CLAM SHELL FORM BIOMEDICAL DEVICE BATTERIES

CROSS-REFRENCE TO RELATED APPLICATIONS

This patent application claims the benefit of United States Provisional Patent Application No. 62/393,281 filed September 12, 2016.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to electronic ophthalmic devices, such as wearable lenses, including contact lenses, implantable lenses, including intraocular lenses (IOL's) and any other type of device comprising optical components, and more particularly, to designs and methods to improve the biocompatibility aspects of batteries, particularly by forming clamshell forms made of solid structures. In some other examples, a field of use for the biocompatible batteries may include any biocompatible device or product that requires energy.

2. Description of the Related Art

As electronic devices continue to be miniaturized, it is becoming increasingly more likely to create wearable or embeddable microelectronic devices for a variety of uses. Such uses may include monitoring aspects of body chemistry, administering controlled dosages of medications or therapeutic agents via various mechanisms, including automatically, in response to measurements, or in response to external control signals, and augmenting the performance of organs or tissues. Examples of such devices include glucose infusion pumps, pacemakers, defibrillators, ventricular assist devices and neurostimulators. A new, particularly useful field of application is in ophthalmic wearable lenses and contact lenses. For example, a wearable lens may incorporate a lens assembly having an electronically adjustable focus to augment or enhance performance of the eye. In another example, either with or without adjustable focus, a wearable contact lens may incorporate electronic sensors to detect concentrations of particular chemicals in the precorneal (tear) film. The use of embedded electronics in a lens assembly introduces a potential requirement for communication with the electronics, for a method of powering and/or

re-energizing the electronics including power control or power management circuitry, for interconnecting the electronics, for internal and external sensing and/or monitoring, and for control of the electronics and the overall function of the lens.

The human eye has the ability to discern millions of colors, adjust easily to shifting light conditions, and transmit signals or information to the brain at a rate exceeding that of a high-speed internet connection. Lenses, such as contact lenses and intraocular lenses, currently are utilized to correct vision defects such as myopia (nearsightedness), hyperopia (farsightedness), presbyopia and astigmatism. However, properly designed lenses incorporating additional components may be utilized to enhance vision as well as to correct vision defects.

Contact lenses may be utilized to correct myopia, hyperopia, astigmatism as well as other visual acuity defects. Contact lenses may also be utilized to enhance the natural appearance of the wearer's eyes. Contact lenses or "contacts" are simply lenses placed on the anterior surface of the eye. Contact lenses are considered medical devices and may be worn to correct vision and/or for cosmetic or other therapeutic reasons. Contact lenses have been utilized commercially to improve vision since the 1950s. Early contact lenses were made or fabricated from hard materials, were relatively expensive and fragile. In addition, these early contact lenses were fabricated from materials that did not allow sufficient oxygen transmission through the contact lens to the conjunctiva and cornea which potentially could cause a number of adverse clinical effects. Although these contact lenses are still utilized, they are not suitable for all patients due to their poor initial comfort. Later developments in the field gave rise to soft contact lenses, based upon hydrogels, which are extremely popular and widely utilized today. Specifically, silicone hydrogel contact lenses that are available today combine the benefit of silicone, which has extremely high oxygen permeability, with the proven comfort and clinical performance of hydrogels. Essentially, these silicone hydrogel based contact lenses have higher oxygen permeability and are generally more comfortable to wear than the contact lenses made of the earlier hard materials.

Conventional contact lenses are polymeric structures with specific shapes to correct various vision problems as briefly set forth above. To achieve enhanced functionality, various circuits and components have to be integrated into these polymeric structures. For example, control circuits, microprocessors, communication devices, power supplies, sensors, actuators, light-emitting diodes, and miniature antennas may be integrated into contact lenses via custom-

built optoelectronic components to not only correct vision, but to enhance vision as well as provide additional functionality as is explained herein. Electronic and/or powered contract lenses may be designed to provide enhanced vision via zoom-in and zoom-out capabilities, or just simply modifying the refractive capabilities of the lenses. Electronic and/or powered contact lenses may be designed to enhance color and resolution, to display textural information, to translate speech into captions in real time, to offer visual cues from a navigation system, and to provide image processing and internet access. The lenses may be designed to allow the wearer to see in low-light conditions. The properly designed electronics and/or arrangement of electronics on lenses may allow for projecting an image onto the retina, for example, without a variable-focus optic lens, provide novelty image displays and even provide wakeup alerts. Alternately, or in addition to any of these functions or similar functions, the contact lenses may incorporate components for the noninvasive monitoring of the wearer's biomarkers and health indicators. For example, sensors built into the lenses may allow a diabetic patient to keep tabs on blood sugar levels by analyzing components of the tear film without the need for drawing blood. In addition, an appropriately configured lens may incorporate sensors for monitoring cholesterol, sodium, and potassium levels, as well as other biological markers. This, coupled with a wireless data transmitter, could allow a physician to have almost immediate access to a patient's blood chemistry without the need for the patient to waste time getting to a laboratory and having blood drawn. In addition, sensors built into the lenses may be utilized to detect light incident on the eye to compensate for ambient light conditions or for use in determining blink patterns.

The proper combination of devices could yield potentially unlimited functionality; however, there are a number of difficulties associated with the incorporation of extra components on a piece of optical-grade polymer. In general, it is difficult to manufacture such components directly on the lens for a number of reasons, as well as mounting and interconnecting planar devices on a non-planar surface. It is also difficult to manufacture to scale. The components to be placed on or in the lens need to be miniaturized and integrated onto just 1.5 square centimeters of a transparent polymer while protecting the components from the liquid environment on the eye. It is also difficult to make a contact lens comfortable and safe for the wearer with the added thickness of additional components.

Given the area and volume constraints of an ophthalmic device such as a contact lens, and the environment in which it is to be utilized, the physical realization of the device must

overcome a number of problems, including mounting and interconnecting a number of electronic components on a non-planar surface, the bulk of which comprises optic plastic. Accordingly, there exists a need for providing a mechanically and electrically robust electronic contact lens.

As these are powered lenses, energy, or more particularly current consumption to run the electronics, is a concern given battery technology on the scale for an ophthalmic lens. In addition to normal current consumption, powered devices or systems of this nature generally require standby current reserves, precise voltage control and switching capabilities to ensure operation over a potentially wide range of operating parameters, and burst consumption, for example, up to eighteen (18) hours on a single charge, after potentially remaining idle for years. Accordingly, there exists a need for a for a powered ophthalmic lens that is optimized for low cost, long-term reliable service, safety, size, and speed while providing the requisite power to drive various components, including a variable-focus optic.

One important component of such lenses are the energization elements used to power a lens, which in many cases may be a battery. When using a battery in biomedical type applications, it may be important that the battery structure and design accommodate aspects of biocompatibility. Therefore, a need exists for novel examples of forming biocompatible batteries for use in biocompatible energization elements that may have significantly improved containment aspects.

SUMMARY OF THE INVENTION

Accordingly, improved containment-related strategies and designs for use in biocompatible energization elements are disclosed herein. A Clamshell form may generally relate to shapes that have depressions with a ridge around the edge which may be brought together to seal along the edge. The ridge may be fabricated as a thin feature along the side of the cavity or depression which may be filled with other material. The thin feature beside the battery material may be sealed in various manners to make a hermetic seal. Hermetic seals may be important as has been mentioned for biocompatibility of the battery. Hermetic seals may also be important to the function of the battery, since important battery constituents may be prevented from leaking out of the battery. In some cases, importance of the seal may relate to prevention of material from leaking into the battery.

The clamshell format may allow for the processing of various materials to fill pieces of clamshell with battery chemicals and components and then to afford a reliable and convenient means of processing a seal region to produce a good seal. Various materials may be used to form clamshell parts, including metals, ceramics, glasses, semiconductors and the like. Each of these material types may have different advantages or features associated with them as is discussed here. For example, a semiconductor material may be doped with a dopant to change the conductivity of the material and create contact regions.

In some examples, the seals of the various clamshell examples may be made even more hermetic by coating them and the clamshell material at least in portions of the material surface with a metallic seal. In some examples, an electroless process, either alone or with a subsequent electroplating process, may be used to create a metallic deposit on surfaces that may not be amenable to deposition by electrochemical means directly. A seal improvement and battery integrity may particularly be improved for plastic form battery components.

One general aspect includes a biomedical device including: an electroactive component, and a battery. The battery also includes an anode current collector or else the anode serves as its own collector. The battery also includes a cathode current collector. The battery also includes an anode. The battery also includes a cathode. The battery also includes a clamshell encapsulating the anode and cathode with a first penetration for the anode current collector, a second penetration for the cathode current collector, and a hermetic seal between a top clamshell half and a bottom clamshell half. The battery also includes a metallic coating surrounding at least a portion of an exterior surface of the top clamshell half and the bottom clamshell half, where the metallic coating is deposited with at least a first layer of electroless plating. The battery also includes a first biocompatible encapsulating layer, where the first biocompatible encapsulating layer encapsulates at least the electroactive component and the battery.

One general aspect includes a clamshell battery including: an anode current collector, where the anode current collector is a first metallic film or foil within a top clamshell half; an anode, where an anode chemical(s) is contained within or deposited upon the top clamshell half; a cathode current collector, where the cathode current collector is a second metallic film or foil within a bottom clamshell half; a cathode, where a cathode chemical(s) is contained within or deposited upon the bottom clamshell half; and where the top clamshell half and the bottom clamshell half are formed from one or more of a ceramic, metal, glass or plastic material, and

where a seal is formed between ledge features of the top clamshell half and the bottom clamshell half.

One general aspect includes a clamshell battery including: an anode current collector, where the anode current collector is a first metallic clamshell piece; an anode, where an anode chemical(s) is contained within the first metallic clamshell piece; a cathode current collector, where the cathode current collector is a second metallic clamshell piece; a cathode, where a cathode chemical(s) is contained within the second metallic clamshell piece; an insulating intermediate clamshell piece with a first sealing surface that sealably interfaces with the first metallic clamshell piece and a second sealing surface that sealably interfaces with the second metallic clamshell piece; and a sealing material located in a gap between the first sealing surface and first metallic clamshell.

One general aspect includes a clamshell battery including: an anode current collector, where the anode current collector is a first plastic clamshell piece, where the plastic may be a conductive organic semiconductor; an anode, where an anode chemical(s)is contained within the first plastic clamshell piece; a cathode current collector, where the cathode current collector is a second plastic clamshell piece; a cathode, where a cathode chemical(s)is contained within the second plastic clamshell piece; and a seal including a melted region including ledge regions of the first plastic clamshell piece and the second plastic clamshell piece. In some examples, the second clamshell piece may be a flat piece in a clamshell battery.

One general aspect includes a clamshell battery including: an anode current collector, where the anode current collector is a first semiconductor clamshell piece; an anode, where an anode chemical(s)is contained within the first semiconductor clamshell piece; a cathode current collector, where the cathode current collector is a second semiconductor clamshell piece; a cathode, where a cathode chemical(s)is contained within the second semiconductor clamshell piece; a seal between ledge regions of the first semi-conductor clamshell piece and the second semiconductor clamshell piece; and where isolated regions of the first semiconductor clamshell piece and the second semiconductor clamshell piece are doped to allow current flow in doped regions from within the battery to an external connection.

One general aspect includes a method of manufacturing a clamshell battery including receiving a first clamshell half and a second clamshell half made of insulating material, where clamshell halves have a body region for support of a battery component surrounded by a ledge.

In general, examples the ledge of material may protrude from the edge of material of the body region to form a lip. In some other examples, the ledge may be a flat region at the end of the material forming the body of the clam shell. In still further examples, one of the halves of pieces that form a clamshell battery may have a body and a ledge, while the second piece may be a flat piece where a ledge may be a theoretical feature around or near the periphery of the flat piece. The ledge surfaces of the two pieces, or the ledge of a first piece and a portion of a second flat piece form surfaces that may be sealed around the entire body of the clamshell device.

The method also includes defining a conductive trace in the first clamshell half. The method also includes depositing an anode in the first clamshell half. The method also includes depositing a cathode in the second clamshell half. The method also includes placing a separator film on one or both of the first clamshell half and the second clamshell half. The method also includes depositing an electrolyte into one or both of the first clamshell half and the second clamshell half. The method also includes joining the clamshell halves. The method also includes forming a seal between the ledges of the clamshell halves.

One general aspect includes a method of manufacturing a clamshell battery including receiving a first clamshell half and a second clamshell half made of plastic material, where clamshell halves have a body region for support of a battery component surrounded by a ledge, where the ledge may be used for sealing. The method also includes defining a conductive trace in the first clamshell half. The method also includes depositing an anode in the first clamshell half. The method also includes depositing a cathode in the second clamshell half. The method also includes placing a separator film on one or both of the first clamshell half and the second clamshell half. The method also includes depositing an electrolyte into one or both of the first clamshell half and the second clamshell half. The method also includes joining the clamshell halves. The method also includes forming a seal between the ledges of the clamshell halves, where the forming of the seal includes melting the plastic ledges of the first clamshell half and the second clamshell half together. The method also includes sealing at least portions of a surface of the first clamshell half and the second clamshell half with electroless plating.

One general aspect includes a method of manufacturing a clamshell battery including receiving a first clamshell half made of a semiconducting material and a second clamshell half made of the semiconducting material, where clamshell halves have a body region for support of a battery component surrounded by a ledge, where the ledge may be used for sealing. The method

also includes doping regions of one or both of the first clamshell half and the second clamshell half, where the doping increases conductivity of the material to form a contact region. The method also includes depositing a metallic film upon a surface of the first clamshell half. The method also includes depositing an anode in the first clamshell half. The method also includes depositing a cathode in the second clamshell half. The method also includes placing a separator film on one or both of the first clamshell half and the second clamshell half. The method also includes depositing an electrolyte into one or both of the first clamshell half and the second clamshell half. The method also includes joining the clamshell halves. The method also includes forming a seal between the ledges of the clamshell halves. The method also includes sealing at least portions of the surface of the first clamshell half and the second clamshell half with electroless plating.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features and advantages of the invention will be apparent from the following, more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawings.

Figs.1A-1B illustrate exemplary aspects of energization elements in concert with the exemplary application of contact lenses.

Fig. 2A1 illustrates a cross section of an exemplary clamshell form with in-line ledge features.

Fig. 2A2 illustrates a cross section of an exemplary clamshell form with protruding ledge features.

Fig. 2A3 illustrates a cross section of an exemplary clamshell form with a recessed clamshell half and a flat piece.

Figs. 2B-2E illustrate aspects of an exemplary clamshell form with hermetic sealing.

Figs. 3A-3I illustrate additional exemplary clamshell battery designs.

Fig. 4 illustrates a clamshell design with more than two containment components.

Figs. 5A- 5D illustrate an exemplary plastic clamshell form with electroless deposition and electro-plating for hermetic sealing.

Figs. 6A – 6D illustrate an exemplary shaped clamshell battery design.

Fig. 7 illustrates an exemplary method flow for making a clamshell battery with clamshell halves made of insulating material.

Fig. 8 illustrates an exemplary method flow for making a clamshell battery with clamshell halves made of plastic material.

Fig. 9 illustrates an exemplary method flow for making a clamshell battery with clamshell halves made of metallic material.

Fig. 10 illustrates an exemplary method flow for making a clamshell battery with clamshell halves made of semiconducting material.

DETAILED DESCRIPTION OF THE INVENTION

Methods of forming clamshell form batteries with improved biocompatibility are disclosed in the present application. In the following sections, detailed descriptions of various examples are described. The descriptions of examples are exemplary embodiments only, and various modifications and alterations may be apparent to those skilled in the art. Therefore, the examples do not limit the scope of this application. In some examples, these biocompatible batteries may be designed for use in, or proximate to, the body of a living organism.

Glossary

In the description and claims below, various terms may be used for which the following definitions will apply:

"Anode" as used herein refers to an electrode through which electric current flows into a polarized electrical device, such as a battery, during a discharge cycle. The direction of electric current is typically opposite to the direction of electron flow. In other words, the electrons flow from the anode into, for example, an electrical circuit. As used herein, the same element of a polarized device is referred to as an anode even if during a recharge cycle and other events such as electroplating of the element, standard definitions may call the element differently.

Battery as used herein refers to an electrochemical power source which consists of a single electrochemical cell or a multiplicity of electrochemical cells, suitably connected together to furnish a desired voltage or current. The cells may be primary (non-rechargeable) or secondary (rechargeable) cells.

"Binder" as used herein refers to a polymer that is capable of exhibiting elastic responses to mechanical deformations and that is chemically compatible with other energization element components. For example, binders may include electroactive materials, electrolytes, polymers, etc. In some examples, binder may refer to a substance that holds particles and/or particles + liquid together in a cohesive mass.

“Biocompatible” as used herein refers to a material or device that performs with an appropriate host response in a specific application. For example, a biocompatible device does not have toxic or injurious effects on biological systems.

"Cathode" as used herein refers to an electrode through which electric current flows out of a polarized electrical device, such as a battery, during a discharge cycle. The direction of electric current is typically opposite to the direction of electron flow. Therefore, the electrons flow into the cathode of the polarized electrical device, and out of, for example, the connected electrical circuit. As used herein, the same element of a polarized device is referred to as a cathode even if during a recharge cycle and other events such as electroplating of the element, standard definitions may call the element differently.

“Clamshell” as used herein refers generally to shapes that have depressions with a ridge around the edge which may be brought together to seal along the edge. In some examples, the pieces may be joined together. In other examples, the pieces may exist as separate clamshell portions. In some examples, a clamshell battery may be formed by a first piece that has a depression with a ridge for sealing where the second piece is a flat material which may be sealed to the ridge of the first piece.

“Coating” as used herein refers to a deposit of material in thin forms. In some uses, the term will refer to a thin deposit that substantially covers the surface of a substrate it is formed upon. In other more specialized uses, the term may be used to describe small thin deposits in smaller regions of the surface.

"Electrode" as used herein may refer to an active mass in the energy source. For example, it may include one or both anode and cathode.

"Energized" as used herein refers to the state of being able to supply electrical current or to have electrical energy stored within.

"Energy" as used herein refers to the capacity of a physical system to do work. Many uses of the energization elements may relate to the capacity of being able to perform electrical actions.

"Energy Source" or “Energization Element” or “Energization Device” as used herein refers to any device or layer which is capable of supplying energy or placing a logical or electrical device in an energized state. The energization elements may include batteries. The batteries may be formed from alkaline type cell chemical(s) and may be solid-state batteries or wet cell batteries including aqueous alkaline, aqueous acid or aqueous salt electrolyte chemical(s) or non-aqueous chemical(s), molten salt chemical(s) or chemical(s) known from solid state chemistry. The batteries may be dry cell (immobilized electrolyte) or wet cell (free, liquid electrolyte) types.

"Fillers" as used herein refer to one or more energization element separators that do not react with either acid or alkaline electrolytes. Generally, fillers may include substantially water insoluble materials such as carbon black; coal dust; graphite; metal oxides and hydroxides such as those of silicon, aluminum, calcium, magnesium, barium, titanium, iron, zinc, and tin; metal carbonates such as those of calcium and magnesium; minerals such as mica, montmorollonite, kaolinite, attapulgite, and talc; synthetic and natural zeolites such as Portland cement; precipitated metal silicates such as calcium silicate; hollow or solid polymer or glass microspheres, flakes and fibers; and the like.

"Functionalized" as used herein refers to making a layer or device able to perform a function including, for example, energization, activation, and/or control.

"Mold" as used herein refers to a rigid or semi-rigid object that may be used to form three-dimensional objects from uncured formulations. Some exemplary molds include two mold parts that, when opposed to one another, define the structure of a three-dimensional object.

"Power" as used herein refers to work done or energy transferred per unit of time.

"Rechargeable" or "Re-energizable" as used herein refer to a capability of being restored to a state with higher capacity to do work. Many uses may relate to the capability of being restored with the ability to flow electrical current at a certain rate for certain, reestablished time periods.

"Reenergize" or "Recharge" as used herein refer to restoring to a state with higher capacity to do work. Many uses may relate to restoring a device to the capability to flow electrical current at a certain rate for a certain reestablished time period.

"Released" as used herein and sometimes referred to as "released from a mold" means that a three-dimensional object is either completely separated from the mold, or is only loosely attached to the mold, so that it may be removed with mild agitation.

"Stacked" as used herein means to place at least two component layers in proximity to each other such that at least a portion of one surface of one of the layers contacts a first surface of a second layer. In some examples, a coating, whether for adhesion or other functions, may reside between the two layers that are in contact with each other through said coating.

"Traces" as used herein refer to energization element components capable of connecting together the circuit components. For example, circuit traces may include copper or gold when the substrate is a printed circuit board and may typically be copper, gold or printed film in a flexible circuit. A special type of trace is the current collector. Current collectors are traces with electrochemical compatibility that make the current collectors suitable for use in conducting electrons to and from a cathode or anode of an electrochemical cell.

There may be other examples of how to assemble and configure batteries according to the present invention, and some may be described in following sections. However, for many of these examples, there are selected parameters and characteristics of the batteries that may be described in their own right. In the following sections, some characteristics and parameters will be focused upon.

Exemplary Biomedical Device Construction with Biocompatible Energization Elements

An example of a biomedical device that may incorporate the energization elements, batteries, of the present invention may be an electroactive focal-adjusting contact lens. Referring to Fig. 1A, an example of such a contact lens insert may be depicted as contact lens insert 100. In the contact lens insert 100, there may be an electroactive element 120 that may accommodate focal characteristic changes in response to controlling voltages. A circuit 105, to provide those controlling voltage signals as well as to provide other functions such as controlling sensing of the environment for external control signals, may be powered by a biocompatible battery element 110. As depicted in Fig. 1A, the battery element 110 may be found as multiple major pieces, in

this case three pieces, and may include the various configurations of battery chemical(s) elements as has been discussed. The battery elements 110 may have various interconnect features to join together pieces as may be depicted underlying the region of interconnect 114. The battery elements 110 may be connected to the circuit element 105 that may have its own substrate 115 upon which interconnect features 125 and 130 may be located. The circuit 105, which may be in the form of an integrated circuit, may be electrically and physically connected to the substrate 115 and its interconnect features 125 and 130.

Referring to Fig. 1B, a cross sectional relief of a contact lens 150 may comprise contact lens insert 100 and its discussed constituents. The contact lens insert 100 may be encapsulated into a skirt of contact lens hydrogel 155 which may encapsulate the contact lens insert 100 and provide a comfortable interface of the contact lens 150 to a user's eye.

Electrical Requirements of Microbatteries

Another area for design considerations may relate to the electrical requirements of the device, which may be provided by the battery. In order to function as a power source for a medical device, an appropriate battery may need to meet the full electrical requirements of the system when operating in a non-connected or non-externally powered mode. An emerging field of non-connected or non-externally powered biomedical devices may include, for example, vision-correcting contact lenses, health monitoring devices, pill cameras, and novelty devices. Recent developments in integrated circuit (IC) technology may permit meaningful electrical operation at very low current levels, for example, picoamps of standby current and microamps of operating current. IC's may also permit very small devices.

Microbatteries for biomedical applications may be required to meet many simultaneous, challenging requirements. For example, the microbattery may be required to have the capability to deliver a suitable operating voltage to an incorporated electrical circuit. This operating voltage may be influenced by several factors including the IC process "node," the output voltage from the circuit to another device, and a particular current consumption target which may also relate to a desired device lifetime.

With respect to the IC process, nodes may typically be differentiated by the minimum feature size of a transistor, such as its "so-called" transistor channel. This physical feature, along with other parameters of the IC fabrication, such as gate oxide thickness, may be associated with

a resulting rating standard for “turn-on” or “threshold” voltages of field-effect transistors (FET’s) fabricated in the given process node. For example, in a node with a minimum feature size of 0.5 microns, it may be common to find FET’s with turn-on voltages of 5.0V. However, at a minimum feature size of 90 nm, the FET’s may turn-on at 1.2, 1.8, and 2.5V. The IC foundry may supply standard cells of digital blocks, for example, inverters and flip-flops that have been characterized and are rated for use over certain voltage ranges. Designers chose an IC process node based on several factors including density of digital devices, analog/digital mixed signal devices, leakage current, wiring layers, and availability of specialty devices such as high-voltage FET’s. Given these parametric aspects of the electrical components, which may draw power from a microbattery, it may be important for the microbattery power source to be matched to the requirements of the chosen process node and IC design, especially in terms of available voltage and current.

In some examples, an electrical circuit powered by a microbattery, may connect to another device. In non-limiting examples, the microbattery-powered electrical circuit may connect to an actuator or a transducer. Depending on the application, these may include a light-emitting diode (LED), a sensor, a microelectromechanical system (MEMS) pump, or numerous other such devices. In some examples, such connected devices may require higher operating voltage conditions than common IC process nodes. For example, a variable-focus lens may require 35V to activate. The operating voltage provided by the battery may therefore be a critical consideration when designing such a system. In some examples of this type of consideration, the efficiency of a lens driver to produce 35V from a 1V battery may be significantly less than it might be when operating from a 2V battery. Further requirements, such as die size, may be dramatically different considering the operating parameters of the microbattery as well.

Individual battery cells may typically be rated with open-circuit, loaded, and cutoff voltages. The open-circuit voltage is the potential produced by the battery cell with infinite load resistance. The loaded voltage is the potential produced by the cell with an appropriate, and typically also specified, load impedance placed across the cell terminals. The cutoff voltage is typically a voltage at which most of the battery has been discharged. The cutoff voltage may represent a voltage, or degree of discharge, below which the battery should not be discharged to avoid deleterious effects such as excessive gassing. The cutoff voltage may typically be influenced by the circuit to which the battery is connected, not just the battery itself, for example,

the minimum operating voltage of the electronic circuit. In one example, an alkaline cell may have an open-circuit voltage of 1.6V, a loaded voltage in the range 1.0 to 1.5V, and a cutoff voltage of 1.0V. The voltage of a given microbattery cell design may depend upon other factors of the cell chemical(s) employed. And, different cell chemical(s) may therefore have different cell voltages.

Cells may be connected in series to increase voltage; however, this combination may come with tradeoffs to size, internal resistance, and battery complexity. Cells may also be combined in parallel configurations to decrease resistance and increase capacity; however, such a combination may tradeoff size and shelf life.

Battery capacity may be the ability of a battery to deliver current, or do work, for a period of time. Battery capacity may typically be specified in units such as microamp-hours. A battery that may deliver 1 microamp of current for 1 hour has 1 microamp-hour of capacity. Capacity may typically be increased by increasing the mass (and hence volume) of reactants within a battery device; however, it may be appreciated that biomedical devices may be significantly constrained on available volume. Battery capacity may also be influenced by electrode and electrolyte material as well as other factors such as the physical design of the electrodes, the nature and dimensions of any separator material disposed between the electrodes and the relative proportions of anode, cathode active materials, conductive aids and electrolyte.

Depending on the requirements of the circuitry to which the battery is connected, a battery may be required to source current over a range of values. During storage prior to active use, a leakage current on the order of picoamps to nanoamps may flow through circuits, interconnects, and insulators. During active operation, circuitry may consume quiescent current to sample sensors, run timers, and perform such low power consumption functions. Quiescent current consumption may be on the order of nanoamps to milliamps. Circuitry may also have even higher peak current demands, for example, when writing flash memory or communicating over radio frequency (RF). This peak current may extend to tens of milliamps or more. The resistance and impedance of a microbattery device may also be important to design considerations.

Shelf life typically refers to the period of time which a battery may survive in storage and still maintain useful operating parameters. Shelf life may be particularly important for biomedical devices for several reasons. Electronic devices may displace non-powered devices, as

for example may be the case for the introduction of an electronic contact lens. Products in these existing market spaces may have established shelf life requirements, for example, three years, due to customer, supply chain, and other requirements. It may typically be desired that such specifications not be altered for new products. Shelf life requirements may also be set by the distribution, inventory, and use methods of a device including a microbattery. Accordingly, microbatteries for biomedical devices may have specific shelf life requirements, which may be, for example, measured in the number of years.

In some examples, three-dimensional biocompatible energization elements may be rechargeable. For example, an inductive coil may also be fabricated on the three-dimensional surface. The inductive coil could then be energized with a radio-frequency ("RF") fob. The inductive coil may be connected to the three-dimensional biocompatible energization element to recharge the energization element when RF is applied to the inductive coil. In another example, photovoltaics may also be fabricated on the three-dimensional surface and connected to the three-dimensional biocompatible energization element. When exposed to light or photons, the photovoltaics will produce electrons to recharge the energization element.

In some examples, a battery may function to provide the electrical energy for an electrical system. In these examples, the battery may be electrically connected to the circuit of the electrical system. The connections between a circuit and a battery may be classified as interconnects. These interconnects may become increasingly challenging for biomedical microbatteries due to several factors. In some examples, powered biomedical devices may be very small thus allowing little area and volume for the interconnects. The restrictions of size and area may impact the electrical resistance and reliability of the interconnections.

In other respects, a battery may contain a liquid electrolyte which could boil at high temperature. This restriction may directly compete with the desire to use a solder interconnect which may, for example, require relatively high temperatures such as 250 degrees Celsius to melt. Although in some examples, the battery chemical(s), including the electrolyte, and the heat source used to form solder based interconnects, may be isolated spatially from each other. In the cases of emerging biomedical devices, the small size may preclude the separation of electrolyte and solder joints by sufficient distance to reduce heat conduction.

Modular Battery Components

In some examples, a modular battery component may be formed according to some aspects and examples of the present invention. In these examples, the modular battery assembly may be a separate component from other parts of the biomedical device. In the example of an ophthalmic contact lens device, such a design may include a modular battery that is separate from the rest of a media insert. There may be numerous advantages of forming a modular battery component. For example, in the example of the contact lens, a modular battery component may be formed in a separate, non-integrated process which may alleviate the need to handle rigid, three-dimensionally formed optical plastic components. In addition, the sources of manufacturing may be more flexible and may operate in a more parallel mode to the manufacturing of the other components in the biomedical device. Furthermore, the fabrication of the modular battery components may be decoupled from the characteristics of three-dimensional (3D) shaped devices. For example, in applications requiring three-dimensional final forms, a modular battery system may be fabricated in a flat or roughly two-dimensional (2D) perspective and then shaped to the appropriate three-dimensional shape. In some examples, the battery may be small enough to not perturb a three-dimensional shape even if it is not bent. In some other examples, a coupling of multiple small batteries may fit into a three dimensionally shaped space. A modular battery component may be tested independently of the rest of the biomedical device and yield loss due to battery components may be sorted before assembly. The resulting modular battery component may be utilized in various media insert constructs that do not have an appropriate rigid region upon which the battery components may be formed; and, in a still further example, the use of modular battery components may facilitate the use of different options for fabrication technologies than might otherwise be utilized, such as, web-based technology (roll to roll), sheet-based technology (sheet-to-sheet), printing, lithography, and “squeegee” processing. In some examples of a modular battery, the discrete containment aspect of such a device may result in additional material being added to the overall biomedical device construct. Such effects may set a constraint for the use of modular battery solutions when the available space parameters require minimized thickness or volume of solutions.

Battery Element Internal Seals

In some examples of battery elements for use in biomedical devices, the chemical action of the battery involves aqueous chemical(s), where water or moisture is an important constituent

to control. Therefore, it may be important to incorporate sealing mechanisms that retard or prevent the movement of moisture either out of or into the battery body. Moisture barriers may be designed to keep the internal moisture level at a designed level, within some tolerance. In some examples, a moisture barrier may be divided into two sections or components; namely, the package and the seal.

The package may refer to the main material of the enclosure. In some examples, the package may comprise a bulk material. The Water Vapor Transmission Rate (WVTR) may be an indicator of performance, with ISO, and/or ASTM standards controlling the test procedure, including the environmental conditions operant during the testing. Ideally, the WVTR for a good battery package may be "zero." Exemplary materials with a near-zero WVTR may be glass and metal foils as well as ceramics and metallic pieces. Plastics, on the other hand, may be inherently porous to moisture, and may vary significantly for different types of plastic. Engineered materials, laminates, or co-extrudes may usually be hybrids of the common package materials.

The seal may be the interface between two of the package surfaces. The connecting of seal surfaces finishes the enclosure along with the package. In many examples, the nature of seal designs may make them difficult to characterize for the seal's WVTR due to difficulty in performing measurements using an ISO or ASTM standard, as the sample size or surface area may not be compatible with those procedures. In some examples, a practical manner to testing seal integrity may be a functional test of the actual seal design, for some defined conditions. Seal performance may be a function of the seal material, the seal thickness, the seal length, the seal width, and the seal adhesion or intimacy to package substrates.

In some examples, seals may be formed by a welding process that may involve thermal, laser, solvent, friction, ultrasonic, or arc processing. In other examples, seals may be formed through the use of adhesive sealants such as glues, epoxies, acrylics, natural rubber, synthetic rubber, resins, tars or bitumen. Other examples may derive from the utilization of gasket type material that may be formed from natural and synthetic rubber, polytetrafluoroethylene (PTFE), polypropylene, and silicones to mention a few non-limiting examples. In some examples, the sealing material may be a thermoset, thermoplastic or a combination of a thermoset and a thermoplastic.

In some examples, the batteries according to the present invention may be designed to have a specified operating life. The operating life may be estimated by determining a practical

amount of moisture permeability that may be obtained using a particular battery system and then estimating when such a moisture leakage may result in an end-of-life condition for the battery. For example, if a battery is stored in a wet environment, then the partial pressure difference between inside and outside the battery will be minimal, resulting in a reduced moisture loss rate, and therefore the battery life may be extended. The same exemplary battery stored in a particularly dry and hot environment may have a significantly reduced expectable lifetime due to the strong driving function for moisture loss.

Metal/Metal, Metal/Glass, Metal/Ceramic, Glass/Glass, Semiconductor/Semiconductor and Metal/Semiconductor Seals

There may be numerous means to form a hermetic or well-sealed interface between solid materials that may act as containment for battery chemical(s). Typical means for forming a proper hermetic mechanical bond between solid materials includes soldering, brazing, and welding. These methods may be seen as largely similar, as they all include thermally treating both base materials (the materials to be bonded, which can be either homogeneous or heterogeneous materials) and a filler material that bonds between the two base materials. The main distinctions that exist between these methods may be seen as the specific temperatures that are used to heat the materials for each method and how these temperatures affect the properties of each material when applied over a length of time. More specifically, both brazing and soldering may utilize a temperature that is above the liquidus temperature of the filler material, but below the solidus temperature of both base materials. The main distinction that may exist between brazing and soldering may be seen as the specific temperature that is applied. For example, if the applied temperature is below 450°C, the method may be referred to as soldering, and may be referred to as brazing if the applied temperature is above 450°C. Welding, however, may utilize an applied temperature that is above the liquidus of the filler material and base materials alike.

Each of the aforementioned methods can work for a variety of material combinations, and specific material combinations may be able to be bonded together by more than one of these methods. The optimal choice among those methods, for bonding two materials together, may be determined by any number of characteristics including but not limited to, the specific material properties and liquidus temperatures of the desired materials, other thermal properties of the

desired bonding or filler materials, the skill, timing, and precision of the worker or machine bonding the two materials, and an acceptable level of mechanical or surface damage to the bonded materials by each method. In some examples, consistent with the present invention, the materials used for bonding two materials together may include pure metals such as gold, silver, indium and platinum. It may also include alloys such as silver-copper, silver-zinc, copper-zinc, copper-zinc-silver, copper-phosphorus, silver-copper-phosphorus, gold-silver, gold-nickel, gold-copper, indium alloys and aluminum-silicon. It may also include active braze alloys such as titanium active braze alloys which may include gold, copper, nickel, silver, vanadium or aluminum. There may be other brazing materials which may be consistent with the sealing needs mentioned in the present disclosure.

Different material combinations for each of these bonding methods may include metal/metal, metal/glass, metal/ceramic, glass/glass, semiconductor/semiconductor, and metal/semiconductor.

In a first type of example, a metal seal to metal seal may be formed. Soldering, brazing, and welding, are all very commonly used for metal/metal bonding. Since the material properties of various metals may vary quite widely from metal-to-metal, the liquidus temperature of a metal may typically be the deciding characteristic for which bonding method to use with a desired metal, for example, a base metal may have such a low liquidus temperature that it will melt quickly at brazing temperatures, or a base metal may have such a high liquidus temperature that is does not chemically respond to soldering temperatures to form a proper bond.

In another type of example, a metal-to-glass (or glass to metal) seal may be formed. Due to the inhomogeneity of metal and glass as materials, typical metal/metal bonding methods may not be conducive to the bonding of metals with glass. For example, typical filler materials used in metal/metal soldering may bond well to a metal, but may not react with glass to bond to its surface under thermal treatment. One possibility to overcome this issue may be to use other materials, such as epoxies, that bond to both materials. Typical epoxies have pendant hydroxyl groups in their structure that may allow them to bond strongly to inorganic materials. Epoxy may be easily and cheaply applied between materials, bonding ubiquitously to many types of surfaces. Epoxies may be easily cured as well before or after application through many methods, such as mixing of chemicals that are then quickly applied, thermal, light based, or other types of radiation that introduce energy into the epoxy to induce a bonding/curing reaction, or through

other methods. Many different types of epoxies may have differing desirability for different applications, based on many different properties including, but not limited to, bond strength, ease of applicability, curing method, curing time, bondable materials, and many others. For achieving true hermetic sealing with epoxy, it is vital to consider the leak rates of certain fluids through the epoxy. Hermetic sealing with epoxy, however, offers the flexibility of using copper alloys for wires or pins while still maintaining a hermetic seal, as opposed to less conductive materials that are required for other types of bonding or hermetic sealing. Epoxy seals, however, are typically viable under much more constrained operation temperature ranges than other bonding methods, and may also have a significantly lower bond strength.

In another type of example, a metal-to-ceramic (or ceramic-to-metal) seal may be formed. Brazing may be seen as a typical method for achieving metal-to-ceramic bonding, and there are a multitude of proven and accepted methods for achieving a hermetic seal between the materials. This may include the molybdenum-manganese/nickel plating method, where molybdenum and manganese particles are mixed with glass additives and volatile carriers to form a coating that is applied to the ceramic surface that will be brazed. This coating is processed and then plated with nickel and processed further, to be now readily brazed using standard methods and filler materials.

Thin film deposition is another commonly used brazing method. In this method, a combination of materials may be applied to a nonmetallic surface using a physical vapor deposition (PVD) method. The choice of materials applied may depend on desired material properties or layer thicknesses, and occasionally multiple layers are applied. This method has many advantages including a wide diversity of possible metals for application, as well as speed and proven consistent success with standard materials. There are disadvantages, however, including the need for specialized PVD equipment to apply coatings, the need for complicated masking techniques if masking is desired, and geometric constraints with the ceramic that may prevent uniform coating thicknesses. The PVD layer may include constituents such as titanium, zirconium and hafnium, and in some examples, may be between 100 nanometers to 250 nanometers thick. In some examples a noble over-layer may be deposited comprising constituents such as Gold, Palladium, Platinum or Silver as non-limiting examples.

Nanofoil® material Bonding

A commercially available product called Nanofoil®, a nanotechnology material available from Indium Corporation, may provide a significant example when sealing metal, ceramic and/or semiconductor containment for batteries may be required. In some examples, it may be desirable that any thermal effects in the formation of the seal are as localized to the seal itself as possible. Material composites such as Nanofoil® material may provide significant thermal localization while forming hermetic bonded seals. The Nanofoil® type composite films may be made of hundreds or thousands of nanoscale film levels. In an example, a reactive multi-layer foil is fabricated by vapor-depositing thousands of alternating layers of Aluminum (Al) and Nickel (Ni). These layers may be nanometers in thickness. When activated by a small pulse of local energy from electrical, optical or thermal sources, the foil reacts exothermically. The resulting exothermic reaction delivers a quantifiable amount of energy in thousandths of seconds that heats to very high local temperatures at surfaces but may be engineered not to deliver a total amount of energy that would increase temperature in the metal, ceramic or semiconductor pieces that are being sealed.

S-Bond® sealing

A similar example to Nanofoil® material bonding may be S-Bond® material bonding. S-Bond material may comprise a conventional solder alloy base with the addition of titanium or other rare earth elements to the material and is available from S-Bond Technologies. The active materials like titanium react with oxides or other inert materials at a bonding interface and either chemically bond to them or transport them into the solder melt. Upon heating, the S-bond® materials may melt but still have a thin surface oxide thereupon. When that surface oxide is disrupted, the active material reactions occur with the surface regions of the bond/seal. The oxide may be disrupted with scraping processes, but may also be disrupted with ultrasonics. Therefore, a surface reaction may be initiated at relatively low temperature and a bond may be made to materials that might be difficult to bond otherwise. In some examples, the S-Bond® material may be combined with the Nanofoil® material to form a structure that may be locally bonded without significant thermal load to the rest of the battery system.

Silicon Bonding

Silicon bonding may be achieved with S-Bond® material in some examples. The composition of S-Bond® 220M may be used in some examples to form a solderable interface.

The S-Bond® 220M material may be deposited upon the silicon surface to be bonded/sealed at temperatures ranging from 115-400°C. Therefore, can shaped pieces of silicon may be heavily doped on the closed end, either through the use of doped films such as POCl, through implantation, or through other means of doping. Another means may include oxidizing the body of the semiconductor and then chemically etching the oxide in regions where the dopant is desired. The doped regions may then be exposed to titanium and heated to form a silicide. The regions of the silicon cans that are used to form seals may have S-Bond 220M material applied to them and heated to wet onto the silicon surface, or silicide surface. In some examples a film of Nanofoil® material may be applied in the seal region for subsequent activation. The battery chemical(s), electrolyte and other structures may be formed into the can halves and then the two halves may be placed together. Under the simultaneous activation by ultrasonics and by activation of the Nanofoil® material a rapid, low temperature hermitic seal may be formed.

Battery Module Thickness

In designing battery components for biomedical applications, tradeoffs amongst the various parameters may be made balancing technical, safety and functional requirements. The thickness of the battery component may be an important and limiting parameter. For example, in an optical lens application the ability of a device to be comfortably worn by a user may have a critical dependence on the thickness across the biomedical device. Therefore, there may be critical enabling aspects in designing the battery for thinner results. In some examples, battery thickness may be determined by the combined thicknesses of top and bottom sheets, spacer sheets, and adhesive layer thicknesses. Practical manufacturing aspects may drive certain parameters of film thickness to standard values in available sheet stock. In addition, the films may have minimum thickness values to which they may be specified base upon technical considerations relating to chemical compatibility, moisture/gas impermeability, surface finish, and compatibility with coatings that may be deposited upon the film layers.

In some examples, a desired or goal thickness of a finished battery component may be a component thickness that is less than 220 μm. In these examples, this desired thickness may be driven by the three-dimensional geometry of an exemplary ophthalmic lens device where the battery component may need to be fit inside the available volume defined by a hydrogel lens shape given end user comfort, biocompatibility, and acceptance constraints. This volume and its

effect on the needs of battery component thickness may be a function of total device thickness specification as well as device specification relating to its width, cone angle, and inner diameter. Another important design consideration for the resulting battery component design may relate to the volume available for active battery chemicals and materials in a given battery component design with respect to the resulting chemical energy that may result from that design. This resulting chemical energy may then be balanced for the electrical requirements of a functional biomedical device for its targeted life and operating conditions.

Battery Module Width

There may be numerous applications into which the biocompatible energization elements or batteries of the present invention may be utilized. In general, the battery width requirement may be largely a function of the application in which it is applied. In an exemplary case, a contact lens battery system may have constrained needs for the specification on the width of a modular battery component. In some examples of an ophthalmic device where the device has a variable optic function powered by a battery component, the variable optic portion of the device may occupy a central spherical region of about 7.0 mm in diameter. The exemplary battery elements may be considered as a three-dimensional object, which fits as an annular, conical skirt around the central optic and formed into a truncated conical ring. If the required maximum diameter of the rigid insert is a diameter of 8.50 mm, and tangency to a certain diameter sphere may be targeted (as for example in a roughly 8.40 mm diameter), then geometry may dictate what the allowable battery width may be. There may be geometric models that may be useful for calculating desirable specifications for the resulting geometry which in some examples may be termed a conical frustum flattened into a sector of an annulus.

Flattened battery width may be driven by two features of the battery element, the active battery components and seal width. In some examples relating to ophthalmic devices a target thickness may be between 0.100 mm and 0.500 mm per side, and the active battery components may be targeted at approximately 0.800 mm wide. Other biomedical devices may have differing design constraints but the principles for flexible flat battery elements may apply in similar fashion.

Battery Module Flexibility

Another dimension of relevance to battery design and to the design of related devices that utilize battery based energy sources is the flexibility of the battery component. There may be numerous advantages conferred by flexible battery forms. For example, a flexible battery module may facilitate the previously mentioned ability to fabricate the battery form in a two-dimensional (2D) flat form. The flexibility of the form may allow the two-dimensional battery to then be formed into an appropriate 3D shape to fit into a biomedical device such as a contact lens.

In another example of the benefits that may be conferred by flexibility in the battery module, if the battery and the subsequent device is flexible then there may be advantages relating to the use of the device. In an example, a contact lens form of a biomedical device may have advantages for insertion/removal of the media insert based contact lens that may be closer to the insertion/removal of a standard, non-filled hydrogel contact lens.

The number of flexures may be important to the engineering of the battery. For example, a battery which may only flex one time from a planar form into a shape suitable for a contact lens may have significantly different design from a battery capable of multiple flexures. The flexure of the battery may also extend beyond the ability to mechanically survive the flexure event. For example, an electrode may be physically capable of flexing without breaking, but the mechanical and electrochemical properties of the electrode may be altered by flexure. Flex-induced changes may appear instantly, for example, as changes to impedance, or flexure may introduce changes which are only apparent in long-term shelf life testing.

Battery Shape Aspects

Battery shape requirements may be driven at least in part by the application for which the battery is to be used. Traditional battery form factors may be cylindrical forms or rectangular prisms, made of metal, and may be geared toward products which require large amounts of power for long durations. These applications may be large enough that they may comprise large form factor batteries. In another example, planar (2D) solid-state batteries are thin rectangular prisms, typically formed upon inflexible silicon or glass. These planar solid-state batteries may be formed in some examples using silicon wafer-processing technologies. In another type of battery form factor, low power, flexible batteries may be formed in a pouch construct, using thin foils or plastic to contain the battery chemical(s). These batteries may be made flat (2D), and may be designed to function when bowed to a modest out-of-plane (3D) curvature.

In some of the examples of the battery applications in the present invention where the battery may be employed in a variable optic lens, the form factor may require a three-dimensional curvature of the battery component where a radius of that curvature may be on the order of approximately 8.4 mm. The nature of such a curvature may be considered to be relatively steep and for reference may approximate the type of curvature found on a human fingertip. The nature of a relative steep curvature creates challenging aspects for manufacture. In some examples of the present invention, a modular battery component may be designed such that it may be fabricated in a flat, two-dimensional manner and then formed into a three-dimensional form of relative high curvature.

Battery Element Separators

Batteries of the type described in the present invention may utilize a separator material that physically and electrically separates the anode and anode current collector portions from the cathode and cathode current collector portions. The separator may be a membrane that is permeable to water and dissolved electrolyte components; however, it may typically be electrically non-conductive. While a myriad of commercially-available separator materials may be known to those of skill in the art, the novel form factor of the present invention may present unique constraints on the task of separator selection, processing, and handling.

Since the designs of the present invention may have ultra-thin profiles, the choice may be limited to the thinnest separator materials typically available. For example, separators of approximately 25 microns in thickness may be desirable. Some examples which may be advantageous may be about 12 microns in thickness. There may be numerous acceptable commercial separators include micro fibrillated, microporous polyethylene monolayer and/or polypropylene-polyethylene-polypropylene (PP/PE/PP) trilayer separator membranes such as those produced by Celgard (Charlotte, NC). A desirable example of separator material may be Celgard M824 PP/PE/PP trilayer membrane having a thickness of 12 microns. Alternative examples of separator materials useful for examples of the present invention may include separator membranes including regenerated cellulose (e.g. cellophane).

While PP/PE/PP trilayer separator membranes may have advantageous thickness and mechanical properties, owing to their polyolefinic character, they may also suffer from a number of disadvantages that may need to be overcome in order to make them useful in examples of the

present invention. Roll or sheet stock of PP/PE/PP trilayer separator materials may have numerous wrinkles or other form errors that may be deleterious to the micron-level tolerances applicable to the batteries described herein. Furthermore, polyolefin separators may need to be cut to ultra-precise tolerances for inclusion in the present designs, which may therefore implicate laser cutting as an exemplary method of forming discrete current collectors in desirable shapes with tight tolerances. Owing to the polyolefinic character of these separators, certain cutting lasers useful for micro fabrication may employ laser wavelengths, e.g. 355 nm, that will not cut polyolefins. The polyolefins do not appreciably absorb the laser energy and are thereby non-ablatable. Finally, polyolefin separators may not be inherently wettable to aqueous electrolytes used in the batteries described herein.

Nevertheless, there may be methods for overcoming these inherent limitations for polyolefinic type membranes. In order to present a microporous separator membrane to a high-precision cutting laser for cutting pieces into arc segments or other advantageous separator designs, the membrane may need to be flat and wrinkle-free. If these two conditions are not met, the separator membrane may not be fully cut because the cutting beam may be inhibited as a result of defocusing of or otherwise scattering the incident laser energy. Additionally, if the separator membrane is not flat and wrinkle-free, the form accuracy and geometric tolerances of the separator membrane may not be sufficiently achieved. Allowable tolerances for separators of current examples may be, for example, +0 microns and -20 microns with respect to characteristic lengths and/or radii. There may be advantages for tighter tolerances of +0 microns and -10 microns and further for tolerances of +0 microns and -5 microns. Separator stock material may be made flat and wrinkle-free by temporarily laminating the material to a float glass carrier with an appropriate low-volatility liquid. Low-volatility liquids may have advantages over temporary adhesives due to the fragility of the separator membrane and due to the amount of processing time that may be required to release separator membrane from an adhesive layer. Furthermore, in some examples achieving a flat and wrinkle-free separator membrane on float glass using a liquid has been observed to be much more facile than using an adhesive. Prior to lamination, the separator membrane may be made free of particulates. This may be achieved by ultrasonic cleaning of separator membrane to dislodge any surface-adherent particulates. In some examples, handling of a separator membrane may be done in a suitable, low-particle environment such as a laminar flow hood or a cleanroom of at least class 10,000. Furthermore, the float glass substrate

may be made to be particulate free by rinsing with an appropriate solvent, ultrasonic cleaning, and/or wiping with clean room wipes.

While a wide variety of low-volatility liquids may be used for the mechanical purpose of laminating microporous polyolefin separator membranes to a float glass carrier, specific requirements may be imposed on the liquid to facilitate subsequent laser cutting of discrete separator shapes. One requirement may be that the liquid has a surface tension low enough to soak into the pores of the separator material which may easily be verified by visual inspection. In some examples, the separator material turns from a white color to a translucent appearance when liquid fills the micropores of the material. It may be desirable to choose a liquid that may be benign and "safe" for workers that will be exposed to the preparation and cutting operations of the separator. It may be desirable to choose a liquid whose vapor pressure may be low enough so that appreciable evaporation does not occur during the time scale of processing (on the order of 1 day). Finally, in some examples the liquid may have sufficient solvating power to dissolve advantageous UV absorbers that may facilitate the laser cutting operation. In an example, it has been observed that a 12 percent (w/w) solution of avobenzone UV absorber in benzyl benzoate solvent may meet the aforementioned requirements and may lend itself to facilitating the laser cutting of polyolefin separators with high precision and tolerance in short order without an excessive number of passes of the cutting laser beam. In some examples, separators may be cut with an 8W 355 nm nanosecond diode-pumped solid state laser using this approach where the laser may have settings for low power attenuation (e.g. 3 percent power), a moderate speed of 1 to 10 mm/s, and only 1 to 3 passes of the laser beam. While this UV-absorbing oily composition has been proven to be an effective laminating and cutting process aid, other oily formulations may be envisaged by those of skill in the art and used without limitation.

In some examples, a separator may be cut while fixed to a float glass. One advantage of laser cutting separators while fixed to a float glass carrier may be that a very high number density of separators may be cut from one separator stock sheet much like semiconductor die may be densely arrayed on a silicon wafer. Such an approach may provide economy of scale and parallel processing advantages inherent in semiconductor processes. Furthermore, the generation of scrap separator membrane may be minimized. Once separators have been cut, the oily process aid fluid may be removed by a series of extraction steps with miscible solvents, the last extraction may be performed with a high-volatility solvent such as isopropyl alcohol in some

examples. Discrete separators, once extracted, may be stored indefinitely in any suitable low-particle environment.

As previously mentioned polyolefin separator membranes may be inherently hydrophobic and may need to be made wettable to aqueous surfactants used in the batteries of the present invention. One approach to make the separator membranes wettable may be oxygen plasma treatment. For example, separators may be treated for 1 to 5 minutes in a 100 percent oxygen plasma at a wide variety of power settings and oxygen flow rates. While this approach may improve wettability for a time, it may be well-known that plasma surface modifications provide a transient effect that may not last long enough for robust wetting of electrolyte solutions. Another approach to improve wettability of separator membranes may be to treat the surface by incorporating a suitable surfactant on the membrane. In some cases, the surfactant may be used in conjunction with a hydrophilic polymeric coating that remains within the pores of the separator membrane.

Another approach to provide more permanence to the hydrophilicity imparted by an oxidative plasma treatment may be by subsequent treatment with a suitable hydrophilic organosilane. In this manner, the oxygen plasma may be used to activate and impart functional groups across the entire surface area of the microporous separator. The organosilane may then covalently bond to and/or non-covalently adhere to the plasma treated surface. In examples using an organosilane, the inherent porosity of the microporous separator may not be appreciably changed, monolayer surface coverage may also be possible and desired. Prior art methods incorporating surfactants in conjunction with polymeric coatings may require stringent controls over the actual amount of coating applied to the membrane, and may then be subject to process variability. In extreme cases, pores of the separator may become blocked, thereby adversely affecting utility of the separator during the operation of the electrochemical cell. An exemplary organosilane useful in the present invention may be (3-aminopropyl)triethoxysilane. Other hydrophilic organosilanes may be known to those of skill in the art and may be used without limitation.

Still another method for making separator membranes wettable by aqueous electrolyte may be the incorporation of a suitable surfactant in the electrolyte formulation. One consideration in the choice of surfactant for making separator membranes wettable may be the effect that the surfactant may have on the activity of one or more electrodes within the

electrochemical cell, for example, by increasing the electrical impedance of the cell. In some cases, surfactants may have advantageous anti-corrosion properties, specifically in the case of zinc anodes in aqueous electrolytes. Zinc may be an example of a material known to undergo a slow reaction with water to liberate hydrogen gas, which may be undesirable. Numerous surfactants may be known by those of skill in the art to limit rates of said reaction to advantageous levels. In other cases, the surfactant may so strongly interact with the zinc electrode surface that battery performance may be impeded. Consequently, much care may need to be made in the selection of appropriate surfactant types and loading levels to ensure that separator wettability may be obtained without deleteriously affecting electrochemical performance of the cell. In some cases, a plurality of surfactants may be used, one being present to impart wettability to the separator membrane and the other being present to facilitate anti-corrosion properties to the zinc anode. In one example, no hydrophilic treatment is done to the separator membrane and a surfactant or plurality of surfactants is added to the electrolyte formulation in an amount sufficient to effect wettability of the separator membrane.

Discrete separators may be integrated into a clamshell microbattery by direct placement into a portion of one or sides of a clamshell assembly.

Polymerized Battery Element Separators

In some battery designs, the use of a discrete separator (as described in a previous section) may be precluded due to a variety of reasons such as the cost, the availability of materials, the quality of materials, or the complexity of processing for some material options as non-limiting examples.

A method to achieve a uniform, mechanically robust form-in-place separator may be to use UV-curable hydrogel formulations. Numerous water-permeable hydrogel formulations may be known in various industries, for example, the contact lens industry. An example of a common hydrogel in the contact lens industry may be poly(hydroxyethylmethacrylate) crosslinked gel, or simply pHEMA. For numerous applications of the present invention, pHEMA may possess many attractive properties for use in Leclanché and zinc-carbon batteries. pHEMA typically may maintain a water content of approximately 30-40 percent in the hydrated state while maintaining an elastic modulus of about 100 psi or greater. Furthermore, the modulus and water content properties of crosslinked hydrogels may be adjusted by one of skill in the art by incorporating

additional hydrophilic monomeric (e.g. methacrylic acid) or polymeric (e.g. polyvinylpyrrolidone) components. In this manner, the water content, or more specifically, the ionic permeability of the hydrogel may be adjusted by formulation.

Of particular advantage in some examples, a castable and polymerizable hydrogel formulation may contain one or more diluents to facilitate processing. The diluent may be chosen to be volatile such that the castable mixture may be squeegeed into a cavity, and then allowed a sufficient drying time to remove the volatile solvent component. After drying, a bulk photopolymerization may be initiated by exposure to actinic radiation of appropriate wavelength, such as blue UV light at 420 nm, for the chosen photoinitiator, such as CGI 819. The volatile diluent may help to provide a desirable application viscosity so as to facilitate casting a uniform layer of polymerizable material in the cavity. The volatile diluent may also provide beneficial surface tension lowering effects, particularly in the case where strongly polar monomers are incorporated in the formulation. Another aspect that may be important to achieve the casting of a uniform layer of polymerizable material in the cavity may be the application viscosity. Common small molar mass reactive monomers typically do not have very high viscosities, which may be typically only a few centipoise. In an effort to provide beneficial viscosity control of the castable and polymerizable separator material, a high molar mass polymeric component known to be compatible with the polymerizable material may be selected for incorporation into the formulation. Examples of high molar mass polymers which may be suitable for incorporation into exemplary formulations may include polyvinylpyrrolidone and polyethylene oxide.

In some examples the castable, polymerizable separator may be advantageously applied into a designed cavity, as previously described. In alternative examples, there may be no cavity at the time of polymerization. Instead, the castable, polymerizable separator formulation may be coated onto an electrode-containing substrate, for example, patterned zinc plated brass, and then subsequently exposed to actinic radiation using a photomask to selectively polymerize the separator material in targeted areas. Unreacted separator material may then be removed by exposure to appropriate rinsing solvents. In these examples, the separator material may be designated as a photo-patternable separator.

Multiple Component Separator Formulations

The separator, useful according to examples of the present invention, may have a number

of properties that may be important to its function. In some examples, the separator may desirably be formed in such a manner as to create a physical barrier such that layers on either side of the separator do not physically contact one another. The layer may therefore have an important characteristic of uniform thickness, since while a thin layer may be desirable for numerous reasons, a void or gap free layer may be essential. Additionally, the thin layer may desirably have a high permeability to allow for the free flow of ions. Also, the separator requires optimal water uptake to optimize mechanical properties of the separator. Thus, the formulation may contain a crosslinking component, a hydrophilic polymer component, and a solvent component.

A crosslinker may be a monomer with two or more polymerizable double bonds. Suitable crosslinkers may be compounds with two or more polymerizable functional groups. Examples of suitable hydrophilic crosslinkers may also include compounds having two or more polymerizable functional groups, as well as hydrophilic functional groups such as polyether, amide or hydroxyl groups. Specific examples may include TEGDMA (tetraethyleneglycol dimethacrylate), TrEGDMA (triethyleneglycol dimethacrylate), ethyleneglycol dimethacylate (EGDMA), ethylenediamine dimethyacrylamide, glycerol dimethacrylate and combinations thereof.

The amounts of crosslinker that may be used in some examples may range, e.g., from about 0.000415 to about 0.0156 mole per 100 grams of reactive components in the reaction mixture. The amount of hydrophilic crosslinker used may generally be about 0 to about 2 weight percent and, for example, from about 0.5 to about 2 weight percent. Hydrophilic polymer components capable of increasing the viscosity of the reactive mixture and/or increasing the degree of hydrogen bonding with the slow-reacting hydrophilic monomer, such as high molecular weight hydrophilic polymers, may be desirable.

The high molecular weight hydrophilic polymers provide improved wettability, and in some examples, may improve wettability to the separator of the present invention. In some non-limiting examples, it may be believed that the high molecular weight hydrophilic polymers are hydrogen bond receivers which in aqueous environments, hydrogen bond to water, thus becoming effectively more hydrophilic. The absence of water may facilitate the incorporation of the hydrophilic polymer in the reaction mixture. Aside from the specifically named high molecular weight hydrophilic polymers, it may be expected that any high molecular weight polymer will be useful in the present invention provided that when said polymer is added to an

exemplary silicone hydrogel formulation, the hydrophilic polymer (a) does not substantially phase separate from the reaction mixture and (b) imparts wettability to the resulting cured polymer.

In some examples, the high molecular weight hydrophilic polymer may be soluble in the diluent at processing temperatures. Manufacturing processes which use water or water soluble diluents, such as isopropyl alcohol (IPA), may be desirable examples due to their simplicity and reduced cost. In these examples, high molecular weight hydrophilic polymers which are water soluble at processing temperatures may also be desirable examples.

Examples of high molecular weight hydrophilic polymers may include but are not limited to polyamides, polylactones, polyimides, polylactams and functionalized polyamides, polylactones, polyimides, polylactams, such as PVP and copolymers thereof, or alternatively, DMA functionalized by copolymerizing DMA with a lesser molar amount of a hydroxyl-functional monomer such as HEMA, and then reacting the hydroxyl groups of the resulting copolymer with materials containing radical polymerizable groups. High molecular weight hydrophilic polymers may include but are not limited to poly-N-vinyl pyrrolidone, poly-N-vinyl-2-piperidone, poly-N-vinyl-2-caprolactam, poly-N-vinyl-3-methyl-2-caprolactam, poly-N-vinyl-3-methyl-2-piperidone, poly-N-vinyl-4-methyl-2-piperidone, poly-N-vinyl-4-methyl-2-caprolactam, poly-N-vinyl-3-ethyl-2-pyrrolidone, and poly-N-vinyl-4,5-dimethyl-2-pyrrolidone, polyvinylimidazole, poly-N--N-dimethylacrylamide, polyvinyl alcohol, polyacrylic acid, polyethylene oxide, poly 2 ethyl oxazoline, heparin polysaccharides, polysaccharides, mixtures and copolymers (including block or random, branched, multichain, comb-shaped or star-shaped) thereof where poly-N-vinylpyrrolidone (PVP) may be a desirable example where PVP has been added to a hydrogel composition to form an interpenetrating network which shows a low degree of surface friction and a low dehydration rate.

Additional components or additives, which may generally be known in the art, may also be included. Additives may include but are not limited to ultra-violet absorbing compounds, photo-initiators such as CGI 819, reactive tints, antimicrobial compounds, pigments, photochromic, release agents, combinations thereof and the like.

The method associated with these types of separators may also include receiving CGI 819; and then mixing with PVP, HEMA, EGDMA and IPA; and then curing the resulting mixture with a heat source or an exposure to photons. In some examples the exposure to photons may

occur where the photons' energy is consistent with a wavelength occurring in the ultraviolet portion of the electromagnetic spectrum. Other methods of initiating polymerization generally performed in polymerization reactions are within the scope of the present invention.

Interconnects

Interconnects may allow current to flow to and from the battery in connection with an external circuit. Such interconnects may interface with the environments inside and outside the battery, and may cross the boundary or seal between those environments. These interconnects may be considered as traces, making connections to an external circuit, passing through the battery seal, and then connecting to the current collectors inside the battery. As such, these interconnects may have several requirements. Outside the battery, the interconnects may resemble typical printed circuit traces. They may be soldered to, or otherwise connect to, other traces. In an example where the battery is a separate physical element from a circuit board comprising an integrated circuit, the battery interconnect may allow for connection to the external circuit. This connection may be formed with solder, conductive tape, conductive ink or epoxy, or other means. The interconnect traces may need to survive in the environment outside the battery, for example, not corroding in the presence of oxygen.

As the interconnect passes through the battery seal, it may be of critical importance that the interconnect coexist with the seal and permit sealing. Adhesion may be required between the seal and interconnect in addition to the adhesion which may be required between the seal and battery package. Seal integrity may need to be maintained in the presence of electrolyte and other materials inside the battery. Interconnects, which may typically be metallic, may be known as points of failure in battery packaging. The electrical potential and/or flow of current may increase the tendency for electrolyte to "creep" along the interconnect. Accordingly, an interconnect may need to be engineered to maintain seal integrity.

Inside the battery, the interconnects may interface with the current collectors or may actually form the current collectors. In this regard, the interconnect may need to meet the requirements of the current collectors as described herein, or may need to form an electrical connection to such current collectors.

One class of candidate interconnects and current collectors is metal foils. Such foils are available in thickness of 25 microns or less, which make them suitable for very thin batteries. Such foil may also be sourced with low surface roughness and contamination, two factors which

may be critical for battery performance. The foils may include zinc, nickel, brass, copper, titanium, other metals, and various alloys.

Current Collectors and Electrodes

Many of the current collector and electrode designs are envisioned to be formed by the deposition of metal films upon a sidewall, or by the use of metallic wires as substrates to form the current collectors and electrodes. Examples of these have been illustrated. Nevertheless, there may be some designs that utilize other current collector or electrode designs in a clamshell battery format.

In some examples of zinc carbon and Leclanche cells, the cathode current collector may be a sintered carbon rod. This type of material may face technical hurdles for thin electrochemical cells of the present invention. In some examples, printed carbon inks may be used in thin electrochemical cells to replace a sintered carbon rod for the cathode current collector, and in these examples, the resulting device may be formed without significant impairment to the resulting electrochemical cell. Typically, said carbon inks may be applied directly to packaging materials which may comprise polymer films, or in some cases metal foils. In the examples where the packaging film may be a metal foil, the carbon ink may need to protect the underlying metal foil from chemical degradation and/or corrosion by the electrolyte. Furthermore, in these examples, the carbon ink current collector may need to provide electrical conductivity from the inside of the electrochemical cell to the outside of the electrochemical cell, implying sealing around or through the carbon ink.

Carbon inks also may be applied in layers that have finite and relatively small thickness, for example, 10 to 20 microns. In a thin electrochemical cell design in which the total internal package thickness may only be about 100 to 150 microns, the thickness of a carbon ink layer may take up a significant fraction of the total internal volume of the electrochemical cell, thereby negatively impacting electrical performance of the cell. Further, the thin nature of the overall battery and the current collector in particular may imply a small cross-sectional area for the current collector. As resistance of a trace increases with trace length and decreases with cross-sectional area, there may be a direct tradeoff between current collector thickness and resistance. The bulk resistivity of carbon ink may be insufficient to meet the resistance requirement of thin batteries. Inks filled with silver or other conductive metals may also be considered to decrease

resistance and/or thickness, but they may introduce new challenges such as incompatibility with novel electrolytes. In consideration of these factors, in some examples it may be desirable to realize efficient and high performance thin electrochemical cells of the present invention by utilizing a thin metal foil as the current collector, or to apply a thin metal film to an underlying polymer packaging layer to act as the current collector. Such metal foils may have significantly lower resistivity, thereby allowing them to meet electrical resistance requirements with much less thickness than printed carbon inks.

In some examples, one or more of the clamshell forms may be used as a substrate for electrodes and current collectors, or as current collectors themselves. In some examples, the metals of a clamshell form may have depositions made to their surfaces. For example, metal clamshell pieces may serve as a substrate for a sputtered current collector metal or metal stack. Exemplary metal stacks useful as cathode current collectors may be Ti-W (titanium-tungsten) adhesion layers and Ti (titanium) conductor layers. Exemplary metal stacks useful as anode current collectors may be Ti-W adhesion layers, Au (gold) conductor layers, and In (indium) deposition layers. Other examples of anode and cathode current collects may include nickel, brass, aluminum and copper. Exotic materials may include graphene and carbon nanotubes.

The thickness of the PVD layers may be less than 500 nm in total. If multiple layers of metals are used, the electrochemical and barrier properties may need to be compatible with the battery. For example, copper may be electroplated on top of a seed layer to grow a thick layer of conductor. Additional layers may be plated upon the copper. However, copper may be electrochemically incompatible with certain electrolytes especially in the presence of zinc. Accordingly, if copper is used as a layer in the battery, it may need to be sufficiently isolated from the battery electrolyte. Alternatively, copper may be excluded or another metal substituted.

Wires made from numerous materials may also be used to form current collectors and/or substrates for electrodes. In some examples, the metal conductor may penetrate an insulator material such as glass or ceramic to provide an isolated electrical current collector contact. In some examples the wire may be made of titanium. In other examples, other base metals including but not limited to Aluminum, Tungsten, Copper, Gold, Silver, Platinum may be used and may have surface films applied.

Cathode Mixtures and Depositions

There may be numerous cathode chemical(s) mixtures that may be consistent with the concepts of the present invention. In some examples, a cathode mixture, which may be a term for a chemical formulation used to form a battery's cathode, may be applied as a paste, gel, suspension, or slurry, and may comprise a transition metal oxide such as manganese dioxide, some form of conductive additive which, for example, may be a form of conductive powder such as carbon black or graphite, and a water-soluble polymer such as polyvinylpyrrolidone (PVP) or some other binder additive. In some examples, other components may be included such as one or more of binders, electrolyte salts, corrosion inhibitors, water or other solvents, surfactants, rheology modifiers, and other conductive additives, such as, conductive polymers. Once formulated and appropriately mixed, the cathode mixture may have a desirable rheology that allows it to either be dispensed onto desired portions of the separator and/or cathode current collector, or squeegeed through a screen or stencil in a similar manner. In some examples, the cathode mixture may be dried before being used in later cell assembly steps, while in other examples, the cathode may contain some or all of the electrolyte components, and may only be partially dried to a selected moisture content.

The transition metal oxide may, for example, be manganese dioxide. The manganese dioxide which may be used in the cathode mixture may be, for example, electrolytic manganese dioxide (EMD) due to the beneficial additional specific energy that this type of manganese dioxide provides relative to other forms, such as natural manganese dioxide (NMD) or chemical manganese dioxide (CMD). Furthermore, the EMD useful in batteries of the present invention may need to have a particle size and particle size distribution that may be conducive to the formation of depositable or printable cathode mixture pastes/slurries. Specifically, the EMD may be processed to remove significant large particulate components that may be considered large relative to other features such as battery internal dimensions, separator thicknesses, dispense tip diameters, stencil opening sizes, or screen mesh sizes. Particle size optimization may also be used to improve performance of the battery, for example, internal impedance and discharge capacity.

Milling is the reduction of solid materials from one average particle size to a smaller average particle size, by crushing, grinding, cutting, vibrating, or other processes. Milling may also be used to free useful materials from matrix materials in which they may be embedded, and to concentrate minerals. A mill is a device that breaks solid materials into smaller pieces by

grinding, crushing, or cutting. There may be several means for milling and many types of materials processed in them. Such means of milling may include: ball mill, bead mill, mortar and pestle, roller press, and jet mill among other milling alternatives. One example of milling may be jet milling. After the milling, the state of the solid is changed, for example, the particle size, the particle size disposition and the particle shape. Aggregate milling processes may also be used to remove or separate contamination or moisture from aggregate to produce "dry fills" prior to transport or structural filling. Some equipment may combine various techniques to sort a solid material into a mixture of particles whose size is bounded by both a minimum and maximum particle size. Such processing may be referred to as “classifiers” or “classification.”

Milling may be one aspect of cathode mixture production for uniform particle size distribution of the cathode mixture ingredients. Uniform particle size in a cathode mixture may assist in viscosity, rheology, electroconductivity, and other properties of a cathode. Milling may assist these properties by controlling agglomeration, or a mass collection, of the cathode mixture ingredients. Agglomeration – the clustering of disparate elements, which in the case of the cathode mixture, may be carbon allotropes and transition metal oxides – may negatively affect the filling process by leaving voids in the desired cathode cavity as illustrated in Figs. 11A-11J described in detail below.

Also, filtration may be another important step for the removal of agglomerated or unwanted particles. Unwanted particles may include over-sized particles, contaminates, or other particles not explicitly accounted for in the preparation process. Filtration may be accomplished by means such as filter-paper filtration, vacuum filtration, chromatography, microfiltration, and other means of filtration.

In some examples, EMD may have an average particle size of 7 microns with a large particle content that may contain particulates up to about 70 microns. In alternative examples, the EMD may be sieved, further milled, or otherwise separated or processed to limit large particulate content to below a certain threshold, for example, 25 microns or smaller.

The cathode may also comprise silver oxides, silver chlorides or nickel oxyhydroxide. Such materials may offer increased capacity and less decrease in loaded voltage during discharge relative to manganese dioxide, both desirable properties in a battery. Batteries based on these cathodes may have current examples present in industry and literature. A novel microbattery utilizing a silver dioxide cathode may include a biocompatible electrolyte, for example, one

comprising zinc chloride and/or ammonium chloride instead of potassium hydroxide.

Some examples of the cathode mixture may include a polymeric binder. The binder may serve a number of functions in the cathode mixture. The primary function of the binder may be to create a sufficient inter-particle electrical network between EMD particles and carbon particles. A secondary function of the binder may be to facilitate mechanical adhesion and electrical contact to the cathode current collector. A third function of the binder may be to influence the rheological properties of the cathode mixture for advantageous dispensing and/or stenciling/screening. Still, a fourth function of the binder may be to enhance the electrolyte uptake and distribution within the cathode.

The choice of the binder polymer as well as the amount to be used may be beneficial to the function of the cathode in the electrochemical cell of the present invention. If the binder polymer is too soluble in the electrolyte to be used, then the primary function of the binder – electrical continuity – may be drastically impacted to the point of cell non-functionality. On the contrary, if the binder polymer is insoluble in the electrolyte to be used, portions of EMD may be ionically insulated from the electrolyte, resulting in diminished cell performance such as reduced capacity, lower open circuit voltage, and/or increased internal resistance.

The binder may be hydrophobic; it may also be hydrophilic. Examples of binder polymers useful for the present invention comprise PVP, polyisobutylene (PIB), rubbery triblock copolymers comprising styrene end blocks such as those manufactured by Kraton Polymers, styrene-butadiene latex block copolymers, polyacrylic acid, hydroxyethylcellulose, carboxymethylcellulose, fluorocarbon solids such as polytetrafluoroethylene, cements including Portland cement, among others.

A solvent may be one component of the cathode mixture. A solvent may be useful in wetting the cathode mixture, which may assist in the particle distribution of the mixture. One example of a solvent may be toluene. Also, a surfactant may be useful in wetting, and thus distribution, of the cathode mixture. One example of a surfactant may be a detergent, such as Triton™ QS-44 available from the Dow Chemical Company. Triton™ QS-44 may assist in the dissociation of aggregated ingredients in the cathode mixture, allowing for a more uniform distribution of the cathode mixture ingredients.

A conductive carbon may typically be used in the production of a cathode. Carbon is capable of forming many allotropes, or different structural modifications. Different carbon

allotropes have different physical properties allowing for variation in electroconductivity. For example, the “springiness” of carbon black may help with adherence of a cathode mixture to a current collector. However, in energization elements requiring relatively low amounts of energy, these variations in electroconductivity may be less important than other favorable properties such as density, particle size, heat conductivity, and relative uniformity, among other properties. Examples of carbon allotropes include: diamond, graphite, graphene, amorphous carbon (informally called carbon black), buckminsterfullerenes, glassy carbon (also called vitreous carbon), carbon aerogels, and other possible forms of carbon capable of conducting electricity. One example of a carbon allotrope may be graphite.

In some examples the cathode may be deposited upon a clamshell wall. clamshell walls may be metallic in some examples and may have cathode chemicals such as manganese dioxide electrodeposited upon them. In other examples coatings of electrolytic manganese dioxide may be formed upon cathode collectors.

Anodes and Anode Corrosion Inhibitors

The anode for the clamshell battery of the present invention may, for example, comprise zinc. In traditional zinc-carbon batteries, a zinc anode may take the physical form of a can in which the contents of the electrochemical cell may be contained. For the battery of the present invention, a zinc can may be an example but there may be other physical forms of zinc that may prove desirable to realize ultra-small battery designs.

Electroplating of zinc is a process type in numerous industrial uses, for example, for the protective or aesthetic coating of metal parts. In some examples, electroplated zinc may be used to form thin and conformal anodes useful for batteries of the present invention. Furthermore, the electroplated zinc may be patterned in many different configurations, depending on the design intent. A facile means for patterning electroplated zinc may be processing with the use of a photomask or a physical mask. In the case of the photomask, a photoresist may be applied to a conductive substrate, the substrate on which zinc may subsequently be plated. The desired plating pattern may be then projected to the photoresist by means of a photomask, thereby causing curing of selected areas of photoresist. The uncured photoresist may then be removed with appropriate solvent and cleaning techniques. The result may be a patterned area of conductive material that may receive an electroplated zinc treatment. While this method may

provide benefit to the shape or design of the zinc to be plated, the approach may require use of available photopatternable materials, which may have constrained properties to the overall cell package construction. Consequently, new and novel methods for patterning zinc may be required to realize some designs of thin microbatteries of the present invention.

The zinc mask may be placed and then electroplating of one or more metallic materials may be performed. In some examples, zinc may be electroplated directly onto an electrochemically compatible anode current collector foil such as brass. In alternate design examples where the anode side packaging comprises a polymer film or multi-layer polymer film upon which seed metallization has been applied, zinc, and/or the plating solutions used for depositing zinc, may not be chemically compatible with the underlying seed metallization. Manifestations of lack of compatibility may include film cracking, corrosion, and/or exacerbated H_2 evolution upon contact with cell electrolyte. In such a case, additional metals may be applied to the seed metal-to-affect better overall chemical compatibility in the system. One metal that may find particular utility in electrochemical cell constructions may be indium. Indium may be widely used as an alloying agent in battery grade zinc with its primary function being to provide an anti-corrosion property to the zinc in the presence of electrolyte. In some examples, indium may be successfully deposited on various seed metallizations such as Ti-W and Au. Resulting films of 1-3 microns of indium on said seed metallization layers may be low-stress and adherent. In this manner, the anode-side packaging film and attached current collector having an indium top layer may be conformable and durable. In some examples, it may be possible to deposit zinc on an indium-treated surface, the resulting deposit may be very non-uniform and nodular. This effect may occur at lower current density settings, for example, 20 amps per square foot (ASF). As viewed under a microscope, nodules of zinc may be observed to form on the underlying smooth indium deposit. In certain electrochemical cell designs, the vertical space allowance for the zinc anode layer may be up to about 5-10 microns thick, but in some examples, lower current densities may be used for zinc plating, and the resulting nodular growths may grow taller than the desired maximum anode vertical thickness. It may be that the nodular zinc growth stems from a combination of the high overpotential of indium and the presence of an oxide layer of indium.

In some examples, higher current density DC plating may overcome the relatively large nodular growth patterns of zinc on indium surfaces. For example, 100 ASF plating conditions

may result in nodular zinc, but the size of the zinc nodules may be drastically reduced compared to 20 ASF plating conditions. Furthermore, the number of nodules may be vastly greater under 100 ASF plating conditions. The resulting zinc film may ultimately coalesce to a more or less uniform layer with only some residual feature of nodular growth while meeting the vertical space allowance of about 5-10 microns.

An added benefit of indium in the electrochemical cell may be reduction of H_2 formation, which may be a slow process that occurs in aqueous electrochemical cells containing zinc. The indium may be beneficially applied to one or more of the anode current collector, the anode itself as a co-plated alloying component, or as a surface coating on the electroplated zinc. For the latter case, indium surface coatings may be desirably applied *in-situ* by way of an electrolyte additive such as indium trichloride or indium acetate. When such additives may be added to the electrolyte in small concentrations, indium may spontaneously plate on exposed zinc surfaces as well as portions of exposed anode current collector.

Zinc and similar anodes commonly used in commercial primary batteries may typically be found in sheet, rod, and paste forms. The anode of a miniature, biocompatible battery may be of similar form, e.g. thin foil, or may be plated as previously mentioned. The properties of this anode may differ significantly from those in existing batteries, for example, because of differences in contaminants or surface finish attributed to machining and plating processes. Accordingly, the electrodes and electrolyte may require special engineering to meet capacity, impedance, and shelf life requirements. For example, special plating process parameters, plating bath composition, surface treatment, and electrolyte composition may be needed to optimize electrode performance.

Battery Architecture and Fabrication

Battery architecture and fabrication technology may be closely intertwined. As has been discussed in earlier sections of the present invention, a battery may have the following elements: cathode, anode, separator, electrolyte, cathode current collector, anode current collector, and clamshell form containment. In some examples, designs may have dual-use components, such as, using a metal package clamshell to double as a current collector. From a relative volume and thickness standpoint, these elements may be nearly all the same volume, except for the cathode. In some examples, the electrochemical system may require about two (2) to ten (10) times the

volume of cathode as anode due to significant differences in mechanical density, energy density, discharge efficiency, material purity, and the presence of binders, fillers, and conductive agents.

Biocompatibility Aspects of Batteries

The batteries according to the present invention may have important aspects relating to safety and biocompatibility. In some examples, batteries for biomedical devices may need to meet requirements above and beyond those for typical usage scenarios. In some examples, design aspects may be considered in relation to stressing events. For example, the safety of an electronic contact lens may need to be considered in the event a user breaks the lens during insertion or removal. In another example, design aspects may consider the potential for a user to be struck in the eye by a foreign object. Still further examples of stressful conditions that may be considered in developing design parameters and constraints may relate to the potential for a user to wear the lens in challenging environments like the environment under water or the environment at high altitude in non-limiting examples.

The safety of such a device may be influenced by: the materials that the device is formed with or from; by the quantities of those materials employed in manufacturing the device; and by the packaging applied to separate the devices from the surrounding on- or in-body environment. In an example, pacemakers may be a typical type of biomedical device which may include a battery and which may be implanted in a user for an extended period of time. In some examples, such pacemakers may typically be packaged with welded, hermetic titanium enclosures, or in other examples, multiple layers of encapsulation. Emerging powered biomedical devices may present new challenges for packaging, especially battery packaging. These new devices may be much smaller than existing biomedical devices, for example, an electronic contact lens or pill camera may be significantly smaller than a pacemaker. In such examples, the volume and area available for packaging may be greatly reduced. An advantage of the limited volume may be that amounts of materials and chemicals may be so small as to inherently limit the exposure potential to a user to a level below a safety limit.

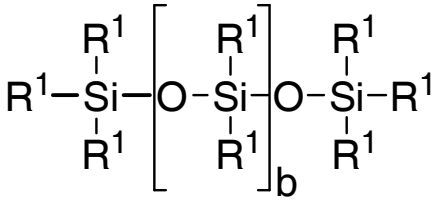
The clamshell based approach particularly when it includes hermetic seals may provide means to enhance biocompatibility. Each of the clamshell components may provide significant barrier to ingress and egress of materials. Further, with many of the hermetic sealing processes as have been described herein, a battery may be formed that has superior biocompatibility.

Contact Lens Skirts

In some examples, a preferred encapsulating material that may form an encapsulating layer in a biomedical device may include a silicone containing component. In an example, this encapsulating layer may form a lens skirt of a contact lens. A “silicone-containing component” is one that contains at least one [-Si-O-] unit in a monomer, macromer or prepolymer. Preferably, the total Si and attached O are present in the silicone-containing component in an amount greater than about 20 weight percent, and more preferably greater than 30 weight percent of the total molecular weight of the silicone-containing component. Useful silicone-containing components preferably comprise polymerizable functional groups such as acrylate, methacrylate, acrylamide, methacrylamide, vinyl, N-vinyl lactam, N-vinylamide, and styryl functional groups.

In some examples, the ophthalmic lens skirt, also called an insert-encapsulating layer, that surrounds the insert may be comprised of standard hydrogel ophthalmic lens formulations. Exemplary materials with characteristics that may provide an acceptable match to numerous insert materials may include, the Narafilcon family (including Narafilcon A and Narafilcon B), and the Etafilcon family (including Etafilcon A). A more technically inclusive discussion follows on the nature of materials consistent with the art herein. One ordinarily skilled in the art may recognize that other material other than those discussed may also form an acceptable enclosure or partial enclosure of the sealed and encapsulated inserts and should be considered consistent and included within the scope of the claims.

Suitable silicone containing components include compounds of Formula I



where

R1 is independently selected from monovalent reactive groups, monovalent alkyl groups, or monovalent aryl groups, any of the foregoing which may further comprise functionality selected from hydroxy, amino, oxa, carboxy, alkyl carboxy, alkoxy, amido, carbamate, carbonate,

halogen or combinations thereof; and monovalent siloxane chains comprising 1-100 Si-O repeat units which may further comprise functionality selected from alkyl, hydroxy, amino, oxa, carboxy, alkyl carboxy, alkoxy, amido, carbamate, halogen or combinations thereof;

where b = 0 to 500, where it is understood that when b is other than 0, b is a distribution having a mode equal to a stated value;

wherein at least one R1 comprises a monovalent reactive group, and in some examples between one and 3 R1 comprise monovalent reactive groups.

As used herein “monovalent reactive groups” are groups that may undergo free radical and/or cationic polymerization. Non-limiting examples of free radical reactive groups include (meth)acrylates, styryls, vinyls, vinyl ethers, C1-6alkyl(meth)acrylates, (meth)acrylamides, C1-6alkyl(meth)acrylamides, N-vinyllactams, N-vinylamides, C2-12alkenyls, C2-12alkenylphenyls, C2-12alkenylnaphthyls, C2-6alkenylphenylC1-6alkyls, O-vinylcarbamates and O-vinylcarbonates. Non-limiting examples of cationic reactive groups include vinyl ethers or epoxide groups and mixtures thereof. In one embodiment, the free radical reactive groups comprise (meth)acrylate, acryloxy, (meth)acrylamide, and mixtures thereof.

Suitable monovalent alkyl and aryl groups include unsubstituted monovalent C1 to C16alkyl groups, C6-C14 aryl groups, such as substituted and unsubstituted methyl, ethyl, propyl, butyl, 2-hydroxypropyl, propoxypropyl, polyethyleneoxypropyl, combinations thereof and the like.

In one example, b is zero, one R1 is a monovalent reactive group, and at least 3 R1 are selected from monovalent alkyl groups having one to 16 carbon atoms, and in another example from monovalent alkyl groups having one to 6 carbon atoms. Non-limiting examples of silicone components of this embodiment include 2-methyl-,2-hydroxy-3-[3-[1,3,3,3-tetramethyl-1-[(trimethylsilyl)oxy]disiloxanyl]propoxy]propyl ester (“SiGMA”),

2-hydroxy-3-methacryloxypropyloxypropyl-tris (trimethylsiloxy)silane,

3-methacryloxypropyltris(trimethylsiloxy)silane ("TRIS"),

3-methacryloxypropylbis(trimethylsiloxy)methylsilane and

3-methacryloxypropylpentamethyl disiloxane.

In another example, b is 2 to 20, 3 to 15 or in some examples 3 to 10; at least one terminal R1 comprises a monovalent reactive group and the remaining R1 are selected from monovalent alkyl groups having 1 to 16 carbon atoms, and in another embodiment from

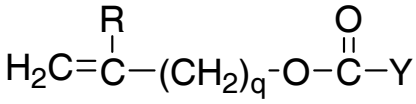
monovalent alkyl groups having 1 to 6 carbon atoms. In yet another embodiment, b is 3 to 15, one terminal R1 comprises a monovalent reactive group, the other terminal R1 comprises a monovalent alkyl group having 1 to 6 carbon atoms and the remaining R1 comprise monovalent alkyl group having 1 to 3 carbon atoms. Non-limiting examples of silicone components of this embodiment include (mono-(2-hydroxy-3-methacryloxypropyl)-propyl ether terminated polydimethylsiloxane (400-1000 MW)) ("OH-mPDMS"), monomethacryloxypropyl terminated mono-n-butyl terminated polydimethylsiloxanes (800-1000 MW), (“mPDMS”).

In another example, b is 5 to 400 or from 10 to 300, both terminal R1 comprise monovalent reactive groups and the remaining R1 are independently selected from monovalent alkyl groups having 1 to 18 carbon atoms, which may have ether linkages between carbon atoms and may further comprise halogen.

In one example, where a silicone hydrogel lens is desired, the lens of the present invention will be made from a reactive mixture comprising at least about 20 and preferably between about 20 and 70%wt silicone containing components based on total weight of reactive monomer components from which the polymer is made.

In another embodiment, one to four R1 comprises a vinyl carbonate or carbamate of the formula:

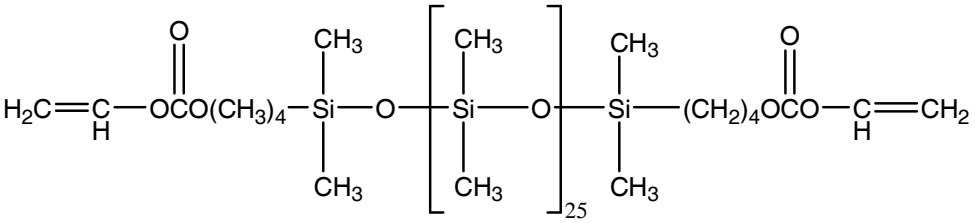
Formula II



wherein: Y denotes O-, S- or NH-;

R denotes, hydrogen or methyl; d is 1, 2, 3 or 4; and q is 0 or 1.

The silicone-containing vinyl carbonate or vinyl carbamate monomers specifically include: 1,3-bis[4-(vinyloxycarbonyloxy)but-1-yl]tetramethyl-disiloxane; 3-(vinyloxycarbonylthio) propyl-[tris (trimethylsiloxy)silane]; 3-[tris(trimethylsiloxy)silyl] propyl allyl carbamate; 3-[tris(trimethylsiloxy)silyl] propyl vinyl carbamate; trimethylsilylethyl vinyl carbonate; trimethylsilylmethyl vinyl carbonate, and



Where biomedical devices with modulus below about 200 are desired, only one R1 shall comprise a monovalent reactive group and no more than two of the remaining R1 groups will comprise monovalent siloxane groups.

Another class of silicone-containing components includes polyurethane macromers of the following formulae:

Formulae IV-VI

(*D*A*D*G)a *D*D*E1;

E(*D*G*D*A)a *D*G*D*E1 or;

E(*D*A*D*G)a *D*A*D*E1

wherein:

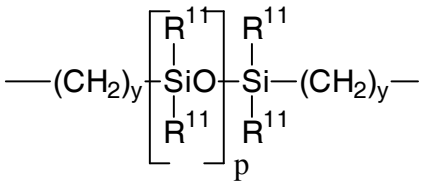
D denotes an alkyl diradical, an alkyl cycloalkyl diradical, a cycloalkyl diradical, an aryl diradical or an alkylaryl diradical having 6 to 30 carbon atoms,

G denotes an alkyl diradical, a cycloalkyl diradical, an alkyl cycloalkyl diradical, an aryl diradical or an alkylaryl diradical having 1 to 40 carbon atoms and which may contain ether, thio or amine linkages in the main chain;

* denotes a urethane or ureido linkage;

a is at least 1;

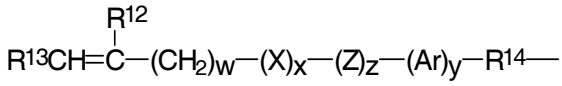
A denotes a divalent polymeric radical of formula:



Formula VII

R11 independently denotes an alkyl or fluoro-substituted alkyl group having 1 to10 carbon atoms, which may contain ether linkages between carbon atoms; y is at least 1; and p provides a moiety weight of 400 to 10,000; each of E and E1 independently denotes a polymerizable unsaturated organic radical represented by formula:

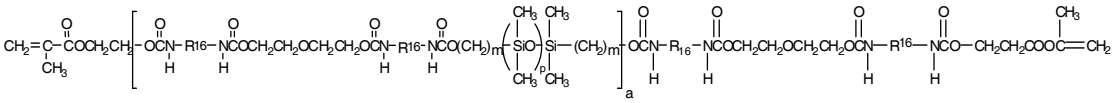
Formula VIII



wherein: R12 is hydrogen or methyl; R13 is hydrogen, an alkyl radical having 1 to 6 carbon atoms, or a —CO—Y—R15 radical wherein Y is —O—,Y—S— or —NH—; R14 is a divalent radical having 1 to 12 carbon atoms; X denotes —CO— or —OCO—; Z denotes —O— or —NH—; Ar denotes an aromatic radical having 6 to 30 carbon atoms; w is 0 to 6; x is 0 or 1; y is 0 or 1; and z is 0 or 1.

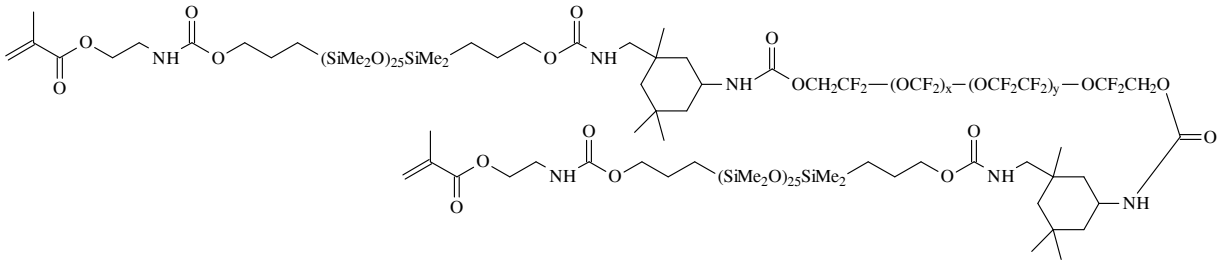
A preferred silicone-containing component is a polyurethane macromer represented by the following formula:

Formula IX



wherein R16 is a diradical of a diisocyanate after removal of the isocyanate group, such as the diradical of isophorone diisocyanate. Another suitable silicone containing macromer is compound of formula X (in which x + y is a number in the range of 10 to 30) formed by the reaction of fluoroether, hydroxy-terminated polydimethylsiloxane, isophorone diisocyanate and isocyanatoethylmethacrylate.

Formula X



Other silicone containing components suitable for use in this invention include macromers containing polysiloxane, polyalkylene ether, diisocyanate, polyfluorinated hydrocarbon, polyfluorinated ether and polysaccharide groups; polysiloxanes with a polar fluorinated graft or side group having a hydrogen atom attached to a terminal difluoro-substituted carbon atom; hydrophilic siloxanyl methacrylates containing ether and siloxanyl linkanges and crosslinkable monomers containing polyether and polysiloxanyl groups. In some examples, the polymer backbone may have zwitterions incorporated into it. These zwitterions may exhibit charges of both polarity along the polymer chain when the material is in the presence of a solvent. The presence of the zwitterions may improve wettability of the polymerized material. In some examples, any of the foregoing polysiloxanes may also be used as an encapsulating layer in the present invention.

Electroless Plating of Metallic Layers to Seal Battery Structures

Metal plating has great utility in many applications, for aesthetic purposes in jewelry or metal appliances, adding corrosion resistance to industrial machinery or surfaces of appliances or materials, or even to add electrical conductivity to a surface, as non-limiting examples. In a biocompatible energization element, plating which surrounds the battery body may be useful to form a sealed barrier to material ingress or egress. There may be numerous methods to plate a metal layer upon a battery structure, but the basic premise may involve depositing a coating or layer of a metallic material on the surface of the exterior surfaces of the battery. Metal plating may be done with numerous types of metals, including copper, nickel, platinum, rhodium, and many others. The result of metal plating may be the depositing of metals on numerous types of other materials, including but not limited to, other metals, semiconductors, or plastics.

Typical examples of metal plating methods may include electroplating and electroless plating; both involve coating a material with a layer of metal. However, electroplating may involve an induced electrical charge on the material to be coated, whereas electroless plating may

not involve electricity, and may involve a chemical reaction that deposits the metal.

Electroplating may involve numerous steps to achieve a desired finish, consistent thickness of deposited material, and other qualities desired in a successful coating. In some examples, a piece may first be thoroughly pre-treated, to ensure effective plating. Pre-treating steps may include, but are not limited to polishing, masking, etching, washing, steam cleaning, rinsing, ultrasonic washing, or electro-cleaning as non-limiting examples. In some examples, the pre-treatment may remove oil, grease, or other contaminants from the surface of a piece to be coated.

After successful pre-treatment, the object to be plated may be placed in a solution bath containing the metal in ionic form to be deposited. Typically, electroplating methods may involve inducing a positive electrical charge to the solution bath, and a negative electrical charge to the object to be plated. This difference in electrical charge may induce an attractive electrical force between the metal particles in the solution bath and the plated object. This attractive force may chemically modify the ionic state and bind the metal particles from the solution bath to the object, coating its surface.

Depending on the composition of the material to be plated and the solution bath, certain conditions including but not limited to, voltage, pH of the solution bath, concentration of metal in the solution, duration of plating and ambient temperature, should preferably be maintained to ensure effective plating. Adjusting these conditions may change various aspects of the plating, including but not limited to the finish of the resulting metal surface, the color of the deposited metal, the speed of deposition, or the thickness of the deposited metal. Other ambient conditions, such as air bubbles or contaminants in the solution bath, may also effect the resulting finish; these imperfections may be resolved by agitating the bath or applying a carbon treatment to the bath, as non-limiting examples. In some examples, it may be important to reduce all causes of imperfections in a plated surface upon a biocompatible energization element; since such imperfections may reduce the effectiveness of a seal.

Various forms of post-treating may also be necessary to ensure success in electroplating, including but not limited to rinsing, steam cleaning, heat drying or other methods.

Electroless plating may involve numerous steps to achieve a desired finish, consistent thickness of deposited material, and other qualities desired in a successful coating. Electroless plating may have the same requirements relating to coating and sealing of a biocompatible

energization element as have been discussed relating to electroplating. First, a piece to be coated may be thoroughly pre-treated, to ensure effective plating. Pre-treating steps may include, but are not limited to cleaning. Cleaning may help remove contaminants and/or debris remaining from any prior processing steps of the object to be coated, as well as oil, grease, or other contaminants from the surface of a piece to be coated. Cleaning may be achieved with acids or other types of cleaning solutions; in choosing the proper cleaning solution, it may be important to consider what material or debris is to be removed, the temperature at which the cleaned piece (and thus solution) are kept during cleaning, the desired concentration of the cleaning solution, how much mechanical work (agitation, etc.) may be required with the cleaner, as well as other possible aspects.

Pre-treating steps may also include etching, masking, rinsing, drying, and submersing the object to be plated in an activator pre-dip solution as well as an activator solution, as non-limiting examples. Etching may involve using a chemical and/or mechanical means, as non-limiting examples, to etch a profile into a work object to be plated, that will serve as a prescribed location for plating. A pre-dip solution may contain ions common to those of the activator solution, which will prepare the work piece for the actual plating; this pre-dip solution may be typically designed to be applied to the work piece and not rinsed off before it is added to the activator solution. A pre-dip solution may be less sensitive to metal ion contamination than an accompanying activator solution. There may be numerous advantages for the use of a pre-dip solution including in a non-limiting sense a result that is less expensive, and may save the activator solution from metal ion contamination, to help the process be more efficient create results of higher quality.

After the pre-dip, an activator solution may be applied to the work piece. An activator may contain certain ions held in a reduced state by other ions in solution; in practice, the reduced ions may be mechanically held to the bonding surface, which act as a catalyst for the chemical reaction that will facilitate electroless plating. While a sufficient layer of activator solution on the surface of the work piece is important to catalyze the electroless plating process, it may be important to note that too thick a layer of activator solution may possibly act as a barrier to proper adhesion of the plated metal, and should be avoided.

Pre-treating steps may also include a post-activation step, or acceleration as it may also commonly be called. This step may serve to enable the activating species, deposited from the

activator solution in the pre-dip step, to be as 'active' as possible, prior to the actual electroless plating step. This step may allow the activating species to interact more readily with the electroless plating solution in the actual plating step; not only may this decrease the initiation time for the electroless plating reaction, it may also minimize the potential of the activating species contaminating the electroless plating solution, increasing the quality of the plating result. If this post-activation step is left out, the activator solution deposited on the work piece may contain marginally adherent species, that may result in contamination of the electroless plating solution and may prolong the initiation of the electroless deposition reaction. In some examples, post-activating solutions may be acidic, and may act to remove metal oxides that can form on the work object surfaces due to rinsing steps between the activator and post-activator; while this is good for the work object, it may serve to contaminate the post-activator, and the solution bath may need to be replenished after it becomes overly concentrated with these metals or other contaminants.

After pre-treatment, a work object may be submersed in a chemical bath, containing the following possible ingredients as non-limiting examples: metal salts (of the metal desired for deposition), a reducing agent, alkaline hydroxide, chelating agents, stabilizers, brighteners, and optionally wetting agents. The reducing agent and hydroxide ions may provide the reducing force necessary for the deposition of the metal contained within the solution bath. The deposition reaction may be initiated by the catalytic species that may have been applied to the surface of the work object during the activator step. Typical electroless plating bath choices may depend on several factors, including but not limited to temperature, desired plating speed, desired plating thickness, and metal concentration (and thus repeatability of the plating reaction for multiple work objects in a single bath, although this repeatability may be seen to depend on many other factors as well).

Improved Mechanical Strength Through Electroless Plating

In some examples, a desirable solution for improving mechanical strength may involve electroless plating as a technique for creating a conformal barrier coating. Principles of electroless plating have been discussed herein. Electroless plating may deposit a conformal metal layer onto a conducting or nonconductive coating. Electroless plating baths have been developed for depositing metals such as nickel, copper, and tin onto plastic surfaces. The electroless plated

metal may then be further plated using electroless plating or electroplating with a wide variety of metals, including nickel, copper, tin, gold, silver, cadmium, and rhodium. In some cases, because of cost, corrosion, and/or mechanical concerns, it may be desirable to use a layered structure incorporating more than one electroplate layer.

The coating may be made arbitrarily thick, and may mechanically reinforce the battery in addition to acting as a barrier. This mechanical reinforcement may force hydrogen out the sides of the cell, reducing or eliminating bulging due to hydrogen gas generation during zinc corrosion. To avoid the creation of a short circuit between the battery terminals due to plating, it may be necessary to mask one or both terminals using a nonconductive material during the plating process.

In some examples a layer may be formed with electroless plating where electroless plating and/or electroplating may be used to create a roughly 1 mil (25 microns) conformal copper coating on them. Platers' tape may be used to mask both terminals of these batteries during plating to avoid short circuiting the batteries during the plating processing.

The tape may next be removed from the terminals, and then the batteries may be aged at room temperature at 50% relative humidity.

Insulating Clamshell Halves in Battery Component Design

In some examples, battery elements may be designed in ways that segment the regions of active battery chemical(s) with robust seals. In some examples, these seals may be hermetic. There may be numerous advantages from the division of the active battery components into hermetically sealed segments which may commonly take the shape of clamshells. Clamshell form batteries with external components made of plastics, metals, glasses or ceramics may form an ideal architectural design aspect. In some examples, the materials may be chosen such that seals that are formed between the materials may be considered "hermetic" in that the diffusion of molecules across the seal may be beneath a specification under a test protocol for the "type of seal, or the type of process used to create the seal." For example, electronic components such as batteries may have a volume of air or a volume "equivalent to an amount of air" within them, and a hermetic specification may relate to a seal having a leak rate less than a certain level that would replace 50% of the volume of the device with air from outside the seal. A large form of a clamshell battery may be formed by one or more of the processes to be discussed in coming

sections of the specification where a low level of leak may be measured to determine the seal is hermetic for the given battery. In practice, small clamshell batteries or microbatteries such as those according to the present disclosure may have a volume on the order of 10^{-4} cm^3 in some examples. The ability of leak detection equipment to measure a sufficiently low leak rate to ascertain that a seal of the microbattery is "hermetic" may beyond the current technology of leak detection; nevertheless, the seal of the microbattery may be termed hermetic because the same processing and materials when applied to a large form of the battery results in a measurably low leak rate sufficient to deem the seal processing and materials to be "hermetic."

In experiments, various materials and seal types have been investigated for sealing aspects. It may be possible to characterize the seal integrity as well as the bulking integrity to transfer of water molecules, using a metric discussed earlier WVTR which related to water vapor transport. As well, the transport of oxygen across a barrier or seal may be measured. The measurements may be characterized as relative amounts in a sense because, the conditions that a sealed battery may be found in may not exactly relate to the conditions of the measurement. In some examples, the WVTR testing may be performed in a dry chamber for example, so that leak detecting equipment may be able to detect the change in water vapor due to transport across the barrier. This compares to an actual device storage in a biomedical device immersed in aqueous solution for example. Nevertheless, the characteristics of films may be quantified in the test conditions to determine what works well in practice for various materials utilized versus their test measurements. In the following table, exemplary results are displayed for various film types and electroless/electroplated films. In the first column bare films and bare films coated with Si02 are quantified for both the oxygen transfer rate (OTR) and the water vapor transport rate (WVTR). Then various thicknesses of film deposition are overlaid. In a relative comparison a bare film may have a ~1300 higher WVTR than a film with approximately 63 microns of copper deposited upon it. (This may be a minimum value since 0.01 is at the machine lower limit of measurement). Thus coating the clamshell battery forms with electroless deposition may be expected to result in significant improvement in the hermetic character of the battery form.

	OTR, cc/m^2-day	WVTR, g/m^2-day
Bare film	5527	13.92
Bare + SiO_x	66.18	1.783

Copper (0.0003")	1.65	0.123
Copper (0.0003" SiO_x)	0.022	0.01
Copper (0.00063")	0.012	0.01
Copper (0.00065" SiO_x)	0.047	0.037
Tin, (0.0006")	545	0.155
Tin (0.0006" SiO_x)	650	0.55
Tin (0.001")	1.067	0.017
Tin (0.001" SiO_x)	561	0.01

Referring to Figs 2A1, 2A2 and 2A3, basic examples of different types of clamshell form batteries are depicted in cross section. The depicted examples are coplanar forms; however, coplanar examples may have similar clamshell forms and are described in later sections. Referring to Fig 2A1, a basic example of a clamshell form battery 200 with a basic casing of an insulator material split into two "shells" is found. The ledge features are in line with the clamshell body. In the example, two components, which may be formed of semiconductors or insulators, define the top clamshell half 211 and the bottom clamshell half 212 each of which may contain both anode chemicals 221 and cathode chemicals 222. In some examples, the clamshell halves may themselves be surrounded with formed metal tubes that surround the material. In some examples, the cathode chemicals 222 and the anode chemicals 221 may be separated by a separator 240. The separator may run down the middle of the bottom clamshell half 212 until the battery structure is closed at which time it abuts the top clamshell half 211. In some examples, such a configuration may be beneficial for physically separating the anode and the cathode and preventing leakage around the top and bottom of the separator. The battery contacts, which are not shown in the cross-section figure, need to be electrically isolated from each other to form a functional battery, since electrical connection would cause the battery chemical(s) to be exhausted. In the first example, the seal 230 may be formed between in line ledge features of two clam shell halves.

Referring to Fig. 2A2 an exemplary modification of the basic form is illustrated with a clamshell form with protruding ledges 201. In some examples a large sealing surface may result from protruded ledges and form a different form of seal 230A. In some examples a significant amount of protrusion may be utilized to form large seals.

Referring to Fig. 2A3, an exemplary modification of the basic form is illustrated where the top clamshell half 211 is a flat form and the bottom clamshell half 212 is a recessed clamshell

form. A periphery of a flat piece may form the equivalent of a ledge feature of a recessed clamshell piece and may abut and seal with a ledge of a recessed clamshell piece.

In the basic examples of Figs. 2A1, 2A2 and 2A3, the clamshell halves being made of insulators or semiconductors electrically separate the anode and cathode. In some other more complicated forms of clamshell batteries, a metal clamshell may be combined with an insulating clamshell. In some other forms, two metal clam halves may be configured with an insulating piece between them. A clamshell formed of insulating material may be a solid, crystalline type insulating material or may be a form of plastic that can also be an insulative material.

As illustrated in the various examples, at least one seal may be formed between the clamshell halves. In the case of more complex structures, a second seal may be added between metal clamshell halves and an intermediate insulating material. The clamshell halves may be a physical piece which itself acts in the containment of material within the battery and as part of the diffusion barrier to inhibit chemical transfer into or out of the battery. In previous discussion, description of various types of seals including hermetic seals and techniques to form them was discussed. Examples of the seal 230, may be metal-to-ceramic or metal-to-glass seals, ceramic to ceramic, ceramic to glass, glass to glass, plastic to ceramic, plastic to glass and other such combinations.

Referring now to Fig. 2B and Fig. 2C, alternative views of the top and bottom clamshell halves from the form of batteries 200, 201 and 202 which are depicted in Figs. 2A1, 2A2 and 2A3 are illustrated. Fig. 2B may represent a top-down view of a bottom half 212 of a clamshell form battery 200 that may be sealed with a top half 211. The bottom half 212 is illustrated without the corresponding anode and cathode chemicals and thus illustrates the cavity that both chemicals occupy. Fig. 2C represents a bottom-up view of the top half 211.

The bottom half 212 of the clamshell form battery may have an anode region 231 or anode cavity. The cavity may have an electrical connection 262 that electrically connects the anode chemical(s) to an anode contact 261 for the battery. The bottom half 212 may also have a cathode region 232 or cathode cavity. The cathode cavity may have an electrical connection 272 that electrically connects the anode chemical(s) to cathode contact 271. In the illustrated example, the cathode contact 271 and the anode contact 261 reside on portions of the same clamshell half. In some other examples, each clamshell may have one contact along with a connection to the appropriate chemical(s).

When the two clamshell halves are brought together, the top piece may be sealed to the bottom piece at the interface between them. Referring again to Fig 2A1, a seal 230 is illustrated. As shown in Fig. 2B, the seal may actually be a ledge of the material of the clamshell. The interior ledge 235 of the bottom half 212 may correspond and contact the interior ledge 237 of the top half 211 of the clamshell. There are also exterior ledges 234 and 235 described in greater detail below. Various types of seals may be formed on these ledges depending on the material of the clamshells. In some examples for ceramic or semiconducting halves, an S-Bond type seal or brazed seals may be formed on metal layers which may be vapor deposited upon the clamshell halves. Proceeding to Fig. 2D, a close-up of the seal area for the exterior ledge 234 of the bottom half 212 is illustrate with a close-up view. The exterior ledge 236 of the top half 211 may interface with the corresponding exterior ledge 234 of the bottom half 212 and the close-up view may show the region where the seal is formed.

Referring to Fig. 2E, an exemplary side view of the sealing area between the bottom half 212 and top half 211 of the clamshell form battery 200 of Fig. 2A1, as well as an example of layers related to the seal before an activation of a Nanofoil® is made, may be seen. It may be apparent that similar situations may result with the clamshell forms of Fig. 2A2 and 2A3. The top clamshell half 211 and a second clamshell half 212 may be coated with a prewet solder layer on each side for a first solder layer 238 and a second solder layer 239. In between the two solder layers a piece of Nanofoil® material 250 may be located. When the Nanofoil® material is activated it may locally melt the solder layers and form a seal 230. The illustration depicts a butt-type joint, but many other joint structures may be possible including overlapping designs, fluted designs and other types of joints where a piece of Nanofoil® may be located between two surfaces to be sealed that have solder coated surfaces. In other examples the structure of Fig. 2E may be formed by depositing a metal layer onto the ledges of the clamshell halves at the regions to be sealed (such as ledges 234-237). The metal surfaces may be used to solder or braze the metals into a hermetic seal.

In other examples, the clamshell pieces may be formed of metallic pieces, with an intermediate piece made of ceramic or other insulating material as an electrically insulating piece between the metal clamshell pieces. In such examples, each metal clamshell may form a seal to the insulating piece in a structure like that illustrated in Fig. 2E.

In still further examples, the clamshell pieces may be formed of plastic materials. The plastic material may have deposited or attached metal regions for electrodes of the battery, but the seals around the lips of the clamshell halves may be sealed with adhesives or melting by such techniques as ultrasonic melt sealing or laser melt sealing.

There may be numerous materials that may be used as light sensitive sealing agents which might be sensitive to light or UV exposure. Any sealant known in the art may be used but in a non-limiting set of examples of branded adhesives may include: DELO Kaitobond OB614, DELO Kaitobond OM VE 115261, Delo LP 424, DELO Photobond LP VE526279, Dymax 1121-420, Dymax 1121-7401, Dymax 1128A-7401, EMI 10590, EMI optocast 3553, Epotek 301, Epotek 301-2, Epotek OG142-112, Epotek OG142-95, Epotek OG603, Henkel Loctite 3341, Henkel Loctite 3922, Henkel Loctite 3942, Henkel Loctite 5055, Henkel Loctite M-11FL, Momentive RTV 615, Momentive UVLSR 2060, Momentive UVLSR 7070, Norland Optical Adhesive 61, Norland Optical Adhesive 68 ,Norland Optical Adhesive 86, NuSil MED-6010, Nusil MED-6400, Permabond UV 632, Tangent 40093, Tangent 7090, and Threebond 30Y-951.

Referring now to Fig. 3A, an alternative example of a clamshell form battery 300 may be found. In the example, two containment components, the top clamshell component 310 and the bottom clamshell component 330 may form encasings that surround the battery material. The components may comprise silicon or ceramic materials, as non-limiting examples. The anode chemicals 312 may be located within the top clamshell component 310. And, the cathode chemicals 340 may be located within the bottom clamshell component 330. In this example, the dimensions of the top component 310 and bottom component 330 may be identical, so that when sealed to each other, they form a clamshell form battery 300 that is geometrically symmetrical about the horizontal axis formed by the seal. In other practical examples, the volume of the anode chemical in the top clamshell component 310 may be less than the volume of the cathode chemical in the bottom clamshell component 330. The cathode chemicals 340 and the anode chemicals 312 may be separated by a separator 320. The battery contacts need to be isolated from each other to form a functional battery, since electrical connection would cause the battery chemical(s) to be exhausted. The top and bottom clamshell components may be formed of various insulator materials such as ceramics, glasses and plastics in non-limiting examples. The seal may be one of the ceramic to ceramic, ceramic to glass, glass to glass, seals as have been described which may form a hermetic seal.

Referring to Fig. 3B an illustration of an exemplary bottom clamshell half 330 is illustrated along with an exemplary top clamshell half 310 in Fig. 3C. The design of the exemplary clamshell battery is for a single cell battery with an external electrical contact on each half-shell. The bottom clamshell half contains a single cavity 332 for the various battery chemical(s). The cavity is surrounded by a ledge 331. An electrical connection 333 joins the cavity region to an exemplary cathode contact 334. Referring again to Fig. 3C the top clamshell half may have a single cavity for anode chemicals 312 or in some other examples a top plate. An electrical connection 313 may connect the anode of the battery to an anode contact 314. A ledge 311 on the top clamshell half overlaps a ledge 331 on the bottom clamshell half, when the top shell half is placed over the bottom shell half.

Referring to Figs. 3D and 3E another example of the type of clamshell battery illustrated in Fig. 3A is illustrated with multiple battery cells and anode and cathode contacts illustrated on a single half-shell piece that is not covered by parts of the bottom clamshell half. The bottom clamshell half 330 has two cavities 351 and 352 with an electrical contact 353 between the cells. The two cavities would function if the chemical(s) stack of the two cavities is inverted from each other; for example, if cavity 352 had anode chemicals below cathode chemicals while cavity 351 has cathode chemicals below anode chemicals. In other examples the opposite stacks could be formed. Referring again to Fig. 3E, the two cavities 358 and 359 may have electrical connections 354 and 355 which connect each of the two cavities to contacts 356 and 357. The ledges 311 and 331 of the top clamshell half 310 and the bottom clamshell half 330 may be used to form hermetic seals in the manners as have been described in the present description.

Referring to Figs. 3F and 3G a similar example of the type of clamshell battery design as illustrated in Figs. 3D and 3E is illustrated again with multiple cells and exposed contacts on one clamshell half. The bottom clamshell half 330 has two cavities 363 and 364 with an electrical contact 365 between the cells. The two cavities would function if the chemical(s) stack of the two cavities is inverted from each other; for example, if cavity 363 had anode chemicals below cathode chemicals while cavity 364 has cathode chemicals below anode chemicals. In other examples the opposite stacks could be formed. Referring again to the top clamshell half 310 of Fig. 3G, the two cavities 361 and 362 may have electrical connections 366 and 367 which connect each of the two cavities to contacts 368 and 369. However, the clamshell halves in this example may be formed of semiconductor material such that electrical connections 366 and 367

may be formed by heavily doping the semiconductor material of the clamshell halves in these regions. In this manner, an electrical contact through the clam shelf half to the external contact may be made in such a manner that does not form a gap in sealing layers. The ledges 311 and 331 of the top clamshell half 310 and the bottom clamshell half 330 may be used to form hermetic seals in the manners as have been described in the present description. Again, these seals may form an extremely hermetically tight seal due to the lack of a physical electrical contact in between the sealing surfaces to bring electrical contact from the battery chemical(s) to the contact regions.

Referring to Figs. 3H and 3I an example where the clamshell is a complete circular form is illustrated. The bottom clamshell half 330 has a single cavity 371 around the full circle with an electrical contact 374. The illustrated case is for a semiconductor form clamshell half with electrical contact of a highly doped region of the semiconductor clamshell. In some examples, the semiconductor material may be an inorganic semiconductor such as silicon where atomic dopants such as phosphorous and boron may alter the conductivity. In some other examples, the semiconductor may be organic semiconductors where molecular doping may moderate the conductivity of certain regions to provide electrical contact. Numerous doped organic semiconductor systems may be used; however, in a non-limiting example poly(3-hexylthiophene) (P3HT) doped with 2,3,5,6-tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4TCNQ) may be used in a polymer matrix. A large area of doped organic semiconductor may be coated with a metallic film for a contact pad. In other examples an insulative or plastic clamshell may have a metal contact penetrating the clamshell half with a good hermetic seal. The cavity may contain the cathode chemical(s) and perhaps a separator. The top clamshell half 310 may have a cavity 370 to contain the anode chemical(s) which may for example be an electrodeposited anode on the clamshell half piece. Again, the top clamshell piece may have a diffused silicon contact region 375. The ledges 311and 331 of the top clamshell half 310 and the bottom clamshell half 330 may be used to form hermetic seals in the manners as have been described in the present description. Since the shape of the battery illustrated is a full circle there are isolated ledges from the top clamshell half ledge 311A and from the bottom clamshell half, ledge 331A. Ledges 331A and 311A may be sealed in the same hermetic sealing manner as the outer ledges. These seals may form an extremely hermetically tight seal due to the lack of a physical electrical contact in between the sealing surfaces to bring electrical contact from the

battery chemical(s) to the contact regions.

In examples for clamshell components made from insulating materials, examples are shown herein for electrical connection that may be made by extending an electrode current collector through a seam region to a contact pad. In other examples, semiconducting clamshell components may be doped to allow for electrical contact to flow through the clamshell body. Other examples may include conductive vias that are etched into the insulating materials and then filled with conductive materials. The deposition of the conductive via materials may be made in such a manner that the seal of the via may maintain a hermetic seal.

In some examples, electrolyte may be filled into a clamshell battery form through a fill port. A vacuum may be pulled on the battery form evacuating gasses through the fill port and electrolyte may entered into the clamshell body through the port. Thereafter, a seal may be formed by filling the fill port with an adhesive or polymerizable material. In some examples, the filling of the fill port may be made before a metal coating of the clamshell battery form is made to improve the hermetic seal.

Metallic clamshell Halves in Battery Component Design

Referring to Fig. 4, an exemplary illustration of a multiple piece clamshell battery is found. In an example, a metallic top clamshell half 410 and a metallic bottom clamshell half 470 may contain the battery elements as discussed for other clamshell examples. Since metallic clamshell halves would short the battery cell if joined together, an insulating interface piece 440 is placed between the clamshell halves and joined at seal 430 and seal 450. The seal may be made in any of the manners for forming hermetic seals as discussed herein. The battery may contain internal support pieces 415 to hold components in place during assembly before the hermetic seals are formed. As well, an anode 420 may be formed on the top clamshell half 410 and a cathode 460 may be deposited or formed into the bottom clamshell half 470 which may be already joined to the insulating interface piece 440.

Plastic Clamshell Halves in Battery Component Design

Referring to Fig.5A, a plastic clamshell example of a biocompatible energization element 500 is illustrated in cross section. A bottom clamshell half 520 may be filled with a central

separator 531, an anode 530, an anode current collector 571, a cathode 532, and a cathode collector 573. A top clamshell half 510 may be sealed to the bottom clamshell half at seal 540 which may be made by melting the plastic pieces into a thick seal at the interface. The seal 541 is illustrated with a "see-through" aspect to illustrate that the clamshell ledges may be melted together to form the seal along the interface of the ledges. A plastic sealed clamshell battery may be made more hermetic by encasing a significant portion of plastic battery body with a deposited metallic film formed by electroless deposition followed by electrodeposition.

In other examples, the plastic stock used to form clamshell pieces may be made from composite plastic material such as polymer, metal film, polymer stacked starting films. Other examples, where a metal film is formed within the clamshell pieces or is coated upon the clamshell pieces before other features are added are possible. It may likewise be possible to add an electroless and/or electroplated film upon clamshells forms that have a metallic film within or upon them already.

Referring to Fig. 5B, a plastic form clamshell battery may be encapsulated with metallic films to improve the hermetic sealing of the clamshell outer layers. The clamshell form surface may be cleaned and treated with acid wash pre-dip to remove contaminates such as residual slurry. Other washes and cleans may include RCA type cleans, SC1 and SC2 type peroxide based cleans, hydrofluoric acid, sulfuric acid and combinations of acids. An accelerator or sensitizer may include proprietary formulations such as a "Type C" solution from Transene Company. An activator may next be used to treat the surface. As a non-limiting example, a "Type D" solution from Transcene Company may be used. Referring to Fig. 5B, the result of this treating is illustrated as layer 560 on the fully formed biocompatible energization element 500 of Figure 5B. Next, the pretreated surface may be immersed into baths for electroless plating, in this example, copper. The battery body that has been pretreated and activated may now be immersed in a mixture of Transene Company "Type A and Type B" electroless copper bath solution at elevated temperature of roughly 40 C for a time to form a number of microns of deposition. The resulting deposition is illustrated as layer 561. In some examples, the surface may be post washed in acids to stabilize the surface.

In some examples, a thicker layer of deposition, perhaps 10 or more microns thick of copper may be deposited upon the electroless layer using copper bath electroplating. The resulting layer of copper is illustrated as layer 562. In some examples, an electroplating treatment

of rhodium may follow the electroplated copper layer as layer 563. Rhodium may stabilize and protect the copper surface; therefore, a thin layer may be added as the top surface in some examples.

If an entire battery element were plated in a copper layer, the two contacts of the battery would be shorted and the battery would be non-functional. Therefore, one or both contacts of the battery can be protected before plating to prevent formation around the contacts and isolate the contact. Referring to Fig. 5C, an exemplary top view of a plastic clamshell structure battery before plating is illustrated on the battery of Figure 5A with the cathode contact 574, a dashed line to indicate the feature is hidden behind a protective film 575, and the anode contact 572. Electrical connection layers may be used to form an electrical connection between the battery anodes and cathodes through their collectors to respective contact pads. A protective film 575, such as plater's tape' may be placed around the cathode contact, the cathode collector and its associated electrical connection layer. The remaining surface of the battery may be coated with the electroless and electroplating layers as illustrated in Fig. 5B. The fact that the contact region may have non-plated surface of the laminate structure may not be an issue for sealing the battery. In some examples, the contacts may be made long enough so that there is a relatively large seal near the contact. In a different sense, operation of a primary battery may result in the generation of gases such as hydrogen gas. The presence of a region around one or more of the contacts which is not as well sealed may be advantageous since it may create a path that may allow generated gases to slowly dissipate through.

Referring to Fig. 5D, an exemplary illustration is shown after coating the plastic clamshell examples with plater's tape or other protective film. The deposited film 576 may cover the entire structure with the exception of the region that is protected with a protected film. In the illustrated example the anode contact region including anode contact 572 and anode current collector 571 is covered with the electroless and electroplated films thereupon. Whereas, the cathode contact 574 and cathode current collector 573 is not coated. In some examples, the anode contacts may also be shielded from deposition. As well the example illustrates coating of plastic films with electroless plating, in other examples other materials such as insulators, glasses and the like may be treated and coated with electroless plating as well.

Referring to Fig. 6A, irregularly shaped clamshell form batteries with non-rectangular cross-sections are illustrated. There may be numerous other irregular shapes that a clamshell may

take. In some examples, a plastic clamshell form in an irregular shape may be extruded or pressed into a shape determined by a mold. In Fig. 6A, the irregular shape of the cross section may be designed to better conform to a shape of space in a typical contact lens form. The bottom clamshell half 620 may slope away from the center of the lens, in the direction towards the outer portions of a contact lens that the battery form may be embedded within. The bottom clamshell half 620 may be filled with cathode chemicals 630 in some examples. The second clamshell half, the top clamshell half 610, may be formed to match with internal and external ledge regions 611 along which the clamshell may be sealed. Sealing may be performed by ultrasonic melting in some examples. The top clamshell 610 may be configured with a separator 631 as well as anode chemical(s) 632. The clamshell structure may be filled with electrolyte before or after sealing where a fill port may be employed with vacuum filling techniques when the filling is done after sealing. In some examples, other forms of electrolyte such as polymer electrolytes as described previously may be used in the various clamshell concepts.

Referring to Fig. 6B, an exemplary plastic clamshell battery is illustrated. The top clamshell piece 610 and bottom clamshell piece 620 are joined with a thick molten seal edge 640 of the ledge regions of the clamshell pieces. There may be numerous ways to melt the ledge regions of the clamshell pieces into thick molten seals. Referring to Figs. 6C and 6D, exemplary bottom clamshell Fig. 6C and top clamshell Fig 6D pieces are illustrated from a top down perspective. The irregular shape shown in the cross section of Fig. 6A is found in the portions of the clamshell batteries that are within the various cavities in some examples. The bottom clamshell piece 620 of Fig. 6C has cavities 651 and 652 with this cross-sectional shape. As well in the bottom clamshell piece 620 of Fig. 6C there may be ledges 661 and internal electrical connection features 653. As well in the top clamshell piece 610 of Fig. 6D there may be ledges 611, cavities 658 and 659, electrical connections 654 and 655, and contacts 656 and 657 in similar geometrical placements as other clamshell battery examples that have been discussed.

Methods of Fabricating Clamshell Batteries

Referring now to Fig. 7, a flow chart 700 with exemplary method steps for forming a clamshell form battery with insulating containment material is illustrated. By nature of being clamshell form batteries, certain method steps, such as depositing components vital for battery chemical(s) as a non-limiting example, may be shared amongst the different processes for

forming clamshell form batteries that possess different containment materials; on the other hand, there may also be certain significant differences in method steps amongst clamshell form batteries that possess different containment materials, for example, the exact sealing methods used to seal the containment components. First, at step 702, a set of clamshell halves made of insulating material are received. These halves comprise the containment components used to ultimately enclose and seal the clamshell form battery, and may be the base components for forming the battery. Optional method steps follow at steps 704 and 706; after receiving the insulating material halves, they may be optionally coated, on their internal halves, with a vapor deposited film for conductivity, step 704, or may be optionally coated, on their ledges, with a metallic film for sealing, step 706. These steps may be pre-activation steps, as previously described in the present specification, that may aid in forming insulator to insulator seals, and may either individually or jointly occur. Subsequently, in step 708, conductive traces may be defined in the clamshell halves. These traces may be used to electrically connect important functional battery chemical(s) components, define and connect contacts for the battery, or for other purposes previously described in the present specification. Next in step 710, an anode may be deposited on one of the clamshell halves, and subsequently in step 712, a cathode may be deposited on one of the clamshell halves. As has been illustrated in previous sections, amongst the various options batteries may be formed in cofacial and coplanar configurations. In the cofacial configurations the clamshell half that the anode is deposited or place in may be different from the clamshell half that the cathode is placed in. In a coplanar configuration, however, since the anode and cathode lie on the same plane, they may both be placed in the same clamshell half. In a coplanar configuration, the second clamshell piece may serve a capping and sealing function. The anode and cathode deposited in these steps may be placed in a location that interfaces properly with the previously defined conductive traces of step 708. Next, in step 714, a separator may be coated or placed on one or both of the filled clamshell halves; this coating or placed separator film may be used to physically and/or electrically separate the anode and cathode components from each other, as previously described in the present specification. In step 716, an electrolyte may be deposited into each or at least one of the anode and cathode filled clamshell halves; as previously described in the present specification, an electrolyte may be vital to battery chemical(s), to enable ion transfer that establishes a potential difference, allowing the battery to function. Afterwards, in step 718, the two clamshell halves may be joined together, and

a seal may be formed between the ledges of the clamshell halves. Even further in optional step 720, at least portions of the surface of the clamshell halves may be optionally sealed with electroless and/or electroplating. The aforementioned pre-activation steps, may be vital towards activation and seal forming in these steps 718 and 720. As an additional non-limiting example, the seal forming may also take place with a cut piece of Nanofoil® that may be placed over the sealing area. After activation, the Nanofoil® will melt the solder and form a soldered hermetic joint. In some examples, other forms of insulator to insulator seal may be formed in manners previously described in the present specification.

Referring now to Fig. 8, a flow chart 800 with exemplary method steps for forming a clamshell form battery with plastic containment material is illustrated. First, at step 802, a set of clamshell halves made of plastic material are received. These halves comprise the containment components used to ultimately enclose and seal the clamshell form battery, and may be seen as the base components for forming the battery. Optional method steps follow at steps 804 and 806; after receiving the plastic material halves, they may be optionally coated, on their internal halves, with a vapor deposited film for conductivity, step 804, or may be optionally coated, on their ledges and surfaces, with a metallic film for connecting the inside to the outside of the battery, step 806. These steps may also act as pre-activation steps in regions of the clamshell, as previously described in the present specification, that may aid in seals, and may either individually or jointly occur. Subsequently, in step 808, conductive traces may be defined in the clamshell halves. These traces may be used to electrically connect important functional battery chemical(s) components, define and connect contacts for the battery, or for other purposes previously described in the present specification. Next in step 810, an anode may be deposited on one of the clamshell halves, and subsequently in step 812, a cathode may be deposited on one of the clamshell halves. As has been illustrated in previous sections, amongst the various options batteries may be formed in cofacial and coplanar configurations. In the cofacial configurations the clamshell half that the anode is deposited or place in may be different from the clamshell half that the cathode is placed in. In a coplanar configuration, however, since the anode and cathode lie on the same plane, they may both be placed in the same clamshell half. In a coplanar configuration, the second clamshell piece may serve a capping and sealing function. The anode and cathode deposited in these steps may be placed in a location that interfaces properly with the previously defined conductive traces of step 808. Next, in step 814, separator film may be coated

or placed on one or both of the filled clamshell halves; this separator film may be used to physically and/or electrically separate the anode and cathode components from each other, as previously described in the present specification. In step 816, an electrolyte may be deposited into each or at least one of the anode and cathode filled clamshell halves; as previously described in the present specification, an electrolyte may be vital to battery chemical(s), to enable ion transfer that establishes a potential difference, allowing the battery to function. Afterwards, in step 818, the two clamshell halves may be joined together, and a melted seal may be formed between the ledges of the clamshell halves. Even further in step 820, at least portions of the surface of the clamshell halves may be sealed with electroless and/or electroplating. The aforementioned pre-activation steps, may be vital towards activation and seal forming in these steps 818 and 820. In some examples, other forms of plastic to plastic seal may be formed in manners previously described in the present specification. The various processing examples as have been discussed previously may be used in addition to those steps identified in Fig. 8 or they may replace some of the exemplary processing steps.

Referring now to Fig. 9, a flow chart 900 with exemplary method steps for forming a clamshell form battery with metallic containment material and an intermediate separator piece is illustrated. First, at step 902, a set of clamshell halves made of metallic material are received. The halves comprise the containment components used to ultimately enclose and seal the clamshell form battery, and may be seen as the base components for forming the battery. Optional follow at steps 904, 906, and 908; after receiving the plastic material halves, they may be optionally coated, on their internal and/or external surfaces, with a coating for insulating characteristics, or may be optionally coated, on their ledges, with an insulating coating, step 906. As a metallic containment component may be entirely conductive on each of its surfaces and ledges, these steps may be important to limit conductivity in certain areas, to prevent shorts or other issues that may prevent the clamshell form battery from working properly. Subsequently, in step 908, conductive traces may be defined in the clamshell halves; in certain cases, after an insulating coating has been added, additional conductive traces may need to be subsequently added, to reconnect conductive portions of the metallic containment material that were insulated from each other with the coating. These traces may be used to electrically connect important functional battery chemical(s) components, define and connect contacts for the battery, or for other purposes previously described in the present specification. Next in step 910, an anode may

be deposited on one of the clamshell halves, and subsequently in step 912, a cathode may be deposited on one of the clamshell halves. As has been illustrated in previous sections, amongst the various options batteries may be formed in cofacial and coplanar configurations. In the cofacial configurations the clamshell half that the anode is deposited or place in may be different from the clamshell half that the cathode is placed in. In a coplanar configuration, however, since the anode and cathode lie on the same plane, they may both be placed in the same clamshell half. In a coplanar configuration, the second clamshell piece may serve a capping and sealing function. The anode and cathode deposited in these steps may be placed in a location that interfaces properly with the previously defined conductive traces of step 908. Next, in step 914, a separator film may be coated or placed on one or both of the filled clamshell halves; this separator film may be used to physically and/or electrically separate the anode and cathode components from each other, as previously described in the present specification. In step 916, an electrolyte may be deposited into each or at least one of the anode and cathode filled clamshell halves; as previously described in the present specification, an electrolyte may be vital to battery chemical(s), to enable ion transfer that establishes a potential difference, allowing the battery to function. Afterwards, in step 918, the two clamshell halves may be joined together with the intermediate insulating piece, and a seal may be formed between the ledges of the clamshell halves and ledges of the intermediate piece. Even further in optional step 920, at least portions of the surface of the clamshell halves may be optionally sealed with electroless and/or electroplating. The aforementioned pre-activation steps, may be used for activation and seal forming in these steps 918 and 920.

Referring now to Fig. 10, a flow chart 1000 with exemplary method steps for forming a clamshell form battery with semiconductor containment material is illustrated. First, at step 1002, a set of clamshell halves made of semiconductor material are received. The halves comprise the containment components used to ultimately enclose and seal the clamshell form battery, and may be the base components for forming the battery. In some examples, the clamshell material may be an inorganic semiconductor such as silicon for example, in other examples an organic semiconductor material may be used. Optionally at step 1004; after receiving the semiconducting material halves, they may be coated, on their internal and/or external surfaces, with a coating for insulating characteristics. At step 1006, the semiconducting material of the clamshell halves may be doped to increase the conductivity of the material

significantly. In this manner contact regions for the battery may be formed without any seals being required. Subsequently, in step 1008, conductive traces may be defined in the clamshell halves. These traces may be used to electrically connect important functional battery chemical(s) components, define and enhance the doped contact regions for the battery, or for other purposes previously described in the present specification. Next in step 1010, an anode may be deposited on one of the clamshell halves, and subsequently in step 1012, a cathode may be deposited on another of the clamshell halves. The anode and cathode deposited in these steps may be placed in a location that interfaces properly with the previously defined conductive traces of step 1008. Next, in step 1014, a separator film may be placed on one or both of the filled clamshell halves; this coat or separator film may be used to physically and/or electrically separate the anode and cathode components from each other, as previously described in the present specification. In step 1016, an electrolyte may be deposited into each or at least one of the anode and cathode filled clamshell halves; as previously described in the present specification, an electrolyte may be vital to battery chemical(s), to enable ion transfer that establishes a potential difference, allowing the battery to function. Afterwards, in step 1018, the two clamshell halves may be joined together, and a seal may be formed between the ledges of the clamshell halves. Additionally, in particular for examples with organic semiconductor material form clamshell halves at step 1020, at least portions of the surface of the clamshell halves may be sealed with electroless and/or electroplating. The aforementioned pre-activation steps, may be vital towards activation and seal forming in these steps 1018 and 1020. In some examples, other forms of metal-to-metal seals may be formed in manners previously described in the present specification.

The biocompatible batteries may be used in biocompatible devices such as, for example, implantable electronic devices, such as pacemakers and micro-energy harvesters, electronic pills for monitoring and/or testing a biological function, surgical devices with active components, ophthalmic devices, microsized pumps, defibrillators, stents, and the like.

Specific examples have been described to illustrate sample embodiments for the cathode mixture for use in biocompatible batteries. These examples are for said illustration and are not intended to limit the scope of the claims in any manner. Accordingly, the description is intended to embrace all examples that may be apparent to those skilled in the art.

CLAIMS

1. A clamshell battery comprising:

an anode current collector, wherein the anode current collector is a first metallic film within a top clamshell half;

an anode, wherein an anode chemical(s) is contained within or deposited upon the top clamshell half;

a cathode current collector, wherein the cathode current collector is a second metallic film within a bottom clamshell half;

a cathode, wherein a cathode chemical(s) is contained within or deposited upon the bottom clamshell half; and

wherein the top clamshell half and the bottom clamshell half are formed from one or more of a ceramic, glass or plastic material, and wherein a seal is formed between ledge features of the top clamshell half and the bottom clamshell half

and wherein a sealing material located between the ledge features of the top clamshell half and the bottom clamshell half comprises one of an epoxy adhesive, a solder and a plurality of thin layers of metallic films, wherein a first thin layer of metallic film is deposited upon a second layer of metallic film, wherein the first thin layer of metallic film is chemically reactive with the second layer of metallic film releasing energy to rapidly heat the layers, and wherein a chemical reaction is activated by an energetic pulse of energy.

2. The clamshell battery of Claim 1 wherein the solder comprises titanium to enhance adherence upon a ceramic or glass surface.

3. The clamshell battery of Claim 1 wherein the energetic pulse comprises photons, electrons or thermal energy.

4. The clamshell battery of Claim 1 further comprising a metallic coating surrounding at least a portion of an exterior surface of the clamshell battery, wherein the metallic coating is deposited with electroless plating.

5. The clamshell battery of Claim 1 wherein the sealing material located in a gap between a first sealing surface and a first metallic clamshell comprises a conventional solder alloy base with an addition of titanium, wherein the titanium reacts with surface materials of the ceramic upon exposure to ultrasonic energy.

6. A clamshell battery comprising:

an anode current collector, wherein the anode current collector is a first metallic clamshell piece;

an anode, wherein an anode chemical(s) is contained within the first metallic clamshell piece;

a cathode current collector, wherein the cathode current collector is a second metallic clamshell piece;

a cathode, wherein a cathode chemical(s) is contained within the second metallic clamshell piece;

an insulating intermediate clamshell piece with a first sealing surface that sealably interfaces with the first metallic clamshell piece and a second sealing surface that sealably interfaces with the second metallic clamshell piece; and

a sealing material located in a gap between the first sealing surface and first metallic clamshell.

wherein the sealing material located in the gap between ledge features of the first metallic clamshell piece and the insulating intermediate clamshell piece comprises one of an epoxy adhesive, a conventional solder alloy base with an addition of titanium, wherein the titanium reacts with surface materials of the intermediate clamshell piece upon exposure to ultrasonic energy and a plurality of thin layers of metallic films, wherein a first thin layer of metallic film is deposited upon a second layer of metallic film, wherein the first thin layer of metallic film is chemically reactive with the second layer of metallic film releasing energy to rapidly heat the layers, and wherein a chemical reaction is activated by an energetic pulse of energy.

7. The clamshell battery of Claim 6 wherein the energetic pulse comprises photons, electrons or thermal energy.

8. The clamshell battery of Claim 6 further comprising a metallic coating surrounding at least a portion of an exterior surface of the clamshell battery, wherein the metallic coating is deposited with electroless plating, wherein at least a fully surrounding portion of the intermediate clamshell piece is blocked from receiving a metallic coating and maintains an insulating aspect between the first metallic clamshell piece and the second metallic clamshell piece.

9. A clamshell battery comprising:

an anode current collector, wherein the anode current collector is a first plastic clamshell piece;

an anode, wherein an anode chemical(s) is contained within the first plastic clamshell piece;

a cathode current collector, wherein the cathode current collector is a second plastic clamshell piece;

a cathode, wherein a cathode chemical(s) is contained within the second plastic clamshell piece; and

a seal comprising a melted region comprising ledge regions of the first plastic clamshell piece and the second plastic clamshell piece.

wherein a sealing material located between the ledge features of the first plastic clamshell piece and the second plastic clamshell piece comprises a plurality of thin layers of metallic films, wherein a first thin layer of metallic film is deposited upon a second layer of metallic film, wherein the first thin layer of metallic film is chemically reactive with the second layer of metallic film releasing energy to rapidly heat the layers, and wherein a chemical reaction is activated by an energetic pulse of energy.

10. The clamshell battery of Claim 9 wherein a shape of the first plastic clamshell piece and the second plastic clamshell piece comprises an irregular cross sectional profile that is shaped to fill volume within an ophthalmic lens.

11. The clamshell battery of Claim 9 wherein the energetic pulse comprises photons, electrons or thermal energy.

12. The clamshell battery of Claim 9 wherein a metallic film coats portions of the interior surfaces of the first plastic clamshell piece and the second plastic clamshell piece, wherein the metallic film coating on the first clamshell plastic piece is electrically isolated from the metallic film coating on the second clamshell plastic piece when the clamshell battery is not connected to an electrical device.

13. The clamshell battery of Claim 9 further comprising a metallic coating surrounding at least a portion of an exterior surface of the clamshell battery, wherein the metallic coating is deposited with electroless plating, wherein at least one of a first anode contact and a first cathode contact is shielded from receiving plating and is electrically isolated from the metallic coating.

14. A clamshell battery comprising:

an anode current collector, wherein the anode current collector is a first semiconductor clamshell piece;

an anode, wherein an anode chemical(s) is contained within the first semiconductor clamshell piece;

a cathode current collector, wherein the cathode current collector is a second semiconductor clamshell piece;

a cathode, wherein a cathode chemical(s) is contained within the second semiconductor clamshell piece;

a seal between ledge regions of the first semiconductor clamshell piece and the second semiconductor clamshell piece; and

wherein isolated regions of the first semiconductor clamshell piece and the second semiconductor clamshell piece are doped to allow current flow in doped regions from within the battery to an external connection.

15. The clamshell battery of Claim 14 wherein a shape of the first semiconductor clamshell piece and the second semiconductor clamshell piece comprises an irregular cross sectional

profile that is shaped to fill volume within an ophthalmic lens.

16. The clamshell battery of Claim 14 wherein a sealing material located between the ledge features of the first plastic clamshell piece and the second semiconductor clamshell piece comprises a plurality of thin layers of metallic films, wherein a first thin layer of metallic film is deposited upon a second layer of metallic film, wherein the first thin layer of metallic film is chemically reactive with the second layer of metallic film releasing energy to rapidly heat the layers, and wherein a chemical reaction is activated by an energetic pulse of energy.

17. The clamshell battery of Claim 16 wherein the energetic pulse comprises photons, electrons or thermal energy.

18. The clamshell battery of Claim 14 wherein a metallic film coats portions of the interior surfaces of the first semiconducting clamshell piece and the second semiconducting clamshell piece, wherein the metallic film coating on the first clamshell piece is only electrically connected to the metallic film coating on the second clamshell piece through the anode, a separator and the cathode when the clamshell battery is not connected to an electrical device.

19. The clamshell battery of Claim 14 further comprising a metallic coating surrounding at least a portion of an exterior surface of the clamshell battery, wherein the metallic coating is deposited with electroless plating, wherein at least one of a first anode contact and a first cathode contact is shielded from receiving plating and is electrically isolated from the metallic coating.

20. A method of manufacturing a clamshell battery comprising:

receiving a first clamshell half and a second clamshell half made of insulating material, wherein clamshell halves have a body region for support of a battery component surrounded by a ledge, wherein the ledge may be used for sealing;

defining a conductive trace in the first clamshell half;

depositing an anode in the first clamshell half;

depositing a cathode in the second clamshell half;

placing a separator film on one or both of the first clamshell half and the second clamshell half;

depositing an electrolyte into one or both of the first clamshell half and the second clamshell half;

joining the clamshell halves; and

forming a seal between the ledges of the clamshell halves.

21. The method of Claim 20 further comprising sealing at least portions of a surface of the first clamshell half and the second clamshell half with electroless plating.

22. The method of Claim 21 further comprising plating the clamshell battery with electroplating.

23. The method of Claim 20 further comprising coating at least a first portion of one or both of the first clamshell half and the second clamshell half with a vapor deposited metallic film.

24. The method of Claim 20 further comprising coating at least a first portion of the ledges of one or both of the first clamshell half and the second clamshell half with a metallic film for sealing.

25. The method of Claim 20 further comprising placing the clamshell battery into an ophthalmic device.

26. The method of Claim 25 wherein the ophthalmic device is a contact lens.

27. A method of manufacturing a clamshell battery comprising:

receiving a first clamshell half and a second clamshell half made of plastic material, wherein clamshell halves have a body region for support of a battery component surrounded by a ledge, wherein the ledge may be used for sealing;

defining a conductive trace in the first clamshell half;

depositing an anode in the first clamshell half;

depositing a cathode in the second clamshell half;

placing a separator film on one or both of the first clamshell half and the second clamshell half;

depositing an electrolyte into one or both of the first clamshell half and the second clamshell half;

joining the clamshell halves;

forming a seal between the ledges of the clamshell halves, wherein the forming of the seal comprises melting the plastic ledges of the first clamshell half and the second clamshell half together; and

sealing at least portions of a surface of the first clamshell half and the second clamshell half with electroless plating.

28. The method of Claim 27 further comprising plating the clamshell battery with electroplating.

29. The method of Claim 27 further comprising coating at least a first portion of one or both of the first clamshell half and the second clamshell half with a vapor deposited metallic film.

30. A method of manufacturing a clamshell battery comprising:

receiving a first clamshell half made of a semiconducting material and a second clamshell half made of the semiconducting material, wherein clamshell halves have a body region for support of a battery component surrounded by a ledge, wherein the ledge may be used for sealing;

doping regions of one or both of the first clamshell half and the second clamshell half, wherein the doping increases conductivity of the material to form a contact region;

depositing a metallic film upon a surface of the first clamshell half;

depositing an anode in the first clamshell half;

depositing a cathode in the second clamshell half;

placing a separator film on one or both of the first clamshell half and the second clamshell half;

depositing an electrolyte into one or both of the first clamshell half and the second clamshell half;

joining the clamshell halves;

forming a seal between the ledges of the clamshell halves; and

sealing at least portions of the surface of the first clamshell half and the second clamshell half with electroless plating.

31. The method of Claim 30 further comprising plating the clamshell battery with electroplating.

32. The method of Claim 30 further comprising coating at least a first portion of one or both of the first clamshell half and the second clamshell half with a vapor deposited insulating film.

33. The method of Claim 30 further comprising placing the clamshell battery into an ophthalmic device.

34. The method of Claim 33 wherein the ophthalmic device is a contact lens.

35. A biomedical device incorporating a clamshell battery as claimed in claim 4 or claim 8 or claim 13.

36. A biomedical device as claimed in claim 35, wherein the device further comprises a first biocompatible encapsulating layer, wherein the first biocompatible encapsulating layer encapsulates at least the electroactive component and the battery.