The Patent Landscape of Silicon Nanowire Energy Storage Devices

Douglas Sharrott* and Erin J.D. Austin**

Abstract

Lithium ion batteries are used in portable electronic devices, power tools, and electric vehicles. Recently, substantial venture capital and private equity investments have been made to introduce new lithium batteries with enhanced energy densities based on silicon nanowires. In this article, patent lawyers Douglas Sharrott and Erin J.D. Austin explore the patent landscape surrounding use of silicon nanowires in energy storage devices. They identify companies developing silicon nanowire technologies for energy storage applications; highlight exemplary patents directed to silicon nanowire structures and production methods as well as patents directed to using silicon nanowires for energy storage; and explore patent infringement issues.

Introduction

Existing lithium ion batteries of the type commonly used in portable electronic devices and some electric vehicles have generally employed graphite anodes.[1] Energy density improvements for such batteries have slowed as battery makers approach graphite's theoretical capacity of about 370 mAh/g.[2] But while six carbon (graphite) atoms are required to bind one lithium ion, a single silicon atom can bind four lithium ions.[3] Thus, silicon's theoretical capacity of approximately 4,200 mAh/g makes it an attractive material for developing lithium ion batteries with higher energy

* Douglas Sharrott is a partner at Fitzpatrick, Cella, Harper & Scinto where he specializes in computers, electric systems and materials, and the mechanical arts. Mr. Sharrott has been listed in *The Legal 500*, and he has been named as one of the top ten intellectual property lawyers influencing nanotechnology. He may be reached by e-mail at dsharrott@fchs.com.

** Erin J.D. Austin is an associate at Fitzpatrick, Cella, Harper & Scinto. She may be reached by e-mail at eaustin@fchs.com.

[1] *See* Mark J. Armstrong et al., *Evaluating the Performance of Nanostructured Materials as Lithium-ion Battery Electrodes*, 7 NANO RES. 1, 2, 3 (2014); Prachi Patel, *Nanostructured Silicon Key to Better Batteries*, IEEE SPECTRUM (Aug. 15, 2011), available at http://spectrum.ieee.org/consumer-electronics/portable-devices/nanostructured-silicon-key-to-better-batteries.

[2] *See* Armstrong, *supra* note 1, at 3; Hui Wu & Yi Cui, *Designing Nanostructured Si Anodes for High Energy Lithium Ion Batteries*, 7 NANO TODAY 414 (2012).

[3] Armstrong, *supra* note 1, at 3; Wu, *supra* note 2, at 415.

storage capacities.[4] Companies such as 3M, LG Chem, Panasonic, and Sanyo, as well as the Department of Energy's Pacific Northwest National Laboratory, have been reported to be exploring the use of silicon anodes for energy storage.[5]

However, exploiting silicon's lithium-absorbing capacity has presented a number of technological challenges. For example, silicon can expand by as much as 400% upon charging with lithium ions, leading to pulverization and capacity fading after only a few charging cycles.[6] Silicon nanostructures, such as silicon nanowires, can better withstand repeated charging cycles because their increased surface-to-volume ratio helps to accommodate the strain caused by absorbing a large volume of lithium ions.[7] Several companies are now racing to try to bring silicon nanowire (SiNW)-based energy storage products to the marketplace.[8] Meanwhile, researchers have applied for and obtained a number of patents directed to SiNW technology including SiNW structures, methods for making and processing SiNWs, and SiNW energy storage applications including batteries.

This article explores the patent landscape related to using SiNWs for energy storage. Part II surveys some of the companies developing SiNW technology for energy storage applications, focusing on companies founded within the last decade. Part III identifies exemplary patents directed to SiNW structures and production methods, as well as a number of patents directed to using SiNW technology for energy storage.[9] Part IV explores patent infringement questions that may be raised by making and assembling SiNW energy storage products abroad, and then importing those products for sale in the United States.

Companies Developing SiNW-Based Energy Storage Technology

The following are examples of companies reporting that they are pursuing SiNW energy storage applications, with a focus on newer companies developing this technology:

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[4] *E.g.*, Armstrong, *supra* note 1, at 3; Candace K. Chan et al., *High-performance Lithium Battery Anodes Using Silicon Nanowires*, 3 NATURE NANOTECHNOLOGY 31 (2008); Wu, *supra* note 2, at 415.

[5] *See* Xiaolin Li et al., *Mesoporous Silicon Sponge as an Anti-Pulverization Structure for High-Performance Lithium-Ion Battery Anodes*, NATURE COMMC'NS (July 8, 2014), available at http://www.nature.com/ncomms/2014/140708/ncomms5105/full/ncomms5105.html; Ji-Guang Zhang et al., *Large-Scale Production of Si-Nanowires for Lithium Ion Battery Applications*, Abstract 1183, 214th Meeting of the Electrochemical Society (Oct. 15, 2008), available at http://ma.ecsdl.org/content/MA2008-02/12/1183.full.pdf; Patel, *supra* note 1; Kevin Bullis, *Tesla to Use High-Energy Batteries from Panasonic*, MIT TECHNOLOGY REVIEW (Jan. 13, 2010), http://www.technologyreview.com/news/417084/tesla-to-use-high-energy-batteries-from-panasonic/; Katherine Bourzac, *Longer-Running Electric-Car Batteries*, MIT TECHNOLOGY REVIEW (Sept. 23, 2009), http://www.technologyreview.com/news/415424/longer-running-electric-car-batteries/; Jeff St. John, *Amprius Gets $30M Boost for Silicon-Based Lithium-Ion Batteries*, GREENTECH MEDIA (Jan. 6, 2014), http://www.greentechmedia.com/articles/read/amprius-gets-30m-boost-for-silicon-based-li-ion-batteries.

[6] Armstrong, *supra* note 1, at 3; Chan, *supra* note 4, at 31; Wu, *supra* note 2, at 415-16.

[7] Armstrong, *supra* note 1, at 2, 3; Chan, *supra* note 4, at 31, 33; Wu, *supra* note 2, at 417.

[8] *E.g.*, Jared Newman, *Amprius Begins Shipping a Better Smartphone Battery*, TIME, May 23, 2013, available at http://techland.time.com/2013/05/23/amprius-begins-shipping-a-better-smartphone-battery/; St. John, *supra* note 5.

[9] While this article reports on the general subject matter of these patents, it takes no position on their validity or the scope of the protection that they may provide. Additionally, this article focuses on issued patents, not pending patent applications.

Amprius, Inc.

Amprius, co-founded in 2008 by Stanford professor Dr. Yi Cui, is said to be working to develop new types of lithium ion batteries for personal electronic devices and electric vehicles.[10] Amprius has received a grant from the U.S. Department of Energy to work in conjunction with Nissan, BASF, and Yardney Technical Products on developing new vehicle batteries that pair Amprius's SiNW anode with BASF's cathodes.[11] In 2013, Amprius shipped a first-generation battery that uses a nanostructure material including both silicon and carbon.[12] According to one source, Amprius aims to bring SiNW-based batteries to market in 2015.[13] Amprius has R&D labs in California and China, and a pilot production line in China.[14]

Bandgap Engineering, Inc.

Bandgap, co-founded in 2007 by Dr. Marcie Black, is working to commercialize SiNW technology for use in solar cells.[15] Bandgap reports that its technology is also useful for battery applications, and that it is partnering with other companies to commercialize its technology for such applications.[16]

Nanosys, Inc. /OneD Material LLC

Nanosys previously received a U.S. Department of Energy grant to develop silicon anode materials for the electric vehicle market, and has reported developing an anode using SiNW on a graphite powder substrate.[17] OneD Material, formed in 2013, acquired Nanosys's technology and other assets for energy storage applications.[18]

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[10] Bullis, *Startup Gets $30 Million to Bring High-Energy Silicon Batteries to Market*, MIT TECHNOLOGY REVIEW (Jan. 10, 2014), available at http://www.technologyreview.com/news/523296/startup-gets-30-million-to-bring-high-energy-silicon-batteries-to-market/; Mike Ross, *New Nanostructure for Batteries Keeps Going and Going . . .*, SLAC TODAY (May 10, 2012), available at https://news.slac.stanford.edu/features/new-nanostructure-batteries-keeps-going-and-going.

[11] U.S. Dept. of Energy, FISCAL YEAR 2013 ANNUAL PROGRESS REPORT FOR ENERGY STORAGE R&D, 63-65 (Feb. 2014), available at http://energy.gov/sites/prod/files/2014/05/f15/APR13_Energy_Storage_d_III_Adv_Battery_Dev_0.pdf.

[12] Bullis, *supra* note 10; Newman, *supra* note 8; St. John, *supra* note 5.

[13] St. John, *supra* note 5.

[14] Press Release, Amprius, Inc., Amprius Raises $30M to Accelerate Commercialization of High Energy Batteries (Jan. 6, 2014), http://amprius.com/news/news_amprius_20140106.htm.

[15] Bandgap Engineering, Inc., *Nano-Silicon*, http://www.bandgap.com/nano-silicon-14.html (last visited Aug. 10, 2014) [hereinafter *Bandgap: Nano-Silicon*]; Bandgap Engineering, Inc., *Bandgap Board of Directors*, http://www.bandgap.com/management.html (last visited Aug. 12, 2014); Shravan Kumar Chunduri, *Closing the Gap*, 11 PHOTON INTERNATIONAL 138 (2012).

[16] *Bandgap: Nano-Silicon*, *supra* note 15; Bandgap Engineering, Inc., *Nano-Silicon: Batteries*, http://www.bandgap.com/battery-2014.html (last visited Aug. 10, 2014).

[17] U.S. Dept. of Energy, *supra* note 11, at 69-74; St. John, *supra* note 5; Nanosys, Inc., Press Release, Commercialization of High-Capacity Electric Vehicle Battery Materials by Nanosys Approved for by DOE in $11 Million Program (Aug. 10, 2011), http://www.nanosysinc.com/press-releases/2011/08/11/commercialization-of-high-capacity-electric-vehicle-battery-materials-by-nanosys-approved-for-by-doe-in-11-million-program.

[18] OneD Material LLC, http://www.onedmaterial.com/ (last visited Aug. 12, 2014).

Nexeon Ltd.

Nexeon is a 2006 spin-out from the UK's Imperial College.[19] Nexeon advertises that it has developed a "drop-in" approach for incorporating its silicon anode technology into existing battery manufacturing processes, and that it will license and support implementation of its patented technologies.[20] It was also previously reported that Sony engaged in talks about testing Nexeon's battery technology.[21] Nexeon opened an office in Japan last year,[22] and it recently reported completing construction of a process development and manufacturing facility in Oxfordshire, UK.[23]

The Patent Landscape for Energy Storage Using SiNW

Given the commercial potential for SiNW-based products for energy storage, a number of entities have applied for and obtained patents directed to SiNWs, themselves, as well as processes for making and manipulating them, and article of manufacture incorporating SiNWs. Below we survey some patents that may be of interest to those following the development of SiNW energy storage products.

This part of the article is divided into two sections based on the claimed subject matter:[24] first, patents claiming SiNW structures and production methods, and second, patents claiming applications of SiNW technology in the energy storage field.[25]

Examples of Patents Claiming SiNW Structures and Production Methods

Table 1 below provides examples of patents claiming SiNWs and processes for making them. Such claims may cover SiNWs and manufacturing processes whether such are used for energy storage or other applications. Thus, even though the representative claims presented below may not refer specifically to energy storage applications, they still have the potential to be relevant to SiNW energy storage products.

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[19] Nexeon Ltd., *History*, http://www.nexeon.co.uk/about/history/ (last visited Aug. 5, 2014); St. John, *supra* note 5.

[20] Nexeon Ltd., *Benefits of Nexeon Technology*, http://www.nexeon.co.uk/technology/benefits-of-nexeon-technology/ (last visited Aug. 12, 2014); Nexeon Ltd., *Licensing*, http://www.nexeon.co.uk/technology/licensing/ (last visited Aug. 12, 2014).

[21] Laura Chesters, *Nexeon Tips Magic Dust Into Our Batteries*, THE INDEPENDENT (Dec. 4, 2011), http://www.independent.co.uk/news/business/analysis-and-features/nexeon-tips-magic-dust-into-our-batteries-6271847.html.

[22] Nexeon Ltd., Press Release, Nexeon Appoints Industry Heavyweight and Opens Japan Office (Aug. 5, 2013), http://www.nexeon.co.uk/news/nexeon-appoints-industry-heavyweight-and-opens-japan-office/.

[23] Nexeon Ltd., Press Release, Nexeon Completes Commissioning of State-of-the-Art Manufacturing Facility (Apr. 24, 2014), http://www.nexeon.co.uk/news/nexeon-completes-commissioning-of-state-of-the-art-manufacturing-facility/.

[24] A patent's claims define the scope of the property rights conferred by the patent. *Phillips v. AWH Corp.*, 415 F.3d 1303, 1312 (Fed. Cir. 2005) (en banc) (internal quotations omitted).

[25] It is possible for a single patent to contain claims directed to SiNWs structures and/or production methods, as well as claims directed to applications of SiNW technology in the energy storage field.

Table 1: Examples of Patents Claiming SiNW Structures and Production Methods

Patent #[26]	Assignee	Representative Claim(s)
6,313,015	City University of Hong Kong	1. A method of growing silicon nanowires comprising activating vapor phase silicon monoxide or suboxide carried in an inert gas, wherein silicon nanowires are grown from activating vapor phase silicon monoxide or suboxide.
6,465,132	Agere Systems Guardian Corp.	1. An article including a nanowire structure comprising (i) an alloy substrate comprised of at least a first phase and a second phase, wherein the first phase is catalytic to provide reactivity for the growth of nanowires and the second phase is less catalytic than the first phase, and (ii) a plurality of small diameter nanowires attached to the first phase of the alloy substrate. 13. The article of claim 1 in which the plurality of nanowires are selected from carbon nanotubes, semiconductor wires comprising silicon or germanium, ceramic wires comprising at least one of boride, carbide, and nitride, metallic nanowires, and nanowires having a heterojunction.
6,831,017	Integrated Nanosystems, Inc.	1. A method for forming a plurality of catalyst sites from which to grow nanowires for a nanowire device that has a substrate with an upper surface, the method comprising: depositing a layer of catalyst on the upper surface of the substrate; and heating the substrate and catalyst sufficiently to cause the catalyst to migrate along the surface of the substrate to form individual clumps of catalyst, wherein the clumps serve as the catalyst sites for nanowire growth.[27]
7,105,428 7,273,732 7,666,791	OneD Material LLC	7,105,732: 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. 13. The method of claim 1, wherein the first precursor gas mixture comprises SiH_4, $SiCl_4$ or SiH_2Cl_2, and further comprises B_2H_6, $POCl_3$ or PH_3. 14. The method of claim 1, wherein the second precursor gas mixture

[26] Where one entity has been granted a series of related patents (a "patent family") each having some claims of potential interest, the patents in that family are listed together in this article's tables.

[27] The '017 Patent discusses precursors for growing silicon nanowires at col. 5, lns. 15-18.

Patent #[26]	Assignee	Representative Claim(s)
		comprises SiH_4, Si_2H_6, $SiCl_4$ or SiH_2Cl_2, and further comprises B_2H_6, $POCl_3$ or PH_3. 18. A method for producing nanowires, comprising: depositing one or more nucleating particles on a substrate material; heating the nucleating particles to a first temperature at which a first precursor gas has a eutectic phase with the nucleating particles; contacting the nucleating particles with a first precursor gas mixture comprising the first precursor gas to initiatie [sic] nanowire growth, wherein the first precursor gas mixture comprises at least one atomic species that aids in orienting the nanowires; contacting the nucleating particles with a second precursor gas mixture comprising a second precursor gas that has a eutectic phase with the nucleating particles at a second temperature that is lower than the first temperature; and heating the nucleating particles to the second temperature. 19. The method of claim 18, wherein the first precursor gas mixture comprises $SiCl_4$ or SiH_2Cl_2. 20. The method of claim 19, wherein the second precursor gas mixture comprises SiH_4 or Si2H_6 [sic]. 7,273,732: 1. A method of harvesting a nanowire, comprising the steps of: (a) growing a desired portion of the nanowire; (b) growing a sacrificial portion of the nanowire which is doped differently than the desired portion of the nanowire; (c) differentially removing the sacrificial portion of the nanowire; and (d) removing a growth stub from the desired portion of the nanowire. 8. The method of claim 1, wherein the desired portion of the nanowire includes Si or Ge. 7,666,791: 1. A method for producing nanowires comprising: (a) providing a substrate material having one or more nucleating particles deposited thereon in a reaction chamber; (b) introducing a precursor gas mixture into the reaction chamber to initiate nanowire growth, wherein the precursor gas mixture comprises $SiCl_4$ or SiH_2Cl_2; (c) introducing an independent chlorine gas species separate from the precursor gas mixture into the reaction chamber to control etching to promote oriented nanowire growth; and (c) growing nanowires at the site of the nucleating particles.
6,872,645	OneD Material LLC	6,872,645: 1. A method of depositing a population of nanowires on a surface of a substrate substantially in a desired orientation, comprising:

Patent #[26]	Assignee	Representative Claim(s)
7,151,209		providing one or more fluid channels on the surface of the substrate, wherein at least one fluid channel has at least one of a widened region or a thinned region along a length of the channel; flowing a first fluid containing nanowires over the surface in a first direction through the one or more fluid channels, the first direction being parallel to a desired longitudinal orientation of the nanowires; and permitting a population of nanowires in the first fluid to become immobilized onto the surface, a longitudinal dimension of the nanowires from the first fluid being substantially oriented in the first direction.[28] 7,151,209: 1. A method of harvesting a nanostructure from a substrate, the nanostructure comprising at least a first region comprising a first material and a second region comprising a second material, wherein the first material is differentially etchable from the second material, the method comprising etching away the first material of the nanostructure to release the nanostructure from the substrate at the first region. 13. A method of harvesting a nanostructure from a substrate, the nanostructure comprising at least a first region comprising a first material and a second region comprising a second material, wherein the first material comprises silicon and the second material comprises germanium and the first material is differentially etchable from the second material, the method comprising etching away the first material of the nanostructure to release the nanostructure from the substrate at the first region.
7,446,024	Hewlett-Packard Development Company, L.P.	1. A method of growing nanowires with a narrow diameter distribution, said method comprising: providing a substrate having a first surface; providing a plurality of nanoparticles having a distribution of particle sizes on said first surface; initiating growth of nanowires by a vapor-liquid-solid technique; and terminating growth of said nanowires, wherein said nanowires grow at a rate that depends on the diameter of said nanowire, with larger diameter nanowires growing faster. 3. The method of claim 1 wherein said nanowires comprise a semiconductor material. 4. The method of claim 3 wherein said semiconductor material is selected from the group consisting of silicon and germanium. 5. The method of claim 4 wherein said semiconductor material is

[28] The ’645 Patent refers to silicon nanowires at, e.g., col. 13, lns. 54-58 and 16, lns. 26-29 (Example 1).

Patent #[26]	Assignee	Representative Claim(s)
		silicon and said vapor employed in said vapor-liquid-solid technique comprises a gas selected from the group consisting of silane, dichlorosilane, and silicon tetrachloride
7,696,105 8,207,521	Samsung Electronics Co., Ltd.	7,696,105: 1. A method for producing nanowires, comprising wet etching the surface of a silicon substrate to leave defect sites, exposing the wet-etched silicon substrate to deionized water or air to form an oxide layer thereon, and heating the resulting silicon substrate in a furnace while feeding a nanowire precursor into the furnace to grow silicon nanowires from silicon nuclei formed within the oxide layer. 8,207,521: 1. A catalyst-free single crystal silicon nanowire consisting of: silicon; and at least one dopant, wherein the catalyst-free single crystal silicon nanowire has a diameter of about 2 nanometers to about 200 nanometers and a length of about 10 nanometers to about 1,000 micrometers.
7,985,454	OneD Material LLC	1. A method to produce a catalytic-coated nanowire growth substrate for nanowire growth, comprising: (a) depositing a buffer layer on a substrate; (b) treating the buffer layer with boiled water or steam following the depositing in step (a) to enhance interactions between the buffer layer and catalyst particles; and (c) depositing catalytic particles on a surface of the buffer layer following the treating in step (b). 12. A method to grow silicon nanowires, comprising: (a) depositing Al_2O_3 on a silicon substrate; (b) treating the Al_2O_3 coated substrate in boiling water following the depositing in step (a); (c) soaking the Al_2O_3 coated silicon substrate in a Au colloid solution following the treating in step (b); and (d) growing nanowires from the Au colloid particles deposited in step (c) above on the Al_2O_3 coated silicon substrate. 13. A method to grow oriented silicon nanowires, comprising: (a) depositing ZnO on a silicon substrate; (b) soaking the ZnO coated silicon substrate produced in step (a) in an Au colloid solution; and (c) growing oriented silicon nanowires.
8,110,510	Merck Patent GmbH	1. A method for producing nanowires, comprising: exposing at least one nanowire precursor to metal nanoparticles in a nanowire growth solution comprising an organic solvent in a non-supercritical state, whereby the metal nanoparticles act as seed particles for the growth of the nanowires, wherein the nanowires comprise a material selected from the group consisting of (a) Group IV elements, (b) Group II elements other than cadmium, (c) Group VI elements other than tellurium, (d) combinations of a Group III element and a Group

Patent #[26]	Assignee	Representative Claim(s)
		V element which include at least one element selected from the group consisting of aluminum and, nitrogen, and (e) GaP. 5. The method of claim 1, wherein the Group IV nanowires are silicon nanowires. 18. A method for producing nanowires, comprising: exposing at least one nanowire precursor to metal nanoparticles in a nanowire growth solution comprising an organic solvent in a non-supercritical state, whereby the metal nanoparticles act as seed particles for the growth of the nanowires, wherein the metal nanoparticles comprise a metal selected from the group consisting of bismuth, tin, aluminum and lead and further wherein the nanowires comprise (a) an element selected from the group consisting of Group IV elements, (b) a combination of a first element selected from the group consisting of Group III elements and a second element selected from the group consisting of Group V elements, and (c) a combination of a first element selected from the group consisting of Group II elements other than cadmium, and a second element selected from the group consisting of Group IV elements other than tellurium. 21. The method of claim 20, wherein the nanowires are Si nanowires. 30. A method for producing nanowires, comprising: exposing at least one nanowire precursor to metal nanoparticles in a nanowire growth solution comprising an organic solvent in a non-supercritical state, whereby the metal nanoparticles act as seed particles for the growth of the nanowires, wherein the nanowires comprise a material selected from the group consisting of (a) Group IV elements, (b) Group II elements other than cadmium, (c) Group VI elements other than tellurium, (d) combinations of a Group III element and a Group V element including at least one of aluminum and nitrogen, and (e) GaP. 42. The method of claim 30, wherein the nanowire precursor is trisilane. 43. The method of claim 30, wherein the nanowires comprise a material selected from the group consisting of Si and Ge, and wherein the metal nanoparticles comprise a material selected from the group consisting of bismuth and indium.
8,143,143 8,791,449	Bandgap Engineering, Inc.	8,143,143: 1. A process for etching a silicon-containing substrate to form structures, comprising the steps of: (a) depositing nanoparticles on the surface of a silicon-containing substrate, (b) depositing metal on top of the nanoparticles and silicon in such a way that the metal is present and touches silicon where etching is desired and is blocked from touching silicon or not present elsewhere, and (c) contacting

Patent #[26]	Assignee	Representative Claim(s)
		the metallized substrate with an etchant aqueous solution comprising about 2 to about 49 weight percent HF and an oxidizing agent, wherein the process results in nanowire arrays in which the average diameter of the nanowires is less than about 125 nm. 8,791,449: 1. A nanowire array comprising polycrystalline silicon, wherein the nanowires of the array have their lengthwise directions at a non-zero angle to a silicon-containing substrate, wherein the array is formed by etching a substrate composed primarily of amorphous.
8,258,049	Samsung Electronics Co., Ltd.	1. A method of manufacturing a nanowire, comprising: forming a polycrystalline nanowire on a substrate; and changing the polycrystalline nanowire to a single crystalline nanowire, wherein the forming the polycrystalline nanowire includes forming a layer selected from the group consisting of a silicon (Si) nanowire, a germanium (Ge) nanowire and a silicon germanium (SiGe) nanowire.
8,318,604	The Board of Trustees of the Leland Stanford Junior University	1. A method for forming a substrate comprising a plurality of projections, wherein the method comprises: forming a mask layer on a first surface of the substrate, wherein the substrate comprises a first material, and wherein the mask layer comprises a plurality of first particles of a second material, and further wherein the plurality of first particles is arranged as a monolayer on the first surface; modifying the size of the first particles after the first particles are disposed on the first surface; and etching the substrate in a first etch, wherein the first etch etches the first material at a faster rate than that the second material.[29]
8,574,942	Unist Academy-Industry Research Corporation	1. A method of preparing a silicon nanowire, comprising: forming a catalyst layer comprising metal particles separated from one another on a silicon material; selectively etching the silicon material contacting the metal particles; and removing the metal particles, wherein the forming of a catalyst layer comprises: forming mask particles with a material different from the metal particles and the silicon material; and forming the metal particles among the mask particles.
8,734,659	Bandgap Engineering, Inc.	1. A process for etching a silicon-containing substrate to form structures comprising the steps of: (a) depositing and patterning metal onto a silicon-containing substrate in such a way that the metal is present and touches silicon where etching is desired and is blocked from touching silicon or not present elsewhere, (b) submerging the metallized substrate into an etchant aqueous solution comprising about 4 to about 49 weight percent HF and an oxidizing agent, thus producing a metallized substrate with one or more trenches, wherein

[29] The '604 Patent refers to making nanopillars with diameters substantially equal to those of particles having approximately 50-800 nM diameters. U.S. Patent 8,318,604, col. 4, lns. 65-67, col. 7, lns. 10-11.

Patent #[26]	Assignee	Representative Claim(s)
		the trenches have an aspect ratio larger than about 80:1 and have smooth sidewalls, (c) optionally employing a second different silicon etch to remove nanowires inside the one or more trenches, wherein the patterning of metal takes place by using photolithography, surface stamping, screen-printing, or dip-pen techniques.
8,771,498	General Research Institute for Nonferrous Metals	1. An electrochemical method for producing Si nanowires and/or Si nanotubes directly from a silicon compound SiO_2 powder, the method comprising: providing an electrolysis cell having a cathode, an anode and an electrolyte comprising a metal compound molten salt to carry out an electrolysis; using the silicon compound SiO_2 powder as the cathode and immersing the cathode in the electrolyte; applying a cell voltage between the cathode and the anode in the electrolysis cell; and forming, on the cathode, an electrolysis product comprising one or more of Si nanowires and Si nanotubes, wherein the cell voltage applied between the cathode and the anode is less than 3.2V, and the cell voltage applied between the cathode and the anode is less than a decomposition potential of the electrolyte, and the electrolyte comprises CaO formed by hydrolysis of molten salt $CaCl_2$ during a melting process at a high temperature.
8,772,174	Nexeon Ltd.	1. A method of treating silicon to form elongate structures on a treated surface, the method comprising a nucleation step in which metal is deposited on the silicon surface and an etching step in which silicon underlying the deposited metal is etched, wherein a. the nucleation step comprises exposing a silicon containing material to a solution comprising HF at a concentration of less than 5M and 0.002 to 0.2M of metal ions capable of nucleating on and forming a porous layer comprising regions of elemental metal on the silicon surface; and b. the etching step comprises i. exposing the silicon surface comprising regions of elemental metal to a solution comprising HF at a concentration of greater than 5M and 0.001 to 0.70M of an oxidant selected from the group comprising O_2, O_3, H_2O_2, the acid, ammonium or alkali metal salt of NO_3^-, $S_2O_8^{2-}$, $B_4O_7^{2-}$ and ClO_4^- or a mixture thereof; and ii. adding oxidant to the solution during etching to maintain the concentration of oxidant within the above range. 28. A method according to claim 1 wherein the elongate structures are selected from pillars, rods, columns, nanowires, tubes, fibers, ribbons and flakes.

Example of Patents Claiming SiNW Energy Storage Applications

Table 2 below provides examples of patents claiming technologies that use SiNWs for energy storage applications (e.g., anodes and batteries):

Table 2: Examples of SiNW Energy Storage Patents

Patent #	Assignee	Representative Claim(s)
6,334,939 6,514,395	The University of North Carolina at Chapel Hill	6,334,939: 1. An alloy comprising nanostructures of at least one of: silicon, silicon oxide, germanium, germanium oxide, and aluminum; and an alkali metal, said alloy having a reversible storage capacity of the alkali metal of at least 900 mAh/g and an irreversible storage capacity of the alkali metal of less than 500 mAh/g. 2. The alloy of claim 1, wherein the alloy is silicon-based and the nanostructures comprise silicon nanostructures. 3. The alloy of claim 1, wherein said nanostructures comprise at least one of a rod, wire-like shape, or spherical particles. 4. The alloy of claim 3, wherein the rod or wire-like shape has a diameter of about 1-50 nm and a length of about 0.5 10 μm. 5. The alloy of claim 1, wherein the alkali metal comprises lithium. 6,514,395: 1. An article of manufacture comprising: an electrically conductive substrate; and a film disposed on said substrate, said film comprising a material of at least one of germanium and silicon nanostructures, said material having a reversible capacity of at least 900 mAh/g and an irreversible capacity of less than 200 mAh/g. 3. The article of claim 1, wherein said article comprises an electrode.
7,402,829 7,683,359 7,842,535 8,017,430 8,384,058	Nexeon Ltd.	7,402,829: 1. An energy storage device comprising: an anode comprising an array of sub-micron silicon structures supported on a silicon substrate; and a cathode comprising lithium, arranged to form a battery. 8. A device according to claim 5 wherein the pillars are 0.1 to 1.0 microns in diameter and 1 to 10 microns in height. 15. An electrode for a battery comprising sub-micron silicon pillars supported on a silicon substrate and arranged to form a battery with a lithium cathode and a lithium-based electrolyte. 7,683,359: 1. An energy storage device comprising: an anode comprising an array of sub-micron structures comprising silicon, on a substrate; a cathode comprising lithium; and a lithium-based electrolyte,

Patent #	Assignee	Representative Claim(s)
		arranged to form a battery. 6. A device according to claim 1 wherein the array of sub-micron structures comprise an array of sub-micron pillars. 9. A device according to claim 6 wherein the pillars are 0.1 to 1.0 microns in diameter and 1 to 10 microns in height. 13. A battery including an anode comprising: an array of sub-micron pillars comprising silicon fabricated on a substrate; and a lithium cathode, wherein a compound film is formed on the pillars in a charging step. 17. An electrode for a battery comprising sub-micron pillars comprising silicon supported on a substrate and arranged to form a battery with a lithium cathode and a lithium-based electrolyte. 19. An energy storage device comprising: an anode comprising an array of submicron structures comprising silicon, supported on a substrate; a cathode comprising lithium; and an electrolyte comprising lithium. 7,842,535: 1. A method of fabricating an energy storage device comprising the steps of: forming an anode comprising an array of sub-micron silicon structures supported on a silicon substrate; forming a cathode comprising lithium; and arranging the anode and cathode in communication to form a battery. 5. A method according to claim 1 wherein the step of forming the array of submicron silicon structures comprises forming an array of sub-micron silicon pillars. 8. A method according to claim 5 wherein the step of forming the pillars comprises forming pillars which are 0.1 to 1.0 microns in diameter and 1 to 10 microns in height. 8,017,430: 1. A method of fabricating an energy storage device comprising the steps of: forming an anode comprising an array of spaced elongated structures extending from a substrate, wherein the elongated structures comprise silicon; forming a cathode; and arranging the anode and cathode in communication to form a battery. 7. A method according to claim 1 wherein the step of forming the elongated structures comprises forming elongated structures which are 0.1 to 1.0 microns in diameter. 11. A method of fabricating an energy storage device comprising the

Patent #	Assignee	Representative Claim(s)
		steps of: forming an anode comprising: providing a substrate comprising silicon, removing material from the substrate to form a plurality of spaced pillars on the substrate; forming a cathode; and arranging the anode and cathode in communication to form a battery. 16. A method according to claim 11 wherein the step of forming the pillars comprises forming pillars which are 0.1 to 1.0 microns in diameter. 22. A method of fabricating an energy storage device comprising the steps of: forming an anode comprising a plurality of spaced elongated structures each mounted at one end to a substrate and extending away therefrom, wherein the elongated structures comprise silicon; forming a cathode; and arranging the anode and cathode in communication to form a battery. 28. A method according to claim 22 wherein the step of forming the elongated structures comprises forming elongated structures which are 0.1 to 1.0 microns in diameter. 8,384,058: 1. An electrode for a battery comprising a plurality of silicon-comprising elongated structures extending from a substrate and arranged to engage with a lithium-based cathode and a lithium-based electrolyte, wherein the elongated structures have a length greater than 1 micron.
7,816,031	The Board of Trustees of the Leland Stanford Junior University	1. A battery, comprising: an ion transporter to transport ions; a first current collector on one side of the ion transporter; and a second current collector, located on another side of the ion transporter, including a substrate and a plurality of solid nanowires including silicon or a silicon alloy that are growth-rooted from the substrate and that interact with the ions, wherein the growth-rooted solid nanowires have a stable energy capacity greater than about 2000 mAh/g. 5. A battery, comprising: an ion transporter to transport ions; a substrate; a first current collector on one side of the ion transporter; and a second current collector, located on another side of the ion transporter, including the substrate and a plurality of solid nanowires including silicon or a silicon alloy that are growth-rooted from the substrate and that interact with the ions, wherein the growth-rooted solid nanowires have a stable energy capacity greater than about 2000 mAh/g over at least ten discharge and charge cycles, and each of the plurality of nanowires having an outer surface with molecules that interact with the ions. 12. A battery, comprising: an ion transporter to transport ions; a

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		substrate; a first current collector on one side of the ion transporter; and a second current collector, located on another side of the ion transporter, including the substrate and a plurality of solid nanowires including silicon or a silicon alloy that are growth-rooted from the substrate and that interact with the ions, wherein the growth-rooted solid nanowires have a stable energy capacity greater than about 2000 mAh/g over at least ten discharge and charge cycles, and each of the plurality of nanowires having an outer surface with molecules that interact with the ions, wherein each of a majority of the nanowires have an angle greater than about 60 degrees from an end of the nanowire located on and connected to the substrate and a second end of the nanowire, the angle being such that 90 degrees is perpendicular to a surface of the substrate at which the first end is located.
7,829,225	Commissariat a l'Energie Atomique	1. A lithium microbattery comprising at least one first electrode, consisting of a plurality of protruding electrode components defining substantially empty gaps between them, a second electrode and an electrolyte localized between both electrodes, characterized in that the electrolyte is solid, and held above the gaps by electrode components, wherein the substantially empty gaps compensate for an increase in volume related to the insertion of lithium in the components. 7. The lithium microbattery according to claim 1, wherein the first electrode is the anode. 8. The lithium microbattery according to claim 7, wherein the electrode components are carbon or silicon nanotubes or nanowires.
8,101,298 8,597,831	Nexeon Ltd.	8,101,298: 1. A method of creating a cell electrode for an electrochemical cell, the method comprising: etching a silicon or silicon-based substrate to form fibres; detaching the fibres from the substrate; depositing a slurry containing a plurality of the fibres to form a layer of fibres; wherein at least some of the fibres cross over to provide intersections. 2. A method of creating a cell electrode for a battery, the method comprising: etching a silicon or silicon-based substrate, comprising n-type or p-type silicon, to form fibres; detaching the fibres from the substrate; and forming a layer of fibres in which the fibres cross over each other to provide multiple intersections. 3. A method as claimed in claim 2 in which the fibres have transverse dimensions in the range 0.08 to 0.5 microns. 4. A method as claimed in claim 3 wherein the fibres have a length in

Patent #	Assignee	Representative Claim(s)
		the range of 20 to 300 microns. 5. A method as claimed in claim 2 in which the fibres have an aspect ratio greater than 40:1. 8,597,831: 1. An electrode for an electrochemical cell, the electrode comprising an electrically interconnected mass comprising: elongated structures, wherein the elongated structures are capable of being reversibly charged and discharged and at least some of the elongated structures cross over each other to provide intersections and a porous structure, and wherein the elongated structures comprise silicon; at least one of a binder and an electronic additive; wherein the elongated structures and the at least one of the binder and the electronic additive cooperate to define a porous composite electrode layer. 6. An electrode as claimed in claim 1 wherein the elongated structures have a transverse dimension in the range 0.08 to 0.5 microns and/or a length in the range of 20 to 300 microns. 14. An electrode for an electrochemical cell, the electrode comprising an electrically interconnected mass comprising: elongated structures, wherein the elongated structures are electrochemically active such that they are capable of lithium insertion and removal and at least some of the elongated structures cross over each other to provide intersections and a porous structure, and wherein the elongated structures comprise silicon; wherein the electrically interconnected mass has a percentage pore volume of about 10-30 percent. 17. An electrode as claimed in claim 14 wherein the elongated structures have an aspect ratio of greater than 40:1. 20. An electrode for an electrochemical cell, the electrode comprising: elongated structures, wherein at least some of the elongated structures cross over each other to provide intersections and a porous structure, wherein the elongated structures comprise silicon; wherein the intersections comprise a disrupted crystalline or amorphous structure which welds the elongated structures to one another. 23. An electrode as claimed in claim 20 wherein the silicon comprising fibers have an aspect ratio of greater than 40:1.
8,435,676	NanoteK Instruments, Inc.	1. An electrochemical cell electrode comprising a mixed nano-filament composition, said composition comprising an aggregate of: a) nanometer-scaled, electrically conductive filaments that are interconnected, intersected, or percolated to form a porous,

Patent #	Assignee	Representative Claim(s)
		electrically conductive filament network, wherein said filaments have a length and a diameter or thickness, and the diameter or thickness is less than 500 nm with a length-to-diameter or length-to-thickness aspect ratio greater than 10 and said conductive filaments are selected from nano-scaled graphene platelets with a length-to-width ratio greater than 3, metal nano wires, metal-coated fibrils, and combinations thereof; and b) multiple nanometer-scaled, electro-active filaments comprising therein or thereon an electro-active material capable of absorbing and desorbing lithium ions wherein said electro-active filaments have a diameter or thickness less than 500 nm; wherein the electro-active filaments comprise an active material selected from the group consisting of: a) silicon (Si), germanium (Ge), lead (Pb), antimony (Sb), bismuth (Bi), zinc (Zn), aluminum (Al), and cadmium (Cd); b) alloys or intermetallic compounds of Si, Ge, Pb, Sb, Bi, Zn, Al, or Cd with other elements, wherein said alloys or compounds are stoichiometric or non-stoichiometric; c) oxides, carbides, nitrides, sulfides, phosphides, selenides, and tellurides of Si, Ge, Pb, Sb, Bi, Zn, Al, Fe, or Cd, and their mixtures or composites; and d) combinations thereof; and wherein said electro-active filaments and said electrically conductive filaments are intertwined to form a mat, web, or porous paper structure in which at least an electro-active filament is in electrical contact with at least an electrically conductive filament. 5. The mixed nano-filament composition of claim 1 wherein said electro-active filaments comprise a nanowire selected from the group consisting of nanowires of Ge, Si, their oxides, carbides, nitrides, sulfides, phosphides, selenides, and tellurides, and combinations thereof. 7. The mixed nano-filament composition of claim 5 wherein said electro-active filaments comprise Si nanowires.
8,440,350	GM Global Technology Operations LLC	1. A lithium-ion electrochemical cell comprising a negative electrode comprising a current collector carrying a negative electrode active material; a positive electrode comprising a current collector carrying a positive electrode active material; a liquid electrolyte containing lithium ions, the liquid electrolyte contacting both electrode materials and providing transport of lithium ions between the negative electrode active material and positive electrode active material; and a separator preventing electrical contact between the positive and negative electrodes while providing transport of lithium ions between the electrode materials; the negative electrode active material and positive electrode active material being formed of different compositions with each electrode active material composition being subject to lithiation and de-lithiation during discharge and charge cycling of the electrochemical cell; at least one of the negative electrode and positive electrode further comprising: a metallic current collector sheet having opposing sheet surfaces and being formed of a metal composition that is not subject to lithiation,

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		or volume change due to lithiation, in the cycling of the electrochemical cell; electrode active material formed on at least one of the current collector sheet surfaces; the electrode active material being formed as nanosized bodies that extend outwardly from the sheet surface a distance of at least one micrometer, with each body being in electrical contact with the current collector sheet and having a cross-sectional thickness less than five hundred nanometers, the bodies of electrode active material experiencing repeated volume changes during lithiation and de-lithiation of cell cycling; and a body of an elastic shape memory alloy formed against at least one portion of each body of the electrode active material. 6. A lithium-ion electrochemical cell comprising a negative electrode comprising a current collector carrying a negative electrode active material; a positive electrode comprising a current collector carrying a positive electrode active material; a liquid electrolyte containing lithium ions, the liquid electrolyte contacting both electrode active materials and providing transport of lithium ions between the negative electrode active material and positive electrode active material; and a separator preventing electrical contact between the positive and negative electrodes while providing transport of lithium ions between the electrode materials; the negative electrode active material and positive electrode active material being formed of different compositions with each electrode material composition being subject to lithiation and de-lithiation during discharge and charge cycling of the electrochemical cell; the negative electrode further comprising: a metallic current collector sheet having opposing sheet surfaces and a thickness up to about thirty micrometers, the current collector sheet being formed of a metal composition that is not subject to lithiation, or volume change due to lithiation, in the cycling of the electrochemical cell; negative electrode active material formed on at least one of the current collector sheet surfaces; the negative electrode active material being formed as nanosized bodies that extend outwardly from the sheet surface a distance of at least one micrometer with each body being in electrical contact with the current collector sheet and having a cross-sectional thickness less than five hundred nanometers, the bodies of electrode active material experiencing repeated volume changes during lithiation and de-lithiation of cell cycling; and a body of an elastic shape memory alloy formed against at least one portion of each body of the electrode active material. 9. A lithium-ion electrochemical cell as recited in claim 6 in which the negative electrode active material comprises at least one element selected from the group consisting of silicon, tin, and graphite. 11. A lithium-ion electrochemical cell as recited in claim 6 in which the negative electrode active material is formed as nanowires each attached at an end to a base of shape memory alloy which in turn is

Patent #	Assignee	Representative Claim(s)
		formed on a surface of the metal current collector sheet.
8,450,012	Amprius, Inc.	1. An electrode layer for use in a rechargeable battery, the electrode layer comprising: interconnected hollow nanostructures having shells around internal cavities,[30] wherein the shells comprise a high capacity electrochemically active material, a conductive substrate underlying the interconnected hollow nanostructures, wherein at least some of the interconnected hollow nanostructures are interconnected at points above the conductive substrate; and wherein the internal cavities provide free space for the high capacity active material to swell into during cycling of the rechargeable battery. 10. A lithium ion battery comprising: an electrode layer comprising: interconnected hollow nanostructures having shells around internal cavities, wherein the shells comprise a high capacity electrochemically active material, a conductive substrate underlying the interconnected hollow nanostructures, wherein at least some of the interconnected hollow nanostructures are interconnected at points above the conductive substrate; and wherein the internal cavities provide free space for the high capacity active material to swell into during cycling of the rechargeable battery.
8,574,942	Unist Academy-Industry Research Corporation	8. A method of fabricating a lithium secondary battery, comprising: forming a silicon material on a current collector layer; forming a catalyst layer comprising metal particles arranged at a predetermined distance on the silicon material which is formed on the current collector layer; etching the silicon material using the metal particles as a catalyst to form silicon nanowires; and removing the metal particles.
8,603,195	Applied Materials, Inc.	1. A method of producing an energy storage device, comprising: positioning an anodic current collector into a processing region; depositing one or more three-dimensional electrodes separated by a finite distance on a surface of the anodic current collector such that portions of the surface of the anodic current collector remain exposed; selectively depositing an insulator layer on the exposed portions of the surface of the anodic current collector such that portions of the one or more three-dimensional electrodes remain exposed; depositing a conformal polymeric layer over the insulator layer and the exposed portions of the one or more three-dimensional electrodes using iCVD techniques comprising: flowing a gaseous monomer into the processing region; flowing a gaseous initiator into the processing region through a heated filament to form a reactive gas mixture of the gaseous monomer and the gaseous initiator, wherein the heated filament is heated to a temperature between about 300° C. and about 600° C., wherein the insulator layer

[30] In this patent, the battery's electrode uses hollow nanostructures ("nanotubes") rather than nanowires.

Patent #	Assignee	Representative Claim(s)
		prevents deposition of the conformal polymeric layer onto the surface of the anodic current collector; depositing a conformal layer of cathodic material over the conformal polymeric layer; and depositing a cathodic current collector over the conformal layer of cathodic material.
8,637,185	Amprius, Inc.	1. A lithium ion battery electrode for use in a lithium ion battery, the lithium ion battery electrode comprising: a conductive substrate having open structures and a fractional void volume of at least about 25% such that the conductive substrate includes internal open spaces; and a nanostructured active material formed on the conductive substrate and in direct electronic communication therewith for inserting and removing lithium ions to and from the nanostructured active material during battery cycling, wherein the nanostructured active material includes one or more nanostructures completely within the internal open spaces of the conductive substrate, and wherein the nanostructured active material comprises one or more materials selected from the group consisting of silicon, germanium, and tin. 5. The lithium ion battery electrode of claim 1, wherein the nanostructured active material comprises nanowires. 17. A method of manufacturing an electrode for use in a lithium ion battery, the method comprising: providing a conductive substrate having open structures and a fractional void volume at least about 25% such that the conductive substrate includes internal open spaces; and depositing a nanostructured active material comprising one or more materials selected from the group consisting of silicon, germanium, and tin on the conductive substrate, wherein depositing the nanostructured active material includes depositing nanostructures within the internal open spaces of the conductive substrate such that the one or more nanostructures are completely within the internal open spaces of the conductive substrate; wherein the deposited nanostructured active material is configured for inserting and removing lithium ions during battery cycling. 20. A lithium ion battery comprising: a conductive substrate having open structures and a fractional void volume of at least about 25% such that the conductive substrate includes internal open spaces; and nanostructured active material formed on the conductive substrate, wherein one or more nanostructures are completely within the internal open spaces of the conductive substrate, and the nanostructured active material and conductive substrate are in direct electronic communication therewith, for inserting and removing lithium ions during battery cycling, and wherein the nanostructured active material comprises one or more materials selected from the group consisting of silicon, germanium, and tin.

Patent #	Assignee	Representative Claim(s)
8,642,211	Nexeon Ltd.	1. An electrode comprising silicon-comprising fibres, wherein the silicon-comprising fibres are arranged to cross over each other to provide multiple intersection points, and characterized in that two or more of the fibres are bonded to each other at intersection points to form a bonded felt before any lithiation or delithiation of the silicon comprising fibres, and wherein the two or more fibres are made of the same material and have substantially the same dimensions. 3. The electrode as claimed in claim 1 in which the fibres have transverse dimensions in the range 0.08 to 0.5 microns and a length in the range 20 to 300 microns. 4. The electrode as claimed in claim 1 in which the fibres have an aspect ratio of about 100:1. 13. A lithium rechargeable cell anode comprising a layer of silicon-comprising fibres, wherein the silicon comprising fibres are arranged to cross over each other to provide multiple intersection points and characterized in that two or more of the fibres are bonded to each other at intersection points to form a bonded felt before any lithiation or delithiation of the silicon-comprising fibres, and wherein the fibres are single crystal fibres. 20. An electrode for a lithium ion battery comprising an electrochemically active material comprising a layer of silicon-comprising fibres, wherein the silicon-comprising fibres are arranged to cross over each other to provide multiple intersection points, and characterized in that at least two of the silicon-comprising fibres are bonded to each other at intersection points to form a bonded felt before any lithiation or delithiation of the electrochemically active material. 22. The electrode as claimed in claim 20 in which the fibres have transverse dimensions in the range 0.08 to 0.5 microns and a length in the range 20 to 300 microns. 23. The electrode as claimed in claim 20 in which the fibres have an aspect ratio of about 100:1.
8,791,449	Bandgap Engineering, Inc.	3. A process of manufacturing an anode material for lithium ion batteries comprising nanostructured silicon, comprising the step of etching a silicon-containing substrate using a metal as a catalyst, wherein the nanostructured silicon comprises silicon nanowires, wherein the silicon nanowires are formed by etching a substrate composed primarily of amorphous or polycrystalline silicon.

Patent Infringement Issues Related To Foreign-Made SiNW Energy Storage Devices

SiNW energy storage products are predicted to reach the marketplace in the near future. As several manufacturers of these products, including those discussed above in Parts **Error! Reference source not found.**-0, are located overseas, it is likely that batteries or components thereof incorporating SiNW technology will be made abroad for import into and sale in the United States. Such scenarios may give rise to questions about which entities involved in the supply chain might be found liable for infringing patents covering SiNWs, processes for making them, and energy storage devices incorporating them. Assume, for example, that Company A manufactures a SiNW anode and sells it to a battery manufacturer, Company B. In turn, Company B makes a lithium ion battery using the anode, which it then sells to Company C for incorporation into a consumer electronic device. If the anode, battery, and device were made abroad, and then Company C imports the device for sale to U.S. customers, which company or companies in the supply chain might be held liable if the battery's SiNW anode infringes a U.S. patent?[31]

As a preliminary matter, practicing a U.S.-patented invention in a foreign country does not, by itself, infringe the U.S. patent. The Supreme Court of the United States has explained, "[t]he right conferred by a patent under our law is confined to the United States and its territories, and infringement of this right cannot be predicated of acts wholly done in a foreign country." [32] However, where there is some connection between a party's actions and the U.S., questions may arise about potential liability for U.S. patent infringement.[33] Below, we explore some of the U.S. patent laws that may be implicated by the scenario described above. [34]

The discussion is structured according to the two general categories into which patent infringement is customarily divided: direct and indirect.[35] Direct infringement refers to acts that the patent laws define as infringement, whereas indirect infringement refers to inducing or contributing to another's direct infringement.[36]

Direct Infringement

It is an act of direct infringement to make, use, offer to sell, or sell within the U.S., or to import into the U.S., any patented invention during the patent's term without the patent owner's

[31] This article considers liability for infringement of a U.S. patent under the U.S. patent laws. It does not address possible liability for infringement of foreign patents. Also, it does not address other issues that can arise if a U.S. patent owner wishes to pursue an infringement claim against a foreign entity such as jurisdiction, venue, service of process, evidence, and cross-border enforcement of any award.

[32] *Dowagiac Mfg. Co. v. Minn. Moline Plow Co.*, 235 U.S. 641, 650 (1915) (citation omitted).

[33] In an infringement suit, the patent owner must allege, and bears the burden of proving, that the accused infringer's unauthorized acts occurred in the U.S. DONALD S. CHISUM, CHISUM ON PATENTS § 16.05[1] (Matthew Bender 2012).

[34] This article focuses on patent infringement under 35 U.S.C. § 271. Other U.S. laws may also be applicable to the hypothetical fact pattern presented in Section 0. For example, the Tariff Act prohibits importation into the U.S., the sale for importation, or the sale within the U.S. after importation by the owner, importer, or consignee, of articles that infringe U.S. patents or are made by U.S.-patented processes. 19 U.S.C. § 1337(a)(1)(B). Such issues are not addressed here.

[35] CHISUM, *supra* note 33, at § 17.01.

[36] *Id.*

authorization.[37] It is also an act of direct infringement to, without authority, import into the U.S., or offer to sell, sell, or use within the U.S. a product made by a patented process unless (1) it is materially changed by subsequent processes, or (2) it becomes a trivial and nonessential component of another product.[38,39]

In several cases, courts have held that foreign manufacturers were not liable for direct infringement where the products they made and sold abroad were subsequently imported into or sold in the U.S. by others. These cases illustrate the principle mentioned above that infringement cannot be based on actions performed wholly outside of the U.S. For example, in *Pfizer Inc. v. Aceto Corp.*, [40] Pfizer sued Chinese flavor manufacturer Anhui Hefei Flavour Factory ("Anhui") for infringement under § 271(g) based on Anhui's manufacture in China of a flavor enhancer. Anhui sold the flavor enhancer in China to another Chinese corporation, which in turn sold it to a Delaware corporation that imported the product into the U.S.[41] The court found that Anhui was not subject to infringement liability as an "importer" under these circumstances.[42]

Disputes may arise as to whether a sale or offer for sale occurred in the U.S. depending upon the situation's particular facts. The U.S. Patent Act does not expressly define what it means by "sell" or "offer to sell,"[43] other than to say an "offer to sell" is one in which the sale will occur during the patent's term.[44] The U.S. Court of Appeals for the Federal Circuit has noted that a "sale" has both physical and conceptual components – the physical components include the seller's and buyer's physical locations and possibly the shipping route between them, whereas the conceptual component is the point at which the transaction is deemed to have occurred as a matter of commercial law.[45] That Federal Circuit has applied contract law principles when determining the location of a "sale" or "offer for sale" in the context of patent infringement.[46] As illustrated by the representative cases discussed below, this analysis can be complicated, requiring consideration of many case-specific factors.

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[37] 35 U.S.C. § 271(a). Offering for sale and importing were made infringing acts by amendments to § 271(a) that took effect in 1996. Pub. L. No. 103-465, § 533(a)(1)-(4), 108 Stat. 4809 (Dec. 8, 1994).

[38] 35 U.S.C. § 271(g). Section 271(g) was enacted in 1988 to provide holders of U.S. process patents with a remedy where someone carries out the process abroad and imports the resulting product into the U.S. Pub. L. No. 100-418, § 9003, 102 Stat. 1563 (Aug. 23, 1988). The remedies under this section supplement those available from the International Trade Commission under 19 U.S.C. § 1337. *See Bayer AG v. Housey Pharms., Inc.*, 340 F.3d 1367, 1373 (Fed. Cir. 2003).

[39] Section 271(g) also includes an exhaustion provision: "In an action for infringement of a process patent, no remedy may be granted for infringement on account of the noncommercial use or retail sale of product unless there is no adequate remedy under this title for infringement on account of the importation or other use, offer to sell, or sale of that product."

[40] 853 F. Supp. 104, 105 (S.D.N.Y. 1994).

[41] *Id.*

[42] *Id.* at 106; *accord Tec Air, Inc. v. Nippondenso Mfg. U.S., Inc.*, 1997 WL 49300, at *4 (N.D. Ill. Jan. 30, 1997). The court explained that Pfizer could seek redress from the Delaware corporation responsible for the importation. *Pfizer Inc.*, 853 F. Supp. at 106.

[43] *NTP, Inc. v. Res. in Motion, Ltd.*, 418 F.3d 1282, 1319 (Fed. Cir. 2005).

[44] 35 U.S.C. § 271(i).

[45] *See N. Am. Philips Corp. v. Am. Vending Sales, Inc.*, 35 F.3d 1576, 1579 (Fed. Cir. 1994).

[46] *See MEMC Elec. Materials, Inc. v. Mitsubishi Materials Silicon Corp.*, 420 F.3d 1369, 1376-77 (Fed. Cir. 2005); *Rotec Indus., Inc. v. Mitsubishi Corp.*, 215 F.3d 1246, 1254-55 (Fed. Cir. 2000).

For example, in *MEMC Elec. Materials, Inc. v. Mitsubishi Materials Silicon Corp.*,[47] patentee MEMC sued several companies for infringing its patent covering single crystal silicon wafers. Some of the defendants (collectively, "SUMCO") manufactured wafers in Japan and sold them to Samsung Japan Corporation ("Samsung Japan"), which, in turn, sold the wafers to Samsung Austin Semiconductor ("Samsung Austin") located in Austin, Texas.[48] MEMC argued that SUMCO effectively offered to sell and sold its wafers to Samsung Austin in the U.S. because SUMCO e-mailed Samsung Austin test data as a pre-requisite for shipment authorization; SUMCO applied shipping labels to its packages indicating Austin, Texas as the destination; and SUMCO provided Samsung Austin with follow-up technical support from time to time.[49] The Federal Circuit disagreed, concluding that that those activities were insufficient to prove a sale or offer for sale in the U.S.[50] In reaching its decision, the Court stated that MEMC did not prove that any contractual negotiations occurred in the U.S., and also noted that Samsung Japan (not Samsung Austin) was responsible for placing the purchase orders, designating a third-party packaging company to transport the wafers to Samsung Austin, arranging the packaging and shipping, and paying SUMCO after the wafers were delivered.[51]

As another example, in *Litecubes, LLC v. N. Light Products, Inc.*,[52] patentee Litecubes alleged that defendant Light Products (d/b/a GlowProducts.com) infringed its patent by selling certain novelty items (specifically, artificial ice cubes containing an L.E.D. and a battery) to U.S. customers.[53] Canadian corporation GlowProducts argued that although it sold products directly to U.S. customers, the type of shipment method it used was such that the sale effectively occurred in Canada, after which the U.S. customers themselves imported the goods into the U.S.[54] The Federal Circuit rejected GlowProducts' argument, upholding the jury's finding that the sale occurred in the U.S.[55]

It may also be possible for a foreign seller's involvement in U.S. sales-related activity to provide a basis for infringement liability.[56] In *Ensign-Bickford Co. v. ICI Explosives USA Inc.*,[57] ICI Canada

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[47] 420 F.3d at 1371-72.

[48] *Id.* at 1372.

[49] *Id.* at 1374-75.

[50] *Id.* at 1377.

[51] *Id.* at 1376-77. MEMC also alleged that SUMCO was liable for inducing infringement under 35 U.S.C. § 271(b), a concept discussed in Section 0, below. On remand from the Federal Circuit, the district court held that MEMC failed to prove direct infringement and, accordingly, denied MEMC's motion for summary judgment for inducement. *MEMC Elec. Materials, Inc. v. Mitsubishi Materials Silicon Corp.*, 2006 WL 463525, at *17 (N.D. Cal. Feb. 24, 2006), *aff'd in part, vacated in part, dismissed in part* 248 F. App'x 199 (Fed. Cir. 2007), *cert. denied*, 552 U.S. 1243 (2008).

[52] 523 F.3d 1353 (Fed. Cir. 2008).

[53] *Id.* at 1358.

[54] *Id.* at 1359. According to the Court, GlowProducts shipped the accused products "f.o.b." ("free on board") from its Canadian offices to U.S. customers. The Court stated that this meant the goods were delivered to a location, such as a transportation depot, where legal title and the risk of loss passed from the seller to the buyer. *Id.* at 1358.

[55] *Id.* at 1372.

[56] *See* Troy Petersen, *U.S. Infringement Liability for Foreign Sellers of Infringing Products*, 2 DUKE LAW & TECH. REV. 1, 3 (2003), available at http://scholarship.law.duke.edu/cgi/viewcontent.cgi?article=1101&context=dltr.

[57] 817 F. Supp. 1018 (D. Conn. 1993).

moved to dismiss patentee Ensign-Bickford's infringement claim, arguing that it had not sold the accused explosive initiation device in the U.S. ICI Canada's argument was premised on the fact that its sales contract with co-defendant ICI USA provided for delivery "f.o.b." in Canada.[58] The court denied the motion to dismiss, stating that ICI Canada could be found to have sold the accused devices in the U.S. based on its regular participation in U.S. meetings with ICI USA concerning planning and marketing for U.S. sales, and because ICI received payment from ICI USA via a U.S. bank.[59]

Further questions may arise with respect to the territorial scope of the "offer to sell" prohibition.[60] Some district courts have held that contracting in the U.S. to manufacture, sell, and deliver products entirely outside the U.S. is not an act of direct infringement because an infringing "offer to sell" requires contemplation of a U.S. sale.[61] Other courts have focused on whether the offer occurred in the U.S., reasoning that requiring the contemplated sale to be in the U.S. would make the "offer to sell" language superfluous and be detrimental to the patentee's opportunity to offer sales.[62] These courts have held that an offer in the U.S. to engage in a sale abroad can be infringement.[63] The Federal Circuit has acknowledged that it "has yet to define the full territorial scope of the 'offers to sell' offense in § 271(a)."[64] However, it has issued some decisions concerning that topic. For example, in *Transocean Offshore Deepwater Drilling, Inc. v. Maersk Contractors USA, Inc.*,[65] the Court held that an offer made in Norway by one U.S. company to another U.S. company to sell a product within the U.S., for delivery and use in the U.S., constituted an infringing offer to sell.[66] The Court stated that the focus of the "offer to sell" inquiry should be the location of the future sale, not the location of the offer.[67] However, *Transocean* did not directly address whether an offer made in the U.S. for a sale contemplated to occur abroad constitutes an infringing offer for sale.

As can be seen from the foregoing, analyzing which entities may be liable for direct infringement can require consideration of not only U.S. patent laws, but also the interplay of patent law with commercial law. Further, the law is unsettled regarding whether certain actions, particularly

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[58] *Id.* at 1024-25.

[59] *Id.* at 1025-26.

[60] *See Semiconductor Energy Lab. Co. v. Chi Mei Optoelectronics Corp.*, 531 F. Supp. 2d 1084, 1110-11 (N.D. Cal. 2007) (whether an offer for sale made in the U.S. can constitute direct infringement if the product is ultimately sold in a foreign country is an unsettled question).

[61] *See, e.g.*, *Semiconductor Energy Lab. Co.*, 531 F. Supp. 2d at 1111; *Wing Shing Products (BVI), Ltd. v. Simatelex Manufactory Co., Ltd.*, 479 F. Supp. 2d 388, 407 (S.D.N.Y. 2007); *Cybiotronics, Ltd. v. Golden Source Elecs., Ltd.*, 130 F. Supp. 2d 1152, 1167-71 (C.D. Cal. 2001), *appeal dismissed per stipulation*, 19 F. App'x 861 (Fed. Cir. 2001); *Quality Tubing v. Precision Tube Holdings Corp.*, 75 F. Supp. 2d 613, 621-25 (S.D. Tex. 1999).

[62] *See, e.g.*, *Wesley Jessen Corp. v. Bausch & Lomb, Inc.*, 256 F. Supp. 2d 228 (D. Del. 2003); *SEB v. Montgomery Ward & Co.*, 412 F. Supp. 2d 336, 341-42 (S.D.N.Y. 2006).

[63] *See Wesley Jessen Corp.*, 256 F. Supp. 2d at 234-35; *SEB*, 412 F. Supp. 2d at 341-42.

[64] *SEB S.A. v. Montgomery Ward & Co., Inc.*, 594 F.3d 1360, 1375 (Fed. Cir. 2010), *aff'd*, *Global-Tech Appliances, Inc. v. SEB S.A.*, 131 S. Ct. 2060 (2011).

[65] 617 F.3d 1296 (Fed. Cir. 2010). Maersk filed a petition for writ of certiorari to the Supreme Court of the United States on July 6, 2013, but the case was dismissed under Rule 46 (by agreement of the parties) on May 21, 2014. Supreme Court of the United States, Docket for 13-43, *Maersk Drilling USA, Inc. v. Transocean Offshore Deepwater Drilling, Inc.*, http://www.supremecourt.gov/Search.aspx?FileName=/docketfiles/13-43.htm (last visited Aug. 8, 2014).

[66] *Transocean Offshore Deepwater Drilling*, 617 F.3d at 1309-10.

[67] *Id.* at 1309.

various forms of offers to sell having both U.S. and extraterritorial aspects, constitute direct infringement of U.S. patents.

In the hypothetical fact pattern presented above, Companies A and B should not be liable for direct infringement of any U.S. patent based on practicing a patented invention (e.g., making or selling U.S.-patented SiNWs or using a U.S.-patented process to make them) wholly outside of the United States. However, the infringement analysis with respect to Companies A and B is more complicated if they engage in activities within the U.S. such as offering to sell their products (even if the sales are contemplated to occur abroad) or participating in activities directed toward generating U.S. sales. Moreover, as the manufacturer and importer of the final product, Company C could be liable for patent infringement based on its importation, offer to sell, and sale in the U.S. of products containing or made using U.S.-patented SiNW technology.

Indirect Infringement

The Patent Act provides for two types of indirect infringement: contributory infringement and inducement.[68] Contributory infringement is defined as offering to sell, selling, or importing into the U.S. a component of a patented invention with the knowledge that it is especially made or adapted for use in an infringement.[69] The component must be "a material part of the invention" and not "a staple article or commodity of commerce suitable for substantial noninfringing use."[70] The Patent Act's inducement provision states "[w]hoever actively induces infringement of a patent shall be liable as an infringer."[71] Inducement requires showing that the indirect infringer knowingly and specifically intended to encourage direct infringement by another.[72]

Read literally, the contributory infringement statute requires that a party offer to sell or sell "*within the United States*" or import "*into the United States*" a component of the patented invention, thereby apparently excluding making and selling a component of a U.S.-patented invention in another country.[73] This interpretation is consistent with the Federal Circuit's statement in *DSU Medical Corp. v. JMS Co.*[74] that contributory infringement "has a territorial limitation requiring contributory acts to occur in the U.S."[75] In that case, patentee DSU sued Australian company ITL for infringement of a patent directed to a guarded, winged-needle assembly that could reduce the risk of accidental needle-stick injuries.[76] ITL manufactured an open-shell guard that it sold to a

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[68] 35 U.S.C. §§ 271(b) (inducement), 271(c) (contributory infringement).

[69] 35 U.S.C. § 271(c).

[70] *Id.*

[71] 35 U.S.C. § 271(b).

[72] *See Limelight Networks, Inc. v. Akamai Techs., Inc.*, No. 12-786, slip. op. at 5-6 (S. Ct. June 2, 2014); *Global-Tech Appliances, Inc. v. SEB S.A.*, 131 S. Ct. 2060, 2069-70 (2011); *MEMC Electronic Materials*, 420 F.3d at 1378. Willful blindness—e.g., taking steps to avoid knowing that a product is patented where a party believes there is a high probability it is—can support a finding that the party had the knowledge it sought to avoid. *Global-Tech Appliances*, 131 S. Ct. at 2068-72 (2011).

[73] 35 U.S.C. § 271(c); CHISUM, *supra* note 33, at § 16.05[1][e]. The territorial limitation recited in § 271(c) was added in a 1994 amendment. Pub. L. § 533(a)(2), 108 Stat. 4809 (Dec. 8, 1994); *see also* CHISUM, *supra* note 33, at § 16.05[1][e].

[74] 471 F.3d 1293 (Fed. Cir. 2006).

[75] *Id.* at 1304.

[76] *Id.* at 1297.

distributor in Singapore and Malaysia.[77] The open-shell guards did not infringe DSU's claims, but the distributor closed the guards around needle sets, thereby making an infringing device that it imported into and sold in the U.S.[78] The Federal Circuit upheld the jury's finding that ITL did not engage in contributory infringement, stating that there was no evidence that ITL contributed to any infringement in the U.S.[79]

Unlike direct and contributory infringement, it appears that inducement may be premised entirely on extraterritorial activities.[80] For example, in *Crystal Semiconductor Corp. v. Tritech Microelectronics Int'l, Inc.*,[81] the Federal Circuit upheld a jury verdict that a foreign manufacturer induced infringement based on its manufacture and sale of audio chips in Singapore. Crystal Semiconductor owned a U.S. patent directed to a method for using clock technology.[82] Tritech, a company with facilities in Singapore and California, manufactured audio chips in Singapore and sold them worldwide.[83] This included selling chips to co-defendant OPTi, which in turn sold the chips to the U.S. PC market.[84] The Federal Circuit upheld the jury's finding that while Tritech did not, itself, practice the patented method in the U.S., its acts in connection with selling its chips to OPTi constituted inducement.[85]

Some commentators have suggested that the Federal Circuit's subsequent statements in *Shockley v. Arcan, Inc.*[86] appear to contradict *Crystal Semiconductor*.[87] In *Shockley*, the Court stated that a manufacturer could not be liable for infringement under 35 U.S.C. § 271 where it manufactured products that another entity sold in the U.S. because all of that manufacturer's activities took place in China.[88] The Court's *Shockley* opinion does not specifically address inducement,[89] and while the Court's statement was phrased broadly, the defendants in that case had argued on appeal that the patent owner did not squarely raise the issue of inducement in front of the district court.[90] More recently, in *DSU Medical Corp.*, the Federal Circuit quoted a jury instruction stating "induced infringement does not require any activity by the indirect infringer in

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77 *Id.* at 1299.

78 *Id.* ITL also sent additional open-shell guards to the U.S., but those guards were not shown to have been put into an infringing closed-shell configuration in the U.S. *Id.* at 1302, 1304.

79 *Id.* at 1303.

80 *See* Bernard Chao, *Reconciling Foreign and Domestic Infringement*, 80 UMKC L. REV. 607, 616-28 (2012); Nicholas Oros, *Infringement Twice Removed: Inducement of Patent Infringement for Overseas Manufacture of Infringing Products Imported by Another*, 10 COMP. L. REV. & TECH. J. 163, 172-73 (2006).

81 246 F.3d 1336 (Fed. Cir. 2001).

82 *Id.* at 1343.

83 *Id.* at 1344.

84 *Id.*

85 *Id.* at 1351. For commentary stating that the *Crystal Semiconductor* decision did not squarely address the extraterritorial application of § 271(b), *see, e.g.*, *Wing Shing Products (BVI), Ltd. v. Simatelex Manufactory Co., Ltd.*, 479 F. Supp. 2d 388, 409-10 (S.D.N.Y. 2007); Chao, *supra* note 80 at 620.

86 248 F.3d 1349, 1364 (Fed. Cir. 2001).

87 Oros, *supra* note 80, at 171-72.

88 *Shockley*, 248 F.3d at 1364.

89 *See id.*

90 Reply Brief for Defendant-Appellant Arcan, Inc. at 42, 43, *Shockley*, 248 F.3d 1349 (Nos. 99-1580, 99-1603), 2000 WL 34030968, at *42, *43.

this country, as long as the direct infringement occurs here."[91] Some have opined that the Court's quotation of this instruction suggests that the Federal Circuit agrees that inducement under § 271(b) has an extraterritorial reach.[92]

Several district courts have also concluded that inducement may be found based on activities in foreign countries. For example, in *Wing Shing Products (BVI), Ltd. v. Simatelex Manufactory Co.*,[93] Wing Shing sued Hong Kong corporation Simatelex for infringing a design patent for coffeemakers.[94] Simatelex manufactured and delivered coffeemakers to Sunbeam in China, and Sunbeam transported them into the U.S.[95] The Court found that Simatelex was not liable for direct infringement because it did not sell, import, or offer to sell the coffeemakers in the U.S.[96] However, it found Simatelex did induce infringement.[97] The Court stated that it was undisputed that Simatelex knew about Wing Shing's design patent and that Simatelex's coffeemakers infringed it.[98] Further, the Court determined that there was no genuine issue as to whether Simatelex knew the coffeemakers were destined for the U.S. given the terms of its supply agreement with Sunbeam.[99] On those facts, the court granted Wing Shing summary judgment on its inducement claim.[100] As another example, in *Honeywell Int'l, Inc. v. Acer Am. Corp.*,[101] a district court stated that, under current law, inducement can extend to extraterritorial activities, and thus the court there granted patent owner Honeywell's motion for discovery related to a foreign defendant's activities outside the U.S.[102]

The cases discussed above illustrate that manufacturing abroad by itself is not necessarily sufficient to avoid liability for patent infringement. Even when companies perform activities overseas, they may nonetheless be exposed to liability for indirect infringement of U.S. patents. In particular, while conducting activities wholly in another country may insulate a party from liability for contributory infringement, such measures do not appear sufficient to shield that party from liability for inducement under the current state of the law. Applying these considerations to the hypothetical scenario presented above, Companies A and B might be found liable for inducement if Company C commits direct infringement, and if Companies A and B are found to have knowingly and specifically intended to encourage that infringement.

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[91] *DSU Med. Corp. v. JMS Co.*, 471 F.3d 1293, 1305 (Fed. Cir. 2006).

[92] *Wing Shing Prods. (BVI), Ltd. v. Simatelex Manufactory Co.*, 479 F. Supp. 2d 388, 410 (S.D.N.Y. 2007); Chao, *supra* note 80, at 622-23.

[93] 479 F. Supp. 2d 388.

[94] *Id.* at 392.

[95] *Id.* at 394. The supply agreement between Simatelex and Sunbeam was executed in Hong Kong, it stated that it was deemed to have been made in Florida, and it provided that the contracting parties agreed their rights and liabilities would be determined under Delaware law. *Id.*

[96] *Id.* at 401-07.

[97] *Id.* at 411.

[98] *Id.* at 393, 394, 408.

[99] *Id.* at 409.

[100] *Id.* at 411.

[101] 655 F. Supp. 2d 650 (E.D. Tex. 2009).

[102] *Id.* at 661.

Conclusion

Development of SiNW technology has advanced significantly over the past decade, and is now protected by U.S. patents of various scope. Accordingly, when SiNW energy storage products reach the U.S. marketplace, especially those made abroad, they are likely to encounter patent infringement issues of the types that are increasingly common in the global economy, such as determining which companies in a transnational supply chain may be held liable for U.S. patent infringement. These issues are complicated because the extraterritorial reach of U.S. patent laws remains unsettled. The development and commercialization of SiNW energy storage products will be awaited with interest from both technological and legal perspectives.