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(54) METHOD AND APPARATUS FOR PROTECTING AGAINST BALLISTIC PROJECTILES

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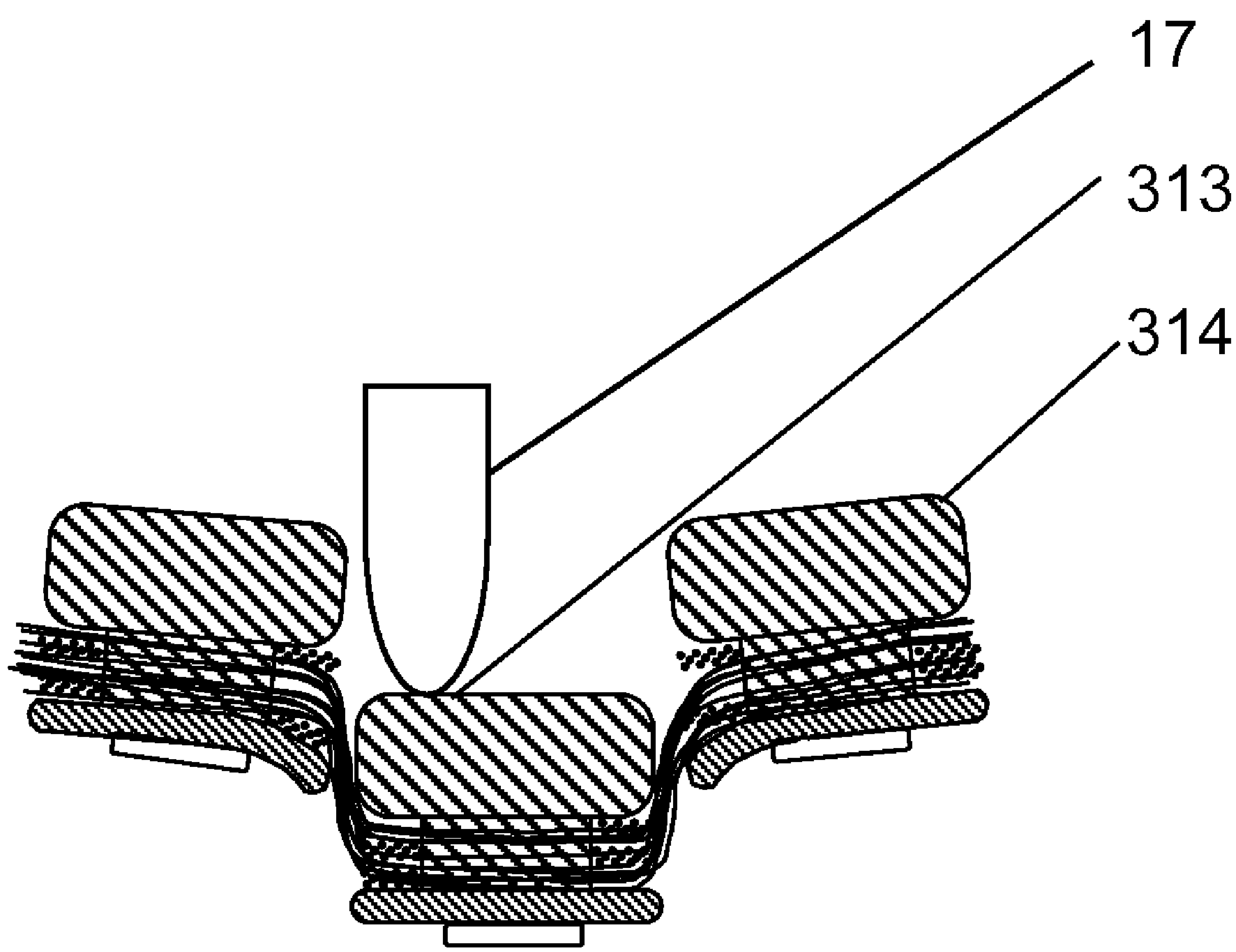
(57) **ABSTRACT**

A composite material comprising a multitude of masses and fibers supported on a flexible substrate arranged in a manner to absorb energy from a ballistic projectile and thereby protect persons or property from ballistic injury or damage. An array of small, tough disc-like masses are suspended in a three dimensional cradle of high-tensile elastomeric fibers such that energy from an incoming ballistic projectile is first imparted to one or more masses and the motion of the masses are restrained by tensile strain of elastomeric fibers substantially in the direction of travel of the incoming projectile. The projectile is eventually decelerated to harmless velocity through a combination of transfer of momentum to the masses and the elastic and plastic tensile deformation of the fibers. One or more layers of the composite material can be assembled to form body protective armor ("bullet-proof vest") or property protective armor, the number and characteristics of the layers being adjusted according to the specific ballistic threat anticipated.



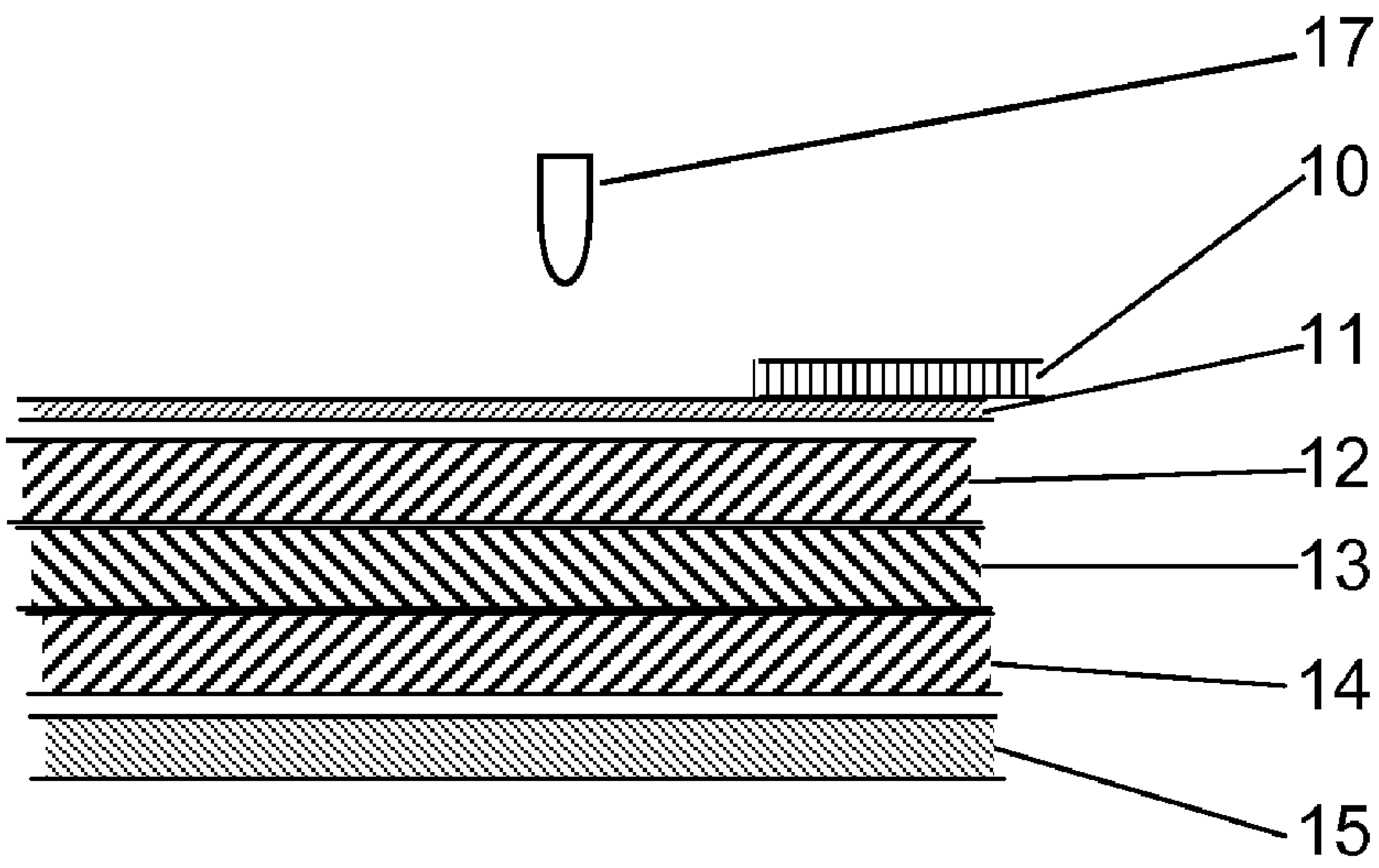



FIG. 1

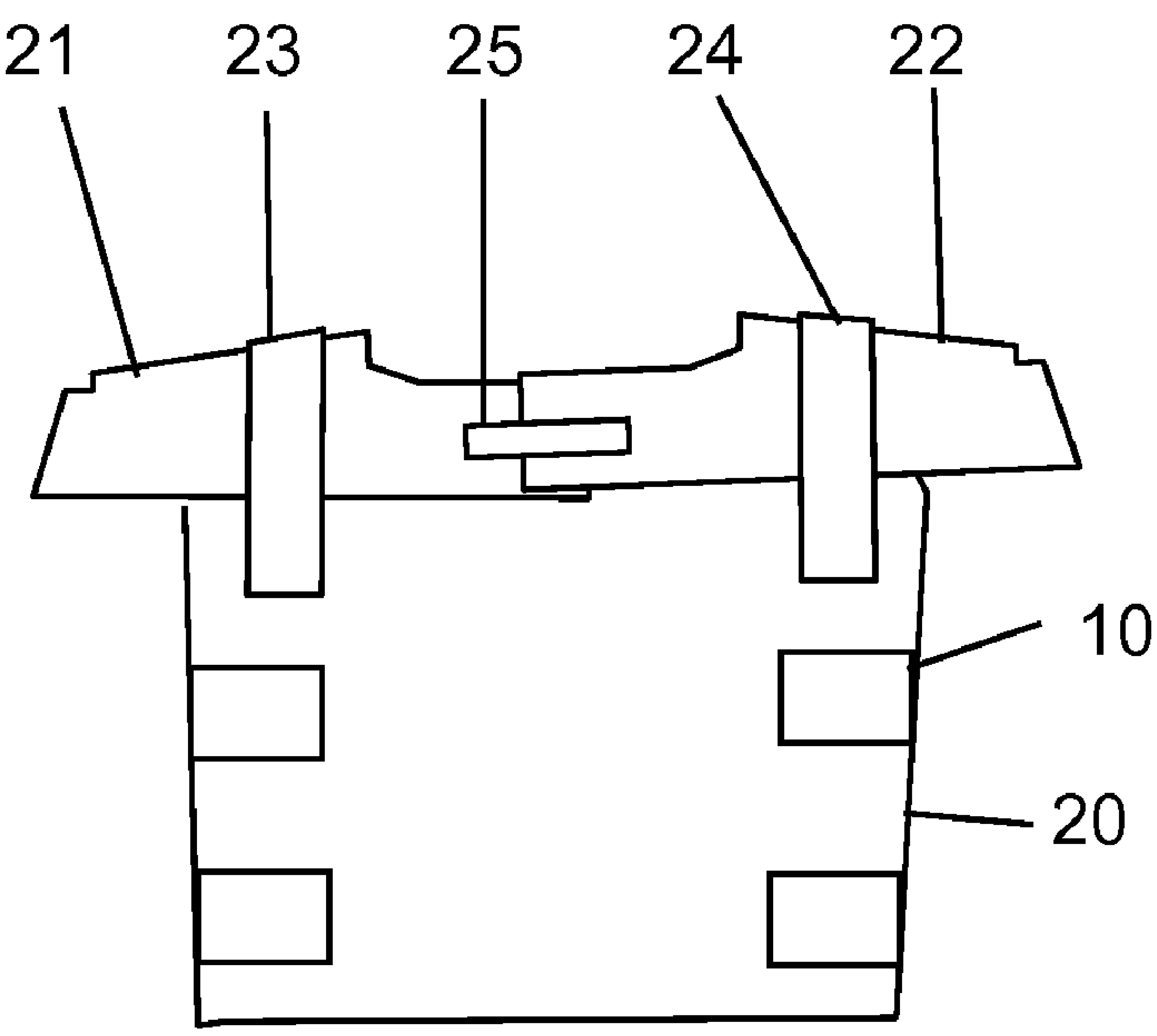



FIG. 2

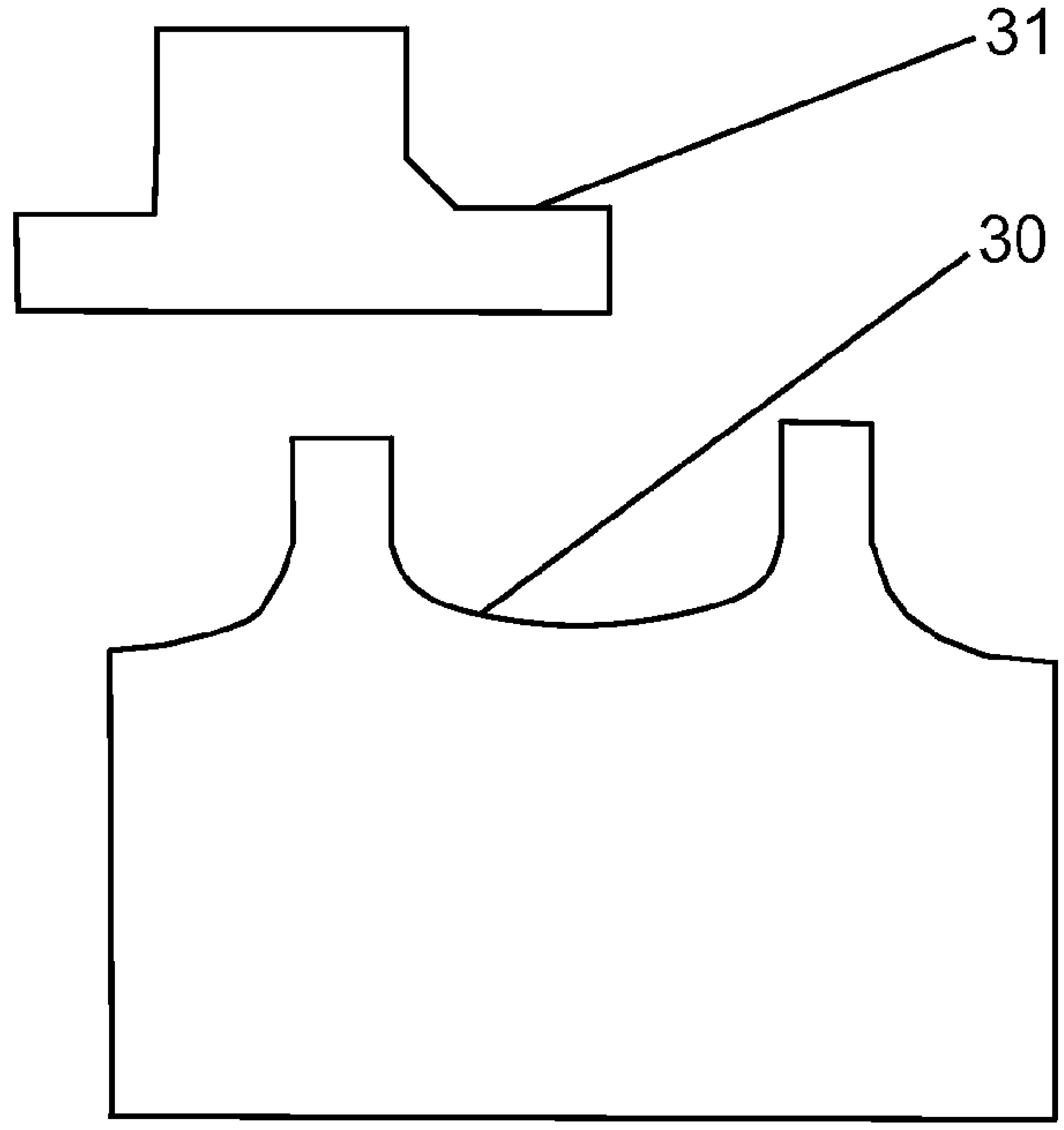



FIG. 3

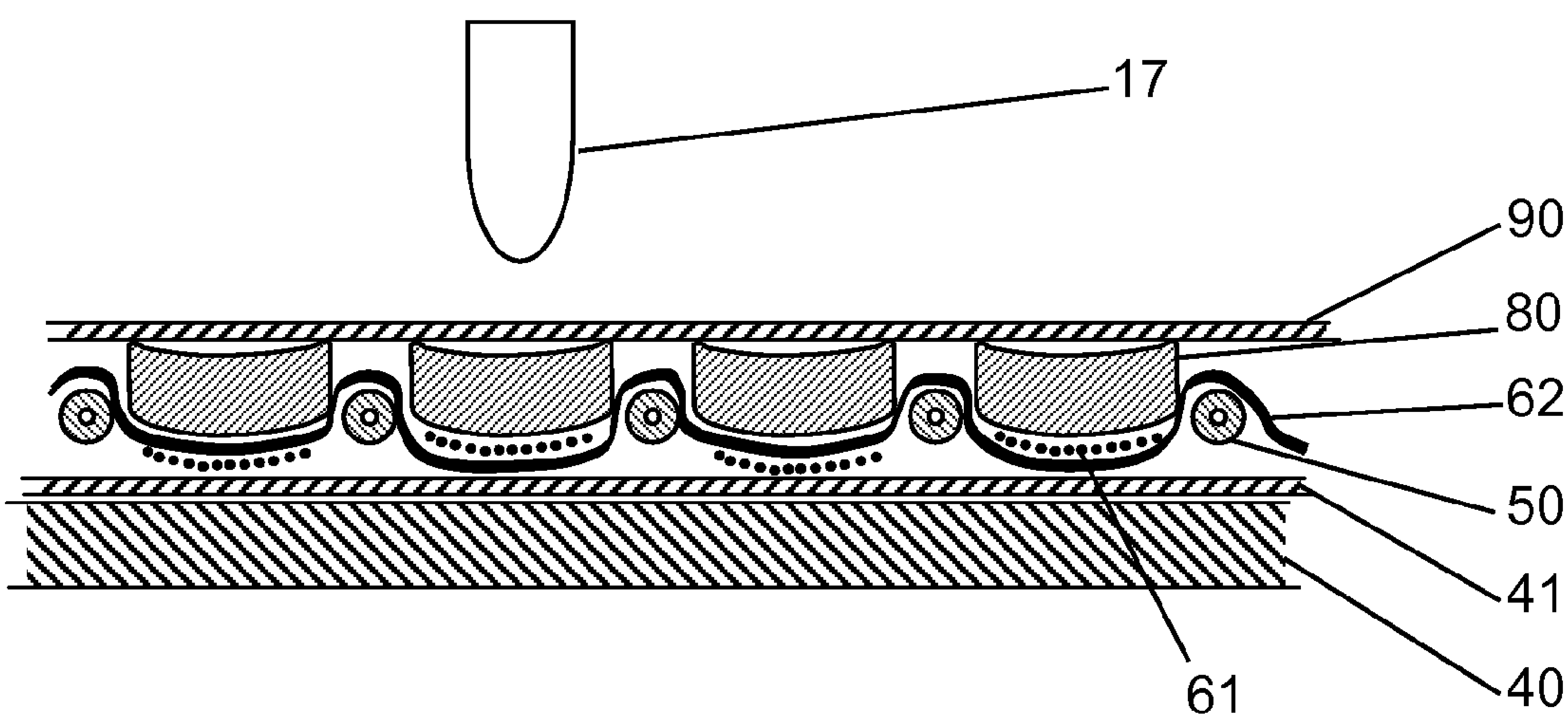



FIG. 4

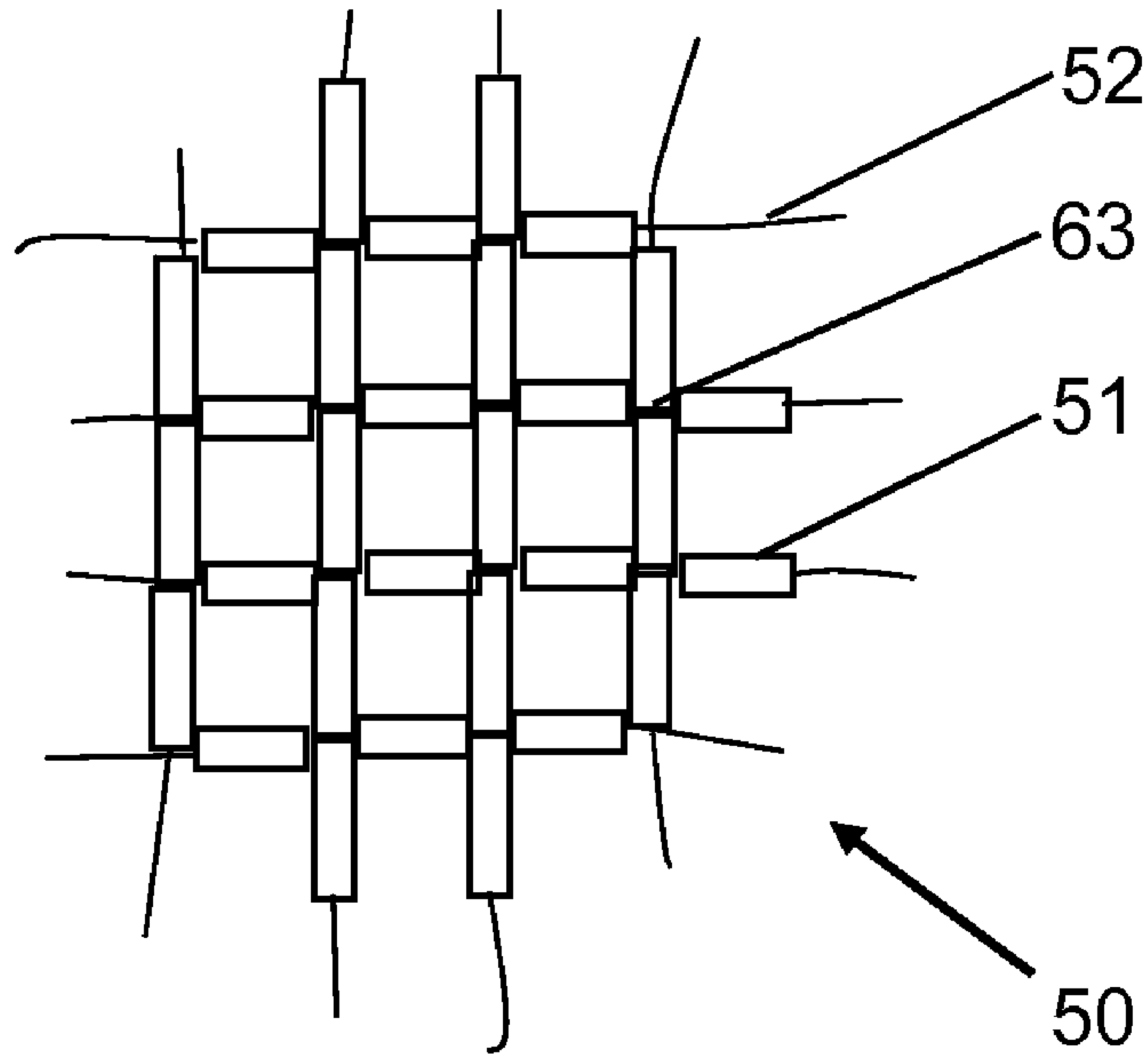



FIG. 5

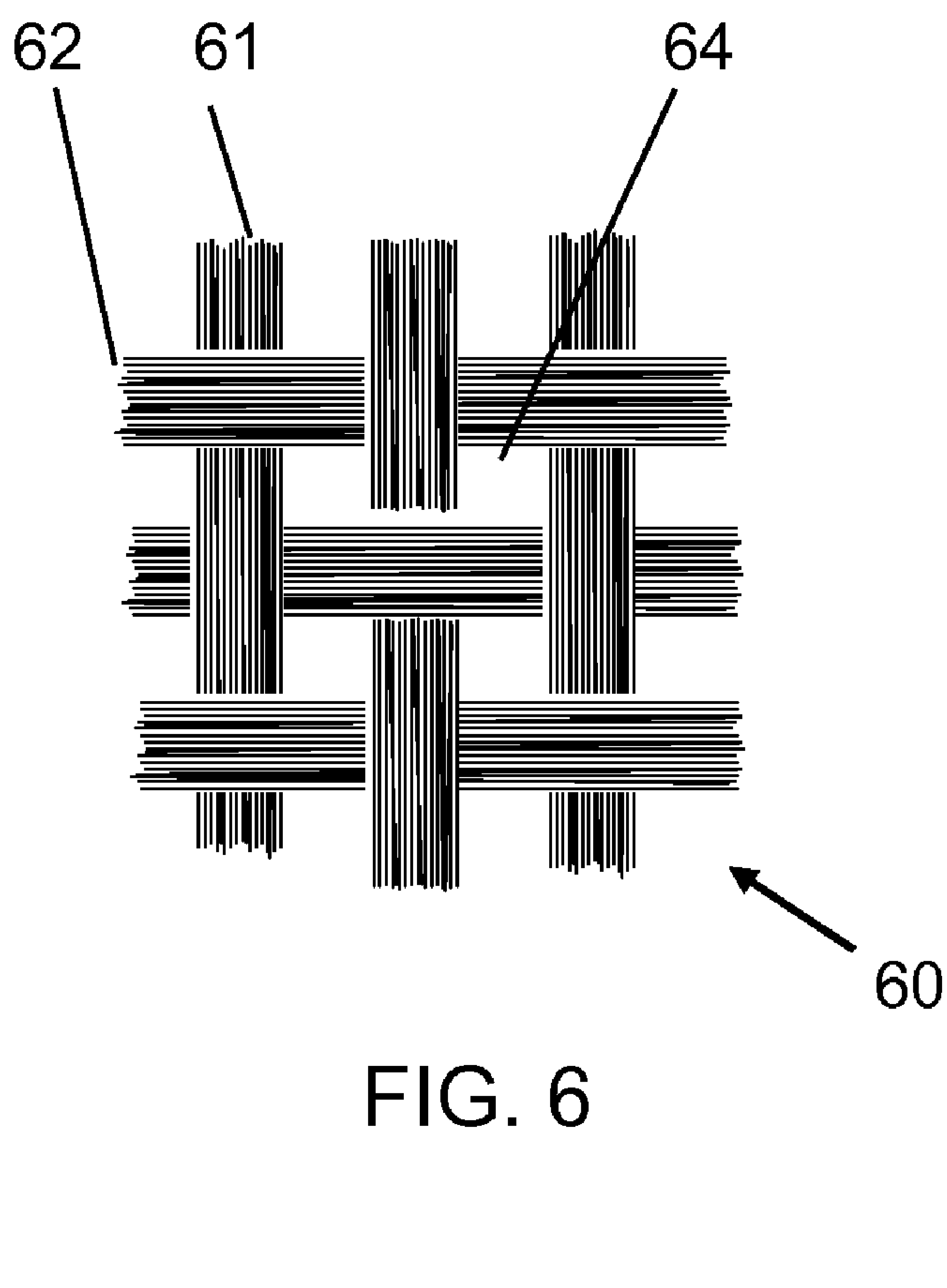



FIG. 6

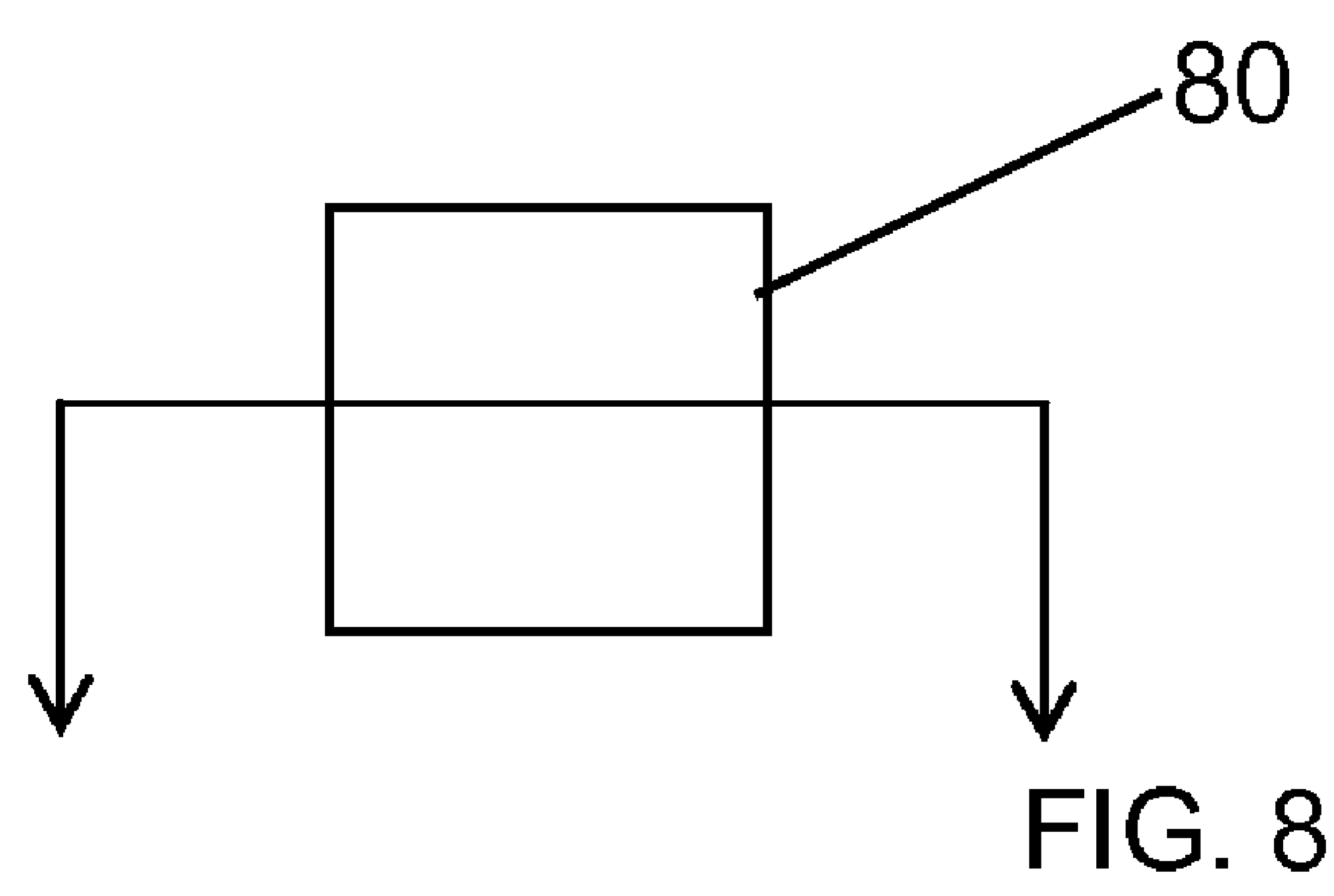



FIG. 7

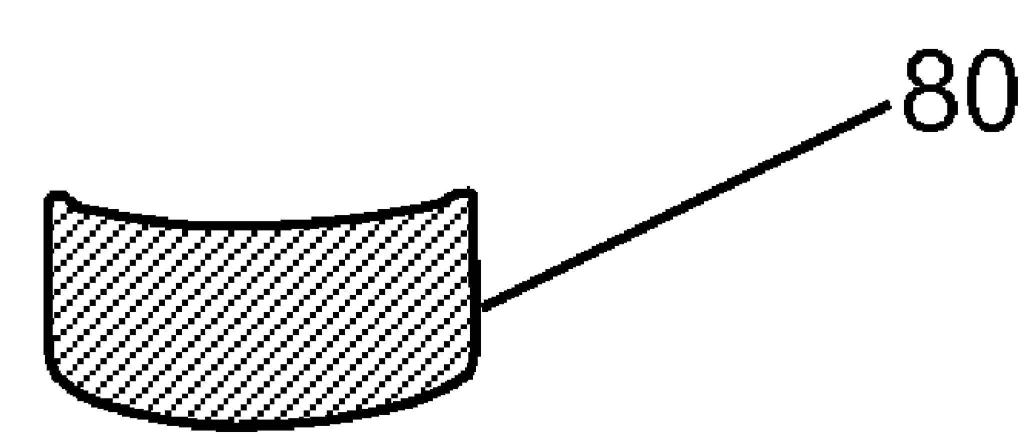



FIG. 8

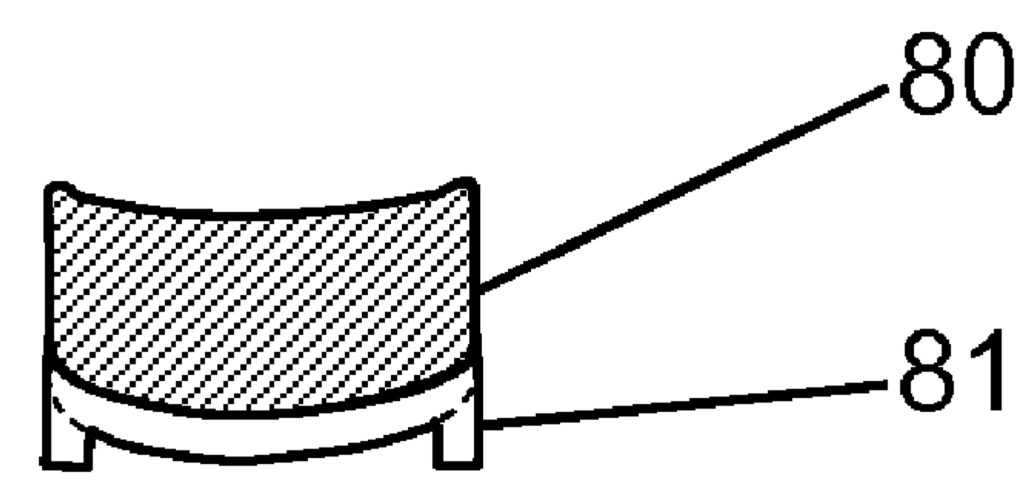



FIG. 9

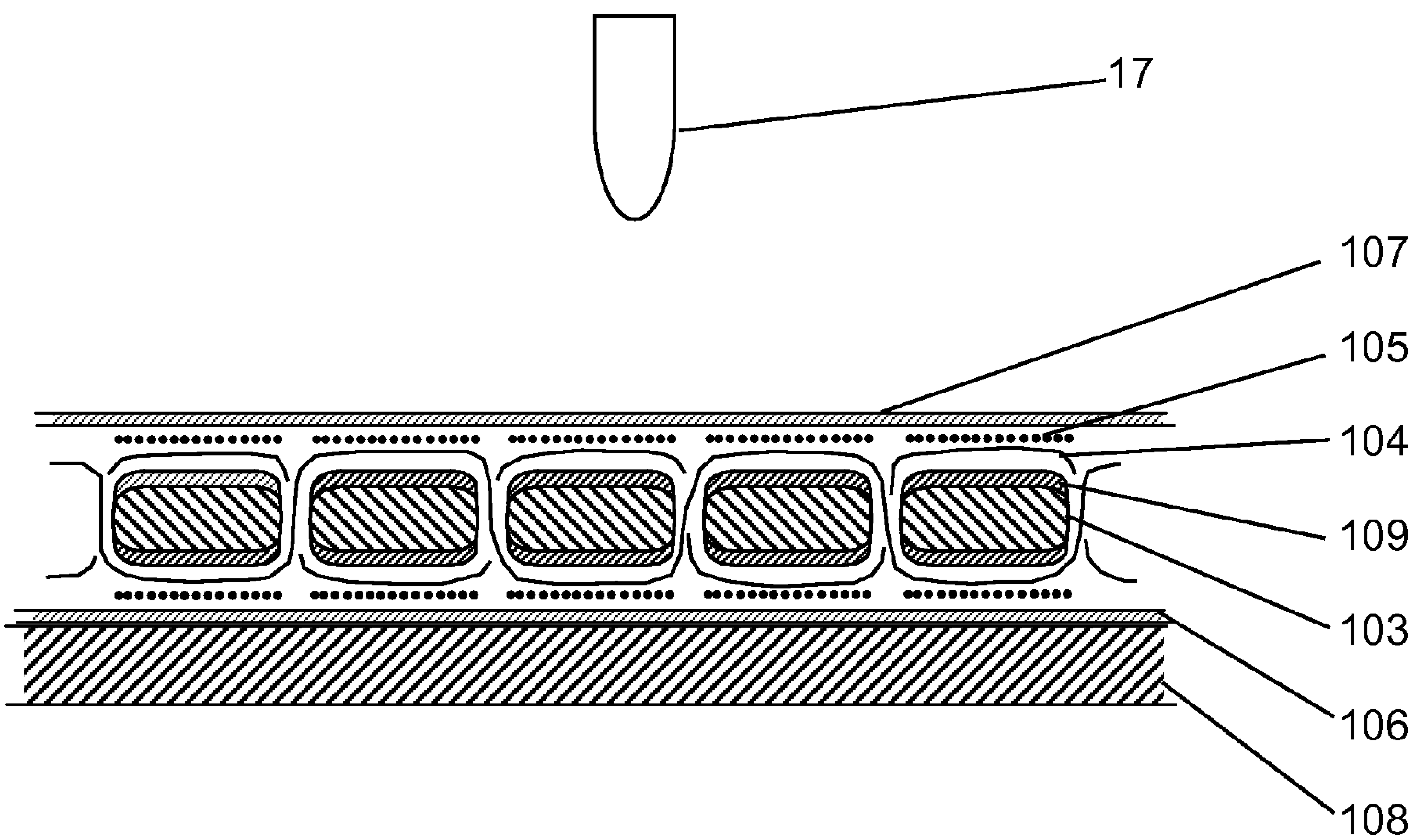



FIG. 10

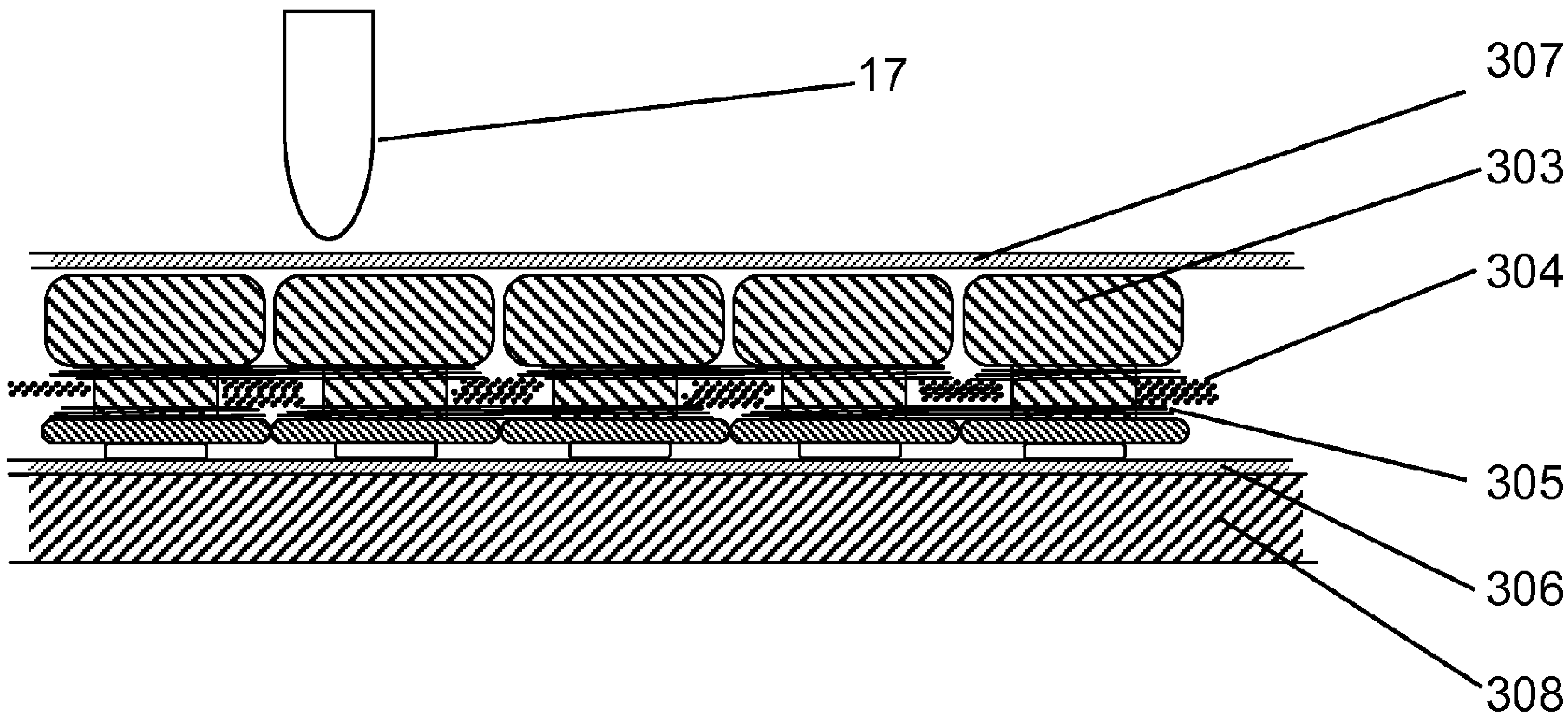



FIG. 11

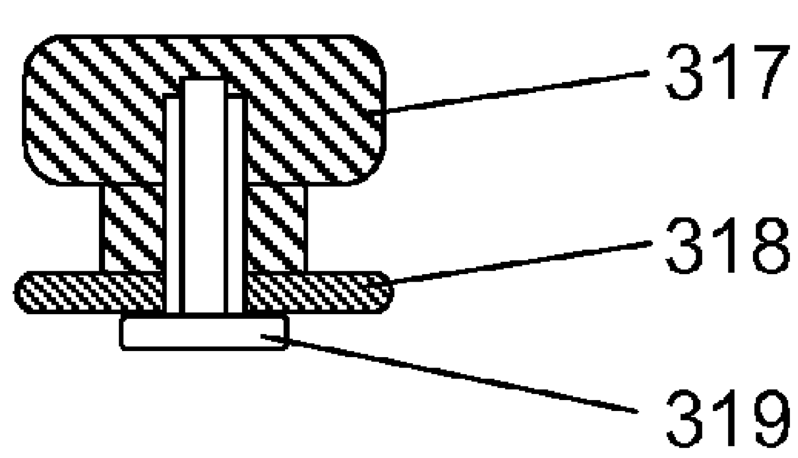



FIG. 12

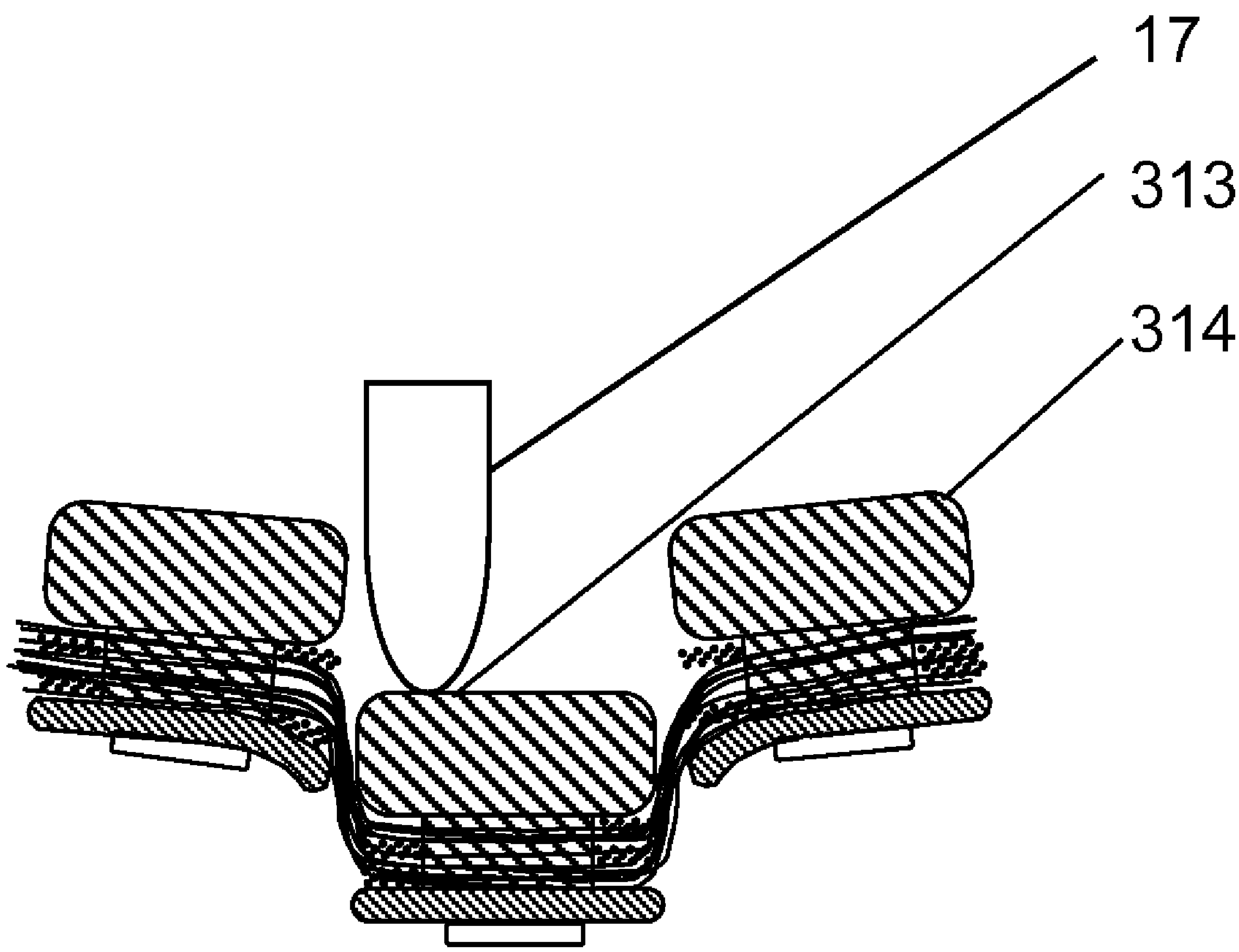



FIG. 13

# METHOD AND APPARATUS FOR PROTECTING AGAINST BALLISTIC PROJECTILES

## BACKGROUND—FIELD OF INVENTION

**[0001]** The present invention is in the field of protection of persons or property against kinetic missiles such as firearm bullets, specifically contemplated is application as ballistic body-armor (or "bullet-proof vests") and also the protection of vehicles, including aircraft, and sensitive property such as communications equipment by providing flexible, light-weight protection against small arms and high-velocity rifle bullets.

## BACKGROUND—DESCRIPTION OF PRIOR ART

**[0002]** The mechanical challenges of arresting a high velocity projectile have focused prior and current art on materials with extreme mechanical properties. The practical problem is that the kinetic energy of a high velocity ballistic projectile is high while the cross section is small, resulting in a very high specific energy upon initial impact. Under such conditions, inertial forces typically dominate over mechanical properties and the projectile will tend to punch through a layer of material as the localized stresses greatly exceed the shear, compressive and tensile strengths for most materials. As a result current art is typically focused on materials such as strong metals, ceramics and ballistic polymer fibers which possess extreme mechanical properties, such as shear modulus, tensile modules, and fracture toughness. Current art focuses on placing sufficient amount of suitable material in the path of the projectile, so that the projectile is stopped. In some cases the art (Yeshuin et al) uses masses of glass or ceramic to deflect the path of the projectile so that it may be more easily arrested by ballistic fibers.

**[0003]** Ballistic protection or armor is typically one of three types: (i) solid material plate, (ii) layered ballistic fiber, or (iii) composite construction of hard materials supported by ballistic fiber. Each of these types has certain practical advantages and practical limitations.

**[0004]** Solid plate material is typically either a tough metal plate, or a hard ceramic plate, or a combination of metal, ceramic and sometimes composite fiber or solid polymer. Ceramic materials used as ballistic protective plates include titanium nitride, aluminum nitride, silicon carbide. Metals used include hard or ductile steels, hard (e.g. type 7075-T6) or ductile (e.g. type 5053) aluminum alloys and titanium. Solid plate designs are inflexible, and often heavy. Composite materials include glass or polyaramide fibers in epoxy resin. Solid polymer materials include ultra-high molecular weight polyethylene (UHMW PE). Information on these materials and their application to ballistic armor is widely available in the literature, though specific details are not always accessible due to proprietary nature of some materials. Example information on commercial ceramic materials for ballistic use has been summarized in "Improving Ceramic Armor Performance" January 2006, Cerradyne Ltd. An overview of U.S. and international metallic armor materials and specifications can be found at web page www.niistali.ru/science/br_stali_en.htm dated May 2007.

**[0005]** Practical use in protective body armor of solid plate material is commonly restricted to small critical protection areas, such as over the heart, used in combination with layered ballistic fiber vests. "Selection and Application Guide to Personal Body Armor" NIJ Guide 100-01, U.S. Dept of Justice, November 2001, provides historical background on various types of protective body armor (ballistic and non-ballistic) and guide to selection and use of personal protective armor of various types.

**[0006]** Ballistic fiber is a descriptive term applied to a number of polymer fibers which have mechanical characteristics suited to projectile deceleration and capture. Ballistic fiber strands can be built up into cloths by weaving or into felts. Ballistic fibers are typically either polyamide or polyethylene polymers. Examples are of Kevlar 129 and Kevlar 49 (both Trade Mark, E.I. Du Pont), Spectra 900 and Spectra 1000 (both Trade Mark, Allied Chemicals) and Dyneema (Trade Mark DFS Industries, Holland). The currently commercially available ballistic fibers are well known to one practiced in the art. The application of Kevlar to bullet proof body armor is widely described in United States patents, including U.S. Pat. No. 5,392,686, which describes an extendable flexible bullet proof shield for persons constructed using ballistic fiber material and a transparent solid plastic bullet proof material, U.S. Pat. No. 5,370,035, which describes a bullet proof curtain for use in vehicles constructed using ballistic fiber material, and the like. Further description is also provided in publications by fiber manufacturers, such as, "Kevlar Tech Guide" DuPont, April 2000. U.S. Pat. No. 6,705,197, Neal et al, describes a bullet proof vest comprising an outer layer of woven polyaramide fiber and a second, inner layer of polyethylene woven fiber, which more effectively protects against a bullet by utilizing the respective mechanical properties of polyaramide and polyethylene layers appropriate to the first and later stages of bullet retardation by the double layer material. Recent developments in fiber weaving have made cloths with three dimensional weaves available, which can be formed into composite materials. U.S. Pat. No. 5,085,252, Mohammed M et al "Method of Forming Variable Cross-Sectional Shaped Three Dimensional Fabrics" described a way of constructing such materials. Application of three dimensional weave composite fiber materials to ballistic armor is described in "Ballistic Resistance of 2D and 3D Woven Sandwich Composites" Journal of Sandwich Structures and Materials 2007; 9; 283 Grogan et al, referenced below. Transonite™ (Martin Marietta, Inc) is material which incorporates layers and trusses of three dimensional weave fiber composite around an expanded foam core to provide a lightweight blast resistant panels for buildings and structures.

**[0007]** Ballistic fiber vests are generally effective at providing protection against standard hand gun bullets, but are not effective protection against high velocity rifle bullets. For this reason, portions of solid material plates, so called "trauma plates" are normally added as an outer layer to provide additional protection to vital organs.

**[0008]** Various designs for bullet proof materials have been proposed based on combining smaller pieces of solid material with one or more layers of woven ballistic fiber in order to provide a flexible garment which benefits from the ballistic protection properties of both solid materials and the layered ballistic fiber. In some designs, a final inner layer of relatively soft elastomeric, energy absorbing material is used as a final layer where penetration protection has been provided by outer layers.

**[0009]** "Ballistic Resistance of 2D and 3D Woven Sandwich Composites" Journal of Sandwich Structures and Materials 2007; 9; 283 Grogan et al, further describes a ballistic protective armor comprising layers of compliant ballistic woven fiber and a layer of ceramic, or other hard strike face impact resisting material. The design thus explained further utilizes a multidimensional weave ("3D weave") ballistic fabric to improve the mechanical properties of the fabric. It is noted here that in contrast to the present invention, the function of the ceramic layer and the fiber layers thus described are essentially separate and or sequential, and furthermore the concept and function of kinetic mass retardation is not integral to that design.

**[0010]** U.S. Pat. No. 4,483,020, Dunn describes a bullet proof vest comprising interlocking plates together with layer of ballistic fiber cloth which provides a flexible vest construction.

**[0011]** U.S. Pat. No. 4,660,223, Fritch et al, describes a flexible protective garment constructed of titanium plates of area ranging from approximately 5.08 to 15.24 centimeters (2 inches to 6 inches) square and approximately 1 mm thick, bonded into a several layers of Kevlar fiber felt. This design is suited to defeating knife attacks and low energy bullets.

**[0012]** U.S. Pat. No. 5,134,725 Yeshrun et al, describes a flexible ballistic protective garment material constructed using small axi-symmetrical or centro-symmetrical bodies of glass or ceramic material together with one or more layers of ballistic fiber material, the function of the bodies being to deflect an incoming ballistic projectile so that it may be retarded by the ballistic fiber layer(s). The bodies of glass or ceramic are not supported within or integral to, an individual layer of ballistic fiber, nor are successive layers of the glass ceramic bodies separated by a layer of ballistic fibers.

**[0013]** U.S. Pat. No. 5,200,256, Dunbar describes a layered material construction comprising an outer, i.e. first impacted, layer of woven ballistic fiber impregnated with resin, followed by one or more intermediate layer of metal mesh, typically stainless steel, followed by a final layer of elastomeric foam material. The compound material provides lightweight ballistic protection for vehicles and aircraft.

**[0014]** U.S. Pat. No. 6,745,661, Neal et al, and U.S. Pat. No. 6,035,438 Neal et al, both describe a bullet proof vest constructed with an overlapping two dimensional array of compound ceramic and fiber discs, enclosed on either side by a layer of woven ballistic fiber, and backed by a further layer of ballistic fiber, followed by a further layer of soft woven ballistic fiber. The possibility of a multiplicity of similarly constructed layers is also disclosed.

**[0015]** The disclosure of each of the above mentioned United States patents is hereby incorporated by reference into this specification. These patents, together with the commercial references mentioned provide an overview of the prior and current art in small arms ballistic protection, including current practice in flexible and solid body designs for ballistic body armor.

Standards for Ballistic Protection.

**[0016]** Performance standards for ballistic protection are issued by various national and international agencies, including CRISAT, which is short for Collaborative Research Into Small Arms Technology, and is the EU-Nato standard in the manufacture of military equipment. The CRISAT Target is defined as a 1.6 mm Titanium plate supplemented by 20 layers of Kevlar. Weapons are measured against this standard in respect to its ability to penetrate it, and protective equipment is manufactured to adhere to it. Both the Underwriters Laboratories (UL Standard 752) and the United States National Institute of Justice (NIJ Standard 0101.04) have specific performance standards for bullet resistant vests used by law enforcement. These standards relate to the type of projectile to be blocked, and the amount of deformation allowable at the protected, or inside, side of the vest.

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| | | |
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## OBJECTS AND ADVANTAGES

**[0017]** The method of the present invention differs from prior art first in that a mass of tough material is used not in an attempt to directly block the projectile, nor to deflect it, but to couple mass to it, and thus slow it down by transfer of kinetic energy. This process then may be repeated in sequential stages, whereby additional mass is coupled progressively to the projectile, causing more and more kinetic energy to be transferred from it.

**[0018]** Second, the method provides a method of restraining the motion of the coupled masses and projectiles, using a network of fibers. The fibers are constructed into a three dimensional arrangement which allows the fibers to elongate elastically or plastically under favorable mechanical conditions so that they exert a progressive restraining force.

**[0019]** The nature of the restraining force is also of novel design in the present invention, being of two combined sources. First, the fibers stretch and provide restraint due to their own tensile modulus. Second the fibers couple force to surrounding adjacent masses, causing these masses also to experience acceleration, and thereby coupling kinetic energy from the projectile to surrounding masses which are themselves not necessarily directly impacted by the projectile.

**[0020]** The manner in which energy is coupled to adjacent masses is by tensile loading of the fibers substantially in the direction of the fibers longitudinal axis and substantially in the direction of the projectile prior to impact. These features are novel and are an important advance in ballistic protection because the design of the invention is such that the energy transfer and tensile loading can be accomplished well with the material properties of currently available materials and still be able to defeat hard, high velocity ballistic projectiles, which are capable of lethally penetrating many types of conventional "bullet proof vests".

**[0021]** The design also provides an intrinsically flexible material, which is suitable for bullet proof vests; it does not have to be further modified, or made up into separate small pieces joined together in order to be flexible. The resulting accomplishment is exemplified in the embodiments described below, namely flexible, light bullet proof vest capable of defeating high velocity rifle bullets at close range. The composite armor can be formed into complex shapes and thus made into protective clothing that can protect much of the body, not only just the vital organs.

**[0022]** The second embodiment described herein is particularly straightforward to manufacture and utilizes readily available materials, and therefore could be deployed to serving armed forces economically and quickly. The method of the invention is also scalable, and the size and dimensions of the internal components can be adjusted to defeat heavy caliber projectile or artillery shells, however, such embodiments would not reasonably qualify as light weight for use in personal body armor such as a bullet proof vest.

**[0023]** Several variations to the three primary embodiments are described which incorporate additional novel construction arrangements and additional methodologies for dissipating kinetic energy from the projectile to the mass and fiber framework of the composite armor material by incorporating elastomeric and plastic deformation processes and dynamic rearrangement of the material 3D structure progressively under ballistic loading to facilitate ease of manufacturing and production of high performance armor on a volume basis.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0024]** The patent or application file contains reference to following figures:

**[0025]** FIG. **1** shows a cross section through five layers of a bulletproof vest.

**[0026]** FIG. **2** shows front view of an assembled bullet proof vest showing the front (chest) protection, the left and the right shoulder protection and the Velcro™ straps used to assemble the vest.

**[0027]** FIG. **3** shows a layer of an unassembled bullet proof vest in part; the front (chest) piece and one shoulder piece, unassembled, and flat.

**[0028]** FIG. **4** shows a cross section through one ballistic defeating layer of the vest of the first embodiment.

**[0029]** FIG. **5** shows the arrangement and construction of a grid of tubes used in the construction of the first embodiment of the invention.

**[0030]** FIG. **6** shows the arrangement and layout of x and y direction fibers prior to assembly on to the tubular grid of the first embodiment.

**[0031]** FIG. **7** shows a plan view (in the plane of the composite armor material of the vest) of one mass used in the first embodiment.

**[0032]** FIG. **8** shows a cross section through one mass used in the first embodiment.

**[0033]** FIG. **9** shows a cross section through one mass used in the first embodiment located on a protective spacer washer.

**[0034]** FIG. **10** shows a cross section through one ballistic retarding layer of the second embodiment.

**[0035]** FIG. **11** shows a cross section through one ballistic retarding layer of the third embodiment.

**[0036]** FIG. **12** shows a cross section through one mass of the third embodiment and its sub assemblies.

**[0037]** FIG. **13** shows a cross section illustration of nominal deformation and geometric rearrangement under ballistic loading in the third embodiment.

## DETAILED DESCRIPTION

**[0038]** The invention provides for a composite material that protects against specific ballistic threats, and is flexible and relatively light in weight. The invention can be fashioned into protective body armor ("bullet-proof vests"), and other protective coverings, including supplementary protection for conventional bullet proof vests. ("Bullet-proof vest" is a commonly used term for ballistic body armor, and in many cases it is a misnomer, because many such vests do not in fact provide protection against rifle fire. Nevertheless, the term is common usage and the concept it conveys is well understood, so it is used here with that understanding.)

**[0039]** Three practical embodiments of the invention will now be described, which explain its construction, method of operation and unique features.

### The First Embodiment

**[0040]** The first embodiment is a flexible bullet proof vest which provides the wearer protection from high velocity, high power rifle fire to within the inner surface deflection limit of 4.4 centimeters (1.73 inches) specified by the United States National Institute of Justice (NIJ Standard 0101.04). By high velocity, high power rifle, we specifically consider the standard NATO 7.62×51 mm cartridge, which is a common threat in current warfare. This first embodiment of the invention is designed to protect to NIJ Standard 0101.04 Type III which protects against 7.62 mm Full Metal Jacketed (FMJ) bullets (U.S. Military designation M80), with nominal masses of 9.6 grams (148 grains) at a reference velocity of 847 meters/second (2780 ft/s). The concept of flexibility is important in bullet proof vests. A solid or stiff vest is extremely uncomfortable to a human user, and can result in the vest not being worn. Non-flexible vests exist, but tend to be constructed to provide minimal essential body coverage, and projectiles can enter though the shoulders and other unprotected areas and still reach vital organs. For reasonable comfort, a bullet proof vest needs to be able to flex about +/−30 degrees per foot of material length, plus is should allow the shoulders to rise and drop by 7.62 centimeters (3 inches).

### Construction of the First Embodiment

**[0041]** The bullet-proof vest of the first embodiment, hereinafter referred to as "vest", is constructed of five layers. A cross section through the layers is shown in FIG. **1**. An incoming bullet (**17**) is shown in FIG. **1** as a reference for the direction of anticipated threat. In the following, the terms "first" and "outer" shall refer to the side of the vest from which a bullet comes, i.e. the first impacted, and the term "inner" shall refer to the side closest to the wearer.

**[0042]** With reference to FIG. **1**, the first and outermost layer (**11**) is of medium weight polyester fabric, with conventional Velcro™ patches (**10**) sewn and bonded to it to facilitate attachment of accessories and to facilitate securing of the vest around the wearer. Layer (**11**), is incidental to the ballistic function of the vest. As an alternative to conventional polyester fabric a tough breathable waterproof fabric, such as conventional rip-stop Gortex™ could be used. Behind layer (**11**) are three similar layers: the second layer (**12**), the third layer (**13**), and the fourth layer (**14**), each of special composite material which have ballistic protection function, the detailed construction of which are described immediately below. The innermost fifth layer (**15**) is the layer closest to the vest wearer and is a "comfort layer", essentially incidental to the ballistic function of the vest. Layers **11-15** may be in direct contact with each other at some places and not in direct contact at other places in the vest, according to how the garment is flexed. Minimal separation of the layers is assured through the inclusion of thin elastomeric foam material.

**[0043]** The final assembled vest is depicted in FIG. **2**.

**[0044]** The construction of layer (**12**), is described in detail now. The construction of the other two ballistic function layers, (**13**) and (**14**), is substantially similar to the construction of this layer (**12**). Layer (**12**) is comprised of six sub-layers, as shown in FIG. **4**. The construction is described starting with the innermost sub-layer, i.e. that which is closest to the wearer.

**[0045]** The innermost sub-layer is 0.635 centimeter (0.25 inch) thick elastomeric foam sheet (**40**). This innermost sub-layer is actually added to the layer as a final step, after the assembly of the rest of the layer, which will now be described. A thin first substrate sub-layer (**41**) of high tensile ballistic fiber is constructed with an open weave. Spectra 900 is a suitable fiber, but others could be used, as could various weave directions or alternatively a low density unwoven felt. The weave is made with 650 Dernier (60 filament) fibers at a weave density of 4.72 per centimeter (12 per inch). Next a mesh sub-layer (**50**) is constructed of short pieces of metal tube as shown in FIG. **5**.

**[0046]** In FIG. **5**, the pieces of metal tube (**51**) are threaded onto a high tensile fiber (**52**) type Spectra 900™ 1600 Dernier and woven to form a regular square mesh. In this example embodiment the mesh grid spacing is 1.65 centimeters (0.65 inches) and the tubing (**51**) outside diameter is 0.3 centimeters (0.12 inches). The inner diameter of the tubing is 0.127 centimeters (0.05 inches), being sufficient to allow the strands of high tensile fiber (**52**) to pass through, but not large enough to compromise the diametric compression strength of the tube. The integrity of the tube under compression is important to the function of the vest, although some deformation in operation is acceptable. Metal has been specified for the tube, although other material which has high compressive strength and toughness, such as composites and ceramics, could be used. In this embodiment 310 annealed stainless steel tubing is used. The fibers which run though the tubes are pulled to low tension (20 to 50 N), but not slack, and tied off at the edges. The mesh is constructed to the desired shape and size of layer (**12**) as predetermined by the shape and size of the final assembled vest. During construction, the fibers are flexibly bonded in place to the inside of the tubes by conventional adhesive such as room temperature vulcanizing silicone adhesive using a small amount of adhesive inside a piece of tube approximately every 5.08 centimeters (2 inches). This bonding is incidental to the ballistic function of the vest, and provides ease in handling the material during assembly. The flexible bond allows the fibers to stretch under stress. The resulting mesh is mildly flexible but retains its essentially square matrix structure when handled.

**[0047]** Next, on top of the tubular mesh, i.e. towards the outside of the vest, is placed a sub-layer of 90 degree woven ballistic fiber cloth (**60**) shown in FIG. **6**. Strand orientations other than 90 degrees could be used; 90 degrees is specified here for ease of manufacture. The 90 degree weave is not a complete weave, there are holes or void spaces as shown in FIG. **6**. The runs of x-axis fibers (**62**) are each 1.27 centimeters (0.5 inches) wide and then separated by a space of 0.635 centimeters (0.25 inches). The runs of y-axis fibers (**61**) are also each 1.27 centimeters (0.5 inches) wide and then separated by a space of 0.635 centimeters (0.25 inches). The resulting cloth (**60**) is a square woven cloth with holes (**64**) of size 0.635×0.635 centimeters (0.25×0.25 inches) spaced apart by 1.27 centimeters (0.5 inches) in both x and y directions. The cloth (**60**) is laid over the mesh (**50**) and pressed into it, so that the holes (**64**) line up with the intersection joints (**63**) of the mesh, and then the weave of the cloth is depressed into each void in the mesh.

**[0048]** On top of the cloth are placed a plurality of small metal discs (**80**), arranged in a regular square matrix layout with one disc located at each of the voids of the mesh (**50**). The detail of each disc is shown in plan view in FIG. **7** and cross section in FIG. **8**. The discs are square with rounded corners of size 1.27 centimeters (0.50 inches) square and 0.81 centimeters (0.32 inches) thick. Although square discs in a regular square matrix have been specified, other tessellating shapes and arrangements, such as hexagonal discs in a 120 degree arrangement are viable alternatives, with corresponding adjustment in mesh (**50**) layout and cloth (**60**) weave, and would alter the mechanical properties of the material if desired. The innerside of each disc (**80**), which is closest to the cloth (**60**), is radiused with a convex radius of 3.56 centimeters (1.4 inches) and further rounded edges. The outer side is radiused concavely, so the thickness of the disc is roughly uniform across its area.

**[0049]** The discs are CNC milled from sheet metal and inspected and deburred and finished by hand to remove any rough edges. The rounded edges are important and prevent the disc cutting the fibers of the cloth against the mesh. Metal has been specified for the disc material, although other materials which have high compressive and ballistic shear strength and toughness, such as composites and ceramics, could be used. The selection of the material of the disc is important to the function of the vest. This embodiment uses conventional 7475-T6 aluminum which has a density of 2.81 g/cc (0.102 lbs/cu.in.). If the density of the disc material is high, and the anticipated projectile mass is low, then the spacing of the mesh needs to be reduced, otherwise the disc becomes too thin and will puncture or shear on impact. The thickness of the disc is determined by the mass and energy of the projectile(s) to be blocked and by the density of the disc and its material properties, as specified in the operation of the vest below.

**[0050]** In a variation to this embodiment, shown in FIG. **9**, a 0.2 centimeter (0.08 inch) thick plastic spacer (**81**) is between the cloth (**60**) and each disc (**80**). The spacer (**81**) has the outer face conformal to the disc and the inner face smooth and rounded except that each corner is thickened forming a small post at each corner which serves to help keep the fibers of the cloth (**60**) in place. The spacer provides lubrication for the fibers to slide over the disc surface and it also provides compliant compressive cushion during ballistic loading.

**[0051]** On top of the discs (**80**) is a second thin substrate sub-layer (**90**) identical to the first substrate sub-layer (**41**). It is constructed of high tensile ballistic fiber and with an open weave. Spectra 900 is a suitable fiber, but others could be used. The weave is made with bundles of 650 Dernier fibers at 4.72 per centimeter (12 per inch).

**[0052]** The six sub-layers of the ballistic layer (**12**) are assembled together as follows: the innermost substrate sub-layer (**41**), the metal mesh sub-layer (**50**), the cloth sub-layer (**60**), the discs (**80**) and final substrate sub-layer (**90**) are bonded and loosely sewn together. The bonding is done with conventional UV-6800™ (Eclectic Products Inc., LA) flexible adhesive. The purpose of the bonding and sewing is to keep the sub-layers of layer together and preserve the general arrangement of the components but maintain general flexibility. The adhesive allows the fibers to slide over the disc and mesh surfaces during ballistic loading of the armor, but will retain its bond integrity during general handling and normal wear so as to hold the garment together for day to day usage i.e. when not ballistically loaded. The adhesive is applied to the outer and inner faces of the discs (**80**), wetting through the fibers of the cloth (**60**) and the substrate layers (**41**) and (**90**). The sewing is done using Spectra 900 1200 Dernier 10 fiber bundles and one loop sewn through all the sub-layers at each node of the mesh and tied off, binding the entire layer together. A practical alternative to adhesive and sewing would be to encapsulate the whole layer in room temperature vulcanizing silicone adhesive in a vacuum environment to extract trapped air or encapsulating the sub-layers in a two-component polymer foam in a mold. The result is a flexible but tough, mechanically stable, layer with a two-dimensional array of metal discs supported on a cradle of high tensile fiber which is in turn supported on metal mesh.

**[0053]** The overall size and shape of each layer is determined according to the need. In this case the size and approximate shape of the outermost ballistic layer for a medium size vest as shown in FIG. **3**, which shows only the front piece (**30**) and the left shoulder-neck piece (**31**). The back piece is similar to the front piece, and the right shoulder-neck piece is a mirror image of the left. The cloth (**60**) is constructed oversize and then trimmed after assembly of the aforementioned sub-layers thus far to approximately 5.08 centimeters (2 inches) oversize with respect to the plan size of the mesh (**50**). Any loose fibers (**61**) or (**62**) are removed from the edge and the extended fiber ends are folded under the mesh (**50**) and bonded with UV-6000™ on to the weave of fibers (**61**) and (**62**). This finishes the ends of the fibers in the ballistic layer. Finally the assembled sub-layers just described at bonded to a sheet of 0.635 centimeter (0.25 inch) thick flexible elastomeric foam (**40**), type K-Flex LS S2S™ (Noel Group, LLC, NC) or similar alternative, and bonded to it using K-Flex 720 LVOC™ (Noel Group, LLC, NC) adhesive. Note that this elastomeric foam is not sewn together with the other sub-layers of the ballistic layer.

**[0054]** There are two more similarly constructed ballistic layers, i.e. a total of three, in the vest. To reduce the weight, increase flexibility and provide less abrupt edges when assembled together, the three ballistic layers are not constructed of exactly identical size and shape. Also, different parts of the vest are subject to different levels of threat and some areas of the vest overlap with other parts when the whole is assembled, and these factors are considered in determining the final shape and extent of each ballistic layer, so that the overall vest performance and function are optimized.

**[0055]** In this embodiment, the first ballistic layer (**12**) is larger in plan (size) than the next layer (**14**), which is larger than the next layer (**15**). For ease of manufacture, the construction of the three ballistic layers can be of identical construction. However, for ballistic performance it is desirable to change the dimensions of the mesh and discs for each specific layer, because the projectile slows and adds mass as it passes though each layer. For this embodiment, the disc size for layer (**12**) has been specified as 1.27 centimeters square (0.5 inches square). The disc size for layer (**13**) is 1.65 centimeters square (0.65 inches square), and the disc size for layer (**14**) is 2.54 centimeters square (1.0 inches square). The mesh size of each layer is increased accordingly by using longer sections of the tube (**51**), so that the mesh size is 0.381 centimeters (0.15 inches) larger than the disc size in each layer. All of the discs in this embodiment are 0.81 centimeters (0.32 inches) thick. The fact that the disc thicknesses for each of the three ballistic layers has been selected to be the same is a matter of convenience of manufacture, and will not be achievable in many other configurations or embodiments of the invention. The disc properties, including thickness must be calculated for each layer and the specifically contemplated ballistic loading, according to the mass, velocity and cross sectional area of the impacting projectile. For layer (**13**), the expected impacting projectile is not the bullet, but several possible combinations of bullet and disc from layer (**12**). Similarly, for layer (**14**), the expected impacting projectile is several possible combinations of bullet, discs from layer (**13**) and discs from layer (**12**). However, there is also possibility the bullet will impact in such a way as to miss a disc at the second layer (**12**). Therefore the ballistic characteristics of the discs in the third layer (**13**) cannot be too different from that of layer (**12**) and must be suitable as providing first line defense if the bullet squeezes past the discs in layer (**12**).

**[0056]** The innermost layer of the vest, layer (**15**), is medium weight cotton fabric cross hatched sewn at 5.08 centimeter (2 inch) spacing on to 0.51 centimeter (0.2 inch) thick polyester quilting; the cotton fabric is closest to the wearer. The purpose of layer (**15**) is largely oriented towards user comfort, and it is essentially incidental to the ballistic function of the vest, except that it provides a small amount of additional separation of the ballistic layers from the wearer, which is always favorable in reducing deformation of the wearer's body upon impact by a bullet, as the vest structure itself deforms in the course of retarding and defeating a projectile.

**[0057]** The assembly of the layers to form the vest is described below. Only the assembly of the front piece of the vest is described, as the assembly of the back and shoulder pieces are carried out in similar fashion. Other pieces of body or property protective armor could also be similarly assembled using the method described; the plan shape and layout would need to be adjusted according to the application.

**[0058]** The three ballistic layers and outermost fabric layer of the front piece of the vest are formed into shape around a mannequin torso of appropriate size and first bonded together using three 5.08 centimeter (2 inch) wide stripes of UV-6800™ between each pair of layers as follows: first the fourth layer (**14**) is placed on the mannequin and a vertical stripe of adhesive run down the center of the chest and another stripe down from the shoulder line on either side. It is easier if the mannequin is placed on its back for this process. Then the third layer (**13**) is placed on top of layer (**14**) in the correct position. Next adhesives stripes are placed on the layer (**13**) and the second layer (**12**) placed on top of it. Next adhesives stripes are placed on layer (**12**) and the first layer (**11**) placed on top of it. When the adhesive has dried, the bonded-together layers can be handled for further assembly. The three ballistic layers and outermost layer are then sewn together at a few points using 650 Dernier Spectra 900 fiber; specifically along the centers of the vertical adhesive stripes, sewn at 7.62 centimeter (3 inch) spacing. Sewing is effected by carefully threading the needle though the mesh and disc layers from the inside and the needle is passed carefully through the composite material. At each point, eight loops of fiber are sewn and tied off.

**[0059]** Next the innermost layer (**15**) is placed under the other layers and the whole is loosely sewn together around the edges approximately 1.27 centimeters (0.5 inches) from the outer edge using 650 Dernier Spectra 900 fiber. As with the previously mentioned sewing, the pathway for the needle has to be carefully passed through the multiple layers from the inside. The outer seam is then taped to 1.91 centimeters (0.75) inches, i.e. with 3.81 centimeter (1.5 inch) tape and the tape bonded in place with UV-6800™ adhesive.

**[0060]** The design of the vest is such that the material from the front and back pieces overlap slightly at the side seams and are fastened by conventional Velcro™, which allows adjustment of fit. The Velcro™ panels (**10**), are sewn onto layer (**11**) before assembly of the vest. In addition to the conventional "A" shape vest, FIG. **2** (**20**), comprised of a front piece and a back piece, there is a separate two-part piece which protects the shoulders and neck, and allows freedom of movement of the shoulders. This additional shoulder piece is shown in FIG. **2** (**21**) and (**22**) and the flat plan shape of its outermost ballistic layer is shown (left side only) in FIG. **3** (**31**). It is attached to the vest "A" body (**20**) by Velcro™ elastic straps (**23**) and (**24**) which pass over each shoulder and the left and right pieces are flexibly joined at the neck by Velcro™ (**25**).

Operation of the Vest

**[0061]** We will consider the normal impact on the vest of a high power high velocity rifle bullet at very close range, specifically a NATO 7.62 mm Full Metal Jacketed (FMJ) bullet with mass of 9.6 grams (148 grain) at an unretarded reference velocity of 847 m/s (2780 ft/s).

**[0062]** The bullet passes unaffected through the first layer (**11**) in FIG. **1**, which is incidental to the ballistic function of the vest. The bullet then contacts the first ballistic layer (**12**). We shall assume for now that it impacts on a disc. This assumption will be addressed later. In an ideal, lossless interaction, the bullet and disc would rebound with a relative separation velocity equal in magnitude but opposite in direction to that prior to impact, in accordance with the laws of conservation of momentum and conservation of energy. However, in practice, the impact is not lossless. Energy is dissipated in several manners, including the deformation of the bullet, deformation of the disc and deformation of the structure supporting the disc in space. Furthermore, the impact is not an instantaneous event, but in practice it is a progressive event, during which both the bullet and the disc move, substantially in the original direction of the bullet prior to impact. During the event the disc is deforming and accelerating, and the bullet is deforming and decelerating. The bullet/disc interaction is complex and the outermost, first impacted, surface of the disc first accelerates, and then decelerates. Provided that the bullet does not puncture and entirely pass though the disc, it is reasonable to assume that bullet and disc move forward together for at least a short distance after the initial impact. The criterion that the bullet does not puncture and pass through the disc is met if the disc is designed correctly. Specifically the disc should be light, so there are no significant inertial forces restraining it, it should be of high shear strength and toughness under ballistic loading, which is dependent on the material selection and thickness to area ratio. Because of the speed of ballistic interactions, normal mechanical properties of materials do not apply and special ballistic material properties need to be specifically considered in material selection and component design, as would be known to one practiced in the art. With this in mind it is a relatively straight forward computation for one skilled in the art to determine what plan dimension (and therefore mass) of disc of a given thickness and material would cause it to be punctured by a given projectile if that plan dimension were to be exceeded. The maximum disc size and the mass that would not be punctured for a given impacting projectile could then be correspondingly calculated. The ballistic design of specific projectiles also has bearing on disc puncture and penetration and would need to be factored into the calculation, and again this would be well recognized and understood by one skilled in the art. Accordingly, the optimal mass and dimensions of a disc could be calculated and selected to defeat a selected projectile type or range of projectile types for a given configuration of armor to be constructed.

**[0063]** In addition to the deformation of the bullet and disc, the structure supporting the disc also deforms and moves. This is central to the operation of the vest. Specifically the fibers (**61**) and (**62**) of the cloth (**60**) will be in tension as a result of the motion of the disc (**80**). The fibers will be restrained by their path around the mesh (**50**) and under adjacent discs, and the tension will cause the mesh to move or deform, also in the direction of the bullet, or the adjacent discs to move in the opposite direction to the bullet, or both, or the mesh and adjacent discs to move in the direction of the bullet. Which of these happens depends on the specific nature of the bullet impact, its point of impact and direction. However, the effect in operation of the vest is the same in each case: namely the fibers (**61**) and (**62**) will be in tension due to the movement of the disc (**80**) and will be restrained by inertial forces of the surrounding mesh and discs. There is a further beneficial effect of this process which is to add effective mass to the bullet and disc pair, further decelerating the pair due to conservation of momentum by coupling mass through the fibers in tension to some of the adjacent discs and tubes.

**[0064]** In this specific embodiment, the total mass of one disc (**80**) and four tubes (**51**) of the mesh (**50**) of layer (**12**) is designed to be 7 grams, which is equal to 73% of the mass of an M80 bullet. This has been calculated to provide sufficient retardation of a range of threats, equivalent to M80 bullets or lesser projectiles, including for example NATO 5.56 mm cartridge and various handgun cartridges, as applied to the outer layer of a multi layer vest. The number and nature of the fibers (**61**) and (**62**) are calculated so as to strain elastically under the load of the moving bullet and disc pair, but not to rupture. (Obviously damage will occur around the impact zone and rupture will occur locally thereabouts as a result.) Plastic deformation also may occur, as would progressive rupture when using a combination of dissimilar fibers in the cloth (**60**). If the tensile stiffness of the cloth (**60**) is too great, the effect will be to directly couple a large effective mass to the disc (**80**), in which case it will not accelerate freely on impact and will be more susceptible to being punctured by the bullet. Therefore, the number and nature of fibers (**61**) and (**62**) in the cloth (**60**) is also calculated to be sufficiently compliant to allow the bullet and disc pair to move though the mesh. The elastic, or plastic, elongation of the fibers (**61**) and (**62**) in tension is central to the function of the invention. Specifically, the construction of the ballistic layers (**12**), (**13**) and (**14**), arranges the fibers (**61**) and (**62**) so that they elongate in tension substantially in the direction of original travel of the bullet. This arrangement is advantageous over other ballistic fiber fabrics, where the bullet impact is substantially normal to the direction of the fibers and the fibers are first subject to lateral compression and shear loading and the mechanical advantage of the tensile strength of the fibers is rarely achieved. Another advantage of the method described here is that the fibers are buffered from contact with the actual bullet by the disc (**80**) and the fibers contact the smooth surfaces of the mesh tubes (**51**) and the discs (**80**) under load, which is further supplemented in the variation shown in FIG. **9** by the compressing and lubricating spacer (**81**).

**[0065]** The bullet and disc pair will continue to be decelerated by the fibers (**61**) and (**62**) and the mass coupled by the fibers, which will typically be part of the mesh, until they contact the next layer of the vest, which is the second ballistic layer (**13**). This occurs after the bullet and disc pair have traveled a distance of 0.635 centimeters (0.25 inches) or more if there is separation between the layers due to folding, for example. At this point, depending on the exact bullet type, trajectory, angle of incidence, etc. the velocity of the bullet disc pair at the disc leading face will be of the order of 60 percent of the initial bullet velocity. Depending on the material of the bullet, the rear of the bullet will still be traveling with slightly higher velocity and the bullet will still be deforming. The deceleration from impact velocity is due to the combined effects of adding mass and the tensile restraint of the fibers (**61**) and (**62**) and the energy of deformation of the various components including the bullet itself. The bullet and disc pair now impact a disc from layer (**13**). The mass of this disc is greater than that of the disc of layer (**12**). The deceleration process described above in relation to the bullet impacting layer (**12**) now applies to the bullet and disc impacting the second ballistic layer (**13**).

**[0066]** The possibility that the bullet misses a disc in layer (**12**) and impacts in between discs is now considered. In this case the bullet will experience some deceleration due to contact with the mesh and partial contact with one or more discs. The same consideration applies in the case that a bullet impacts the corner or edge of a disc of the first ballistic layer, in which case the bullet will experience energy transfer, and therefore deceleration, also due to the rotation and possible shearing of the disc and/or lateral acceleration of one or more discs. (In both cases work will still also be done by the deformation of the bullet and discs or other vest components.) However, the function of the vest prevails in both these cases, because of the multi-layer construction. If a bullet misses a disc of layer (**12**) then it will likely impact a disc of layer (**13**). The tubes (**51**) and (**52**) of the mesh (**50**) are themselves of armor type material and will serve to partially deform the bullet and absorb some of its kinetic energy. The discs of the second ballistic layer could be forcibly aligned by the construction of the vest to protect the area between the gaps in the discs of the first ballistic layer, but preserving this arrangement will tend to reduce the flexibility of the final garment and would be suited to more rigid applications. The discs of layer (**13**), although larger than those of layer (**12**), are also designed to retard a direct impacting bullet. Therefore the dimensions and mass of the discs of the second ballistic layer are calculated not to be too large in area and mass. If by chance a bullet misses the discs of the first and second ballistic layers, then it will be retarded by the third ballistic layer. Overall, a bullet will experience some deceleration in each ballistic layer, even if it does not impact a disc directly and experience optimal deceleration. The net effect of the design is that due to the cumulative effect of the three ballistic layers the bullet will be sufficiently decelerated so as not to puncture the third and final ballistic layer.

**[0067]** An alternative embodiment of the invention could also be considered here, where a conventional ballistic fiber construction vest is worn under a single layer of the current invention corresponding to layer (**12**). The kinetic energy and cross sectional area of the bullet and disc pair after passing through layer (**12**) are similar to that of a hand gun projectile such as a 0.45 ACP caliber, and conventional ballistic fiber vests are generally effective at stopping such projectiles.

Description of Second Embodiment of the Invention

**[0068]** A second embodiment of the invention will now be disclosed. It is also a bullet proof vest, hereafter referred to as vest. This second embodiment differs from the first embodiment in the construction of the ballistic layers, which will be described in detail. However the principles of operation and function are the same as in the first embodiment. The general assembly and construction of the final garment is essentially similar to that of the first embodiment and will not be described here.

**[0069]** The vest is constructed of five layers. There are three ballistic function layers, as with the first embodiment. The outermost first layer (**11**) and innermost fifth layer (**15**) are the same as described in the first embodiment.

**[0070]** Details of the construction of the first ballistic layer of the second embodiment vest are shown in the cross section in FIG. **10**. A plurality of square cross section discs (**103**) arranged in a regular square matrix pattern are supported in a flexible three dimensional framework of high tensile polymer fibers (**104**) and (**105**). The discs (**103**) are 1.21 centimeters by 1.21 centimeters by 0.66 centimeters (0.475 inches by 0.475 inches by 0.26 inches) quartz fiber composite material, with 60% fiber volume fraction, conventional multi-directional weave fabric, embedded in a toughened cyanate ester resin. The discs have rounded and smoothed edges. On both faces of each disc is placed a 0.127 centimeter (0.05 inch) thick spacer (**109**) of UHMW PE material, each conformal to the face of the disc and smooth on the other side. The spacer is held in place during assembly using a small amount of conventional viscous adhesive such as UV-6000™, noting that it is difficult to bond to UHMW PE, but that the bond is not necessary to the ballistic function of the vest. Calculation of mass, dimensions and selection of material properties are the same as those for the discs (**80**) considered above in the first ballistic layer (**12**) of the first embodiment of the invention.

**[0071]** Strands of ballistic fiber (**104**) are wound alternately over and under adjacent discs in the x-direction and tied off at the end of a line of discs of length corresponding to the desired dimensions of the overall garment. The fibers (**104**) are spread evenly across the surface of each disc so that the entire surface area of the disc is covered with fiber. Then strands of ballistic fiber (**105**) are wound alternately over and under adjacent discs in the y-direction, such that the entire surface area of each disc is also covered by fibers in the y-direction. This process binds the lines of discs first created by weaving the x-direction fibers (**105**) together, and now creating a cloth of 90 degree weave fibers encasing a plurality of regularly spaced discs (**103**). The fiber type is Spectra 900™ 1600 Dernier, and the density of the weave is such that 48 fibers are spread linearly across each disc in both x and y directions. The considerations as to fiber type are the same as discussed above in the first embodiment. An alternative embodiment using a large number of fibers comprised of a combination of 20% Spectra 900™ and 80% commercial high density high tenacity polyester fibers could be employed, the arrangement providing a progressive load as the less elastic fibers will fail in tension first. As with the first embodiment, arrangements other than regular square matrix and weaves other than 90 degree could be alternately employed, providing adjustment in the composite material properties.

**[0072]** Two thin substrate sub-layers (**106**) and (**107**) of high tensile ballistic fiber are constructed with an open weave and are placed either side of the disc-weighted fiber cloth just constructed. Spectra 900 is a suitable fiber, but others could be used. The weave is made with bundles of 650 Dernier fibers at 4.72 per centimeter (12 per inch). The substrate layers, fiber cloth and discs are bonded to each other by placing a small amount of diluted flexible adhesive such as type UV-6800™ at each disc, first on one side and then the other. It is noted that for the function of the vest, the restraining shear loading imparted by the adhesive should be less than the tensile stress in the fibers, and this is easily achieved with practical materials. Finally, a sub-layer of 0.635 centimeter (0.25 inch) thick elastomeric foam (**108**), type K-Flex LS S2S™ (Noel Group, LLC, NC) or similar, is bonded to the innermost side of the composite substrate (**106**), fiber, disc and substrate (**107**) just assembled. The mechanical properties of the elastomeric foam are not important to the ballistic retardation function of the vest in this embodiment, though selection of the material could further enhance performance. What is most pertinent in the present embodiment is that the sub-layer of elastomeric foam (**108**) ensures a minimum separation between adjacent ballistic layers, allowing the fibers (**105**) and (**106**) to stretch under ballistic load and the bullet's energy to be coupled to surrounding discs by the network of fibers. In an alternative embodiment to the present, the elastomeric sub-layer could supplement or replace the retarding and energy coupling function of the fibers (**105**) and (**106**) if constructed out of material with appropriate mechanical properties such as fiber reinforced rubber.

**[0073]** A second ballistic layer is constructed essentially identically to the first ballistic layer just described, except that the disc size is 1.78 centimeters by 1.78 centimeters by 0.81 centimeters (0.7 inches by 0.7 inches by 0.32 inches), and the overall plan shape and size of the layer is smaller than the first ballistic layer.

**[0074]** A third and final ballistic layer is constructed essentially identically to the first and second ballistic layers just described, except that the disc size is 2.67 centimeters by 2.67 centimeters by 0.56 centimeters (1.05 inches by 1.05 inches by 0.22 inches), and the overall plan shape and size of the layer is smaller than the second ballistic layer.

**[0075]** The three ballistic layers are placed between a first, outermost layer and fifth innermost layer as in the first embodiment and assembled into a completed garment in similar fashion to the first embodiment.

**[0076]** Although the construction of the second embodiment differs from the first, the function is very similar. A 7.62 NATO FMJ bullet impacting the first ballistic layer causes a disc (**103**) to accelerate and also causes the ballistic fibers (**105**) and (**106**) to elongate in tension. The addition of mass to the bullet and the extension of the fibers and the coupling of additional mass though the fibers all cause the bullet to be decelerated, as well as the deformation of the bullet and disc. These effects are repeated as the combined bullet and disc impact the second and eventually third ballistic layers.

**[0077]** One final variation to the above embodiment is described. In this variation the discs are constructed not as discs per se but as a series of stacked plates. The dimensions of the plates in the first layer are 1.27 centimeters by 0.254 centimeters (0.5 inches by 0.1 inches) in area, and 0.762 centimeters (0.3 inches) in thickness, and of material 7475-T61 aluminum alloy. The plates have rounded-off corners. The orientation of thickness in this case being the same as that used in the above descriptions, i.e. the plates are aligned edge-on to the ballistic threat direction. Fibers are woven alternately over and under the individual plates in the x-direction, as with the discs previously. The plates are canted 45 degrees to the direction of the fiber weave. In the next line the plates are canted 45 degrees in the opposite direction, making a sort of herringbone pattern of plates. Then the y-direction fibers are woven alternately over and under each line of plates just constructed with the x-direction fibers. The herringbone arrangement makes the composite armor material less flexible (it is still flexible) in the x-direction than if they are arranged orthogonally, but it improves ballistic performance. There are many alternate weaving patterns which will be obvious to one practiced in the art that could be employed that will effectively encompass the plates within the weave and provide for tensile elongation of the fibers in the direction essentially normal to the plane of the layer under ballistic loading. Although regularly rectangular plates have been described in this instance, other three dimensional shapes and aspect ratios are specifically contemplated, including but not limited to three dimensional shapes which partially enclose some or all of the fibers in the locality of specific disc, and shapes and forms comprised of or assembled from more than one part.

## Description of Third Embodiment of the Invention

**[0078]** A third embodiment of the invention will now be disclosed. It is also a bullet proof vest, hereafter referred to as vest. This third embodiment differs in construction of the ballistic layers, one of which will be described in detail, however the principles of operation and function are the same as in the first and second embodiment. The general assembly and construction of the final garment is essentially similar to that of the first and second embodiment and will not be described.

**[0079]** The vest is constructed of five layers. There are three ballistic function layers, as with the first embodiment. The outermost first layer (**11**) and innermost fifth layer (**15**) are the same as described in the first embodiment.

**[0080]** Details of the construction of the first ballistic layer of the third embodiment vest will now be described with reference to FIGS. **11**, **12** and **13**.

**[0081]** A plurality of square cross section multi-component discs (**303**) arranged in a regular square matrix pattern is supported in a flexible framework of high tensile polymer fibers (**304**) and (**305**). Each disc has a main and outer component which itself has two parts (made of one piece of material): a 1.2 centimeters square (0.475 inches square) cross section in the plane of the material and of thickness 0.635 centimeters (0.25 inches) and a central round stem part of diameter 0.762 centimeters (0.3 inches) and 0.457 centimeters thick (0.18 inches). As shown in FIG. **12**, each disc (**303**) is comprised of an outer component (**317**) just described of 7075-T6 aluminum, an inner component (**318**) of conventional cyanate ester resin impregnated quartz composite which is 1.2 centimeters square (0.475 inches square) cross section and 0.254 centimeters (0.1 inches) thick and a 316 stainless steel screw (**319**) which is threaded into the outer component (**317**). Fibers (**304**) and (**305**) are woven substantially in the x and y directions between the discs to form the composite armor material. The fibers (**304**) and

(**305**) are also woven and or wound around adjacent discs regularly and randomly to bind and secure the whole construction together. Additionally, some fibers are threaded and looped around the x and y fiber bundles between the discs to add robustness to the construction. The layer is constructed by weaving the fibers as just described across, between and around the disc outer components (**317**) which are laid out in an x-y matrix for assembly, then the inner components (**318**) are screwed in place with screws (**319**) and a securing layer of conventional flexible adhesive such as UV-6000™ is applied. The remainder of the construction of the ballistic layers of the third embodiment and of the five layers of the vest of the third embodiment are the same as for the second embodiment and will not be described here.

**[0082]** Under ballistic impact of a projectile on one disc, the disc will move substantially in the direction of impact and substantially normally to the plane of the material, and the general arrangement of the composite material will be deformed and rearranged temporarily. Under this rearranged geometry, as depicted in FIG. **13**, the further motion of the impacted disc will be restrained by the tensile elongation of fibers taking place substantially in the direction of motion of disc and the ballistic impact. FIG. **13** illustrates a condition of a ballistic projectile having impacted a first disc (**313**) of the layer and caused the layer to deform and dynamically rearrange geometrically such that tensile elongation of fibers occurs between disc (**313**) and adjacent disc(s) (**314**). The projectile and disc will both deform severely on impact, which is not shown in FIG. **13** for purposes of clarity. Intrinsic and implicit in the design of the third embodiment and variants thereof is the concept that under ballistic load the geometry of the fibers and discs will rearrange prior to ultimate tensile stress from the natural or rest or pre-ballistically loaded configuration. Further, the arrangement of discs and fibers allows for limited localized slideable movement of the fibers over the discs; as deformation of the initial arrangement occurs under loading, the tension in the fibers increases, and eventually at an amount predetermined by the specific arrangement, friction causes the fibers to bind against the discs, thus causing any further deformation to be done as work against tensile extension of fibers. In this example embodiment as described the discs (**303**) have been made of three parts and are screwed together, but other configurations can be readily contemplated by one skilled in the art. The construction is such that the fibers and discs are engaged in a 3D matrix such that under ballistic loading the structure is altered by first slidable motion of discs relative to fibers and that any disc first impacted by a ballistic projectile imparts or couples energy to adjacent discs by tensile extension of fibers wholly or in part substantially in the direction of the ballistic impact.

**[0083]** The ballistic sub layer of the third embodiment just described is sandwiched between and bonded to supporting sub layers (**306**), (**307**), (**308**) in FIG. **11** corresponding to sub layers (**106**), (**107**), (**108**) respectively in FIG. **10** previously described for second embodiment. The construction is similar to those previously described for the first and second embodiments and will not be repeated here.

**[0084]** The above method and all its embodiments and variations may be used to protect persons and property against kinetic missiles such as firearm bullets. The invention is scalable, such that basic design is applicable to protection from heavier caliber weapons, such as .50 caliber armor-piercing bullets or larger shells, including cannon and artillery shells, by adjusting the size of the components and the material calculations according to the method described and the number of layers appropriate to the protection required.

**[0085]** The present invention is therefore well-adapted to carry out the objects and attain the ends mentioned, as well as those that are inherent therein. While the invention has been depicted, described and is defined by references to examples of the invention, such a reference does not imply a limitation on the invention, and no such limitation is to be inferred. The invention is capable of considerable modification, alteration and equivalents in form and function, as will occur to those ordinarily skilled in the art having the benefit of this disclosure. The depicted and described examples are not exhaustive of the invention. Consequently, the invention is intended to be limited only by the spirit and scope of the appended claims, giving full cognizance to equivalents in all respects.

What is claimed is:

**1**. A ballistic projectile defeating protective armor designed to protect persons and property comprising a plurality of small masses and a framework of fibers which partially restrain movement of said masses under ballistic load.

**2**. The armor of claim **1** where said fibers are arranged around the masses in a multi-dimensional framework, where the arrangement of said framework is central to the function of the armor.

**3**. The armor of claim **1** where the arrangement of the fibers is such that said fibers may elongate in tension in a direction substantially corresponding to the direction of the ballistic projectile prior to impact on the armor.

**4**. The armor of claim **1** which imparts force by the said mass or masses first impacted ballistically to adjacent masses through a combination of compressive force in the elastomeric material and tensile force in the reinforcing fibers.

**5**. The armor of claim **2** where the fibers are arranged in a three-dimensional framework around each individual mass.

**6**. The armor of claim **2** where at least part of the direction of the weave of the fibers around the masses is substantially in the direction aligned with the anticipated ballistic threat.

**7**. The armor of claim **2** where at least part of the direction of the weave of the fibers is in a direction substantially normal to the local plane of the material.

**8**. The armor of claim **2** where the fibers are wound or woven alternately in regular or random or pseudo random fashion around or about masses.

**9**. The armor of claim **2** where said fibers are first aligned substantially in the x and y directions substantially normal to the direction of the anticipated ballistic impact and are locally rearranged upon ballistic impact such that the displacement of one mass under ballistic load relative to adjacent masses causes a rearrangement of the 3D geometry from the rest geometry to a geometry where tensile elongation of said fibers occurs substantially in the direction of the direction of the ballistic load.

**10**. The armor of claim **2** where under ballistic load the geometry of the fibers and masses dynamically rearrange to a 3D geometry of fibers and masses prior to the ultimate tensile stress being attained in all said fibers local to the ballistically impacted mass.

**11**. The armor of claim **2** which is constructed to be flexible to facilitate elastic flexing of said armor material at a bend rate of 20 degrees or more from the neutral position per linear foot of material.

**12**. The armor of claim **2** where the dimensions and material properties of the masses are calculated to optimally retard one or more specific ballistic threats, such as rifle bullets, cannon shells, or artillery shells of specified caliber and performance.

**13**. The armor of claim **2** where the dimensions and material properties of the masses are calculated to optimally retard one or more specific ballistic threats, such as rifle bullets, cannon shells, or artillery shells of specified caliber and performance and prevent punch through of the mass by the specific threat projectile.

**14**. The armor of claim **2** combined with at least one layer of woven ballistic cloth material.

**15**. The armor of claim **2** where retardation of the ballistic projectile is achieved through transfer of kinetic energy from the ballistic projectile to one or more masses.

**16**. The armor of claim **2** where retardation of the ballistic projectile is achieved through elastic or plastic elongation of fibers which are or become arranged substantially in the direction normal to the local plane of the material.

**17**. The armor of claim **2** where retardation of the ballistic projectile is achieved through elastic or plastic elongation of fibers substantially in the direction of the projectile prior to impact.

**18**. The armor of claim **2** where the retardation of the ballistic projectile is achieved through a combination of the transfer of kinetic energy to masses and the elastic or plastic elongation of fibers substantially in the direction of the projectile prior to impact.

**19**. The armor of claim **2** where the retardation of the ballistic projectile is achieved through a combination of the transfer of kinetic energy to masses and the elastic or plastic elongation of fibers substantially in the direction of the projectile prior to impact and deformation of the masses and solid material directly in contact with the masses and or fibers.

**20**. The armor of claim **2** where adjacent masses are configured in tessellating shapes.

**21**. The armor of claim **2** where the tensile strength of the material of the fibers is greater than 400 Mega Pascals.

**22**. The armor of claim **2** where the fibers are made from more than one tensile strength material.

**23**. The armor of claim **2** where the masses are constructed of one or more of the following ballistic shear resistant materials: metal, ceramic, ceramic composite, fiber composite, and or quartz composite.

**24**. The armor of claim **2** where the mass of an individual mass is less than one point three times the mass of the anticipated threat projectile.

**25**. The armor of claim **2** where the mass and size of said mass are small enough so that the mass will accelerate with an impacting ballistic projectile and not be punctured by said projectile and the mass imparts a retarding force on the projectile.

**26**. The armor of claim **2** where the masses are further supported by an elastomeric or plastic material which deforms compressively as a result of ballistic impact on one or more masses.

**27**. The armor of claim **2** where the armor material is encapsulated in elastomeric or plastic material by a process of injection or molding or vulcanizing.

**28**. The armor of claim **2** where the cross section of the masses orthogonal to the nominal direction of the ballistic threat is smaller in at least one dimension than the diameter of the anticipated ballistic projectile.

**29**. The armor of claim **2** where the fibers are woven into a fabric or cloth and the masses are interwoven into said fabric or cloth.

**30**. The armor of claim **2** where said masses are each manufactured of one or more component parts and enclose said fibers wholly or partially so as to effectively restrain and limit relative motion between said fiber and said masses.

**31**. The armor of claim **2** where the motion of a mass is restrained by the framework of fibers, and said restraining imparts a retarding force.

**32**. A bullet proof vest constructed of one or more layers of the armor of claim **2**.

**33**. A bullet proof vest constructed of two or more layers of the armor of claim **2** where said layers are separated by a layer of elastomeric material which deforms compressively under ballistic load.

**34**. A bullet proof vest constructed of one or more layers of the armor of claim **2** and one or more layers of conventional woven ballistic fiber cloth.

**35**. The armor of claim **1** where the masses have smooth and rounded surfaces in contact with the fibers so that the fibers may slide locally over the surface of the masses during ballistic load.

**36**. The armor of claim **35** where a solid spacer of plastic material is placed between the fibers and the masses, where said plastic material deforms and flows under ballistic loading.

**37**. The armor of claim **1** comprising multiple layers of a plurality of said masses and three dimensional framework of fibers which restrain movement of the masses under ballistic load.

**38**. The armor of claim **37** where the mass of the individual masses in the layer first impacted by the ballistic projectile is less than the mass of the individual masses in subsequently impacted layers.

**39**. The armor of claim **2** where upon ballistic impact of a ballistic projectile on a mass, said mass moves by a limited amount in a direction which is substantially the direction of travel of the ballistic projectile prior to impact.

**40**. The armor of claim **39** where the motion of the mass causes tensile stress in the fibers supporting said mass.

**41**. The armor of claim **40** where said tensile stress causes tensile elongation of the fibers at least part of said elongation is substantially in the direction of the motion of the mass.

**42**. The armor of claim **41** where the tensile elongation of some or all of said fibers causes energy to be absorbed.

**43**. The armor of claim **41** where the tensile elongation of some or all of said fibers results in tensile failure of some or all of said fibers.

**44**. The armor of claim **2** where the tensile stress imparted in the fibers by the motion of the mass or masses first impacted by a ballistic projectile causes a force to be imparted to one or more adjacent masses.

**45**. The armor of claim **44** where the force imparted by said first impacted mass or masses to said adjacent masses is imparted substantially by the tensile stress in the supporting fibers substantially in the direction of motion of the first impacted mass or masses.

**46**. The armor of claim **44** where the summed mass of the plurality of said masses which are adjacent to and directly mechanically coupled by said fibers to a mass which is first impacted by a ballistic projectile, or to masses which are first impacted by a ballistic projectile if more than one mass is directly in the path of said projectile, is greater than twice the mass of the anticipated threat projectile.

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