



(22) Date de dépôt/Filing Date: 2000/02/22  
(41) Mise à la disp. pub./Open to Public Insp.: 2001/07/24  
(45) Date de délivrance/Issue Date: 2005/09/20  
(30) Priorité/Priority: 2000/01/24 (09/490,355) US

(51) Cl.Int.<sup>7</sup>/Int.Cl.<sup>7</sup> H01M 10/26  
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(54) Titre : ADDITIFS A BASE DE SULFITES POUR DES PILES RECHARGEABLES A ELECTROLYTE NON AQUEUX  
(54) Title: SULFITE ADDITIVES FOR NONAQUEOUS ELECTROLYTE RECHARGEABLE CELLS

(57) **Abrégé/Abstract:**

A lithium ion electrochemical cell having high charge/discharge capacity, long cycle life and exhibiting a reduced first cycle irreversible capacity, is described. The stated benefits are realized by the addition of at least one sulfite additive to an electrolyte comprising an alkali metal salt dissolved in a solvent mixture that includes ethylene carbonate, dimethyl carbonate, ethylmethyl carbonate and diethyl carbonate. The preferred additive is an alkyl sulfite compound.



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## ABSTRACT

A lithium ion electrochemical cell having high charge/discharge capacity, long cycle life and exhibiting a reduced first cycle irreversible capacity, is described. The stated benefits are realized by the addition of at least one sulfite additive to an electrolyte comprising an alkali metal salt dissolved in a solvent mixture that includes ethylene carbonate, dimethyl carbonate, ethylmethyl carbonate and diethyl carbonate. The preferred additive is an alkyl sulfite compound.

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SULFITE ADDITIVES FOR NONAQUEOUS  
ELECTROLYTE RECHARGEABLE CELLS

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## BACKGROUND OF INVENTION

The present invention generally relates to an alkali metal electrochemical cell, and more particularly, to a rechargeable alkali metal cell. Still more particularly, the present invention relates to a lithium ion electrochemical cell activated with an electrolyte having an additive provided to achieve high charge/discharge capacity, long cycle life and to minimize the first cycle irreversible capacity. According to the present invention, the preferred additive to the activating electrolyte is a sulfite compound.

Alkali metal rechargeable cells typically comprise a carbonaceous anode electrode and a lithiated cathode electrode. Due to the high potential of the cathode material (up to 4.3V vs. Li/Li<sup>+</sup> for Li<sub>1-x</sub>CoO<sub>2</sub>) and the low potential of the carbonaceous anode material (0.01V vs. Li/Li<sup>+</sup> for graphite) in a fully charged lithium ion cell, the choice of the electrolyte solvent system is limited. Since carbonate solvents have high oxidative stability toward typically used lithiated cathode materials and good kinetic stability toward carbonaceous anode materials, they are generally used in lithium ion cell electrolytes. To achieve optimum cell performance (high rate capability and long cycle life),

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5 solvent systems containing a mixture of a cyclic carbonate  
(high dielectric constant solvent) and a linear carbonate (low  
viscosity solvent) are typically used in commercial secondary  
cells. Cells with carbonate based electrolytes are known to  
10 deliver more than 1000 charge/discharge cycles at room  
temperature.

Applicant's U.S. patent 6,153,338 is directed to a  
quaternary mixture of organic carbonate solvents in the  
activating electrolyte for a lithium ion cell capable of  
15 discharge at temperatures below  $-20^{\circ}\text{C}$  and down to as low as  
 $-40^{\circ}\text{C}$  while exhibiting good cycling characteristics. The  
quaternary solvent system includes ethylene carbonate (EC),  
dimethyl carbonate (DMC), ethylmethyl carbonate (EMC) and  
diethyl carbonate (DEC).

20  
Lithium ion cell design generally involves a trade off in  
one area for a necessary improvement in another, depending on  
the targeted cell application. The achievement of a lithium-  
ion cell capable of low temperature cycleability by use of the  
25 above quaternary solvent electrolyte, in place of a typically  
used binary solvent electrolyte (such as 1.0M  
 $\text{LiPF}_6/\text{EC}:\text{DMC}=30:70$ , v/v which freezes at  $-11^{\circ}\text{C}$ ), is obtained at  
the expense of increased first cycle irreversible capacity  
during the initial charging (approximately 65 mAh/g graphite  
30 for 1.0M  $\text{LiPF}_6/\text{EC}:\text{DMC}:\text{EMC}:\text{DEC}=45:22:24.8:8.2$  vs. 35 mAh/g  
graphite for 1.0M  $\text{LiPF}_6/\text{EC}:\text{DMC}=30:70$ ). Due to the existence of  
this first cycle irreversible capacity, lithium ion cells are  
generally cathode limited. Since all of the lithium ions,  
which shuttle between the anode and the cathode during  
35 charging and discharging originally come from the lithiated  
cathode, the larger the first cycle irreversible capacity, the  
lower the cell capacity in subsequent cycles and the lower the



5 cell efficiency. Thus, it is desirable to minimize or even eliminate the first cycle irreversible capacity in lithium ion cells while at the same time maintaining the low temperature cycling capability of such cells.

10 According to the present invention, these objectives are achieved by providing an organic sulfite in the quaternary solvent electrolyte. Lithium ion cells activated with these electrolytes exhibit lower first cycle irreversible capacities relative to cells activated with the same quaternary solvent electrolyte devoid of the sulfite additive. As a result,  
15 cells including the sulfite additive present higher subsequent cycling capacity than control cells. The cycleability of the present invention cells at room temperature, as well as at low temperatures, i.e., down to about  $-40^{\circ}\text{C}$ , is as good as cells activated with the quaternary electrolyte devoid of a sulfite  
20 additive.

#### SUMMARY OF THE INVENTION

It is commonly known that when an electrical potential is initially applied to lithium ion cells constructed with a  
25 carbon anode in a discharged condition to charge the cell, some permanent capacity loss occurs due to the anode surface passivation film formation. This permanent capacity loss is called first cycle irreversible capacity. The film formation process, however, is highly dependent on the reactivity of the  
30 electrolyte components at the cell charging potentials. The electrochemical properties of the passivation film are also dependent on the chemical composition of the surface film.

The formation of a surface film is unavoidable for alkali metal systems, and in particular, lithium metal anodes, and  
35 lithium intercalated carbon anodes due to the relatively low potential and high reactivity of lithium toward organic electrolytes. The ideal surface film, known as the solid-

5 electrolyte interphase (SEI), should be electrically  
insulating and ionically conducting. While most alkali metal,  
and in particular, lithium electrochemical systems meet the  
first requirement, the second requirement is difficult to  
achieve. The resistance of these films is not negligible, and  
10 as a result, impedance builds up inside the cell due to this  
surface layer formation which induces unacceptable  
polarization during the charge and discharge of the lithium  
ion cell. On the other hand, if the SEI film is electrically  
conductive, the electrolyte decomposition reaction on the  
15 anode surface does not stop due to the low potential of the  
lithiated carbon electrode.

Hence, the composition of the electrolyte has a  
significant influence on the discharge efficiency of alkali  
metal systems, and particularly the permanent capacity loss in  
20 secondary cells. For example, when 1.0M  $\text{LiPF}_6/\text{EC}:\text{DMC}=30:70$  is  
used to activate a secondary cell, the first cycle  
irreversible capacity is approximately 35 mAh/g of graphite.  
However, under the same cycling conditions, the first cycle  
irreversible capacity is found to be approximately 65 mAh/g of  
25 graphite when 1.0M  $\text{LiPF}_6/\text{EC}:\text{DMC}:\text{EMC}:\text{DEC}=45:22:24.8:8.2$  is used  
as the electrolyte. Further, lithium ion cells activated with  
the binary solvent electrolyte of ethylene carbonate and  
dimethyl carbonate cannot be cycled at temperatures less than  
about  $-11^\circ\text{C}$ . The quaternary solvent electrolyte of the  
30 previously referenced U.S. patent 6,153,338, which enables  
lithium ion cells to cycle at much lower temperatures, is a  
compromise in terms of providing a wider temperature  
application with acceptable cycling efficiencies. It would be  
highly desirable to retain the benefits of a lithium ion cell  
35 capable of operating at temperatures down to as low as about  
 $-40^\circ\text{C}$  while minimizing the first cycle irreversible capacity.



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According to the present invention, this objective is achieved by adding a sulfite additive in the above described quaternary solvent electrolytes. In addition, this invention may be generalized to other nonaqueous organic electrolyte systems, such as binary solvent and ternary solvent systems, as well as the electrolyte systems containing solvents other than mixtures of linear or cyclic carbonates. For example, linear or cyclic ethers or esters may also be included as electrolyte components. Although the exact reason for the observed improvement is not clear, it is hypothesized that the sulfite additive competes with the existing electrolyte components to react on the carbon anode surface during initial lithiation to form a beneficial SEI film. The thusly formed SEI film is electrically more insulating than the film formed without the sulfite additive and, as a consequence, the lithiated carbon electrode is better protected from reactions with other electrolyte components. Therefore, lower first cycle irreversible capacity is obtained.

In a preferred embodiment, the invention comprises an electrochemical cell which comprises:

- a) a negative electrode which intercalates with an alkali metal;
- b) a positive electrode comprising an electrode active material which intercalates with the alkali metal;
- c) a nonaqueous electrolyte activating the negative and the positive electrodes; and
- d) a sulfite additive of the formula  $R^1OS(=O)(OR^2)$  provided in the electrolyte

wherein:

$R^1$  is a group which has at least one unsaturated hydrocarbon containing a  $C(sp^2 \text{ or } sp^3)-C(sp^3)$  bond unit having the  $C(sp^3)$  carbon directly

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connected to the  $-OSO_2-$  functional group; and  
R<sup>2</sup> is selected from the group consisting of a  
hydrogen atom and an organic group containing  
1 to 12 carbon atoms;

5 wherein when R<sup>2</sup> is a hydrogen then R<sup>1</sup> is an unsaturated  
hydrocarbon having 3-12 carbon atoms; and

wherein when R<sup>2</sup> is an organic group containing 1 to 12  
carbon atoms then R<sup>1</sup> has the structure (R<sup>3</sup>) (R<sup>4</sup>) (R<sup>5</sup>)C- wherein:

- 10 i) R<sup>3</sup> is selected from the group consisting of an  
aromatic group, an unsaturated organic group  
and an unsaturated inorganic group; and
- 15 ii) R<sup>4</sup> and R<sup>5</sup> are independently selected from the  
group consisting of an aromatic group, an  
unsaturated organic group, an unsaturated  
inorganic group and a saturated organic group  
containing from 1 to 11 carbon atoms.

These and other objects of the present invention will  
become increasingly more apparent to those skilled in the  
art by reference to the following description.

## 20 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A secondary electrochemical cell constructed according  
to the present invention includes an anode active material  
selected from Groups IA, IIA, or IIIB of the Periodic Table  
of Elements, including the alkali metals lithium, sodium,  
25 potassium, etc. The preferred anode active material  
comprises lithium.

In secondary electrochemical systems, the anode  
electrode comprises a material capable of intercalating and  
de-intercalating the alkali metal, and preferably lithium.  
30 A carbonaceous anode comprising any of the various forms of



5 carbon (e.g., coke, graphite, acetylene black, carbon black,  
glassy carbon, etc.) which are capable of reversibly retaining  
the lithium species, is preferred. Graphite is particularly  
preferred due to its relatively high lithium-retention  
10 carbonaceous material are particularly advantageous because  
the fibers have excellent mechanical properties which permit  
them to be fabricated into rigid electrodes that are capable  
of withstanding degradation during repeated charge/discharge  
cycling. Moreover, the high surface area of carbon fibers  
15 allows for rapid charge/discharge rates. A preferred  
carbonaceous material for the anode of a secondary  
electrochemical cell is described in applicant's U.S.  
Patent No. 5,443,928 to Takeuchi et al.

20 A typical secondary cell anode is fabricated by mixing  
about 90 to 97 weight percent graphite with about 3 to 10  
weight percent of a binder material which is preferably a  
fluoro-resin powder such as polytetrafluoroethylene (PTFE),  
polyvinylidene fluoride (PVDF),  
25 polyethylenetetrafluoroethylene (ETFE), polyamides and  
polyimides, and mixtures thereof. This electrode active  
admixture is provided on a current collector such as of a  
nickel, stainless steel, or copper foil or screen by  
casting, pressing, rolling or otherwise contracting the  
30 active admixture thereto.

The anode component further has an extended tab or lead  
of the same material as the anode current collector, i.e.,  
preferably nickel, integrally formed therewith such as by  
welding and contacted by a weld to a cell case of conductive  
35 metal in a case-negative electrical configuration.  
Alternatively, the carbonaceous anode may be formed in some

5 other geometry, such as a bobbin shape, cylinder or pellet to allow an alternate low surface cell design.

The cathode of a secondary cell preferably comprises a lithiated material that is stable in air and readily handled. Examples of such air-stable lithiated cathode materials  
10 include oxides, sulfides, selenides, and tellurides of such metals as vanadium, titanium, chromium, copper, molybdenum, niobium, iron, nickel, cobalt and manganese. The more preferred oxides include  $\text{LiNiO}_2$ ,  $\text{LiMn}_2\text{O}_4$ ,  $\text{LiCoO}_2$ ,  $\text{LiCo}_{0.92}\text{Sn}_{0.08}\text{O}_2$  and  $\text{LiCo}_{1-x}\text{Ni}_x\text{O}_2$ .

15 Before fabrication into an electrode for incorporation into an electrochemical cell, the lithiated active material is preferably mixed with a conductive additive. Suitable conductive additives include acetylene black, carbon black and/or graphite. Metals such as nickel, aluminum, titanium  
20 and stainless steel in powder form are also useful as conductive diluents when mixed with the above listed active materials. The electrode further comprises a fluoro-resin binder, preferably in a powder form, such as PTFE, PVDF, ETFE, polyamides and polyimides, and mixtures thereof.

25 To discharge such secondary cells, the lithium ion comprising the cathode is intercalated into the carbonaceous anode by applying an externally generated electrical potential to recharge the cell. The applied recharging electrical potential serves to draw the alkali metal ions from the  
30 cathode material, through the electrolyte and into the carbonaceous anode to saturate the carbon comprising the anode. The resulting  $\text{Li}_x\text{C}_6$  electrode can have an x ranging between 0.1 and 1.0. The cell is then provided with an electrical potential and is discharged in a normal manner.

35 An alternate secondary cell construction comprises intercalating the carbonaceous material with the active alkali material before the anode is incorporated into the cell. In



5 this case, the cathode body can be solid and comprise, but not  
be limited to, such materials as manganese dioxide, silver  
vanadium oxide, copper silver vanadium oxide, titanium  
disulfide, copper oxide, copper sulfide, iron sulfide, iron  
disulfide and fluorinated carbon. However, this approach is  
10 compromised by the problems associated with handling lithiated  
carbon outside of the cell. Lithiated carbon tends to react  
when contacted by air.

The secondary cell of the present invention includes a  
separator to provide physical segregation between the anode  
15 and cathode active electrodes. The separator is of an  
electrically insulative material to prevent an internal  
electrical short circuit between the electrodes, and the  
separator material also is chemically unreactive with the  
anode and cathode active materials and both chemically  
20 unreactive with and insoluble in the electrolyte. In  
addition, the separator material has a degree of porosity  
sufficient to allow flow therethrough of the electrolyte  
during the electrochemical reaction of the cell. The form of  
the separator typically is a sheet which is placed between the  
25 anode and cathode electrodes. Such is the case when the anode  
is folded in a serpentine-like structure with a plurality of  
cathode plates disposed intermediate the anode folds and  
received in a cell casing or when the electrode combination is  
rolled or otherwise formed into a cylindrical "jellyroll"  
30 configuration.

Illustrative separator materials include fabrics woven  
from fluoropolymeric fibers of polyethylenetetrafluoroethylene  
and polyethylenechlorotrifluoroethylene used either alone or  
laminated with a fluoropolymeric microporous film. Other  
35 suitable separator materials include non-woven glass,  
polypropylene, polyethylene, glass fiber materials, ceramics,  
a polytetrafluoroethylene membrane commercially available



5 under the designation ZITEX (Chemplast Inc.), a polypropylene membrane commercially available under the designation CELGARD (Celanese Plastic Company, Inc.) and a membrane commercially available under the designation DEXIGLAS (C.H. Dexter, Div., Dexter Corp.).

10 The choice of an electrolyte solvent system for activating an alkali metal electrochemical cell, and particularly a fully charged lithium ion cell is very limited due to the high potential of the cathode material (up to 4.3V vs. Li/Li<sup>+</sup> for Li<sub>1-x</sub>CoO<sub>2</sub>) and the low potential of the anode  
15 material (0.01V vs. Li/Li<sup>+</sup> for graphite). According to the present invention, suitable nonaqueous electrolytes are comprised of an inorganic salt dissolved in a nonaqueous solvent and more preferably an alkali metal salt dissolved in a quaternary mixture of organic carbonate solvents comprising  
20 dialkyl (non-cyclic) carbonates selected from dimethyl carbonate (DMC), diethyl carbonate (DEC), dipropyl carbonate (DPC), ethylmethyl carbonate (EMC), methylpropyl carbonate (MPC) and ethylpropyl carbonate (EPC), and mixtures thereof, and at least one cyclic carbonate selected from propylene  
25 carbonate (PC), ethylene carbonate (EC), butylene carbonate (BC) and vinylene carbonate (VC), and mixtures thereof. Organic carbonates are generally used in the electrolyte solvent system for such battery chemistries because they exhibit high oxidative stability toward cathode materials and  
30 good kinetic stability toward anode materials.

Preferred electrolytes according to the present invention comprise solvent mixtures of EC:DMC:EMC:DEC. Most preferred volume percent ranges for the various carbonate solvents include EC in the range of about 10% to about 50%; DMC in the  
35 range of about 5% to about 75%; EMC in the range of about 5% to about 50%; and DEC in the range of about 3% to about 45%. Electrolytes containing this quaternary carbonate mixture

5 exhibit freezing points below  $-50^{\circ}\text{C}$ , and lithium ion cells activated with such mixtures have very good cycling behavior at room temperature as well as very good discharge and charge/discharge cycling behavior at temperatures below  $-20^{\circ}\text{C}$ .

10 Known lithium salts that are useful as a vehicle for transport of alkali metal ions from the anode to the cathode, and back again include  $\text{LiPF}_6$ ,  $\text{LiBF}_4$ ,  $\text{LiAsF}_6$ ,  $\text{LiSbF}_6$ ,  $\text{LiClO}_4$ ,  $\text{LiAlCl}_4$ ,  $\text{LiGaCl}_4$ ,  $\text{Li}(\text{SO}_2\text{CF}_3)_3$ ,  $\text{LiNO}_3$ ,  $\text{LiN}(\text{SO}_2\text{CF}_3)_2$ ,  $\text{LiSCN}$ ,  $\text{LiO}_3\text{SCF}_2\text{CF}_3$ ,  $\text{LiC}_6\text{F}_5\text{SO}_3$ ,  $\text{LiO}_2\text{CCF}_3$ ,  $\text{LiSO}_3\text{F}$ ,  $\text{LiB}(\text{C}_6\text{H}_5)_4$  and  $\text{LiCF}_3\text{SO}_3$ , and mixtures thereof. Suitable salt concentrations typically  
15 range between about 0.8 to 1.5 molar.

In accordance with the present invention, at least one organic sulfite additive is provided in the electrolyte. The sulfite additive preferably has the general formula  $\text{R}^1\text{OS}(=\text{O})(\text{OR}^2)$ , wherein  $\text{R}^1$  and  $\text{R}^2$  are the same or different and  
20 they can both be a hydrogen atom or an organic group containing 1 to 12 carbon atoms, and wherein at least  $\text{R}^1$  has the structure  $(\text{R}^3)(\text{R}^4)(\text{R}^5)\text{C}-$  if  $\text{R}^2 \neq \text{H}$  with at least  $\text{R}^3$  being an aromatic substituent or an unsaturated organic or inorganic group and wherein if any of the remaining groups of  $\text{R}^4$  and  $\text{R}^5$   
25 is a saturated organic group, the saturated organic group contains 1 to 11 carbon atoms.

The greatest effect is found when diallyl sulfite, methyl benzyl sulfite, ethyl benzyl sulfite, propyl benzyl sulfite, butyl benzyl sulfite, pentyl benzyl sulfite, methyl allyl  
30 sulfite, ethyl allyl sulfite, propyl allyl sulfite, butyl allyl sulfite, pentyl allyl sulfite, mono-methyl sulfite, mono-ethyl sulfite, mono-butyl sulfite, mono-propyl sulfite, mono-pentyl sulfite, mono-allyl sulfite, mono-benzyl sulfite and dibenzyl sulfite, and mixtures thereof are used as  
35 additives in the electrolyte.

The above described compounds are only intended to be exemplary of those that are useful with the present invention,



5 and are not to be construed as limiting. Those skilled in the art will readily recognize sulfite compounds which come under the purview of the general formula set forth above and which will be useful as additives for the electrolyte to reduce voltage delay according to the present invention.

10 While not intending to be bound by any particular mechanism, it is believed that due to the presence of the sulfite additive comprising at least one unsaturated hydrocarbon containing a  $C(sp^2 \text{ or } sp^3)-C(sp^3)$  bond unit having the  $C(sp^3)$  carbon directly connected to the  $-OSO_2-$  functional  
15 group, the bond between oxygen and at least one of the group  $R^1$  and  $R^2$  is readily severed and the sulfite intermediate is able to compete effectively with the other electrolyte solvents or solutes to react with lithium and form a sulfite salt, i.e., lithium sulfite, or the lithium salt of a sulfite reduction  
20 product on the surface of the anode. The resulting salt is more conductive than lithium oxide which may form on the anode in the absence of the organic sulfite additive.

In fact, it is believed that the lithium sulfite or the lithium salt of a sulfite reduction product on the surface of  
25 the anode provides for the existence of charge delocalization due to resonance equilibration at the anode surface. This equilibration allows lithium ions to travel easily from one molecule to the other via a lithium ion exchange mechanism. As a result, beneficial ionic conductance is realized.  
30 Accordingly, it is believed that the present organic sulfite compounds compete more effectively with the other solvents in the electrolyte to form an ionically more conductive and electrically more insulative film than is provided by alkyl sulfites and cyclic sulfites such as ethylene sulfite and  
35 propylene sulfite, for example. As a consequence, the chemical composition and perhaps the morphology of the carbonaceous anode surface protective layer is believed to be



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5 changed with concomitant benefits to the cell's cycling characteristics.

The assembly of the cell described herein is preferably in the form of a wound element cell. That is, the fabricated cathode, anode and separator are wound together in a  
10 "jellyroll" type configuration or "wound element cell stack" such that the anode is on the outside of the roll to make electrical contact with the cell case in a case-negative configuration. Using suitable top and bottom insulators, the wound cell stack is inserted into a metallic case of a  
15 suitable size dimension. The metallic case may comprise materials such as stainless steel, mild steel, nickel-plated mild steel, titanium or aluminum, but not limited thereto, so long as the metallic material is compatible for use with components of the cell.

20 The cell header comprises a metallic disc-shaped body with a first hole to accommodate a glass-to-metal seal/terminal pin feedthrough and a second hole for electrolyte filling. The glass used is of a corrosion resistant type having up to about 50% by weight silicon such  
25 as CABAL<sup>TM</sup> 12, TA 23 or FUSITE<sup>TM</sup> 425 or FUSITE<sup>TM</sup> 435. The positive terminal pin feedthrough preferably comprises titanium although molybdenum, aluminum, nickel alloy, or stainless steel can also be used. The cell header comprises elements having compatibility with the other components of the  
30 electrochemical cell and is resistant to corrosion. The cathode lead is welded to the positive terminal pin in the glass-to-metal seal and the header is welded to the case containing the electrode stack. The cell is thereafter filled with the electrolyte solution comprising at least one of the  
35 sulfite additives described hereinabove and hermetically sealed such as by close-welding a stainless steel ball over the fill hole, but not limited thereto.

5           The above assembly describes a case-negative cell, which  
is the preferred construction of the exemplary cell of the  
present invention. As is well known to those skilled in the  
art, the exemplary electrochemical system of the present  
invention can also be constructed in a case-positive  
10 configuration.

          The concentration limit for the sulfite additive is  
preferably about 0.001M to about 0.20M. The beneficial effect  
of the sulfite additive will not be apparent if the additive  
concentration is less than about 0.001M. On the other hand,  
15 if the additive concentration is greater than about 0.20M, the  
beneficial effect of the additive will be canceled by the  
detrimental effect of higher internal cell resistance due to  
the thicker anode surface film formation and lower electrolyte  
conductivity.

20           It is appreciated that various modifications to the  
inventive concepts described herein may be apparent to those  
of ordinary skill in the art without departing from the spirit  
and scope of the present invention as defined by the appended  
claims.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE  
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An electrochemical cell, which comprises:

a) a negative electrode which intercalates with an  
5 alkali metal;

b) a positive electrode comprising an electrode  
active material which intercalates with the alkali metal;

c) a nonaqueous electrolyte activating the negative  
and the positive electrodes; and

10 d) a sulfite additive of the formula  $R^1OS(=O)(OR^2)$   
provided in the electrolyte

wherein:

15  $R^1$  is a group which has at least one  
unsaturated hydrocarbon containing a  $C(sp^2$  or  
 $sp^3)-C(sp^3)$  bond unit having the  $C(sp^3)$   
carbon directly connected to the  $-OSO_2-$   
functional group; and

20  $R^2$  is selected from the group consisting of a  
hydrogen atom and an organic group  
containing 1 to 12 carbon atoms;

wherein when  $R^2$  is a hydrogen then  $R^1$  is an unsaturated  
hydrocarbon having 3-12 carbon atoms; and

wherein when  $R^2$  is an organic group containing 1 to 12  
carbon atoms then  $R^1$  has the structure  $(R^3)(R^4)(R^5)C-$

25 wherein:

i)  $R^3$  is selected from the group consisting of  
an aromatic group, an unsaturated organic  
group and an unsaturated inorganic group;  
and

30 ii)  $R^4$  and  $R^5$  are independently selected from the  
group consisting of an aromatic group, an



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unsaturated organic group, an unsaturated inorganic group and a saturated organic group containing from 1 to 11 carbon atoms.

2. The electrochemical cell of claim 1 wherein the additive is selected from the group consisting of diallyl sulfite, methyl benzyl sulfite, ethyl benzyl sulfite, propyl benzyl sulfite, butyl benzyl sulfite, pentyl benzyl sulfite, methyl allyl sulfite, ethyl allyl sulfite, propyl allyl sulfite, butyl allyl sulfite, pentyl allyl sulfite, mono-allyl sulfite, mono-benzyl sulfite, dibenzyl sulfite, and mixtures thereof.

3. The electrochemical cell of claim 1 wherein the sulfite additive is present in the electrolyte in a range of about 0.001M to about 0.20M.

4. The electrochemical cell of claim 1 wherein the electrolyte includes a quaternary, nonaqueous carbonate solvent mixture.

5. The electrochemical cell of claim 1 wherein the electrolyte comprises at least one linear carbonate selected from the group consisting of dimethyl carbonate, diethyl carbonate, dipropyl carbonate, ethylmethyl carbonate, methylpropyl carbonate, ethylpropyl carbonate, and mixtures thereof.

6. The electrochemical cell of claim 5 wherein the electrolyte comprises at least three of the linear carbonates.

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7. The electrochemical cell of claim 1 wherein the electrolyte comprises at least one cyclic carbonate selected from the group consisting of ethylene carbonate, propylene carbonate, butylene carbonate, vinylene carbonate, and mixtures thereof.

8. The electrochemical cell of claim 1 wherein the electrolyte comprises ethylene carbonate, dimethyl carbonate, ethylmethyl carbonate and diethyl carbonate.

9. The electrochemical cell of claim 8 wherein the ethylene carbonate is in the range of about 10% to about 50%, the dimethyl carbonate is in the range of about 5% to about 75%, the ethylmethyl carbonate is in the range of about 5% to about 50%, and the diethyl carbonate is in the range of about 3% to about 45%, by volume.

10. The electrochemical cell of claim 1 wherein the electrolyte includes an alkali metal salt selected from the group consisting of  $\text{LiPF}_6$ ,  $\text{LiBF}_4$ ,  $\text{LiAsF}_6$ ,  $\text{LiSbF}_6$ ,  $\text{LiClO}_4$ ,  $\text{LiAlCl}_4$ ,  $\text{LiGaCl}_4$ ,  $\text{LiNO}_3$ ,  $\text{LiC}(\text{SO}_2\text{CF}_3)_3$ ,  $\text{LiN}(\text{SO}_2\text{CF}_3)_2$ ,  $\text{LiSCN}$ ,  $\text{LiO}_3\text{SCF}_2\text{CF}_3$ ,  $\text{LiC}_6\text{F}_5\text{SO}_3$ ,  $\text{LiO}_2\text{CCF}_3$ ,  $\text{LiSO}_3\text{F}$ ,  $\text{LiB}(\text{C}_6\text{H}_5)_4$ ,  $\text{LiCF}_3\text{SO}_3$ , and mixtures thereof.

11. The electrochemical cell of claim 10 wherein the alkali metal is lithium.

12. The electrochemical cell of claim 1 wherein the negative electrode comprises a negative electrode active material selected from the group consisting of coke, carbon black, graphite, acetylene black, carbon fibers, glassy carbon, and mixtures thereof.

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13. The electrochemical cell of claim 1 wherein the negative electrode active material is mixed with a fluoro-resin binder.

5 14. The electrochemical cell of claim 1 wherein the positive electrode comprises a positive electrode active material selected from the group consisting of lithiated oxides, lithiated sulfides, lithiated selenides and lithiated tellurides of the group selected from vanadium, titanium, chromium, copper, molybdenum, niobium, iron,  
10 nickel, cobalt, manganese, and mixtures thereof.

15. The electrochemical cell of claim 14 wherein the positive electrode active material is mixed with a fluoro-resin binder.

15 16. The electrochemical cell of claim 14 wherein the positive electrode active material is mixed with a conductive additive selected from the group consisting of acetylene black, carbon black, graphite, nickel powder, aluminum powder, titanium powder, stainless steel powder, and mixtures thereof.

20 17. An electrochemical cell, which comprises:  
a) a negative electrode which intercalates with lithium;  
b) a positive electrode comprising an electrode active material and which intercalates with lithium; and  
25 c) an electrolyte solution activating the anode and the cathode, the electrolyte including an alkali metal salt dissolved in a quaternary, nonaqueous carbonate solvent mixture of ethylene carbonate, dimethyl carbonate,



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ethylmethyl carbonate and diethyl carbonate; and

d) a sulfite additive of the formula  $R^1OS(=O)(OR^2)$  provided in the electrolyte

wherein:

5  $R^1$  is a group which has at least one unsaturated hydrocarbon containing a  $C(sp^2$  or  $sp^3)-C(sp^3)$  bond unit having the  $C(sp^3)$  carbon directly connected to the  $-OSO_2-$  functional group; and

10  $R^2$  is selected from the group consisting of a hydrogen atom and an organic group containing 1 to 12 carbon atoms;

wherein when  $R^2$  is a hydrogen then  $R^1$  is an unsaturated hydrocarbon having 3-12 carbon atoms; and

15 wherein when  $R^2$  is an organic group containing 1 to 12 carbon atoms then  $R^1$  has the structure  $(R^3)(R^4)(R^5)C-$  wherein:

i)  $R^3$  is selected from the group consisting of an aromatic group, an unsaturated organic group and an unsaturated inorganic group; and

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ii)  $R^4$  and  $R^5$  are independently selected from the group consisting of an aromatic group, an unsaturated organic group, an unsaturated inorganic group and a saturated organic group containing from 1 to 11 carbon atoms.

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18. The electrochemical cell of claim 17 wherein the sulfite additive is selected from the group consisting of diallyl sulfite, methyl benzyl sulfite, ethyl benzyl sulfite, propyl benzyl sulfite, butyl benzyl sulfite, pentyl benzyl sulfite, methyl allyl sulfite, ethyl allyl

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sulfite, propyl allyl sulfite, butyl allyl sulfite, pentyl allyl sulfite, mono-allyl sulfite, mono-benzyl sulfite, dibenzyl sulfite, and mixtures thereof.

5 19. The electrochemical cell of claim 17 wherein the ethylene carbonate is in the range of about 10% to about 50%, the dimethyl carbonate is in the range of about 5% to about 75%, the ethylmethyl carbonate is in the range of about 5% to about 50%, and the diethyl carbonate is in the range of about 3% to about 45%, by volume.

10 20. The electrochemical cell of claim 17 wherein the electrolyte includes an alkali metal salt selected from the group consisting of  $\text{LiPF}_6$ ,  $\text{LiBF}_4$ ,  $\text{LiAsF}_6$ ,  $\text{LiSbF}_6$ ,  $\text{LiClO}_4$ ,  $\text{LiAlCl}_4$ ,  $\text{LiGaCl}_4$ ,  $\text{LiNO}_3$ ,  $\text{LiC}(\text{SO}_2\text{CF}_3)_3$ ,  $\text{LiN}(\text{SO}_2\text{CF}_3)_2$ ,  $\text{LiSCN}$ ,  $\text{LiO}_3\text{SCF}_2\text{CF}_3$ ,  $\text{LiC}_6\text{F}_5\text{SO}_3$ ,  $\text{LiO}_2\text{CCF}_3$ ,  $\text{LiSO}_3\text{F}$ ,  $\text{LiB}(\text{C}_6\text{H}_5)_4$ ,  $\text{LiCF}_3\text{SO}_3$ ,  
15 and mixtures thereof.

21. A method for providing an electrochemical cell, comprising the steps of:

a) providing a negative electrode which intercalates with an alkali metal;

20 b) providing a positive electrode comprising an electrode active material which intercalates with the alkali metal;

c) activating the negative and positive electrodes with a nonaqueous electrolyte; and

25 d) a sulfite additive of the formula  $\text{R}^1\text{OS}(=\text{O})(\text{OR}^2)$  provided in the electrolyte

wherein:

$\text{R}^1$  is a group which has at least one unsaturated hydrocarbon containing a  $\text{C}(\text{sp}^2$  or



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$sp^3$ )-C( $sp^3$ ) bond unit having the C( $sp^3$ ) carbon directly connected to the -OSO<sub>2</sub>- functional group; and

5 R<sup>2</sup> is selected from the group consisting of a hydrogen atom and an organic group containing 1 to 12 carbon atoms;

wherein when R<sup>2</sup> is a hydrogen then R<sup>1</sup> is an unsaturated hydrocarbon having 3-12 carbon atoms; and

10 wherein when R<sup>2</sup> is an organic group containing 1 to 12 carbon atoms then R<sup>1</sup> has the structure (R<sup>3</sup>) (R<sup>4</sup>) (R<sup>5</sup>)C- wherein:

i) R<sup>3</sup> is selected from the group consisting of an aromatic group, an unsaturated organic group and an unsaturated inorganic group; and

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ii) R<sup>4</sup> and R<sup>5</sup> are independently selected from the group consisting of an aromatic group, an unsaturated organic group, an unsaturated inorganic group and a saturated organic group containing from 1 to 11 carbon atoms.

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22. The method of claim 21 including selecting the sulfite additive from the group consisting of diallyl sulfite, methyl benzyl sulfite, ethyl benzyl sulfite, propyl benzyl sulfite, butyl benzyl sulfite, pentyl benzyl sulfite, methyl allyl sulfite, ethyl allyl sulfite, propyl allyl sulfite, butyl allyl sulfite, pentyl allyl sulfite, mono-allyl sulfite, mono-benzyl sulfite, dibenzyl sulfite, and mixtures thereof.

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23. The method of claim 21 wherein the sulfite additive is present in the electrolyte in a range of about

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0.001M to about 0.20M.

24. The method of claim 21 including providing the electrolyte comprising a quaternary, nonaqueous carbonate solvent mixture.

5           25. The method of claim 21 wherein the electrolyte comprises at least one linear carbonate selected from the group consisting of dimethyl carbonate, diethyl carbonate, dipropyl carbonate, ethylmethyl carbonate, methylpropyl carbonate, ethylpropyl carbonate, and mixtures thereof.

10           26. The method of claim 25 wherein the electrolyte comprises at least three of the linear carbonates.

15           27. The method of claim 21 wherein the electrolyte comprises at least one cyclic carbonate selected from the group consisting of ethylene carbonate, propylene carbonate, butylene carbonate, vinylene carbonate, and mixtures thereof.

            28. The method of claim 21 wherein the electrolyte comprises ethylene carbonate, dimethyl carbonate, ethylmethyl carbonate and diethyl carbonate.

20           29. The method of claim 28 wherein the ethylene carbonate is in the range of about 10% to about 50%, the dimethyl carbonate is in the range of about 5% to about 75%, the ethylmethyl carbonate is in the range of about 5% to about 50%, and the diethyl carbonate is in the range of  
25           about 3% to about 45%, by volume.



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30. The method of claim 21 wherein the electrolyte includes an alkali metal salt selected from the group consisting of  $\text{LiPF}_6$ ,  $\text{LiBF}_4$ ,  $\text{LiAsF}_6$ ,  $\text{LiSbF}_6$ ,  $\text{LiClO}_4$ ,  $\text{LiAlCl}_4$ ,  $\text{LiGaCl}_4$ ,  $\text{LiNO}_3$ ,  $\text{LiC}(\text{SO}_2\text{CF}_3)_3$ ,  $\text{LiN}(\text{SO}_2\text{CF}_3)_2$ ,  $\text{LiSCN}$ ,  $\text{LiO}_3\text{SCF}_2\text{CF}_3$ ,  
5  $\text{LiC}_6\text{F}_5\text{SO}_3$ ,  $\text{LiO}_2\text{CCF}_3$ ,  $\text{LiSO}_3\text{F}$ ,  $\text{LiB}(\text{C}_6\text{H}_5)_4$ ,  $\text{LiCF}_3\text{SO}_3$ , and mixtures thereof.

31. The method of claim 21 including providing the alkali metal as lithium.

10 32. The method of claim 21 including providing the positive electrode comprising a positive electrode active material selected from the group consisting of lithiated oxides, lithiated sulfides, lithiated selenides and lithiated tellurides of the group selected from vanadium, titanium, chromium, copper, molybdenum, niobium, iron,  
15 nickel, cobalt, manganese, and mixtures thereof.

20 33. The method of claim 21 including providing the negative electrode comprising a negative electrode active material selected from the group consisting of coke, carbon black, graphite, acetylene black, carbon fibers, glassy carbon, and mixtures thereof.