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(54) **MULTI-STRUCTURE METAL MATRIX COMPOSITE ARMOR WITH INTEGRALLY CAST HOLES**

(76) Inventors: **Richard W. Adams**, Bolton, MA (US); **James P. Sorensen**, Eagan, MN (US)

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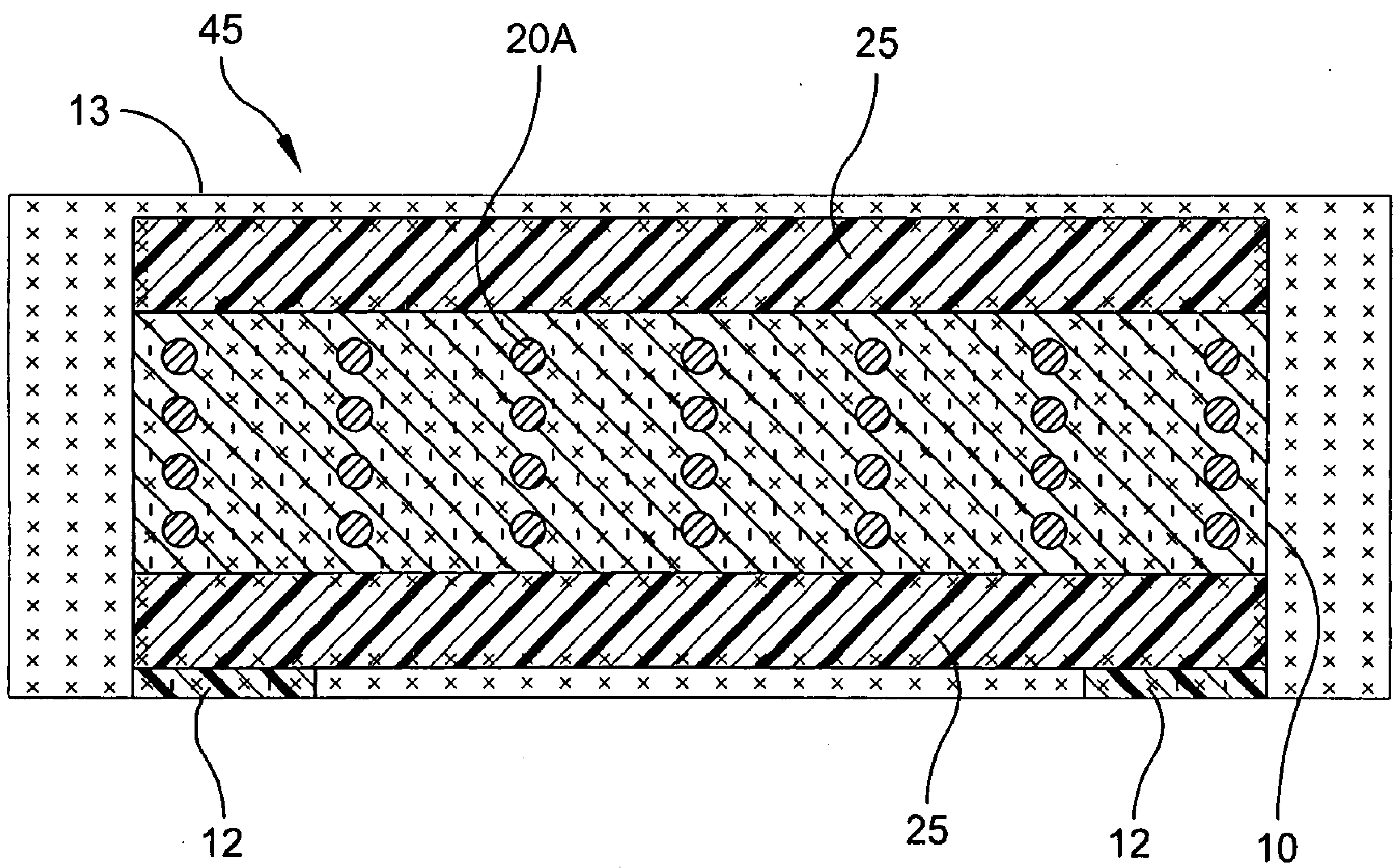
(57) **ABSTRACT**

A lightweight armor system according to the present invention includes one or more material layers having a fraction of void volume and at least one of those material layers having holes of various sizes and designs integrated therein. The material layers are infiltrated with liquid metal which solidifies within the materials open porosity to bind the layers together to create a coherent integral structure. The holes may be in the form of tubes which are impervious to metal infiltration and reduce the weight of the armor system while contributing to projectile deflection.

A process for producing a lightweight armor system is disclosed which comprises the steps of 1.) forming holes in a preform containment layer 2.) positioning sealed tubes in the formed holes so that the tubes run through the thickness of the preform 3.) positioning at least one preform w/ sealed tubes within a mold chamber of a closed mold and 4.) infiltrating the mold with a liquid metal.



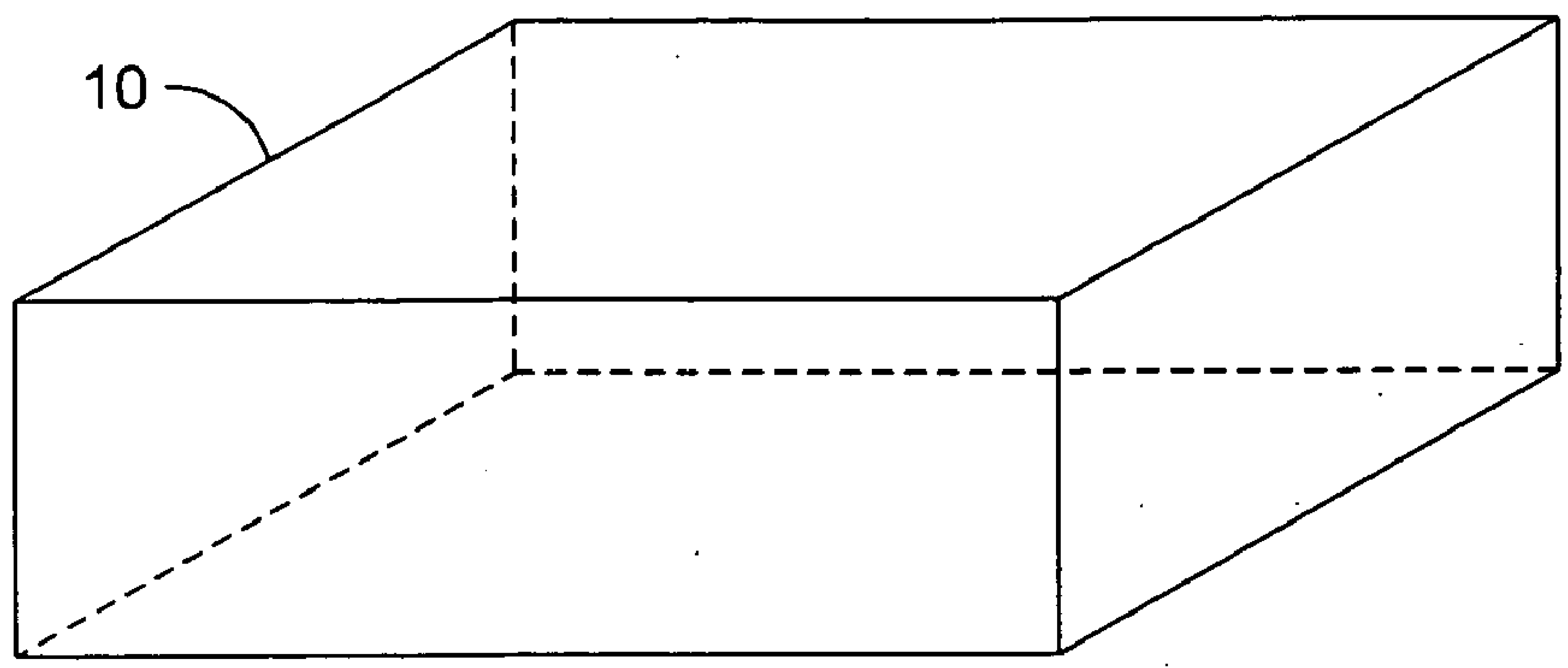


FIG. 1

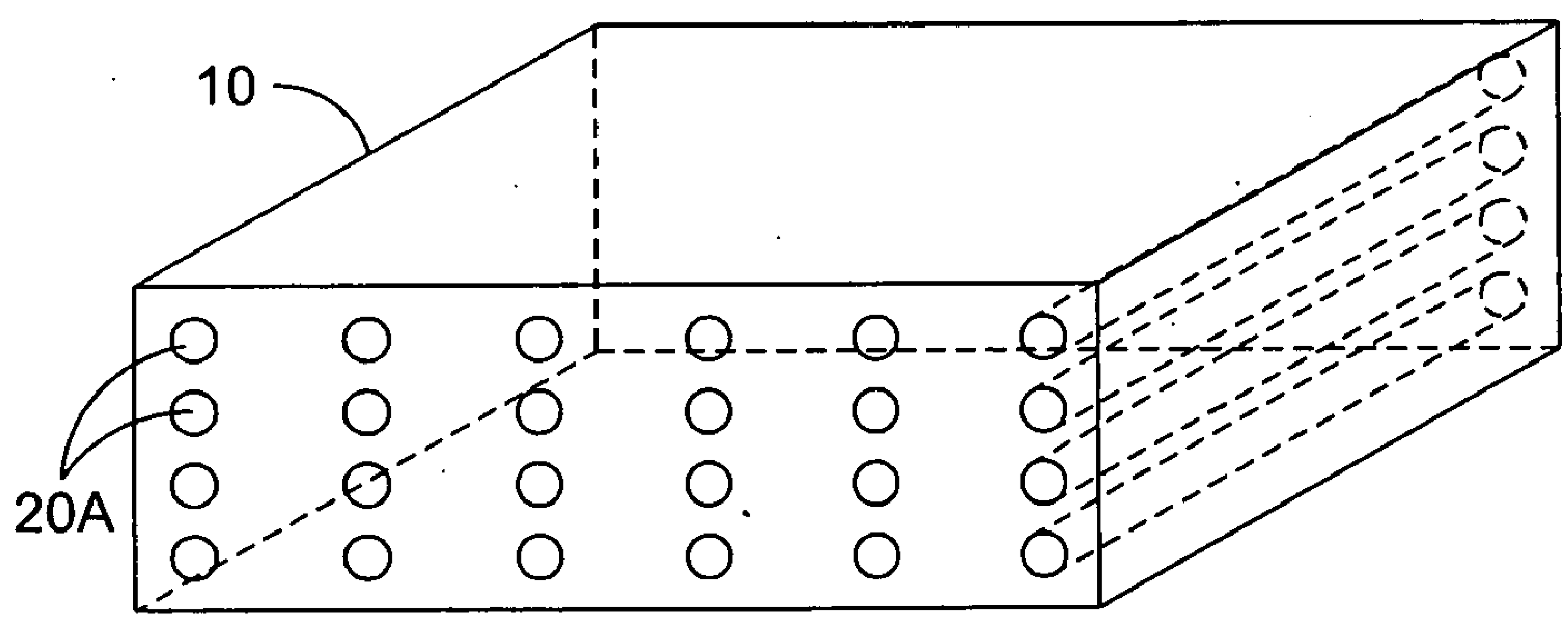


FIG. 2

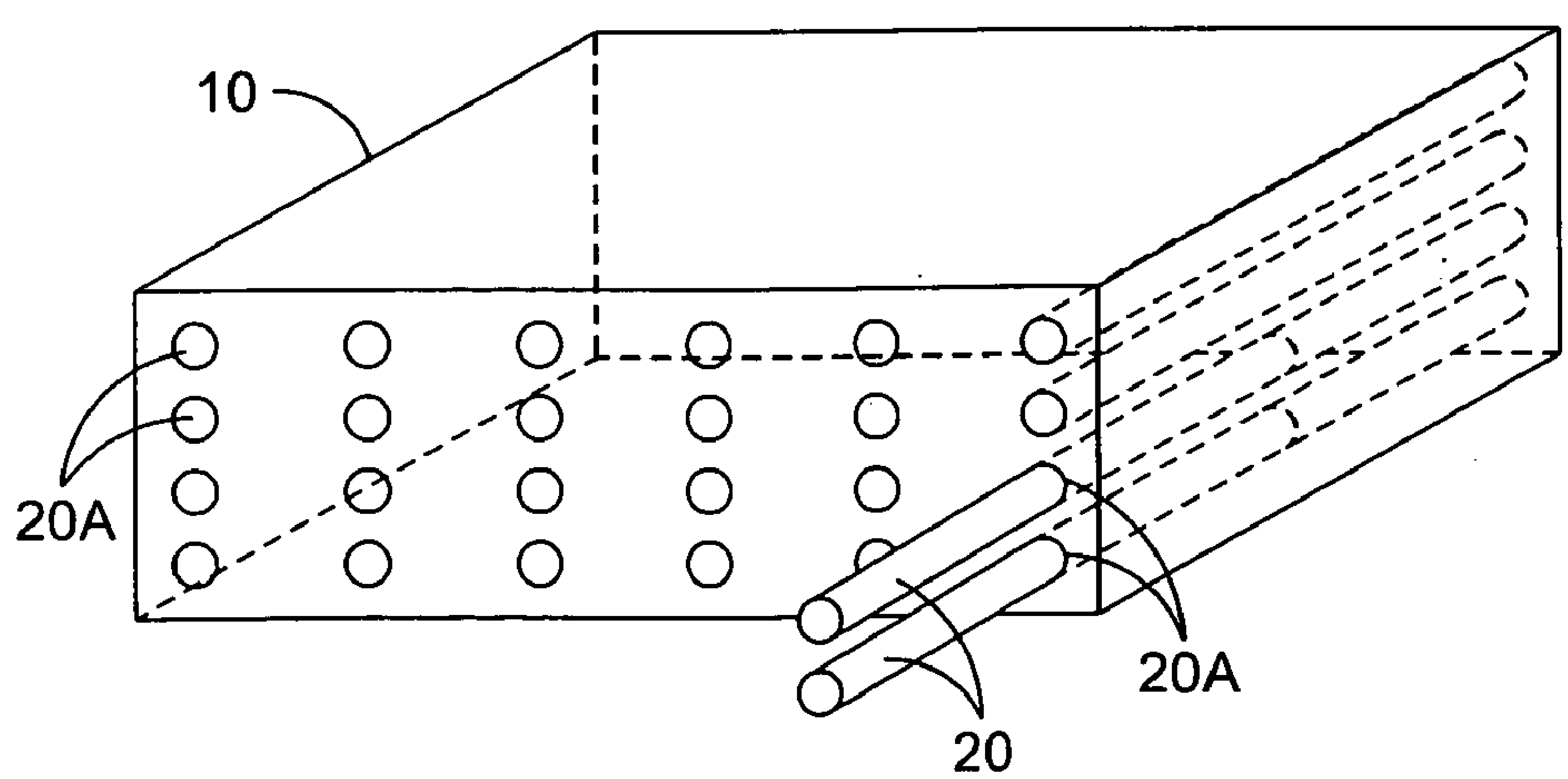


FIG. 3

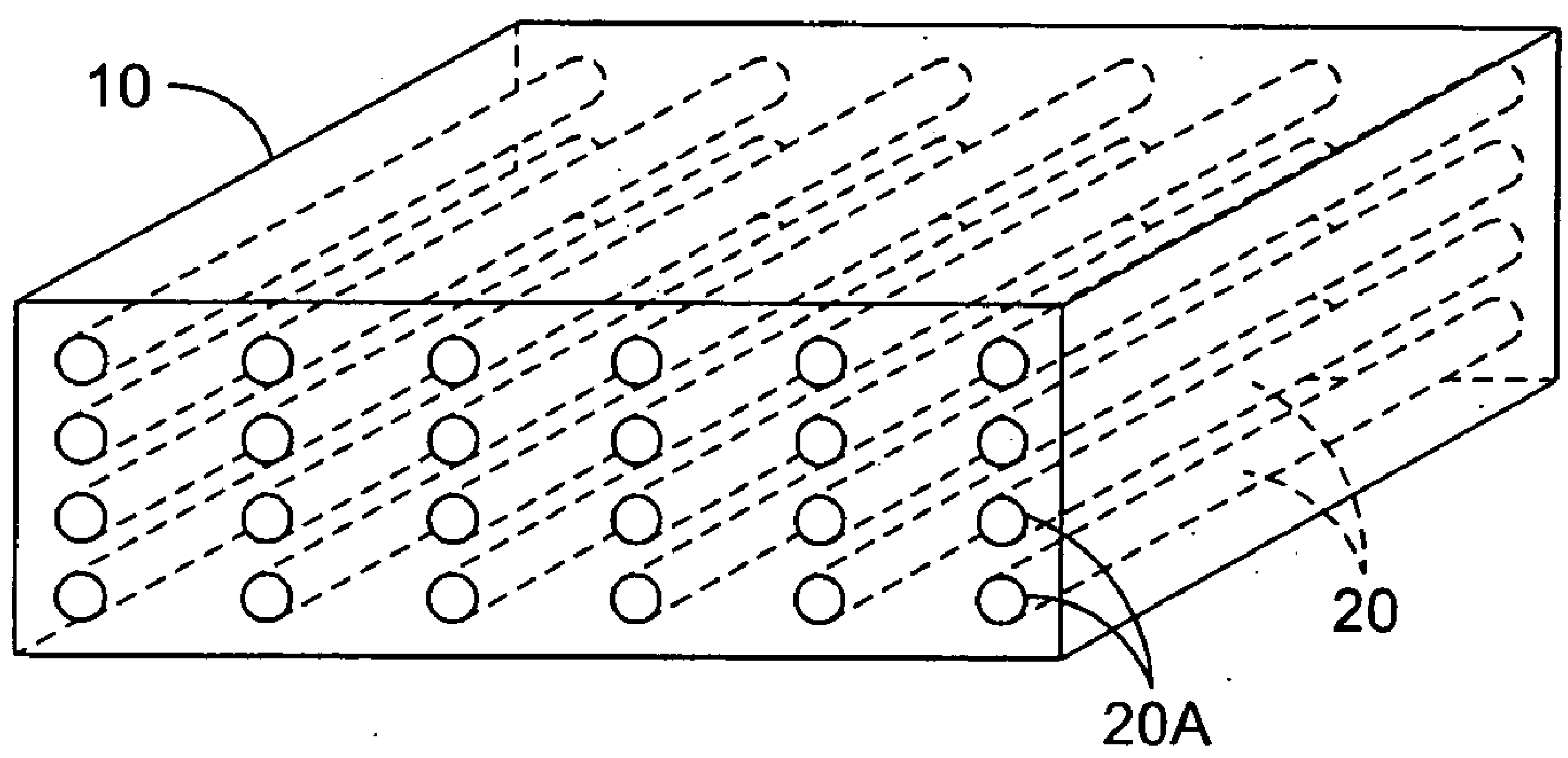


FIG. 4

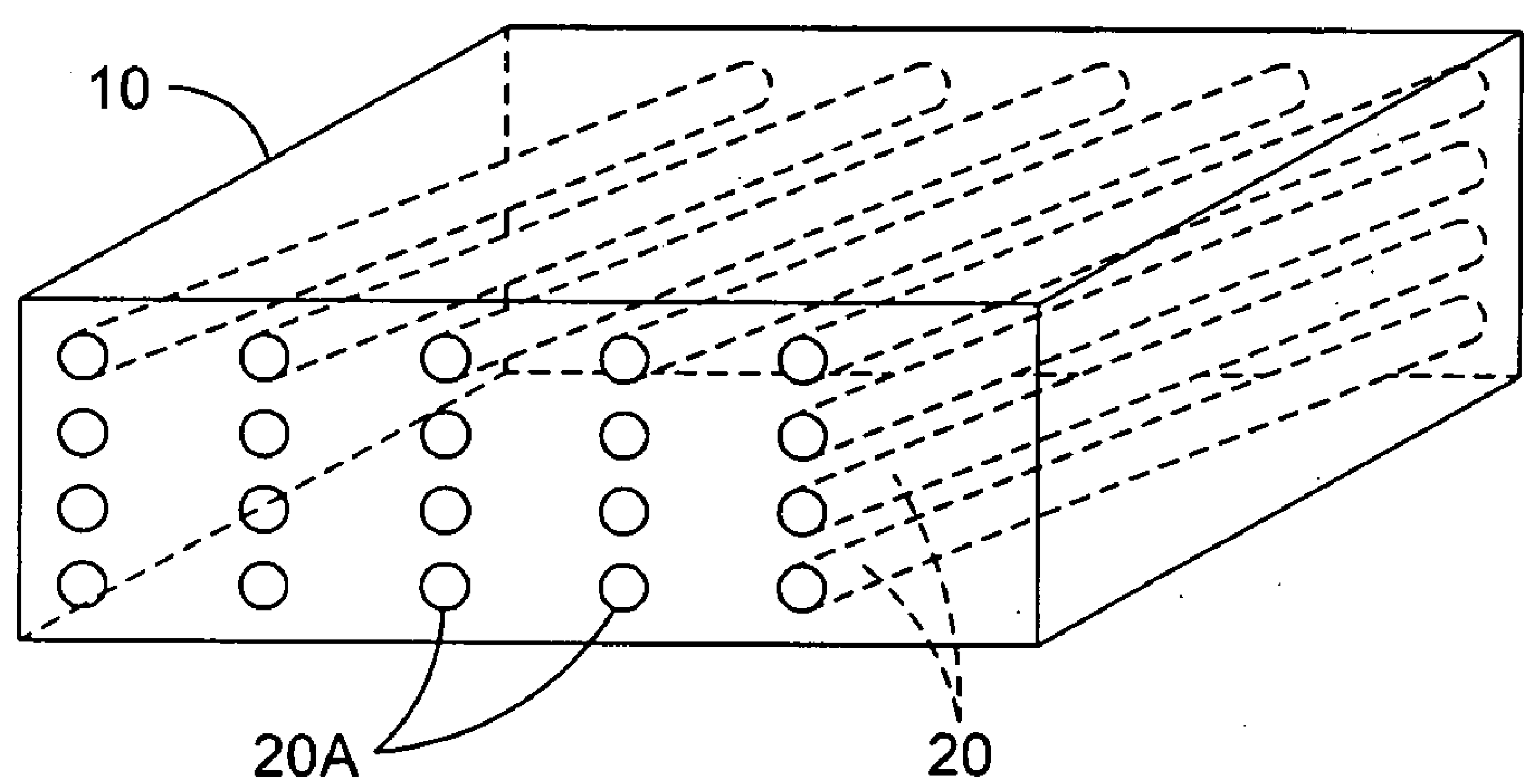


FIG. 5

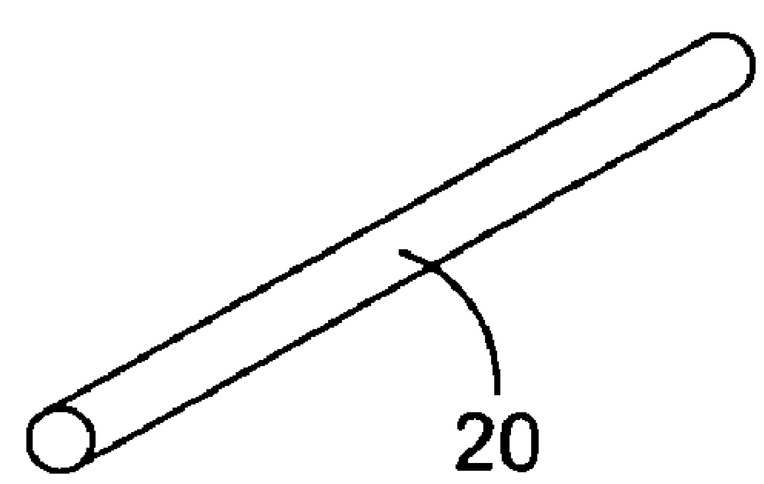


FIG. 6

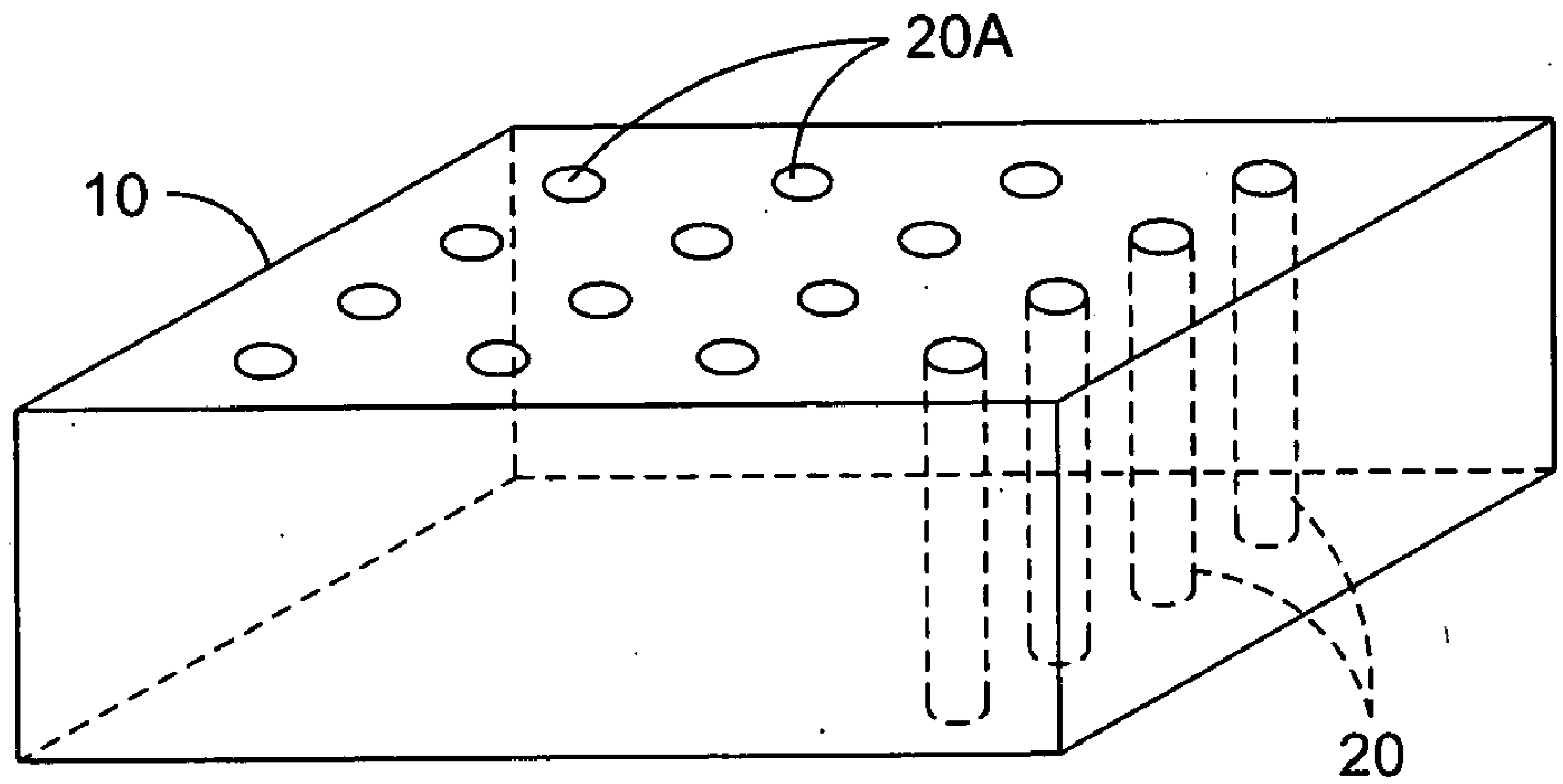


FIG. 7

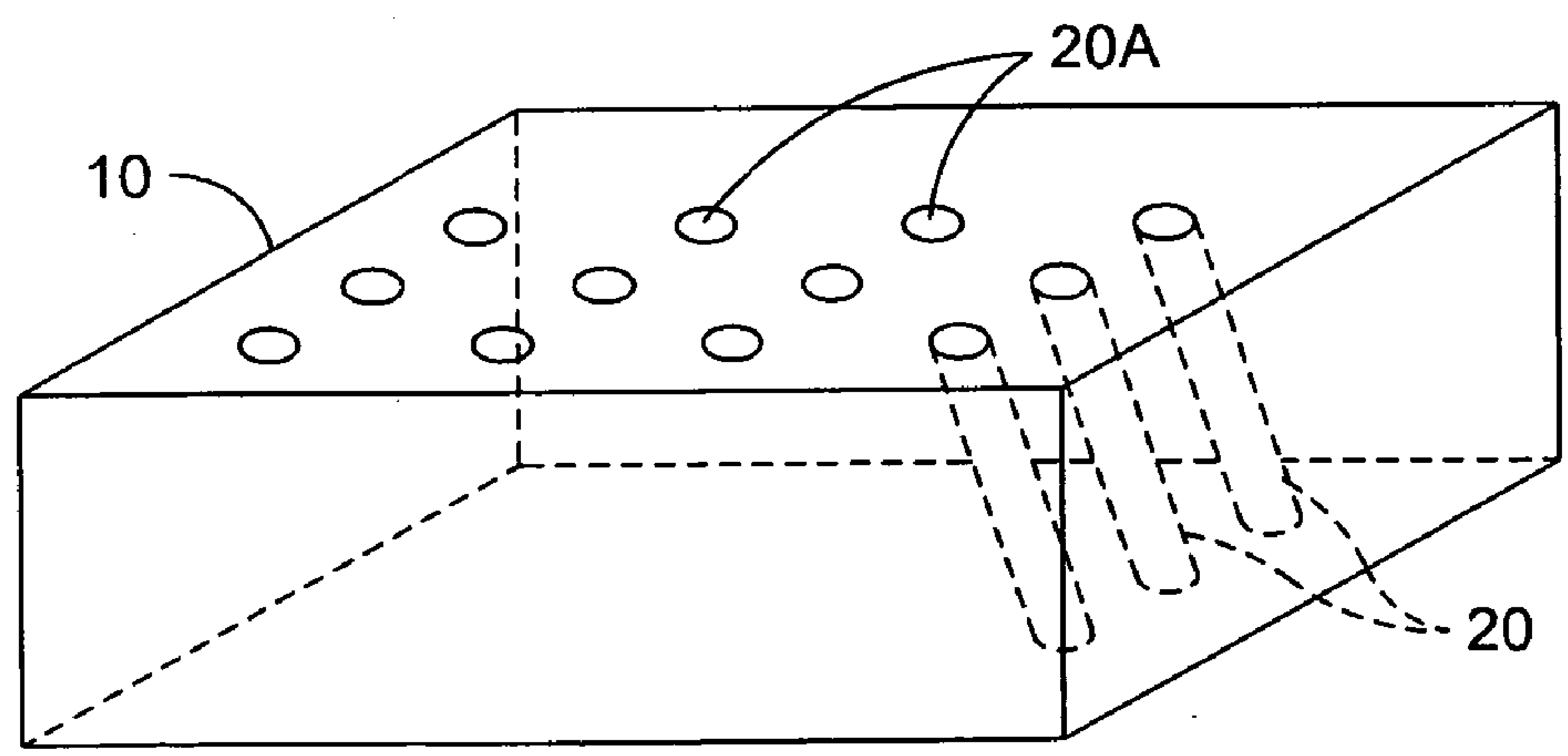


FIG. 8

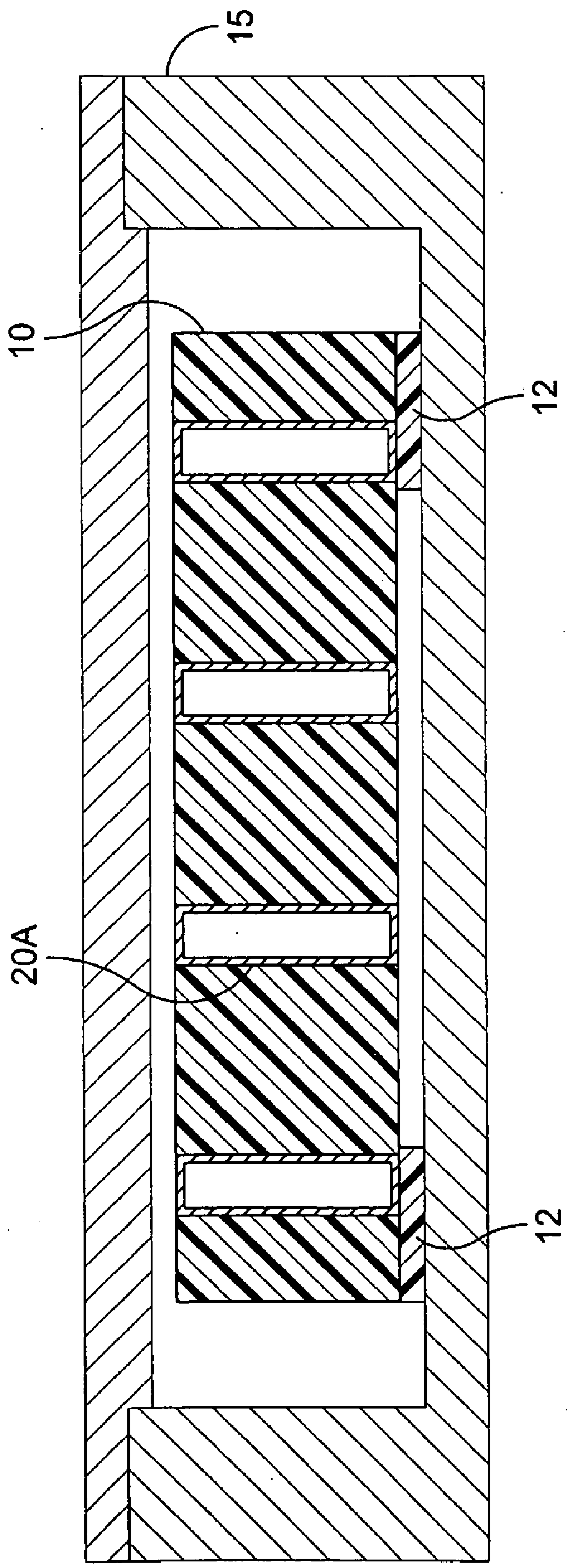


FIG. 9

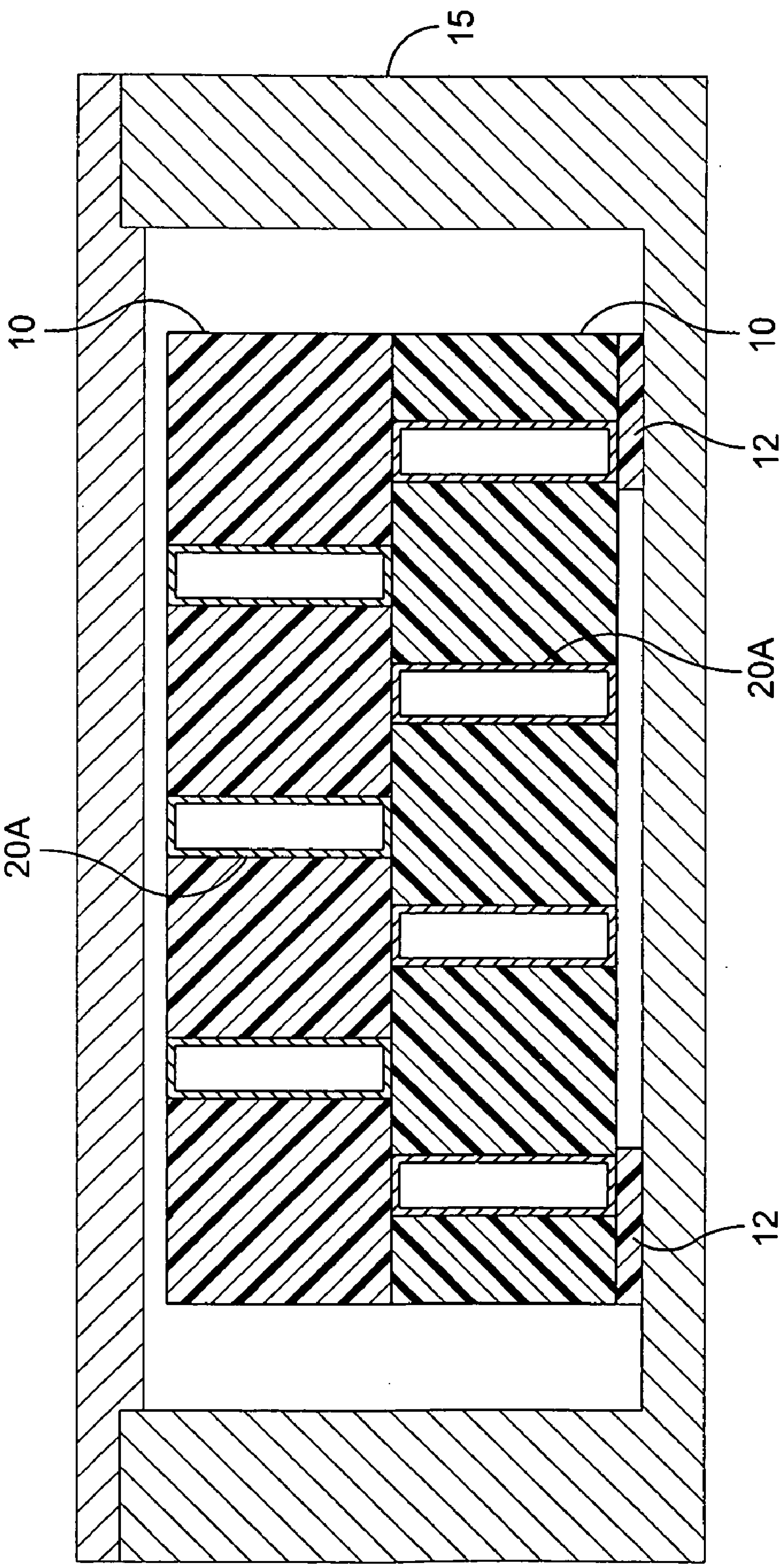


FIG. 10

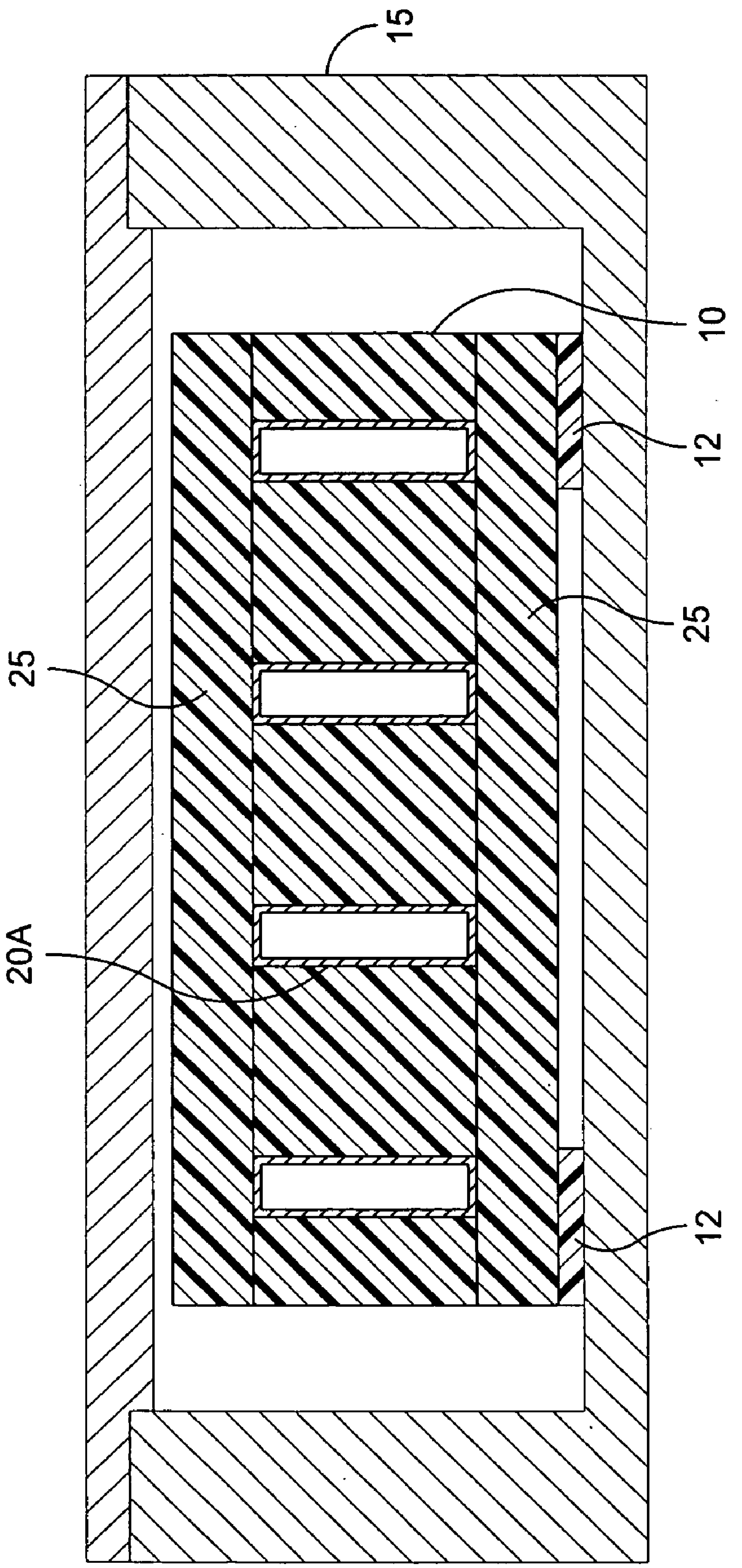


FIG. 11

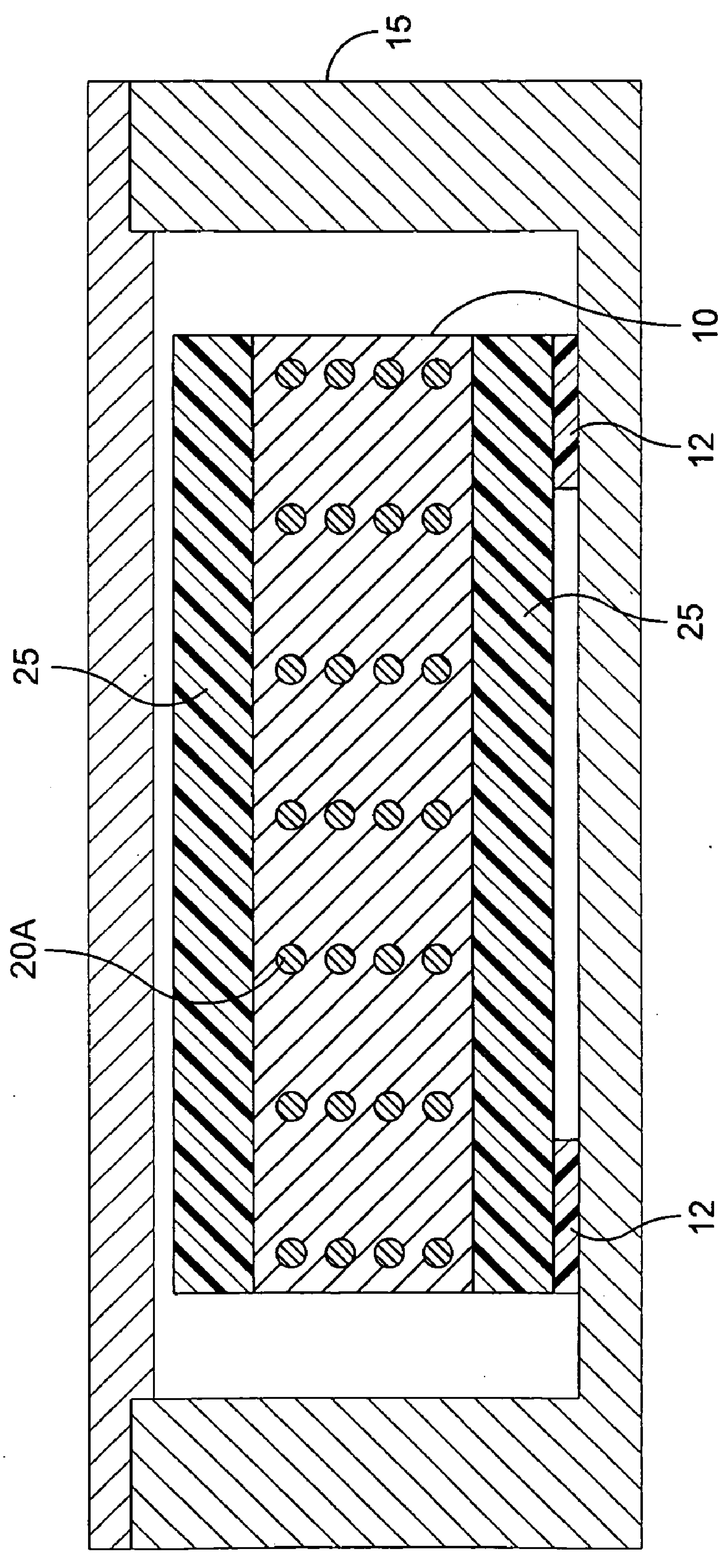


FIG. 12

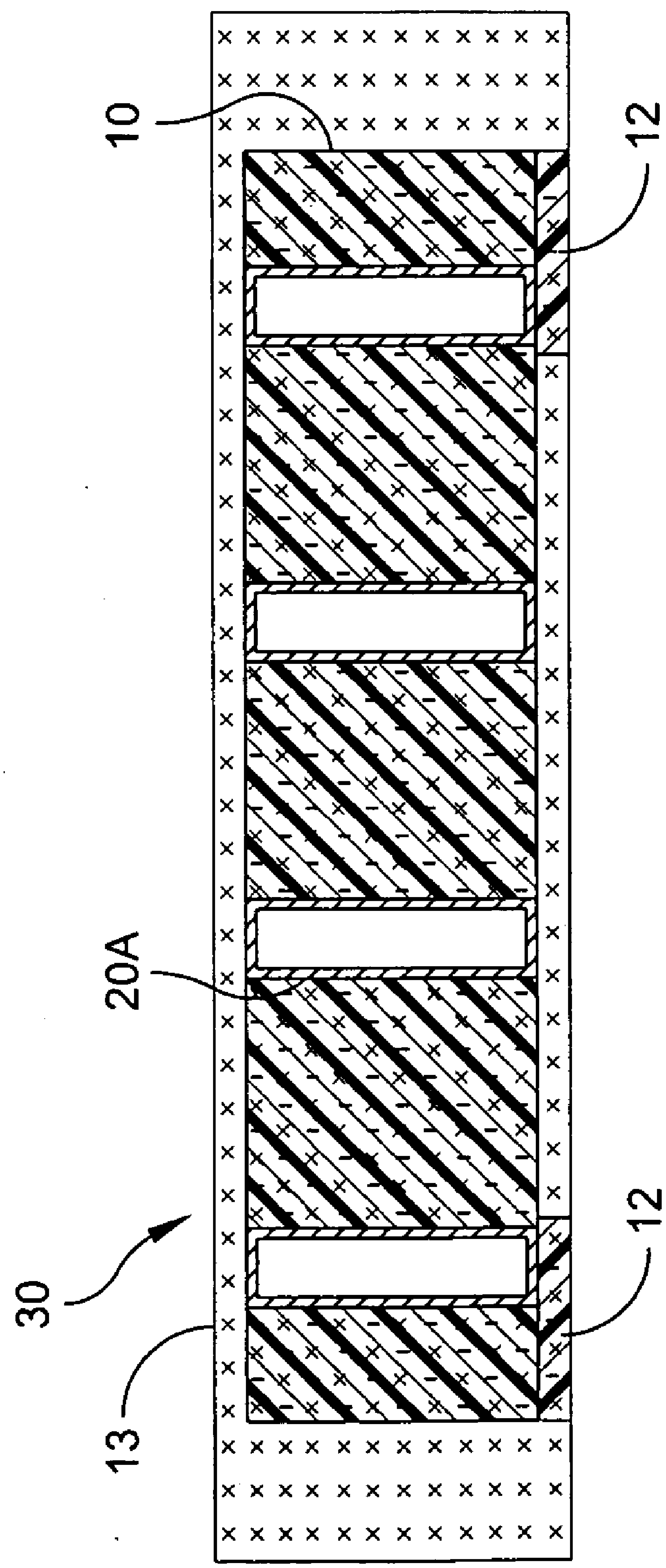


FIG. 13

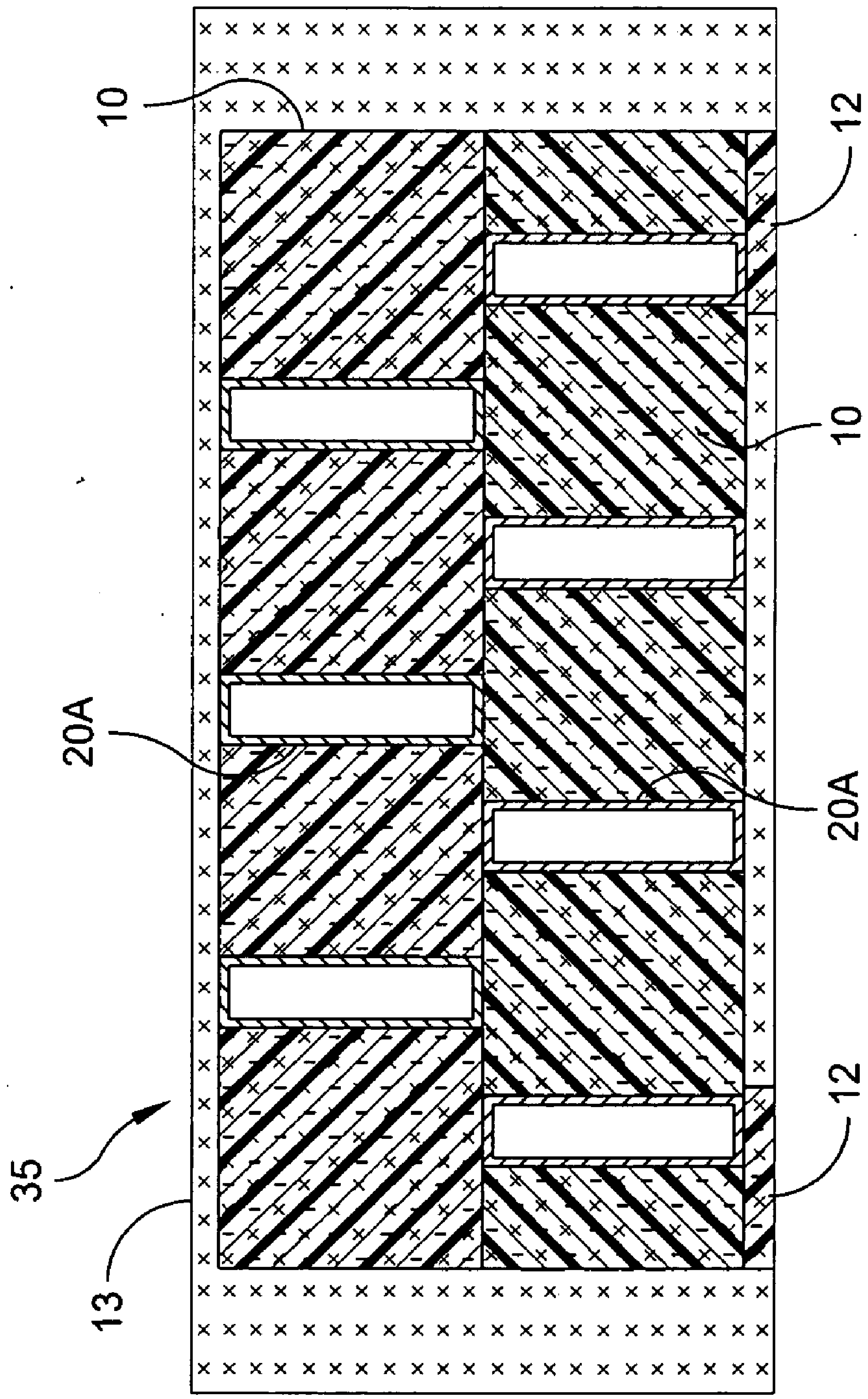


FIG. 14

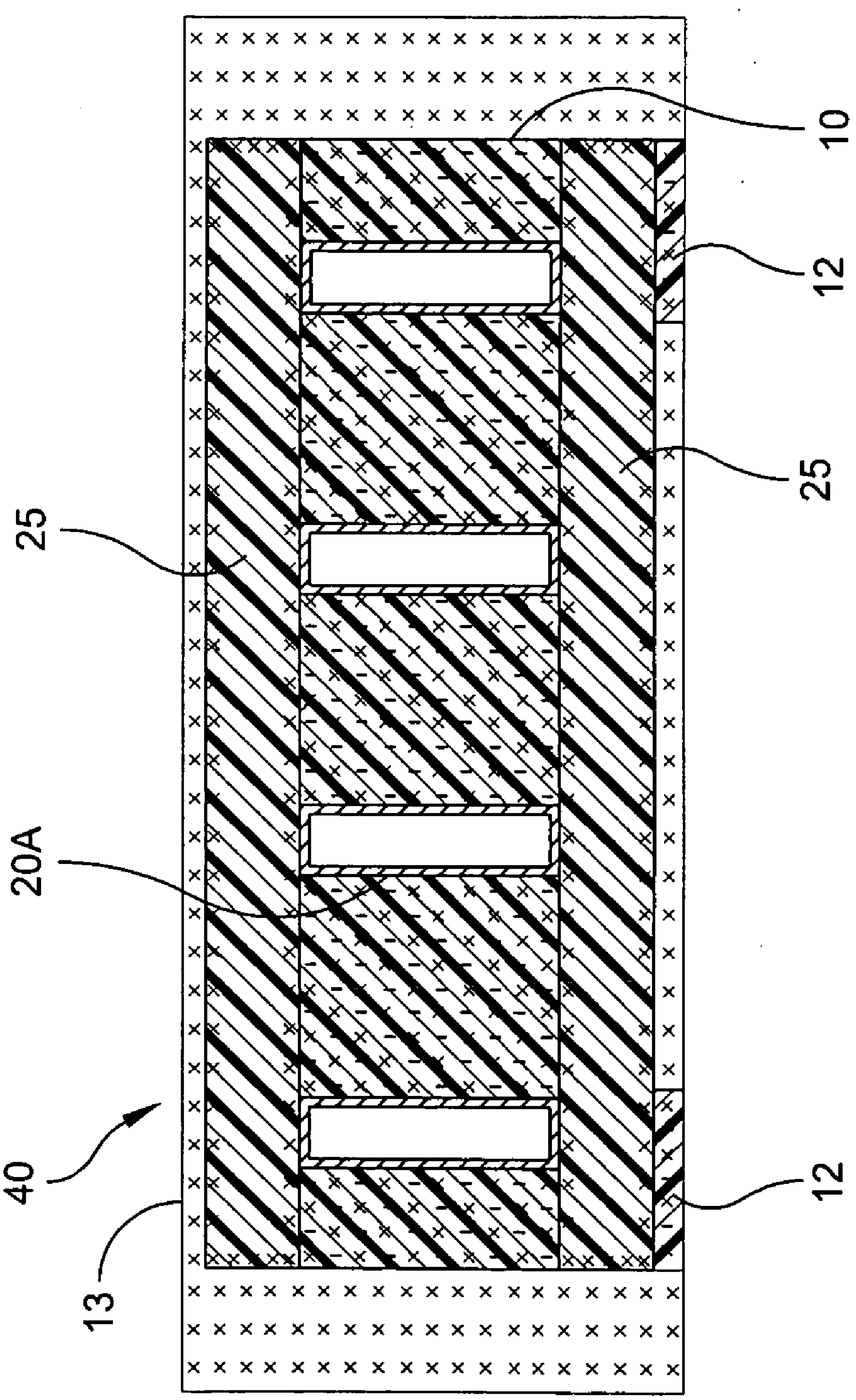


FIG. 15

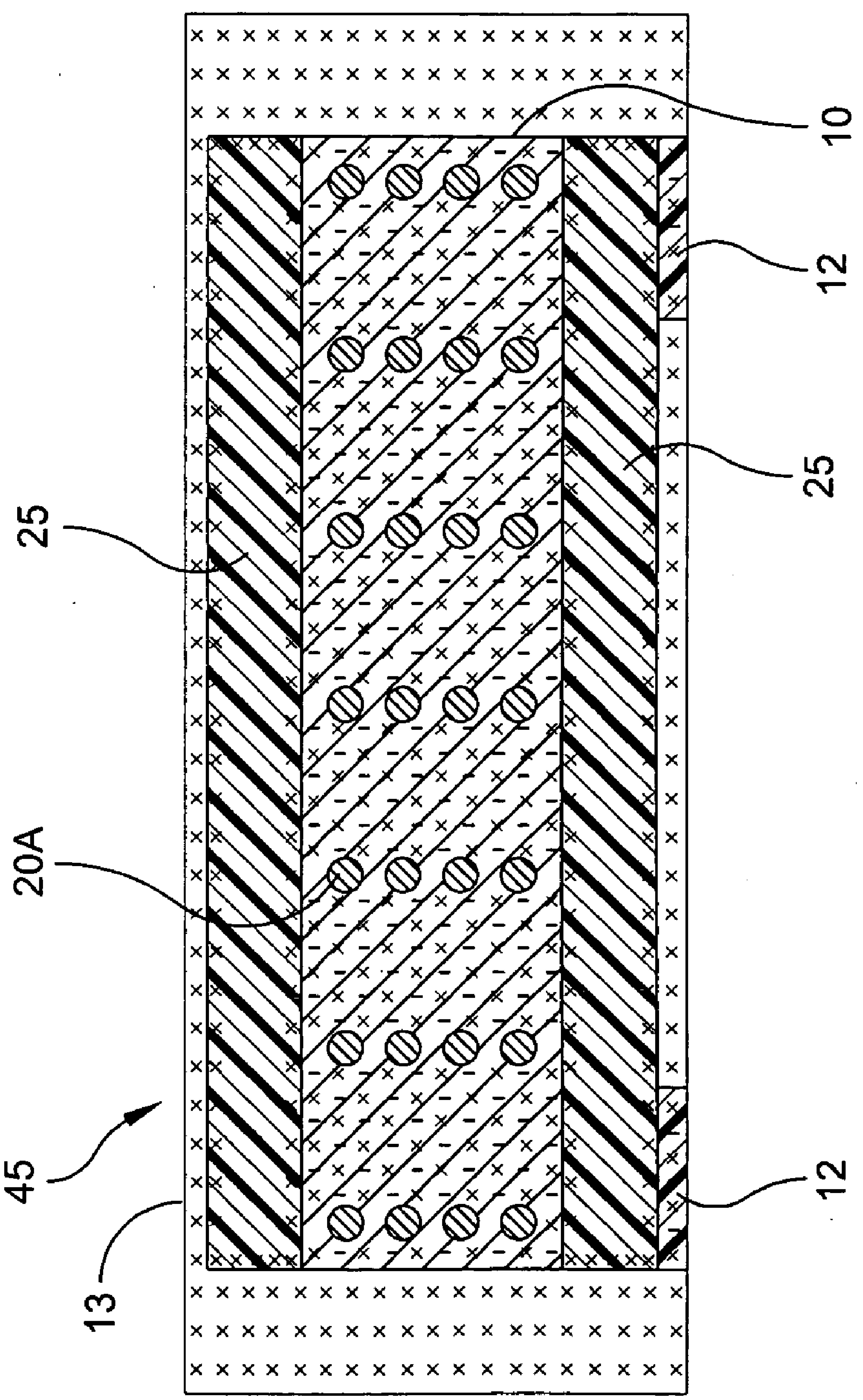


FIG. 16

MULTI-STRUCTURE METAL MATRIX COMPOSITE ARMOR WITH INTEGRALLY CAST HOLES

FIELD OF THE INVENTION

[0001] This invention relates to lightweight armor systems in general and more specifically to a method for producing an armor system utilizing metal matrix composite plates having integrally cast holes to save weight and more effectively initiate projectile deflection.

BACKGROUND OF THE INVENTION

[0002] Many different kinds of lightweight armor systems are known and are currently being used in a wide range of applications, including, for example, aircraft, light armored vehicles, and body armor systems, wherein it is desirable to provide protection against bullets and other projectiles.

[0003] While early armor systems tended to rely on a single layer of a hard and brittle material, such as a ceramic material, it was soon realized that the effectiveness of the armor system could be improved considerably if the ceramic material were affixed to or "backed up" with an energy absorbing material, such as high strength Kevlar fibers. The presence of the energy absorbing backup layer tends to reduce the spallation caused by impact of the projectile with the ceramic material or "impact layer" of the armor system, thereby reducing the damage caused by the projectile impact.

[0004] Testing has demonstrated that such multi-layer armor systems tend to stop projectiles at higher velocities than do the ceramic materials when utilized without the backup layer. While such multi-layer armoring systems are being used with some degree of success, they are not without their problems. For example, difficulties are often encountered in creating a multi-hit capability armor with multi-layered material structure having both sufficient mechanical strength as well as sufficient bond strength at the layer interfaces.

[0005] It has been discovered by the present inventors that an armor system comprised of layers of dense ceramic with no interior open porosity and containment layers having a predetermined fraction of open porosity, combined within a metal-matrix, is promising in terms of performance.

[0006] It has been further discovered that the use of containment layers comprised of integrally cast holes further reduces weight of the armor system and effectively initiates projectile deflection.

[0007] A specific type of armor which is well-known in the art is referred to generically as P900 armor. The P900 armors refer to a class of applique armors which consist of two metal plates of a predetermined thickness which are in a stacked configuration and which are spaced apart from one another. Both of the metal plates have holes of various designs. These holes have been punched out or drilled in a perpendicular fashion through the armor plates. The holes in the two armor plates are arranged such that when a projectile penetrates the P900 plates, the projectile is broken due to the asymmetrical load placed on the projectile. The spacing to the substrate further amplifies projectile breakup which consequently allows the projectile effect to be more easily absorbed and withstood by the substrate. The well-known prior art P900 armor has previously been fabricated only from annealed, wrought steel plates. Said plates are mechanically punched or drilled to form the holes and subsequently straightened, heat treated and cut to the desired shape and size.

[0008] This prior art process of making the P900 armor carries with it many disadvantages. For example, the use of punching or drilling techniques is limited by the thickness of the steel plate and the design of the holes to be punched or drilled. Moreover, the punching or drilling techniques produce excessive amounts of waste of steel plate (approximately 60%). The punching or drilling techniques further create sharp edges on the armor plates which make their handling difficult.

[0009] U.S. Pat. No. 5,007,326, to Gooch, Jr. et al. discloses a Cast Single Plate P900 Armor. The armor includes a cast metal plate or plates of predetermined thickness which have slotted holes of various sizes and designs. The slotted holes are sufficiently small so, that a projectile is unable to pass therethrough without disrupting the armor. Moreover, the slotted holes of the defensive applique armor are cast at obliquity. The cast armor of Gooch further discloses an optional thin, cast metal layer. Said optional layer may be positioned either within or external to the basic cast armor plate. The presence of an optional thin, cast metal layer provides reinforcement protection against any projectile effect and aids in the breakup of a projectile.

[0010] The armor system of Gooch is produced through the use of the well known "lost foam process." See Metals Handbook, Volume 15, pp. 230-234 (1988). This casting process encompasses creating a styrofoam master plate which would represent the structure of the applique armor. The styrofoam master plate is then coated with a commercially available sand slurry mixture which hardens onto the surface of the plate. Finally, a castable metal is poured down and along the coated styrofoam master plate. Said poured, castable metal replaces the styrofoam within the master and produces an exact copy of the styrofoam master plate. Hence, the name "lost foam process." The use of any castable metal is within the scope of Gooch. Among the preferred castable metals which may be used are aluminum, steel, stainless steel and titanium. Although only one cast single plate P900 armor may be needed to protect a substrate, Gooch contemplates a plurality of plates utilized.

[0011] The combination of a metal matrix composite armor having integrally cast holes and the process for producing said armor utilizing metal infiltration casting is neither taught or suggested in the prior art.

SUMMARY OF THE INVENTION

[0012] A lightweight armor system according to the present invention includes one or more containment layers having slotted holes of various sizes and designs. Additional layers of containment material (without slotted holes) and/or material layers of dense material may be added to the armor system either between the slotted holed containment layers or stacked on the top or bottom of the slotted holed containment layers. The dense layers can include an infinite combination of dense material types and geometries. These dense layers may comprise inorganic material systems such as ceramics, metals or composites with dense microstructures.

[0013] Other dense layers include ceramic structures containing interior voids or hollow regions and ceramic fabrics including ceramic-fiber weaves. The geometries can be in the form of flat plates of varying thickness, of multiple sequences and combinations of the dense materials, and in the forms of spikes, spheres, rods, etc. The containment layers may be ceramic particulate, metal particulate, or fiber reinforced material with an interconnected metal matrix (no open porosity once infiltrated unless closed pores or void spaces), and with or without integrally cast holes.

[0014] The dense layers and containment layers are infiltrated with liquid metal which solidifies within the materials open porosity thereby binding the layers together to create a coherent integral structure. The dense layers can be selected according to their denseness and fraction of void volume at the material surface that are to be infiltrated with liquid metal.

[0015] The selection of different dense and containment material types allows the designer to vary thermal expansion coefficients throughout the structure to create varying stress states for increased effectiveness of the armor system. The selection of different material types may also be based on strength, toughness, and weight attributes of the individual material types desirable for projectile impact protection.

[0016] A process for producing a lightweight armor system comprises the steps of 1.) forming holes in a preform containment layer 2.) positioning sealed tubes in the formed holes so that the tubes run through the thickness of the preform 3.) positioning at least one preform w/ sealed tubes within a mold chamber of a closed mold and 4.) infiltrating the mold with a liquid metal. Step 3 may optionally comprise the placement of dense layers or preform containment layers (without integrally cast holes) between or on the top or bottom of the preform containment layer (with integrally cast holes). The liquid metal is introduced under pressure into the casting mold infiltrating the dense layers and the containment layers throughout their open porosity. The mold chamber is fabricated to create the final shape or closely approximate that desired of the final product.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The invention is best understood from the following detailed description when read in connection with the accompanying drawings, which illustrate an embodiment of the present invention:

[0018] FIG. **1** is a perspective view of a containment layer preform **10**.

[0019] FIG. **2** is a perspective view of containment layer preform **10** after holes **20**A have been molded-in, formed, or cut through the thickness of preform **10**.

[0020] FIG. **3** illustrates the placement of sealed tubes **20** within holes **20**A.

[0021] FIG. **4** illustrates sealed tubes **20** fully inserted within containment layer preform **10** and horizontally placed.

[0022] FIG. **5** illustrates tubes **20** fully inserted within containment layer preform **10** at an oblique angle.

[0023] FIG. **6** illustrates a hermetically sealed tube **20**.

[0024] FIG. **7** illustrates fully inserted tubes **20** within containment layer preform **10** and vertically placed.

[0025] FIG. **8** illustrates the vertically placed tubes of FIG. **7** at an oblique angle.

[0026] FIG. **9** illustrates the containment layer preform **10** of FIG. **7** placed within mold cavity **15** on spacers **12**.

[0027] FIG. **10** illustrates two containment layer preforms **10**, with offset vertically placed tubes, stacked and placed within mold cavity **15**.

[0028] FIG. **11** illustrates dense layers **25** placed on the top and bottom of containment layer preform **10**, sitting within mold **15** on spacers **12**.

[0029] FIG. **12** illustrates the containment layer preform **10** of FIG. **4** with dense layers **25** placed on the top and bottom of containment layer preform **10**, sitting within mold **15** on spacers **12**.

[0030] FIG. **13** illustrates the resulting armor plate **30** after metal infiltration casting of FIG. **9**, and removal from mold **15**.

[0031] FIG. **14** illustrates the resulting armor plate **35** after metal infiltration casting of FIG. **10**, and removal from mold **15**.

[0032] FIG. **15** illustrates the resulting armor plate **40** after metal infiltration casting of FIG. **11**, and removal from mold **15**.

[0033] FIG. **16** illustrates the resulting armor plate **45** after metal infiltration casting of FIG. **12**, and removal from mold **15**.

DETAILED DESCRIPTION OF THE INVENTION

[0034] A lightweight armor system according to the present invention is best seen in the embodiments illustrated in FIGS. **13-16** and is formed by the process illustrated in FIGS. **1-12**. In the preferred embodiment, a method of forming a lightweight armor plate comprises the steps of first providing a ceramic reinforcement preform **10** (alternatively referred to as containment layer) consisting of at least 60 percent volume fraction of ceramic particles or fibers as illustrated in FIG. **1**. Ceramic particles are the preferred reinforcing material preform **10** but ceramic or metal in the form of particulates or fibers may also be used. The ceramic and/or metal particulate or fiber reinforcement preform **10** within the metal matrix include materials such as aluminum oxide, carbon, graphite, silicon carbide, boron carbide, titanium, tungsten, molybdenum, copper, aluminum and other anticipated ceramics or metal materials. Other reinforcement preform **10** material may include SAFFIL material consisting of discontinuous ceramic or alumina fibers at a length of 0.02 to 4 inches, and with a reinforcement volume as low as about 2%. Such discontinuous fiber reinforcement produces a more ductile Meal Matrix Composite (MMC) after metal infiltration compared to a Silicon Carbide particulate reinforcement at about 60% volume. The reinforcement preform **10** body may be at a thickness of 0.5 mm or more.

[0035] The preform reinforcement structures have an interior open porosity between about 30% and about 98% prior to metal infiltration. The preforms **10** have a predetermined fraction of void volume or open structure throughout the material structure, or can be open spaces in a closed mold, that are filled with molten metal subsequent to metal infiltration casting.

[0036] A process of forming a reinforcement preform constituent or containment layer, which may be utilized in subject invention, is disclosed in U.S. Pat. No. 5,047,182, incorporated herein by reference for all it discloses.

[0037] Next, holes **20**A are either cast directly into the preform **10** at the time of preform manufacture or they are machined through the preform **10** by CNC machining or other methods known in the art. The density of the holes can range between 20 percent and 80 percent and may be cast linearly (FIGS. **2-5**) or non-linearly throughout the preform. The diameter of the holes can range from about ⅛ inch to about 1 inch or more for circular holes. The holes may be formed normal or at an oblique angle as illustrated in FIGS. **4** and **5**. The holes may be set in the preform either horizontally or vertically as illustrated in FIGS. **2** and **7**. The shape of the hole is not restricted and may be elliptical, oval, round, square or rectangular.

[0038] Next, an array of tubes **20**, are fitted in holes **20**A (for circular hole configuration), and in the preferred embodiment, run through the thickness of the preform **10**, as illustrated in FIGS. **3** and **4**., In an alternative embodiment the tubes may run through only a portion of the preform **10**. The tubes **20** comprise hollow metal or ceramic "cans" which may be hermetically sealed. In one embodiment, the tubes **20** are sealed and consist of a thin outer skin of metal, the metal capable of withstanding the metal infiltration temperatures without losing strength or reacting adversely with the molten metal, and able to not deform under the pressure of infiltration casting. Alternatively, the tubes **20** may be filled with a non-compressible material such as ceramic, metal particulates, or inorganic salts, able to maintain sufficient strength at the infiltration temperatures to prevent the tube **20** from deforming or collapsing.

[0039] The preform **10** is next set in the mold cavity **15** on top of spacers **12** as illustrated in FIG. **9**. The spacers **12** act to create a space between the preform **10** and the mold cavity **15** inner surface. In an alternative embodiment, a plurality of preforms **10** may be stacked as illustrated in FIG. **10**. In this embodiment holes **20**A of said plurality of preforms **10** would be offset from each other as illustrated in FIG. **10**. If desired, dense layers **25** may be stacked on the top and bottom of preform **10** as illustrated in FIGS. **11** and **12**, or may alternatively be layered between the stacked layers of preforms **10** (not shown) where a plurality of preforms **10** are set in the mold cavity **15**.

[0040] Alternatively, the dense layers may be replaced with preforms **10** (without holes). The shape of the "layup" (stacked layers of dense and preform material layers) is determined by the dimensions of the casting cavity used to create a single integrated solid structure. The dense layers **25** may comprise a microstructure designed without interconnected porosity and having a predetermined fraction of void volume or open structure at its surface that is filled with molten metal subsequent to metal infiltration casting. The dense layer may also have no open porosity at its surface.

[0041] Dense layer **25** may be dense ceramic such as aluminum oxide, silicon carbide, boron carbide, silicon nitride, chemical vapor deposit diamond at a thickness of 0.5 mm to 50 mm. Dense layer **25** may be a dense metal such as titanium, tungsten, molybdenum, and depleted uranium at a thickness of 0.25 mm to 50 mm. Other suitable dense materials include but are not limited to glass-ceramics, and other inorganic material systems which are compatible with molten metal processing and which can contribute to ballistic resistance of the integrated system.

[0042] Dense materials such as high strength steels, metal alloys, and ceramic alloys may be used in subject invention. Dense material layers **25** include between 0 and 20% surface porosity with the interior of the dense materials not susceptible to metal infiltration. FIGS. **15** and **16** illustrate dense layers **25** having a percentage of open porosity at their surface that is infiltrated with metal denoted by symbol "xxx". The dense materials may include "voids" or open spaces within their interior, however, no interconnected porosity is present which would provide a path for metal infiltration from the surface to the interior of dense layer **25**. The spacer material **12** may comprise either dense or containment material described above.

[0043] Referring to FIGS. **13**-**16**, the layered materials are illustrated after metal infiltration casting and subsequent removal from the closed mold as a single integral unit. The metal infiltrant contained within the layered materials is denoted by the drawing symbol "xxx". The layered materials would be set into a casting mold in an amount necessary to conform to the shape of the mold. FIG. **13** illustrates a single preform **10** or containment layer. Following infiltration casting the preform **10** becomes metal rich or metal matrix composite, however the interior volume of the tubes **20** are void of metal infiltrant. A metal skin **13** is formed around the stacked material layers and sealed tubes **20** and has a thickness of from about 0.000 to about 0.030 inches.

[0044] It is understood that the "layup" disclosed herein is illustrative of several embodiments of subject invention and that subject invention may comprise other combinations of dense layers and containment layers. The volume fraction of dense reinforcement material is determined by its type, and selected according to desired ballistic resistance properties and threat type, and by the final CTE requirement of the particular layer of the integrated structure.

[0045] For example, in the case of a SiC particulate containment layer infiltrated with molten aluminum, the volume fraction of SiC is in the range of 0.15 to 0.70 and is sufficient to obtain composite CTE values in the range of 6 to 13 or more ppm/degree Celsius when exposed to temperatures in the range of −50 to 150 degree celsius.

[0046] In a structure having graphite fiber containment layer, the volume fraction of 0.60 graphite fibers is sufficient enough to produce CTE values of less than 5 ppm/degree Celsius. A dense layer of SiC (Silicon Carbide) ceramic plate may have a CTE value of 4 ppm/degree celsius.

[0047] The stacked material "layups" of dense layers and containment layers, as illustrated in FIGS. **1**-**12**, are placed into a mold cavity suitable for molten metal infiltration casting. The mold cavity is typically prepared from a die suitable for molten metal infiltration casting with the dimensions defined to produce a multi-structure metal matrix composite. The layered material embodiments, as illustrated in FIGS. **1**-**12**, are infiltrated with molten aluminum to form a metal matrix bonded composite in the desired product shape geometry. At this point the containment layer now becomes impregnated with metal and can alternatively be referred to as a "Metal Matrix Composite" MMC, layer.

[0048] Referring to FIGS. **13**-**16**, any open surface voids within the dense layers **25** are filled with aluminum during the Al infiltration process. Mechanical and chemical reactive surface bonding allows the dense material metal infiltrated surface to bond to adjacent dense layers and containment layers (with and without sealed tubes) and open porosity within the containment layers is filled with aluminum during metal infiltration casting.

[0049] Upon completion of the Al infiltration process all dense layers and containment layers are bonded together and encapsulated by aluminum skin **13**. The Al infiltration process causes aluminum to penetrate throughout the overall structure into the containment layers (and to surfaces of sealed tubes) and at the surfaces of the dense reinforcement layers. The Al infiltrant solidifies within and around the material layers extending from one layer interface to the next, thus binding the layers together and integrating the structure.

[0050] While molten aluminum is the embodiment illustrated other suitable metal infiltrants include but are not limited to aluminum alloys, copper, titanium and magnesium, and other metal alloys cast from the molten liquid phase. The liquid metal infiltration process is described in U.S. Pat. No. 3,547,180 and incorporated herein by reference for all that it discloses. A significant advantage of a lightweight armor system as illustrated in FIGS. **13-16** is that the various layers thereof comprise different dense and containment material layers which have different properties to increase the overall effectiveness of the armor system.

[0051] Metal Matrix Composite (MMC) armor plates with holes can replace P900 armor at less weight. The particles give the plate hardness and the holes enable the projectile to be deflected and it's energy dispersed without destroying the entire plate.

[0052] The thermal expansion coefficient, hardness, strength, fracture toughness, and ductility performance of various materials combined with open cavities created by sealed tubes can optimally defeat the ballistics threat. For example, a fiber or particulate or Al-rich containment layer acts to compress and contain the dense materials within. The dense material closest to the strike face may be of the hardest type, having less fracture toughness while an adjacent dense layer may have a greater resistance to crack propagation (fracture toughness) and therefore increase multi-hit capability. The containment layers surrounding the dense layers act to constrain and contain the ballistics damage and minimize crack propagation.

[0053] For example, the dense layers have a high compressive strength and acoustic impedance, thus making them ideal for the hard, projectile-shattering medium. The metal matrix composite interlayers or "containment layers" mechanically constrain (i.e. supports) the dense layers and sealed tubes. The compression and containment provided in the dense, containment layers, and sealed tube cavities of the structure improves the performance of the armor system. The metal matrix composite containment layers also dissipate and attenuate the stress wave and energy produced by the projectile impact. The energy dissipation function is enhanced by the variable ratio of dense and ductile containment layers and the volume and shape of void structures formed within the tubes.

[0054] These differing material properties tend to absorb or attenuate the shock wave more effectively than is generally possible with a material that has uniform material properties throughout. Utilizing material layers of different CTE values and which are strongly bound both mechanically and chemically produces compressive and tensioned layers throughout the composite armor after metal infiltration and solidification.

[0055] It should be understood that the preceding is merely a detailed description of one embodiment of this invention and that numerous changes to the disclosed embodiment can be made in accordance with the disclosure herein without departing from the spirit or scope of the invention. Rather, the scope of the invention is to be determined only by the appended claims and their equivalents.

We claim:

1. An integrated layered armor, comprising:

A plurality of layers comprising:

at least one dense layer and at least one containment layer,

at least one of said at least one containment layer comprising a plurality of holes integrated therein, said at least one containment layer and said at least one dense layer having a fraction of void volume prior to metal infiltration, said at least one containment layer and said at least one dense layer further comprising a metal, said metal infiltrated within said void volumes of said of least one containment layer and said at least one dense layer, said plurality of holes not infiltrated with said metal,

said metal infiltration binding said plurality of layers together to form an integrated structure by infiltrating said void volumes of said plurality of containment layers and said void volume of said dense layers, encapsulating said plurality of layers to form an integrated layered armor in the desired product shape geometry.

2. An integrated layered armor as in claim **1**, further including at least one metal enveloping layer, said metal enveloping layer encapsulating said at least one containment layer and said at least one dense layer.

3. An integrated layered armor as in claim **1**, wherein said containment layer fraction of void volume prior to metal infiltration is between about 30% and about 98%.

4. An integrated layered armor as in claim **1**, wherein said surface void volume of said at least one dense layer prior to metal infiltration is 20% or less, said at least one dense layer having no interconnected porosity which would provide a path for metal infiltration from the surface to the interior of said at least one dense layer.

5. An integrated layered armor as in claim **1**, wherein said at least one containment layers comprises a reinforcement material of ceramic, glass, or glass-ceramic, including oxides and non-oxides, selected from the group consisting of silicon carbide, aluminum oxide, silicates, boron-carbide, graphite and carbon, and in the form of particles, flakes, continuous and discontinuous fibers.

6. An integrated layered armor as in claim **1**, wherein said at least one of said at least one containment layers comprises a plurality of holes having a density between 20 and 80 percent.

7. An integrated layered armor as in claim **1**, wherein said at least one containment layers comprises a metal reinforcement.

8. An integrated layered armor as in claim **1**, wherein at least one of said at least one dense layer comprises a ceramic material selected from the group consisting of aluminum oxide, silicon carbide, boron carbide, silicon nitride and chemical vapor deposit diamond.

9. An integrated layered armor as in claim **8**, wherein said at least one of said at least one dense layer is a least 0.25 mm thick.

10. An integrated layered armor as in claim **1**, wherein at least one of said at least one dense layer comprises a metal material selected from the group consisting of titanium, tungsten, molybdenum, and depleted uranium.

11. An integrated layered armor as in claim **2** wherein said metal infiltrant and said metal enveloping layer are selected from the group consisting of aluminum alloys, copper, titanium, and magnesium.

12. An integrated layered armor as in claim **1**, wherein said plurality of holes includes metal or ceramic tubes integrated therein.

13. An integrated layered armor as in claim **12**, wherein said tubes are sealed.

14. An integrated layered armor as in claim **1**, wherein said plurality of holes are set in obliquity.

15. An integrated layered armor as in claim **1**, wherein said plurality of holes range from about 1/16 inch to about 1 inch in diameter.

16. An integrated layered armor as in claim **1**, wherein said plurality of holes in at least one of said containment layers is offset from said plurality of holes in another containment layer.

17. An integrated layered armor as in claim **12**, wherein said metal tube includes a reinforcement material therein.

18. An integrated layered armor as in claim **1**, wherein said plurality of holes integrated within said containment layer, are aligned horizontally.

19. An integrated layered armor as in claim **1**, wherein said plurality of holes integrated within said containment layer, are aligned vertically.

20. An integrated layered armor as in claim **1**, wherein said plurality of holes run through the entire length of said at least one of said at least one containment layer.

21. A method of producing an armor plate comprising the steps of:

Forming a plurality of holes in a reinforcement material layer;

Positioning sealed hollow tubes in said plurality of holes;

Placing said reinforcement material layer including said hollow tubes in a sealed mold cavity suitable for infiltration casting; and

Infiltrating under pressure said sealed mold cavity with liquid metal.)

22. A method as in claim **21**, further comprising prior to the step of infiltrating said sealed mold cavity, the step of :

Placing at least one dense material layer in said sealed mold cavity.)

23. A method as in claim **21**, further comprising prior to the step of infiltrating said sealed mold cavity, the step of:

Placing at least one containment material layer in said sealed mold cavity.)

24. A method as in claim **21**, including after the step of infiltrating said mold cavity with a liquid metal, the steps of:

Cooling said armor plate until said metal infiltrant solidifies, and

Removing said armor plate from said sealed mold cavity.)

25. An armor, comprising:

at least one containment layer, at least one of said at least one containment layer comprising a plurality of sealed tubes integrated therein, said at least one containment layer having a fraction of void volume prior to metal infiltration, said at least one containment layer further comprising a metal, said metal infiltrated within said void volumes of said at least one containment layer, said sealed tubes not infiltrated with said metal.)

26. An integrated layered armor as in claim **25**, further including at least one metal enveloping layer, said metal enveloping layer encapsulating said at least one containment layer.)

27. An integrated layered armor as in claim **25**, wherein said containment layer comprises a discontinuous fiber material reinforcement perform.)

28. An integrated layered armor as in claim **27**, wherein said discontinuous fiber material comprises discontinuous fibers at a length of about 0.02 to about 4 inches.)

29. An integrated layered armor as in claim **27**, wherein said discontinuous fiber material has a volume of about 2 percent or more.)

30. An integrated layered armor as in claim **1**, wherein said at least one dense layer has zero void volume, said dense layer not infiltrated with metal.

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