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(54) **NONAQUEOUS LIQUID ELECTROLYTE**

(76) Inventors: **Bookeun Oh**, 2844 Windsor Dr. #106,
Lisle, IL (US) 60532; **Khalil Amine**,
6813 Penner Pl., Downers Grove, IL
(US) 60516; **Yoo-Eup Hyung**, 2745
Bristol Dr. #309, Lisle, IL (US) 60532;
Donald R. Vissers, 611 Clover Ct.,
Naperville, IL (US) 60540; **Hisashi
Tsukamoto**, 28445 Via Joyce Dr.,
Saugus, CA (US) 91350

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U.S.C. 154(b) by 1021 days.

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filed on Mar. 22, 2002, now abandoned.

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H01M 6/16 (2006.01)
(52) **U.S. Cl.** **429/313**; 429/317; 429/347;
429/307
(58) **Field of Classification Search** 429/300,
429/313, 317, 307, 347; 252/62.2
See application file for complete search history.

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Primary Examiner—Tracy Dove
(74) *Attorney, Agent, or Firm*—Guerilovich Dodd & Lindsey,
LLP

(57) **ABSTRACT**

Disclosed is a nonaqueous and nonvolatile liquid type poly-
meric electrolyte comprising poly(siloxane-g-ethylene
oxide). This electrolyte provides significant safety and stabil-
ity. The present invention solves the problems of volatility,
flammability and chemical reactivity of lithium ion type elec-
trolytes. The disclosed electrolyte exhibits excellent stability,
conductivity and low impedance characteristics. The electro-
lyte comprises a new class of structural siloxane polymers
with one or more poly(ethylene oxide) side chains. The inor-
ganic siloxanes comprising the main backbone of the copoly-
mers are thermally very stable and resistant to decomposition
by heat. Because the main chain of the disclosed class of
electrolytes is an Si—O linkage, initiation of the combustion
cycle is inhibited or prevented.

24 Claims, 6 Drawing Sheets
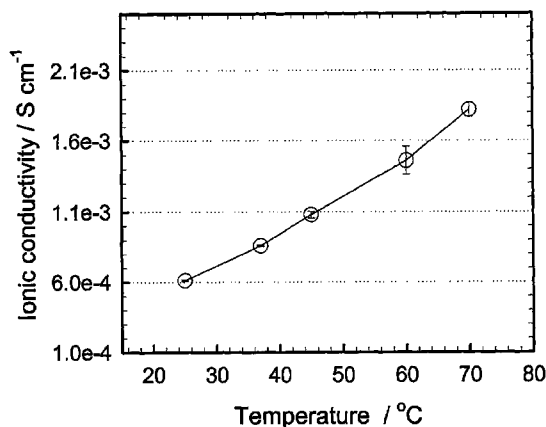
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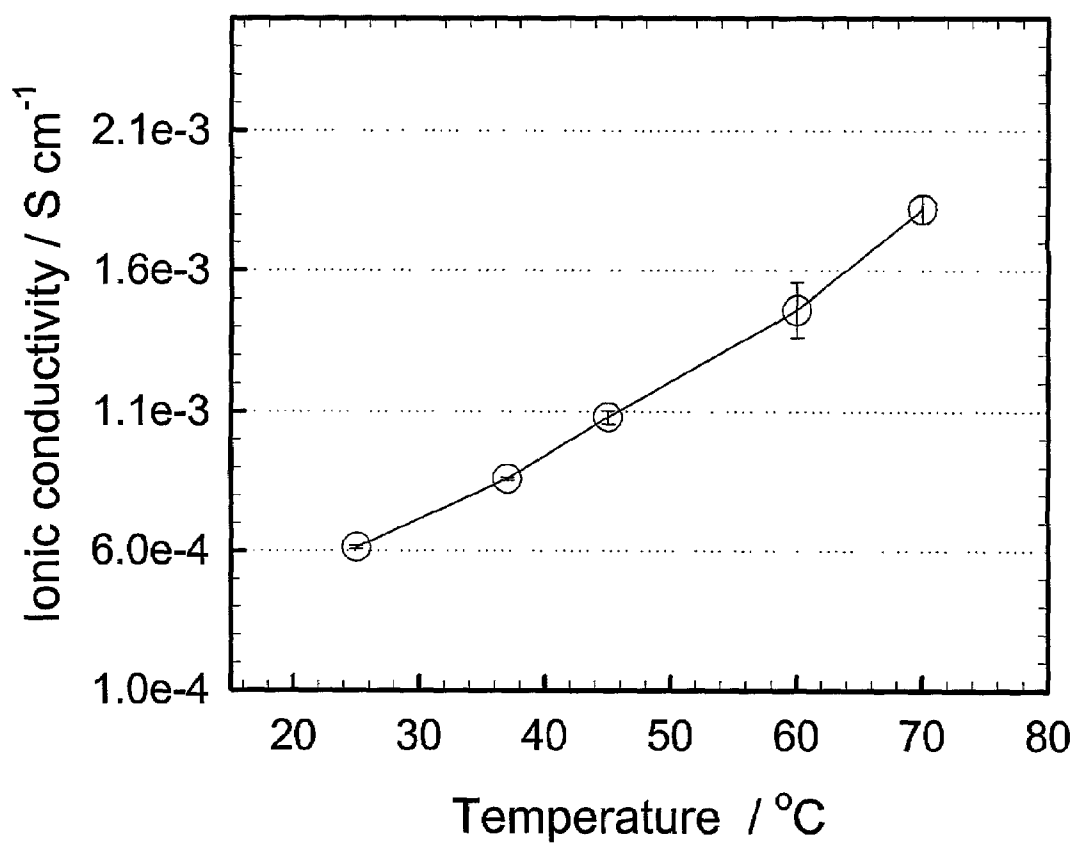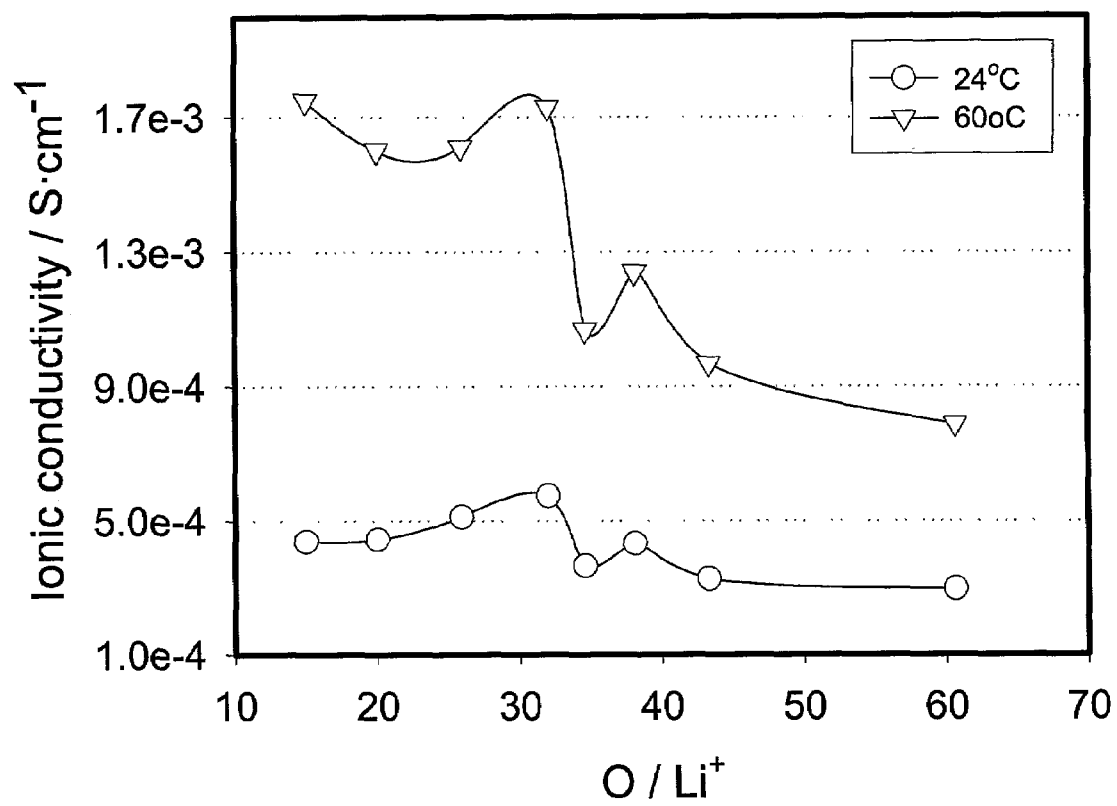
FIGURE 1
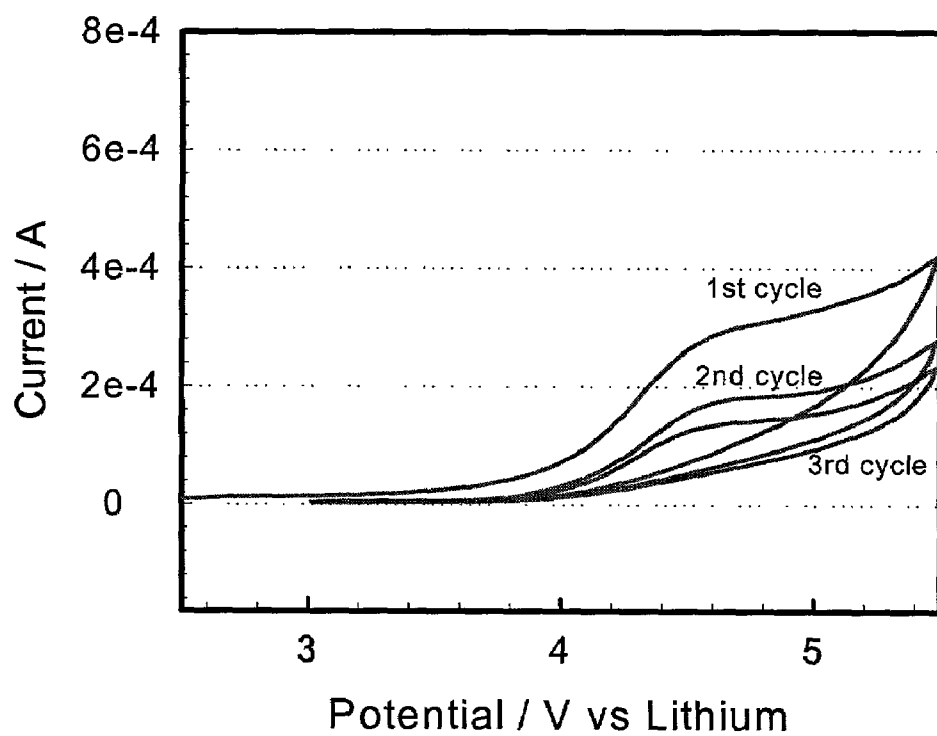
FIGURE 2a
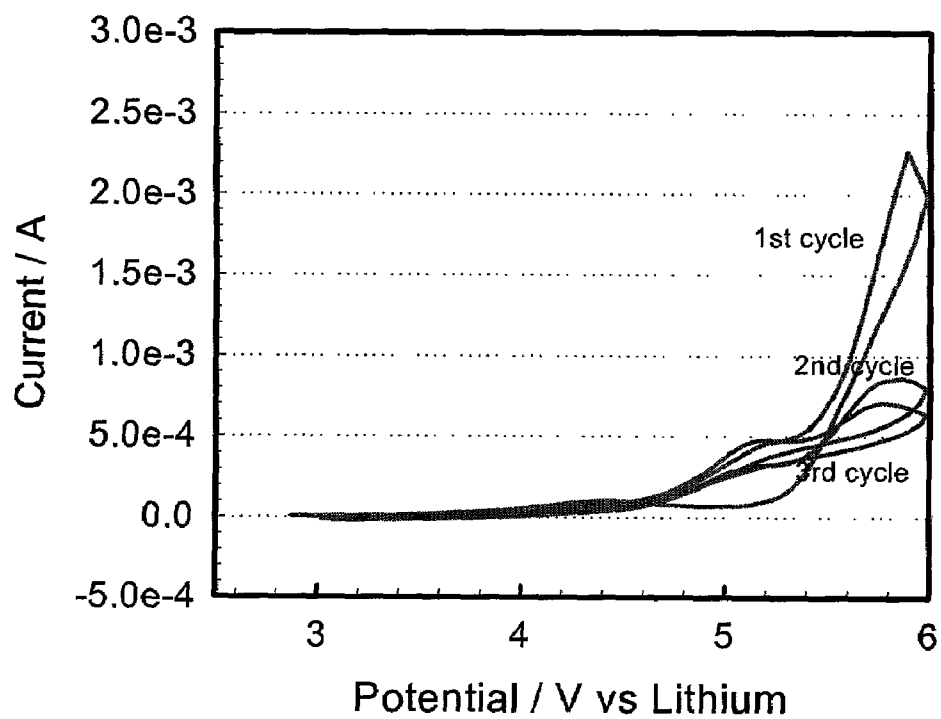
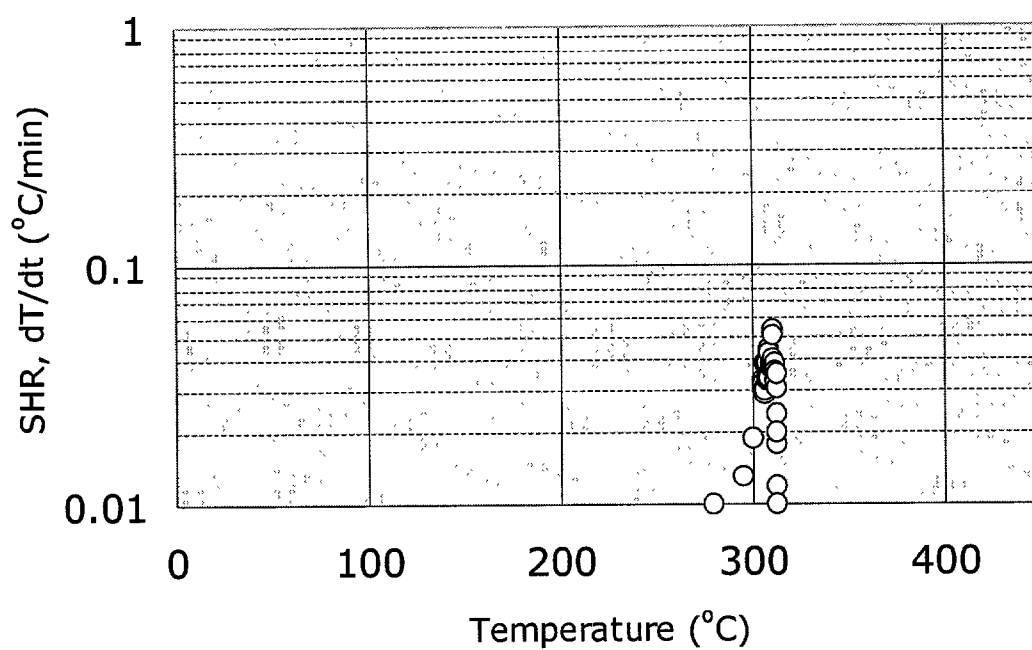
FIGURE 2b

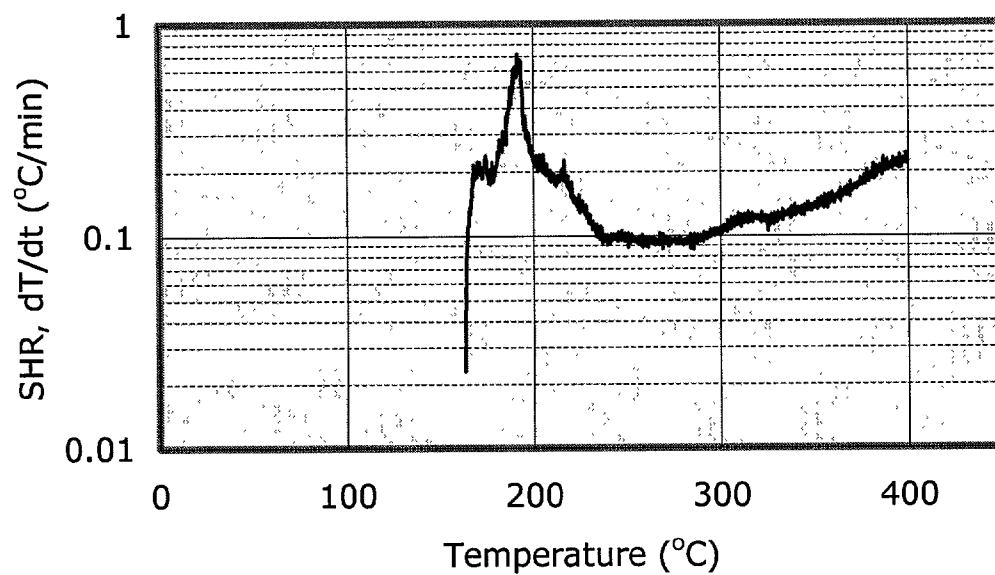**FIGURE 3**
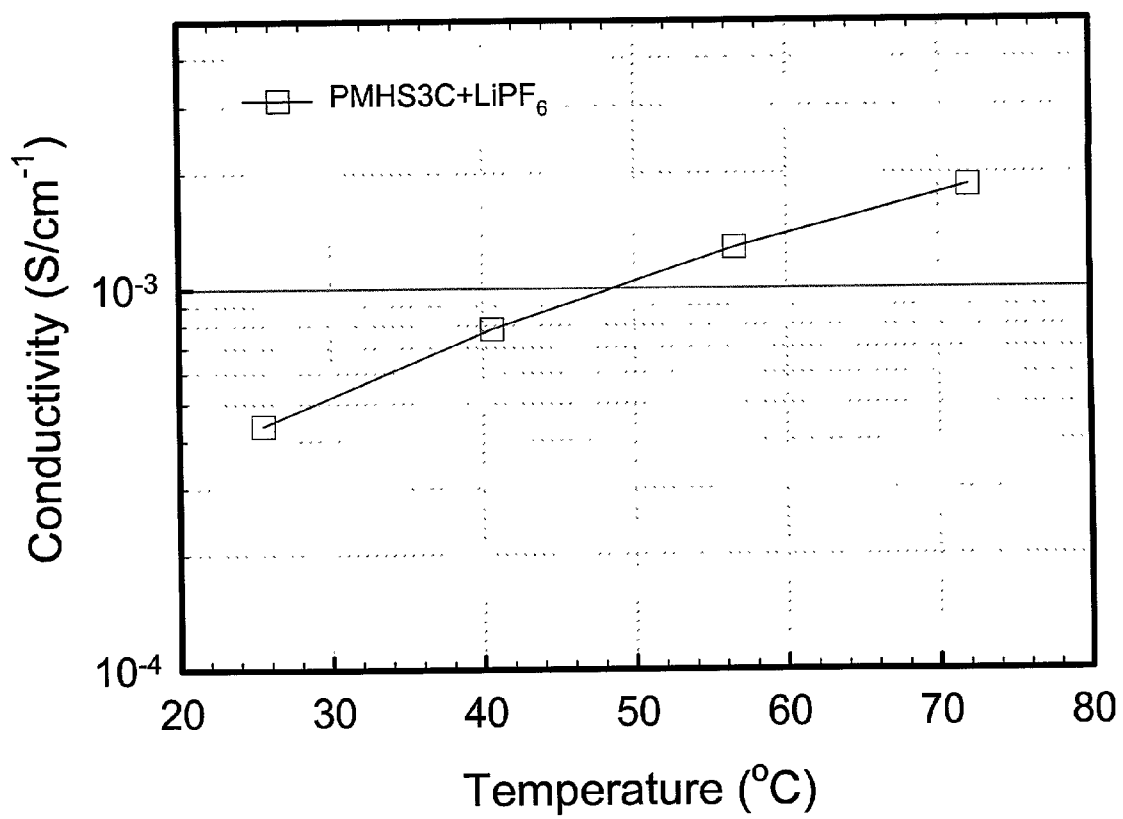
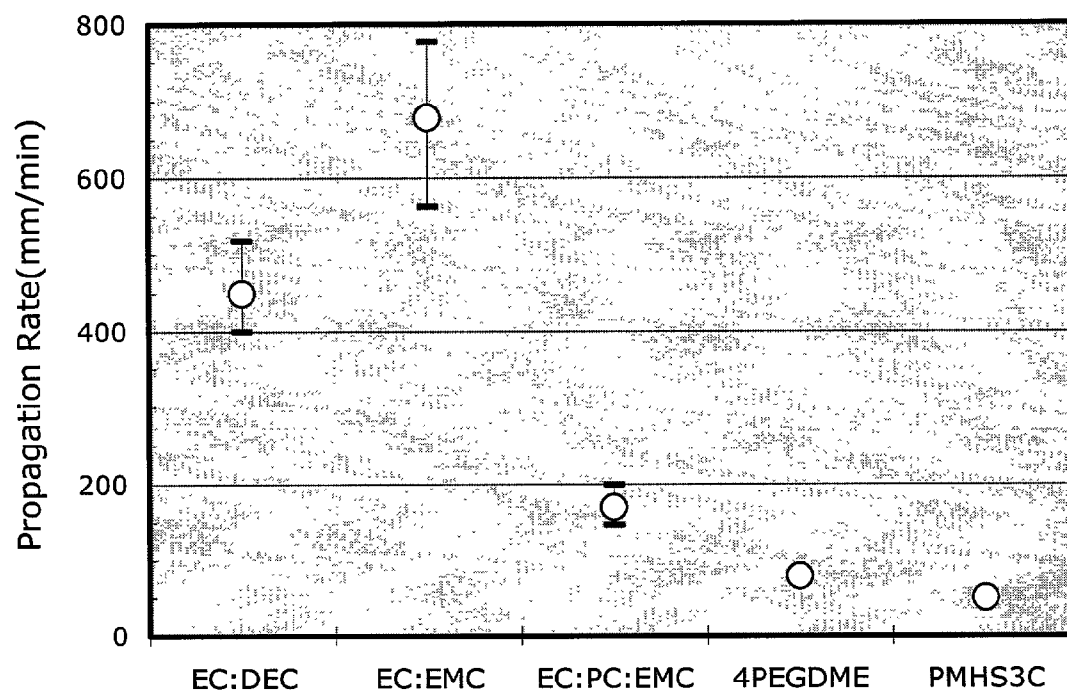FIGURE 4

FIGURE 5a

FIGURE 5b

FIGURE 6

NONAQUEOUS LIQUID ELECTROLYTE

REFERENCE TO PRIOR FILED APPLICATIONS

This application is a Continuation-in-Part of application Ser. No. 10/104,352 filed Mar. 22, 2002 now abandoned titled "Solid Polymer Electrolyte and Method of Preparation" to Oh et al., the disclosure of which is incorporated herein by reference.

GOVERNMENT LICENSE RIGHTS

FIELD OF THE INVENTION

The present invention relates to electrochemical storage devices containing a nonaqueous electrolyte with high ionic conductivity and nonvolatile characteristics. More particularly, the present invention relates to liquid type polymeric electrolytes that are superior in ionic conductivity, thermal stability and safety to most of those currently being used in lithium-ion cells today.

BACKGROUND OF THE INVENTION

The demand for lithium secondary batteries to meet high power and high-energy system applications has resulted in substantial research and development activities to improve their safety, as well as performance. As the world becomes increasingly dependent on portable electronic devices, and looks toward increased use of electrochemical storage devices for vehicles, power distribution load leveling and the like, it is increasingly important that the safety of such devices be paramount, especially as these devices are being used in such environments as airliners and space vehicles. The effort to date has included research in flame-retardants, solid polymer electrolytes and new electrolyte concepts with improved thermostability. Thus, the development of highly conductive electrolytes, free of any problems associated with volatile and combustible solvents, is of paramount importance. Electrolytes based on polymeric structures have basically better heat and chemical resistance than conventional organic carbonate-based electrolytes and can thus reduce many chemical side reactions occurring in lithium secondary batteries. Although, polymeric based electrolytes have many advantages over carbonate solvent based electrolytes, their application in lithium secondary batteries has been limited due to their low ionic conductivity, usually below 10^{-5} S/cm at room temperature.

To solve this problem, new electrolyte concepts are needed. The new electrolytes should be nonvolatile materials that have excellent electrochemical properties, such as high ionic conductivity of over 10^{-4} S/cm at room temperature and wide electrochemical stability windows of over 4.5 V (based on lithium metal).

Accordingly, the present inventors have developed a new type of ionically conductive electrolyte based on various polymeric structures, especially having a poly(siloxane-g-

ethylene oxide) composition which overcomes the above mentioned problems of volatility, flammability and chemical reactivity inside of the lithium battery. The proposed liquid type poly(siloxane-g-ethylene oxide) materials also have an excellent electrochemical stability window and favorable room temperature ionic conductivity.

Carbonate solvents, such as ethylene carbonate and ethylmethyl carbonate used for conventional lithium battery electrolytes can easily bum from low temperature sources of ignition and generate flame, carbon dioxide and H_2O during thermal degradation. This is a critical problem in high capacity battery applications like lithium batteries for electric vehicles (EV) and satellites. Polymeric materials, however, usually have a somewhat different combustion mechanism than the carbonates. The initial stage of a fire occurs when a heat source decomposes the polymeric materials to flammable volatile products. Thus, for continuous burning to occur, (a) the application of heat must be sufficient to decompose the polymer, (b) the temperature must be sufficient to ignite the products of decomposition, and (c) the amount of heat transferred from the flame back to the polymer must be sufficient to maintain the cycle. In general, polymeric materials are more thermally stable than low molecular weight chemicals like the organic carbonates because they are not volatile and are vaporized at much higher temperatures.

The present inventors have carefully considered the combustion mechanisms of polymeric materials and concluded that to stop the propagation of the burning cycle one needed to develop new polymer materials that are thermally more stable and capable of dissolving the lithium salts to prepare electrolytes for electrochemical devices such as lithium batteries and/or capacitors. The present inventors have developed new structural siloxane polymers with one or more poly(ethylene oxide) side chains. Siloxanes are very thermally stable and are decomposed by heat with difficulty. Only a few flammable by-products are formed during the thermal decomposition of such polymers because their main chain is a Si—O linkage. Thus, its presence in the proposed polymers will delay the initiation of the combustion cycle.

Due to the merits of siloxane-poly(ethylene oxide) graft copolymers, substantial research has been done. See, for example, U.S. Pat. No. 5,112,512 to Nakamura and U.S. Pat. No. 6,124,062 to Horie et al. also describing siloxane-poly (ethylene oxide) graft copolymers (as a polymeric electrolyte material. The '512 patent discloses a crosslinked polymer electrolyte based on the graft copolymers, but its ionic conductivity is too low for room temperature applications. The '062 patent discloses direct use of siloxane-poly(ethylene oxide) grafted copolymers as a liquid for a lithium battery electrolyte with ionic conductivity of around 10^{-4} S/cm at ca. 25° C. (See General Formula I). The conductivity of the material disclosed in the '062 patent is disadvantageously low. In addition, the cost of such material is relatively high. The present inventors have discovered a much improved material with higher conductivity and lower cost.

General formula (I) (as disclosed in the '062 patent):
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wherein R is alkyl group.

The present inventors developed an improved liquid state siloxane polymer with one or more poly(ethylene oxide) side chains to ensure thermal stability and electrochemical properties. Poly(ethylene oxides) (PEO) in poly(siloxane-g-ethylene oxide) materials of this invention (see general formula II) are directly bonded to a Si atom. Poly(siloxane-g-ethylene oxide) materials of the present invention are easily synthesized through a simple dehydrocoupling reaction with simple metal carbonate based catalysts and the cost for synthesis of

poly(siloxane-g-ethylene oxide) of this invention is much lower than the cost of synthesis of general formula (I) with a propylene spacer between siloxane and PEO. The present inventors also control the viscosity of the materials to get high ionic conductivities of around 10^{-3} S/cm at room temperature.

General formula (II):

$$-(Si-O)_n$$
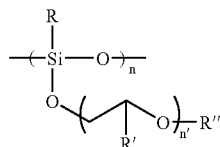
where R and R″ are alkyl groups and R′ is hydrogen or alkyl group.

As compared to the material disclosed in the '062 patent, ionic conductivity is improved by changing the chemical structure of siloxane, that is, directly grafting ethylene oxide onto Si atom without any alkyl carbon spacer between them. Changing the structure in this way increases hydrophilicity and solubility, leading to higher conductivity.

OBJECTIVES OF THE INVENTION

A primary objective of the present invention is to provide a safe liquid electrolyte for use in lithium ion type cells and allied devices such as super capacitors and hybrid devices. Specifically, a primary objective is to reduce or eliminate problems associated with volatility, flammability and chemical reactivity of liquid electrolytes.

A further objective of the invention is to provide a lithium-based secondary battery, capacitor or hybrid device with enhanced safety and excellent performance characteristics by use of the present polymeric electrolyte.

SUMMARY OF THE INVENTION

Accordingly, the present invention relates to lithium-based secondary batteries with a nonaqueous and nonvolatile polymeric electrolyte with high room temperature ionic conductivity with enhanced safety.

The invention also relates to nonaqueous and nonvolatile polymeric electrolytes processing controlled viscosity for the high-energy lithium secondary battery applications, especially for electric vehicles and satellite applications.

To fulfill the above objectives, the nonaqueous and non-volatile polymeric electrolyte solutions in the present invention is prepared by using the compositions which comprise poly(siloxane-g-ethylene oxide) in a liquid state with proper viscosity and a dissolved lithium salt.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a trace of measured ionic conductivity vs. temperature for a cell made according to the present invention.

FIGS. 2a and 2b are traces of cyclic voltammetry measurements to determine electrochemical stability of samples made according to the present invention.

FIG. 3 is a trace of measured ionic conductivity showing the effect of doping level, on the ionic conductivity of poly(siloxane-g-3 ethylene oxide) electrolyte at two different temperatures.

FIG. 4 is a trace of measured ionic conductivity of poly(siloxane-g-3 ethylene oxide) electrolyte with $LiPF_6$ in place of LiTFSI at a doping level of 32:1.

FIG. 5a is a data trace from accelerating rate calorimetry (ARC) tests of the electrolyte of the present invention.

FIG. 5b is a comparative data trace from ARC tests of liquid electrolyte $LiPF_6$ in a mixture of ethylene carbonate and ethyl methyl carbonate.

FIG. 6 is a graph of the results of comparative flame tests based on Underwriters Laboratories UL94 standard.

DETAILED DESCRIPTION OF THE INVENTION

The electrolyte solution of the present invention comprises siloxane polymers with one or more poly(ethylene oxide) as a side chain (see general formula II above). The inorganic siloxane main body ensures flame-retardancy and chemical stability, and poly(ethylene oxide) side chains give ionic conducting phases. A poly(ethylene oxide) group is directly grafted to silicon atoms in the siloxane polymer. The poly(siloxane-g-ethylene oxides) of the present invention are easily synthesized through simple dehydrogenation reactions to avoid problems that come from the use of metal catalysts such as platinum.

The poly(siloxane-g-ethylene oxide) easily dissolves lithium salt and has enough flexibility to transport lithium ions. Through the viscosity control of the poly(siloxane-g-ethylene oxide), the polymeric electrolyte solution provides excellent ionic conductivity of around 10^{-3} S/cm at room temperature.

The salt to be used in the present invention is not particularly limited, as long as it serves as an electrolyte for a lithium secondary battery, capacitor, or other electrochemical device. Examples of specific lithium salts include, but are not limited to, $LiClO_4$, $LiBF_4$, $LiAsF_6$, $LiPF_6$, $LiCF_3SO_3$, $Li(CF_3SO_2)_2$ N, $LiC(CF_3SO_2)_3$, $LiN(SO_2C_2F_5)_2$, lithium alkyl fluorophosphates, and mixtures thereof. Other salts may be used, particularly alkali metal salts or quaternary ammonium salts having an anion selected from the group consisting of: ClO_4^-, BF_4^-, AsF_6^-, PF_6^-, $CF_3SO_3^-$, $(CF_3SO_2)_2N^-$, $(CF_3SO_2)_3C^-$, $(C_2F_5SO_2)_2N^-$, $PF_3(C_2F_5)_3^-$, $PF_3(CF_3)_3^-$, and $B(C_2O_4)_2^-$.

Further examples (without the intent to limit the scope of the invention) found to be beneficial are lithium bis(chelato) borates having from five to seven membered rings as follows:

Five-membered rings

Where R is H or an alkyl group.

Six-membered ring   Seven-membered ring
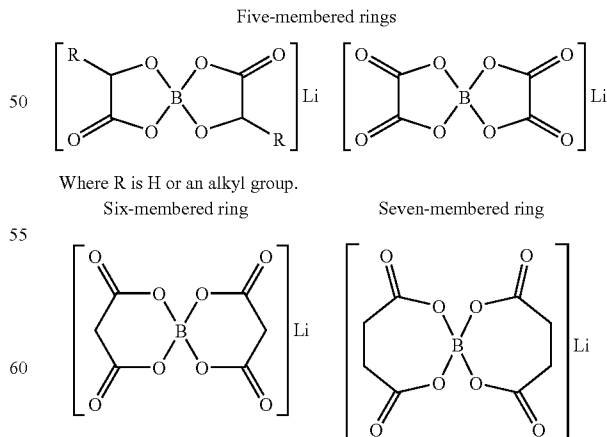
The oxygen versus Li ratio (doping level) is preferably 5:1 to 50:1. If the doping level is greater than 50:1, the ionic conductivity of the resulting polymeric electrolyte is undesir-

ably decreased because of the number of ions present in the solid polymer electrolyte. If the doping level is smaller than 5:1, the lithium salt is not sufficiently dissociated in the resulting polymeric electrolyte and the association of lithium ion reduces the ionic conductivity. Preferably, the average molecular weight of the poly(siloxane-g-ethylene oxide) should not exceed 20,000 g/mol. The dynamic viscosity of the poly(siloxane-g-ethylene oxide) is best in the range of 200 cPs, should preferably not exceed 1,000 cPs to 2,000 cPs, and should never exceed 10,000 cPs.

The present invention covers both polymeric electrolytes as well as the lithium secondary batteries that use them in the same way that the carbonate based electrolytes are applied in the state-of-the-art Li-ion batteries today. A lithium secondary battery with the polymeric electrolyte solution of this invention as a conducting medium can be fabricated by injecting the polymeric electrolyte solution into a spiral wound cell or prismatic type cell. It can be also coated onto the surface of electrodes and assembled with a porous separator to fabricate single or multi-stacked cells that are packaged with plastic pouches. Similarly, the electrolyte of the present invention may be used in ultra capacitors (also known as super capacitors) and hybrid devices incorporating aspects of batteries and capacitors.

In situ tests: Type 2032 button cells were assembled for the evaluation of cell performance with a MAG-10 anode, and $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ as a cathode. Celgard® 2500 (microporous polypropylene membrane, available from CELGARD Inc.) was used as a separator. These cells contained MAG-10 graphite, with 8 wt % PVDF binder/poly(siloxane-g-3 ethylene oxide), doping level of 32:1 with LiTFSI, electrolyte/$LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$, 8 wt % PVDF, 4 wt % SFG-6 graphite, and 4 wt % carbon black. The effective cell area was 1.6 cm^2. Charge and discharge rate were C/10. There was no degradation peak caused by the metal oxide up to 4.1V and the specific charge capacity was over 140 mAh/g.

FIG. 1 shows the effect of temperature on the ionic conductivity of poly(siloxane-g-3 ethylene oxide) electrolyte (see general formula III). Poly(siloxane-g-3 ethylene oxide) and $Li(CF_3SO_2)_2N$ were mixed with a doping level of 32:1. The ionic conductivity of the polymeric electrolytes at temperatures ranging from 25 to 70° C. were measured from the AC impedance curves from type 2030 button cells assembled by injecting the polymeric electrolyte between two stainless steel discs with a glass filter (750 micron thick) to prevent short circuits. The measuring frequency range was from 1 MHz to 10 Hz.

General formula (III):

$$\begin{array}{c} CH_3 \\ | \\ -(-Si-O-)_n \\ | \\ O \diagup\!\!\!\diagdown\!\!\!\diagup\!\!\!\diagdown O)_3 \end{array}$$
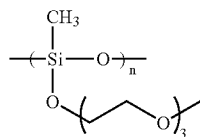
Poly(siloxane-g-3 ethylene oxide) electrolyte shows an excellent ionic conductivity of 8.6×10^{-4} S/cm at 37° C.

FIGS. 2a and 2b show the electrochemical stability of poly(siloxane-g-3 ethylene oxide) and poly(siloxane-g-7 ethylene oxide) (see general formula IV) electrolytes, respectively. Poly(siloxane-g-ethylene oxides) and $Li(CF_3SO_2)_2N$ were mixed with a doping level of 32:1. The electrochemical stability window of the polymer electrolytes were determined by cyclic voltammetry with type 2030 button cells assembled by sandwiching a glass filter containing the polymer electro-

lyte between a stainless steel disc as a working electrode and a lithium metal disc as a combined counter and reference electrode. These polymeric electrolytes were found to show excellent electrochemical stability windows over 0 to 4.5V (vs. Li) and only a minimal decomposition peak around 4.5V during the first anodic sweep. In the case of poly(siloxane-g-7 ethylene oxide), which is more stable, the stability window reaches ca. 5.5V.

General formula (IV)

$$\begin{array}{c} CH_3 \\ | \\ -(-Si-O-)_n \\ | \\ O \diagup\!\!\!\diagdown\!\!\!\diagup\!\!\!\diagdown O)_{7.2} \end{array}$$
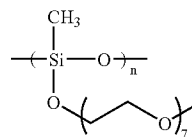
FIG. 3 is a trace of measured ionic conductivity vs. doping level at two different temperatures (24° C. and 60° C.). These data show the effect of doping level, O vs. Li$^+$, on the ionic conductivity of poly(siloxane-g-3 ethylene oxide) electrolyte (see general formula III). A doping level of 32:1 is an optimum formulation regardless temperature. In the case of doping level of 15:1, there is an improvement of ionic conductivity at 60° C. owing to the additional dissociation of lithium cluster formed at 24° C. A high concentration of lithium salt generally creates clusters at lower temperature, but can be dissociated a bit by increasing temperature.

FIG. 4 shows the ionic conductivity of poly(siloxane-g-3 ethylene oxide) electrolyte with LiPF$_6$ in place of LiTFSI at a doping level of 32:1. Even though LiPF$_6$ has smaller anion than LiTFSI, the ionic conductivity values are similar to that shown in FIG. 1. This is due to the highly flexible structure of poly(siloxane-g-3 ethylene oxide). The highly flexible structure of the siloxane electrolyte of this invention can overcome the lack of plasticizing effect by the anion part of lithium salt. Poly(siloxane-g-3 ethylene oxide) has the additional advantage of increasing the variety of usable lithium salts over that of General formula (I) (as disclosed in the '062 patent), siloxane with alkyl carbon spacer between Si and polyethylene oxide. This comes from the fact that the rotation barrier of the Si—O bond is less than 0.2 kcal, but that of Si—CH$_3$ is 1.6 kcal (see, C. F. Rome, Hydrocarbon Asia, May/June (2001) 42-49).

FIG. 5(a) shows thermal stability of poly(siloxane-g-3 ethylene oxide) electrolyte at a doping level of 32:1 with LiPF$_6$, using accelerating rate calorimetry ("ARC"). A heat-wait-search sequence was applied. Sample weight for the test was 500 mg. Each sample was introduced in a 2¼"×¼" diameter stainless steel bomb for the ARC test.

ARC is more sensitive test method than differential scanning calorimetry ("DSC"). In a heat-wait-search sequence, ARC will search an exothermic reaction for 30 minutes at every 5° C. change from the starting temperature. In DSC, a 5 or 10° C./min heating rate is usually used and the sample quantity is only about 2 to 5 μL. In the case of some chemicals, the exothermic peak by DSC comes later than ARC due to its much faster scan rate than ARC.

Although solid LiPF$_6$ itself decomposes to PF$_5$ and LiF at about 250° C., as measured by the DSC method, (see, N. Katayama et al., J. Power Sources, 2001, in press at time of application) and PF$_5$ reacts with solvents for further thermal decomposition, poly(siloxane-g-3 ethylene oxide) electrolyte has an exothermic peak above 300° C. This means that poly(siloxane-g-3 ethylene oxide) has excellent chemical stability even at an elevated temperature.

FIG. 5b shows comparative data from an ARC test of a widely used liquid electrolyte, 1.2M LiPF$_6$ in ethylene carbonate (EC):ethyl methyl carbonate (EMC) (3:7 weight ratio). This sample was tested in the same way as in FIG. 5a. Its exothermic peak is detected before 200° C. (approximately 220° C. of onset temperature by DSC; see, N. Katayama et al., J. Power Sources, 2001, in press at time of application). It is thus found that the siloxane main backbone of poly(siloxane-g-ethylene oxide) significantly enhances the thermal stability of the electrolyte.

FIG. 6 is a graph of the results of a flame tests (propagation rate) based on Underwriters Laboratories UL94 standard. Flammability of poly(siloxane-g-3 ethylene oxide) electrolyte, doping level of 32:1 with LiPF$_6$, was investigated using modified UL-94HB Horizontal Burning Test. Detail compositions of the test samples are listed in Table 1.

TABLE 1

	Composition	Other
EC:DEC	1 M LiPF$_6$ in EC:DEC (1:1 by wt)	
EC:EMC	1.2 M LiPF$_6$ in EC:EMC (3:7 by wt)	
EC:PC:EMC	1 M LiPF$_6$ in EC:PC:EMC (3:3:4 by wt)	
4PEGDME	Poly(ethylene glycol) dimethyl ether + LiPF$_6$	4 ethylene oxide O/Li$^+$ = 20:1
PMHS3C	Poly(siloxane-g-3 ethylene oxide) + LiPF$_6$	O/Li$^+$ = 32:1

UL intends this standard to serve as a preliminary indication of the acceptability of materials for use as part of electronic goods, lithium batteries, etc. with respect to flammability. The modified UL-94HB test uses a ¼"×5.5" silanized glass wool wick specimen soaked with the electrolyte samples held at one end in a horizontal position with marks at 1.00" and 4.94" from the free end. The specimen contains 5 g of electrolyte. A flame is applied to the free end for 30 seconds or until the flame front reaches the 1" mark. If combustion continues the duration is timed between the 1.00" mark and the 4.94" mark. If combustion stops before the 4.94" mark, the time of combustion and the damaged length between the two marks are recorded. A set of five specimens is tested. If two specimens from the set of five fail to comply, then a second set of five are tested. All five of this second set must comply. Propagation rate of flame is given by the following equation:

Propagation Rate=Distance (cm)/Elapsed time (min)

Poly(siloxane-g-3 ethylene oxide) electrolyte shows outstanding flame resistance. Its propagation rate is significantly lower than conventional liquid electrolyte for lithium ion batteries and low molecular weight polyethylene oxide electrolyte. This is because the inorganic siloxane backbone naturally acts as a combustion inhibitor.

It should be apparent that the present invention solves the long-felt need to create safe, high energy electrochemical storage devices having liquid electrolytes. Such devices promise to have high energy rate capabilities as well as high energy density. Batteries containing the present electrolyte, especially large batteries such as those used in electric vehicles, would be inherently safer than those with more volatile, flammable and unstable electrolytes.

Having described the present invention, it should be apparent to the reader that many variations of the present invention are possible without departure from the scope of the present invention. The specific implementations disclosed above are by way of example and for the purposes of enabling persons
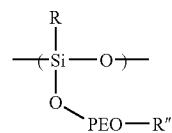
skilled in the art to implement the invention only. Accordingly, the invention is not to be limited except by the appended claims and legal equivalents.
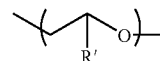
We claim:

1. A battery, comprising:
an electrolyte that includes a poly(siloxane-g-ethylene oxide) with repeating units represented by general formula

where PEO represents a poly(ethylene oxide) group having repeating units represented by

and having a terminal oxygen linked directly to R″, R represents an alkyl group, R' is a hydrogen or alkyl group, and R″ is an alkyl group; and
at least one salt dissolved in the electrolyte.

2. The battery of claim 1, wherein an average molecular weight of the poly(siloxane-g-ethylene oxide) does not exceed 20,000 g/mol.

3. The battery of claim 1, wherein at least one salt is a lithium salt.

4. The battery of claim 1, wherein the dissolved salt includes at least one quatemary ammonium salt having an anion selected from the group consisting of: ClO_4^-, BF_4^-, AsF_6^-, PF_6^-, $CF_3SO_3^-$, $(CF_3SO_2)_2N^-$, $(CF_3SO_2)_3C^-$, $(SO_2C_2F_5)_2N^-$, $PF_3(C_2F_5)_3^-$, $PF_3(CF_3)_3^-$, and $B(C_2O_4)_2^-$.

5. The battery of claim 1, wherein the salt includes $LiClO_4$, $LiBF_4$, $LiAsF_6$, $LiPF_6$, $LiCF_3SO_3$, $Li(CF_3SO_2)_2N$, $LiC(CF_3SO_2)_3$, $LiN(SO_2C_2F_5)_2$, $LiPF_3(C_2F_5)_3$, $LiPF_3(CF_3)_3$, $LiB(C_2O_4)_2$, or mixtures thereof.

6. The battery of claim 1, wherein at least one salt is a lithium bis(chelato)borate having five to seven membered rings.

7. The battery of claim 1, wherein the electrolyte is non-volatile.

8. The battery of claim 1, wherein the electrolyte has an ionic conductivity of at least 6×10^{-4} S/cm at room temperature and at least 8.4×10^{-4} S/cm at 37° C.

9. The battery of claim 1, wherein the battery is a secondary battery.

10. The battery of claim 1, further comprising:
a lithium metal oxide or lithium metal phosphate positive electrode, at least one porous separator, and at least one lithium-carbon, lithium-alloy, or lithium metal negative electrode.

11. The secondary battery of claim 9, wherein at least one salt is a lithium salt.

12. The battery of claim 1, wherein the dissolved salt includes $LiCF_3SO_3$.

13. The battery of claim 1, wherein the dissolved salt includes $Li(CF_3SO_2)_2N$.

14. The battery of claim 1, wherein the dissolved salt includes $LiC(CF_3SO_2)_3$.

15. The battery of claim **1**, wherein the dissolved salt includes $LiN(SO_2C_2F_5)_2$.

16. The battery of claim **1**, wherein the dissolved salt includes $LiPF_6$.

17. The battery of claim **1**, wherein the dissolved salt includes $LiAsF_6$.

18. The battery of claim **1**, wherein the dissolved salt includes $LiBF_4$.

19. The battery of claim **1**, wherein the dissolved salt includes $LiClO_4$.

20. The electrochemical device of claim **9**, wherein the dissolved salt includes at least one electrolyte salt from the

following group: $LiClO_4$, $LiBF_4$, $LiAsF_6$, $LiPF_6$, $LiCF_3SO_3$, $Li(CF_3\ SO_2)_2N$, $LiC(CF_3SO_2)_3$, $LiN(SO_2C_2F_5)_2$, $LiPF_3(C_2F_5)_3$, $LiPF_3(CF_3)_3$,$LiB(C_2O_4)_2$.

21. The battery of claim **1**, wherein the dissolved salt includes $LiPF_3(C_2F_5)_3$.

22. The battery of claim **1**, wherein the dissolved salt includes $LiPF_3(CF_3)_3$.

23. The battery of claim **1**, wherein the dissolved salt includes $LiB(C_2O_4)_2$.

24. The battery of claim **1**, wherein R' is an alkyl group.

* * * * *