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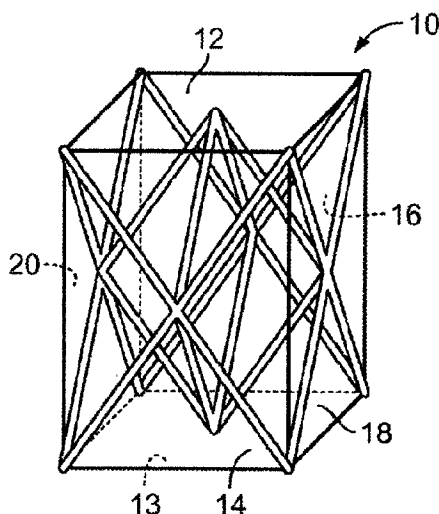
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(54) Title: SPORTING GOODS INCLUDING MICROLATTICE STRUCTURES



(57) Abrégé/Abstract:

A sporting good implement, such as a hockey stick or ball bat, includes a main body. The main body may be formed from multiple layers of a structural material, such as a fiber-reinforced composite material. One or more microlattice structures may be positioned between layers of the structural material. One or more microlattice structures may additionally or alternatively be used to form the core of a sporting good implement, such as a hockey-stick blade. The microlattice structures improve the performance, strength, or feel of the sporting good implement.



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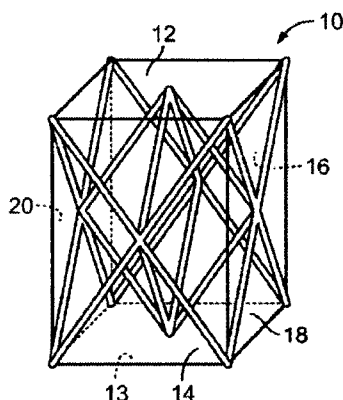


FIG. 1

(57) Abstract: A sporting good implement, such as a hockey stick or ball bat, includes a main body. The main body may be formed from multiple layers of a structural material, such as a fiber-reinforced composite material. One or more microlattice structures may be positioned between layers of the structural material. One or more microlattice structures may additionally or alternatively be used to form the core of a sporting good implement, such as a hockey-stick blade. The microlattice structures improve the performance, strength, or feel of the sporting good implement.

WO 2015/175541 A1

SPORTING GOODS INCLUDING MICROLATTICE STRUCTURES

BACKGROUND

[0001] Lightweight foam materials are commonly used in sporting good implements, such as hockey sticks and baseball bats, because their strength-to-weight ratios provide a solid combination of light weight and performance. Lightweight foams are often used, for example, as interior regions of sandwich structures to provide lightweight cores of sporting good implements.

[0002] Foamed materials, however, have limitations. For example, foamed materials have homogeneous, isotropic properties, such that they generally have the same characteristics in all directions. Further, not all foamed materials can be precisely controlled, and their properties are stochastic, or random, and not designed in any particular direction. And because of their porosity, foamed materials often compress or lose strength over time.

[0003] Some commonly used foams, such as polymer foams, are cellular materials that can be manufactured with a wide range of average-unit-cell sizes and structures. Typical foaming processes, however, result in a stochastic structure that is somewhat limited in mechanical performance and in the ability to handle multifunctional applications.

SUMMARY

[0004] A sporting good implement, such as a hockey stick or ball bat, includes a main body. The main body may be formed from multiple layers of a structural material, such as a fiber-reinforced composite material. One or more microlattice structures may be positioned between layers of the structural material. One or more microlattice structures may additionally or alternatively be used to form the core of a sporting good implement, such as a hockey-stick blade. The microlattice structures improve the performance, strength, or feel of the sporting good implement. Other features and advantages will appear hereinafter.

[0004A] In accordance with one aspect, there is provided a sport helmet. The sport helmet comprises a first surface and a second surface opposite one another. The sport helmet comprises a lattice between the first surface and the second surface of the helmet.

[0004B] In accordance with another aspect, there is provided a sport helmet. The sport helmet comprises an outer shell and a liner disposed within the outer shell. The liner comprises a lattice. The lattice occupies at least a majority of a dimension from an exterior surface of the outer shell to an interior surface of the liner.

[0004C] In accordance with another aspect, there is provided a sport helmet. The sport helmet comprises an outer shell and a liner disposed within the outer shell. The liner comprises a lattice. The lattice is curved.

[0004D] In accordance with another aspect, there is provided a sport helmet. The sport helmet comprises a first surface and a second surface opposite one another. The sport helmet comprises a lattice formed of flexible material, configured to deform from an initial shape upon an impact on the sport helmet and recover the initial shape thereafter to absorb at least part of the impact, and disposed between the first surface and the second surface of the helmet. The lattice comprises a predefined arrangement of structural members intersecting one another at nodes. Respective ones of the nodes of the lattice are spaced from one another in three orthogonal directions that include a thickness-wise direction of the sport helmet from the first surface of the sport helmet to the second surface of the sport helmet.

[0004E] In accordance with another aspect, there is provided a sport helmet. The sport helmet comprises an outer shell and a liner disposed within the outer shell and comprising a lattice. The lattice is formed of flexible material, configured to deform from an initial shape upon an impact on the sport helmet and recover the initial shape thereafter to absorb at least part of the impact, and occupies at least a majority of a dimension from an exterior surface of the outer shell to an interior surface of the liner. The lattice comprises a predefined arrangement of structural members intersecting one another at nodes. Respective ones of the nodes of the

lattice are spaced apart from one another in three orthogonal directions that include a thickness-wise direction of the sport helmet from the exterior surface of the outer shell to the interior surface of the liner.

[0004F] In accordance with another aspect, there is provided a sport helmet. The sport helmet comprises an outer shell and a liner disposed within the outer shell and comprising a lattice. The lattice is formed of flexible material and configured to deform from an initial shape upon an impact on the sport helmet and recover the initial shape thereafter to absorb at least part of the impact. The lattice comprises a predefined arrangement of structural members intersecting one another at nodes. Respective ones of the nodes of the lattice are spaced apart from one another in three orthogonal directions that include a thickness-wise direction of the sport helmet from an exterior surface of the outer shell to an interior surface of the liner.

[0004G] In accordance with another aspect, there is provided a sport helmet. The sport helmet comprises an outer shell and a liner disposed within the outer shell and comprising a lattice. The lattice is formed of flexible material and is configured to deform from an initial shape upon an impact on the sport helmet and recover the initial shape thereafter to absorb at least part of the impact. The lattice comprises an arrangement of structural members intersecting one another at nodes. Respective ones of the nodes of the lattice are spaced apart from one another in three orthogonal directions that include a thickness-wise direction of the sport helmet from

an exterior surface of the outer shell to an interior surface of the liner. The structural members of the lattice are created and polymerized separately from one another.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] In the drawings, wherein the same reference number indicates the same element throughout the views:

[0006] Fig. 1 is a perspective view of a microlattice unit cell, according to one embodiment.

[0007] Fig. 2 is a side view of the unit cell of Fig. 1 with a collimated beam of light directed through an upper-right corner of the cell.

[0008] Fig. 3 is a side view of the unit cell of Figs. 1 and 2 with a collimated beam of light directed through an upper-left corner of the cell.

[0009] Fig. 4 is a perspective view of a microlattice unit cell resulting from repeating the processes illustrated in Figs. 3 and 4, according to one embodiment.

[0010] Fig. 5 is a perspective view of a hexagonal unit cell with a collimated beam of light directed through an upper-right region of the cell, according to one embodiment.

[0011] Fig. 6 is a perspective view of a hexagonal microlattice unit cell resulting from repeating the process illustrated in Fig. 5, according to one embodiment.

[0012] Fig. 7 is a side view of multiple microlattice unit cells of uniform density connected in a row, according to one embodiment.

[0013] Fig. 8 is a side view of multiple microlattice unit cells of varying density connected in a row, according to one embodiment.

[0014] Fig. 9 is a side-sectional view of a hockey-stick blade including a microlattice core structure, according to one embodiment.

[0015] Fig. 10 is a top-sectional view of a hockey-stick shaft including a microlattice core structure between exterior and interior laminates of the shaft, according to one embodiment.

[0016] Fig. 11 is a top-sectional view of a hockey-stick shaft including a microlattice core structure in an interior cavity of the shaft, according to one embodiment.

[0017] Fig. 12 is a top-sectional view of a hockey-stick shaft including a microlattice core structure in an interior cavity of the shaft, according to another embodiment.

[0018] Fig. 13 is a side-sectional view of a portion of a hockey-skate boot including a microlattice core structure between exterior and interior layers of boot material.

[0019] Fig. 14 is a side-sectional view of a portion of a sports helmet including a microlattice core structure between exterior and interior layers of the helmet.

[0020] Fig. 15 is a top-sectional view of a bat barrel including a microlattice core structure between exterior and interior layers of the bat barrel.

[0021] Fig. 16 is a perspective, partial-sectional view of a ball-bat joint including a microlattice core structure between exterior and interior layers of the joint.

DETAILED DESCRIPTION OF THE DRAWINGS

[0022] Various embodiments of the invention will now be described. The following description provides specific details for a thorough understanding and

enabling description of these embodiments. One skilled in the art will understand, however, that the invention may be practiced without many of these details. Additionally, some well-known structures or functions may not be shown or described in detail so as to avoid unnecessarily obscuring the relevant description of the various embodiments.

[0023] The terminology used in the description presented below is intended to be interpreted in its broadest reasonable manner, even though it is being used in conjunction with a detailed description of certain specific embodiments of the invention. Certain terms may even be emphasized below; however, any terminology intended to be interpreted in any restricted manner will be overtly and specifically defined as such in this detailed description section.

[0024] Where the context permits, singular or plural terms may also include the plural or singular term, respectively. Moreover, unless the word "or" is expressly limited to mean only a single item exclusive from the other items in a list of two or more items, then the use of "or" in such a list is to be interpreted as including (a) any single item in the list, (b) all of the items in the list, or (c) any combination of items in the list. Further, unless otherwise specified, terms such as "attached" or "connected" are intended to include integral connections, as well as connections between physically separate components.

[0025] Micro-scale lattice structures, or "microlattice" structures, include features ranging from tens to hundreds of microns. These structures are typically

formed from a three-dimensional, interconnected array of self-propagating photopolymer waveguides. A microlattice structure may be formed, for example, by directing collimated ultraviolet light beams through apertures to polymerize a photomonomer material. Intricate three-dimensional lattice structures may be created using this technique.

[0026] In one embodiment, microlattice structures may be formed by exposing a two-dimensional mask, which includes a pattern of circular apertures and covers a reservoir containing an appropriate photomonomer, to collimated ultraviolet light. Within the photomonomer, self-propagating photopolymer waveguides originate at each aperture in the direction of the ultraviolet collimated beam and polymerize together at points of intersection. By simultaneously forming an interconnected array of these fibers in three-dimensions and removing the uncured monomer, unique three-dimensional, lattice-based, open-cellular polymer materials can be rapidly fabricated.

[0027] The photopolymer waveguide process provides the ability to control the architectural features of the bulk cellular material by controlling the fiber angle, diameter, and three-dimensional spatial location during fabrication. The general unit-cell architecture may be controlled by the pattern of circular apertures on the mask or the orientation and angle of the collimated, incident ultraviolet light beams.

[0028] The angle of the lattice members with respect to the exposure-plane angle are controlled by the angle of the incident light beam. Small changes in this

angle can have a significant effect on the resultant mechanical properties of the material. For example, the compressive modulus of a microlattice material may be altered greatly with small angular changes within the microlattice structure.

[0029] Microlattice structures can provide improved mechanical performance (higher stiffness and strength per unit mass, for example), as well as an accessible open volume for unique multifunctional capabilities. The photopolymer waveguide process may be used to control the architectural features of the bulk cellular material by controlling the fiber angle, diameter, and three-dimensional spatial location during fabrication. Thus, the microlattice structure may be designed to provide strength and stiffness in desired directions to optimize performance with minimal weight.

[0030] This manufacturing technique is able to produce three-dimensional, open-cellular polymer materials in seconds. In addition, the process provides control of specific microlattice parameters that ultimately affect the bulk material properties. Unlike stereolithography, which builds up three-dimensional structures layer by layer, this fabrication technique is rapid (minutes to form an entire part) and can use a single two-dimensional exposure surface to form three-dimensional structures (with a thickness greater than 25 mm possible). This combination of speed and planar scalability opens up the possibility for large-scale, mass manufacturing. The utility of these materials range from lightweight energy-absorbing structures, to thermal-management materials, to bio-scaffolds.

[0031] A microlattice structure may be constructed by this method using any polymer that can be cured with ultraviolet light. Alternatively, the microlattice structure may be made of a metal material. For example, the microlattice may be dipped in a catalyst solution before being transferred to a nickel-phosphorus solution. The nickel-phosphorus alloy may then be deposited catalytically on the surface of the polymer struts to a thickness of around 100 nm. Once coated, the polymer is etched away with sodium hydroxide, leaving a lattice geometry of hollow nickel-phosphorus tubes.

[0032] The resulting microlattice structure may be greater than 99.99 percent air, and around 10 percent less dense than the lightest known aerogels, with a density of approximately 0.9 mg/cm^3 . Thus, these microlattice structures may have a density less than 1.0 mg/cm^3 . A typical lightweight foam, such as Airex C71, by comparison, has a density of approximately 60 mg/cm^3 and is approximately 66 times heavier.

[0033] Further, the microengineered lattice structure has remarkably different properties than a bulk alloy. A bulk alloy, for example, is typically very brittle. When the microlattice structure is compressed, conversely, the hollow tubes do not snap but rather buckle like a drinking straw with a high degree of elasticity. The microlattice can be compressed to half its volume, for example, and still spring back to its original shape. And the open-cell structure of the microlattice allows for fluid flow within the microlattice, such that a foam or elastomeric material, for example,

may fill the air space to provide additional vibration damping or strengthening of the microlattice material.

[0034] The manufacturing method described above could be modified to optimize the size and density of the microlattice structure locally to add strength or stiffness in desired regions. This can be done by varying:

- the size of the apertures in the mask to locally alter the size of the elements in the lattice;
- the density of the apertures in the mask to locally alter the strength or dynamic response of the system; or
- the angle of the incident collimated light to change the angle of the elements, which affects the strength and stiffness of the material.

[0035] The manufacturing method could also be modified to include fiber reinforcement. For example, fibers may be arranged to be co-linear or co-planar with the collimated ultraviolet light beams. The fibers are submersed in the photomonomer resin and wetted out. When the ultraviolet light polymerizes the photomonomer resin, the resin cures and adheres to the fiber. The resulting microlattice structure will be extremely strong, stiff, and light.

[0036] Figs. 1-8 illustrate some examples of microlattice unit cells and microlattice structures. Fig. 1 shows a square unit cell 10 with a top plane 12 and a bottom plane 13 defining the cell shape. This is a single cell that would be adjacent

to other similar cells in a microlattice structure. The cell 10 is defined by a front plane 14, an opposing rear plane 16, a right-side plane 18, and a left-side plane 20. It will be used as a reference in the building of a microlattice structure using four collimated beams controlled by a mask with circular apertures to create a lattice structure with struts of circular cross section.

[0037] Fig. 2 shows a side view of the unit cell 10 with a dashed line 22 indicating the boundary of the cell 10. A collimated beam of light 24 is directed at an angle 26 controlled by a mask with apertures (not shown). A light beam 28 is oriented through an upper-right-corner node 30 and a lower-left-corner node 32. A parallel beam of light 34 is directed through a node 36 positioned on the center of right-side plane 18 and through a node 38 on the center of bottom plane 13. Similarly, a light beam 40 is directed through a node 42 positioned on the center of top plane 12 and through a node 44 positioned on the center of left-side plane 20. These light beams will polymerize the monopolymer material and fuse to other polymerized material.

[0038] Fig. 3 shows a side view of the unit cell 10 with a dashed line 22 indicating the boundary of the cell 10. A collimated beam of light 46 is directed at an angle 48 controlled by a mask with apertures (not shown). A light beam 50 is oriented through the upper-left-corner node 52 and lower-right-corner node 54. A parallel beam of light 56 is directed through a node 58 positioned on the center of left-side plane 20 and through a node 38 on the center of bottom plane 13. Similarly, a parallel light beam 62 is directed through a node 42 positioned on the

center of top plane 12 and through a node 66 positioned on the center of right-side plane 18. These light beams will polymerize the monopolymer material and fuse to other polymerized material.

[0039] This process is repeated for the other sets of vertical planes 12 and 14 resulting in the structure shown in Fig. 4. Long beams 14a and 14b on front plane 14 are parallel to respective beams 12a and 12b on rear plane 12. Long beams 18a and 18b on right plane 18 are parallel to respective beams 20a and 20b on left plane 20. Short beams 70a, 70b, 70c, and 70d connect at upper node 42 centered on top plane 12, and are directed to the center-face nodes 72a, 72b, 72c, and 72d. Similarly, short beams 74a, 74b, 74c, and 74d connect at lower node 38 centered on bottom plane 13 and connect to the short beams 70a, 70b, 70c, and 70d and center-face nodes 72a, 72b, 72c, and 72d.

[0040] Alternatively, a hexagonal shaped cell can be constructed as shown in Fig. 5. A hexagonal unit cell 80 is defined by a hexagonal shaped top plane 82 and opposing bottom plane 84. Vertical plane 86a is opposed by vertical plane 86b. Vertical plane 88a is opposed by vertical plane 88b. Vertical plane 90a is opposed by vertical plane 90b. A collimated light beam 92 is directed at an angle 94 controlled by a mask with apertures (not shown). A beam 96 is formed through upper node 98 and lower node 100 on vertical plane 88a. Similarly, a beam 96a is formed through upper node 98a and lower node 100a on vertical plane 88b. A face-to-node beam 102 that is parallel to beams 96 and 96a is formed from the center 104 of top face 82 to the lower node 106. Another face-to-node beam 108 that is

parallel to beams 96, 96a, and 102 is formed from the center 110 of bottom plane 84 to upper node 112.

[0041] This process is repeated for the remaining two sets of vertically opposed planes to create the cell structure shown in Fig. 6. The resulting structure has two sets of node-to-node beams in each of the six vertical planes. It also has six face-to-node beams connected at the center node 104 of top plane 82, and six face-to-node beams connected at the center node 110 of bottom plane 84.

[0042] Cell structures 10 and 80 shown in Figs. 4 and 6, respectively, are merely examples of structures that can be created. The cell geometry may vary according to the lattice structure desired. And the density of the microlattice structure may be varied by changing the angle of the beams.

[0043] Fig. 7 is a side view of multiple square cells, such as multiple unit cells 10, connected in a row. This simplified view shows the regular spacing between beams, and the equal cell dimensions. Dimension 112 denotes the width of a single cell unit. $\text{Dimension } 112 = 112a = 112b = 112c$, such that all cells are of uniform size and dimensions. The long beam 122 connects corner node 114 to corner node 116. Similarly, long beam 124 connects corner nodes 118 and 120. Short beams 126a, 126b, 126c, and a fourth short beam (not visible) connect to upper-center-face node 130. Similarly, short beams 128a, 128b, 128c, and a fourth short beam (not visible) connect to lower-center-face node 132.

[0044] Fig. 8 represents an alternative design in which the density of the microlattice structure varies. To the left of line 134, the microlattice structure 136 has spacing as shown in Fig. 7. To the right of line 134, the microlattice structure 138 has spacing that is tighter and more condensed. In addition, the angle 142 of the beams is greater for structure 138 than the angle 140 for structure 136. Thus, structure 138 provides more compression resistance than structure 136.

[0045] Other design alternatives exist to vary the compression resistance of the microlattice structure. For example, the size of the lattice beams may vary by changing the aperture size in the mask. Thus, there are multiple ways to vary and optimize the local stiffness of the microlattice structure.

[0046] The microlattice structures described above may be used in a variety of sporting-good applications. For example, one or more microlattice structures may be used as the core of a hockey-stick blade. The stiffness and strength of the microlattice may be designed to optimize the performance of the hockey-stick blade. For example, the density of the microlattice may be higher in the heel area of the blade—where pucks are frequently impacted when shooting slap-shots or trapping pucks—than in the toe region or mid-region of the blade. Further, the microlattice may be more open or flexible toward the toe of the blade to enable a faster wrist shot or to enhance feel and control of the blade.

[0047] One or more microlattice structures may also be used to enhance the laminate strength in a hockey-stick shaft, bat barrel, or bat handle. Positioning the

microlattice as an inter-laminar ply within a bat barrel, for example, could produce several benefits. The microlattice can separate the inner barrel layers from the outer barrel layers, yet allow the outer barrel to deflect until the microlattice reaches full compression, then return to a neutral position. The microlattice may be denser in the sweet-spot area where the bat produces the most power, and more open in lower-power regions to help enhance bat power away from the sweet spot.

[0048] For a hockey-stick shaft or bat handle, the microlattice may be an interlaminar material that acts like a sandwich structure, effectively increasing the wall thickness of the laminate, which increases the stiffness and strength of the shaft or handle.

[0049] One or more microlattice structures may also be used in or as a connection material between a handle and a barrel of a ball bat. Connecting joints of this nature have traditionally been made from elastomeric materials, as described, for example, in U.S. Patent No. 5,593,158. Such materials facilitate relative movement between the bat barrel and handle, thereby absorbing the shock of impact and increasing vibration damping.

[0050] A microlattice structure used in or as a connection joint provides an elastic and resilient intermediary that can absorb compression loads and return to shape after impact. In addition, the microlattice can be designed with different densities to make specific zones of the connection joint stiffer than others to provide desired performance benefits. The microlattice structure also offers the ability to

tune the degree of isolation of the barrel from the handle to increase the amount of control and damping without significantly increasing the weight of the bat.

[0051] Microlattice structures may also be used in helmet liners to provide shock absorption, in bike seats as padding, or in any number of other sporting-good applications. Figs. 9-16 illustrate some specific examples.

[0052] Fig. 9 shows a sandwich structure of a hockey-stick blade 150. The top laminate 152 and bottom laminate 154 of the blade 150 may be constructed of fiber-reinforced polymer resin, such as carbon-fiber-reinforced epoxy, or of another suitable material. A microlattice core 156 is positioned between the top and bottom laminates 152, 154. The microlattice core 156 may optionally vary in density such that it is lighter and more open in zone 158 (for example, at the toe-end of the blade), and denser and stronger in zone 160 (for example, at the heel-end of the blade).

[0053] Fig. 10 shows a hockey-stick shaft 160 including a microlattice structure 162 acting as a core between an exterior laminate 166 and an interior laminate 168. Optionally, the microlattice 162 structure may have increased density in one or more shaft regions, such as in region 164 where more impact forces typically occur. Using the microlattice in this manner maintains sufficient wall thickness to resist compressive forces, yet reduces the overall weight of the hockey-stick shaft relative to a traditional shaft.

[0054] Fig. 11 shows a hockey-stick shaft 170 with a microlattice structure 172 in an interior cavity of the shaft 170. In this embodiment, the microlattice structure is denser in regions 174 and 176 than in the central region 172. The microlattice structure is oriented in this manner to particularly resist compressive forces directed toward the larger dimension 178 of the shaft 170.

[0055] Fig. 12 shows an alternative embodiment of a hockey-stick shaft 180 with a microlattice structure 182 in an interior cavity of the shaft. In this embodiment, the microlattice structure is more dense in regions 184 and 186 than in the central region 182. The microlattice structure is oriented in this manner to particularly resist compressive forces directed toward the smaller dimension 188 of the shaft 180.

[0056] Fig. 13 shows a cross section of a portion of a hockey skate boot 190. A microlattice structure 192 is sandwiched between the exterior material 194 and interior material 196 of the boot. The microlattice structure 192 may be formed as a net-shape contour, or formed between the exterior material 194 and the interior material 196. The exterior material 194 and interior material 196 may be textile-based, injection molded, a heat formable thermoplastic, or any other suitable material.

[0057] Figure 14 shows a cross section of a portion of a helmet shell 200. A microlattice structure 202 is sandwiched between the exterior material 204 and interior material 206 of the helmet. The microlattice structure 202 may be created as a net-shape contour, or formed between the exterior material 204 and the interior

material 206. The exterior material 204 and interior material 206 may be textile-based, injection molded, a heat formable thermoplastic, or any other suitable material. The interior material 206 may optionally be a very light fabric, depending on the density and design of the microlattice structure 202. The microlattice structure 202 may optionally be a flexible polymer that is able to deform and recover, absorbing impact forces while offering good comfort.

[0058] Figure 15 shows a cross-sectional view of a bat barrel 210 with a microlattice structure 212 sandwiched between an exterior barrel layer or barrel wall 214 and an interior barrel layer or barrel wall 216. The microlattice structure 212 may be formed as a straight panel that is rolled into the cylindrical shape of the barrel, or it may be formed as a cylinder. The microlattice structure 212 is able to limit the deformation of the exterior barrel wall 214 and to control the power of the bat while facilitating a light weight. The microlattice structure 212 may additionally or alternatively be used in the handle of the bat in a similar manner.

[0059] Figure 16 shows a conical joint 220 that may be used to connect a bat handle to a bat barrel. A microlattice structure 222 is sandwiched or otherwise positioned between an exterior material 224 and interior material 226 of the joint 220. The joint 220 may be bonded to the barrel and the handle of the bat or it may be co-molded in place. The barrel and handle may be a composite material, a metal, or any other suitable material or combination of materials. The microlattice structure 222 provides efficient movement of the barrel relative to the handle, and it further absorbs impact forces and dampens vibrations.

[0060] Any of the above-described embodiments may be used alone or in combination with one another. Further, the described items may include additional features not described herein. While several embodiments have been shown and described, various changes and substitutions may of course be made, without departing from the spirit and scope of the invention. The invention, therefore, should not be limited, except by the following claims and their equivalents.

CLAIMS:

1. A sport helmet comprising:
 - a first surface and a second surface opposite one another; and
 - 5 - a lattice formed of flexible material, configured to deform from an initial shape upon an impact on the sport helmet and recover the initial shape thereafter to absorb at least part of the impact, and disposed between the first surface and the second surface of the helmet;wherein: the lattice comprises a predefined arrangement of structural members
- 10 intersecting one another at nodes; and respective ones of the nodes of the lattice are spaced from one another in three orthogonal directions that include a thickness-wise direction of the sport helmet from the first surface of the sport helmet to the second surface of the sport helmet.
- 15 2. The sport helmet of claim 1, comprising a liner that comprises the lattice.
3. The sport helmet of any one of claims 1 and 2, wherein a density of the lattice is variable.
- 20 4. The sport helmet of claim 1, wherein a spacing of the structural members of the lattice is variable.
5. The sport helmet of claim 1, wherein respective ones of the structural members of the lattice vary in size.
- 25 6. The sport helmet of claim 1, wherein respective ones of the structural members of the lattice vary in orientation.
7. The sport helmet of any one of claims 1 to 6, wherein a resistance to
- 30 compression of the lattice is variable.
8. The sport helmet of any one of claims 1 to 7, wherein a stiffness of the lattice is variable.

9. The sport helmet of any one of claims 1 to 8, wherein a first zone of the lattice is stiffer than a second zone of the lattice.
10. The sport helmet of claim 9, wherein: a third zone of the lattice is stiffer than
5 the second zone of the lattice; and the second zone of the lattice is disposed between the first zone of the lattice and the third zone of the lattice.
11. The sport helmet of any one of claims 1 to 10, wherein an openness of the lattice is variable.
10
12. The sport helmet of any one of claims 1 to 8 and 11, wherein a first zone of the lattice is more open than a second zone of the lattice.
13. The sport helmet of claim 12, wherein: a third zone of the lattice is less open
15 than the first zone of the lattice; and the first zone of the lattice is disposed between the second zone of the lattice and the third zone of the lattice.
14. The sport helmet of any one of claims 1 to 13, comprising: a first layer adjacent to the lattice and constituting at least part of the first surface of the sport
20 helmet; and a second layer adjacent to the lattice and constituting at least part of the second surface of the sport helmet.
15. The sport helmet of claim 14, wherein the first layer is injection-molded.
- 25 16. The sport helmet of any one of claims 14 and 15, wherein the second layer comprises textile material.
17. The sport helmet of any one of claims 14 to 16, wherein a material of the first layer and a material of the second layer are different.
30
18. The sport helmet of any one of claims 1 to 17, wherein the lattice occupies at least a majority of a cross-sectional dimension of the sport helmet from the first surface of the sport helmet to the second surface of the sport helmet.
- 35 19. The sport helmet of any one of claims 1 to 18, wherein the lattice is curved.

20. The sport helmet of any one of claims 1 to 19, wherein the lattice is entirely polymeric.
- 5 21. The sport helmet of any one of claims 1 to 20, comprising filling material that fills at least part of hollow space of the lattice.
22. The sport helmet of claim 21, wherein the filling material comprises foam.
- 10 23. The sport helmet of claim 21, wherein the filling material comprises elastomeric material.
24. The sport helmet of claim 21, wherein the filling material is configured to dampen vibrations.
- 15 25. The sport helmet of any one of claims 1 to 24, wherein the lattice is optically formed.
26. The sport helmet of claim 25, wherein the lattice is optically formed by collimated light beams.
- 20 27. The sport helmet of any one of claims 25 and 26, wherein the lattice is optically formed by ultraviolet light.
- 25 28. The sport helmet of claim 1, wherein the nodes of the lattice are disposed in at least three levels that are spaced apart from one another in the thickness-wise direction of the sport helmet from the first surface of the sport helmet to the second surface of the sport helmet.
- 30 29. The sport helmet of claim 1, wherein the nodes of the lattice are disposed in at least four levels that are spaced apart from one another in the thickness-wise direction of the sport helmet from the first surface of the sport helmet to the second surface of the sport helmet.

30. The sport helmet of claim 1, wherein the nodes of the lattice are disposed in at least five levels that are spaced apart from one another in the thickness-wise direction of the sport helmet from the first surface of the sport helmet to the second surface of the sport helmet.
- 5
31. The sport helmet of any one of claims 1 to 3 and 7 to 27, wherein the structural members of the lattice comprise struts.
32. The sport helmet of any one of claims 1 to 3 and 7 to 27, wherein the structural members of the lattice extend in at least four different directions.
- 10
33. The sport helmet of any one of claims 1 to 3 and 7 to 27, wherein the structural members of the lattice extend in at least five different directions.
34. The sport helmet of any one of claims 1 to 3 and 7 to 27, wherein the structural members of the lattice extend in a multitude of different directions.
- 15
35. The sport helmet of any one of claims 1 to 3, 7 to 27 and 31 to 35, wherein the lattice is configured to be compressed to half of a volume of the lattice and recover the volume of the lattice.
- 20
36. The sport helmet of any one of claims 1 to 35, wherein the structural members of the lattice are created and polymerized separately from one another.
37. A sport helmet comprising:
- an outer shell; and
 - a liner disposed within the outer shell and comprising a lattice;
- wherein: the lattice is formed of flexible material, configured to deform from an initial shape upon an impact on the sport helmet and recover the initial shape thereafter to absorb at least part of the impact, and occupies at least a majority of a dimension from an exterior surface of the outer shell to an interior surface of the liner; the lattice comprises a predefined arrangement of structural members intersecting one another at nodes; and respective ones of the nodes of the lattice are spaced apart from one another in three orthogonal directions that include a thickness-wise
- 25
- 30

direction of the sport helmet from the exterior surface of the outer shell to the interior surface of the liner.

5 38. The sport helmet of claim 37, wherein a density of the lattice is variable.

 39. The sport helmet of any one of claims 37 and 38, wherein a spacing of the structural members of the lattice is variable.

10 40. The sport helmet of any one of claims 37 to 39, wherein given ones of the structural members of the lattice vary in size.

 41. The sport helmet of any one of claims 37 to 40, wherein adjacent ones of the structural members of the lattice vary in orientation.

15 42. The sport helmet of any one of claims 37 to 41, wherein a resistance to compression of the lattice is variable.

 43. The sport helmet of any one of claims 37 to 42, wherein a stiffness of the lattice is variable.

20 44. The sport helmet of any one of claims 37 to 43, wherein a first zone of the lattice is stiffer than a second zone of the lattice.

 45. The sport helmet of claim 44, wherein: a third zone of the lattice is stiffer than
25 the second zone of the lattice; and the second zone of the lattice is disposed
between the first zone of the lattice and the third zone of the lattice.

 46. The sport helmet of any one of claims 37 to 43, wherein an openness of the lattice is variable.

30 47. The sport helmet of any one of claims 37 to 43 and 46, wherein a first zone of the lattice is more open than a second zone of the lattice.

48. The sport helmet of claim 47, wherein: a third zone of the lattice is less open than the first zone of the lattice; and the first zone of the lattice is disposed between the second zone of the lattice and the third zone of the lattice.
- 5 49. The sport helmet of any one of claims 37 to 48, wherein the outer shell is injection-molded.
50. The sport helmet of any one of claims 37 to 49, wherein the interior surface of the liner comprises textile material.
- 10 51. The sport helmet of any one of claims 37 to 50, wherein the lattice is curved.
52. The sport helmet of any one of claims 37 to 51, wherein the lattice is entirely polymeric.
- 15 53. The sport helmet of any one of claims 37 to 52, comprising filling material that fills at least part of hollow space of the lattice.
54. The sport helmet of claim 53, wherein the filling material comprises foam.
- 20 55. The sport helmet of claim 53, wherein the filling material comprises elastomeric material.
56. The sport helmet of claim 53, wherein the filling material is configured to dampen vibrations.
- 25 57. The sport helmet of any one of claims 37 to 56, wherein the lattice is optically formed.
- 30 58. The sport helmet of claim 57, wherein the lattice is optically formed by collimated light beams.
59. The sport helmet of any one of claims 57 and 58, wherein the lattice is optically formed by ultraviolet light.
- 35

60. The sport helmet of any one of claims 37 to 59, wherein the structural members of the lattice extend in at least five different directions.
61. The sport helmet of any one of claims 37 to 59, wherein the structural members of the lattice extend in a multitude of different directions.
62. The sport helmet of any one of claims 37 to 61, wherein the lattice is configured to be compressed to half of a volume of the lattice and recover the volume of the lattice.
63. The sport helmet of any one of claims 37 to 62, wherein the structural members of the lattice are created and polymerized separately from one another.
64. A sport helmet comprising:
- an outer shell; and
 - a liner disposed within the outer shell and comprising a lattice;
- wherein: the lattice is formed of flexible material and configured to deform from an initial shape upon an impact on the sport helmet and recover the initial shape thereafter to absorb at least part of the impact; the lattice comprises a predefined arrangement of structural members intersecting one another at nodes; and respective ones of the nodes of the lattice are spaced apart from one another in three orthogonal directions that include a thickness-wise direction of the sport helmet from an exterior surface of the outer shell to an interior surface of the liner.
65. The sport helmet of claim 64, wherein a density of the lattice is variable.
66. The sport helmet of any one of claims 64 and 65, wherein a spacing of the structural members of the lattice is variable.
67. The sport helmet of any one of claims 64 to 66, wherein given ones of the structural members of the lattice vary in size.
68. The sport helmet of any one of claims 64 to 67, wherein adjacent ones of the structural members of the lattice vary in orientation.

69. The sport helmet of any one of claims 64 to 68, wherein a resistance to compression of the lattice is variable.
70. The sport helmet of any one of claims 64 to 69, wherein a stiffness of the
5 lattice is variable.
71. The sport helmet of any one of claims 64 to 70, wherein a first zone of the lattice is stiffer than a second zone of the lattice.
- 10 72. The sport helmet of claim 71, wherein: a third zone of the lattice is stiffer than the second zone of the lattice; and the second zone of the lattice is disposed between the first zone of the lattice and the third zone of the lattice.
73. The sport helmet of any one of claims 64 to 72, wherein an openness of the
15 lattice is variable.
74. The sport helmet of any one of claims 64 to 70 and 73, wherein a first zone of the lattice is more open than a second zone of the lattice.
- 20 75. The sport helmet of claim 74, wherein: a third zone of the lattice is less open than the first zone of the lattice; and the first zone of the lattice is disposed between the second zone of the lattice and the third zone of the lattice.
76. The sport helmet of any one of claims 64 to 75, wherein the lattice occupies
25 at least a majority of a dimension from the exterior surface of the outer shell to the interior surface of the liner.
77. The sport helmet of any one of claims 64 to 76, wherein the outer shell is injection-molded.
30
78. The sport helmet of any one of claims 64 to 77, wherein the interior surface of the liner comprises textile material.
79. The sport helmet of any one of claims 64 to 78, wherein the lattice is curved.
35

80. The sport helmet of any one of claims 64 to 79, wherein the lattice is entirely polymeric.
81. The sport helmet of any one of claims 64 to 80, comprising filling material that
5 fills at least part of hollow space of the lattice.
82. The sport helmet of claim 81, wherein the filling material comprises foam.
83. The sport helmet of claim 81, wherein the filling material comprises
10 elastomeric material.
84. The sport helmet of claim 81, wherein the filling material is configured to dampen vibrations.
- 15 85. The sport helmet of any one of claims 64 to 84, wherein the lattice is optically formed.
86. The sport helmet of claim 85, wherein the lattice is optically formed by collimated light beams.
20
87. The sport helmet of any one of claims 85 and 86, wherein the lattice is optically formed by ultraviolet light.
88. The sport helmet of any one of claims 64 to 87, wherein the structural
25 members of the lattice extend in at least five different directions.
89. The sport helmet of any one of claims 64 to 87, wherein the structural members of the lattice extend in a multitude of different directions.
- 30 90. The sport helmet of any one of claims 64 to 89, wherein the lattice is configured to be compressed to half of a volume of the lattice and recover the volume of the lattice.
91. The sport helmet of any one of claims 64 to 90, wherein the structural
35 members of the lattice are created and polymerized separately from one another.

92. A sport helmet comprising:
- an outer shell; and
 - a liner disposed within the outer shell and comprising a lattice;
- 5 wherein: the lattice is formed of flexible material and is configured to deform from an initial shape upon an impact on the sport helmet and recover the initial shape thereafter to absorb at least part of the impact; the lattice comprises an arrangement of structural members intersecting one another at nodes; respective ones of the nodes of the lattice are spaced apart from one another in three orthogonal directions
- 10 that include a thickness-wise direction of the sport helmet from an exterior surface of the outer shell to an interior surface of the liner; and the structural members of the lattice are created and polymerized separately from one another.
93. The sport helmet of claim 92, wherein a density of the lattice is variable.
- 15 94. The sport helmet of any one of claims 92 and 93, wherein a spacing of the structural members of the lattice is variable.
95. The sport helmet of any one of claims 92 to 94, wherein given ones of the
- 20 structural members of the lattice vary in size.
96. The sport helmet of any one of claims 92 to 95, wherein adjacent ones of the structural members of the lattice vary in orientation.
- 25 97. The sport helmet of any one of claims 92 to 96, wherein a resistance to compression of the lattice is variable.
98. The sport helmet of any one of claims 92 to 97, wherein a stiffness of the
- 30 lattice is variable.
99. The sport helmet of any one of claims 92 to 98, wherein a first zone of the lattice is stiffer than a second zone of the lattice.

100. The sport helmet of claim 99, wherein: a third zone of the lattice is stiffer than the second zone of the lattice; and the second zone of the lattice is disposed between the first zone of the lattice and the third zone of the lattice.
- 5 101. The sport helmet of any one of claims 92 to 100, wherein an openness of the lattice is variable.
102. The sport helmet of any one of claims 92 to 98 and 101, wherein a first zone of the lattice is more open than a second zone of the lattice.
- 10 103. The sport helmet of claim 102, wherein: a third zone of the lattice is less open than the first zone of the lattice; and the first zone of the lattice is disposed between the second zone of the lattice and the third zone of the lattice.
- 15 104. The sport helmet of any one of claims 92 to 103, wherein the lattice occupies at least a majority of a dimension from the exterior surface of the outer shell to the interior surface of the liner.
- 20 105. The sport helmet of any one of claims 92 to 104, wherein the outer shell is injection-molded.
106. The sport helmet of any one of claims 92 to 105, wherein the interior surface of the liner comprises textile material.
- 25 107. The sport helmet of any one of claims 92 to 106, wherein the lattice is curved.
108. The sport helmet of any one of claims 92 to 107, wherein the lattice is entirely polymeric.
- 30 109. The sport helmet of any one of claims 92 to 108, comprising filling material that fills at least part of hollow space of the lattice.
110. The sport helmet of claim 109, wherein the filling material comprises foam.

111. The sport helmet of claim 109, wherein the filling material comprises elastomeric material.
112. The sport helmet of claim 109, wherein the filling material is configured to dampen vibrations.
113. The sport helmet of any one of claims 92 to 112, wherein the lattice is optically formed.
114. The sport helmet of claim 113, wherein the lattice is optically formed by collimated light beams.
115. The sport helmet of any one of claims 113 and 114, wherein the lattice is optically formed by ultraviolet light.
116. The sport helmet of any one of claims 92 to 115, wherein the structural members of the lattice extend in at least five different directions.
117. The sport helmet of any one of claims 92 to 115, wherein the structural members of the lattice extend in a multitude of different directions.
118. The sport helmet of any one of claims 92 to 117, wherein the lattice is configured to be compressed to half of a volume of the lattice and recover the volume of the lattice.

1/3

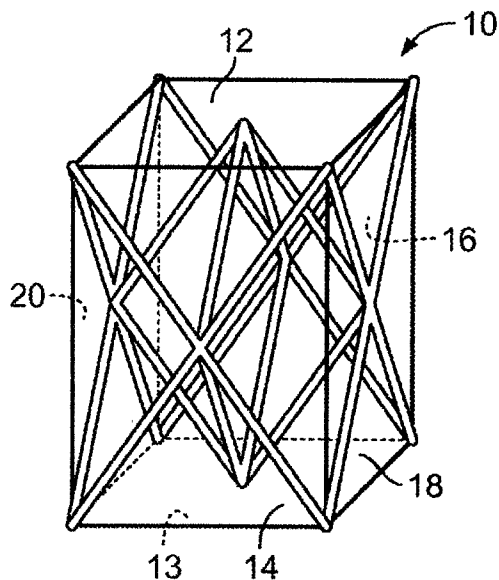


FIG. 1

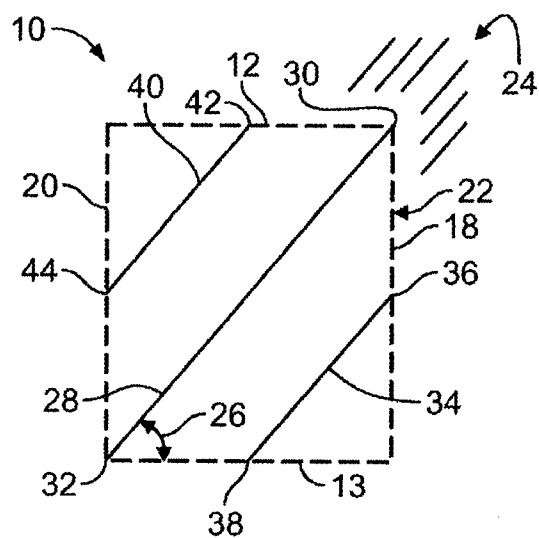


FIG. 2

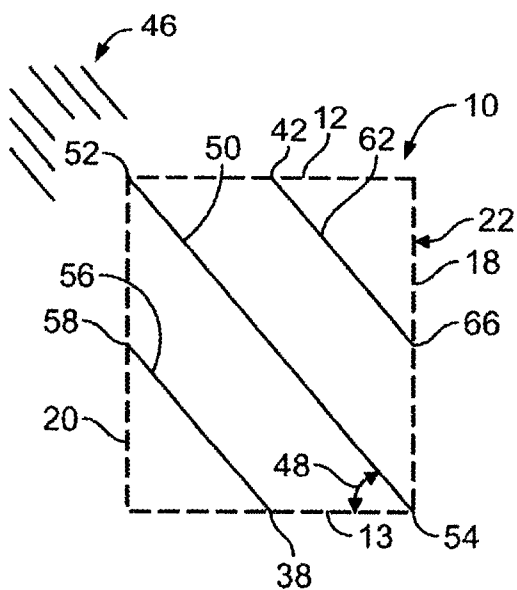


FIG. 3

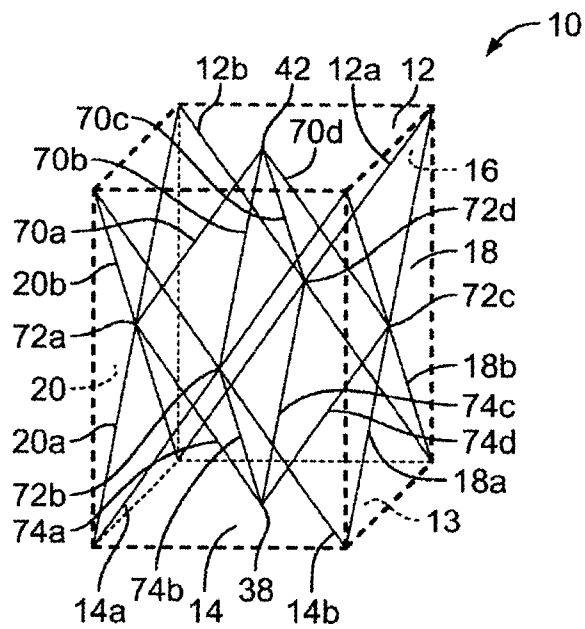


FIG. 4

2/3

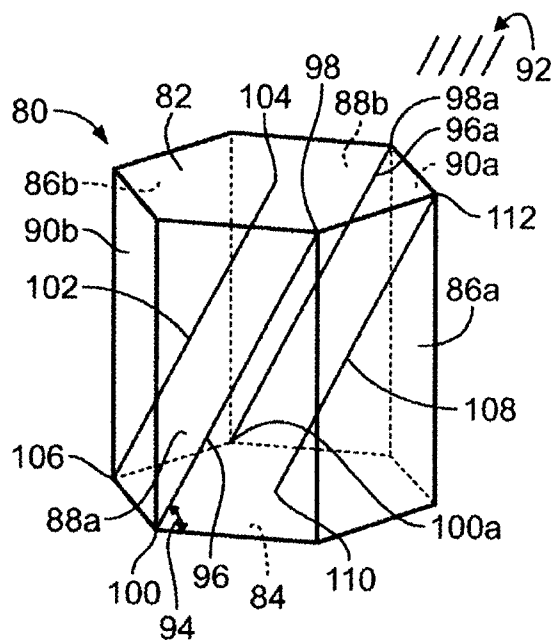


FIG. 5

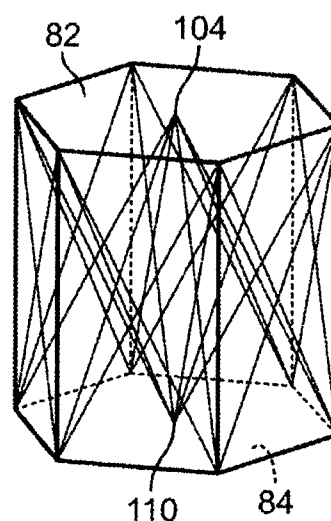


FIG. 6

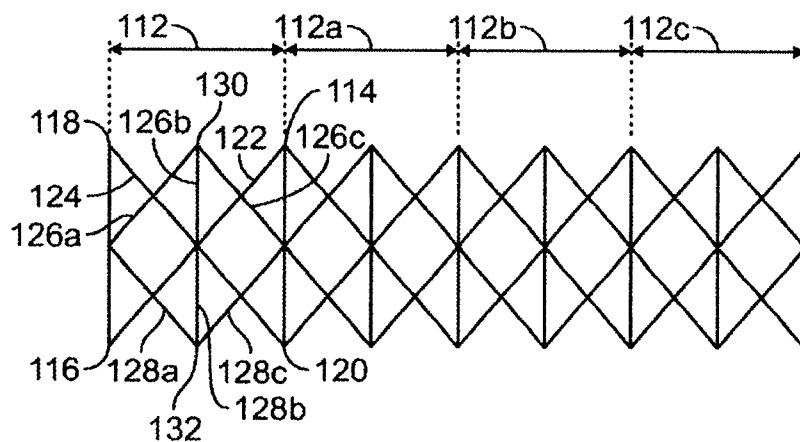


FIG. 7

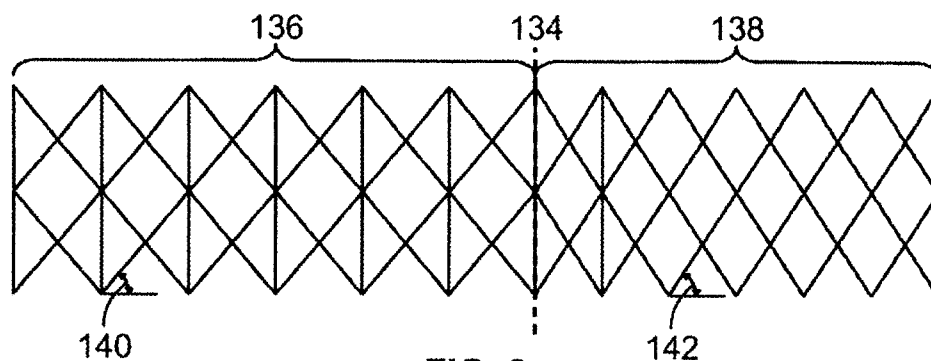


FIG. 8

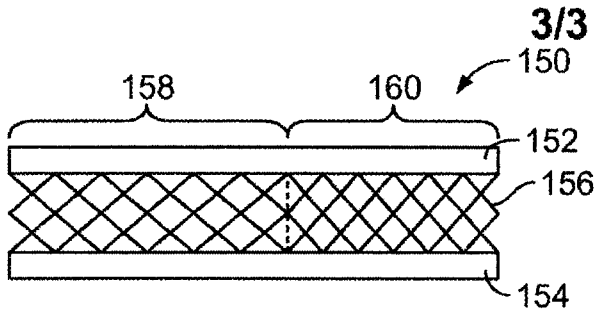


FIG. 9

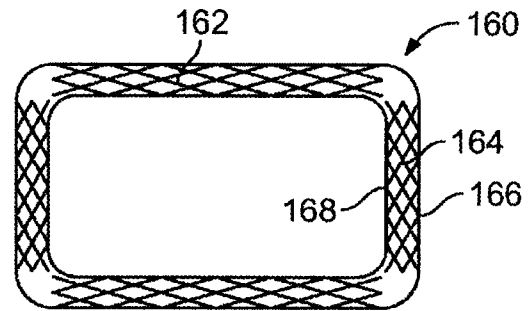


FIG. 10

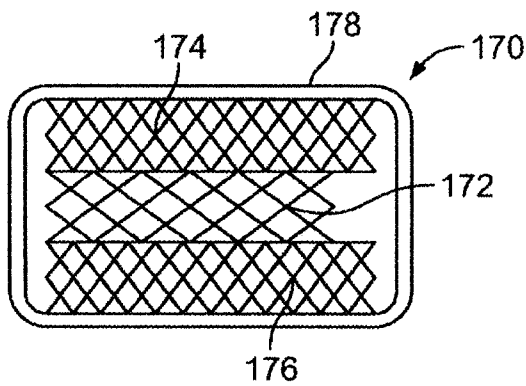


FIG. 11

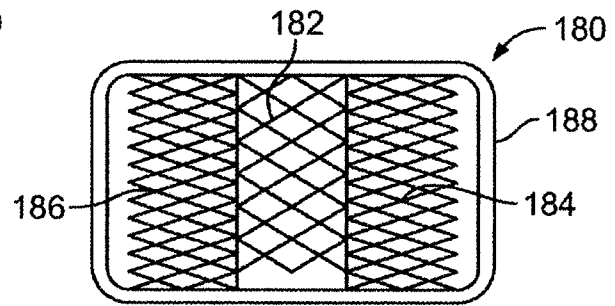


FIG. 12

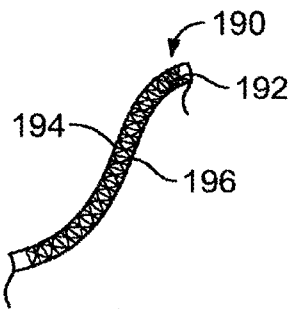


FIG. 13

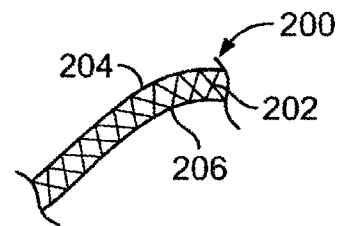


FIG. 14

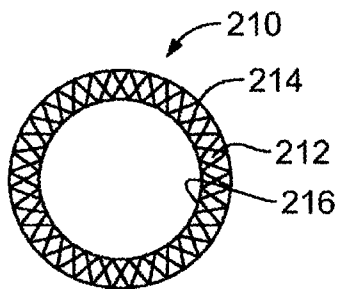


FIG. 15

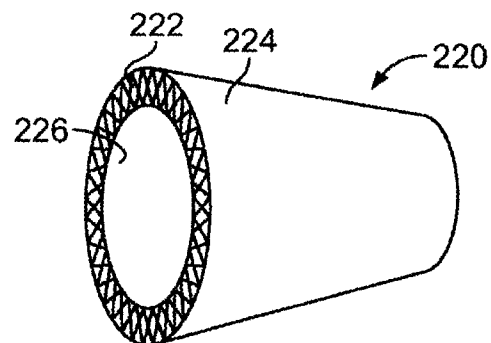


FIG. 16

