

CLAIMS

1. An electrode for metal-ion battery, the electrode comprising an active layer in electrical contact with a current collector, wherein the active layer comprises:
- 5 (i) a plurality of porous particles comprising an electroactive material selected from silicon, germanium, tin, aluminium and mixtures thereof, wherein the porous particles have a D_{50} particle diameter in the range of ~~0-50.8~~ to 18 μm , and an intra-particle porosity in the range of from 40 to 90%; and
- (ii) a plurality of carbon particles selected from one or more of graphite, soft carbon and hard carbon and having a D_{50} particle diameter in the range of from 1 to 50 μm
- 10 wherein the active layer comprises at least 50% by weight of the carbon particles (ii), and wherein the ratio of the D_{50} particle diameter of the carbon particles (ii) to the D_{50} particle diameter of the porous particles (i) is in the range of from 1.5 to 30.
2. An electrode according to claim 1, wherein the porous particles (i) comprise at least 60 wt% of the electroactive material.
- 15 3. An electrode according to claim 2, wherein the porous particles (i) comprise at least 60 wt% silicon or tin.
4. An electrode according to claim 3, wherein the porous particles (i) comprise at least 60 wt% silicon.
5. An electrode according to claim 4, wherein the porous particles (i) comprise at least
- 20 85 wt% silicon.
6. An electrode according to claim 4, wherein the porous particles (i) comprise at least 60 wt% silicon or tin and up to 40 wt% aluminium and/or germanium.
7. An electrode according to claim 6, wherein the porous particles (i) comprise at least 95 wt% silicon or tin and up to 5 wt% aluminium and/or germanium.
- 25 8. An electrode according to claim 6 or claim 7, wherein the porous particles (i) comprise at least 0.01 wt% aluminium and/or germanium.
9. An electrode according to any one of the preceding claims, wherein the porous particles (i) comprise no more than 10 wt% of one or more additional elements selected from antimony, copper, magnesium, zinc, manganese, chromium, cobalt, molybdenum, nickel,

beryllium, zirconium, iron, sodium, strontium, phosphorus, tin, ruthenium, gold, silver, and oxides thereof, based on the total weight of the porous particles (i).

10. An electrode according to claim 9, wherein the porous particles (i) comprise no more than 10 wt% of one or more of nickel, silver or copper, based on the total weight of the porous particles (i).

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~~11. An electrode according to any one of the preceding claims, wherein the D_{50} particle diameter of the porous particles (i) is at least 0.8 μm .~~

~~12~~11. An electrode according to claim ~~11~~1, wherein the D_{50} particle diameter of the porous particles (i) is at least 3 μm .

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~~13~~12. An electrode according to any one of the preceding claims, wherein the D_{50} particle diameter of the porous particles (i) is no more than 15 μm .

~~14~~13. An electrode according to claim ~~13~~12, wherein the D_{50} particle diameter of the porous particles (i) is no more than 8 μm .

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~~15~~14. An electrode according to any one of the preceding claims, wherein the porous particles (i) have a particle size distribution span of 5 or less.

~~16~~15. An electrode according to any one of the preceding claims, wherein the average aspect ratio of the porous particles (i) is less than 3:1.

~~17~~16. An electrode according to any one of the preceding claims, wherein the porous particles (i) are spheroidal particles having an average sphericity S_{av} of at least 0.70.

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~~18~~17. An electrode according to any one of the preceding claims, wherein the porous particles (i) have an intra-particle porosity of at least 45%.

~~19~~18. An electrode according to any one of the preceding claims, wherein the porous particles (i) have an intra-particle porosity of no more than 85%.

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~~20~~19. An electrode according to any one of the preceding claims, wherein the porous particles (i) have a pore diameter distribution having at least one peak at a pore size less than 350 nm as determined by mercury porosimetry.

2420. An electrode according to any one of the preceding claims, wherein the porous particles (i) have a pore diameter distribution having at least one peak at a pore size of more than 50 nm as determined by mercury porosimetry.

5 2221. An electrode according to any one of the preceding claims, wherein the porous particles (i) comprise a network of interconnected irregular elongate structural elements, preferably wherein the particles comprise structural elements having an aspect ratio of at least 2:1.

10 2322. An electrode according to claim 2221, wherein the porous particles (i) comprise structural elements having a smallest dimension less than 300 nm and a largest dimension at least twice the smallest dimension.

2423. An electrode according to any one of the preceding claims, wherein the porous particles (i) have a BET surface area of less than 300 m²/g.

2524. An electrode according to any one of the preceding claims, wherein the porous particles (i) have a BET surface area of at least 10 m²/g.

15 2625. An electrode according to any one of the preceding claims, wherein the carbon particles (ii) are graphite particles.

2726. An electrode according to any one of the preceding claims, wherein the D₅₀ particle diameter of the carbon particles (ii) is at least 5 μm.

20 2827. An electrode according to any one of the preceding claims, wherein the D₅₀ particle diameter of the carbon particles (ii) is no more than 30 μm.

2928. An electrode according to any one of the preceding claims, wherein the carbon particles (ii) are spheroidal particles having an average sphericity S_{av} of at least 0.70.

3029. An electrode according to any one of the preceding claims, wherein the carbon particles (ii) have an average aspect ratio of less than 3:1.

25 3130. An electrode according to any one of the preceding claims, wherein the active layer comprises from 60 to 95 wt% of the carbon particles (ii).

3231. An electrode according to any one of the preceding claims, wherein the active layer comprises from 1 to 30 wt% of the porous particles (i).

3332. An electrode according to claim 3231, wherein the active layer comprises at least 5 wt% of the porous particles (i).

3433. An electrode according to claim 3231 or claim 3332, wherein the active layer comprises no more than 25 wt% of the porous particles (i).

5 3534. An electrode according to any one of the preceding claims, wherein the active layer has an inter-particle porosity of no more than 30%.

3635. An electrode according to any one of the preceding claims, wherein the active layer has an inter-particle porosity of at least 2%.

10 3736. An electrode according to any one of the preceding claims, wherein the active layer has a density in the range of from 1 to 2 g/cm³.

3837. An electrode according to any one of the preceding claims, wherein the percent average cross-sectional area of the active layer occupied by the porous particles (i) is in the range of from 1% to 25%.

15 3938. An electrode according to any one of the preceding claims, wherein the percent average cross-sectional area of the active layer occupied by the carbon particles (ii) is in the range of from 40% to 85%.

4039. An electrode according to any one of the preceding claims, wherein the percent average cross-sectional area of the active layer occupied by the intra-particle pores of the active layer is in the range of from 2% to 30%.

20 4140. An electrode according to any one of the preceding claims, wherein the active layer comprises a binder.

4241. An electrode according to claim 4140, wherein the active layer comprises a binder in an amount of from 0.5 to 20 wt%, based on the total weight of the active layer.

25 4342. An electrode according to any one of the preceding claims, wherein the active layer comprises one or more conductive additives.

4443. An electrode according to claim 4342, wherein the active layer comprises one or more conductive additives in a total amount of from 0.5 to 20 wt%, based on the total weight of the active layer.

4544. An electrode according to any one of the preceding claims, wherein the active layer has a thickness in the range of from 15 μm to 2 mm.

4645. An electrode composition comprising:

(i) a plurality of porous particles comprising an electroactive material selected from silicon, germanium, tin, aluminium and mixtures thereof, wherein the porous particles have a D_{50} particle diameter in the range of ~~0.5~~0.8 to 18 μm , and an intra-particle porosity in the range of from 40 to 90%,

(ii) a plurality of carbon particles selected from graphite, soft carbon and hard carbon and having a D_{50} particle diameter in the range of from 1 to 50 μm ; and

wherein the electrode composition comprises at least 50% by weight of the carbon particles, based on the solids content of the electrode composition, and wherein the ratio of the D_{50} particle diameter of the carbon particles (ii) to the D_{50} particle diameter of the porous particles (i) is in the range of from 1.5 to 30.

4746. An electrode composition according to claim 4645, wherein the porous particles (i) are as defined in any one of claims 2 to 25.

4847. An electrode composition according to claim 4645 or claim 4746, wherein the carbon particles (ii) are as defined in any one of claims 26 to 30.

4948. An electrode composition according to any one of claims 4645 to 4847, comprising from 60 to 95 wt% of the carbon particles (ii), based on the solids content of the electrode composition.

5049. An electrode composition according to any one of claims 4645 to 4948, comprising at least 1 wt% of the porous particles (i), based on the solids content of the electrode composition.

5150. An electrode composition according to any one of claims 4645 to 5049, comprising no more than 30 wt% of the porous particles (i), based on the solids content of the electrode composition.

5251. An electrode composition according to any one of claims 4645 to 5150, comprising a binder.

5352. An electrode composition according to claim 5251, comprising a binder in an amount of from 0.5 to 20 wt%, based on the solids content of the electrode composition.

5453. An electrode composition according to any one of claims 4645 to 5352, comprising one or more conductive additives.

5554. An electrode composition according to claim 5453, comprising one or more conductive additives in a total amount of from 0.5 to 20 wt%, based on the solids content of the electrode composition.

5655. An electrode composition according to any one of claims 4645 to 5554, in the form of a slurry further comprising a solvent.

5756. A method of preparing an electrode, the method comprising:

- (i) preparing a slurry comprising an electrode composition as defined in claim 5655;
- (ii) casting the slurry onto the surface of a current collector; and
- (iii) removing the solvent to form an active layer in electrical contact with the current collector.

5857. A method of preparing an electrode, the method comprising:

- (i) preparing a slurry comprising an electrode composition as defined in claim 5655;
- (ii) casting the slurry onto a template;
- (iii) removing the solvent to form a freestanding film or mat comprising the electrode composition; and
- (iv) attaching the freestanding film or mat from step (iii) to a current collector to form an active layer in electrical contact with the current collector.

5958. A method according to claim 5756 or claim 5857, further comprising the step of densifying the active layer to obtain an active layer density in the range of from 1 to 2 g/cm³.

6059. A rechargeable metal-ion battery comprising: (i) an anode, wherein the anode comprises an electrode as described in any one of claims 1 to 4544; (ii) a cathode comprising a cathode active material capable of releasing and reabsorbing metal ions; and (iii) an electrolyte between the anode and the cathode.

6160. Use of an electrode composition as defined in any one of claims 4645 to 5655 as an anode active material.