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(54) **IMPACT RESISTANT STRUCTURES FOR PROTECTIVE GARMENTS**

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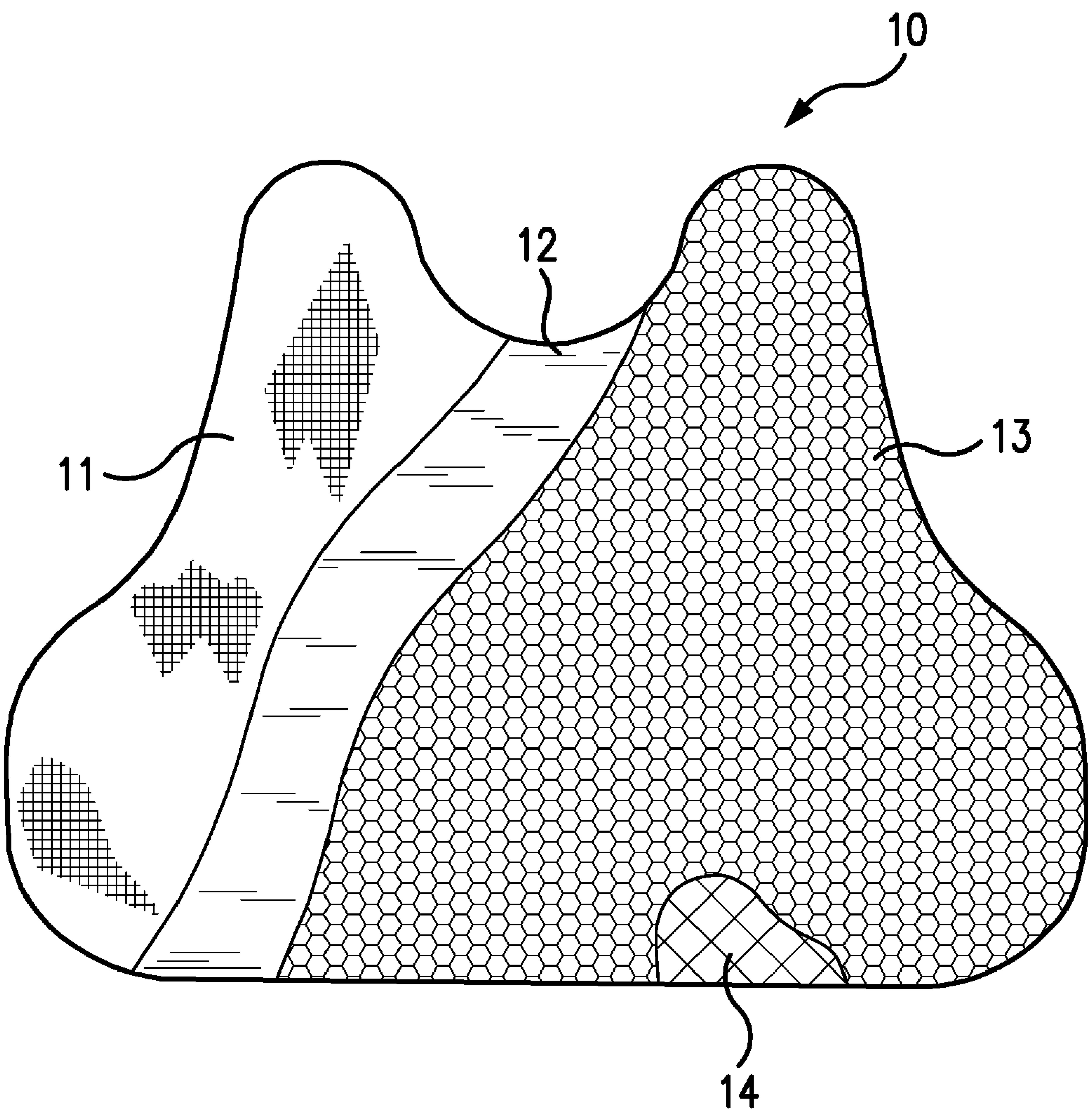
(57) **ABSTRACT**

A multi-layer composite structure is conformable to the contours of the body parts for which protection is required. The composition structure contains a rigid shock-deflecting outer layer, two semi-rigid shock-damping and shock-dissipating middle layers, and a pliable shock-absorbing lower layer. In one embodiment, the structure is designed for impacts associated with contact sports, such as football, hockey and lacrosse. In another embodiment, the structure is designed for military/police applications, in which impacts can be blunt forces, from weapons such as clubs, or penetrative forces, from knives, bullets or shrapnel.



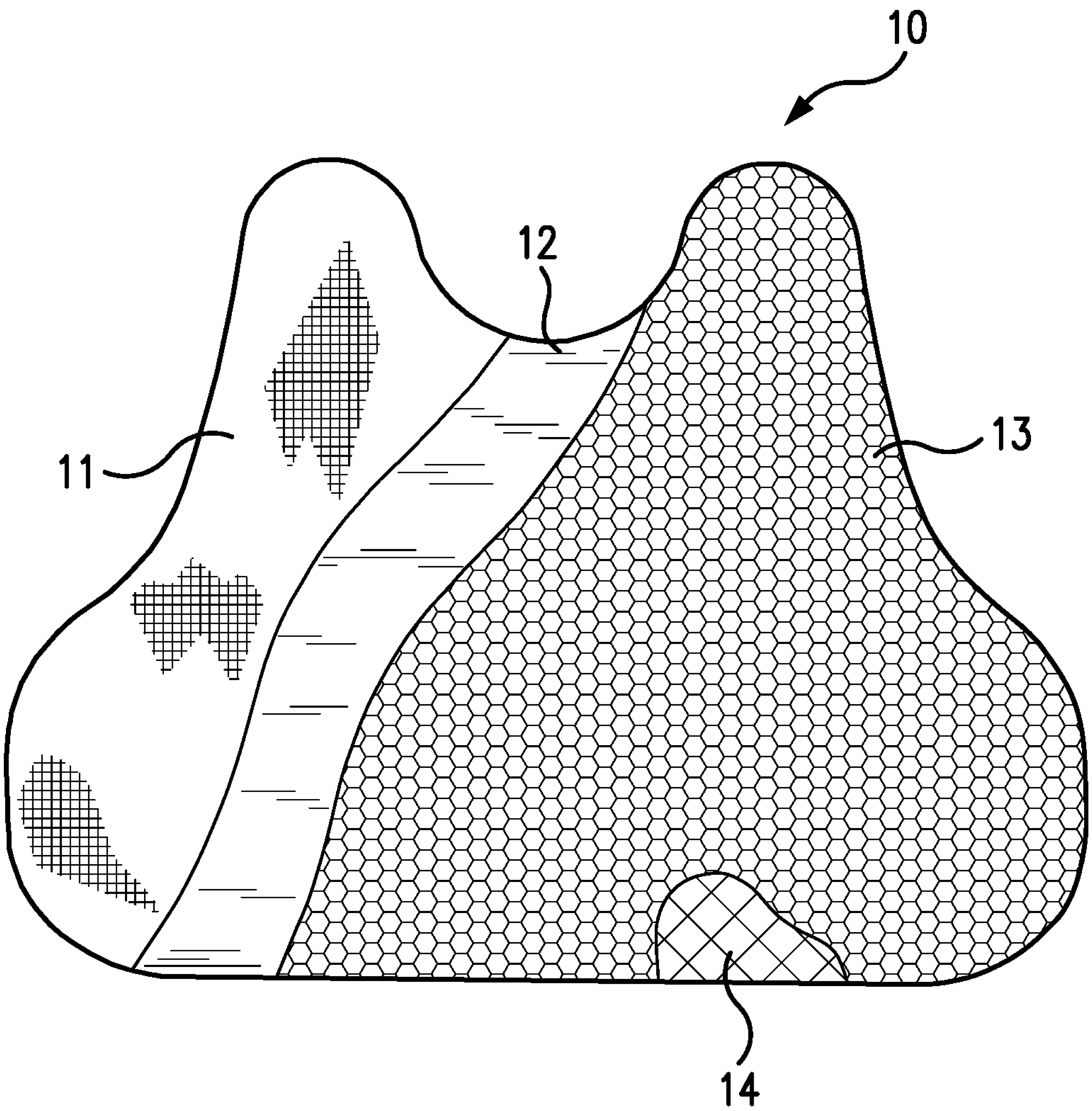


FIG. 1

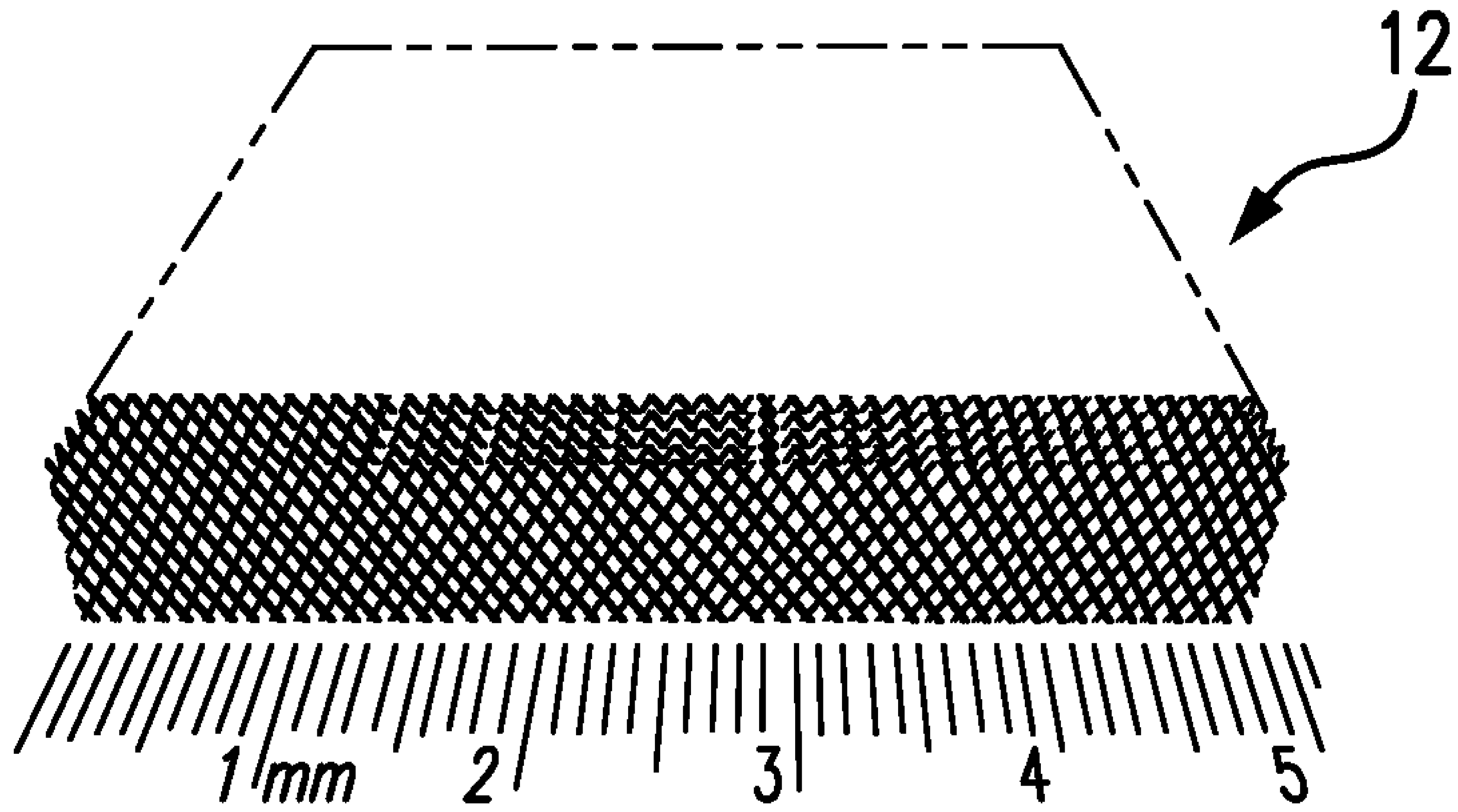


FIG. 2A

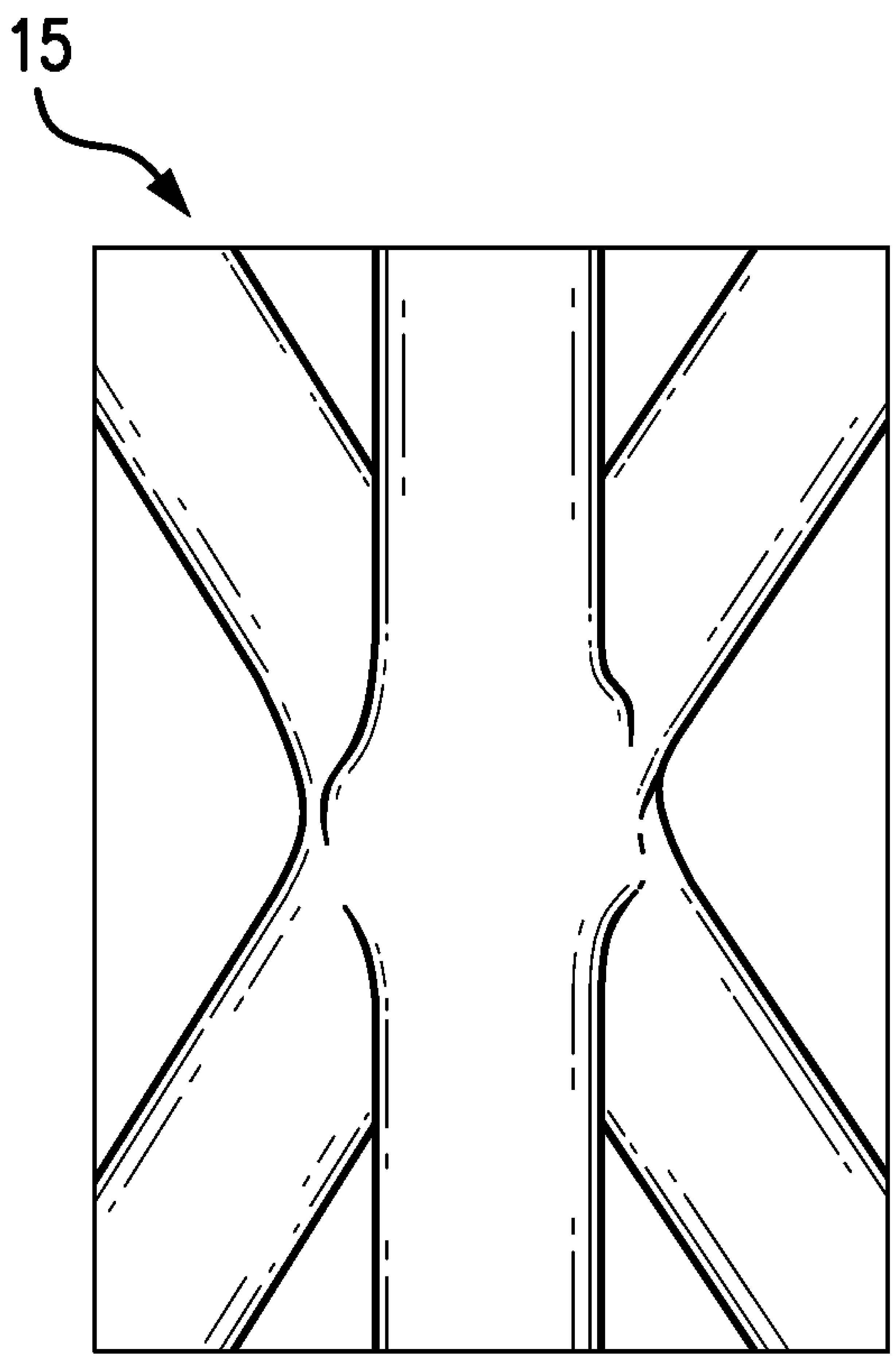


FIG. 2B

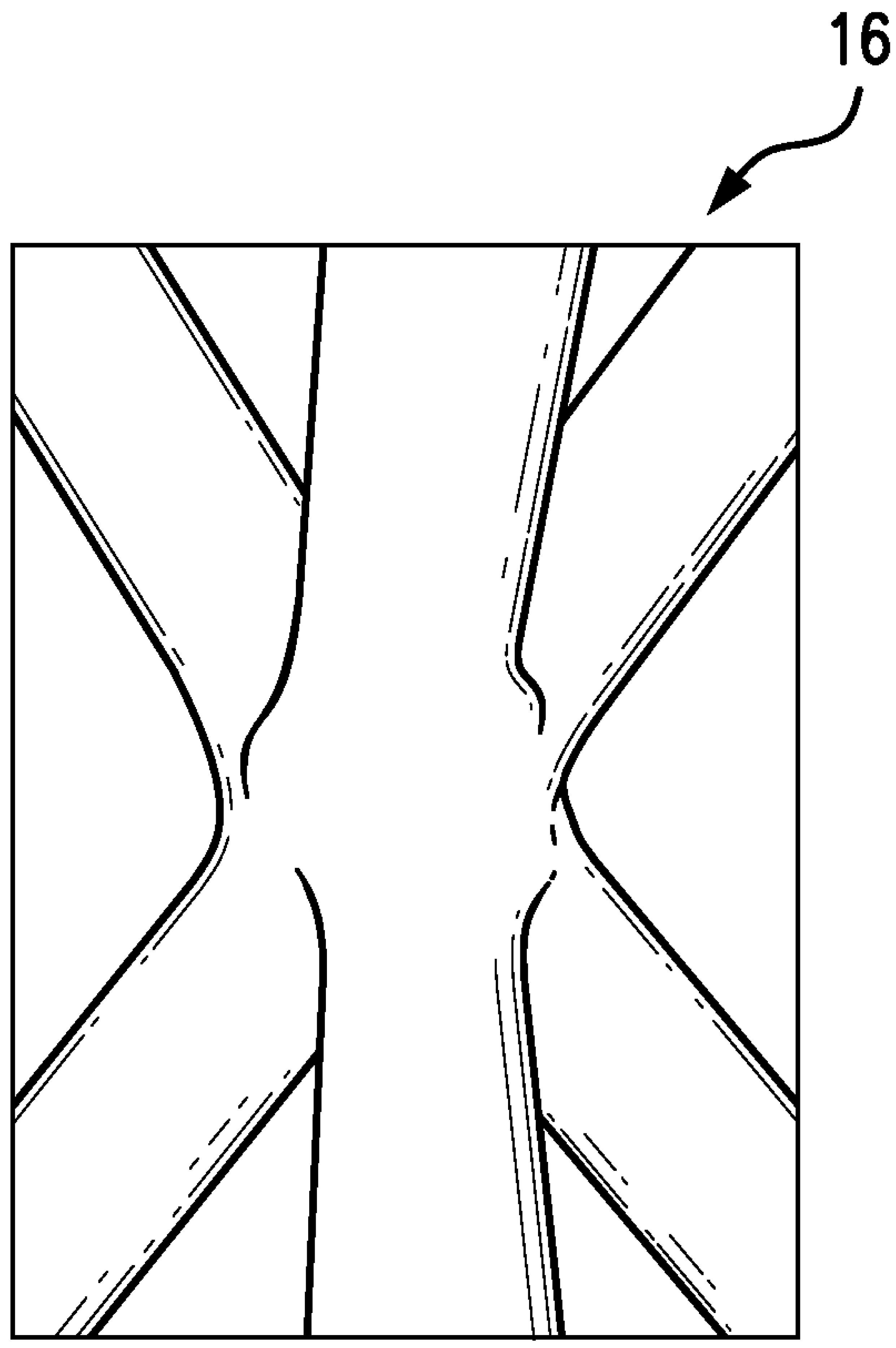


FIG. 2C

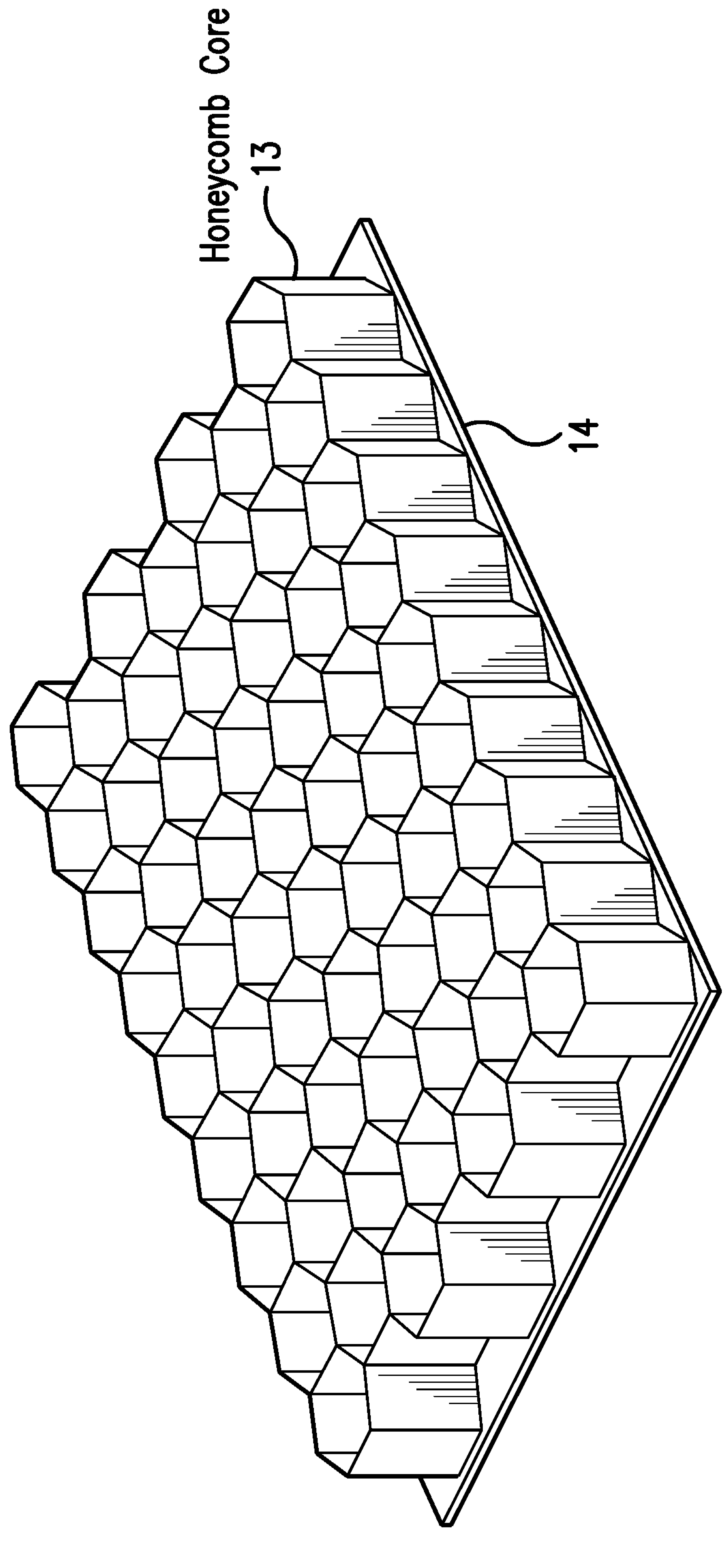


FIG. 3

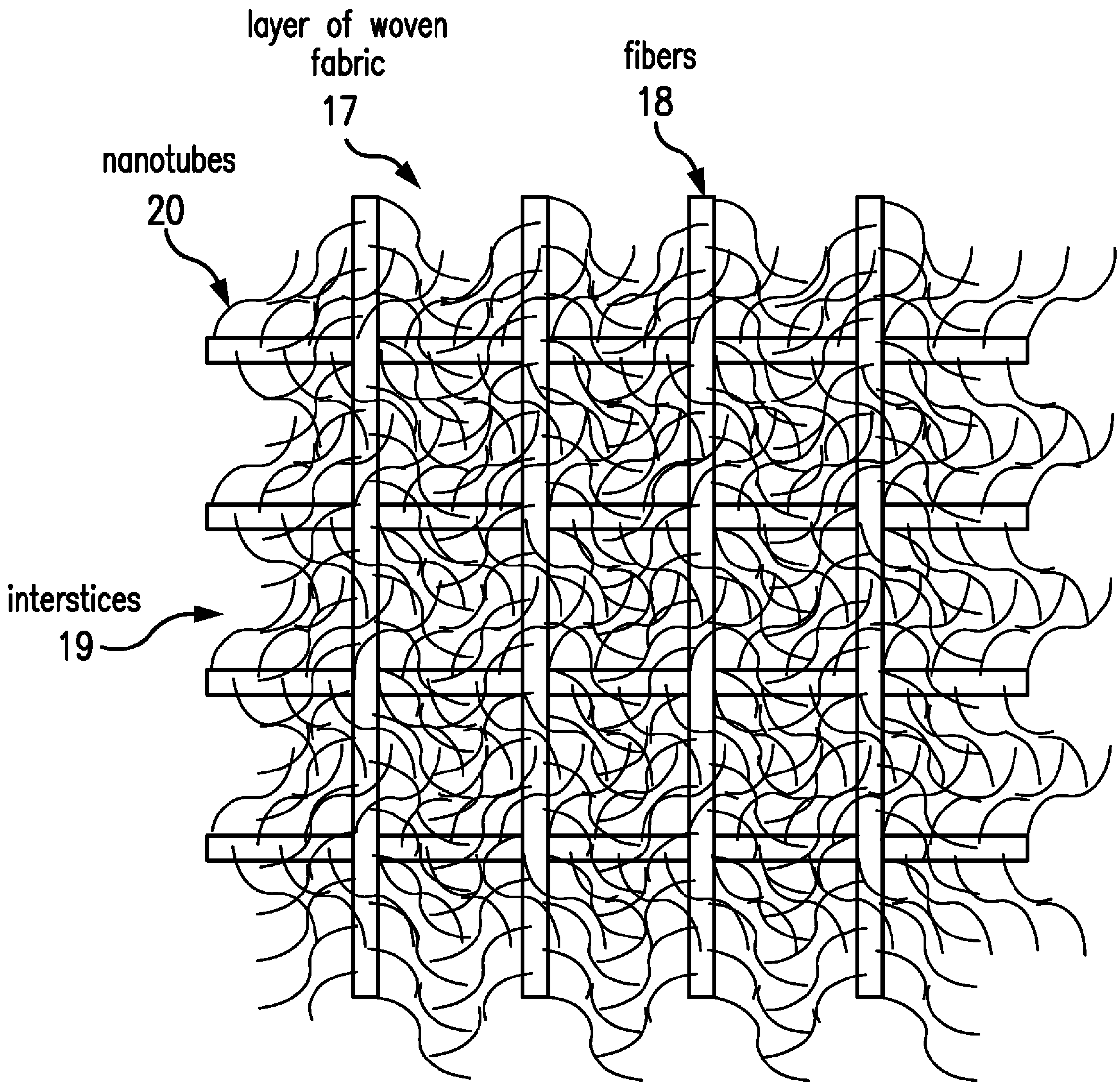

layer of woven fabric
17
fibers
18
nanotubes
20
interstices
19

FIG. 4

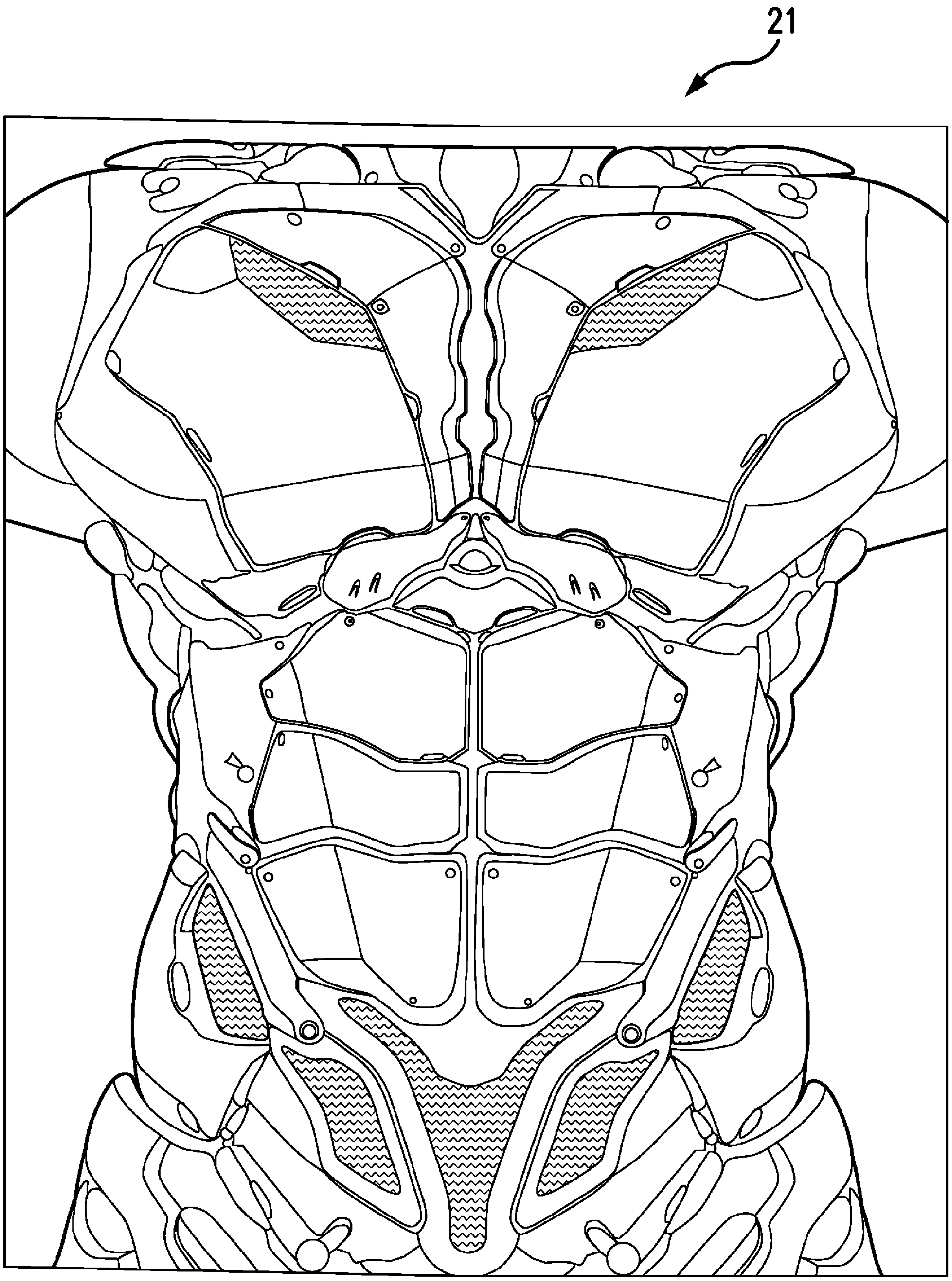


FIG. 5

IMPACT RESISTANT STRUCTURES FOR PROTECTIVE GARMENTS

RELATION TO OTHER APPLICATIONS

[0001] This application claims the benefits of the filing date of U.S. Provisional Patent Application No. 62/407,204, filed Oct. 12, 2016, the disclosure of which is incorporated herein by reference. The present invention is also related to this inventor's U.S. Pat. No. 9,067,122 B2, "Protective Athletic Garment and Method," which is incorporated herein in its entirety.

FIELD OF INVENTION

[0002] The present invention relates to the field of garments adapted to protect a wearer's body from impacts associated with contacts sports and/or military/police activities.

BACKGROUND OF THE INVENTION

[0003] Protective garments for sports, military and police uses have evolved in the direction of becoming lighter, stronger, more mobile, and more wearable. Optionally, the structures comprising such protective garments should be capable of deflecting impact forces, damping their impact, dissipating such forces, absorbing them, and blocking penetration through to the wearer's body.

[0004] The principal problem to be solved in designing such garments is that diverse materials need to be utilized in connection with the foregoing capabilities. The task of integrating such diverse materials into a composite structure requires consideration of their interaction, which should be synergistic, such that the resultant protective effect is greater than the sum of each material's isolated contribution.

SUMMARY OF THE INVENTION

[0005] The present invention comprises a multi-layer composite structure, which is conformable to the contours of the body parts for which protection is required. In one embodiment, the structure is designed for impacts associated with contact sports, such as football, hockey and lacrosse. In another embodiment, the structure is designed for military/police applications, in which impacts can be blunt forces, from weapons such as clubs, or penetrative forces, from knives, bullets or shrapnel.

[0006] In both embodiments, the present invention deploys a structure comprising a rigid shock deflecting outer layer, two semi-rigid shock damping and dissipative middle layers, and a pliable shock absorbing lower layer.

[0007] In the sports embodiments, the outer shock-deflecting layer of each structure is a panel or shell composed of a rigid, light-weight, impact-resistant polymer, polymer blend or ceramic material. The outer layer is sized and contoured to match the body part(s) over which it will be worn. Such sizing and contouring can be done generically according to ranges of different body types, e.g., large men's size, medium men's size, small woman's size, etc.

[0008] Alternately, the outer layer can be tailored to the body shape, size and contours of specific individual wearer's body. Such tailoring can be done by three-dimensional (3D) optical scanning of the covered body part(s) of the individual and use of the 3D optical scanning data in a 3D printer to produce the corresponding panel/shell structure. This 3D optical scanning-printing methodology can also be used to generate partial "exoskeleton" structures, such as breastplates or sleeves.

[0009] Over joints, such as shoulders, elbows, spine and knees, the outer layer structures comprise overlapping, articulated concave shaped panels, which are elastically interconnected so as to move translationally and rotationally with respect to one another. In one embodiment, the articulated plates/panels are interconnected by a semi-rigid track with intervaled notches or detents, along which each plate/panel can move incrementally in relation to the other interconnected plates/panels.

[0010] In the military/police embodiments, the structures of the outer shock-deflecting layer can be the same as those outlined above for the sports embodiments, but they will be composed of a ballistic and puncture resistant material, such as reinforced plastic, reinforced carbon fiber, graphene, titanium metal or aramid fibers.

[0011] In both sports and military/police embodiments, the middle layers of the impact resistant structures according to the present invention comprise a deformable, polymer-based microlattice damping layer above a semi-rigid, polyurethane honeycomb lattice dissipating layer. The microlattice material preferably comprises a three-dimensional interconnected network of hollow nanotubes preferably having tube diameters less than 1 mm, the stress buckling of which damps impact forces.

[0012] Beneath the microlattice damping layer, the semi-rigid honeycomb dissipating material acts as a constraining layer that sandwiches the microlattice material between itself and the rigid outer deflecting layer, thereby improving the damping characteristics of the microlattice. Preferably, the honeycomb dissipating layer comprises open hexagonal cells less than 0.5 inches in diameter.

[0013] The shock absorbing lower layer of the present invention comprises a loose fabric interwoven with carbon nanotube yarn (tube diameter less than 1 mm). In the sports embodiments, the base fabric is preferably woven of a breathable natural or artificial fiber that wicks moisture away from the wearer's skin. In the military/police embodiments, the base fabric is preferably a ballistic and puncture resistant fiber, such as Kevlar®.

[0014] As discussed above, the multi-layered composite impact resistant structures of the present invention can be configured as partial exoskeleton panels, which can in turn be removably interconnected to form a complete exoskeleton body armor for the upper torso, arms, lower torso, legs or a combination of some or all of these.

[0015] The foregoing summarizes the general design features of the present invention. In the following sections, specific embodiments of the present invention will be described in some detail. These specific embodiments are intended to demonstrate the feasibility of implementing the present invention in accordance with the general design features discussed above. Therefore, the detailed descriptions of these embodiments are offered for illustrative and exemplary purposes only, and they are not intended to limit the scope either of the foregoing summary description or of the claims which follow.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] FIG. **1** is a cut-away view of an exemplary impact resistant breastplate structure in accordance with one embodiment of the present invention;

[0017] FIG. **2**A is perspective view of an exemplary microlattice layer comprising a component of one embodiment of the present invention;

[0018] FIG. **2**B is a magnified detail view of the exemplary microlattice of FIG. **2**A under initial compression, showing incipient buckling deformation at microlattice nodes;

[0019] FIG. **2**C is a magnified detail view of the exemplary microlattice of FIG. **2**A under further compression, showing increased buckling deformation at microlattice nodes;

[0020] FIG. **3** is perspective view of an exemplary honeycomb layer comprising a component of one embodiment of the present invention;

[0021] FIG. **4** is a magnified detail view of an exemplary fabric layer comprising a component of one embodiment of the present invention; and

[0022] FIG. **5** is frontal view of an exemplary exoskeleton comprising multiple impact resistant structures according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0023] Referring to FIG. **1**, an exemplary impact resistant breastplate structure **10** comprises a rigid, shock-deflecting outer layer **11**, below which is a deformable, polymer-based microlattice shock-damping layer **12**, below which is a semi-rigid, polyurethane honeycomb lattice dissipative layer **13**, below which is a lower shock-absorbing fabric layer **14**.

[0024] As shown in FIG. **2**A, the microlattice layer **12** comprises a three-dimensional network of hollow nanotubes, preferably having tube diameters less than 1 mm. The nanotubes microscopic structure is depicted in FIGS. **2**B and **2**C, in which the microlattice is under increasing compression, with deformation progressing from incipient buckling at the nodes **15** to more advanced buckling **16**. The buckling at the nanotubes' nodes damps impact forces, and the extremely small aspect ratio of the nanotubes' wall thickness to their diameter enables nearly full deformation recoverability.

[0025] FIG. **3** depicts the semi-rigid, polyurethane honeycomb lattice shock-dissipating layer **13**, which lies below the microlattice layer **12**. Preferably, as shown in FIG. **3**, the honeycomb cells are fused together at their walls without interstitial voids. While open hexagonal cells are depicted for illustrative purposes, it should be understood that any open polygonal-shaped cell can be used, although preferably the number of sides of each all should be five or more. Preferably the honeycomb material **13** is thermoplastic polyurethane and the cells are less than 0.5 inch in diameter. In addition to its shock-dissipating function, the semi-rigid, honeycomb material **13** acts as a constraining layer below the microlattice layer **12**, thereby increasing shock-damping deformation of the microlattice.

[0026] As shown in FIG. **3**, the honeycomb layer attaches to a shock-absorbing lower fabric layer **14**, which is depicted in magnified detail in FIG. **4**. This layer comprises a base layer of woven fabric **17**, consisting of fibers **18** with interstices **19**. Between the fibers **18** and the interstices **19** are interwoven carbon nanotubes **20**, preferably with tube diameter less than 1 mm. In military/police applications, the base fabric **17** is a ballistic and puncture resistant fiber, such as Kevlar®.

[0027] The material composing the rigid, shock-deflecting outer layer **11** of the exemplary breastplate structure **10** can be varied, depending on the application. In sports uses, it is preferably made of a rigid, light-weight, impact-resistant plastic or ceramic material, while in military/police uses, it is preferably composed of a ballistic and puncture resistant material, such as reinforced plastic, titanium metal or aramid fibers.

[0028] As shown in FIG. **5**, a complete or partial exoskeleton **21** can be assembled from articulate panels having the multi-layer composite structure of the present invention.

[0029] Although the preferred embodiment of the present invention has been disclosed for illustrative purposes, those skilled in the art will appreciate that many additions, modifications and substitutions are possible, without departing from the scope and spirit of the present invention as defined by the accompanying claims.

What is claimed:

1. A protective garment comprising:

multiple interconnected impact resistant structures, wherein each impact resistant structure comprises four interconnected layers, consisting of a rigid outer shock-deflecting layer, overlaying a semi-rigid, deformable, polymer-based, microlattice shock-damping layer, overlaying a semi-rigid, polyurethane, honeycomb lattice dissipative layer, overlaying a shock-absorbing lower fabric layer.

2. The protective garment according to claim **1**, wherein the microlattice shock-damping layer comprises a three-dimensional network of multiple hollow polymer nanotubes, having tube diameters less than 1 mm, and wherein the polymer nanotubes are interconnected at multiple nanotube nodes which undergo resilient deformation under an applied stress, thereby effecting a damping of the applied stress.

3. The protective garment according to claim **2**, wherein the honeycomb lattice dissipative layer comprises multiple thermoplastic polyurethane open polygonal cells, less than 0.5 inches in diameter, having cell walls that are fused together without interstitial voids, and wherein the transmission of the applied stress through the open polygonal cells dissipates the applied stress, and wherein the honeycomb lattice dissipative layer constrains the microlattice shock-damping layer, thereby increasing the resilient deformation of the nanotube nodes and increasing the damping of the applied stress.

4. The protective garment according to claim **3**, wherein the shock-absorbing lower fabric layer comprises a base woven layer, consisting of multiple woven fibers with interstices, and multiple carbon nanotubes, less than 1 mm in diameter, which are interwoven between the woven fibers and the interstices.

5. The protective garment according to claim **4**, wherein the woven fibers of the base woven layer are breathable natural or artificial fibers that wick moisture.

6. The protective garment according to claim **4**, wherein the woven fibers of the base woven layer are ballistic and puncture resistant.

7. The protective garment according to claim **5**, wherein the outer shock-deflecting layer comprises a rigid, lightweight, impact-resistant plastic, polymer, polymer blend, or ceramic material.

8. The protective garment according the claim **6**, wherein the outer shock-deflecting layer comprises a rigid plastic or metal material which is ballistic and puncture resistant.

9. The protective garment according to claim **7**, wherein the outer shock-deflecting layer comprises one or more panels or shells, each of which is sized and contoured to conform to a size and a shape of a covered body part over which the panel or shell is to be worn.

10. The protective garment according to claim **8**, wherein the outer shock-deflecting layer comprises one or more panels or shells, each of which is sized and contoured to conform to a size and a shape of a covered body part over which the panel or shell is to be worn.

11. The protective garment according to claim **9**, wherein each of the panels or shells are sized and contoured by 3D printing in conjunction with 3D optical scanning of the covered body part.

12. The protective garment according to claim **10**, wherein each of the panels or shells are sized and contoured by 3D printing in conjunction with 3D optical scanning of the covered body part.

13. The protective garment according to claim **9**, wherein the covered body part is a body joint, and wherein the outer shock-deflecting layer comprises multiple overlapping, articulated concave panels, which are elastically interconnected so as to move translationally and rotationally with respect to one another.

14. The protective garment according to claim **10**, wherein the covered body part is a body joint, and wherein the outer shock-deflecting layer comprises multiple overlapping, articulated concave panels, which are elastically interconnected so as to move translationally and rotationally with respect to one another.

15. The protective garment according to claim **11**, wherein the covered body part is a body joint, and wherein the outer shock-deflecting layer comprises multiple overlapping, articulated concave panels, which are elastically interconnected so as to move translationally and rotationally with respect to one another.

16. The protective garment according to claim **12**, wherein the covered body part is a body joint, and wherein the outer shock-deflecting layer comprises multiple overlapping, articulated concave panels, which are elastically interconnected so as to move translationally and rotationally with respect to one another.

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