In view of the limitations of current lithium batteries, there is a need for development of a rechargeable lithium battery that overcomes or at least ameliorates, one or more of the disadvantages described above.

## Summary

There is provided an electrolyte comprising lithium difluoro(oxalate)borate (LiDFOB) and a carbonate solvent, wherein LiDFOB is present at a concentration in the range of 1.5 M to 3 M. In an aspect, there is provided an electrolyte comprising lithium difluoro(oxalate)borate (LiDFOB), an additional salt, a carbonate solvent and a co-solvent, wherein LiDFOB is present at a concentration in the range of 1.5 M to 3 M, wherein the electrolyte does not comprise lithium salts other than LiDFOB, wherein the carbonate solvent is ethylene carbonate, propylene carbonate or a combination thereof, and wherein the co-solvent is selected from the group consisting of diethyl carbonate, dimethyl carbonate, gamma-butyrolactone, 1,2-dimethyoxyethane and combinations thereof.

Advantageously, the electrolyte as defined above comprises a high concentration of LiDFOB. This concentration may be significantly higher than in conventional electrolytes, and the electrolyte may be used in a battery to confer high cycling performance. Advantageously, the high concentration of the LiDFOB in the range of 1.5 M to 3 M may retain the battery's specific capacity at high cycle numbers. The good thermal stability of the electrolyte may further advantageously allow smooth lithium plating of the counter electrode on the anode side or the anode at an elevated temperature. The use of the electrolyte as defined above may facilitate a capacity retention of 65% for an anode-free battery after 100 cycles or 70% for a battery with a lithium metal anode after 200 cycles.

Further advantageously, the electrolyte as defined above may have a high cycling stability even when heated to a temperature of up to at least 80 $^{o}$C. Therefore, when the electrolyte as defined above is used in an electrochemical cell and operating at an elevated temperature in the range of, for example 40 $^{o}$C to 60 $^{o}$C, the electrolyte may still be stable, in contrast to conventionally used solvents such as fluoroethylene carbonate (FEC) which may degrade at temperatures as low as 40 $^{o}$C. A cell operating at elevated temperatures with the electrolyte as defined above, may exhibit about 5 % higher specific capacity and about 50 % lower electrochemical impedance than a cell operating at room temperature.

Further advantageously, the electrolyte comprising the carbonate solvent as defined above may have better cycling properties compared to, for example, an electrolyte comprising an ether. Ether-based electrolytes may not be suitable in applications with high energy cathodes operating at a voltage above 4.0 V due to a narrow voltage stability window. However, the electrolyte as defined above may advantageously be suitable for such applications.

Further advantageously, the electrolyte as defined above may facilitate reversible and smooth lithium plating of a counter electrode on the anode side or an anode when used in a cell, which may further contribute to the high cycling performance of the cell.

More advantageously, it may be the combination of the specific concentration of LiDFOB and the carbonate solvent as defined above that confers the advantages to the electrolyte as outlined above.

In another aspect, there is provided a rechargeable battery comprising the electrolyte as described herein, a cathode layer, an anode layer and a separator.

Advantageously, the rechargeable battery as defined herein may have a high capacity of up to 2.8Ah. Further, advantageously, the rechargeable battery as defined above may have a high energy density and specific energy. This may be due to the absence of a thick graphite layer or a thick lithium layer as an anode in the battery, which may in turn be due to the electrolyte as defined above facilitating a reversible and smooth lithium plating of a counter electrode on the anode side or an anode in the cell.

Further advantageously, the rechargeable battery as defined above may exhibit similar or better performance as batteries comprising a dual-salt electrolyte, even if a dual-salt electrolyte is not used. That is, the rechargeable battery as defined above may achieve just as high or better performance as a battery using a dual-salt electrolyte, even when only a single-salt electrolyte is used.

There is also provided a method of preparing the electrolyte as described herein, comprising the step of dissolving LiDFOB in a carbonate solvent, wherein LiDFOB is present at a concentration in the range of 1.5 M to 3 M. In another aspect, there is provided a method of preparing the electrolyte as described herein, comprising the step of dissolving the LiDFOB in the carbonate solvent and co-solvent, and adding the additional salt before or after the dissolving step.

Advantageously, the method as defined above circumvents the use of conventionally used solvents such as fluroethylenecarbonate (FEC) which are expensive, and require to be stored at low temperature in the range of 2 °C to 8 °C. The method as defined above further circumvents the use of ether solvents which may have a narrow voltage stability window. Advantageously, the method may produce an electrolyte with high thermal stability. The electrolyte may be stably heated to at least 80 °C. The method as described above may therefore allow the electrolyte to be prepared using reagents that can be stored at room temperature or above, making the method of preparation significantly more convenient, while maintaining a high performance of the electrolyte.

Further advantageously, the method may produce an electrolyte suitable for use in a rechargeable battery with high cycling stability. The use of the electrolyte may have a capacity retention of 65% for an anode-free battery after 100 cycles or 70% for a battery with a lithium metal anode after 200 cycles.

## Definitions

The following words and terms used herein shall have the meaning indicated:

“Electrolyte” for the purposes of this disclosure refers to a medium comprising ions dissolved in a liquid that conducts cations between two or more electrodes when a voltage is applied.

"Alkyl" as a group or part of a group refers to a straight or branched aliphatic hydrocarbon group, preferably a $C_1$–$C_6$ alkyl unless otherwise noted. Examples of suitable straight and branched $C_1$-$C_6$ alkyl substituents include methyl, ethyl, n-propyl, 2-propyl, n-butyl, sec-butyl, t-butyl, hexyl, heptyl, octyl and the like. The group may be a terminal group or a bridging group.

# Claims

1. An electrolyte comprising lithium difluoro(oxalate)borate (LiDFOB), an additional salt, a carbonate solvent and a co-solvent, wherein LiDFOB is present at a concentration in the range of 1.5 M to 3 M, wherein the electrolyte does not comprise lithium salts other than LiDFOB, wherein the carbonate solvent is ethylene carbonate, propylene carbonate or a combination thereof, and wherein the co-solvent is selected from the group consisting of diethyl carbonate, dimethyl carbonate, gamma-butyrolactone, 1,2-dimethyoxyethane and combinations thereof.

2. The electrolyte according to claim 1, wherein the solvent and the co-solvent have a volume ratio in the range of 8:2 to 1:9.

3. The electrolyte according to any one of the preceding claims, wherein a concentration of the additional salt is in the range of 10 μM to 2 M.

4. The electrolyte according to any one of the preceding claims, wherein the electrolyte has a water content in the range of 0 ppm to 1000 ppm.

5. A rechargeable battery comprising the electrolyte according to any one of the preceding claims, a cathode layer, an anode layer and a separator.

6. The rechargeable battery according to claim 5, further comprising a case.

7. The rechargeable battery according to claim 5 or 6, wherein the cathode layer comprises a cathode, and an aluminium foil or a conductive mesh.

8. The rechargeable battery according to claim 7, wherein the cathode comprises a cathode material, a conductive additive and a polymer binder.

9. The rechargeable battery according to claim 8, wherein the cathode material is selected from the group consisting of nickel cobalt manganese oxides (NCM), nickel cobalt aluminium oxides (NCA), lithium cobalt oxide, lithium manganese oxide, lithium iron phosphate and any combination thereof, the conductive additive is selected from the group consisting of carbon black, carbon nanotubes, graphene and any combination thereof, or the polymer binder is selected from the group consisting of polyvinylidene fluoride (PVDF), poly-o-methoxyaniline (POMA), poly(3,4-ethylenedioxythiophene) (PEDOT), polyaniline (PANI), polyacrylonitrile (PAN), poly(acrylic acid) (PAA) and any combination thereof.

10. The rechargeable battery according to any one of claims 5 to 9, wherein the anode layer comprises copper, nickel, titanium, stainless steel, lithium or a mixture thereof.

11. The rechargeable battery according to any one of claims 5 to 10, wherein the rechargeable battery comprises multiple cathode layers, multiple anode layers and multiple separators.

12. A method of preparing the electrolyte according to any one of claims 1 to 4, comprising the step of dissolving the LiDFOB in the carbonate solvent and co-solvent, and adding the additional salt before or after the dissolving step.

13. The method according to claim 12, further comprising a step of drying the LiDFOB or the carbonate solvent before the dissolving step.

14. The method according to claim 13, wherein in the drying step, the LiDFOB is heated at a temperature of at least 120 $^{o}$C for a duration of at least 5 hours, or the carbonate solvent is dried with a desiccant for a duration of at least 48 hours.

15. The method according to any one of claims 12 to 14, further comprising a mixing step before the dissolving step, wherein the carbonate solvent is mixed with the co-solvent.