thin liquid film gas uptake technique is used to measure the diffusivity of CO\(_2\) in eight

![Figure 7](https://example.com/figure7.png)

**Figure 7.** (a) Clark’s original design of O\(_2\) sensor, proposed in 1956. (b) Micro-electrode has been used to enhance diffusion at the electrode surface using Clark’s protocol on 1978 (c) Compton et al. proposed 3 electrode design which shows possibility toward membrane free gas sensors (d) Compton et al. proposed RTIL as electrolyte which eliminates the need of membrane to design gas sensors.
commercially available RTIL in different temperature. The measured CO₂ diffusion coefficient was 1 × 10⁻⁶ cm²/s and they compared their result with other reported protocol for measurement of diffusion coefficient of CO₂ in RTIL surface.⁴⁶ Although there were many reports for amperometric CO₂ gas sensors, still some ambiguity was there which drove this research in more advanced direction. Following the footprints of RTIL based amperometric CO₂ gas sensors; our group looked for the specificity of RTIL toward CO₂. Graef et al. reported stable, sensitive and invariance CO₂ sensor based on [C2mim][BF₄] and [C2mim][NTF₂]. A comparative study has been established using spiral screen-printed carbon electrode and interdigitated gold electrode. EIS was measured to check the electrical double layer capacitance and shift from baseline upon addition of CO₂ with N₂ carrier gas. It was found that [C2mim][NTF₂] shows most consistent behavior compared to [C2mim][BF₄] in terms of sensitivity measured as a function of electrical double layer capacitance. The electrode surface also found to play an important role as gold interdigitated electrode was found to be more efficient rather than spiral carbon electrode.⁴⁷ In another report our group utilized fluorinated ionic liquid to study the CO₂ gas sensing on gold interdigitated electrode, depicted in Figure 8.

Two different fluorinated RTIL: [C2mim][BF₄] and [C2mim][FAP] was utilized and EIS was measured to see the interaction of CO₂, ranging from 10–300 ppm with both the fluorinated ionic liquid. Electrical double layer capacitance was measured using EIS and it was found that [C2mim][BF₄] shows more stability compared to although both shows nano-farad deviation from baseline.⁴⁸ Our group, Bhide et al., utilized [MMIM][MeSO₄] and [C2mim][NTF₂] coated on a 2 electrode gold interdigitated electrode and exposed to 25–65% relative humidity to fabricate a humidity sensor. The capacitance was measured at different temperature and it was found that [C1mim][MeSO₄] showed greater sensitivity to humidity than the fluorinated RTIL [C2mim][NTF₂] due to stronger hydrogen bond interaction with RTIL. The thermal stability of the RTIL (>100°C) encourages the fabrication of humidity sensor compared to other thermally unstable substance. The group later put forward in dual absorb electrochemical sensor for the detection of CO₂ and relative humidity using room temperature ionic liquid. Electrochemical window voltages on the performance of non-fluorinated and fluorinated RTILs – 1-methyl-3-methyl imidazolid methane sulphonate [C1mim][MeSO₄], [C2mim][NTF₂], and 1-ethyl-3-methylimidazolium tri(perfluoroethyl)trifluorophosphorate [C2mim][FAP] toward duplex sensing of CO₂ and relative humidity for environmental applications was investigated. It was found that the anion moiety plays a crucial role for duplex sensing. The electrical double layer capacitance was measured in different CO₂ concentrations and different humidity. It was found that from the EIS data that the non-fluorinated [C1mim][MeSO₄] possessed more affinity toward humidity. In the other hand fluorinated RTIL [C2mim][NTF₂] shows more affinity toward CO₂.⁴⁹

Transient Double Potential Amperometry (TDPA) is a widely used method in electrochemistry due to its accuracy, stability and relative ease of operation. The technique is utilized in an unstirred cell. In response to a potential step perturbation, electrochemically active species will diffuse to the surface of the working electrode as a function of the potential applied. At the onset of a forward potential step, a large current arising from ion flux to the electrode surface to balance the change in potential gives rise to a capacitive current, which decays rapidly. The concentration of electrochemically active species near the electrode surface decays with distance from the electrode and the arrival of species to the surface is diffusion limited. Therefore, faradaic current near the electrode surface decays over time as the mass transport limit is reached. The same process, but opposite reaction, arises in the reverse step.⁵⁰ These currents provide a typical exponential decay curve, which is governed by the Cottrell equation. The technique was used in gas sensor experiment by Mason et al.⁵¹ Micro-fabricated gold interdigitated electrode was printed over porous PTFE by photolithography. RTIL is used as an electrolyte and O₂ sensor is fabricated with a very good sensitivity and rapid measurement. Use of RTIL for gas sensor is inevitable but the leakage of liquid RTIL can be a challenge for handling. Hence there are many reports where RTIL is mixed with polymer to get an RTIL/IL composite. The composite discussed above used to make practical reference electrode. Zhang et al. used [C4mim][BF₄] mixed with two different polymer nafion and PVDF and used to fabricate O₂ sensor. Their experimental result depicts a significant improvement in sensing property and excellent stability of the film.⁵² There are many important works published in this regard which cannot be reviewed in a single paper. We have tried to review the most important publications in this field. There are still a lots of room to be addressed such as specificity, possibility of multiplex array sensing and mostly stability of the RTIL film with its maximum degree of freedom.

Conclusions and Future Prospectus

This article has put a perspective toward history and recent developments of RTIL based sensor, starting from electrical and electrochemical property of RTIL which can be up taken for several applications in electrochemical point of view. Electrical and electrochemical window were discussed of few very popular room temperature ionic liquids. We have discussed various RTIL base electrochemical sensor used to detect heavy metals like copper, cadmium, lead etc and important chemical species like phenolic compounds, hydroquinone etc. New bio based ionic liquid was synthesized and used to extract immunoglobulin-G and agaroase, were discussed thoroughly. Technologies like alternative of liquid KCl in reference electrode was also discussed comprehensively. Prime focus was made in RTIL based gas sensors where various reports were discussed ranging from environmental monitor to detection of several important gases. Fundamentals behind their transduction principle was also discussed thoroughly.

Based on the work reviewed here, it was observed although we have reached many important milestones using RTIL as an electrolyte especially for gas sensor, there is still a room, full of opportunity is awaiting especially in this area. RTIL can be functionalized to obtain selective recognition of gas molecule to interact, which will avoid unnecessary interferences. Extensive study by Compton et al. gave us a new degree of freedom where microelectrode along with RTIL can replace the conventional bulk electrode/membrane/electrolyte interface. This can lead to electrochemical gas sensors without membrane where multiple RTIL can be tried out to be as a successor. Transient Double potential amperometry can also be an excellent choice rather than conventional amperometry as it is an excellent tool specifically for measurement for gas diffusion to the electrode surface. Finally, as Newton said “I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me”. Hence, there will be a never-ending limit of scientific discovery, especially in the field of sensor for human need.
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References

1. J. P. Hallett and T. Welton, Chem. Res., 111, 3508 (2011).
2. P. Walden, Bull. Acad. Imper. Sci. (St. Petersburg), 8, 405 (1914).
3. F. H. Hurley and T. P. Wier, J. Electrochem. Soc., 98, 207 (1951).
4. M. J. Earle and K. R. Seddon, Pure Appl. Chem., 72, 1391 (2000).
5. K. Marsh, J. Boxall, and R. Lichtenhaler, Fluid Phase Equilib., 219, 93 (2004).
6. L. Vendra et al., Scr. Mater., 8, 847 (2006).
7. A. P. Fro, H. Kremer, and A. Leipertz, J. Phys. Chem. B, 112, 12420 (2008).
8. C. Schreiner, S. Zugmann, R. Hartl, and H. J. Goeres, J. Chem. Eng. Data, 55, 1784 (2010).
9. G. Sun, K. Li, and C. Sun, J. Power Sources, 162, 1444 (2006).
10. J.-K. Chang et al., Langmuir, 25, 11955 (2009).
11. D. S. Firaha, M. Kavalchuk, and B. Kirchner, J. Solution Chem., 44, 838 (2015).
12. P. D. A. Bastos, F. S. Oliveira, L. P. N. Rebelo, A. B. Pereiro, and I. M. Marrucho, Fluid Phase Equilib., 389, 48 (2015).
13. G. Yu, X. Li, X. Liu, C. Asuman, and X. Chen, Ind. Eng. Chem. Res., 50, 2236 (2011).
14. J. S. Wilkes, J. A. Levisky, R. A. Wilson, and C. L. Hussey, Inorg. Chem., 21, 1263 (1982).
15. B. Garcia, S. Lavallée, G. Perron, C. Michot, and M. Armand, Electrochim. Acta, 49, 4583 (2004).
16. E. G. Yanes, S. R. Gratzi, M. J. Baldwin, S. E. Robison, and A. M. Stalcup, Anal. Chem., 73, 3838 (2001).
17. C. A. Zell and W. Freyland, Langmuir, 19, 7445 (2003).