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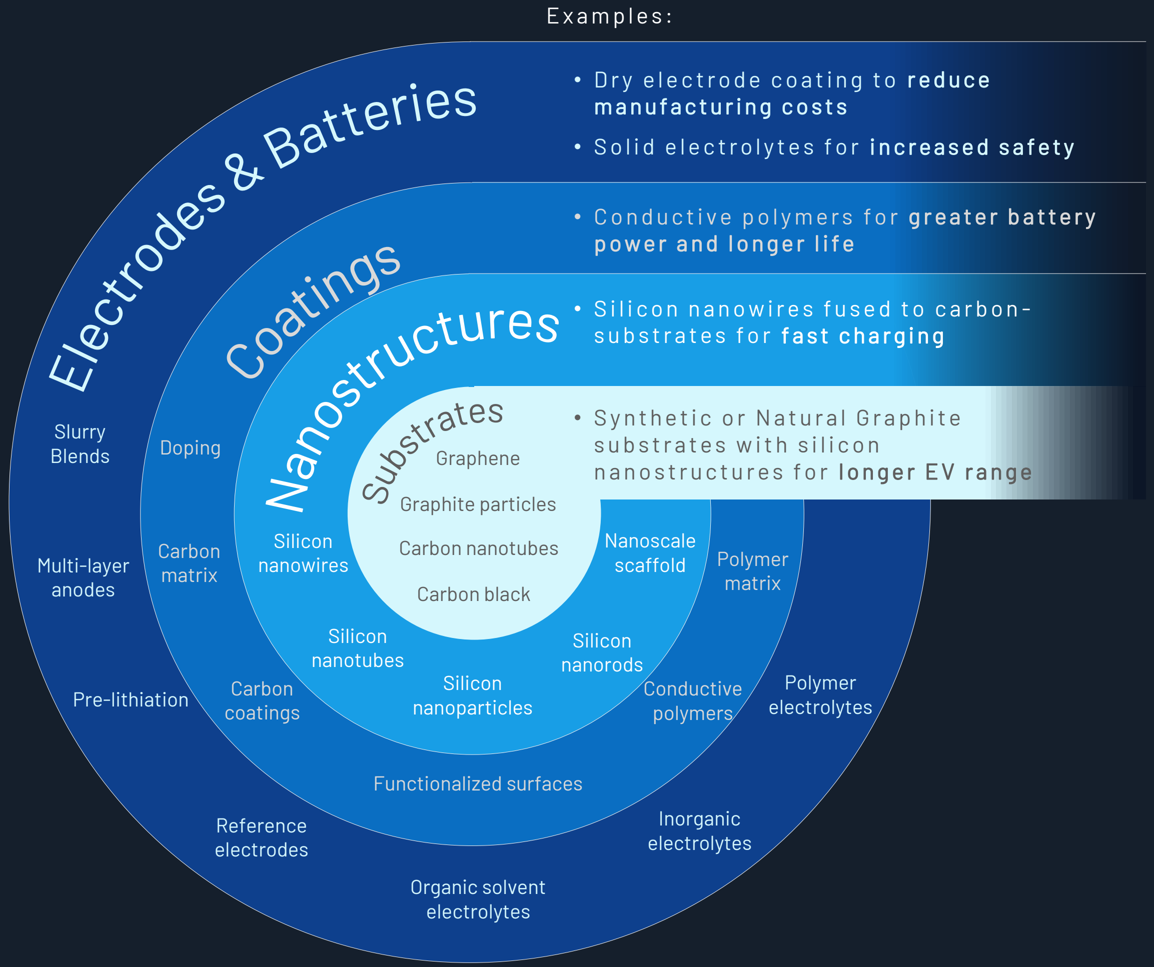
SINANODE Intellectual Property Assets

OneD patent portfolio technology map

- The SINANODE inventions provide a **technology platform**
- EV Customers can optimize silicon-based anode active materials in numerous ways, **enhancing rather than displacing** various substrates from multiple suppliers
- The IP portfolio provides additional inventions to **optimize anode electrode design & manufacturing**
- The IP portfolio supports road map to new cell designs, including with solid state electrolytes



Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US10/405992	US 6962823	US	Methods of making, positioning and orienting nanostructures, nanostructure arrays and nanostructure devices	1-Apr-03	8-Nov-05
US11/142563	US 7151209	US		31-May-05	19-Dec-06
US11/000557	US 7164209	US		1-Dec-04	16-Jan-07

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/342087	US 7228050	US	Nanocomposite	26-Jan-06	5-Jun-07
US12/554232	US 8041171	US		4-Sep-09	18-Oct-11
US10/656916	US 7068898	US		4-Sep-03	27-Jun-06
US12/212014	US 7603003	US		17-Sep-08	13-Oct-09
EP20030749453	EP 1537445	DE	Nanocomposite	4-Sep-03	1-Aug-12

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/681058	US7932511	US	Large-area nano-enabled macro electronic substrates and uses therefor	1-Mar-07	26-Apr-11
US10/674060	US7067867	US		30-Sep-03	27-Jun-06
US11/760382	US7851841	US		8-Jun-07	14-Dec-10
US11/106340	US7135728	US		13-Apr-05	14-Nov-06
US11/004380	US7064372	US		3-Dec-04	20-Jun-06
US11/490637	US7233041	US		21-Jul-06	19-Jun-07
US11/602783	US7427328	US		21-Nov-06	23-Sep-08
US11/405864	US7262501	US		18-Apr-06	28-Aug-07
US13/218286	US8293624	US		25-Aug-11	23-Oct-12
US12/940789	US8030186	US		5-Nov-10	4-Oct-11
KR20057005436	KR101191632	KR	Large-area nano-enabled macro electronic substrates and uses therefor	30-Sep-03	17-Oct-12
JP2014184819	JP6047533	JP		11-Sep-14	21-Dec-16
CN2003825485	CN1745468	CN		30-Sep-03	1-Sep-10

Notable Inventor: *Chunming Niu, PhD*

Dr. Niu is Professor & Director at the Center of Nanomaterials for Renewable Energy at Xian Jiaotong University. He was the Director of Chemistry at Nanosys from 2001 to 2007.

Before joining Nanosys, Dr. Niu worked on nanomaterial synthesis and characterization for almost ten years at Hyperion Catalysis where he was responsible for the development of several new nanomaterials and applications, including new catalysts for nanotube growth, ceramic nanofibrils/nanowhiskers, nanotube ceramic/polymer composites and a novel carbon nanotube-based electrode for high power supercapacitors.

Dr. Niu spent his postdoctoral fellowship in the laboratory of Professor Charles Lieber at Harvard University.

He received his PhD Degree in Solid-State Chemistry from Brown University and his M.S. Degree in Chemistry from Nanjing University.

Dr. Niu has co-authored over 30 publications and 20 patents.

Exemplary composite and anode claims EP '058 (Niu et al.)

1. **An electrode catalyst support composite** suitable for use in a membrane electrode assembly comprising:
   a plurality of nanowires grown on a substrate surface, the nanowires comprising silicon; and a polymer electrolyte.
2. **The composite** of claim 1, wherein the substrate surface comprises graphite or carbon.

...

13. **The composite** of claim 1, wherein the nanowires comprise a core and one or more shell layers disposed on the core.

...

15. **An anode** comprising the composite of claim 1.

Exemplary production method claim US '428 (Niu et al.)

1. **A method for producing nanowires**, comprising:
   depositing one or more nucleating particles on a substrate material;
   heating the nucleating particles to a first temperature;
   contacting the nucleating particles with a first precursor gas mixture to create a liquid alloy droplet to initiate nanowire growth;
   heating the alloy droplet to a second temperature, wherein the first temperature is higher than the second temperature; and
   contacting the alloy droplet with a second precursor gas mixture, whereby nanowires are grown at the site of the alloy droplet.

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/226187	US7083104	US	Applications of nano-enabled large area microelectronic …	14-Sep-05	3-Aug-06
US10/674071	US7051945	US		30-Sep-03	30-May-06
US11/647584	US7619562	US	Phased array systems	29-Dec-06	17-Nov-09
TW20030127018	TWI319201	TW	Applications of nano-enabled …	30-Sep-03	1-Jan-10

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US10/833944	US7985475	US	Super-hydrophobic surfaces, methods of their construction and uses therefor	27-Apr-04	26-Jul-11
JP20060532490	JP4871726	JP		27-Apr-04	8-Feb-12

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/225951	US7468315	US	System and process for producing nanowire composites and electronic substrates therefrom	14-Sep-05	23-Dec-08
US12/274904	US7795125	US		20-Nov-08	14-Sep-10
US10/910800	US7091120	US		4-Aug-04	23-Dec-08
CN2004828982	CN1863954	CN	System and process for producing nanowire composites and …	4-Aug-04	31-Jul-13
KR20067002377	KR101132076	KR		4-Aug-04	2-Apr-12

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US10/673669	US7102605	US	Integrated displays using nanowire transistors	30-Sep-03	5-Sep-06
US11/490630	US7701428	US		21-Jul-06	20-Apr-10
JP20050500327	JP4669784	JP		30-Sep-03	13-Apr-11

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/075361	US7057881	US	Nanofiber surface-based capacitors	8-Mar-05	6-Jun-06
US11/330557	US7116546	US		12-Jan-06	3-Oct-06
US11/507267	US7295419	US		21-Aug-06	13-Nov-07
US11/840414	US7466533	US		17-Aug-07	16-Dec-08
US12/970774	USRE43868	US		16-Dec-10	25-Dec-12

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US12/236209	US7985454	US	Systems and methods for nanowire growth and manufacturing	23-Sep-08	26-Jul-11

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US10/656911	US7662313	US	Oriented nanostructures and methods of preparing	4-Sep-03	16-Feb-10

Exemplary composition claims JP '362 (Zhu et al.)

(NON-OFFICIAL TRANSLATION)

35. **A composition** comprising

a porous substrate and a population of silicon nanowires attached thereto, wherein one end of a member nanowire is attached to the substrate and the other end of the member nanowire comprises copper, a copper compound, and/or a copper alloy, wherein the other end of the member nanowire comprises copper silicide.

36. **A composition** comprising

a porous substrate and a population of silicon nanowires attached thereto, wherein one end of a member nanowire is attached to the substrate and the other end of the member nanowire comprises copper, a copper compound, and/or a copper alloy, wherein the nanowires comprise a monocrystalline core and a shell layer, wherein the shell layer comprises amorphous silicon, polycrystalline silicon, or a combination thereof.

…

44. **The composition** of any one of claims 35-38, wherein the substrate comprises a plurality of silica particles, a plurality of carbon sheets, carbon powder, graphite, graphene, graphene powder, carbon fibers, carbon nanostructures, carbon nanotubes, carbon black, a mesh, or a fabric.

…

46. **A battery slurry** comprising the composition of any one of claims 35-38.

47. **A battery anode** comprising the composition of any one of claims 35-38.

48. **A battery** comprising the composition of any one of claims 35-38.

Exemplary electrode additive claims KR '416 (Zhu et al.)

(NON-OFFICIAL TRANSLATION)

1. **An additive** that is to be added to a slurry when manufacturing a battery electrode, the additive comprising

Si-based nanowires grown on a carbon-based substrate, wherein each of the Si-based nanowires has a covalently bonded shell comprising carbon.

…

4. **A battery electrode** internally including one or more active materials, comprising one or more carbon-based substrates and Si-based nanowires grown on the carbon-based substrates,

wherein the Si-based nanowires have a core-shell structure, with the core comprising Si and the shell comprising C.

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Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/226027	US7754524	US	Methods, devices and compositions for depositing and orienting nanostructures	14-Sep-05	13-Jul-10
US10/673092	US7067328	US		25-Sep-03	27-Jun-06
US11/507631	US7829351	US		21-Aug-06	11-Sep-10
KR20067008013	KR101126899	KR	Methods, devices and compositions for depositing and orienting nanostructures	15-Sep-04	19-Mar-12
JP20060528061	JP4927542	JP		15-Sep-04	5-Sep-12
TW20040128549	TWI375730	TW		21-Sep-04	11-Jan-12

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/839778	US7767102	US	Systems and methods for harvesting and integrating nanowires	16-Aug-07	3-Aug-10
US11/117702	US7344961	US		29-Apr-05	18-Mar-08
US11/117707	US7339184	US		29-Apr-05	4-Mar-08

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US10/941746	US8025960	US	Porous substrates, articles, systems and compositions comprising nanofibers and …	15-Sep-04	27-Sep-11
US11/331445	US7553371	US		11-Jan-06	30-Jun-09
US14/506591	US10279341	US		3-Oct-14	7-May-19
JP20120107611	JP5604620	JP	Porous substrates, articles, systems and compositions …	9-May-12	8-Oct-14
JP20090526640	JP5081916	JP		22-Aug-07	28-Nov-12

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/117703	US7105428	US	Systems and methods for nanowire growth and harvesting	29-Apr-05	12-Sep-06
US11/490636	US7273732	US		21-Jul-06	25-Sep-07
US11/839335	US7666791	US		15-Aug-07	23-Feb-10
CN2005821904	CN101010780	CN	Systems and methods for nanowire growth and harvesting	29-Apr-05	25-Jul-12
CN20111192086	CN102351169	CN		29-Apr-05	27-Nov-13

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/399307	US7745498	US	Nanowire dispersion compositions and uses thereof	6-Apr-06	29-Jun-10

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/291484	US7560366	US	Nanowire horizontal growth and substrate removal	1-Dec-05	14-Jan-09

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/643025	US7741197	US	Systems and methods for harvesting and reducing contamination in nanowires	20-Dec-06	22-Jun-10

Exemplary article claims JP '620 (Niu et al.)

(NON-OFFICIAL TRANSLATION)

1. **An article**, comprising:

a substrate comprising carbon or graphite having a plurality of apertures disposed therethrough, the substrate comprising an overall surface area that includes an interior wall surface area of the plurality of apertures; and

a plurality of silicon nanofibers comprising an elongated structure made of silicon, each silicon nanofiber being grown from and integrally attached to at least a portion of the overall surface area of the substrate;

wherein at least a portion of **the silicon nanofibers are attached to and distributed over a portion of the interior wall surface area of the plurality of apertures**, and wherein the plurality of apertures comprises a plurality of pores disposed through the substrate.

…

6. **The article** of claim 1, wherein the plurality of nanofibers **are substantially only attached to the interior wall surfaces of the apertures**.

…

8. **The article** of claim 1, wherein the plurality of **nanofibers are electrically coupled to the substrate**.

Exemplary material and battery claims CN '801 (Niu et al.)

(NON-OFFICIAL TRANSLATION)

10. **A nanowire structure**, comprising:

a core containing less than 0.5% carbon;

an interfacial carbide layer formed on the core; and

a carbon-based structure formed on the interfacial carbide layer,

wherein the carbon-based structure comprises nanowires and/or nanographitic plates.

11. **The nanowire structure** of claim 10, wherein the carbon-based structure comprises at least one nanographitic plate.

12. **The nanowire structure** of claim 10, wherein the core comprises a semiconductor material.

…

30. **An interconnected nanowire network** comprising a plurality of the nanowire structures of claim 11, wherein the one or more nanographitic plates connect the nanowire structures.

31. The structure of claim 30, wherein the **nanowires cores are silicon cores**

32. **A lithium battery** comprising: an anode comprising the interconnected nanowire network of claim 30; a cathode; a separator; and a lithium electrolyte.

33. **The lithium battery** of claim 32, wherein the nanowire cores are Si cores.

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Composite materials and production methods - Exemplary Claims

Exemplary composition and article claims US '369 (Niu et al.)

1. **A composition** comprising:
   a plurality of nanowires attached directly to a support structure comprising graphite, carbon or a carbon composition, the nanowires comprising crystalline silicon, polycrystalline silicon, amorphous silicon, or a mixture thereof; and an electrolyte.
2. **The composition** of claim 1, wherein the nanowires are dispersed within the electrolyte.
3. **The composition** of claim 1, wherein a portion of the electrolyte is attached to the nanowires.

...

15. **The composition** of claim 1, wherein the **composition is porous**, wherein the porous composition comprises pores disposed between the nanowires of the plurality of nanowires.
21. **An electrode** comprising the composition of claim 1
22. **An anode** comprising the composition of claim 1
23. **An article**, comprising:
   an anode; **a cathode**; **an electrolyte**, and wherein the anode comprises a substrate and a plurality of nanowires attached directly to the substrate, the substrate comprises graphite, carbon or a carbon composition, and the nanowires comprise crystalline silicon, polycrystalline silicon, amorphous silicon, or a mixture thereof.

Exemplary composite and anode claims US '475 (Niu et al.)

1. **A composite** comprising:
   a plurality of nanowires attached directly to a support structure comprising graphite, carbon or a carbon composition, the nanowires comprising crystalline silicon, polycrystalline silicon, amorphous silicon, or a mixture thereof; and a polymer electrolyte.
2. **The composite** of claim 1, wherein the nanowires are dispersed within the polymer electrolyte.
3. **The composite** of claim 1, wherein a portion of the polymer electrolyte is attached to the nanowires.

...

15. **The composite** of claim 1, wherein the composite is porous, wherein the porous composite comprises pores disposed between the nanowires of the plurality of nanowires.
17. **The composite** of claim 1, wherein the nanowires comprise silicon or silicon carbide.
18. **The composite** of claim 1, wherein the nanowires comprise a core and one or more shell layers disposed on the core.

...

21. **An electrode** comprising the composite of claim 1.
22. **An anode** comprising the composite of claim 1.

Exemplary nanowires material and method claims US '341 (Niu et al.)

1. **A method of producing nanowires**, the method comprising:
   providing a porous substrate comprising a plurality of carbon black particles;
   depositing metal colloid catalyst on at least a portion of the overall surface area of the carbon black particles;
   feeding the carbon black particles having the metal colloid catalyst deposited thereon with a reactive gas comprising silane (SiH_4); and
   growing silicon nanowires in situ from the metal colloid catalyst deposited on the carbon black particles using a Vapor-Liquid-Solid (VLS) synthesis process, wherein the grown silicon nanowires are attached to and extend from at least a portion of the overall surface of the carbon black particles and have an aspect ratio greater than 10 and a cross sectional dimension less than 100 nm, and wherein the diameter of the carbon black particles is greater than 20 times and less than 1000 times the average cross-sectional dimension of the silicon nanowires.

...

5. **A porous substrate** for an article comprising:
   a plurality of carbon black particles having silicon nanowires grown on and attached to at least a portion of the overall surface of the carbon black particles, said silicon nanowires extending from said surface, wherein the silicon nanowires have an aspect ratio greater than 10 and a cross sectional dimension less than 100 nm, and wherein the carbon black particles are conductive and have a diameter greater than 20 times and less than 1000 times the average cross-sectional dimension of the silicon nanowires.

...

7. **The method** of claim 1, further comprising: after growing, **coating** the silicon nanowires, wherein the coating material is different from silicon.

...

16. **The porous substrate** of claim 5, wherein the carbon black particles and the silicon nanowires are at least partially **encapsulated with a matrix material**.

Exemplary electrode assembly claims US '703 (Zhu et al.)

1. **A catalyst support for a membrane electrode assembly** of a power source, comprising one or more SiC nanostructures, wherein the SiC nanostructures have at least one metal catalyst disposed thereon, wherein the SiC nanostructures comprise SiC nanopowder, wherein the SiC nanopowder is cross-linked by graphene sheets.

...

17. **The catalyst support** of claim 1, wherein **the power source is a battery**

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/601842	US7939218	US	Nanowire structures comprising carbon	20-Nov-06	10-May-11
US11/808760	US7842432	US		12-Jun-07	30-Nov-10
US12/391057	US8278011	US		23-Feb-09	2-Oct-12
US14/505182	USRE45703	US		2-Oct-14	29-Sep-15
US14/868273	USRE46921	US		28-Sep-15	26-Jun-18
US16/017678	USRE48084	US		25-Jun-18	7-Aug-20
CN2006843546	CN101563801	CN	Nanowire structures comprising carbon	20-Nov-06	27-Mar-13
KR20087015163	KR101390619	KR		20-Nov-06	30-Apr-14
CA20062624776	CA2624776	CA		20-Nov-06	12-May-15
JP20080541404	JP5474352	JP		20-Nov-06	16-Apr-14
TW20060143081	TWI436942	TW		21-Nov-06	11-May-14
EP20060838053	FR1952467	FR		20-Nov-06	12-Oct-11
EP20060838053	GB1952467	GB		20-Nov-06	12-Oct-11
EP20060838053	IE1952467	IE		20-Nov-06	12-Oct-11
EP20060838053	DE602006025118.1	DE		20-Nov-06	12-Oct-11
AU20110211404	AU2011211404	AU		12-Aug-11	22-Dec-11

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/979949	US7968474	US	Methods for nanowire alignment and deposition	9-Nov-07	28-Jun-11
US13/113680	US8252164	US		23-May-11	28-Aug-12
JP20090533413	JP5009993	JP	Methods for nanowire alignment and deposition	9-Nov-07	29-Aug-12
TW20070142497	TWI463713	TW		9-Nov-07	12-Jan-14

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/935884	US7776760	US	Systems and methods for nanowire growth	6-Nov-07	17-Aug-10
CN2007849370	CN101573778	CN		6-Nov-07	2-Jan-13

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/641939	US7951422	US	Methods for oriented growth of nanowires on patterned substrates	20-Dec-06	31-May-11
US11/641946	US7785922	US		5-Aug-08	26-Jan-10
KR20087018738	KR101287350	KR	Methods for oriented growth of nanowires on patterned substrates	20-Dec-06	23-Jul-13
EP20060851310	DE602006044733.7	DE		20-Dec-06	4-Mar-15
CN2006845385	CN101331590	CN		20-Dec-06	20-Apr-11
AU20060343556	AU2006343556	AU		20-Dec-06	31-Aug-10

Exemplary material and method claims US '218 (Niu et al.)

1. **A nanowire** comprising a carbon-based layer, wherein the carbon-based layer is substantially devoid of basal plane carbon.

...

3. **The nanowire** of claim 1, further comprising a core.

4. **The nanowire** of claim 3, wherein the core comprises a semiconductor material.

...

15. **A method of manufacturing a nanowire**, comprising:

(a) heating a nanowire core; and

(b) contacting the nanowire core with one or more carbon-comprising gases to form a carbon-based layer on the nanowire core, wherein the carbon-based layer is substantially devoid of basal plane carbon.

Exemplary electrochemical cell claims US '921 (Goldman et al.)

16. **An electrochemical cell** comprising: a plurality of nanowires grown on and attached directly to a support structure comprising graphite, carbon, or a carbon composite, wherein the nanowires comprise silicon, and the nanowires are cross-linked by graphene sheets.

...

18. **The electrochemical cell** of claim 16, wherein the electrochemical cell is a battery.

...

21. **The electrochemical cell** of claim 16, wherein an outer shell of the nanowires comprises carbon

Exemplary electrochemical cell claims US '084 (Goldman et al.)

16. **An electrochemical cell** comprising: a support structure comprising a plurality of nanowires grown on and attached directly to graphite, carbon, or a carbon composite; wherein the nanowires form a porous structure comprising an interconnected network of nanowires cross-linked by graphene sheets; and wherein the nanowires comprise a silicon-comprising core and at least one carbon-comprising outer shell.

...

21. **The electrochemical cell** of claim 16, further comprising **an electrolyte**.

...

21. **The electrochemical cell** of claim 21, wherein **the electrolyte comprises a polymer**.

...

26. **The electrochemical cell** of claim 16, wherein the electrochemical cell is a lithium-ion battery comprising an anode comprising the support structure.

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Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US12/234104	US7977007	US	Nanowire-based membrane electrode assemblies for fuel cells	19-Sep-08	12-Jul-11
US11/295133	US7179561	US		6-Dec-05	20-Feb-07
US11/642241	US7977013	US		20-Dec-06	12-Jul-11
US13/551230	US8440369	US		17-Jul-12	14-May-13
US13/149527	US8357475	US		31-May-11	22-Jan-13
CN2005842287	CN101107737	CN	Nanowire-based membrane electrode assemblies for fuel cells	6-Dec-05	21-Mar-12
CN20091207967	CN101707256	CN		6-Dec-05	6-Nov-13
EP20050853082	GB1829141	GB		6-Dec-05	29-May-13
EP20050853082	DE602005039842.2	DE		6-Dec-05	29-May-13
KR20077015612	KR101405353	KR		6-Dec-05	11-Jun-14
JP20070545554	JP5277451	JP		6-Dec-05	28-Aug-13
EP20110193293	GB2432058	GB		6-Dec-05	17-Jul-13
EP20110193293	DE602005040506.2	DE		6-Dec-05	17-Jul-13
AU20050314211	AU2005314211	AU		6-Dec-05	8-Jul-10

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US11/936590	US7786024	US	method of fabricating electrical device	7-Nov-07	31-Aug-10

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US12/114446	US7892610	US	Aligned nanowires and other …	2-May-08	22-Feb-11
KR20097025545	KR101502870	KR	Aligned nanowires and other electrical apparatus and method for printing a system	5-May-08	17-Mar-15
JP20100507581	JP5606905	JP		5-May-08	15-Oct-14
TW20080116662	TWI359784	TW		6-May-08	

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US12/331150	US8999851	US	Method to form substrate elements	9-Dec-08	7-Apr-15
JP20100537943	JP5496105	JP	Method to form substrate elements	9-Dec-08	21-May-14
TW20080148251	TWI501316B	TW		11-Dec-08	21-Sep-15

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
JP20110533334	JP5484477	JP	Fuel cell membrane electrode	22-Oct-09	7-May-14

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US13/124800	US9006133	US	Electrochemical catalysts for fuel cells	22-Oct-09	14-Apr-15
JP20110533335	JP5497049	JP		22-Oct-09	21-May-14

Notable Inventor: *Yimin Zhu, PhD*

Dr. Zhu has extensive experience in battery, fuel cell and their hybrid system development, as well as the development and production of nanomaterials for these platforms.

Since 2007, Dr. Zhu has been instrumental in the development, production, commercialization of SiNANOde® battery and fuel cell technologies first at Nanosys, and later at OneD Battery Sciences, where he is now Chief Technology Officer, leading the R&D team at and the collaboration with the R&D and Manufacturing teams at OneD's industry partners.

Dr. Zhu has authored over 60 peer-reviewed papers and presented in various conferences. Dr. Zhu holds over 65 energy storage worldwide patents & applications and has dedicated himself to R&D and commercialization of energy storage nanomaterials and devices since 1998, first at Yamanashi University (NEDO Researcher Zero Emission EVs) and then in 2001 at Los Alamos National Laboratory (Scientist – Catalyst and Fuel Cells).

Exemplary composition claims JP '607JP '620 (Zhu et al.)

(NON-OFFICIAL TRANSLATION)

4. **A battery electrode**, comprising

A current collector, and a coating layer formed on the current collector, the coating layer comprising a slurry comprising a mixture of graphite, carbon, a polymer binder and an additive, the additive comprising Si-based nanowires disposed on a carbon-based substrate,

wherein the carbon-based substrate is in the form of graphite particles having diameter between 5 microns and 50 microns;

wherein the Si-based nanowires are directly grown on and attached to the surface of the graphite particles and have a core-shell heterostructure; and

wherein the additive comprises 1 weight % to 80 weight % of the slurry.

…

8. **A method of preparing a battery electrode** comprising:

providing an additive comprising a plurality of Si-based nanowires disposed on a carbon-based substrate, *wherein* the carbon-based substrate is in the form of graphite particles having diameter of 5 microns to 50 microns and *wherein* the Si-based nanowires are grown directly on and attached to the surface of the graphite particles and have a core-shell heterostructure;

mixing the additive with graphite, carbon, and a polymer binder to form a slurry, the weight % ratio of the additive in the slurry being between 1% and 80%; and

forming the slurry into the battery anode electrode.

…

15. **A battery**, comprising:

The battery electrode according to claim 4; A cathode; and an electrolytic separator positioned between the battery electrode and the cathode.

Production methods for nanostructures, composites and battery components - Exemplary Claims

Exemplary method claim US '207 (Zhu et al.)

1. **A method for producing nanowires**, the method comprising:

providing a porous substrate having catalyst nanoparticles disposed thereon, wherein the porous substrate comprises a population of particles comprising at least one of graphite particles, graphene particles, carbon black particles, or carbon nanotubes and wherein the catalyst nanoparticles comprise copper, a copper compound, and/or a copper alloy;

loading the porous substrate into a reaction vessel wherein the population of particles with the catalyst nanoparticles disposed thereon form a packed bed in the reaction vessel; and

growing nanowires on the porous substrate in the reaction vessel from the catalyst nanoparticles via a Vapor-Solid-Solid (VSS) synthesis technique, wherein the growing comprises mixing the packed bed while flowing one or more reactant gases in the reaction vessel during the nanowire growing process.

...

11. The method of claim 1, further comprising, after growing, **applying a carbon coating or a polymer coating to the nanowires**.

Exemplary method claims JP '362 (Zhu et al.)

1. **A method for producing nanostructures**, the method comprising:

providing a porous substrate having catalyst particles disposed thereon, which catalyst particles comprise copper, a copper compound, and/or a copper alloy; and

growing the nanostructures from the catalyst particles wherein the nanostructures comprise a monocrystalline core and a shell layer, wherein the shell layer comprises amorphous silicon, polycrystalline silicon, or a combination thereof.

...

31. **A method for producing silicon nanowires**, the method comprising:

synthesizing colloidal nanoparticles comprising copper and/or a copper compound;

depositing the nanoparticles on a substrate; and

growing the nanowires from the nanoparticles, wherein the copper compound is copper oxide.

Exemplary method claims JP '362 (Zhu et al.)

1. **A method for producing nanostructures**, the method comprising:

providing a porous substrate having catalyst particles disposed thereon, which catalyst particles comprise copper, a copper compound, and/or a copper alloy, wherein: the substrate is a carbon-based substrate and comprises a population of particles having the catalyst particles disposed thereon; and

growing the nanostructures from the catalyst particles, wherein: the substrate particles with catalyst particles disposed thereon are loaded into a reaction vessel and form a packed bed therein, the nanostructures are silicon nanowires grown by a vapour-solid-solid synthesis technique, and the substrate particles are mixed during the growth process.

Exemplary method claim US '699 (Zhu et al.)

1. **A method of forming a lithium-ion battery (LIB) component**, comprising:

providing at least one substrate structure; and

electrochemically depositing a plurality of nanostructures directly onto one or more surfaces of the at least one substrate structure,

wherein the nanostructures are formed via electrochemical deposition without a growth template, and the nanostructures are comprised of crystalline Si and are substantially free of amorphous Si or polycrystalline Si upon formation.

2. The method of claim 1, wherein the LIB component is a LIB anode component.

Exemplary method claim US '467 (Zhu et al.)

1. **A method of manufacturing a carbon-based silicon nanowire composite**, the method comprising:

providing a carbon-based substrate having catalyst nanoparticles deposited on the surface of the carbon-based substrate, wherein the carbon-based substrate comprises at least one of natural graphite particles or synthetic graphite particles, and the catalyst nanoparticles comprise Copper or a Copper oxide;

loading the carbon-based substrate with the catalyst nanoparticles deposited thereon into a plurality of tumbler reactors;

inserting sequentially the plurality of tumbler reactors containing the carbon-based substrate with the catalyst nanoparticles deposited thereon into a LPCVD system comprising a sequence of N active zones separated from each other through N-1 buffer zones, said active zones comprising at least one

heating zone, at least one reaction zone, and at least one cooling zone, and wherein the temperature in two or more of said zones is controlled independently;

heating the carbon-based substrate with the catalyst nanoparticles deposited thereon in one or more of the plurality of tumbler reactors positioned in the at least one heating zone until the carbon-based substrate reaches a specified temperature;

growing silicon-comprising nanowires on carbon-based substrate from the catalyst nanoparticles in one or more of the plurality of tumbler reactors positioned in the at least one reaction zone to form a carbon-based silicon nanowire composite via a Vapor-Solid-Solid (VSS) synthesis technique, wherein the growing comprises mixing the carbon-based substrate while injecting one or more process gases uniformly into one or more of the plurality of tumbler reactors via injection ports positioned along an injection member and *wherein* temperature and concentration of the one or more process gases into one or more of the plurality of tumbler reactors are controlled by computer with automatic software for the production; and

moving periodically the position of the plurality of tumbler reactors in the LPCVD system via the buffer zones under controlled conditions of pressure and temperature so that the at least one reaction zone is continuously growing silicon-comprising nanowires except for the periodic transition of the plurality of tumbler reactors from one active zone to the next.

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US12/772862	US9040208	US	Catalyst layer for fuel cell	3-May-10	26-May-15
JP20100105661	JP5686988	JP	Catalyst layer for fuel cell	30-Apr-10	18-Mar-15

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US12/824485	US8623288	US	Alternative Large Scale Nanowire Growth	28-Jun-10	1-Jul-14

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US12/783243	US10490817	US	Nanostructured materials for battery applications	19-May-10	26-Nov-19
U16/599795	US11233240	US	Nanostructured materials for battery applications	11-Oct-19	NA
US17/024441	US20210005892	US	Nanostructured materials for battery applications	17-Sep-20	NA
US17/192204	US20210210759	US	Nanostructured materials for battery applications	4-Mar-21	NA
JP2012511997	JP5882200	JP	Nanostructured materials for battery applications	19-May-10	3-Sep-16
JP20180017171	JP6732810	JP	Nanostructured materials for battery applications	2-Feb-18	29-Jul-20
JP2020117769	JP2020117769	JP	Nanostructured materials for battery applications	8-Jul-20	NA
JP20160018713	JP6717607	JP	Nanostructured materials for battery applications	2-Feb-18	1-Jul-20
KR20117030289	KR101935416	KR	Nanostructured materials for battery applications	19-May-10	7-Jan-19
KR20187038045	KR102067922	KR	Nanostructured materials for battery applications	19-May-10	17-Jan-20
EP20100778339	EP2433475	CH, CZ, DE, DK, ES, FI, FR, GB, HU, IT, NL, NO, PL, SK, SE	Nanostructured materials for battery applications	19-May-10	21-Apr-21
EP21161119.9	EP3859830	CH, CZ, DE, DK, ES, FI, FR, GB, HU, IT, NL, NO, PL, SK, SE	Nanostructured materials for battery applications	5-Mar-21	NA

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US14/234565	US10243207	US	Nanostructured battery active materials and methods of producing same	24-Jul-12	26-Mar-19
US16/355454	US20190214641	US	Nanostructured battery active materials and methods of producing same	15-Mar-19	11-Jul-19
JP2014522942	JP6142362	JP	Nanostructured battery active materials and methods of producing same	24-Jul-12	7-Jun-17
JP2017078418	JP6345834	JP	Nanostructured battery active materials and methods of producing same	11-Apr-17	20-Jun-18
KR20147004916	KR101895386	KR	Nanostructured battery active materials and methods of producing same	24-Jul-12	7-Sep-18
KR20187025051	KR102051770	KR	Nanostructured battery active materials and methods of producing same	24-Jul-12	3-Dec-19
EP20120817748	EP2736837	CH, CZ, DE, DK, ES, FI, FR, GB, HU, IT, NL, NO, PL, SK, SE	Nanostructured battery active materials and methods of producing same	24-Jul-12	29-Sep-21
EP21199255.7	EP3978426A1	EP	Nanostructured battery active materials and methods of producing same	27-Sep-21	
CN201810147669	CN108452790B	CN	Nanostructured battery active materials and methods of producing same	24-Jul-12	28-Aug-18

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US15/121215	US10367236	US	Anode, cell, and method of stabilizing an anode for use in a lithium ion electrochemical cell	24-Aug-16	3-Jul-19

Exemplary composition claims US '525 (Zhu et al.)

4. **A lithium ion battery (LIB) anode composite structure** comprising:

a plurality of discrete active material nanostructures; and

a plurality of substrate layers characterized in that a bottom one of the plurality of substrate layers comprise a solid conductive layer and other ones of the plurality of substrate layers comprise a plurality of graphite particles;

wherein the plurality of discrete active material nanostructures comprise a core and one or more coating layers, characterized in that the core comprises one or more active materials selected from the group consisting of silicon (Si) and germanium (Ge) and the one or more coating layers comprises a conductive material; and

wherein the plurality of substrate layers and the plurality of discrete active material nanostructures together form a three-dimensional composite structure characterized in that the nanostructures are grown on and attached to one or more surfaces of the plurality of graphite particles of the other ones of the plurality of substrate layers and the other ones of the plurality of substrate layers each have a porosity which increases with a distance from the bottom one of the plurality of substrate layers.

2. **The LIB anode composite structure** of claim 1, wherein the plurality of discrete active material nanostructures comprise one or more selected from the group consisting of **nanowires, nanorods, nanoparticles** and **nanotubes**.

Exemplary composition claims US '236 (Zhu et al.)

1. **A method for conditioning an anode electrode** in an electrochemical cell, the method comprising:

providing an electrochemical cell comprising a silicon-comprising anode electrode, a cathode electrode, an electrolyte, and at least one micro-reference electrode, wherein the cathode electrode over anode electrode capacity ratio is between 1 and 1.3;

conditioning the anode electrode in the electrochemical cell in a half cell mode by passing a current between the anode electrode and the cathode electrode while controlling the potential between the anode electrode and the at least one micro-reference electrode to avoid Li plating until the anode electrode reaches a stabilized state; and

switching the electrochemical cell to a regular full cell mode and applying a CC-CV charging/CC discharging protocol.

...

5. The method of claim 1 further comprising, after switching to full cell mode, applying the charging/discharging protocol via a programmable Battery Management System (BMS), wherein the protocol is based on the anode and the cathode potential profiles based on the electrodes chemistries.

OneD BATTERY SCIENCES

Additives, Electrodes, and Batteries - Exemplary Claims

Exemplary claim US '817 (Zhu et al.)

1. **A battery anode electrode**, comprising:

a current collector; and

a coating layer formed on the current collector, the coating layer comprising a slurry comprising a mixture of graphite, carbon, a polymer binder, and an additive, the additive comprising substantially homogeneous Si-based nanowires and graphite powder,

wherein the Si-based nanowires have a diameter of about 20 nm to about 100 nm and a length of about 0.1 microns to 50 microns, the nanowires being grown directly on and attached to the surface of the graphite powder and having a core-shell structure;

wherein the graphite powder is in the form of separate particles having diameter of about 5 microns to about 50 microns, and wherein the weight % ratio of the additive in the battery slurry is between 1 % and 80%.

Exemplary claims KR '922 (Zhu et al.)

(NON-OFFICIAL TRANSLATION)

1. **An additive** that is to be added to a slurry when manufacturing a battery anode, the additive comprising

Si-based nanostructures grown on and attached to a carbon-based matrix material comprising carbon black, said carbon-based matrix material characterized in that it can bend and flex to accommodate the volume changes associated with the lithiation during repeated charge/discharge cycles of the lithium battery anode,

wherein the nanostructures comprise any of Si-based nanoparticles, Si-based nanorods, Si-based nanowires or a combination thereof, and wherein the Si-based nanostructures have a core shell structure.

...

4. The additive of claim 1, wherein the core of the Si-based nanostructures comprises Si and the shell comprise amorphous C.

...

7. **A battery anode** internally including

one or more active materials comprising Si-based nanostructures grown on and attached to a carbon-based matrix material comprising carbon black, said carbon-based matrix material characterized in that it can bend and flex to accommodate the volume changes associated with the lithiation during repeated charge/discharge cycles of the lithium battery anode,

wherein the nanostructures comprise any of Si-based nanoparticles, Si-based nanorods, Si-based nanowires or a combination thereof, and wherein the Si-based nanostructures have a core shell structure.

...

28. **A Li-ion battery**, comprising: the battery anode according to claim 7; a battery cathode; and an electrolyte

29. The Li-ion battery of claim 28, **wherein** the electrolyte comprises any of an alkali metal salt dissolved in organic solvent, an alkali metal salt mixed with an ionically conducting polymer, or an alkali metal salt mixed with an ionically conducting inorganic material.

Exemplary claim JP '200

(NON-OFFICIAL TRANSLATION)

1. **An additive** that is to be added to a slurry when manufacturing a battery electrode, the additive comprising Si-based nanowires grown on a carbon-based substrate, wherein each of the Si-based nanowires has a covalently bonded shell comprising carbon.

...

3. The additive of claim 1, wherein the carbon-based substrate is carbon black, graphite, graphene, graphene powder or graphite foil.

4. A battery electrode internally including one or more active materials, wherein the one or more active materials comprises one or more carbon-based substrates and Si-based nanowires grown on each of the one or more carbon-based substrates, wherein the Si-based nanowires have a core-shell structure, and the core comprises Si and the shell comprises C.

...

7. A battery, comprising: the battery anode electrode according to Claim 4; a battery cathode electrode, and an electrolyte.

...

9. A method of preparing a battery electrode comprising:

(a) providing a plurality of nanowires grown on a carbon-based substrate;

(b) covalently bonding a shell comprising carbon to the plurality of Si-based nanowires;

(c) mixing the Si-based nanowires with a polymer binder and a carbon-based material to form a slurry; and

(d) forming the slurry into the battery electrode.

Exemplary method claim JP '810

(NON-OFFICIAL TRANSLATION)

1. **A battery anode electrode** comprising a coating layer comprising a mixture of graphite, carbon, a polymer binder and an additive, the additive comprising Si-based nanostructures grown directly on and attached to the surface of a carbon-based matrix material comprising carbon black, said carbon-based matrix material characterized in that it can bend and flex to accommodate the volume changes associated with the lithiation of the Si-based nanostructures during repeated charge/discharge cycles of the battery electrode, and

wherein the Si-based nanostructures have a core-shell structure and comprise any of ***(i)* Si-based nanoparticles** having all dimensions less than 50 nm, ***(ii)* Si-based nanowires** having a diameter of 20 nm to 100 nm and a length of 0.1 µm to 50 µm, or a combination thereof.

...

7. **A battery**, comprising: the battery anode electrode according to Claim 4; a battery cathode electrode, and an electrolyte.

Additives, Electrodes, and Batteries - Exemplary Claims (cont.)

Exemplary claim EP '475 (Zhu et al.)

1. **A battery anode electrode** comprising:

(1) one or more silicon-comprising nanostructures grown on and attached to a carbon based powder comprising graphite particles of 5 μm to 50 μm in size, wherein the

nanostructures are nanowires having a core-shell structure, and wherein the nanowires have a diameter of 20 nm to 200 nm and a length of 0.1 μm to 50 μm,

(2) a carbon-based material, and

(3) a polymer binder that is disposed on the nanostructures, wherein the electrode comprises 1 weight % to 80 weight % of the nanostructures disposed on the carbon-based powder.

2. The **battery anode electrode** of claim 1, wherein the core of the nanowires comprises silicon and the shell of the nanowires comprises carbon.

3. The **battery anode electrode** of claim 1, wherein the carbon-based material is selected from **carbon black**, **graphite**, **graphene**, **graphene powder** and **graphite foil**.

…

12. The **battery anode electrode** of claim 1, wherein the nanostructures are embedded in a Li foil.

13. A **method of preparing a battery anode electrode** as claimed in any one of claims 1-12, the method comprising:

(a) providing one or more silicon-comprising nanostructures grown on and attached to a carbon-based powder comprising graphite particles of 5 μm to 50 μm in size, wherein the nanostructures are nanowires having a core-shell structure, and wherein the nanowires have a diameter of 20 nm to 200 nm and a length of 0.1 μm to 50 μm;

(b) mixing the nanostructures with a polymer binder and a carbon-based material to form a slurry; and

(c) forming the slurry into the battery anode electrode.

14. **A battery** comprising a battery anode electrode as claimed in any one of claims 1-12

15. **The battery** of claim 14, wherein the battery is a Li-ion battery.

Exemplary claim US '525 (Zhu et al.)

1. **A lithium-ion battery (LIB) anode composite structure** comprising:

a plurality of discrete active material nanostructures; and

a plurality of substrate layers characterized in that a bottom one of the plurality of substrate layers comprise a solid conductive layer and other ones of the plurality of substrate layers comprise a plurality of graphite particles;

wherein the plurality of discrete active material nanostructures comprise a core and one or more coating layers, characterized in that the core comprises one or more active materials selected from the group consisting of silicon (Si) and germanium (Ge) and the one or more coating layers comprises a conductive material; and

wherein the plurality of substrate layers and the plurality of discrete active material nanostructures together form a three-dimensional composite structure characterized in that the nanostructures are grown on and attached to one or more surfaces of the plurality of graphite particles of the other ones of the plurality of substrate layers and the other ones of the plurality of substrate layers each have a porosity which increases with a distance from the bottom one of the plurality of substrate layers.

2. **The LIB anode composite structure** of claim 1, wherein the plurality of discrete active material nanostructures comprise one or more selected from the group consisting of nanowires, nanorods, nanoparticles and nanotubes.

…

12. A **LIB anode** comprising the LIB anode composite structure of claim 1.

…

13. A **LIB** comprising: the LIB anode of claim 12; a cathode; a separator material separating the cathode and anode; and, an electrolyte.

…

14. The **LIB** of claim 13, wherein the electrolyte is a **polymer electrolyte**.

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US12/772862	US9040208	US	Catalyst layer for fuel cell	3-May-10	26-May-15
JP20100105661	JP5686988	JP		30-Apr-10	18-Mar-15

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US12/824485	US8623288	US	Alternative Large Scale Nanowire Growth	28-Jun-10	1-Jul-14

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US14/349922	US9812699	US	Silicon nanostructure active materials for lithium-ion batteries and processes, compositions, components, and devices related thereto	2-Oct-12	7-Nov-17
US15/805037	US10355266	US		6-Nov-17	16-Jul-19
US16/513616	US10804525	US		16-Jul-19	13-Oct-20
JP20140534634	JP6385822	JP	Silicon nanostructure active materials for lithium-ion batteries and processes, compositions, components, and devices related thereto	2-Oct-12	5-Sep-18
JP20200168363	JP2021002532A	JP		8-Aug-18	15-Nov-18
EP20120837889	EP2764565A1	EP		2-Oct-12	6-May-15
EP21176687.8		EP		2-Oct-12	NA
KR1020147012081	KR102067635	KR		2-Oct-12	17-Jan-20
KR20207001010	KR102184502	KR		2-Oct-12	23-Jan-20
KR1020207033780	KR102323287	KR		24-Nov-20	5-Nov-21

Application No.	Patent No.	Country	Title	App. Date	Publ. Date
US15/650775	US10862114	US	Manufacturing Apparatus and Method for Making Silicon Nanowires on Carbon Based Powders for Use as Anodes in the Battery Industry	14-Jul-17	8-Dec-20
US15/650797	US20180019468A1	US		14-Jul-17	18-Jan-18
CN201780056498	CN109689567A	CN	Manufacturing Apparatus and Method for Making Silicon Nanowires on Carbon Based Powders for Use as Anodes in the Battery Industry	14-Jul-17	26-Apr-19
KR20197004648	KR20190030723A	KR		14-Jul-17	22-Mar-19
JP2019502003	JP2019527187	JP		14-Jul-17	27-Sep-19
EP20170828578	EP3484810A2	EP		14-Jul-17	22-May-19
EP20200195843	EP3778471B1	CH, CZ, DE, DK, ES, FI, FR, GB, HU, IT, NL, NO, PL, SK, SE		14-Jul-17	17-Feb-21

Exemplary composition claims EP ‘830 (Zhu et al.)

4. **A battery anode electrode** comprising:

(1) one or more silicon-comprising nanostructures grown on and attached to a carbon-based powder comprising graphite particles of 5 µm to 50 µm in size, wherein the nanostructures are nanowires having a core-shell structure, and wherein the nanowires have a diameter of 20 nm to 200 nm and a length of 0.1 µm to 50 µm, and wherein the nanowires comprise Li inserted in the nanowires,

(2) a carbon-based material, and

(3) a conductive polymer that is disposed on the nanostructures,

wherein the electrode comprises 1 weight% to 80 weight% of the nanostructures disposed on the carbon-based powder.

2. The **battery anode electrode** of claim 1, wherein the conductive polymer is polypyrrole, polythiophene, polyethylene oxide, polyacrylonitrile, poly(ethylene succinate), polypropylene, poly(β-propiolactone), a sulfonated fluoropolymer, polyimide or poly(acrylic acid).

3. The **battery anode electrode** of claim 1, wherein the carbon-based material is selected from **carbon black**, **graphite**, **graphene**, **graphene powder** and **graphite foil**.

...

10. A **battery** comprising:

a battery anode electrode as claimed in any one of claims 1-9,

a cathode, and

a separator positioned between the anode and the cathode.