

plete Specification

WITH HIGH SPECIFIC ENERGY Field of the Invention

The present invention relates to lead-acid batteries. The present invention particularly relates to a method for reducing the weight of lead-acid batteries, and a process for producing the same, thereby increasing their specific energy.

Related Art

A battery is a device which stores electrical energy such that the energy is available at desired times on demand. Batteries typically comprise two electrodes, i.e. an anode (negative plate) and a cathode (positive plate) placed in an electrolyte. Electrical energy is generally obtained from a battery as and when desired by connecting the electrical appliance to be operated across its negative and positive plates, as is well known in the relevant art.

Lead-acid batteries are in widespread use in 'automobiles, boats, aeroplanes, and for uninterrupted power supply units. In a conventional design, the negative and positive plates/grids of lead-acid batteries are implemented using lead alloys having lead in abundant proportions (including pure lead). In these electrodes, a primary role of lead/lead alloy is to facilitate electrical conduction during battery charging and discharging.

Although lead alloys are not generally as good electrical conductors as metals such as copper, they are often preferred over other metals due to the stability they provide during battery charging and discharging, and their relatively low cost. Specifically, lead/lead alloys are typically able to withstand appreciably the highly corrosive environment created by the acid electrolyte. Metals more conductive than lead are either quickly corroded in acids (e.g., aluminum, copper) or too expensive to be commercially viable (e.g., platinum).

In lead-acid batteries, the framework of a battery plate that supports the active material and also serves as the current collector is referred to as the "grid". Pasted grids are generally referred to as plates. By definition, the electrode is an electronic conductor, which acts as a source or a sink of electrons involved in electrochemical reactions taking place in such a battery.

While plates/grids made of lead/lead alloys are reasonably stable in the acidic environment of the lead-acid battery, they are nevertheless corroded during the normal operation of the battery, limiting the lifetime of such a battery. It is thus desirable to provide protection against such corrosion, so as to enhance the durability of lead-acid batteries.

Furthermore, due to the high mass-density of lead (11.3 grams cm³), lead-acid batteries are usually heavy. It is often desirable that batteries store high energy, but weigh less.

Accordingly, a metric referred to as specific energy, which is measured by the number of watt hours (Wh) of energy stored in a battery per kilogram weight (kg) of the battery (abbreviated as Wh/kg), is often used to measure the efficacy or desirability of a battery.

Thus, it is generally desirous to provide batteries with high specific energy.

For example, electric vehicles (EVs) for neighborhood applications, such as hospitals, industrial parks, holiday resorts, residential communities, and city centers, require batteries with high specific energy because, otherwise, the traction of the heavy batteries would in itself consume a sizeable fraction of the stored energy of the batteries. It is estimated that, for such applications, batteries with specific energy of 40-50 Wh/kg would be more appropriate. By contrast, many lead-acid batteries currently available in the market have energy density of

Specific energy are generally important also in portable systems, in which the weight of each component/sub-system matters. Batteries with high specific energy would also be advantageous in conventional automobiles with internal combustion engines, where fuel efficiency would be marginally enhanced when batteries are lighter, as well as in hybrid EVs. In attempting to achieve a significant reduction in the total weight of a lead-acid battery, an effective approach, would be to reduce the weight of the plates/grids constituting the electrodes of the battery. This may be accomplished by replacing the electrode structure made entirely of lead/lead alloy with a structure that uses a lightweight material, which merely acts as a physical support (substrate), and is covered by a relatively thin copper and lead alloy flash layer (or laminate) that performs the charge/discharge functions of the battery. The use of such a composite structure for the battery plate/grid, instead of a relatively thick plate made entirely of lead alloy, can result in a significant reduction in the total weight of each plate/grid. A corresponding increase in the specific energy of the lead-acid battery then ensues. However, the use of a relatively thin layer of lead increases the need for its protection against corrosion in the strong acid environment of the lead-acid battery. Some of such example approaches are briefly described below.

For example, US Patent 4,221,854, titled, "Lightweight laminated grid for lead-acid storage batteries", issued to Hammar et al. (hereafter Hammar) describes a lead-acid battery in which a grid/plate comprises a substrate made of a polymer (such as polyvinylchloride) laminated with a thin lead/lead alloy foil. This combination reduces the weight of the battery plate/grid, contributing to an increase in the specific energy of the battery. However, Hammar does not appear to describe a corrosion resistant coating (and/or a process for forming the same on the substrate). As a result, the plate/grids of Hammar may be susceptible to corrosion in acid electrolytes, thereby limiting the durability of the corresponding batteries.

US Patent 4,713,306, titled, "Battery Element and Battery Incorporating Doped Tin Oxide Coated Substrate" issued to Pinsky et al (hereafter "Pinsky") describes a battery element useful as at least a portion (which appears to mean the grid) of the positive plate coated with electrically conductive doped tin oxide. The tin oxide coating does not appear to be meant to provide protection to the grid against acid corrosion since the grid made of glass fibre is inherently resistant to acid corrosion.

US Patent 5,643,696, titled, "Battery plates with lightweight cores" issued to Rowlette describes battery plates/grids made of metallic substrates (aluminum or titanium or their alloys) coated with lead/lead alloy. These metallic substrates may still have unacceptably high mass density (e.g. Aluminum has an approximate mass density of 2.7 grams cm³). Accordingly, it may be desirable to produce batteries using substrates made of materials having an even lower mass density.

Another example approach is described in US Patent 6,232,017, titled "Grid for lead-acid battery", issued to Tsuchida et al (hereafter "Tsuchida"), in which polyamide and glass fibers are used to construct a composite battery plate/grid. The weight of the grid is reduced, in comparison with conventional grids made entirely of lead/lead alloys, by using the low density of polyamide to form a support structure, and a glass fiber sheet coated by a thin layer

collecting part of the battery plate/grid. However, a
plates/grids appears to be absent in Tsuchida, just as it is
the embodiments susceptible to acid corrosion.

In US Patent 6,316,148, titled, "Foil-encapsulated, lightweight, high energy electrodes for lead-acid batteries", Timmons et al (hereafter Timmons) describe another approach to reduce the weight of lead-acid batteries. The electrodes are made of non-lead substrates (such as aluminum) encapsulated by thin sheets of conductive foils of lead/lead alloy, that conduct electricity. The foils, being corrosion-resistant, protect the substrate from acid corrosion. The weight of the battery is reduced by the use of non-lead substrates with mass density no greater than 70% of the mass density of lead. However, Timmons also appears to suffer from the same inadequacies of Hammar and Tsuchida in that a corrosion-resistant coating of the plate/grid appears to be absent.

In addition to providing high specific energy, it is desirable to produce batteries meeting several other requirements. For example, it is desirable to use cost-effective material for the substrates to reduce the overall cost of producing batteries. The overall manufacturing technology would further need to allow thin coatings of lead alloy on such a cost-effective and lightweight substrate material. The technology would further need to allow corrosion resistant coatings to be applied to the plates/grids, in order to enhance the durability of the resulting lead-acid batteries.

One problem with the use of a low cost material, which also has a low mass density as the substrate is that the melting point of such a material may be low, making it incompatible with several technologies employed in the manufacture of lead-acid batteries. Similar incompatibility may also exist when applying a corrosion resistant coating with sufficiently good electrical conductivity on the lead alloy layer.

For example, formation of such a corrosion-resistant coating, as that of tin oxide, on the lead/lead alloy layer of the battery plate/grid usually requires a temperature significantly higher than 327°C, the melting point of lead. In particular, the formation of a tin oxide layer by the simple and convenient "dip coating" method requires calcination at a temperature in the range 450-600°C, as described in the article titled, "Development of positive electrodes with SnO₂ coating by applying a sputtering technique for lead-acid batteries", by Kurisawa et al., published in Journal of Power Sources 95 (2001) pp. 125 -129 (hereafter "Kurisawa").

Object of the invention

The main object of the invention is to provide a corrosion resistant grid structure used in a lead-acid battery.

Summary of the invention

Accordingly, the present invention provides An electrochemical method of manufacturing a corrosion resistant grid structure used in a lead-acid battery, said method comprising coating of substrate material such as herein described, with a metal layer of copper or nickel and a subsequent layer of lead/lead alloy followed by the electrodeposition of an organic material such as polyaniline and similar other organic material, over the above said lead/lead alloy layer by using an electrolyte such as oxalic acid to obtain a corrosion resistant grid structure used in a lead-acid battery.

he low mass density is preferably less than about 1.5
nt is preferably less than about 175°C.
on the substrate material used is plastic.

In another embodiment of the invention the organic material used is acrylonitrile butadiene styrene.

In another embodiment of the invention the material comprises a polymer.

In a further embodiment of the invention the polymer comprises a plastic.

In another embodiment of the invention the metal layer is not more than 10 micrometers in thickness, lead/lead alloy layer is not more than 100 micrometers in thickness, and the protective layer is not more than 15 micrometers in thickness.

In another embodiment of the invention the metal layer used supports the adhesion of lead/lead alloy layer

In another embodiment of the invention the battery comprises:

a positive plate; and

a negative plate containing a grid structure, grid structure comprising:

a substrate made from acrylonitrile butadiene styrene having a mass density of less than 2.5 grams cm³, and a melting point lower than 300°C;

a metal layer of copper or nickel deposited on substrate;

a lead/lead alloy layer deposited on metal layer, wherein the metal layer supports adhesion of lead/lead alloy layer; and

a electrically conductive and a corrosion-resistant polyaniline layer providing corrosion protection for said lead/lead alloy layer.

In another embodiment of the invention the battery comprises:

a container for holding a negative plate and a positive plate; and

an electrolyte such as oxalic acid also located within the container.

In a further embodiment of the invention the copper or nickel metal layer is not more than 10 micrometers in thickness, lead/lead alloy layer is not more than 100 micrometers in thickness, and metal compound layer is not more than 15 micrometers in thickness.

In another embodiment of the invention the anode also comprises the substrate, the metal layer, the lead alloy layer and the organic material layer.

In another embodiment of the invention the faradaic efficiency of the battery is 90%.

In a further embodiment of the invention the battery experiences 38% increase in capacity at low discharge rate of C/20 and 50% of capacity at high discharge rate of 3C in relation to its capacity at C/5 rate.

In another embodiment of the invention the battery exhibits 25% increase in its capacity at 50°C in relation to its capacity at 25°C. At temperatures below 25°C, the capacity values of the battery were found to decrease with 38% capacity in comparison to the capacity value observed at 25°C.

In another embodiment of the invention the battery accepts 90% of charge within 1.5 hours of charge in high rate charging.

In another embodiment of the invention the self-discharge of the battery is found to be 0.3 % / Day.

In another embodiment of the invention the capacity loss is minimal during 100 cycles.

In another embodiment of the invention the lead/lead alloy of a grid is deposited by potentiostatic deposition of polyaniline from about 0.1N polyaniline solution in oxalic acid, by placing the grid in between two auxiliary platinum foil electrodes

In a further embodiment of the invention the organic material is selected from polyaniline and similar other organic material.

In another embodiment of the invention the electrochemical coating process is performed a

ive layer of a desired thickness.

Brief Description of the Drawings

The present invention will be described with reference to the accompanying drawings, wherein:

Figures (Fig.) 1A and 1B are diagrams illustrating the details of grid/plate structure in an embodiment of the present invention;

Figure 2 is a flowchart illustrating the method of fabricating the grids according to an aspect of the present invention;

Figure 3 is an example model illustrating the details of lead-acid batteries in an embodiment of the present invention;

Figure 4 is the charge /discharge plot of a lead-acid battery in an embodiment of the present invention;

Figure 5 is the discharge capacity data for the lead-acid batteries obtained at 25°C at (i) C/20, (ii) C/15, (iii) C/10, (iv) C/5, (v) C/3, (vi) C/2, and (vii) C, (viii) 2C, and (ix) 3C rates in an embodiment of the present invention;

Figure 6 is the discharge capacity data for the lead-acid batteries obtained at C/5 rate at (i) -20°C, (ii) 0°C, (iii) 25°C, and (iv) 50°C in an embodiment of the present invention;

Figure 7 is the high rate charging data for the lead-acid batteries obtained at 25°C at (i) 2C, (ii) C, (iii) C/2, (iv) C/3, (v) C/5, (vi) C/10, and (vii) C/20, and (viii) constant potential charging in an embodiment of the present invention;

Figure 8 is the high rate charging data for the lead-acid batteries after 5 days of storage in discharge condition obtained at 25°C at (i) 2C, (ii) C, (iii) C/2, (iv) C/3, (v) C/5, (vi) C/10, and (vii) C/20, and (viii) constant potential charging in an embodiment of the present invention;

Figure 9 is the discharge data obtained at 25°C at C/5 rate for the lead-acid batteries of the present invention after charging as per schedule shown in Fig. 8; (a) before storage, and (b) after storage for 5 days in discharge state; and Figure 10 is the cycle-life data for the lead-acid batteries after 100 cycles at 25°C in an embodiment of the present invention. Detailed description of the invention

It is stated in the abstract of Kurisawa that, "... it is impossible to apply this (dip coating) method to a Pb (lead) substrate ...", appearing to imply that the calcination temperature required to form the protective tin oxide layer in this method is incompatible with the lead/lead alloy plate/grid.

Attempts have therefore been made by Kurisawa to use coating technologies that employ low temperatures. For example, Kurisawa describes using vacuum-based thin film technology to form protective SnO₂ coatings on lead grids. In such a coating process, the temperature of the lead grid to be coated does not exceed approximately 120°C. Specifically, Kurisawa teaches using the radio frequency (RF) sputtering technique to deposit a 15 micrometer-thick SnO₂ coating onto a 500 micrometer-thick lead plate. Such a protective coating of SnO₂ on the relatively thin lead plate/grid, has been shown in Kurisawa to be effective in reducing positive plate/grid corrosion in lead-acid batteries and in improving the specific energy of the batteries thereby.

However, sputtering-is generally a slow process (e.g., Kurisawa indicates a rate of 0.4 micrometer/hour), which may require that the substrate (along with the lead alloy coating) be subjected to ambient temperatures (e.g., 120°C in Kurisawa) for many hours. The prolonged exposure to such ambient temperatures may compromise the mechanical integrity of the plates/grids having low melting points, even if the ambient temperatures are lower than the melting point of the materials forming the substrate and the coatings.

By a line-of-sight deposition process, both sides of an anode and a cathode can be formed in a single step, unless complex and expensive equipment is used. The cost of forming a corrosion-resistant coating on a battery plate/grid by such a sputtering process is likely to be high, which may not be acceptable in several applications. It is noteworthy that SnC₂ is unstable in H₂SO₄ below 0.5V vs. Pb/PbSO₄.

Therefore, what is also desirable is a process, which allows the corrosion-resistant coating of lead/lead alloy layers to be formed on battery plates/grids constructed from a lightweight, inexpensive material, usually having a low melting point. Such plates/grids may then be used to fabricate lead-acid batteries, which would have a higher specific energy and a longer lifetime than the conventional lead-acid batteries.

An embodiment of a grid structure (used in a lead-acid battery) may contain a substrate made from a material having a mass density of less than 2.5 grams cm³, and a melting point lower than 300°C. A metal layer may be deposited on the substrate. A lead/lead alloy layer may be deposited on the metal layer, wherein the metal layer supports adhesion of said lead/lead alloy layer. An electrically conductive and corrosion-resistant layer provides corrosion protection for the lead/lead alloy layer. Due to the low mass density of the substrate, a high specific energy could be obtained.

In an embodiment, the substrate is made of plastic, a polymer. The embodiment may be implemented with the metal layer being not more than 10 micrometers in thickness, the lead/lead alloy layer being not more than 100 micrometers in thickness, and the protective layer being not more than 15 micrometers in thickness. The electrically conductive and corrosion-resistant layer may contain polyaniline or a similar organic metal.

A method according to another aspect of the present invention enables a grid structure to be manufactured. The method may include coating a substrate with a metal compound, wherein the substrate is previously coated with a metal layer and a lead/lead alloy layer. The substrate is then subjected to electrochemical deposition of a polyaniline or similar organic material film to form an electrically conducting and corrosion-resistant organic material layer on the lead/lead alloy layer. The electrodeposition of polyaniline on oxidized metal surfaces like lead is a ticklish problem because of two competing anodic reactions, viz. the formation of metal oxide and oxidative polymerization of aniline monomer within the vicinity of the anode.

The novelty of the present invention lies in the use of a reducing acid like oxalic acid as an electrolyte for anodic deposition of polyaniline over lead/lead alloy layer to prevent the formation of the oxide layer on the lead/lead alloy surface due to its reducing action. It is noteworthy that the approach described under this invention is altogether different from the approach described by Chen and Kwok under US Patent 6,617,071 B2 and its European equivalent EP 126,049 A1 where the claims are made for a high power lead-acid plate covered with a conducting polymer matrix of preferably polyaniline and its derivatives, which is then coated with nano-size particles of active material such as lead sulfate and a

The novelty of the invention lies in electrochemical process for the deposition of based on polyaniline on lead given conditions in the absence of which lead mixed oxide to lead dioxide hindering the deposition of polyaniline on lead.

Additional features of the invention are described in detail below with reference to the accompanying drawings. 1. Overview and Discussion of the Invention

A lead-acid battery according to an aspect of the present invention is implemented using a plate/grid structure containing four layers: substrate, metal layer, lead layer and a fourth layer, which is electrically conductive and corrosion-resistant.

The substrate is formed with a material of low density, which acts as the base on which other layers are deposited. The metal layer (copper or nickel) is chosen to operate as a seed layer for the deposition of a layer of lead as the next layer and also to improve conductivity in addition to providing adhesive support for the lead layer in addition to improve conductivity.

Lead layer comprising pure lead or alloys of lead provides the electrical path for charge/discharge of the battery. The fourth layer, which is electrically conducting, operates also as a protective layer against corrosion of the underlying lead/lead alloy layer.

Due to use of a low-density material for the substrate, the weight of each plate/grid is reduced leading to a corresponding increase in the specific energy of the lead-acid battery. By choosing a low-melting point and low density material for the substrate, e.g., plastic polymer, its cost can be reduced, which makes the battery cheaper. As the plates/grids are of low weight, the battery container, which encloses and supports them may also be made lighter, leading to further increase in the specific energy of the lead-acid battery.

Another aspect of the present invention allows such a structure to be manufactured potentially at a low cost and in a short time. The structure with the first three layers (substrate, metal, and conductive layer) may be formed in a known way. The fourth layer, an electrically conductive and corrosion resistant (e.g., polyaniline) layer, which protects the metal and lead/lead alloy layers against corrosion, may be formed by applying a suitable organic material (e.g., polyaniline) to the three layer structure. Polyaniline is potentiostatically deposited on lead-coated acrylonitrile butadiene styrene (ABS) grid from 0.1N solution of polyaniline in oxalic acid employing two platinum counter electrodes placed on either side of the lead-coated ABS grid by imposing an electrical potential of 1.5V across the grids, and the counter electrode. After deposition, the grids are washed copiously with deionized water and dried in a hot air oven at 60°C.

Several aspects of the invention are described below with reference to examples for illustration. It should be understood that numerous specific details, relationships, and methods are set forth to provide a full understanding of the invention. One skilled in the relevant art, however, will readily recognize that the invention can be practiced without one or more of the specific details, or with other methods, etc. In other instances, details of well-known structures or operations are not shown for the purpose of brevity and to avoid obscuring the invention.

2. Grid/Plate Structure

Figures 1A and 1B are diagrams illustrating the details of grid/plate structure 100 in an

Figure 1A is a diagram illustrating the details of front
erent layers forming the plate/grid with low mass density
Figure 1B. Grid/plate structure 100 is shown containing
substrate 110, metal layer 120, lead layer 130 and protective, corrosion-resistant layer 140.
Each layer is described below in further detail.

Substrate 110, formed from material with a low mass-density and a low melting point, constitutes the core of a plate/grid on which other layers are deposited. As noted above, the low mass-density and low melting point enable high specific energy lead-acid batteries to be implemented at a low cost. In an embodiment, substrate 110 is implemented using ABS polymer (plastic). Other types of polymers can be used for substrate 110. The generally flexible nature of plastics makes substrate 110 tolerant to mechanical stress. In addition, as polymer plastics such as ABS are not susceptible to corrosion even in concentrated sulfuric acid present in lead-acid batteries, substrate 110 may be further suitable to lead-acid batteries. Metal layer 120 may be formed by a low cost metal such as copper or nickel, even though more expensive metals such as gold can also be used when applications so require. Metal layer 120 may be deposited so as to have the desired thickness (generally less than 10 micrometers). Metal layer 120 operates as a seed layer for the deposition of lead/lead alloy layer 130, while also providing adhesive support to it.

Lead/lead alloy layer 130 may be formed by a thin layer of lead or a lead alloy (e.g., lead-tin alloy) deposited onto metal layer 120. As lead is a high-density material, it may be desirable to keep the lead (or lead alloy) layer appropriately thin to obtain a high specific energy in the resulting lead-acid battery. As is well known in the relevant arts, lead (or lead alloy) layers provide electrical conduction path for charge/discharge of the battery.

Protective layer 140 represents an example of an electrically conductive and corrosion-resistant layer (for example, polyaniline) electrochemically deposited onto lead/lead alloy layer to protect the plate/grid from chemical corrosion.

As noted in the background section above, the deposition of these protective layers may present challenges if oxide layer(s) is (are) present in the underlying layers/substrate. The manner in which such concerns may be addressed is described with reference to an example manufacturing process. 3. Manufacturing Process

Figure 2 is a flowchart illustrating a process for fabricating plates/grids according to an aspect of the present invention. The method is described with reference to Figures 1A and 1B for illustration. However, the method can be implemented in several other embodiments as will be apparent to one skilled in the relevant arts based on the disclosure provided herein. The method begins in step 201 in which control passes to step 210.

In step 210, a substrate is formed from a material of low mass-density and low melting point. Several well-known methods can be used to form the substrate. For example, injection molding may be used to form substrate 110 from the ABS plastic. In the alternative, a stamping process may be used to form substrate 110 from a glass fiber-reinforced plastic. In step 220, a thin metal layer is deposited onto substrate 110 to provide support for, and to enable the deposition of the next lead/lead alloy layer. For example, copper may be used to form this thin metal layer, as it is inexpensive. One of several well-known approaches can be used to form the copper layer on substrate. For illustration, electroless plating process may be used to deposit copper layer on substrate 110. The thin metal layer corresponding to metal

ent adhesion of the next lead layer to the substrate. er is deposited on to the thin metal layer to form the on path of lead-acid batteries. The thin lead/lead alloy layer may be formed by an electroplating process. Steps 250 and 270 can be used to deposit a protective layer, which prevents corrosion of the underlying layers 120 and 130. In step 250, a polyaniline layer is deposited electrochemical!y on the grid from, a 0.1N polyaniline solution in oxalic acid is used. Each grid is placed symmetrically between two auxiliary platinum electrodes.

The substrate resulting from step 250 is a film of polyaniline, which is a corrosion-resistant, and electrically conducting. Rates of corrosion for resultant grids were found to be only one fourth compared to conventional lead grids being employed in lead-acid batteries. In general, step 250 may not be necessary for fabricating the negative plate/grid, as negative plate/grid of a lead-acid battery is less vulnerable to chemical corrosion. However, for ease of manufacturing process, fabrication of the negative grid may be identical to that of positive grid as illustrated above.

It may be appreciated that step 250 may involve a simple process that may be carried out using inexpensive equipment. Step 250 enables the use of lightweight plastic substrate and a thin layer of lead layer 130 (of Figure IB), resulting in a substantial reduction of weight of plates/grids and thus the weight of lead-acid batteries. The method ends in step 299. The manner in which lightweight plates/grids thus manufactured are assembled to provide a lead-acid battery is described below with reference to Figure 3. 4. Lead-Acid Battery Figure 3 is a diagram illustrating the details of a lead-acid battery implemented according to an aspect of the present invention. Battery 300 is shown containing plates/grids 310 and 320, absorbent glass mat 330, lug 340 and container 350. Each component is described below. Each of plates/grids 310 and 320 may contain multiple units of plate/grids formed as illustrated in Figure 2, depending on the amount of energy to be stored and delivered at a desired battery voltage. Plates 310 and 320 may be formed in a known way, for example, by applying lead oxide paste followed by curing. One of the two plates/grids 310 and 320 may be implemented as a negative plate and another as a positive plate, in a known way (based on units of plate/grid 100). Electrolyte and active paste may also be applied between a plurality of plates/grids 310 and 320 in a known way. The separator absorbent glass mat 330 separates plates/grids 310 and 320 from each other. Lug 340 connects the plate straps and may be implemented using light weight material because lug 340 needs only to support low weight plates/grids provided, using various aspects of the present invention. Container 350 generally needs to be made with a strong, leak-proof, and corrosion resistant material. Container 350 may also be made of low mass density material to further reduce the weight of battery 300. Thus, various aspects of the present invention enable lead-acid batteries with high specific energy and long life to be provided at low cost.

Fig.4. illustrates a typical galvanostatic charge-discharge data obtained at 25°C and at 5h-rate (C/5 rate) for a 6V/3.5Ah VRLA battery assembled with light weight grids of the invention described above. Data suggest a faradaic efficiency of 90% for the battery.

Performance characteristics of the battery at different rates ranging between C/20 and 3C rates are shown in Fig. 5. The battery exhibits an increase in capacity of 38% at low discharge rate of C/20 in relation to its capacity value observed at C/5 rate. At high discharge rates of 2C and 3C the observed capacities were 58% and 50% in relation to its capacity value observed at C/5 rate.

ferent temperatures between 50 and -20°C. The battery capacity at 50°C in relation to its capacity at 25°C. At low temperature values of the battery were found to be 38% lower in comparison to the capacity value observed at 25°C.

Fig.7. illustrates the high-rate charging data for a 6V/3.5Ah VRLA battery assembled with light weight grids of the present invention. The data suggest a charge acceptance of 90% within 1.5 hours of charge. It has been seen that the batteries accept 110% charge within 3.5 hours. It is noted that the capacity delivered by high rate charging is similar to conventional charging at constant voltage or constant current. The batteries were kept standing over a period of 5 days in discharge condition and were subsequently subjected to high rate charging and the data is shown in Fig. 8. The data show little change in the charge acceptance of the batteries for the charge rate between C/10 and 2C.

Fig. 9(i) shows the discharge data at C/5 rate for the batteries after charging as per the schedule in Fig. 8. The batteries are subsequently stored in discharged state for 5 days, were then charged as per schedule in Fig. 8., and subsequently discharged at C/5 rate (Fig. 9(b)). A comparison data in Figs. 9(a) and (b) shows little passivation.

The cycle life data for the batteries shown in Fig. 10 indicates the capacity loss to be minimal during 100 charge/discharge cycles.

5. Conclusion

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not to imply any limitation. Thus, the breadth and scope of the present invention should not be limited by any of the exemplary embodiments described above, but should be defined only in accordance with the following claims and their equivalents.

We claim:

1. An electrochemical method of manufacturing a corrosion resistant grid structure used in a lead-acid battery, said method comprising coating of substrate material such as herein described, with a metal layer of copper or nickel and a subsequent layer of lead/lead alloy followed by the electrodeposition of an organic material such as polyaniline and similar other organic material, over the above said lead/lead alloy layer by using an electrolyte such as oxalic acid to obtain a corrosion resistant grid structure used in a lead-acid battery.
2. A method of claim 1, wherein said lead/lead alloy of a grid is deposited by potentiostatic deposition of polyaniline from about 0.1N polyaniline solution in oxalic acid by placing the said grid in between two auxiliary platinum foil electrodes.
3. A method of claim 1, wherein substrate material used is plastic.
4. A method of claim 1, wherein organic material used is acrylonitrile butadiene styrene.
5. A method of claim 1, wherein said electrochemical coating process is performed a plurality of times to achieve said protective layer of a desired thickness.
6. A method of claim 1 wherein said the grid structure made of a substrate material used is acrylonitrile butadiene styrene .
7. A method of claim 1, wherein the said metal layer used supports the adhesion of lead/lead alloy layer
8. A method of claim 1, wherein substrate used has a low mass density preferably less than about 1.5 grams cm³ and low melting point, preferably less than about 175° C.
9. A method of claim 1, wherein polymer used is plastic.
10. A battery comprising: a positive plate, and a negative plate containing a grid structure as described in claim 1, said grid structure comprising of a substrate made from acrylonitrile butadiene styrene having a mass density of less than 2.5 grams cm³, having melting point lower than 300 degrees C; a container for holding said negative plate and said positive plate & an electrolyte such as oxalic acid also located within said container, said copper / nickel



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ness, said lead/lead alloy layer \times 100 micrometers in
layer \times 15 micrometers in thickness.

manufacturing a corrosion resistant grid structure used in a

lead-acid battery substantially as herein describe with reference to examples accompanying
this specification.