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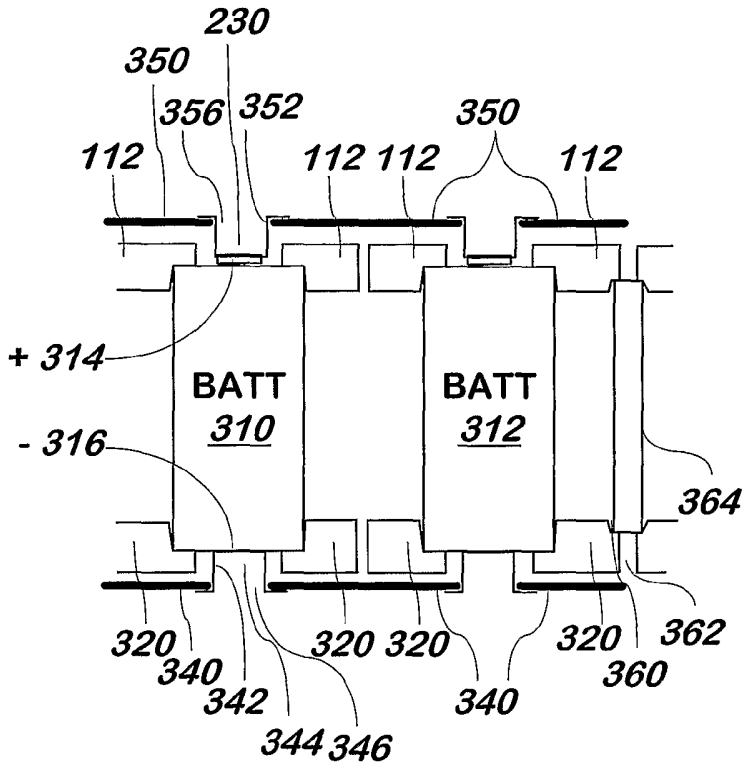
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(54) Title: METHOD AND APPARATUS FOR MOUNTING, COOLING, CONNECTING AND PROTECTING BATTERIES



(57) Abstract: A system and method mounts batteries in a substrate or insert to a substrate, electrically connects them via a set of conductors, and cools them using air, or cooling tubes having a flow of air or coolant running in opposite directions past each of the batteries.

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METHOD AND APPARATUS FOR MOUNTING, COOLING, CONNECTING AND PROTECTING BATTERIES

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Field of the Invention

The present invention is related to battery systems and more specifically to systems containing multiple batteries.

Background of the Invention

Portable electric devices can make use of batteries as a source of power. For example, conventional lithium-ion batteries may be used to power portable or mobile devices.

Conventional batteries generate significant heat from their cores. Exposing a battery to heat can significantly shorten its life, and thus, it is desirable to dissipate the heat from a battery.

To obtain higher current, voltage, or both, from a battery, the battery can be made larger. However, as batteries become larger in size, the ratio of surface area to volume decreases, causing the battery to retain more heat, decreasing its life. As a result, a standard size battery has been developed, referred to as "18650", having dimensions of 18 millimeters by 65 millimeters. Because standard sized batteries can be less expensive to produce than custom-sized batteries, many portable electric devices

employ multiple 18650 batteries, and connect them in series, parallel or both, to obtain the desired current and/or voltage. Another advantage of this form factor is that it is produced in large quantities, allowing the costs of such batteries to be lower than other batteries on a cost per milliwatt-hour basis.

Banks of batteries may be connected in parallel to provide higher currents, in series to provide higher voltages, or both. Conventional banks of batteries connect in parallel multiple batteries in each bank, and then connect the banks in series or parallel to achieve the current and voltage desired. However, other configurations may be used to obtain any desired current and voltage.

Some conventional banks of batteries are mounted into a plastic housing. If there are numerous batteries to be mounted, larger banks of batteries may be assembled. Assembling banks of batteries in a plastic housing can be cumbersome and bulky, so one manufacturer has built banks of conventional batteries in an alternative fashion by gluing batteries together in a side-by-side stack, like stacked firewood, and then connecting the terminals in each battery in the stack using a flexible nickel reed. The positive terminals on one end of the batteries are welded to the reed, and the case, which forms the negative connection, is welded to another reed at the opposite end of the row. All of the reeds at one of each of the ends of the stack are electrically connected and an external means of connection is provided at either end of the stack. The stacks are then used as building blocks to build the desired voltage and current.

However, there are significant problems with this technique. One such problem is that each of the stacks is not physically stable, because the form factor of each battery is not perfectly cylindrical. Instead, each battery is slightly conical, and so the ends of each of the batteries in a stack can shift slightly, causing the joints between the batteries to fail. This makes the glued stacks approach particularly unsuitable for environments in which significant vibration can occur, such as automotive applications. The narrower ends of the batteries can be wrapped with tape to even out the diameter of each end of the batteries, but such wrapping is labor intensive, prone to error and subject to failure.

Another problem with stacks of glued batteries is mechanical strength. A stack is only as mechanically strong as the weakest battery in the stack. If the end of a single battery is crushed, the chemicals in the battery can be compressed, causing a short circuit or other reaction that can heat the battery to an extent that a thermal runaway occurs, in which the heat from the initial reaction causes a

thermal reaction to become self sustaining and propagate until the battery fails. The heat from the battery can cause the adjacent batteries to incur the same thermal reaction until many or all of the batteries in the stack have failed. The heat from multiple such reactions can ignite adjacent materials. Turning the batteries on their sides like stacks of firewood can make the problem worse in certain environments, such as when the stack has a large number of batteries in a vibration-prone environment. The force from the vibrations can cause upper batteries to crush the lower batteries in the stack, causing the lower batteries to fail.

Additionally, conventional banks of batteries suffer from the problem that the conductors running across, and connected to, the positive "button" on top of the batteries can be pressed into the case of the battery during a significant impact, causing a short circuit between the positive button terminal and the electrically negative case. This makes banks of batteries particularly unsuitable for applications such as an electric or hybrid automobile, or other applications in which the batteries are likely to be vibrated or crushed. The case of the battery is insulated by a thin plastic or other material, such as Mylar. However, during an impact, the conductors that draw the positive current from the battery button terminal can burst through this insulating material to the metallic battery case, which is electrically connected to the negative terminal, thereby shorting the battery. Such an occurance could also happen simply due to vibrations occurring over an extended period of time.

Still another problem with batteries that are arranged with their edges contacting is that the heat from the batteries can cause the batteries in the center of the stack to become hotter than the batteries at the edges. As noted above, hotter batteries fail sooner than batteries that remain cool.

When multiple banks of batteries are interconnected, the connections between each bank must be manually made, increasing the costs of manufacturing. Wiring for voltage and temperature sensors at various points in the stack to allow for optimum performance further increase the costs of manufacturing.

Furthermore, the space in which the banks of batteries will be placed may not fit the banks exactly, requiring extra space to be allocated for the batteries, wasting space, and such space may be valuable in certain applications. The banks can each be made relatively smaller to reduce any wasted space, but this approach increases the need for interconnection, adding additional cost and potential points of failure.

What is needed is a system and method for providing multiple batteries in a manner that is physically strong and stable, can resist accidental crushing of one or more batteries, when handled or in an environment of vibration, that can resist crushing a conductor attached to the positive terminal into the negative body of the battery, that operates cooler and at a more even temperature than a glued stack or one in which the edges are otherwise touching, that does not require manual connection of each stack, and that can be shaped to more closely fit the available space.

Summary of Invention

A system and method sandwiches batteries between a rigid substrate that can distribute force across multiple batteries or other structures such as walls placed among the batteries, making them less likely to be crushed when resisting a force applied to the substrate. The substrate can be shaped to approximately fit the cross section of the available space, maximizing the use of the available space. Multiple conductors connected to the batteries via holes in the substrate draw power as well as connect the batteries in parallel, series, or both, to provide the proper current and voltage. However, the holes in the substrate are designed to lessen the likelihood that the conductor connected to the positive terminal will be shorted to the negative body of the battery in the event a force is applied that brings the batteries closer to any of the conductors. Cooling may be accomplished via air cooling or water cooling. Air may be blown among the batteries via holes in the substrates and conductors, and optionally an insert with mounts for the batteries containing integrated air holes to save space. Alternatively, or in addition to the air cooling system, cooling tubes may be run among the batteries to allow heat to be drawn away from the batteries. The cooling tubes are run adjacent to the batteries, in a structure that contains a pair of adjacent cooling tubes. Each adjacent tube has an opposite direction of flow from the other tube, and a connector connects the tubes at one end, allowing the coolant to flow past the batteries in one direction, then loop back in the other direction, to allow the coolant to not only absorb heat from the batteries, but to also maintain a more constant temperature of the batteries than would be possible if coolant having a single direction of flow was run past the batteries. The tubes may be physically connected to each other to allow heat from the tubes to be exchanged, helping to maintain a more even temperature of coolant through the tubes. The more constant temperature is maintained because the coolant along each section of

the adjacent pair of tubes not only exchanges heat with the coolant in the adjacent tube, the coolest sections at the inlet are adjacent to the hottest sections at the outlet.

Brief Description of the Drawings

Figure **1** is a block diagram of a bank of batteries according to one embodiment of the present invention.

Figure **2A** is a diagram showing a creation of a mount and a hole in the substrate used to hold the batteries in the bank according to one embodiment of the present invention.

Figure **2B** is a diagram of four mounts in a substrate used to hold batteries in a bank according to one embodiment of the present invention.

Figure **3** is a side view of batteries in a bank including two substrates and two conductors with electrical connection brackets according to one embodiment of the present invention.

Figure **4** is a diagram of two conductors with a representative bracket, including an alternate view of the bracket to show its geometry according to one embodiment of the present invention.

Figure **5** is a side view of five sets of batteries coupled using conductors according to one embodiment of the present invention.

Figure **6A** is a block diagram of the end conductors from two different stacks of multiple sets of batteries and a connector between the stacks according to one embodiment of the present invention.

Figure **6B** is a diagram of a single connector expansion piece according to one embodiment of the present invention.

Figure **6C** is a diagram of a ledge of the connector expansion piece of Figure **6B** showing a nut inserted therein, and a bolt screwed into the nut according to one embodiment of the present invention.

Figure **7** is a diagram of an expandable connector, including two of the expansion pieces of Figure **6B** according to one embodiment of the present invention.

Figure **8A** is a block diagram of an overhead view of one or more sets of batteries showing the direction of an upper and lower cooling tube coupled to a radiator according to one embodiment of the present invention.

Figure **8B** is a block diagram of an overhead view of one or more sets of batteries showing the direction of an upper and lower cooling tube cooled via a heat exchanger coupled to an air conditioner according to one embodiment of the present invention.

Figure **8C** is a cross sectional view of a structure that contains a pair of tubes according to one embodiment of the present invention.

Figure **9** is a block diagram of the side view of a row of the sets of batteries illustrating the upper and lower tubes from a different perspective than can be shown in Figure **8A**, according to one embodiment of the present invention.

Figure **10A** is a diagram of a portion of an insert including mounts with integrated air holes according to one embodiment of the present invention.

Figure **10B** is a diagram of a mount being drilled according to one embodiment of the present invention.

Figure **10C** is a diagram of the reverse side of a portion of an insert behind a mount according to one embodiment of the present invention.

Figure **10D** is a diagram of three mounts shown from the side, including a key under the insert according to one embodiment of the present invention.

Figure **10E** is a diagram of two air cooled battery assemblies according to one embodiment of the present invention.

Figure **10F** is a diagram of three air cooled battery assemblies according to one embodiment of the present invention.

Figure **11** is a diagram of a substrate and walls according to one embodiment of the present invention.

Figure **12A** is a diagram of a substrate, inserts, a cooling tube assembly and walls according to one embodiment of the present invention.

Figure **12B** is an exploded view of a battery assembly, partially filled with two of the dozens of batteries it may contain according to one embodiment of the present invention.

Figure **13** is a flowchart illustrating a method of assembling substrates, inserts, cooling tubes, walls, batteries, and conductors according to one embodiment of the present invention.

Figure **14** is a flowchart illustrating a method of mounting batteries in a battery assembly according to one embodiment of the present invention.

Figure **15** is a flowchart illustrating a method of mounting batteries according to one embodiment of the present invention.

Detailed Description of a Preferred Embodiment

Referring now to Figure **1**, a substrate used to hold one or more sets of one or more batteries is shown according to one embodiment of the present invention. The batteries used in one embodiment are any conventional rechargeable batteries having an 18650 form factor, but other types of batteries and other form factors may be used.

The substrate **112** may be made of a material that electrically insulates one face of the substrate from the other face. The substrate **112** has at least two faces and may or may not be substantially flat. In one embodiment, the substrate **112** has two primary faces, both of which are made of an electrically insulating material. In one embodiment, the substrate is a single layer of such insulating material, such as fiberglass or plastic, and in another embodiment, one or more layers of a conducting material are formed in the substrate in the manner of a conventional printed circuit board to allow wiring for sensors to be run along as part of the substrate.

The substrate **112** may be cut or formed into a shape that matches or somewhat matches two of the dimensions of a space available for batteries. As shown in the figure, the substrate **112** has an irregular shape, but regular shapes (e.g. a triangle or square) may also be used. This can allow a higher number of batteries to occupy the space available for such batteries than would be possible if the substrate **112** shape did not match the space available. Although the shape of the substrate **112** can help to maximize the number of batteries that can fit into a space, as noted below, in one embodiment, the batteries are not so tightly packed as to have the sides of each battery touching one another, but instead are spaced from one another to allow for cooling and to allow for dimensional tolerance of the batteries. In one embodiment, the batteries are spaced to allow for cooling of the batteries, either by air cooling or cooling via tubes running between the batteries as described in more detail below.

In one embodiment, the substrate **112** has a substantially flat shape. In one embodiment, the substrate **112** is a 3/8 inch thick fiberglass sheet, however, as described below, injection-molded plastic

may be used, as well as other substrates. Any electrically-insulating material may be used for a substrate **112**.

In one embodiment, the substrate is substantially rigid, to allow it to distribute force applied to one portion of the substrate among a wider area. As noted below, batteries are sandwiched between two substrates, and if the substrate is rigid, a force applied perpendicularly to the surface of the substrate **112** external to that of the batteries, will be distributed by the substrate **112** across two or three or four or five or more of the batteries and potentially many more. As noted below, the force may also be applied to spacers, walls or other structured components of the finished assembly. Thus, each of the batteries will be required to withstand only a fraction of the force, making it less likely that the force will crush any battery. In one embodiment, dozens of batteries and spacers and/or walls are sandwiched between a substrate that is sufficiently thick to distribute a force across many of the batteries, making it extremely resistant to crushing. As described below, spacers, walls, or both may be sandwiched between the substrate in addition to the batteries, either near the sides of the substrate or interior thereto or both, and if the spacers or walls have a crushing strength greater than the batteries, the spacers and/or walls add additional crush strength to the sandwich of batteries and substrate.

In one embodiment, each substrate **112** has a mount **110** for the insertion of each battery held by the substrate. In one embodiment, there are multiple mounts on the substrate, allowing a substrate to hold multiple batteries. The mount **110** may be raised from the substrate **112** or recessed into it or both. Batteries are inserted into mounts **110**, which are milled, molded or otherwise formed in the substrate **112** or, as noted below, the mounts may be milled, molded or otherwise formed into an insert to the substrate **112**.

In one embodiment, mount **110** is a well, and such embodiment will now be described, although the description of how the well is used is applicable to any form of mount **110**. In one embodiment, the well extents from one surface of the substrate, part way into the substrate **112**. For example, for a 3/8 inch substrate, the well may be ¼ inch deep. The well may be shaped so that it holds the end of the battery when a battery is pressed into it. In one embodiment, a well is formed as will now be described with reference to Figure **2A**, which shows the various positions of a milling tool used to mill each well in the substrate.

Each well **200** will hold one of the two ends of each battery to be mounted in the substrate.

Referring now to Figure **2A**, a well **200** is shown according to one embodiment of the present invention. In one embodiment, a well **200** is milled using an 11/16 inch mill bit. The end of the bit is brought into contact with the surface of the substrate **112** to drill a pilot hole **210** part way through the substrate, for example ¼ inch deep in a substrate that is thicker than ¼ of an inch. The bit is then moved sideways 12/1000 of an inch from the pilot hole in three or more directions, so as to form "petals" extending from the pilot hole **210**. As shown in the figure, four directions are used to make four petals, with the bit being brought to position **212**, then to position **214**, then back to the position of the pilot hole **210**, and, from the position of the pilot hole, to position **216** and then to position **218**. The bit is moved 12/1000 of an inch from the pilot hole center for each of the four directions. The resulting hole is slightly smaller than the battery at several points **222, 224, 226, 228**, such points being referred to as "teeth". Teeth **222, 224, 226, 228** are thin (e.g. they have about the same or a smaller cross section than the thickness of the substrate that comes in contact with the battery when mounted) or narrow areas of substrate **112** that contact the battery inserted in the mount and hold it at modest to high force per square inch as compared with the other edges of the well **200**, which may not contact the battery at all. The force may be at least large enough so that a battery will not wobble or fall over when inserted into the mount. The teeth **222, 224, 226, 228** may slightly deform when a battery is inserted into the well, allowing the teeth **222, 224, 226, 228** to hold the battery in place when the battery is inserted.

A hole **230** is then drilled from either direction all the way through the substrate **112**. In one embodiment, hole **230** is centered at the pilot hole of the well **200**, and has a diameter approximately equal to, or slightly smaller than, the diameter of the positive button terminal of the battery. In this arrangement, substrate **212** will protect the negative body of the battery from being shorted to the positive terminal in the event that a conductor in contact with the positive terminal of the battery near the face of the substrate **112** outside of the face holding the battery is pushed towards the batteries. The hole **230** will allow electrical connection to the terminals of the battery as described in more detail below. Hole **230** is not considered part of the well **200** or other mount in one embodiment, and in another embodiment, it is.

There are other ways of providing a mount **110** and hole for each end of each battery held by substrate **112**. Referring now to Figure **2B** an alternate manner of providing a mount **110** and a hole in substrate **112** is shown. In this embodiment, substrate **112** may be molded from conventional plastic, such as by using conventional injection molding techniques. Substrate **112** is shown with four wells **240** used to hold the ends of each of four batteries (not shown). Although four wells **240** are shown in one embodiment, there may be any number of wells **240**. The wells **240** are areas of the substrate **112** that are thinner than other areas of the substrate **112**, for example, if the substrate between the wells is generally 1/2" thick plastic, the wells may be formed so that the thickness of the plastic is 1/8" within the well. The side of the substrate **112** opposite the well **240** may be completely flush with the remainder of the substrate. The well **240** forms a depression in the substrate **112** to admit one end of the battery. Each well may have a substantially circular shape, though other shapes may be used. Each well **240** has several fins **244** to hold the battery, the fins **244** having a relatively narrow thickness, such that they can deform when a battery is inserted into the well and operate like the teeth described above. The circular area **246** exposed by the fins **244** is slightly less than the cross section of the end of the battery being inserted, and in one embodiment, the areas **246** may be slightly smaller or larger based on the polarity of the battery end being inserted. A hole **242** is formed or drilled in the substrate **112** to allow electrical connection to the batteries, and serves the same purpose and has the same geometry relative to the well **240** as hole **230** had relative to well **200**.

The holes are shown herein as being round, but holes may have any shape. Holes and the elements that hold the batteries may be any shape.

Referring now to Figure **3**, a cross section of a substrate **112** of Figure **1**, and another substrate **320** sandwiching batteries **310, 312** is shown according to one embodiment of the present invention. In one embodiment, substrate **320** is a mirror image of substrate **112** described above, and otherwise is of similar or identical manufacture as substrate **112**.

Batteries **310, 312** are inserted into one substrate **320**, and then a press may be used to press the opposite substrate **112** onto the other end of the batteries. As noted below, spacers such as spacer **364** may be inserted into spacer wells **360** in substrate **320** before substrate **112** is pressed onto batteries **310, 312** to allow spacer **364** to be a part of the structure containing batteries **310, 312**, spacers **364** and

substrates **112, 320**. Spacer **364** provides added crush strength to the structure formed by the batteries **310, 312** and the substrates **112, 320**, and the screws or other fasteners (not shown) that may connect the substrates **112, 320** to the spacer **364** via hole 362 (and the opposite hole in substrate **112**) provide a clamping force to hold the substrates **112, 320** more securely against the batteries **310, 312.**

Although only two batteries are shown in the Figure, any number of batteries may be employed in a similar fashion. Although only one spacer **364** is shown, any number may be used at the periphery of the substrates **112, 320**, interior thereto, or any of these locations.

Hole **230** and similar hole **344** in the substrates **112, 320** permit electrical connection to battery **310**, and other similar holes on either end of other batteries, permit electrical connection between the terminals **314, 316** of the batteries **310, 312** and two different conductors **340, 350**. In one embodiment, conductors **340, 350** are made of a conducting material such as copper or copper plated metal and have the shape of plates. In one embodiment, the plates are rigid, having a thickness in excess of approximately 20/1000 of an inch. In each conductor **340, 350** are holes **346, 356** placed so that the holes **346, 356** will be approximately at the location of the battery terminals **314, 316** when the conductors **340, 350** are mounted to the substrates **112, 320**. The conductors **340, 350** may be mounted using spacers to hold the conductors **340, 350** slightly off of the substrates **112, 320**, just outside of the area in which the battery is sandwiched, or the conductors **340, 350** may be attached directly to, on the face outside of, their respective substrates **112, 320**. Conductors **340, 350** may be glued to the substrates or may be held down by the welds to the batteries as described below. In one embodiment, conductors **340, 350** are a part of the substrates **112, 320** themselves, in the manner of a printed circuit board.

In one embodiment, the conductors **340, 350** have attached thereto, brackets **342, 352** made of a conducting material, such as tin, nickel or copper. In one embodiment, there is one bracket **342, 352** attached to the conductor **340, 350** per battery **310, 312** that is or will be electrically connected to the conductor **340, 350**, although other embodiments employ multiple brackets as a single strip. In one embodiment, before attaching the conductors to the batteries **310, 312**, the bracket **342, 352** is inserted into a hole **346, 356** in the conductor **340, 350**. In one embodiment, in each conductor **340, 350**, there is one hole **346, 356** and one bracket **342, 352** per battery that a conductor **340, 350** will contact. When all of the brackets **342** of a conductor **340** have been inserted into the holes of that conductor **340**, the

brackets are then wave soldered, welded, infrared reflow soldered or otherwise electrically connected to the conductor **340**, thereby forming an electrical connection between the brackets **340** and the conductor **342**. Other methods of electrically connecting the brackets **342** of a conductor **340** and the conductor **340** may be employed. In one embodiment, the holes **346, 356** in the conductors **340, 350** are on the same centers as, but smaller than, the holes **230, 344** in substrates **112, 320**.

A representative bracket **342** and conductor **340** are shown from a different angle in Figure **4**. As can be seen in Figures **3** and **4**, brackets, such as bracket **342** have a substantially U shape with the ends bent outward so that they can be inserted into the holes such as hole **346**, one bracket per hole. Each bracket may be made of a shape, material or both to allow it to have at least a slight give, to allow the brackets **342** to compensate for variation in battery placement within the mounts and the substrate and optionally, the inserts used to mount the batteries as described herein. In one embodiment, each bracket, or multiple portions of a strip, has a shape substantially as shown in the expanded view of Figure **4** that allows for a spring action to accommodate variations in lengths of the batteries and tolerances in substrates, mounts, and the like. Bends forming the surfaces **420** provide the spring action, with the distance **d** between the underside of the topmost horizontal surface and the underside of the bottommost horizontal surface at least as large as the maximum expected distance between the outside of the conductor **340** and the edge of the any terminal of any of the batteries. Stiffeners **422** are a bent piece of the bracket **342** that helps keep the lowermost horizontal surface substantially flat. The geometry and dimensions of the bracket **342** may be arranged to ensure that if it is crushed into the positive terminal, it does not splay into the negative case of the battery, but instead, side surfaces compress inwards.

Although only one bracket is shown in the Figure, each hole shown may have a bracket inserted in the same manner as is shown and wave soldered to each conductor **340, 412** in one embodiment. In one embodiment, a single bracket **348** in the shape of multiple end-to-end brackets **342** spans multiple holes, to reduce the manufacturing costs of installing multiple brackets.

The holes such as hole **346** are positioned to have the same spacing as the batteries **310, 312** over which they will be positioned so that when a conductor such as conductor **340** is placed into position above or below a set of batteries, that each of the brackets for that conductor will contact a terminal **314**

or **316** of a different one of the batteries in the set or sets of batteries to which the conductor **340** is in physical and electrical contact.

The conductors **340, 350** may be mounted to the substrate **112** or **320** so that each of at least one of the brackets **342, 352** are in contact with at least one terminal **314** or **316** of a battery **310, 312** mounted or to be mounted in substrate **112** and **320**. In one embodiment, the distance **d** of bracket **342** is such that it will extend through the hole **346** in the conductor **340** and the hole in the substrate **320** and any space between the conductor **340** and the substrate **320** and contact a battery **310, 312**, even if the battery **310, 312** is not fully seated into its mount. Bracket **352** is similarly or identically sized for its conductor **350**, substrate **112** and any spacing between the two.

In one embodiment, each bracket **342, 352** may then be physically attached, such as via a weld from a spot welder or laser, to the terminal **314, 316** to which it is connected.

Spacer well **360** admits a metal or plastic spacer **364** with optional holes drilled into both ends of (and optionally, all the way through) the spacer **364** to admit a screw (not shown) to be inserted into hole **362** from under substrate **320** and screwed into the spacer **364**. Another screw may be screwed into the other end of spacer **364** from above substrate **112**. Spacers may be positioned along the periphery of the substrates **320, 112** or interior thereto or both types of positions of spacers may be used.

In one embodiment, the batteries **310, 312** are arranged in sets of one or more batteries **310, 312**, with all of the batteries in the same set being oriented with the same polarity in one direction, and all of the batteries in the set having their terminals **314, 316** electrically connected by, and physically in contact with, the same conductor **340, 350**, although, as noted below, a conductor **340, 350** may be in electrical and physical contact with at least one other set of batteries, oriented with the opposite polarity as the first set, thus forming a series connection between the sets.

Conductors **340, 350** are used to connect the set of batteries **310, 312** in contact with the brackets in parallel with the other batteries of the set, and optionally in series with another set. This may be accomplished by inverting the batteries in an adjacent set and using a single conductor **340, 350** to connect all of the batteries at one end of each set. When this arrangement is used, the batteries in the first set are connected in parallel with each other, as well as in series with the other set. Adjacent sets of batteries may be alternately positioned, with a conductor **340, 350** spanning both sets of batteries on one

side, though all the batteries in one set will contact the same conductor with a different polarity from all the batteries in the other set.

Walls May Support The Substrates

As noted above, batteries, spacers or both may be the primary means of connecting and supporting substrates. However, in another embodiment, perimeter and divider walls are used as one method or the primary method to connect and support the substrates. Referring now to Figure **11**, the substrate shown in Figure **1** is shown with perimeter and divider walls according to one embodiment of the present invention. A perimeter wall **1110** is attached to substrate **1112**. Attachment may be made by means of glue, heat bonding or melting of the wall **1110** to the substrate, or conventional snap together methods or other fasteners via fasteners **1114**. Perimeter wall **1110** may be made of several pieces, with edge or corner connectors connecting each of the pieces. Perimeter wall **1110** may contain connectors such as connector **1116**, which may be a slot or other fastener molded into the perimeter wall **1110**. Connector **1116** attaches to a divider wall **1118**, which may be attached to the substrate **1112** in the same manner as perimeter wall **1110**. As shown in the figure, divider walls such as divider wall **1118** may itself have connectors that hold up still other divider walls.

In one embodiment, perimeter walls **1110** are used to physically protect batteries from outside intrusion, and divider walls **1118** are used to protect batteries, that may be pushed via an unwanted external force, from pushing other batteries nearby, and may also confine any unwanted thermal reactions to a subset of the batteries bounded by one set of walls **1110** or **1118**. In addition, because the side walls of the batteries are connected to the negative terminal, and negative terminals of adjacent batteries may be at different potentials from one another, the use of divider walls **1118** can help prevent short circuits that would otherwise occur if the batteries, having different electrical potentials of their respective cases were to touch cases due to an unwanted force. In one embodiment, either a divider wall or a cooling tube (described below) is used to separate adjacent batteries having negative terminals and cases at differing potentials.

Electrical Connections

Figure **5** shows 5 batteries **500-508** connected in series to increase the voltage to approximately five times the voltage of one battery via conductors **520-530** using the techniques of the present invention

(the substrates, brackets, and spacers have been omitted from the Figure to improve the clarity of the Figure). Although there is only one battery **500-508** in each set in Figure **5**, more than one battery per set connected to the same pair of conductors **520-530** and using the same polarity as each battery **500-508** shown could have been used to increase the current to an approximate multiple of the current of the single battery **500-508**. In one embodiment, end conductors **520, 530** have terminals **540, 542**, which may be screw terminals or an embedded screw post with a nut that is screwed over the screw post. A wire may be attached to each terminal **540, 542** in a conventional manner to allow power from the battery to be brought to a point of use. The point of use may be an electric motor in an electric car in one embodiment of the present invention, and there may be more than one terminal **540, 542** per end conductor **520, 530**, such as is described below. It is noted that in the Figure, conductors **520-530** collectively contact all of the batteries from which current through each conductor **520-530** is provided, but individually, the conductors **520-530** do not contact all of the batteries **500-508** and each conductor **520-530** is at a different electrical potential from the others relative to any other one of the conductors **520-530**.

As shown in the Figure, an odd number of sets of batteries (in the Figure, there is one battery per set) will cause the end conductors **520, 530** to be located on opposite sides of the batteries **500-508**. Having an odd number of sets, where the sets are connected to one another in series as shown, can produce a useful assembly **500** of batteries **500-508** because the assemblies themselves can be coupled in series with a minimum of interconnection. If the sets of batteries are arranged in a pattern that causes the first set and the last set to be near each other (such as if the sets are arranged in a somewhat circular pattern around the assembly, the end conductors can be on opposite sides of the assembly, in the same general region, but without significant cross connection structures, allowing interconnection of assemblies with a minimum of cross connection runs.

Stacks, and the Interconnections Between Them

The batteries sandwiched by substrates and inserts and connected by conductors as described herein may have insulating paper or other insulating material attached thereto, and multiple such assemblies or structures of batteries may be electrically interconnected. Figure **6A** illustrates the end conductors **636, 637** of two different structures, similar to the end conductors **530, 520** of Figure **5**, each

coupled to one or more sets of batteries arranged as described above with respect to Figures **1-5**, with the detail showing the batteries, substrates, remaining conductors and other structures omitted in the Figure to show the interconnections between end conductors of two different structures (the word structure and assembly are used interchangeably herein). End conductor **636** is an end conductor of one structure, and end conductor **637** is an end conductor of another structure, with the structures intended to be electrically connected in series to one another using expandable connector **650**.

Referring now to Figure **6A**, end conductors **636, 637** have a portion rising above the substrate sandwiched between the end conductors **636, 637** and the batteries to which the end conductors **636, 637** are coupled, such portion being illustrated above the dashed line in the Figure, said line representing the top of the substrate. In one embodiment, U-shaped holes **634** are milled into, or formed as part of, the end conductors **636, 637** to allow insertion of terminals **638** of a connector **650** to be inserted therein, when the connector **650** is inserted in the direction of the arrow. Terminals on the opposite side of expandable connector **650** are not visible, but are the same in number as the visible side, and offset from those on the visible side. In one embodiment, there are more U-shaped holes **634** than terminals **638** on one side of the expandable connector **650** to allow each end conductor **636, 637** to operate on either side of connector **650**. Terminals **638**, which may be bolts or screws are then tightened over the end conductors **636, 637** to cause a connection between the end conductors **636, 637** and an expandable conductor **640** made of copper or another conducting material. Expandable conductor **650** is a flat conductor bent in a U cross section, and flexible enough to expand when terminals **638** are tightened.

Expandable connector **650** is shown in greater detail in Figure **6D**. Referring now to Figure **6D**, expandable connector **640** has three primary sets components. There are two expansion pieces **610**, one expandable conductor **640** and six terminals **638**, though other numbers of terminals may be used.

Expansion pieces **610** are shown in greater detail in Figure **6B**. Referring now to Figure **6B**, one embodiment, expansion piece **610** has multiple ledges **616**, each ledge **616** containing a recessed well **612** that holds a nut and prevents it from turning, and may be a tight enough fit to hold the nut in place in the well **612**. The well **612** is about as deep as the nut is thick. Each well **612** has a hole drilled or formed into the center of the well and extending straight through to the opposite side of the ledge **616**. Figure **6B** shows a ledge in greater detail. A nut **630** has been inserted into the well and a bolt **632** has been inserted

from the opposite side of the ledge **616** from the side from which the nut was inserted **630** through the hole in the well and threaded into the nut **630**. As noted below, in practice, the nut will be inserted through a hole in the expansion conductor **640**, which is not shown in Figure **6B**.

Referring now to Figures **6B-6D**, to assemble the expandable connector two expansion pieces **610** are mated together, facing one another so that their ledges **616** are in a single plane, but having their wells facing 180 degrees away from one another. The expansion conductor **640** is slipped over the ledges **616** and bolts or screws are inserted through holes in the expansion conductor and through a hole **614** in the ledge **616** until they reach the nuts **630** at the opposite side of the ledge **616**, and are screwed part way into the nuts **630**. Referring momentarily to Figure **6A**, the expansion connector **650** is slipped between two end conductors as shown in Figure **6A**, and the screws or nuts **632** are tightened.

When the screws or bolts **632** are tightened, they pull the ledges **616** of the expansion connectors **610** apart from one another in opposite directions, with the face of the ledge opposite the well **612** pressing against the nearby area of the expansion conductor **640** to press it into contact with the edge connector **636, 637**, providing an electrical connection that can carry significant current and is physically stable, yet can be disassembled and reassembled as necessary.

Expandable conductor **650** is described herein as connecting two structures in series. However, expandable conductor may be used to connect multiple structures in parallel as well.

Cooling

Liquid Cooling

In one embodiment, the batteries may be liquid cooled via small, thermally conductive tubes through which water or another coolant, such as any conventional anti-freeze mixed with water, oil, or even cold air, may be circulated via conventional means such as a pump.

The tubes absorb heat from the batteries and transfer it to the liquid, coolant or air. The pump may pump the liquid to a radiator where the heat is released to the air near the radiator, or to a heat exchanger that exchanges heat with a refrigerant, such as conventional R-134a, that operates as part of a conventional heat pump, which absorbs heat from the coolant or other liquid and releases it to a radiator. In the event that the batteries are powering an electric car, the radiator may be drawn through the ambient air when the car is in motion to enable additional heat to be released into the air.

Figures **8A** and **9** illustrate the coolant-containing tube, from different perspectives: Figure **8A** is a top view and Figure **9** is a side view of a different set containing a different number of batteries, but is similar to what would be seen by looking from the third row of batteries from the top of Figure **8A** towards the second row of batteries from the top of Figure **8** to show the detail not visible in Figure **8A**. Figure **9** is actually superimposed onto the batteries shown Figure **5**. In one embodiment, one tube **810** is arranged to run near each battery (the position of each battery will roughly correspond to the circles of Figure **8A**) in one or more sets. Referring now to Figures **8A** and **9**, in one embodiment, the tube has an inlet **812** for accepting the liquid, which runs near each of the batteries that it will cool, and then, in one embodiment, the tube turns around via a turnaround section **910** shown in Figure **9** and runs past each battery a second time, either on the same side of the battery as the first run, or on the opposite side. The turnaround section **910** may be outside of the substrate, for example, near inlet **812**, to avoid a joint (between turnaround section **910** and the remainder of the tube **810**) being near the batteries. Conventional heat conductive, but not electrically conductive, potting compound (not shown) or another heat conductive substance, such as KONA 8701-LV-DP heat conductive compound commercially available from Resin Technology Group, LLC, may be poured over the tubes so that it also touches the batteries and helps conduct heat from the batteries to the tubes.

The direction of flow of the coolant in the tubes is shown by the arrows in Figure **9**. An outlet (directly over the inlet **812** in one embodiment) exhausts the coolant to the radiator **814** where the coolant releases its heat, with the coolant being circulated by pump **820**. Because two runs of the tube are used near each battery, with the flow of coolant in the tubes running past each battery being in opposite directions and in the opposite order, the batteries may be cooled more evenly than if a single run were employed. In one embodiment, the two tubes are actually part of a single structure, to allow the heat from the two tubes to be exchanged, further stabilizing the temperature of the coolant in the tubes across the run of the tubes. Referring now to Figure **8C**, a single structure **860** containing two tubes is shown according to one embodiment of the present invention. The structure **860** contains crosspiece **864**, and may be formed as part of a single extruded piece of aluminum or another heat-conductive material. The crosspiece **864** and structure **860** form the two tubes **862, 866** having opposite directions of flow. In one

embodiment, the top tube **862** is coupled to the inlet and in another embodiment, the top tube **862** is coupled to the outlet, though other embodiments may reverse those connections.

In one embodiment, the outer surfaces of the tubes are made of an electrically insulating material so as not to cause shorts between the cases of the batteries, which are electrically connected to the negative battery terminal. Because the negative terminals of different batteries are at different electrical potentials, if the tube touches the batteries, a short could occur if a tube were made of an electrically conductive material. In one embodiment, the tubes are made of aluminum and the outer portion is anodized to cause the outer edges of the aluminum to be a poor conductor.

In one embodiment, instead of a radiator absorbing the heat from the tubes and their contents, in the case of an at least partially electric-powered car or other vehicle, heat from the tubes and their contents may be absorbed by an evaporator in a conventional air conditioning system. Referring now to Figure **8B**, a system for cooling batteries is shown according to one embodiment of the present invention. Elements **810-820** operate as described in Figure **8B** above, except that instead of releasing heat to a radiator **814**, heat from the batteries absorbed by the coolant in the tubes is released to a conventional evaporator **834** in a heat exchanger **836.** Compressor **830** compresses a refrigerant and provides it to a condenser **840**, which may be placed near a fan **842** or other airflow. The refrigerant arrives into an accumulator and is provided to the evaporator **834** and returned to compressor **830**. A heat exchanger **836** allows the evaporator **834** to absorb heat from the tubes, after the coolant has passed by some or all of the batteries. In one embodiment, a single compressor is used to not only cool the batteries, but also the air in the passenger compartment. A second evaporator **844** absorbs heat in air provided to the passenger compartment via a blower **846** and the refrigerant then collects in the accumulator **838**. A diverter valve under control of a microprocessor **850** having sensors **852, 854** to sense the temperature of the batteries and the air in the passenger compartment determines the proper amount of refrigerant to allocate between the evaporator **834** serving the batteries and the evaporator **894** serving the passenger compartment air, based on the temperatures and the requirements of each system.

Air Cooling

The batteries in each set may be air cooled via spaces between the batteries in between which air can blow through. Air cooling may be used in addition to the liquid cooling described above, or in place

of it. In one embodiment, inserts to be added to the substrates are used to mount the batteries using integrated cooling holes and mounts as are described more completely below. The substrate is made of a glass-fiber-containing material for strength and rigidity, yet the insert is made of a more flexible material for better battery holding properties. Both the substrate and the inserts contain air holes into which air may be blown, or out of which air may be removed through suction, or both. The air holes may be integrated with the mounts, so that the air can blow directly into the spaces between the batteries, and yet the mounts do not interfere with the air cooling.

Referring now to Figures **10A-10D**, a portion of an insert **1016** including integrated mounts **1018** with integrated air cooling holes **1012** in each of the mounts **1018**, is shown according to one embodiment of the present invention. In one embodiment, insert **1016** is placed between the substrate and one or more batteries, although in another embodiment, the features of insert **1016** are part of the substrate. In one embodiment, insert is made of any flexible, insulating material and may be different from, or the same material as, the substrate.

Figure **10A** is a top view of a portion of a portion of an insert **1016** with batteries, such as battery **1008** inserted into the mounts **1018**. In one embodiment, some mounts are shared between two or three batteries, such as the mount shown in the center of Figure **10A**. In one embodiment, each mount **1018** has the shape of a short hollow tube that is molded above a hole running through the insert **1016**, with the hollow portion running perpendicular to the substrate **1016**.

A flat cross piece **1010** may be molded between pairs of mounts **1018** just outside the space for the battery **1008** to add strength to the mounts. In one embodiment, cross piece **1010** does not extend the entire distance between nearby mounts, but instead runs a very short distance (about ¼ of that shown), with only one cross piece per mount instead of the three shown. When air cooling is to be used, each of the mounts is over a hole in the substrate to allow air from one side of the substrate through the hole in the insert, and through the mount **1018** to cool the batteries. Air may be removed from in between the batteries or exhausted through the opposite substrate as described below.

Figure **10B** shows a step in the process of building the mounts **1018**, which are injection molded to the insert **1016**. Referring now to Figure **10B**, bit **1020** is drilled into the insert **1016** just under the point where the injection-molded mount **1018** will contact the battery, although in one embodiment, the shape

that would result from such drilling, or another shape that serves the same purposes, is in fact molded into the mounts **1018**, and no drilling occurs. Figure **10C** shows the holes from the underside of the insert **1016** when the main hole for the mount **1018** has three holes, including hole **1014** (also shown from the opposite side in Figure **10A**) drilled at its edge. The holes such as hole **1014** in Figure **10C** drilled by bit **1020** of Figure **10B** allow the mount **1018** to deform when the battery is inserted between the mounts, to prevent the deformity of the mount **1018** that would otherwise occur from deforming the insert and the substrate so as to allow them to maintain their substantially flat shape, and help the mounts **1018** hold battery **1008**.

Figure **10D** is a side view of battery **1008** inserted into the mounts **1018**. Cross piece **1010** is also shown. In one embodiment each battery connection hole **1022** is more clearly shown in Figure **10D**. In one embodiment, there is one key **1022** under each battery, though other embodiments may employ fewer or more keys. Each key is a single, hollow tube extending downward from insert **1016**. The hole in the substrate is similar to hole 230 of Figure **2**, but no mount exists in the substrate. Each key **1022** fits into a different hole in the substrate. Each hole in the substrate is nearly the same diameter as the outer diameter of key **1022**, with the key extending from the bottom of the insert **1016** with a length substantially as long as the substrate is thick. Into the portion of the insert **1016** above key **1022** is a hole, either molded or drilled therein to allow connection to the battery terminals as described above in a manner similar to hole 344 of Figure **3**. The key holds the insert **1016** in place against the substrate, and prevents the potting compound, or other heat conductive material described above, from flowing under the battery terminals, which could otherwise prevent a good electrical connection between the battery and the bracket.

As noted herein, the mounts **1018** are positioned above holes **1024** in the substrate and optionally, the conductors to allow air to flow through, if air cooling is to be used. The insert **1016** is mated to a hole **1026** in substrate **1006** and electrical connection is made with the brackets via hole **1026** and the hole in the key **1022**. The hole in the key opposite the positive terminal of any battery **1008** has a diameter not larger than the positive terminal of the battery **1008** to ensure that the conductor below the substrate **1006** contacting the positive terminal of the battery does not short to the negative case of the battery **1008** if it is pushed towards it.

Referring now to Figure **10E**, two battery assemblies are shown with air handling equipment. In the assembly **1060** on the left, an **1050, 1058** or both draw air from duct **1052**, flowing through cowell **1054** through a single assembly **1060** of batteries with air holes as described above and out duct **1056** in the direction indicated by the arrow. In another embodiment, shown with the assembly **1061** on the right, duct **1056** is not used, and fan **1059** draws air through the top of assembly **1061**. In another embodiment, shown in Figure **10F**, air flows in the direction indicated by the arrow (or in the opposite direction) through multiple assemblies **1074** having air holes as described above via fan **1070** and cowell **1072**. Any space between assemblies **1074** may be covered by ducting.

In one embodiment, the conductors are not adjacent to the substrate, and so a large number of smaller holes may be provided in the conductors to allow air to flow through the conductors generally, but the holes need not be positioned adjacent to a mount in the insert. In such embodiment, the density of holes may be greater around the periphery of the conductor than it is at the center, so as not to interfere with the current carrying capacity of the conductors at locations of high current.

Although the geometries described herein may be used in one embodiment, other embodiments may employ other geometries. For example, in a non-air cooled environment, the mounts need not be mounted over holes in the substrate.

An Example, and a Method

Part of an example assembly according to the present invention is shown in Figure **12A** according to one embodiment of the present invention. Figure **13** describes the method of assembly.

Referring now to Figures **12** and **13**, a substrate **1210** is shown with multiple inserts **1216** mated thereto via keys in the inserts **1216** fitting holes in the substrate **1210**, corresponding to step **1310**. A tubing assembly **1214** is fashioned into shape, for example by bending **1312**, and placed **1314** over the inserts **1216**.

In step **1316**, perimeter walls **1218** are mounted or bonded to the substrate **1210**, and divider walls **1220** are inserted between the perimeter walls and may be mounted or bonded to the substrate **1210**.

Batteries, not shown, are added **1318** to the mounts in the inserts as described above and potting compound or other thermally conductive material may be added to touch each of the batteries and the adjacent section of the tube, and then in step **1320**, a mirror image set of inserts, not shown, are in step

1322, are mounted to a mirror image substrate, not shown, and mounted to the batteries via mounts and to walls **1216, 1218** as described above.

Brackets are connected to conductors **1324** and then connected to the batteries **1326** as described above, offsetting over two sets of batteries, each set having an opposite polarity, to connect the two sets in series, for example. An assembly showing an alternate design, including some of the batteries **1222** and the mirror image substrate **1224** is shown in an exploded view in Figure **12B**. Because Figures **12A** and **12B** are water cooled, the air holes in the substrate near the mounts are not employed.

If there are additional assemblies **1328**, they are built as described in steps **1310-1326** and then connectors may be connected **1330** between the edge connectors of adjacent assemblies as described above.

The steps of Figure **13** may be performed in different order than what is described, or may be interlaced with one another, mounting the batteries and the walls a few at a time, for example.

Other Methods

Referring now to Figure **14**, a method of mounting and electrically connecting batteries is shown according to one embodiment of the present invention. One or two or more substrates with mounts for each battery and holes for electrical connection to the batteries are provided **1410**. In one embodiment, the mounts are molded into the substrate. In another embodiment, the mounts are milled into the substrate, as described above, and will now be described with reference to Figure **15**.

Referring momentarily to Figure **15**, a method of milling battery mounts into a substrate is shown according to one embodiment of the present invention. A first position is selected **1510** and a spinning bit is drilled **1512** part way into the substrate at the first position. A petal is milled **1514** by radiating the drill bit outward from the center of the first position, for example, along a line. The bit is brought back to the center of the first position, and another petal is milled **1516** outward from the center of the first position along any line different from (though potentially 180 degrees from) a line used to mill any other petal for that mount. If there are more petals to mill **1518**, the method continues at step **1516** and if not **1518**, if there are more positions on the substrate in which a mount is desirable or required **1520**, the next position is selected **1526** and the method continues at step **1512** as described above, and otherwise **1520**, holes may be drilled through the substrate into the center of some or all of the mounts **1522** to provide

electrical access and the method terminates **1524**. As noted, batteries may be inserted into the mounts as described below, and the holes drilled in step **1522** may be smaller than the diameter of the positive terminal of the battery to be inserted, so as to protect it from coming into contact with a conductor that may be pushed against it.

Referring again to Figure **14**, multiple batteries are inserted **1412** into the mounts at one substrate, such as the bottom or the top, with one battery per mount in one embodiment. The batteries are inserted as part of sets: the batteries in each set may be inserted with the same polarity of the battery inserted into the mount, but each set may be inserted with polarities inserted that are different from the one or two sets that will be electrically adjacent to it. Spacers may be inserted **1414** into mounts which may or may not be different from the mounts used for the batteries (e.g. the mounts used for the spacers may be narrower than the mounts used for the batteries). In the flowchart, step **1414** follows step **1412**, but the two steps may be performed together, with some batteries being inserted and then one or more spacers, then more batteries and done or more additional spacers, etc. Other steps in the flowchart of Figures **14** or **15** may be performed in this intertwined fashion with other steps or some steps may be performed in a different order than is shown.

One or more cooling tubes may be run **1416** among a path adjacent to some or all of the batteries and the same one or more cooling tubes or a different one or more cooling tubes may be run **1418** back in the opposite direction along the same path or an opposite path. Steps **1416** and **1418** may be combined by running a single cooling tube assembly near each battery. In this manner, each battery is adjacent to two flows, with one in either direction, although other numbers of one or more flows in any number of directions near each battery may also be used. A heat conductive material may be added **1420** to contact the tube or tubes and some or all of the batteries.

Another one or more substrates may be pressed **1422** on to the other end of the batteries that were inserted in step **1412** and the spacers inserted in step **1414** using a conventional press. The other one or more substrates are made with the mounts described above. The mounts may be differently sized depending on the polarity of the battery the mount will accept, or the same sized mount may be used for all polarities. The other one or more substrates of step **1422** may be mirror images of the one or more substrates of step **1414**.

Multiple conductors with holes are provided **1430** as described above. Brackets may be inserted **1432** into the holes and each bracket may be electrically connected **1434** to a conductor, such as by wave soldering the brackets to the connector when most or all of the brackets are in the holes of the connector.

The brackets with the connectors and the batteries mounted in the substrates described above are brought together in steps **1436** and **1438**, which may be performed essentially simultaneously, but will be described separately for ease and clarity of description. One or more brackets electrically attached to the conductors are electrically attached **1436** to one or two sets of batteries via the holes in the substrates. This may be performed by aligning the brackets protruding out of the holes in each of the one or more conductors, with the holes that expose the terminals of the batteries mounted in one or more substrates.

The alignment may cause each conductor to electrically connect one terminal of each battery in a set to the same polarity terminal of all of the other batteries in a set, and optionally to also connect to such terminals the terminals having the opposite polarity of all of the batteries in a different set. For example, if all of the batteries mounted in the substrate are to be divided into sets, and all of the sets are to be connected in series, there will be one conductor spanning one end of each two electrically adjacent pair of sets, with the ends of each set spanned by a single conductor having opposite polarities, and two additional conductors, each spanning one polarity of all of the batteries in one of the two "end" sets.

Thus, in one embodiment, all but one or two of the conductors are each aligned over the terminals of two complete sets of batteries, the batteries in each set being connected at the same polarity with the other batteries in the set by the brackets and conductors when placed in contact thereto. Two sets of batteries may be connected to the same conductor, with each of the two sets having opposite polarities being connected to the conductor. In one embodiment, the electrical attachment also includes a physical attachment, such as by spot welding, pressure contacting or low-temperature soldering each bracket to one terminal of one of the batteries. In one embodiment, each bracket has two or more connections (e.g. spot welds) to at least most of each of the battery terminals for redundancy.

A process similar to the process described above is repeated for the one or more substrates on the other side of the batteries **1438**, with brackets attached to one or more conductors as described above with respect to steps **1430-1434** aligned to fit into the holes in the substrate of the opposite side of the substrate of step **1436** and the brackets are spot welded to, connected, or otherwise electrical brought into

contact with, the terminals inserted into the mounts of that substrate. As noted herein, any conductors spanning two sets of batteries are offset from those of the other substrate so that zero or more conductors can each connect the different polarity terminals in each of two sets of batteries in series, and will, in part, connect the batteries within the set in parallel. It isn't necessary to weld the brackets to the batteries: any electrical connection between the bracket and battery terminal can be used.

The conductors at the ends of each series of sets of batteries may be coupled **1442** to one or more edge terminals and the one or more edge conductors of one pair of substrates that make up a battery assembly may be connected **1440**, either physically, electrically or both, to an edge conduction of an adjacent pair of substrates that make up a battery assembly (each assembled as described above), so as to connect at least some of the batteries in each assembly in series or parallel. In one embodiment, step **1444** is performed via a single solid, but slightly flexible unit, which may be constructed without wires.

What is claimed is:

1. A battery mounting system, comprising:

a plurality of substrates, each comprising a plurality of mounts, at least some of each of the plurality of mounts being aligned over at least one hole through said substrate;

a plurality of batteries, each having at least two terminals inserted into the mounts of at least two of the plurality of substrates; and

a plurality of conductors coupling a terminal of each battery in a set of a plurality of batteries in the plurality of batteries to a terminal of each of the other batteries in the set; and

wherein the substrate is rigid enough to allow a force applied perpendicularly to a surface of the substrate not facing the batteries to be distributed across at least some of the plurality of batteries, or other structures in contact with the substrate.

2. The system of claim 1 wherein each of the mounts comprises a set of at least one narrow portion of the substrate that contacts and holds one of the plurality of batteries.

3. The system of claim 2, wherein the mount comprises a pilot hole and a plurality of petals extending from the pilot hole.

4. The system of claim 2 wherein the mount is milled into the substrate.

5. The system of claim 1 additionally comprising at last one cooling tube running adjacent to the plurality of batteries.

6. The system of claim 5 wherein:

the cooling tube runs adjacent to each of the plurality of batteries at least twice;

the cooling tube has a flow of a coolant; and

the flow of the coolant near each battery occurs in a different direction in at least two of the at least two runs of the cooling tube near each battery.

7. The system of claim 1, wherein the substrate is shaped to substantially fit at least two dimensions of a space available for the batteries.

8. The system of claim 1 wherein:

the plurality of conductors each have a plurality of holes; and

for at least some of the plurality of conductors, inserted into each of the plurality of holes is at least one bracket, each bracket electrically connected to the conductor and protruding from said hole in the conductor and through one of the holes in the substrate so as to come into electrical contact with one of the terminals of at least one of the plurality of batteries;

whereby the plurality of brackets electrically interconnects the conductor with the terminals of the at least some of the plurality of batteries.

9. The system of claim 8, wherein the at least one bracket is physically attached to one of the terminals of each of at least some of the plurality of batteries.

10. The system of claim 1 wherein the terminals of the batteries have a polarity, and at least one conductor is electrically connected to different polarities of different of the at least some of the plurality of batteries.

11. The system of claim 1, wherein the at least one hole in the substrate has a diameter not larger than a diameter of a positive one of the at least two terminals of the plurality of batteries.

12. A method of containing a plurality of batteries, comprising:

mounting the plurality of batteries into mounts in a first substrate, each of at least some of the mounts being located over at least one hole through the substrate, the substrate capable of distributing across at least some of the plurality of batteries a force applied perpendicularly to a surface of the substrate opposite to that facing the plurality of batteries is mounted;

running a cooling tube near each of the plurality of batteries at least one time;

pressing mounts of a second substrate over the batteries, each of the mounts being located over at least one hole through the substrate;

contacting each of a plurality of conductors to one of the terminals of each of at least some of the batteries via the holes in the substrates.

13. The method of claim 12, wherein the contacting step employs, for at least one of the plurality of conductors, a bracket extending through at least one hole in the conductor and at least one hole in the substrate.

14. The method of claim 12, wherein the contacting step comprises welding.

15. The method of claim 12, wherein:

each battery terminal has a polarity; and

at least one conductor is contacted with opposite polarity terminals of each of at least two different batteries in the plurality of batteries.

16. The method of claim 15 wherein at least one conductor is contacted with terminals of at least two batteries having a first polarity, and terminals of at least two different batteries having a second polarity different from the first polarity.

17. The method of claim 12, wherein:

the running the cooling tube step comprises running the cooling tube past each of the batteries in the plurality at least twice;

the cooling tube has a flow of a coolant; and

the flow of the coolant past each battery is in at least two different directions.

18. The method of claim 12, additionally comprising milling the mounts into the substrate.

19. The method of claim 18, wherein the milling step comprises milling a plurality of petals extending from a pilot hole drilled at least part way through the substrate.

20. The method of claim 12, additionally comprising shaping the substrate to substantially conform to at least two dimensions of a space available for batteries.

21. The method of claim 12, additionally comprising:

adding the plurality of batteries, first and second substrate, cooling tube and plurality of conductors, to a housing; and

electrically connecting to a plurality of batteries in an adjacent housing, via a solid conductor having a non-round cross section, the plurality of batteries added to the housing.

22. The method of claim 12, wherein the at least one hole through the substrate is not larger than a diameter of a positive terminal of the plurality of batteries.

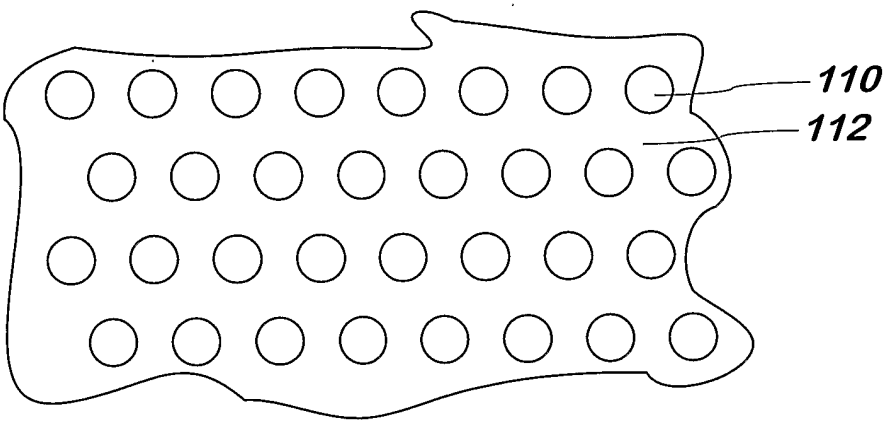


FIG. 1

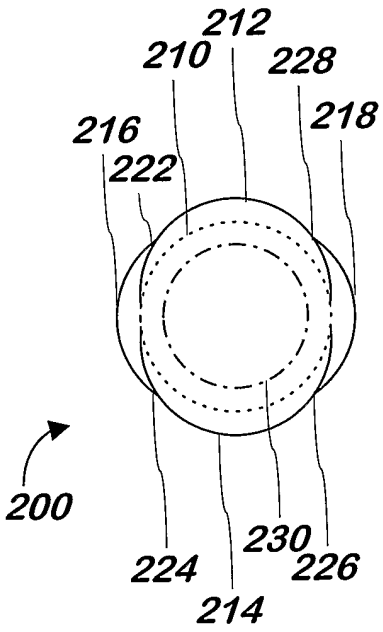


FIG. 2A

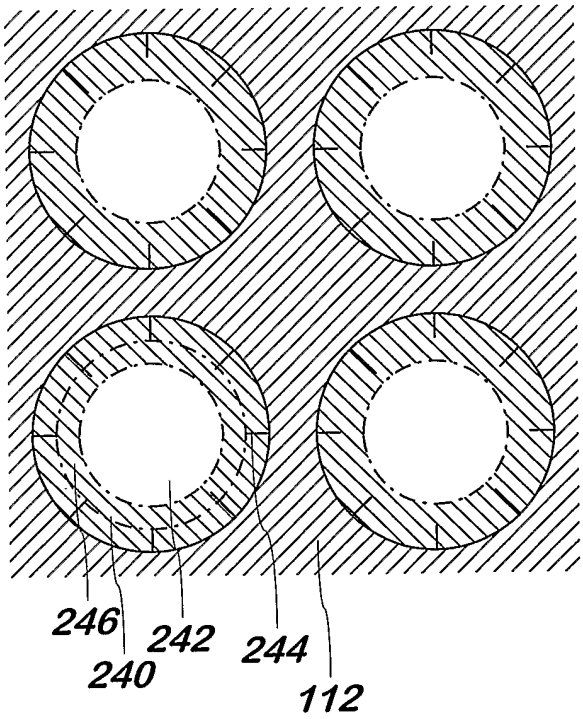


FIG. 2B

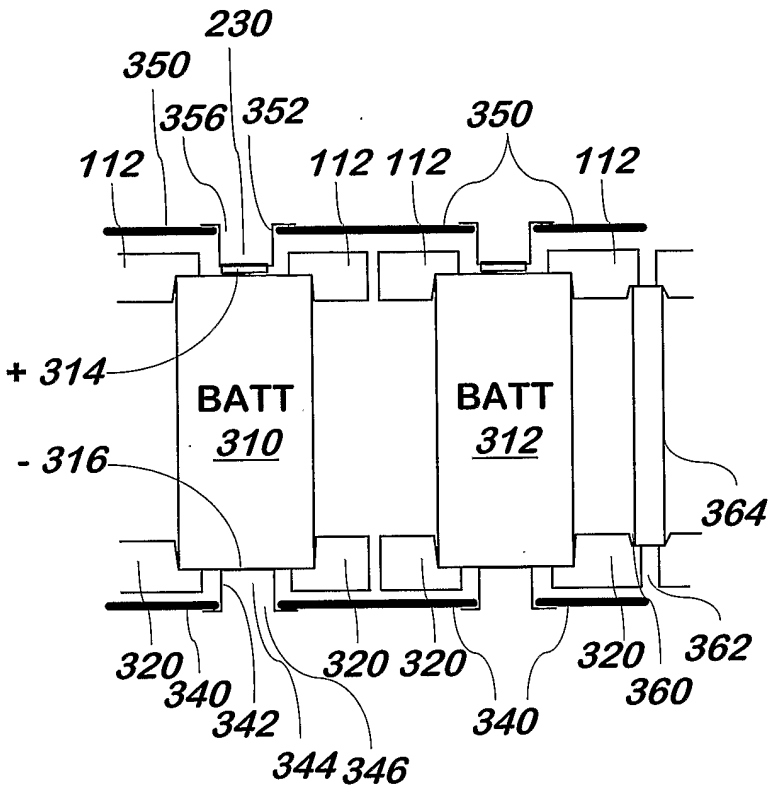

230
350
356
352
350
112
112
112
112
+ 314
BATT
310
BATT
312
- 316
364
320
340
342
344
346
320
320
340
320
360
362

FIG. 3

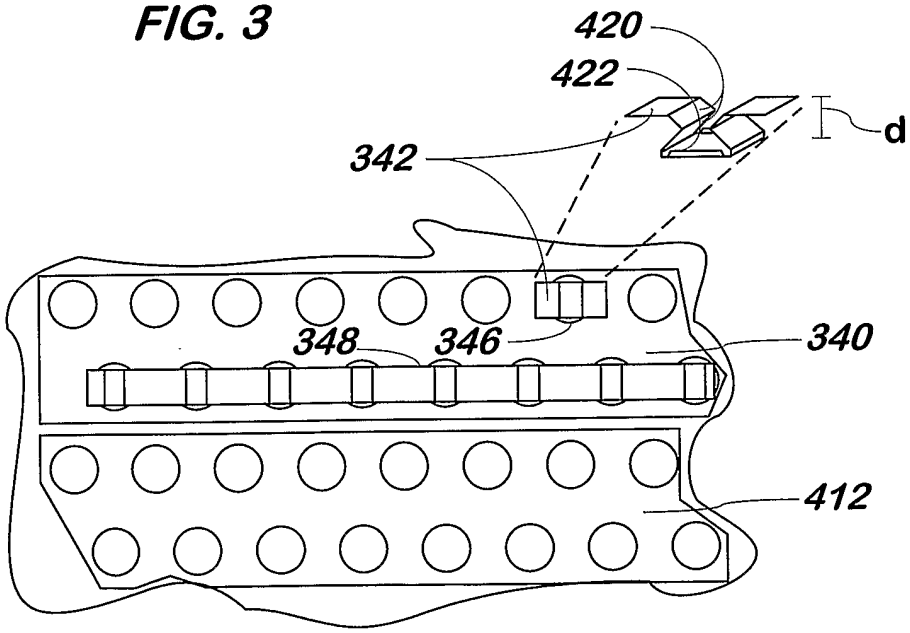

420
422
342
d
348
346
340
412

FIG. 4

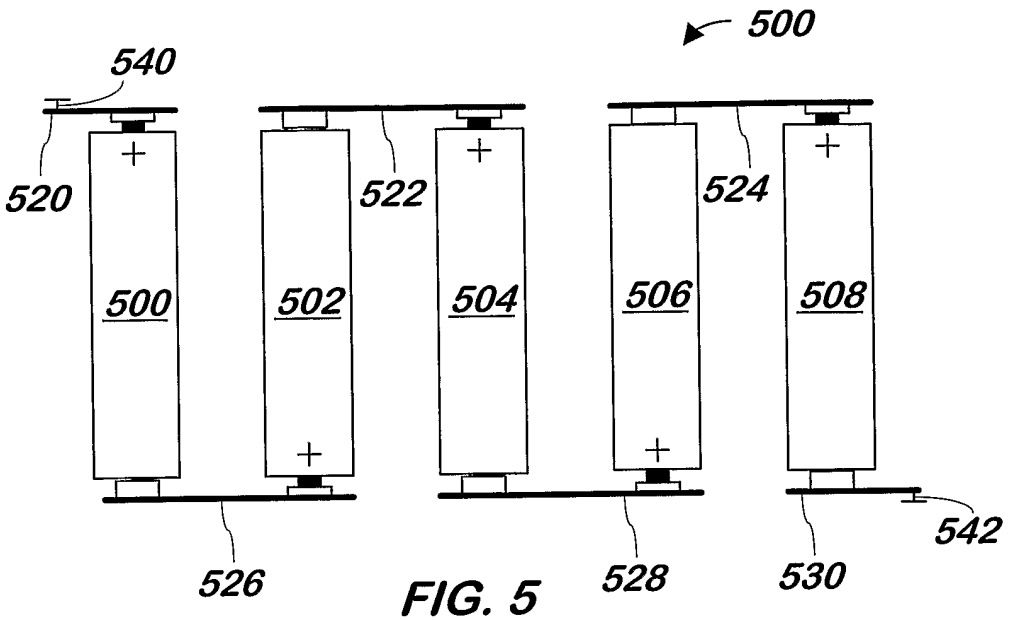

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540
520
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542

FIG. 5

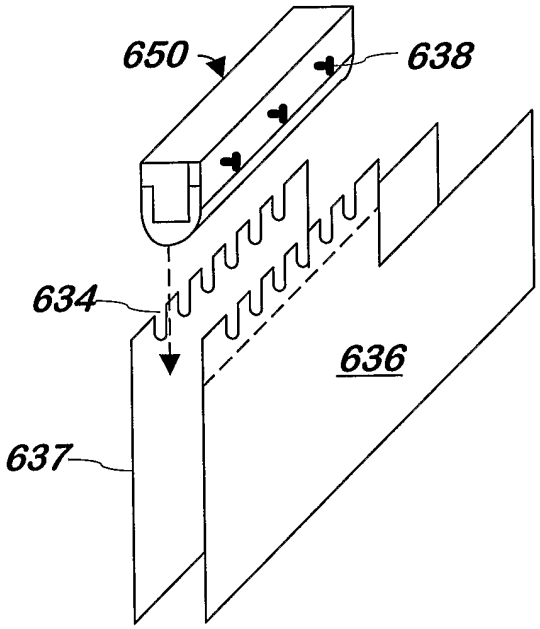

650
638
634
636
637

FIG. 6A

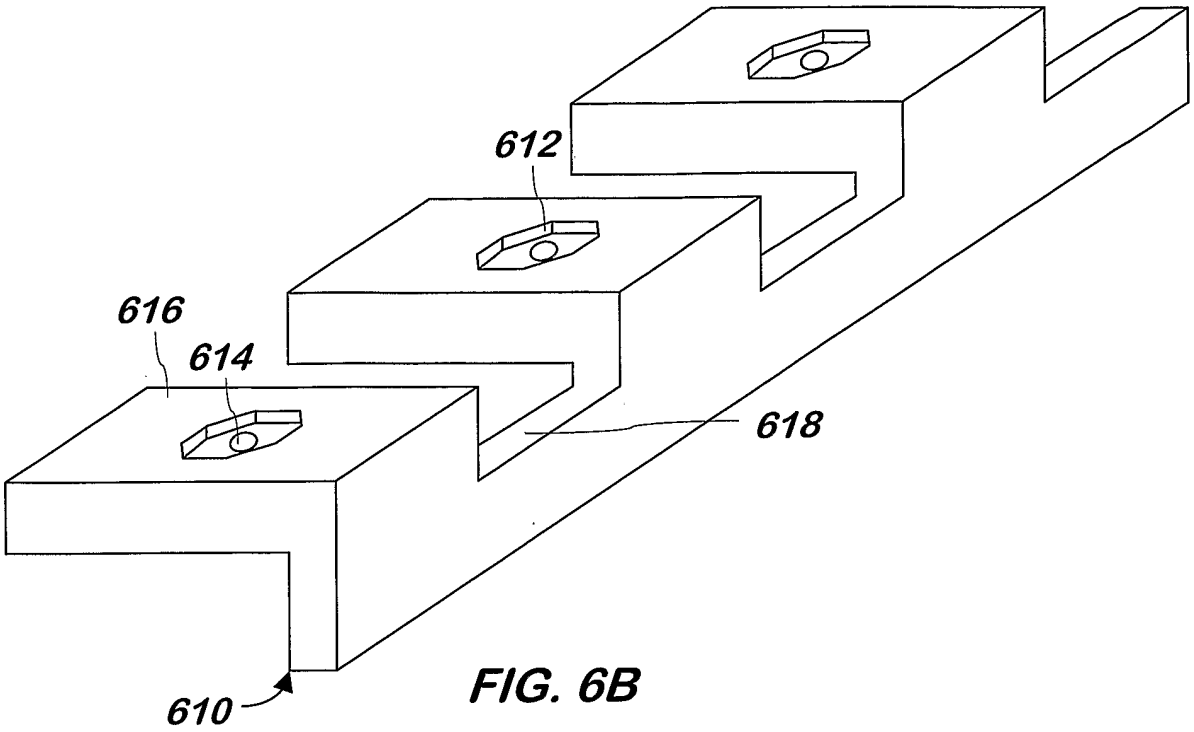


FIG. 6B

FIG. 6C

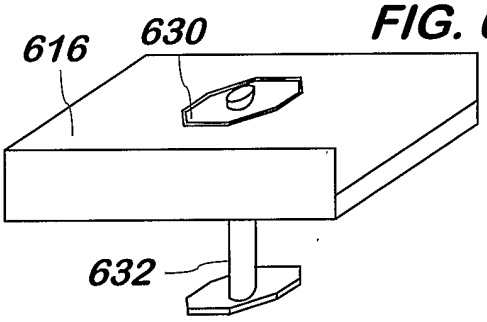


FIG. 6D

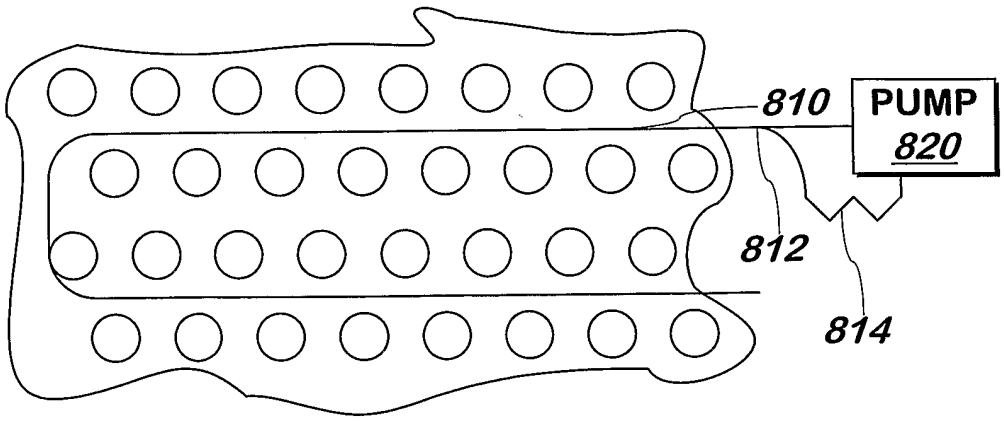


FIG. 8A

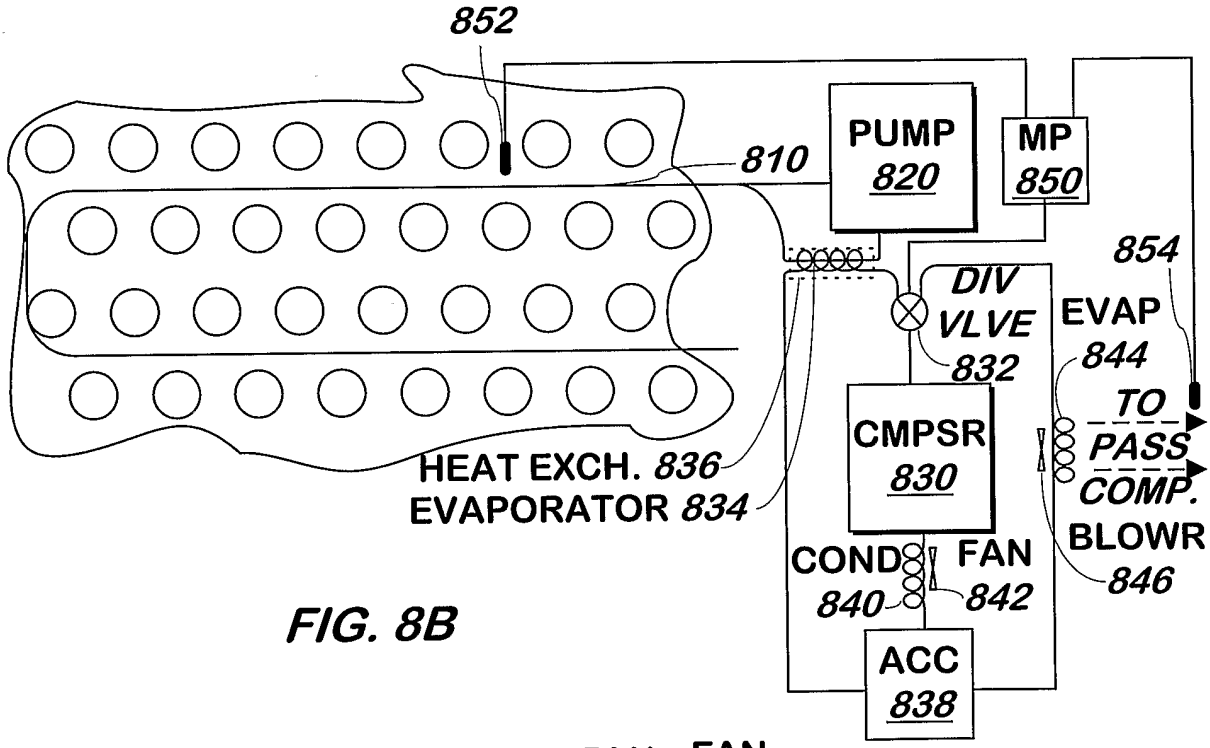
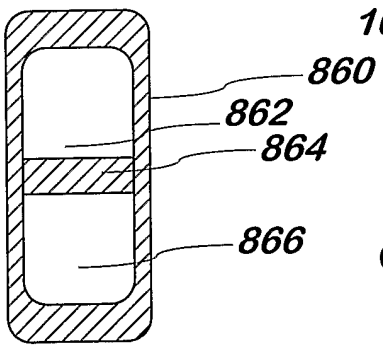


FIG. 8B

FIG. 8C



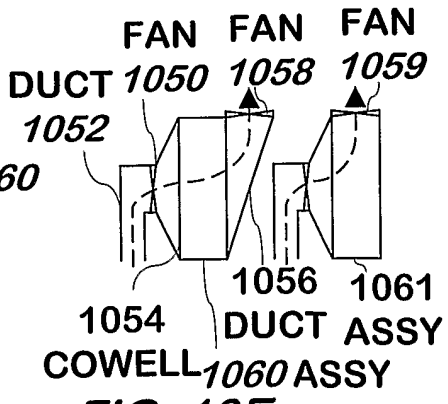


FIG. 10E

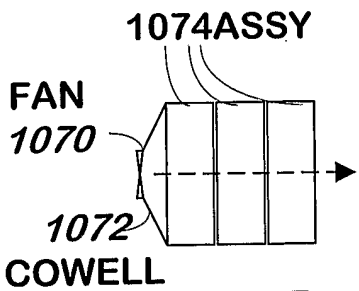


FIG. 10F

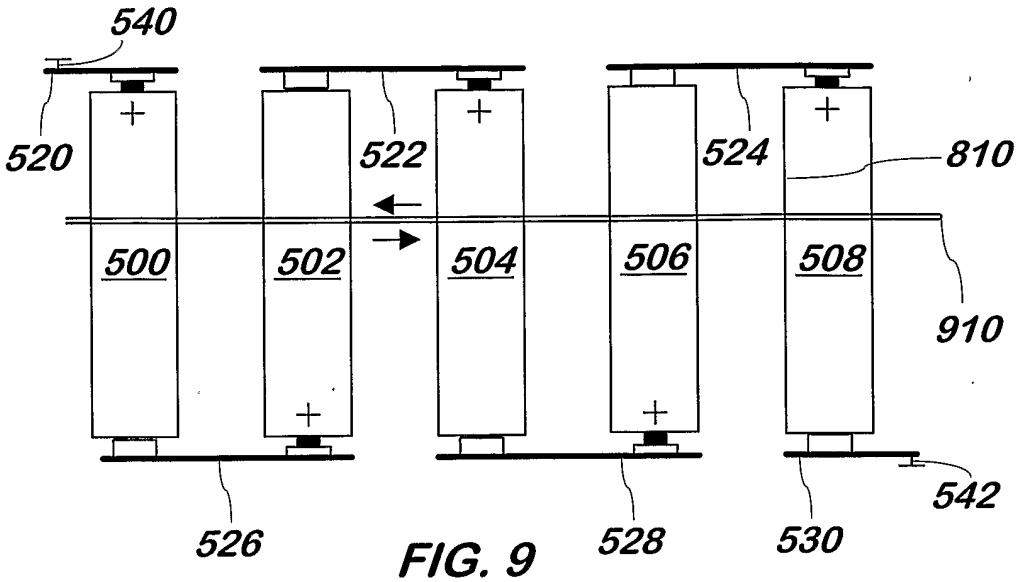


FIG. 9

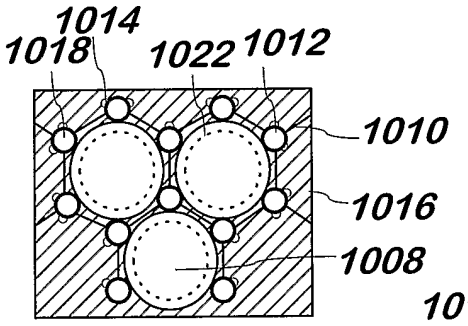


FIG. 10A

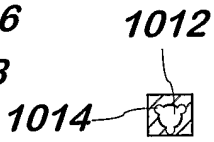


FIG. 10C

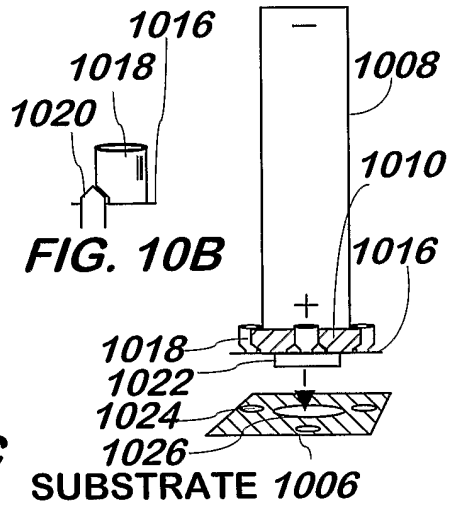
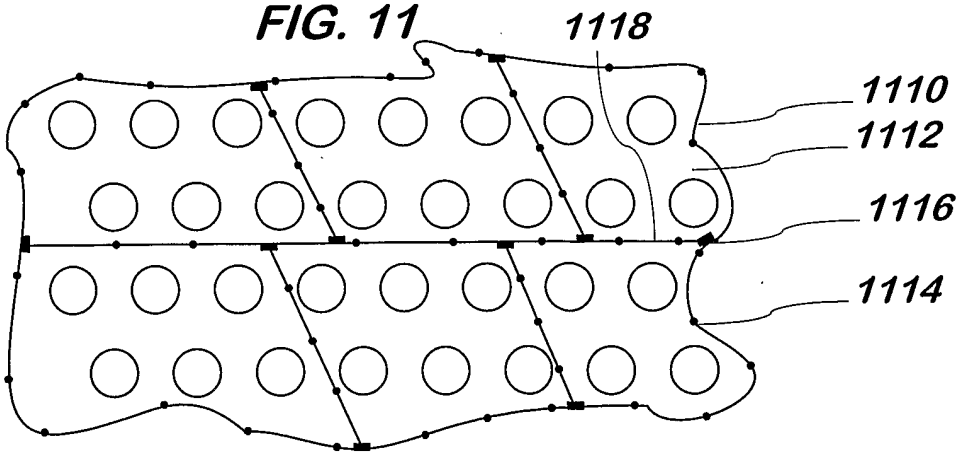


FIG. 10B

FIG. 10D

FIG. 11



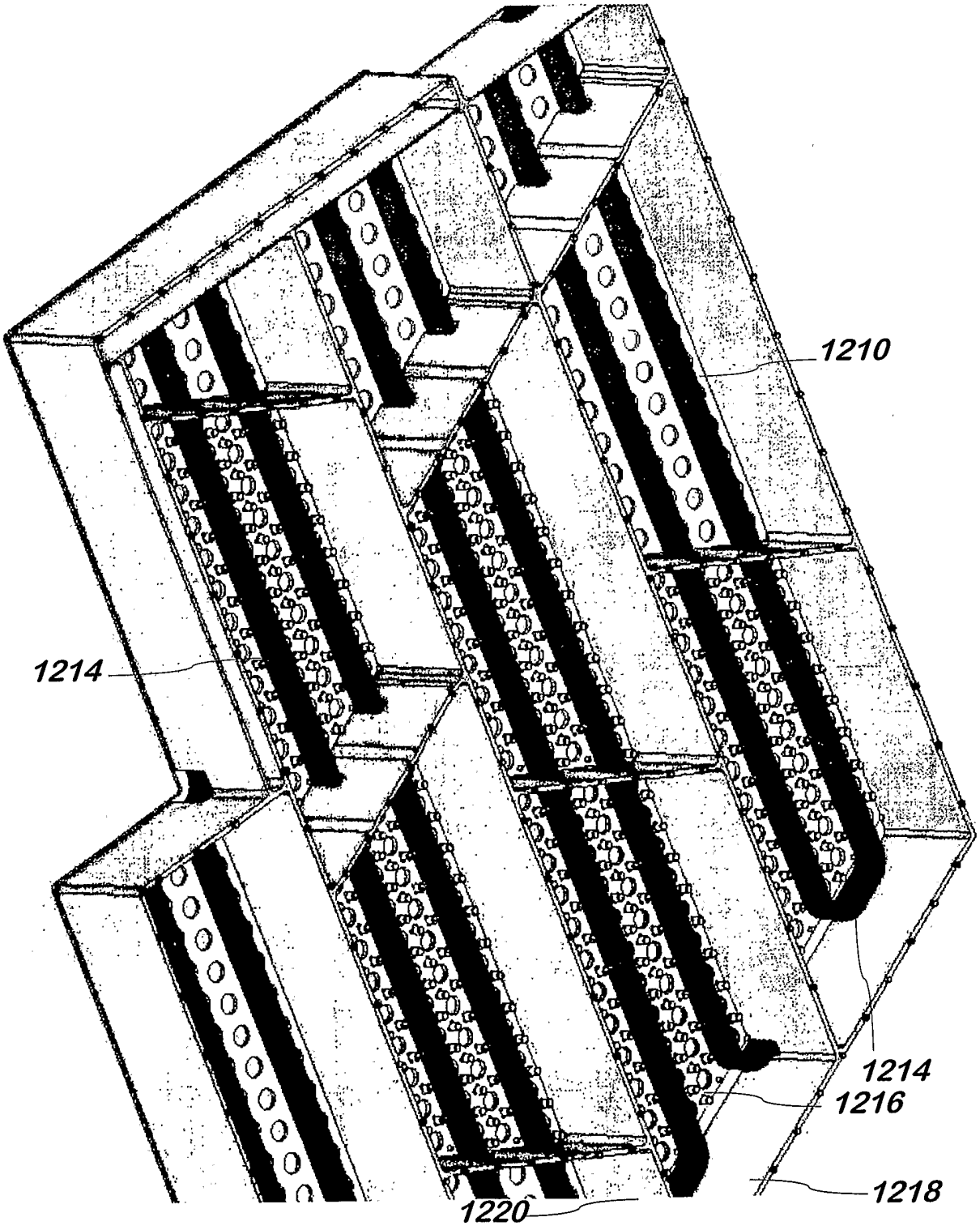


FIG. 12A

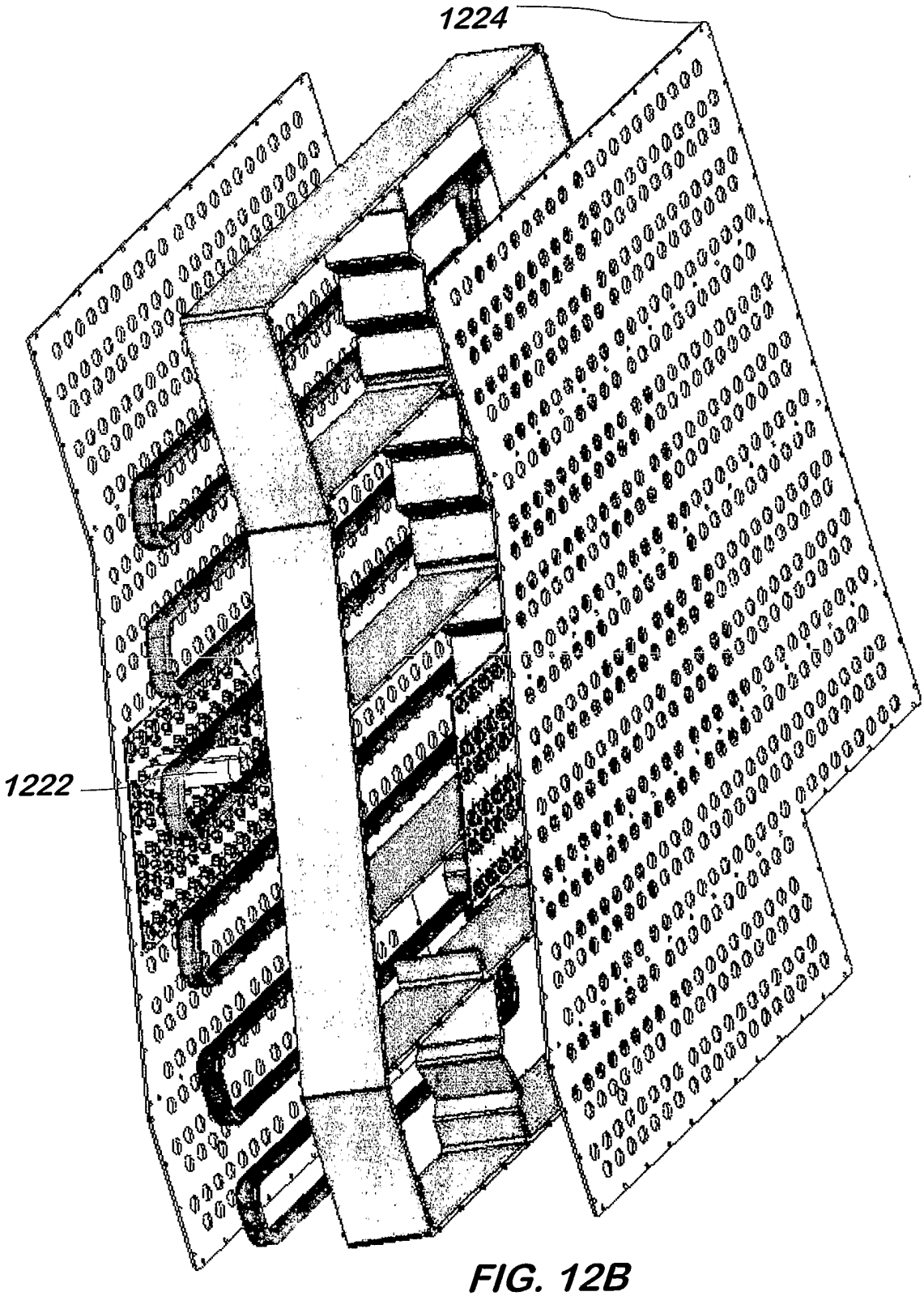


FIG. 12B

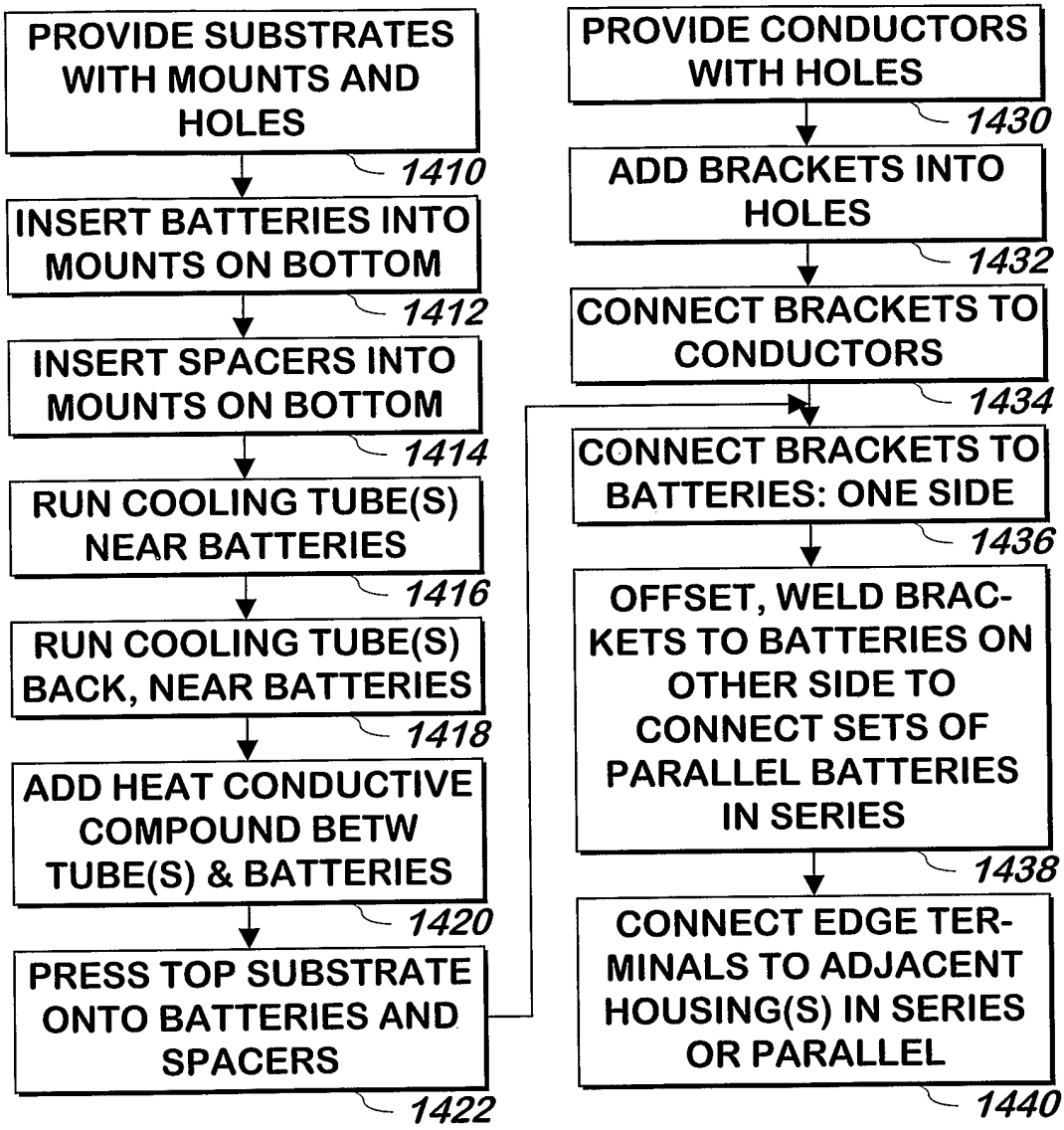

PROVIDE SUBSTRATES WITH MOUNTS AND HOLES
1410
INSERT BATTERIES INTO MOUNTS ON BOTTOM
1412
INSERT SPACERS INTO MOUNTS ON BOTTOM
1414
RUN COOLING TUBE(S) NEAR BATTERIES
1416
RUN COOLING TUBE(S) BACK, NEAR BATTERIES
1418
ADD HEAT CONDUCTIVE COMPOUND BETW TUBE(S) & BATTERIES
1420
PRESS TOP SUBSTRATE ONTO BATTERIES AND SPACERS
1422
PROVIDE CONDUCTORS WITH HOLES
1430
ADD BRACKETS INTO HOLES
1432
CONNECT BRACKETS TO CONDUCTORS
1434
CONNECT BRACKETS TO BATTERIES: ONE SIDE
1436
OFFSET, WELD BRACKETS TO BATTERIES ON OTHER SIDE TO CONNECT SETS OF PARALLEL BATTERIES IN SERIES
1438
CONNECT EDGE TERMINALS TO ADJACENT HOUSING(S) IN SERIES OR PARALLEL
1440

FIG. 14

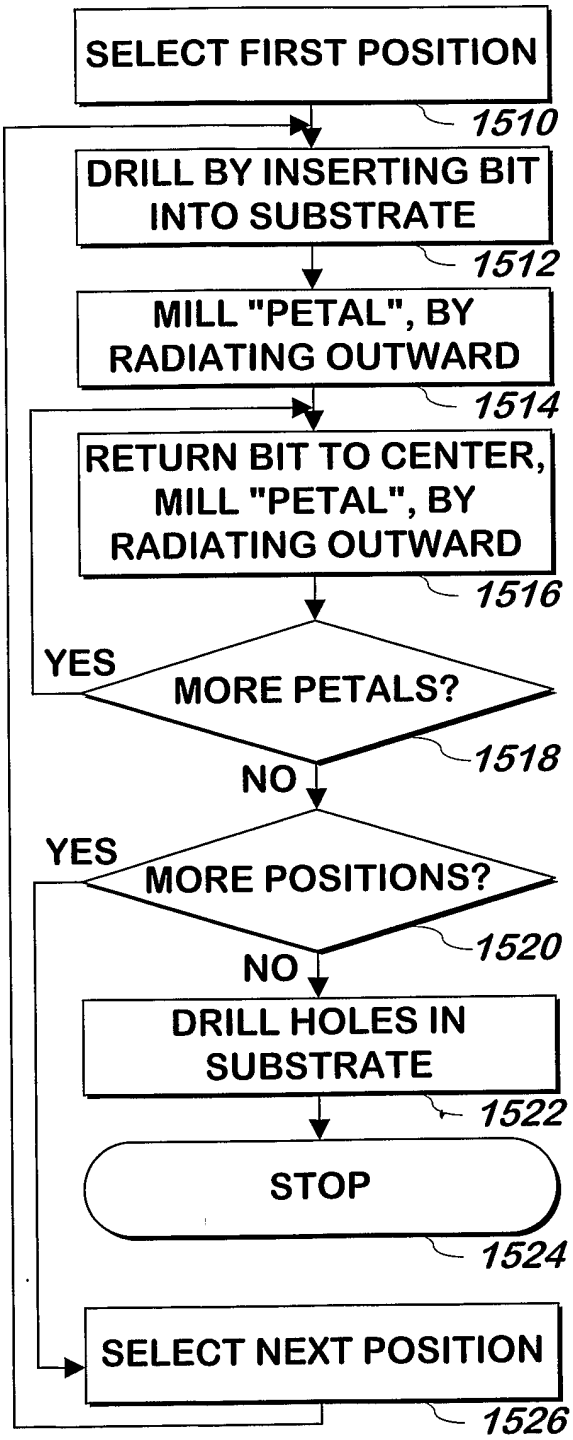

SELECT FIRST POSITION
1510
DRILL BY INSERTING BIT INTO SUBSTRATE
1512
MILL "PETAL", BY RADIATING OUTWARD
1514
RETURN BIT TO CENTER, MILL "PETAL", BY RADIATING OUTWARD
1516
YES
MORE PETALS?
1518
NO
YES
MORE POSITIONS?
1520
NO
DRILL HOLES IN SUBSTRATE
1522
STOP
1524
SELECT NEXT POSITION
1526

FIG. 15

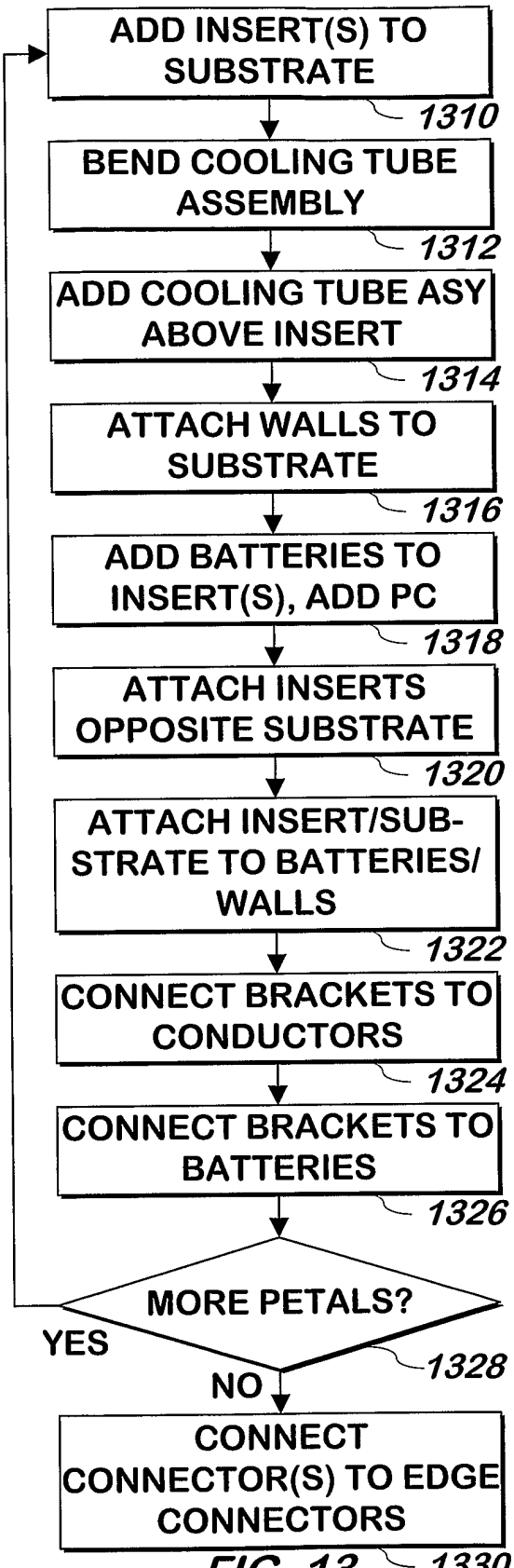

ADD INSERT(S) TO SUBSTRATE
1310
BEND COOLING TUBE ASSEMBLY
1312
ADD COOLING TUBE ASY ABOVE INSERT
1314
ATTACH WALLS TO SUBSTRATE
1316
ADD BATTERIES TO INSERT(S), ADD PC
1318
ATTACH INSERTS OPPOSITE SUBSTRATE
1320
ATTACH INSERT/SUB-STRATE TO BATTERIES/ WALLS
1322
CONNECT BRACKETS TO CONDUCTORS
1324
CONNECT BRACKETS TO BATTERIES
1326
MORE PETALS?
YES
1328
NO
CONNECT CONNECTOR(S) TO EDGE CONNECTORS
1330

FIG. 13