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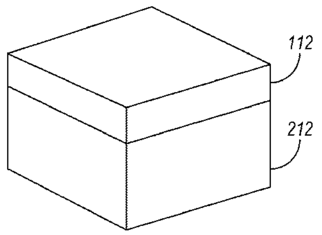
(54) **Title:** FABRICATION OF MICRO/MILLIMETER-SCALE POWER SOURCES AND THE PROCESS FLOW THEREFOR



(57) **Abstract:** A power source for a micro-device is provided. The power source may include a cup, a lid and electrolytes. The cup may be formed of a hard metal material and walls of the cup may define a cavity. An opening in the cup may provide access to the cavity and a surface of the cavity may be deposited with one of an anode or cathode material. The lid may be formed of a hard metal material, the lid may cooperate with the cup to fit into the opening closing off the cavity. The cavity may be coated with the other of the anode or cathode material. Electrolytes may be contained in the cavity.

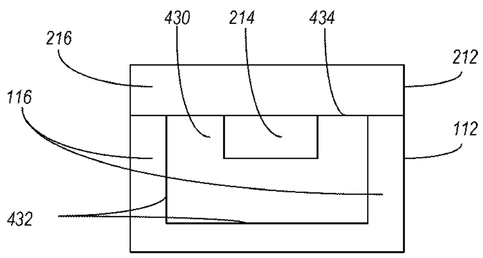


Figure 3

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FABRICATON OF MICRO/MILLIMETER-SCALE POWER SOURCES AND THE PROCESS FLOW THEREFOR

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Number 62/571,817, entitled “Fabrication Of Micro/Millimeter-Scale Power Sources And The Process Flow Therefor,” filed October 13, 2017, the content of which is hereby incorporated by reference in its entirety.

BACKGROUND

[0002] In recent years, electronic industries are breaking previous boundaries of integration and functional density towards miniaturization in autonomous self-powered micro devices. These micro/nano machines are suitable to operate as well as interconnect in different environments to provide, process and store information without connected to any power grids. The autonomous devices should operate in natural, industrial or any in vivo application of human body. As self-directed systems are shrinking day by day, energy storage system required to fit into demand of dimensions and requirement of such small devices.

SUMMARY

[0003] A power source for a micro-device is provided. The power source may include a cup, a lid, electrodes, electrolytes and insulating epoxies. The cup may be formed of a hard metal material and walls of the cup may define a cavity. An opening in the cup may provide access to the cavity and a surface of the cavity may be deposited with one of an anode or cathode material. The lid may be formed of a hard metal material, the lid may cooperate with the cup to fit into the opening closing off the cavity. The cavity may be coated with the other of the anode or cathode material. Electrolytes may be contained in the cavity. The electrochemically and

thermally stable dielectric material may be used to physically distinct and seal the cup and lid.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Figure 1A is a top view of a cup for a power source.

[0005] Figure 1B is a perspective view of the cup for the power source.

[0006] Figure 1C is a side view of the cup for the power source.

[0007] Figure 2A is a top view of a lid for a power source.

[0008] Figure 2B is a perspective view of the lid for the power source.

[0009] Figure 2C is a side view of the lid for the power source.

[0010] Figure 3A is a perspective view of the cup and lid assembled.

[0011] Figure 3B is a side view of the cup and lid assembled.

[0012] Figure 4 is graph illustrating the charge and discharge attributes of the power source at 120° C for 10 µA.

[0013] Figure 5 is graph illustrating the charge and discharge attributes of the power source at 120° C for 10 µA and 20 µA.

[0014] Figure 6A is graph illustrating the charge and discharge attributes of a standard battery.

[0015] Figure 6B is graph illustrating the charge and discharge attributes of the disclosed power source.

[0016] Figure 7A and 7B are graphs illustrating the power source attributes as it controls a sensor through cycles of sleep mode and active mode states.

[0017] Figure 8A and 8B are graphs illustrating the power source attributes during a high temperature charge/discharge test.

DETAILED DESCRIPTION

[0018] Figure 1A is a top view, Figure 1B is a perspective view, and Figure 1C is a side view of a cup for a power source. The cup 112 has a cavity 114 formed by walls 116. Figure 2A is a top view, Figure 2B is a perspective view, and Figure 2C is a side view of a lid for a power source. The lid 212 has a protrusion 114 that extends from a base 116.

[0019] Figure 3A is a perspective view and Figure 3B is a side view of the cup and lid assembled. The lid 212 may cover the cavity 114 in the cup 112. The base 216 may be seated on the walls 116 of the cup 112. Epoxy, adhesive, or another non-conductive fastener may seal the area between the base 216 of the lid 212 and the walls 116 of the cup 112. The protrusion 214 of the lid 212 may extend into the cavity 114 of the cup 112. A electrolytes (and possible a separator) 430 may be inserted into cavity 114 between the lid 212 and the cup 112. An anode or cathode coating may be applied on the surfaces of the protrusion 214 and the bottom surface 434 of the base 216. The bottom and side surfaces 432 of the cup 112 may be coated with the other of the anode or cathode coating. For example if the cup has the anode coating then the lid would have the cathode coating and if the cup has the cathode coating then the lid would have the anode coating. While the power source may be provided in various sizes and shapes. A rectangular or square shape may be particularly beneficial for this device, particularly in SMT implementations. Although, round or polygonal shapes may be utilized.

[0020] In one aspect of the disclosure, the power source for a micro-device is provided. The power source may be a battery, supercapacitor, or other power storage device. The power source may include a cup, a lid, electrolytes, and a dielectric material. The cup may be formed of a hard metal material and walls of the cup may define a cavity. An opening in the cup may provide access to the cavity and a surface of the cavity may be deposited with one of an anode or cathode material. The lid may be formed of a hard metal material, for example the same material as the cup. The lid may cooperate with the cup to fit into the opening closing off the cavity. The lid may be deposited with the other of the anode or cathode material. For example, the cup may be deposited with the anode material and the lid may be deposited with the cathode material or the cup may be deposited with the cathode material and the lid may be deposited with the anode material.

[0021] The electrolytes may be contained in the cavity. The dielectric material may be positioned between the cup and the lid to electrically isolate the cup from the lid. The power source may include an epoxy for sealing the opening in the space between the cup and the lid. The lid may include a protrusion that extends into the cavity. The cathode material may comprise at least one of $LiFePO_4/C$, $LiMn_2O_4$, $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$. The anode material may comprise at least one of Si, Sn, graphite, and Li. The thickness of the walls may be between 50 nanometers and 250 nanometers. The cup may comprise at least one of stainless steel, Cu, and Al. The lid may comprise at least one of stainless steel, Cu, and Al. The dielectric may be deposited onto the cup or the lid. The electrolyte may be filled in the cavity without using separators. The cavity may filled with a separator that is wetted with thermally stable electrolytes. The cavity may be filled with solid or semi-solid electrolytes.

[0022] In another aspect of the disclosure, a method for forming a power source may be provided. The method may include forming the cup, forming the lid, providing electrolytes, providing a dielectric and sealing the cup and lid. The cup may be formed from a hard metal material, wherein walls of the cup defining a cavity and an opening in the cup providing access to the cavity. The lid may be formed from a hard metal material, wherein the lid is shaped to cooperate with the cup to fit into the opening closing off the cavity. The electrolytes may be filled into the cavity. The dielectric may be provided between the cup and the lid. The cup may be sealed to the lid to contain the electrolytes in the cavity. At least one of the lid and the cup may be 3D-printed. The thickness of the walls may be printed to between 50 nanometers and 250 nanometers.

[0023] International Technology Roadmap of Semiconductors (ITRS) forecasts the power consumption in semiconductor industries will be big issue. As circuits shrinks, they requires higher chip operating frequencies, higher interconnects resistance and capacitance as well as gate leakage contribute to increase power requirement in microprocessor units. Semiconductors may be based on micro-electro mechanical system (MEMS) technology to match up the load for making portable devices. Innovations in the miniaturization of autonomous electronic devices and sensors have lead towards the miniaturization of power technologies. For harvesting the energy in these devices, few strategies have been commenced which includes study of energy conversion devices (piezoelectric generators, photovoltaics, thermoelectric, thermostatic and etc) and energy storage devices (e.g. batteries). Though, energy conversion may require an intermittent source of power as well as batteries. Hence, the improvement of a miniaturized energy storage system with large volumetric density may be of essential importance for electronics systems and MEMS applications (like polymer electronics, smart cards, smart sensor, medical implants, transmitters, RFID tags and etc.).

[0024] However present miniaturized commercial batteries have several serious limitations including (i) areal energy (μAh/cm^2), (ii) size (around 80 mm^2) and (iii) thermal stability (up to 85°C). In addition, several microsensors acquiring real time information related to pressure, temperature etc., at extreme environmental conditions demand highly reliable microbatteries sustaining temperatures above 120°C, pressures up to 10,000 psi and delivering power in the order of few mAh/cm^2.

[0025] This disclosure focusses on the miniaturized power source (e.g. battery) packaging by using 3D printer for high temperature (120°C) autonomous microsystem devices. Batteries may contain electrochemically active components which need to be protected from moisture, air and mechanical stresses.

[0026] Packaging battery components within micro/millimeter configurations is challenging for high temperature applications as the smallest packaging components available in market are 7.7D x 3.4H mm. Hence machining methodology and limitations have been explored in depth to design casings that are compatible with the electrochemical reactions.

[0027] Materials and Methods

[0028] Stainless steel casing may be fabricated by using 3D printing techniques. Due to the variation in the nature of electrode/electrolyte materials used, individual components of the battery may be processed using customized methods. In case of electrodes, several fabrication parameters to maintain good adhesion have been optimized with current collector while having high conductivity and essential continuity. For an electrolyte and separator, the major requirements are as follows i) thermal stability with electrode materials, ii) electrochemical stability over the potential range (2.5 -4.5 V) and thermal stability (> 120 °C). These parameters may be optimized further to assemble them in microscale.

[0029] 3D Printing techniques

[0030] In 3D printing, miniaturized battery casings of dimension in micro/millimeter may be fabricated. This battery casing may contain two parts, a bottom case to hold the cathode material and a top case for anode material, an extrusion may be added to the top case which aids in sufficient contact pressure between the anode and cathode material.

[0031] Assembly Battery Components

[0032] Silicon Anode by PECVD

[0033] The conformal coating of silicon on the SS lid may be done using plasma-enhanced chemical vapour deposition (PECVD) technique. The PECVD technique may be tailored by adjusting deposition time, flow rate and power etc. so that deposition of 100 nm of silicon is equivalent to planar thicknesses on SS lid under vacuum

[0034] $LiFePO_4$/C cathode by spray coating method

[0035] Spray ink may be prepared by mixing synthesized powder with super P carbon black and polyvinylidene fluoride (binder) in 80: 10:10 ratios respectively and the mix may be treated with N-Methylpyrrolidin- 2-one (NMP) solvent to form an ink. The ink may be filled in a spray gun and applied uniformly on a bottom cases and then dried. The ratios of NMP and electrode mixtures, spray time, drying temperature etc. may be adjusted to get desired coating of $LiFePO_4/C$ cathode on respective bottom cases.

[0036] RTIL/BN Electrolytes by painting and injection methods

[0037] The most critical sources of problems for the reliable operation of a LIB at high temperatures may be the separator and the electrolyte. With increase in temperature beyond 80 °C, thin polymeric film and organic solvents may be thermally unstable, subsequently the cell may be more prone to failure and there may be safety concerns, exemplified with battery blow-up situations. In this regard, the composite of natural boron nitride (BN) and ionic liquid (RTIL) may be used which can simultaneously act as electrolyte and separator, allowing a battery to work at temperatures as high as 200 °C. However, we have systematically adjusted the composite during their preparation to suit in our mm scale batteries.

[0038] Fabrication using 3D printed casings: Urethane sealant

[0039] Generally, urethane epoxies may be used to protect integrated circuits (IC) from chemical, moisture, salts, biologic organisms, atmospheric contaminates and at same time to providing mechanical strength. Herein, we can use urethanes epoxies (Oxirane, 2,2-[(1-methylethylidene) bis(4,l phenyleneoxymethylene)] bis,homopolymer) to seal our mm batteries. The important characteristics of this epoxy are that "it cures at room temperature" and it gives conformal coating and sealed hermetically. Also, Limestone may be used as another main component in this epoxy to reduce coefficient of temperature expansion. Moreover, it has been found chemically resistant to most of organic solvents and thermally stable up to 200 °C.

[0040] Results and Discussion

[0041] Battery may comprise electrochemically active components which need to be protected from moisture, air and mechanical stresses; therefore, in-order to protect and retain the material characteristics, packaging these materials in a confined enclosure may be of high priority. One of important the parameters to fabricate micro/mm-scale lithium batteries can be epoxy or sealant or adhesive, which would electrically isolate cathode and anode casings and at same time to bind them tightly to regulate liberated electrons for external circuit.

[0042] The performance of Lithium ion battery (4mm)

[0043] Prior to fabricating 3mm battery at 120 °C, rechargeable lithium batteries may be fabricated and tested using 4mm casings (inside the glove box) to verify the feasibility of electrode/electrolyte materials with down-size packaging.

[0044] Figure 4 is graph illustrating the charge and discharge attributes of the power source at 120° C for 10 µA. Line 412 illustrates the charging profile of the power source and line 414 illustrates the discharging profile of the power source. Figure 5 is graph illustrating the charge and discharge attributes of the power source at 120° C for 10 µA and 20 µA. Line 512 illustrates the charging/discharging profile for 10 µA and line 514 illustrates the charging/discharging profile for 20 µA.

[0045] Figure 4 shows electrochemical performance of 4mm battery sealed using urethane epoxy consists of $LiFePO_4/C$ cathode vs. Li/Li+ at C/6 rate. The perfect and well defined charge-discharge voltage plateaus were observed, wherein the appearance of 3.4 V plateaus indicates the Li+ extraction and insertion reaction between $LiFePO_4$ and $FePO_4$ phase. Among the different epoxies used to seal the mm-scale batteries, cells sealed with urethane epoxy exhibits higher discharge capacity (62 µAh) value and minimum polarization (less internal resistance). The discharge capacity of such a urethane epoxy sealed battery exhibits 62 µAh at 120 °C with excellent capacity retention. Herein, the magnitude of capacity is inferior compared to the batteries sealed with other epoxies, which could be corroborated to the chemical and thermal stability of urethane epoxy and added limestone as an additive.

[0046] 3.2 The performance of Lithium ion battery (3mm)

[0047] Figure 6A is graph illustrating the charge and discharge attributes of a standard battery and Figure 6B is graph illustrating the charge and discharge attributes of the disclosed power source. To understand the effect of optimized components for downsize packaging and hence overall electrochemical properties on 3mm batteries, we have compared the present results with standard 2032 (20mm) battery packages tested at 120 C (for controlled experiments). All these experiments are performed using similar electrode and electrolytes materials and obtained results are shown in Figure 6A and 6B. Line 612 illustrates the charge curve and line 614 illustrates the discharge curve for the standard battery. Line 622 illustrates the charge curve and line 612 illustrates the discharge curve for the disclosed power source. Both the type of batteries are fabricated under inert atmosphere (Ar filled glove box) using Li metal anode and BN-RTIL electrolyte and LFP as an active material and quartz membrane as a separator. Galvanostatic measurements conducted at a constant current rate of 0.2 C and 20 μA for 20mm and 3mm batteries respectively. 3mm battery is capable of exhibit 1 mAh. Electrochemical impedance (EIS) tests were performed Bio-Logic electrochemical work station in the frequency range 100MHz to 100 mHz. Typical Nyquest impedance spectra for 20 and 3mm batteries are composed of a semicircle at high frequencies attributed to the charge transfer resistance. The unfinished semicircle with short inclined line in the low frequency region is attributed to Warburg diffusion within the cathode. From Figure 6A and 6B, it is clearly evident that both the batteries exhibit comparable charge- discharge plateaus with slight increase in polarization for 3mm battery (l980 Q). This could be attributed to comparatively smaller size working electrode and in well agreement with the theory based on formula.

[0048] R = p * (L / A)

[0049] Where R is resistance, p is a resistivity of material, L is a length and A is the overall area.

[0050] Figure 7A and 7B are graphs illustrating the power source attributes as it controls a sensor through cycles of sleep mode and active mode states. Line segment 712 illustrates the charging mode and line segment 714 illustrates the mode switching between sleep mode and active mode. Line segment 716 show a blow up of the sleep mode for one cycle and line segment 718 shows a blow up of the active mode for one cycle.

[0051] Battery test as per the sensor requirement includes where Sleep time is 5 mins at 2μA and wake up time 400ms at 15μA.

[0052] With the successful packaging of miniatured batteries and demonstration of its feasibility at 120 C using epoxy, it can be important to showcase further its suitability for sensor requirements to use in micro-sensor and microdevices. In this regard, a galvanostatic/potentiostatic instrument was programmed with the sensor requirements and performed on newly packaged 3mm battery. Figure 7A reveals the input current conditions during charge- discharge process, for example charging at constant current at 10 μA and discharge current at 15μA for 400 mS in a regular 5 minutes interval. However, 2 μA of current continues as background output current. Figure 7B demonstrates output voltage with respect to the time during charge-discharge process. It is noteworthy to know that the performance of 3mm battery is stable (~16h.) at 120 °C under given conditions to be used in sensors.

[0053] Figure 8A and 8B are graphs illustrating the power source attributes during a high temperature charge/discharge test. The test may be referred to as Self Discharge tests at 120°C. Line segment 812 is illustrates a 10 μA charge mode, line segment 814 illustrates a neutral mode with 0 μA flow, and line segment 816 illustrates a 10 μA discharge mode. Line segment 822 is illustrates a 10 μA charge mode, line segment 824 illustrates a neutral mode with 0 μA flow, and line segment 826 illustrates a 10 μA discharge mode.

[0054] Batteries are generally affected by self-discharge. Self-discharge is not a manufacturing process related defect but its battery characteristic, however poor fabrication or packaging materials and improper handling can trigger the problem. Self-discharge is irreversible and it is a permanent process, it is important to understand the self-discharge of any battery before qualifying their commercial viability. Figure 8A illustrates self-discharge experiment performed on 3mm battery at 120 C, herein charging and discharging at constant current of 10μA with rest time of 12h. at 120 C. Interestingly, desirable discharge plateau has been observed even after 12h. self- discharge at 120 C with as low as 4% capacity fade.

[0055] The present disclosure provides a new process flow of fabricating miniaturized rechargeable lithium ion batteries (LIB) that can sustain wide temperatures (-100 to 450 °C), withstand high pressure (up to 50,000 psi), tolerant towards harsh chemicals and deliver exceptional areal capacity (energy density). Advances in the miniaturization of several electronic devices and sensors have occurred at a rate much faster than the miniaturization of powering technologies such as batteries and supercapacitors. The lack of efficient and reliable high energy and power devices with the stability in extreme conditions limits the deployment of autonomous micro-devices and micro-sensors. The currently available miniature batteries and super capacitors have several serious limitations including re-chargeability, (ii) reversibility, (iii) areal energy (Wh/cm^2), (iv) power capability (W/cm^2), (v) thermal stability (up to 85 °C) and (vi) pressure. However, several electronic devices such as microsensors acquiring real time information related to pressure, temperature etc., at extreme environment conditions demand highly reliable micro/millimeter-scale batteries and super capacitors sustaining temperatures beyond 85 °C, pressures up to 50,000 psi and delivering high energy and power.

[0056] In conventional miniature battery and super capacitor packaging methods with various dimensions can pose issues in terms of (i) thermal (ii) pressure, (iii) chemical stabilities and (iv) complicated fabrication methods which involves different packaging components including polymers. For instance, coin cell fabrication can require polymer based 0-ring to separate cathode and anodes parts and at the same time to hold battery components together. Moreover, electrochemically active components occupy only 5-10% of overall volume of coin cell. Also as we scale down these designs (mm-scale to micron), the significant domination of hardware components in the packaging can affect overall areal energy density. Hence, sizing down to micro/millimeter and packaging them in these sizes can be limiting factors for developing high energy miniaturized batteries and supercapacitors. There may be a critical need to advance novel processing and packaging techniques to develop micro/millimeter batteries that can overcome the current limitations of size, energy, power and robustness.

[0057] A process has been developed to fabricate rechargeable lithium batteries and super capacitors that allows design flexibility, easy to manufacture by eliminating several conventional hardware components and works at extreme conditions without losing its aerial capacity and power capability. Using different additive manufacturing process (like 3D printing, CNC, micro electro discharge machining, direct metal laser sintering etc.), a process flow has been developed for batch mode fabrication of battery packaging components that can be scaled down to desired dimensions including micro-meters without much compromising on active area for electrochemically active components such as anode/cathode/electrolytes. The disclosed design allows direct deposition of active battery materials with effective utilization of available space to get overall high areal capacity. Secondly this design allows to use wide range of battery materials which is helpful for different working conditions.

[0058] Fabrication steps for high temperature rechargeable LIB and super capacitors

[0059] In design of casings, the package of the battery includes a cup and lid made from hard metals (such as stainless steel, Cu, Al). These miniaturized energy devices casings may have two parts, a bottom case to hold the cathode materials and a top case for anode materials, an extrusion may be added to the top case which aids in sufficient contact pressure between the anode and cathode materials as shown in Figure 1 . The size and shape of these casings can be tuned as per requirement and applicable to both battery and super capacitors.

[0060] Fabrication steps for high temperature rechargeable LIB and super capacitors

[0061] In design of casings, the package of the battery consists of cup and lid made from hard metals (such as stainless steel, Cu, Al). These miniaturized energy devices casings have two parts, bottom case to hold the cathode materials and top case for anode materials, an extrusion has been added to the top case which aids in sufficient contact pressure between the anode and cathode materials as shown in Figure 1 . The size and shape of these casings can be tuned as per requirement and applicable to both battery and super capacitors.

[0062] Cathode materials of battery have their electrochemical properties which are sensitive to the composition (phase and size of particles). Coating them into a micro/millimeter-scale form factor can be a major challenge as conventional physical or chemical deposition techniques have limitation for processing such materials. The disclosed design allows depositing wide range of thermally stable cathode materials directly on these casings. Slurry made from active cathode materials such as $LiFePO_4/C$, $LiMn_2O_4$, $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$ etc., along with conductive carbon and binders can be coated conformally on these casings using standard techniques like spin/spray/drop/coatings.

[0063] The key components of a Li-ion battery may include the thermally stable anode, its capacity with respect to cathode at extreme conditions governs the energy density of the battery. The disclosed design allows to direct deposit different anode materials such as Si, Sn, graphite, Li and their composites. Casings may be compatible for wide range of deposition techniques such as chemical vapor deposition (for Si and lithium), sputtering/evaporations (for Sn), electrodeposition (for Sn and Li), pre-formulated slurry coating (graphite or other nanocarbons).

[0064] Electrolyte/Separators

[0065] Since anode and cathode materials may be directly deposited on casings, the battery configuration would work (a) by filling electrolyte in the available space between cup and lid (without using traditional separators) or (b) with any traditional separator by wetting it with appropriate thermally stable electrolytes or (c) using semi-solid/solid electrolytes by filling the space between cup and lid.

[0066] Dielectric insulation

[0067] High dielectric material may be used for isolating cup from lid to stop the short circuit between anode and cathode. This high dielectric material may be insulated on the top of the lid.

[0068] Packaging with high thermal epoxies

[0069] One of critical parameters to fabricate micro/millimeter scale lithium batteries can be epoxy or sealant or adhesive, which is electrically insulated in nature, chemically inactive with battery components and at the same time to bind them tightly to regulate liberated electrons for external circuit. It may be very important to know that the stability of selected epoxies with electrodes/electrolytes because it involves electrical energy (voltage) along with thermal energy to make them harder towards their stability. These epoxies should have capacities to withstand high pressure and temperature without rupturing or cracking. Secondly it should have ability to protect battery components from harsh chemicals and provide high mechanical strength.

[0070] Herein, urethane epoxies may be used to seal micro/millimeter batteries. The important characteristics of this epoxy may be that "it cures at room temperature" and it gives conformal coating and sealed hermetically. By adding urethane with limestone, this epoxy allows to reduce coefficient of temperature expansion. Moreover, it has been found chemically resistant to most of organic solvents, thermally stable up to 450 °C, and provides a mechanical strength.

[0071] As a person skilled in the art will readily appreciate, the above description is meant as an illustration of implementation of the principles this disclosure. This description is not intended to limit the scope or application of this system in that the system is susceptible to modification, variation and change, without departing from the spirit of this disclosure, as defined in the following claims.

CLAIMS

1. A battery for a micro-device comprising;

a cup being formed of a hard metal material and walls of the cup defining a cavity, an opening in the cup providing access to the cavity, a surface of the cavity being deposited with one of an anode or cathode material.

a lid formed of a hard metal material, the lid cooperating with the cup to fit into the opening closing off the cavity the other of the anode or cathode material;

electrolytes being contained in the cavity;

a dielectric material being positioned between the cup and the lid to electrically isolate the cup from the lid.

2. The battery according to claim 1, further comprising an epoxy for sealing the opening in the space between the cup and the lid.

3. The battery according to claim 1, wherein the lid includes a protrusion that extends into the cavity.

4. The battery according to claim 1, wherein the cathode material comprises at least one of $LiFePO_4/C$, $LiMn_2O_4$, $LiNi_{1/3}Mn_{1/3}Co_{1/3}O_2$.

5. The battery according to claim 1, wherein the anode material comprises at least one of Si, Si-carbon, Si-Li alloy, Sn, graphite, and Li.

6. The battery according to claim 1, wherein the thickness of the walls is between 50 nanometers and 250 nanometers.

7. The battery according to claim 1, wherein the cup comprises at least one of stainless steel, Cu, and Al.

8. The battery according to claim 1, wherein the lid comprises at least one of stainless steel, Cu, and Al.

9. The battery according to claim 1, wherein the cathode material is deposited onto the cup and the anode material is deposited onto the lid.

10. The battery according to claim 1, wherein the cathode material is deposited onto the lid and the anode material is deposited onto the cup.

11. The battery according to claim 1, wherein the dielectric is deposited onto the lid.

12. The battery according to claim 1, wherein the electrolyte is filled in the cavity without using separators.

13. The battery according to claim 1, wherein the cavity is filled with a separator that is wetted with thermally stable electrolytes.

14. The battery according to claim 1, where the cavity is filled with solid or semi-solid electrolytes.

15. A power source for a device comprising:

a cup being formed of a hard metal material and walls of the cup defining a cavity, an opening in the cup providing access to the cavity;

a lid formed of a hard metal material, the lid cooperating with the cup to fit into the opening closing off the cavity;

electrolytes being contained in the cavity;

a dielectric material being positioned between the cup and the lid.

16. A method for forming a battery, the method comprising the steps of:

forming cup from a hard metal material, wherein walls of the cup defining a cavity and an opening in the cup providing access to the cavity;

forming a lid from a hard metal material, wherein the lid is shaped to cooperate with the cup to fit into the opening closing off the cavity;

providing a electrolytes into the cavity;

providing a dielectric between the cup and the lid;

sealing the cup to the lid to contain the electrolytes in the cavity.

17. The method of claim 16, wherein the at least one of the lid and the cup are 3D-printed.

18. The method of claim 16, wherein the thickness of the walls is between 50 nanometers and 250 nanometers.

19. The method of claim 16, further comprising depositing one of a cathode material or an anode material onto the cup.

20. The method of claim 16, further comprising depositing one of a cathode material or an anode material onto the lid.

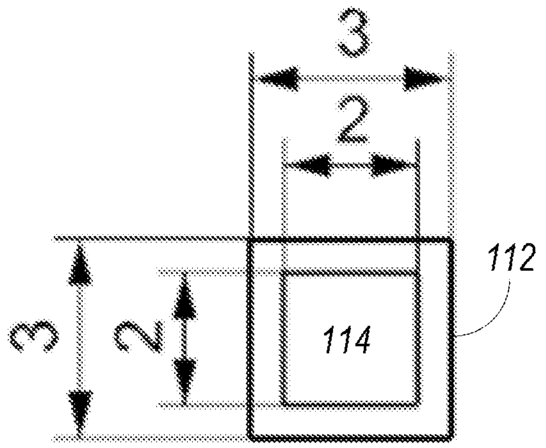


Figure 1A

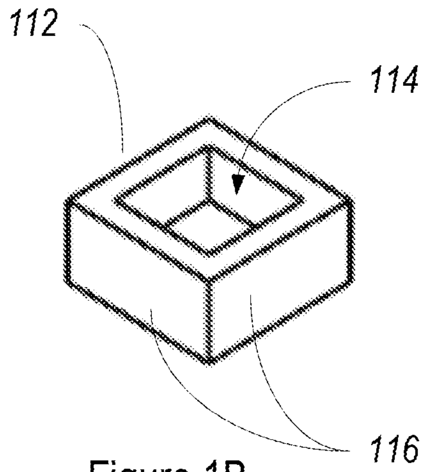


Figure 1B

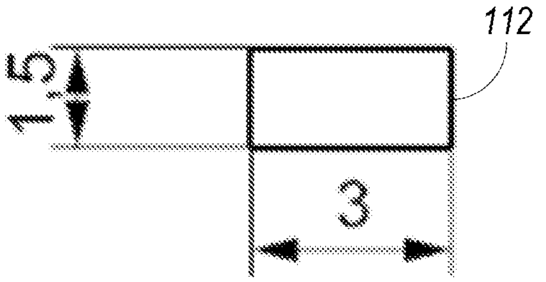


Figure 1C

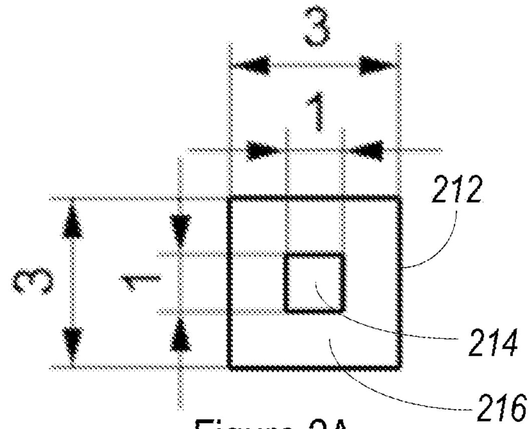


Figure 2A

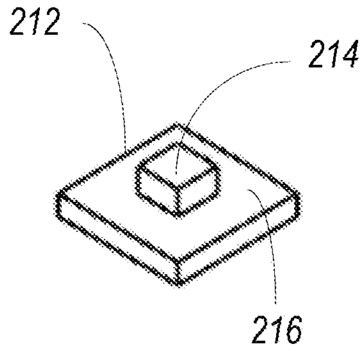


Figure 2B

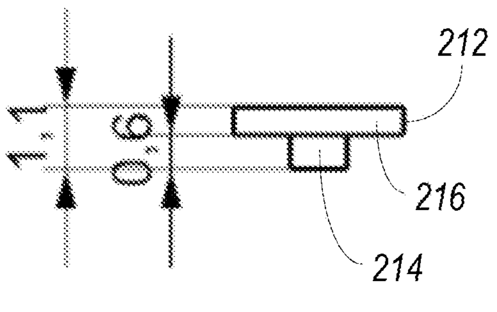


Figure 2C

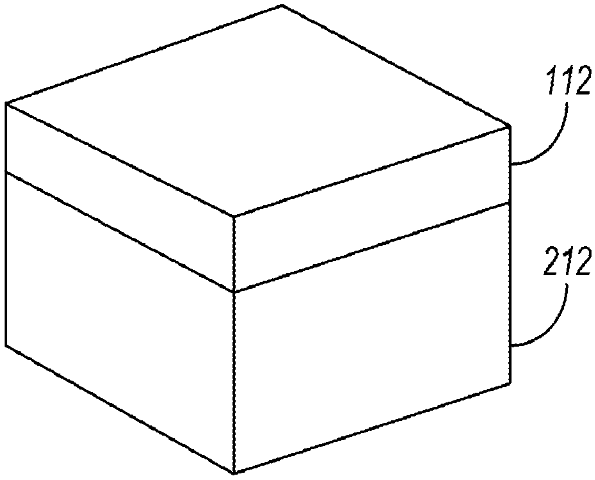


Figure 3A

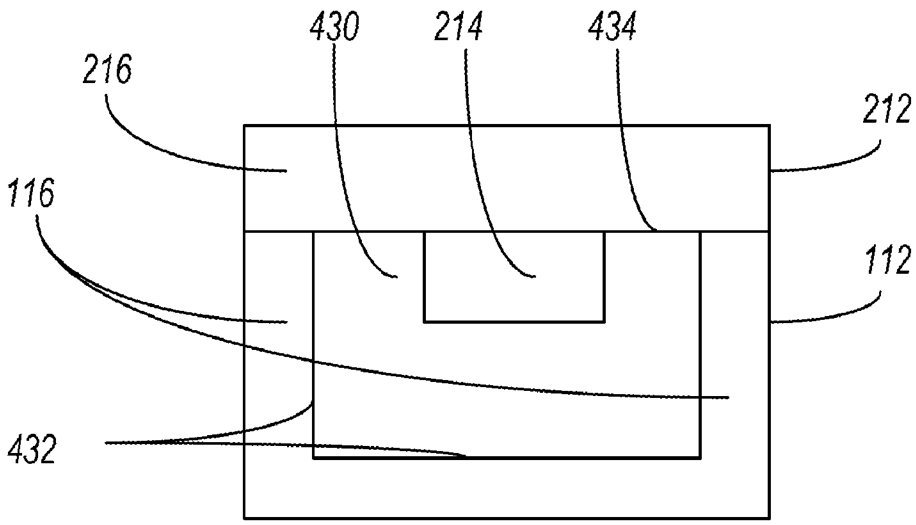


Figure 3B

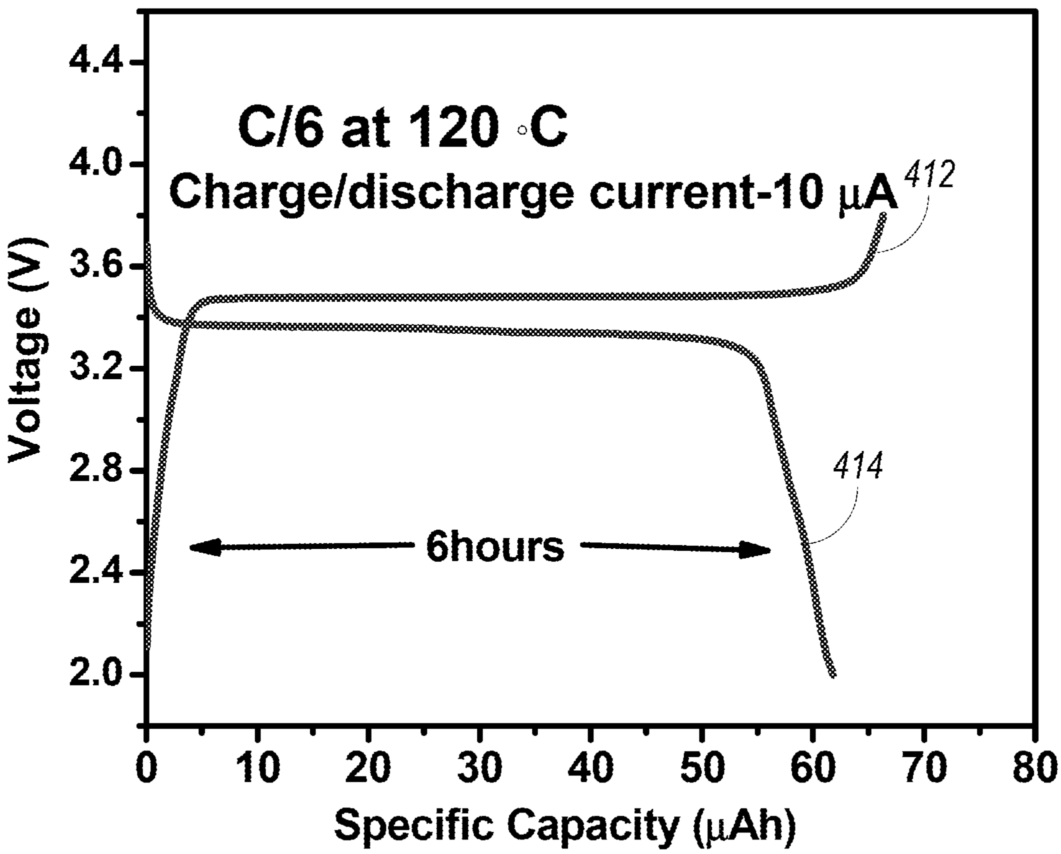

C/6 at 120 ◦C
Charge/discharge current-10 μA
412
414
6hours
Voltage (V)
4.4
4.0
3.6
3.2
2.8
2.4
2.0
0
10
20
30
40
50
60
70
80
Specific Capacity (μAh)

Figure 4

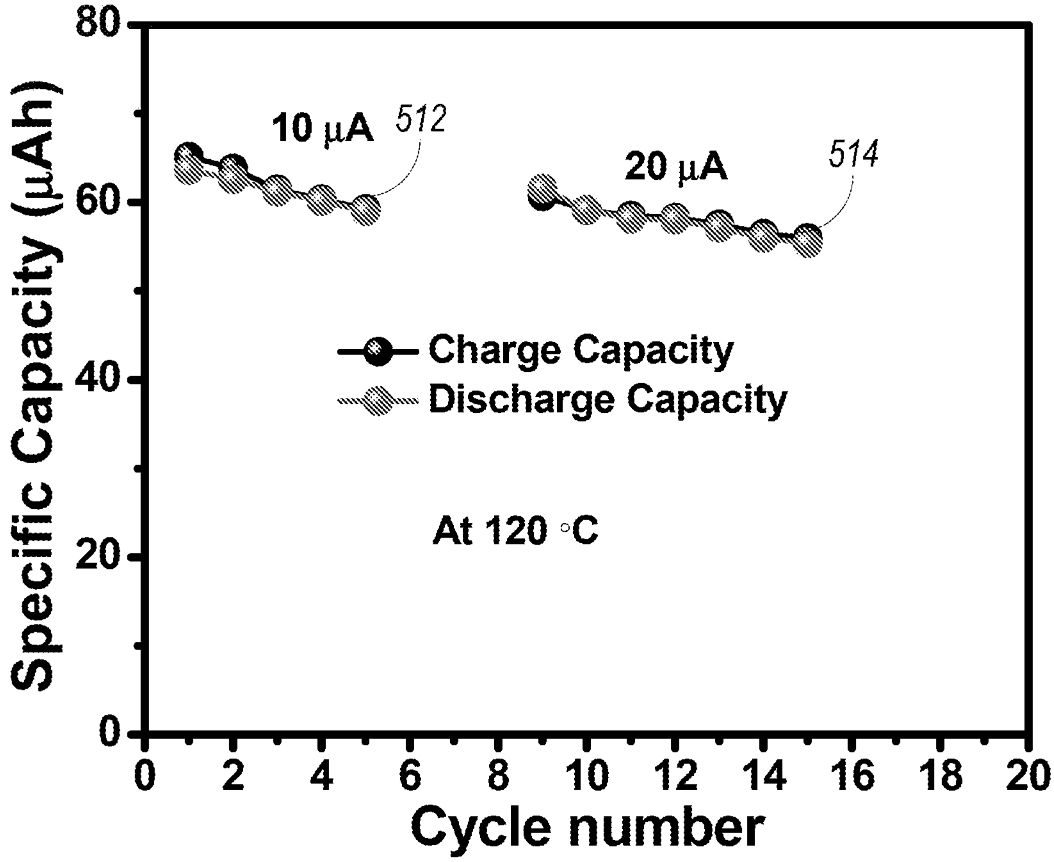

80
60
40
20
0
0 2 4 6 8 10 12 14 16 18 20
Specific Capacity (μAh)
Cycle number
10 μA
512
20 μA
514
Charge Capacity
Discharge Capacity
At 120 °C

Figure 5

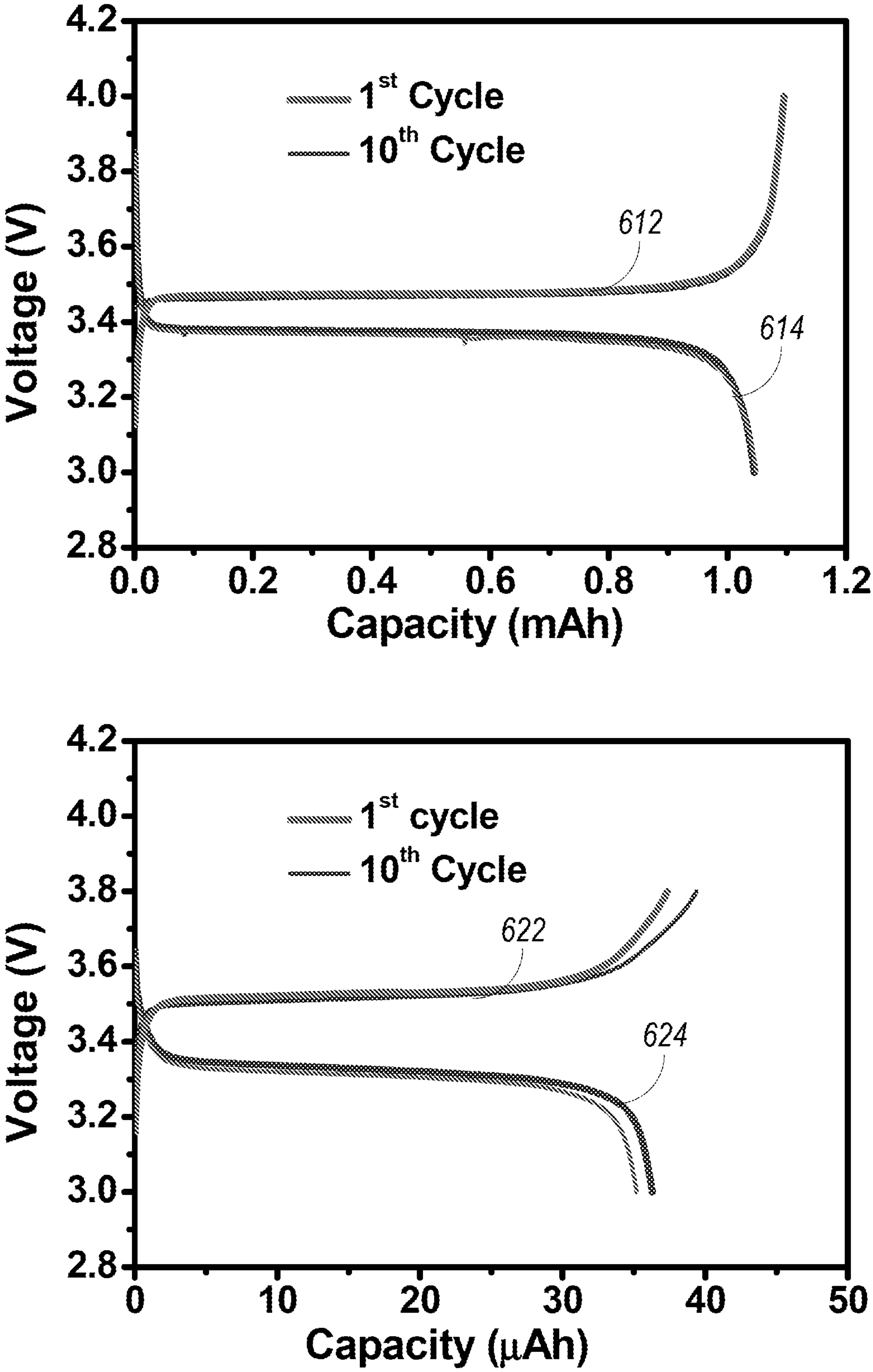
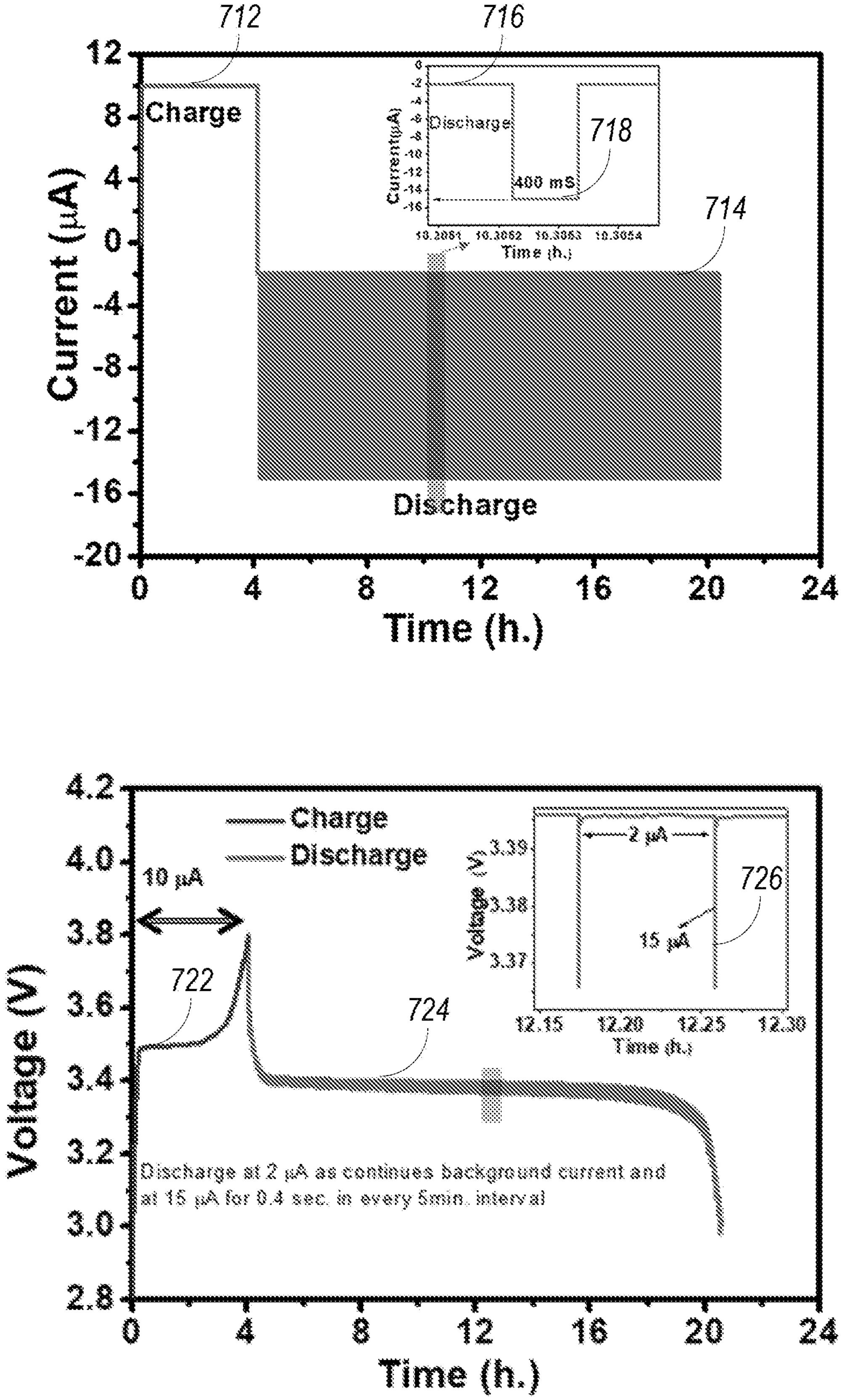

4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
Voltage (V)
1st Cycle
10th Cycle
612
614
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Capacity (mAh)
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
Voltage (V)
1st cycle
10th Cycle
622
624
0
10
20
30
40
50
Capacity (μAh)

Figure 6B



712
716
Charge
Discharge
718
400 mS
714
Current(μA)
Time (h.)
Discharge
Current (μA)
Time (h.)
Charge
Discharge
10 μA
722
724
2 μA
726
15 μA
Voltage (V)
Time (h.)
Discharge at 2 μA as continues background current and at 15 μA for 0.4 sec. in every 5min. interval
Voltage (V)
Time (h.)

Figure 7B

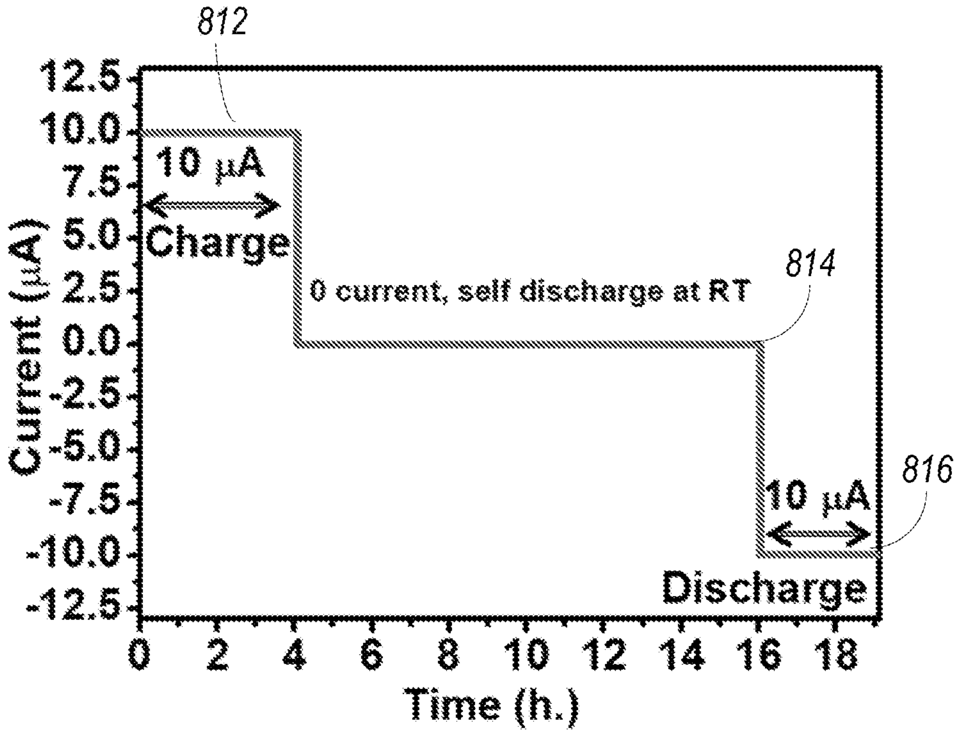


Figure 8A

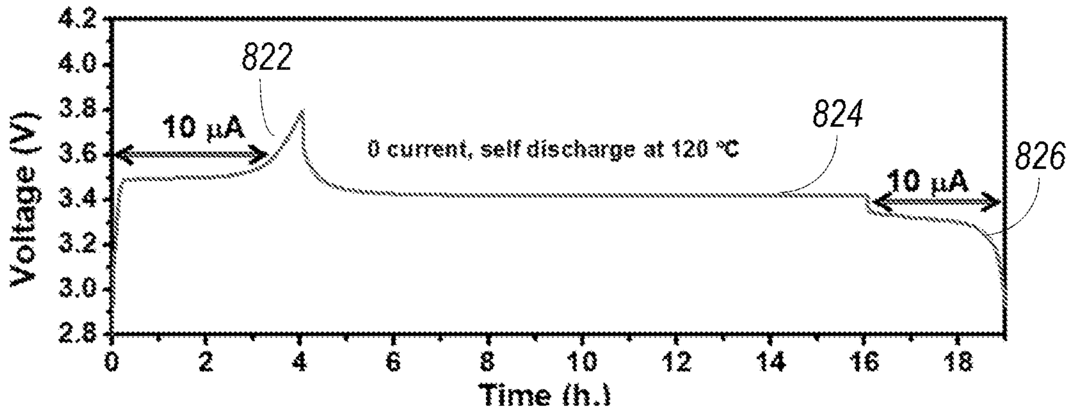


Figure 8B

INTERNATIONAL SEARCH REPORT

International application No. PCT/US 18/55088

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H01M 10/00, H01M 2/02, H01M 2/08 (2018.01)

CPC - H01M 2/0202, H01M 2/08, H01M 10/0436, H01M 10/0585, H01M 2/0212, H01M 2/026, H01M 2/0277, B33Y 80/00, B82 30/00, Y10S 977/948, H01M 2300/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History Document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History Document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ---- Y	US 5,279,905 A (MANSFIELD, JR. et al.) 18 January 1994 (18.01.1994) the entire document, and more specifically: col 1, ln 13-40; col 4, ln 38-68; col 5, ln 1-26; figure	15-16 and 19-20 ---- 1-14 and 17-18
Y	WO 2017/055984 A1 (RAMOT AT TEL AVIV UNIVERSITY LTD.) 6 April 2017 (06.04.2017) pg 1, ln 6-9; pg 2, ln 5-6; pg 3, ln 4-5 and ln 13-18 ; pg 4, ln 5-7 and ln 12-24; pg 8, ln 23-27; pg 9, ln 22-27	1-14 and 17
Y	US 6,586,133 B1 (TEETERS et al.) 1 July 2003 (01.07.2003) col 1, ln 32-50; col 2, ln 37-41	6 and 18
Y	US 2016/0093895 A1 (DU et al.) 31 March 2016 (31.03.2016) para [0002], [0004]-[0005], [0035]	13
A	US 3,841,913 A (ANDERSON) 15 October 1974 (15.10.1974); the entire document	1-20
A	EP 2,690,687 A1 (VARTA MICROBATTERY GMBH) 29 January 2014 (29.01.2014); the entire document	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
12 December 2018	08 JAN 2019

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774