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(54) **THREE-DIMENSIONAL GRID PANEL**

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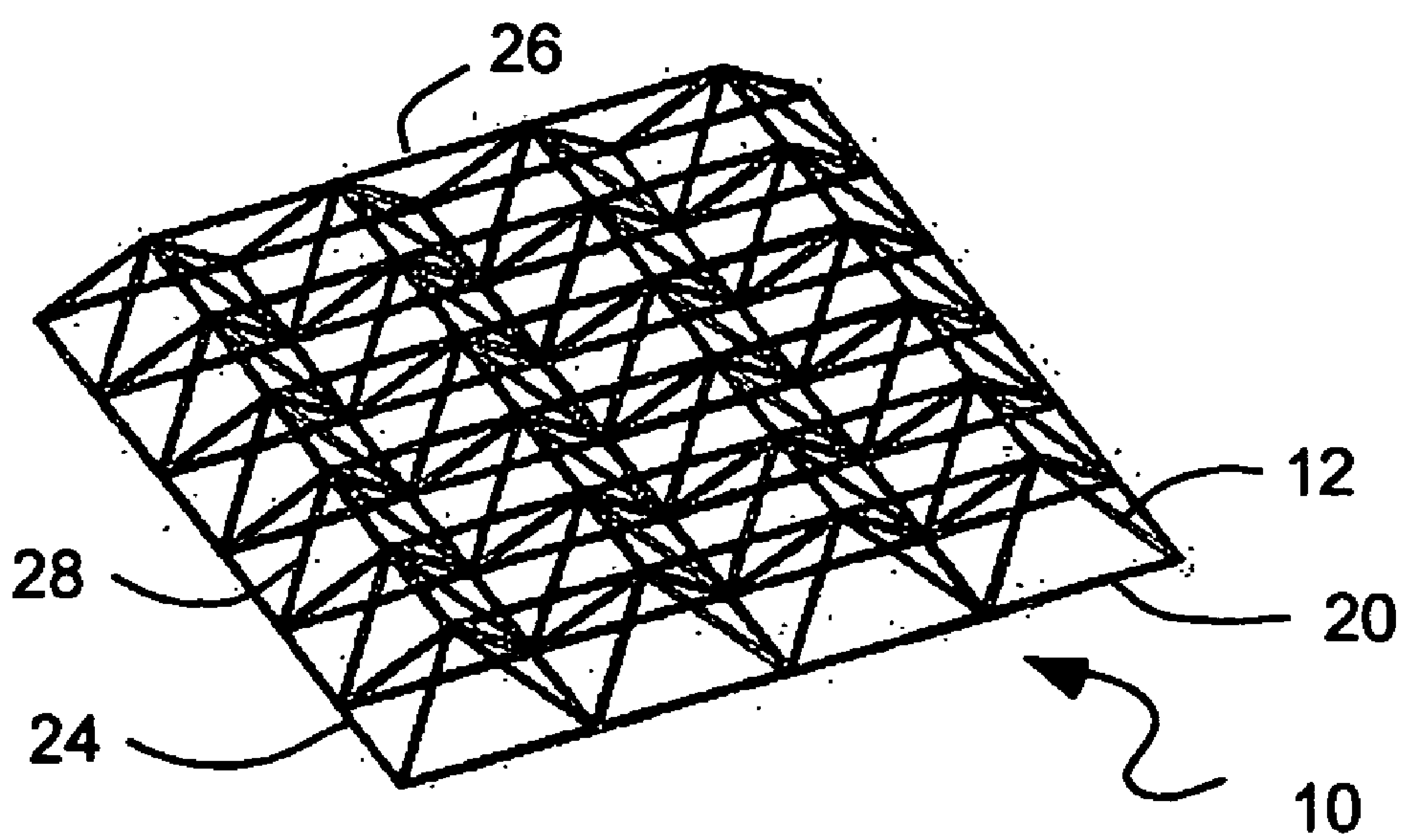
(57) **ABSTRACT**

A three-dimensional grid panel **(10)** includes an intermediate grid **(28)** disposed between and attaching two spaced-apart grids **(24, 26)**. Each of the two spaced-apart grids includes a first plurality of elongated components **(30, 40)**, and a second plurality of elongated components **(32, 42)** oriented transverse to the first plurality of components and intersecting the first plurality of components at nodes. The intermediate grid includes a first plurality of intermediate components **(46)**, each extending between nodes of the two spaced-apart grids, and a second plurality of intermediate components **(48)**, each extending between nodes of the two spaced-apart grids, and oriented transverse to the first plurality of intermediate components.



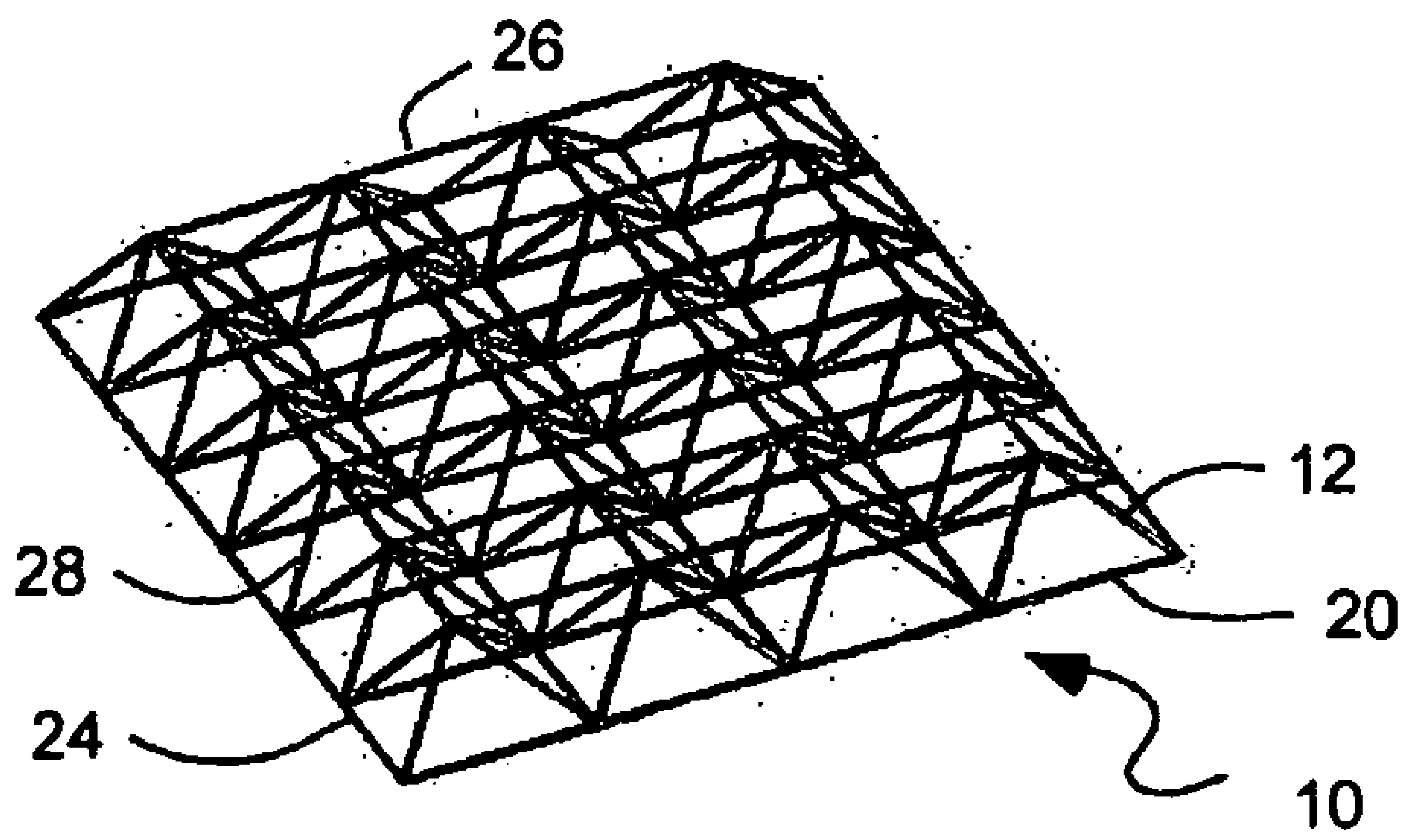


FIG. 1a

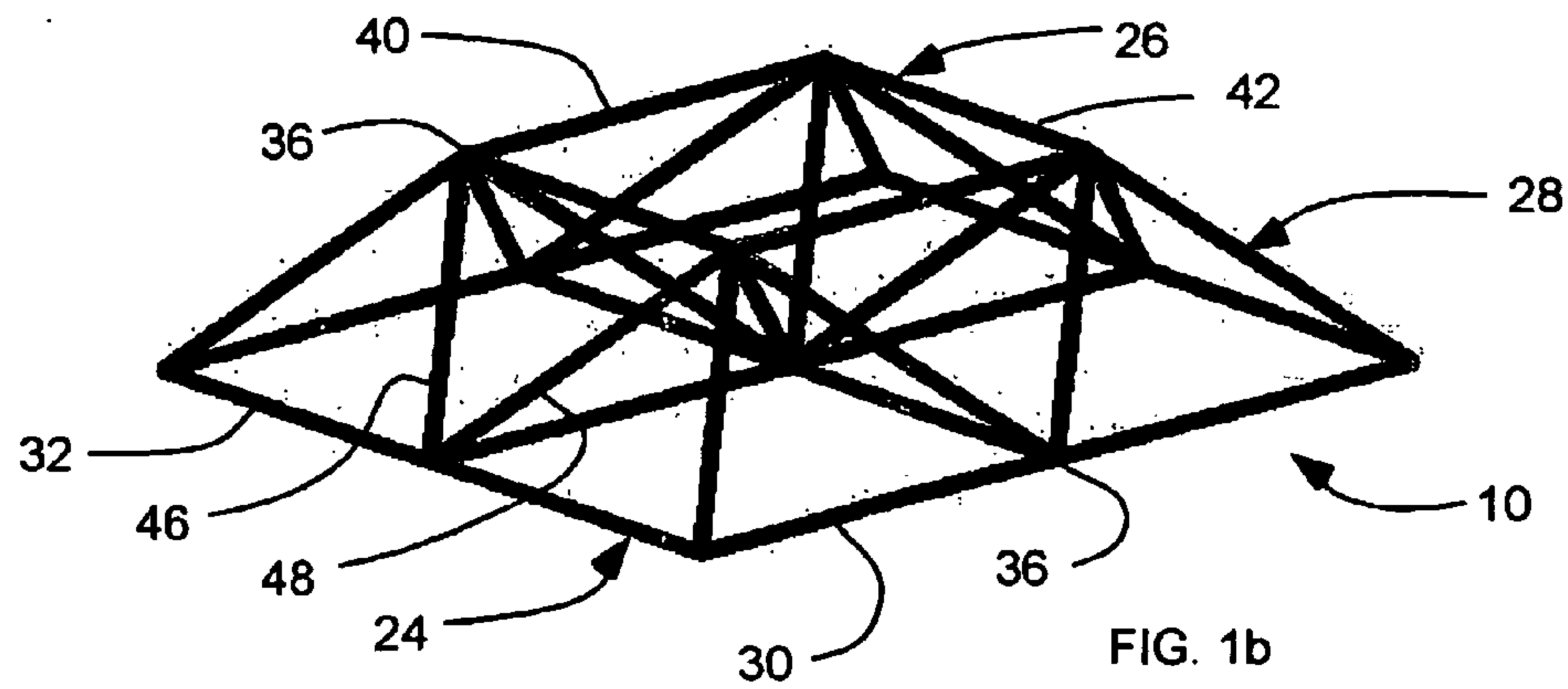


FIG. 1b

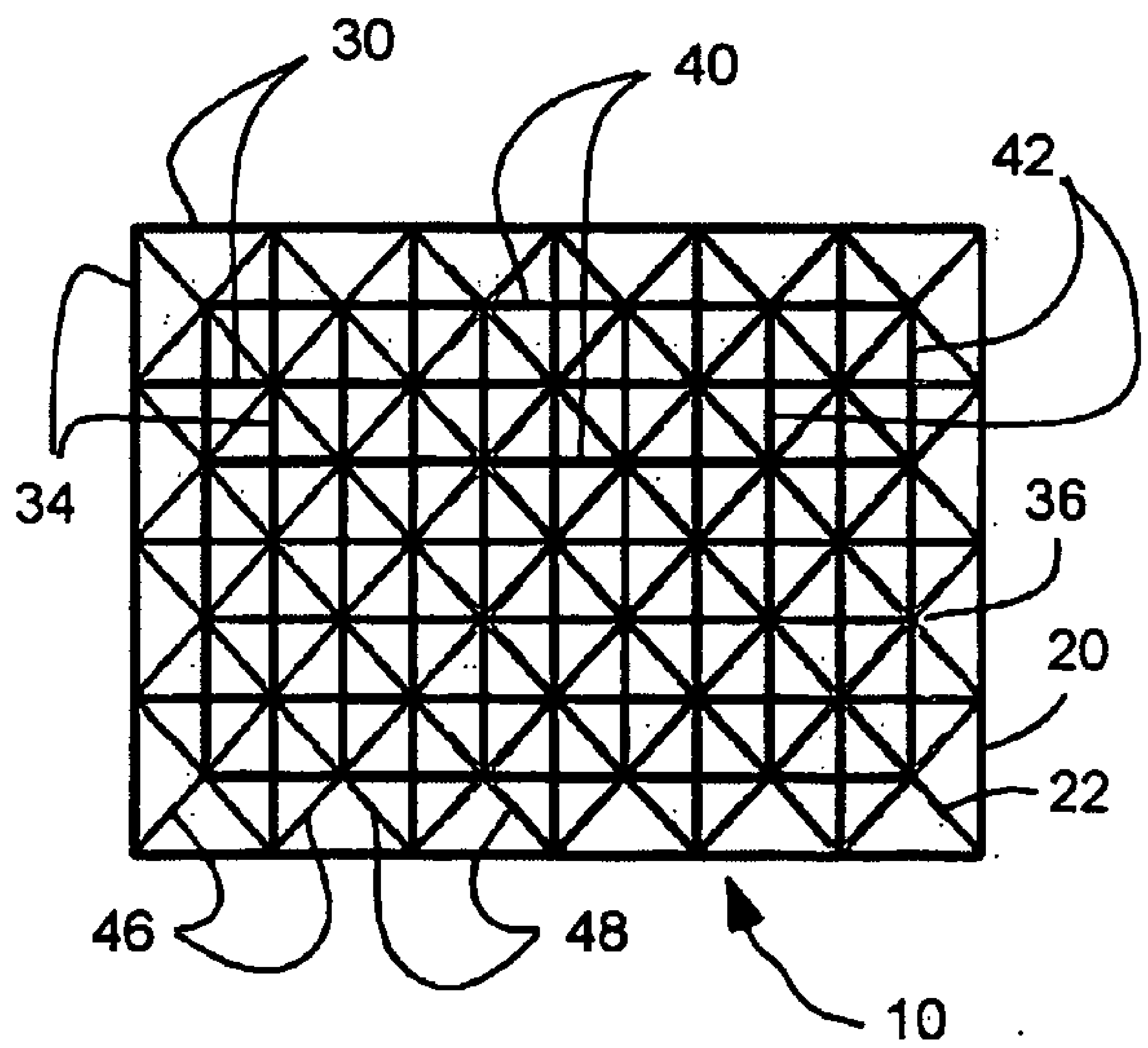


FIG. 1c

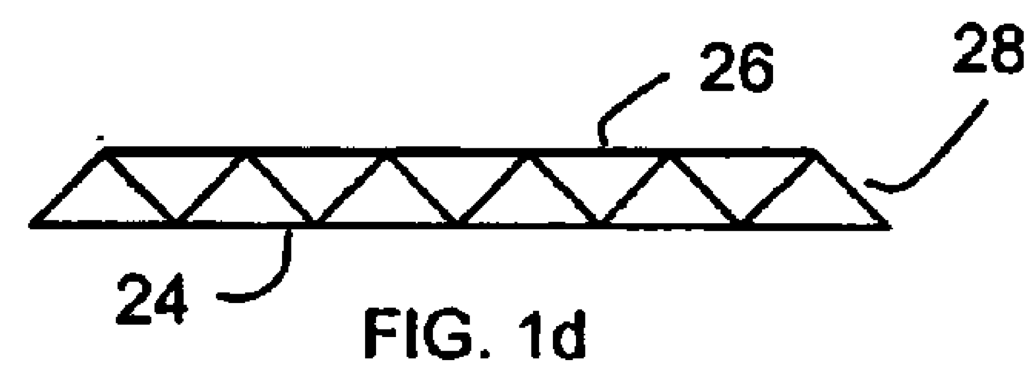


FIG. 1d

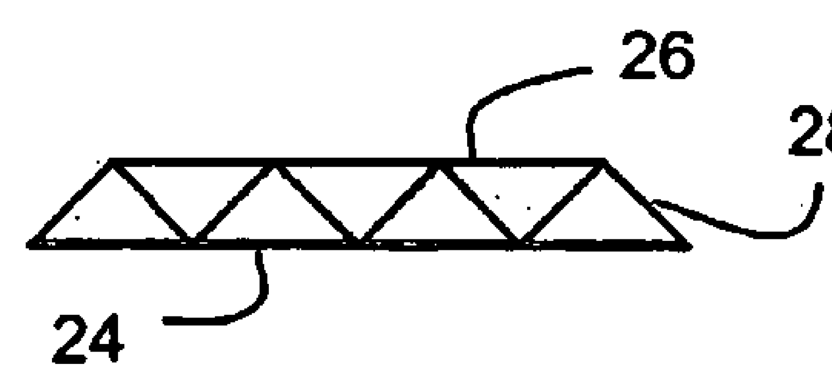


FIG. 1e

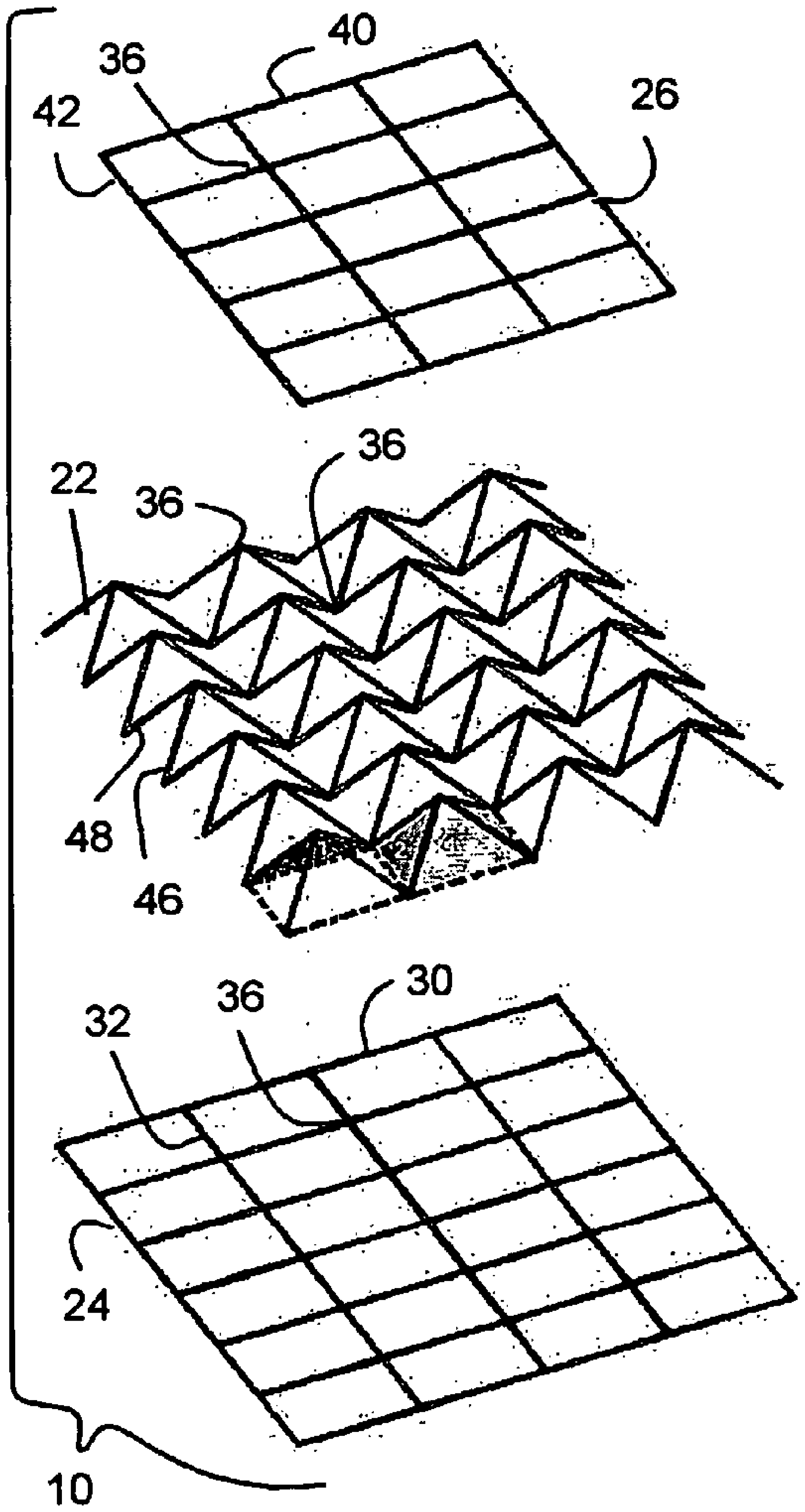


FIG. 1f

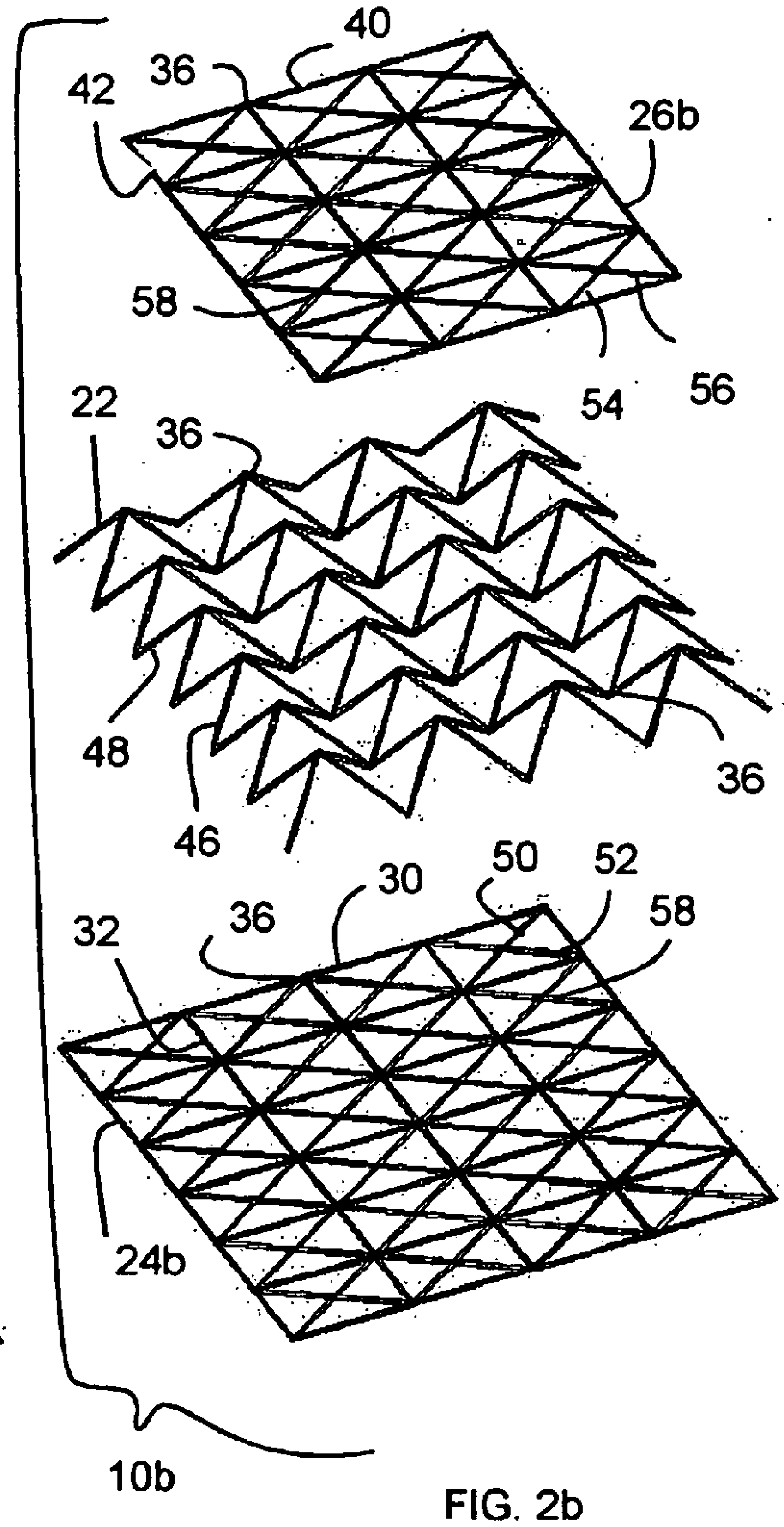


FIG. 2b

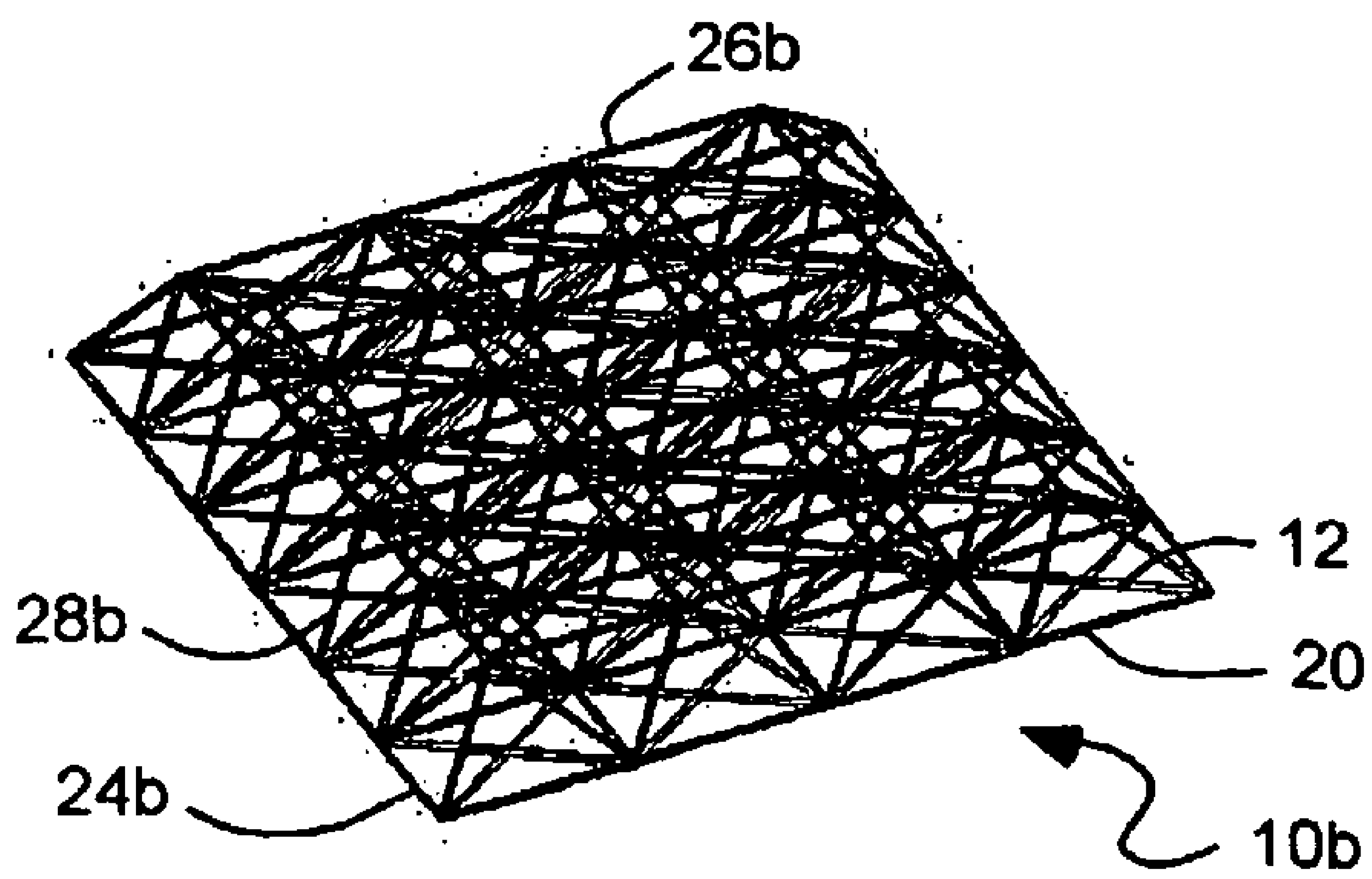


FIG. 2a

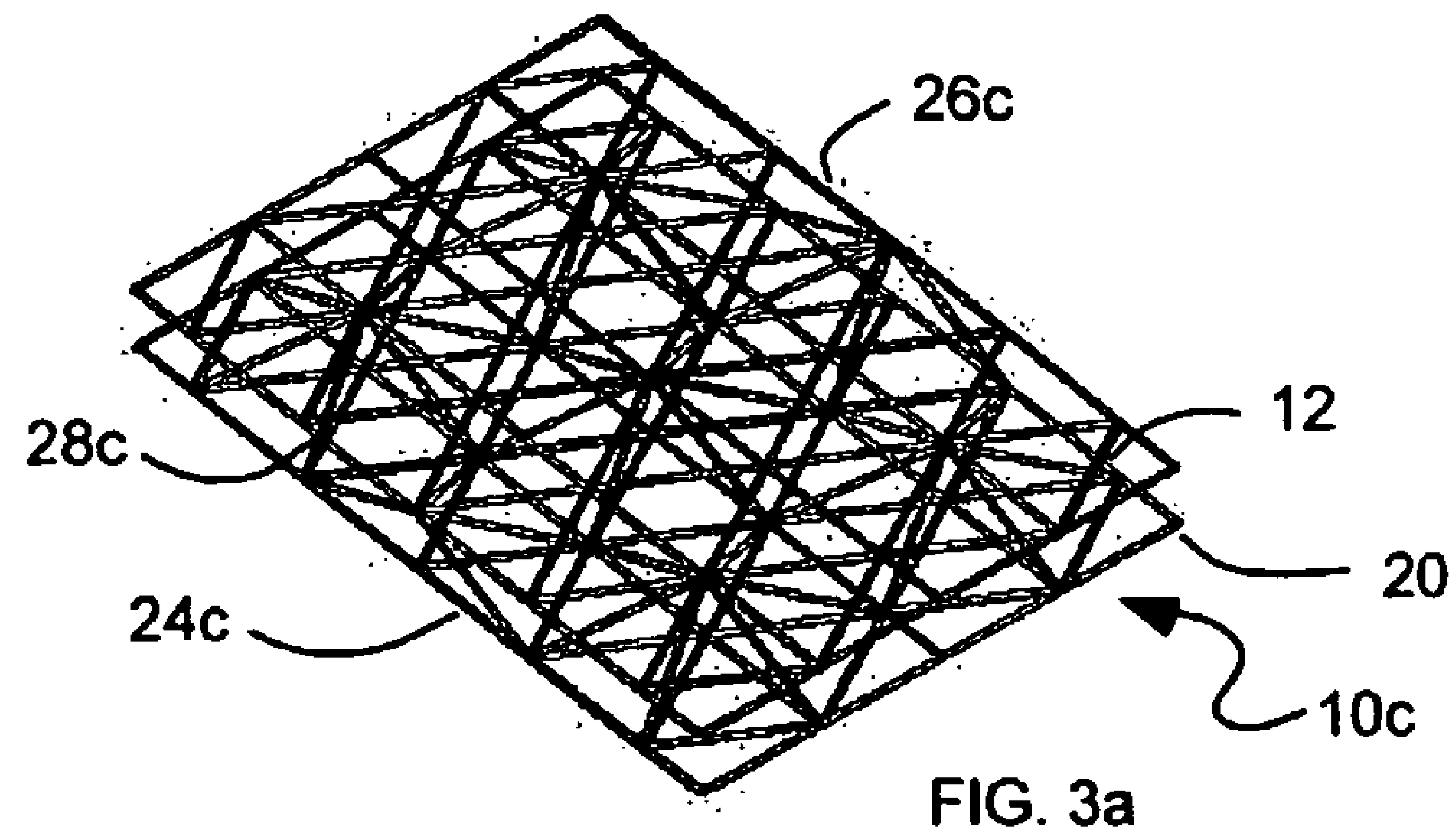

26c
12
28c
20
24c
10c

FIG. 3a

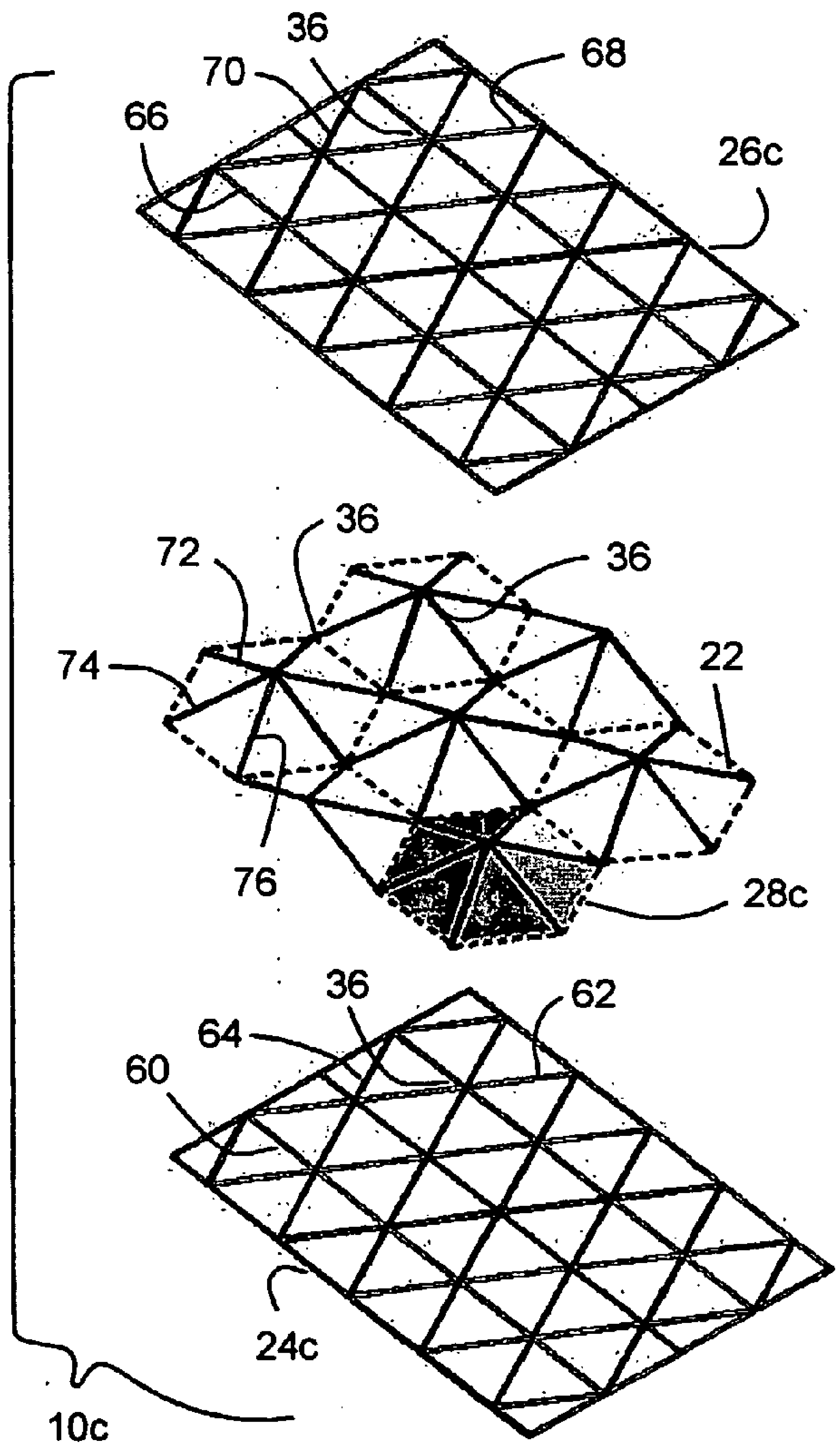

36
70
68
66
26c
36
72
36
74
22
76
28c
36
62
64
60
24c
10c

FIG. 3b

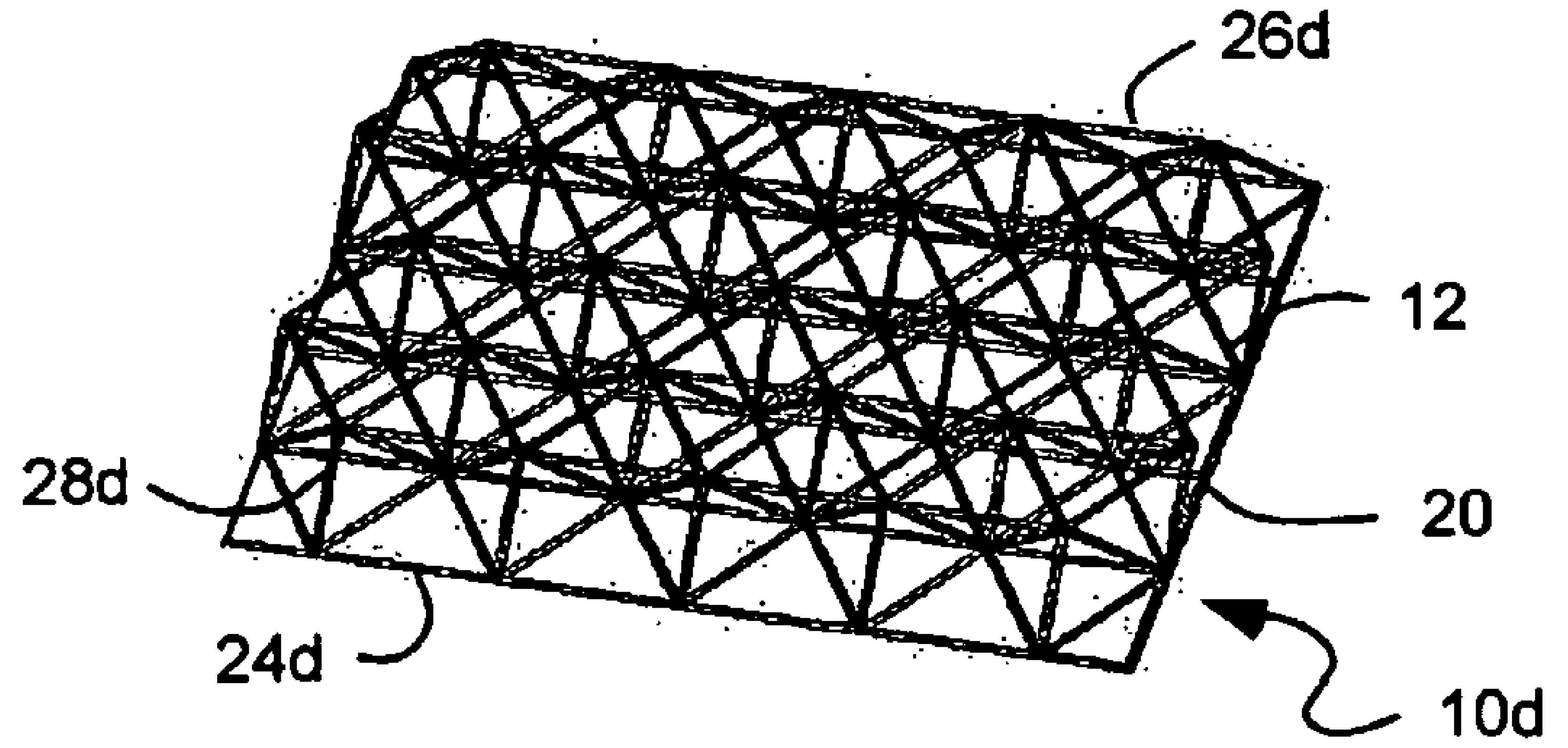


FIG. 4a

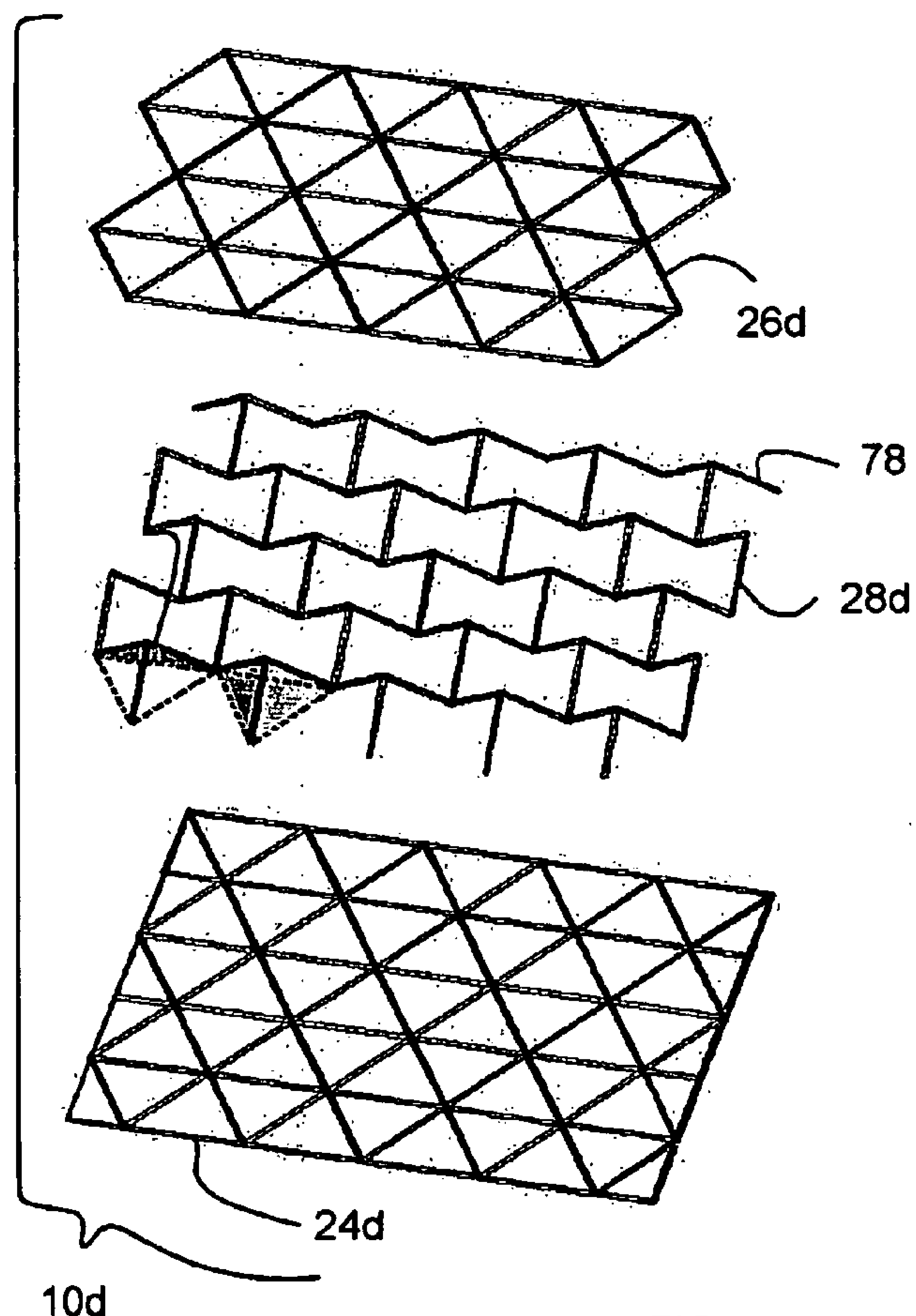


FIG. 4b

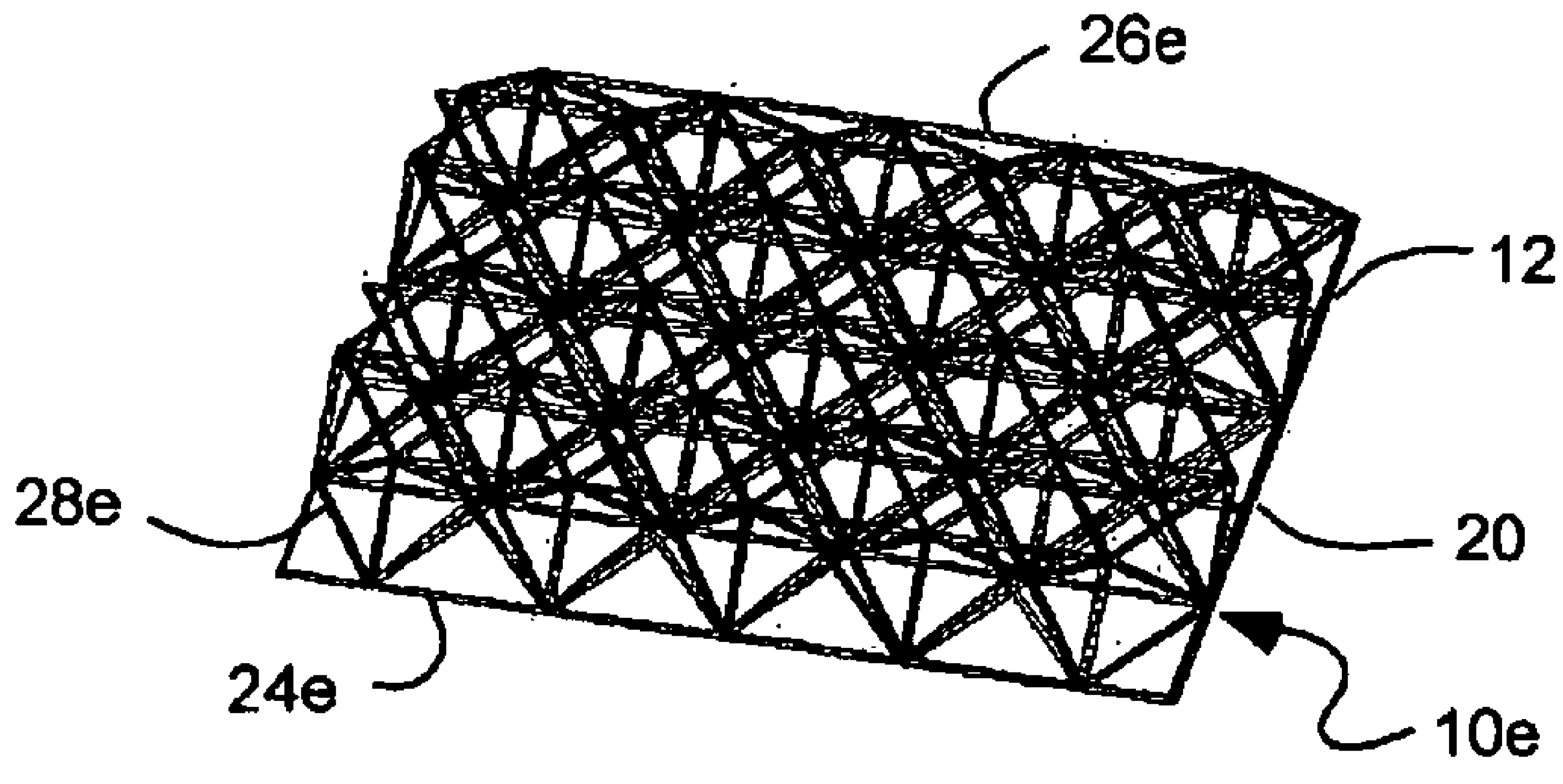


FIG. 5a

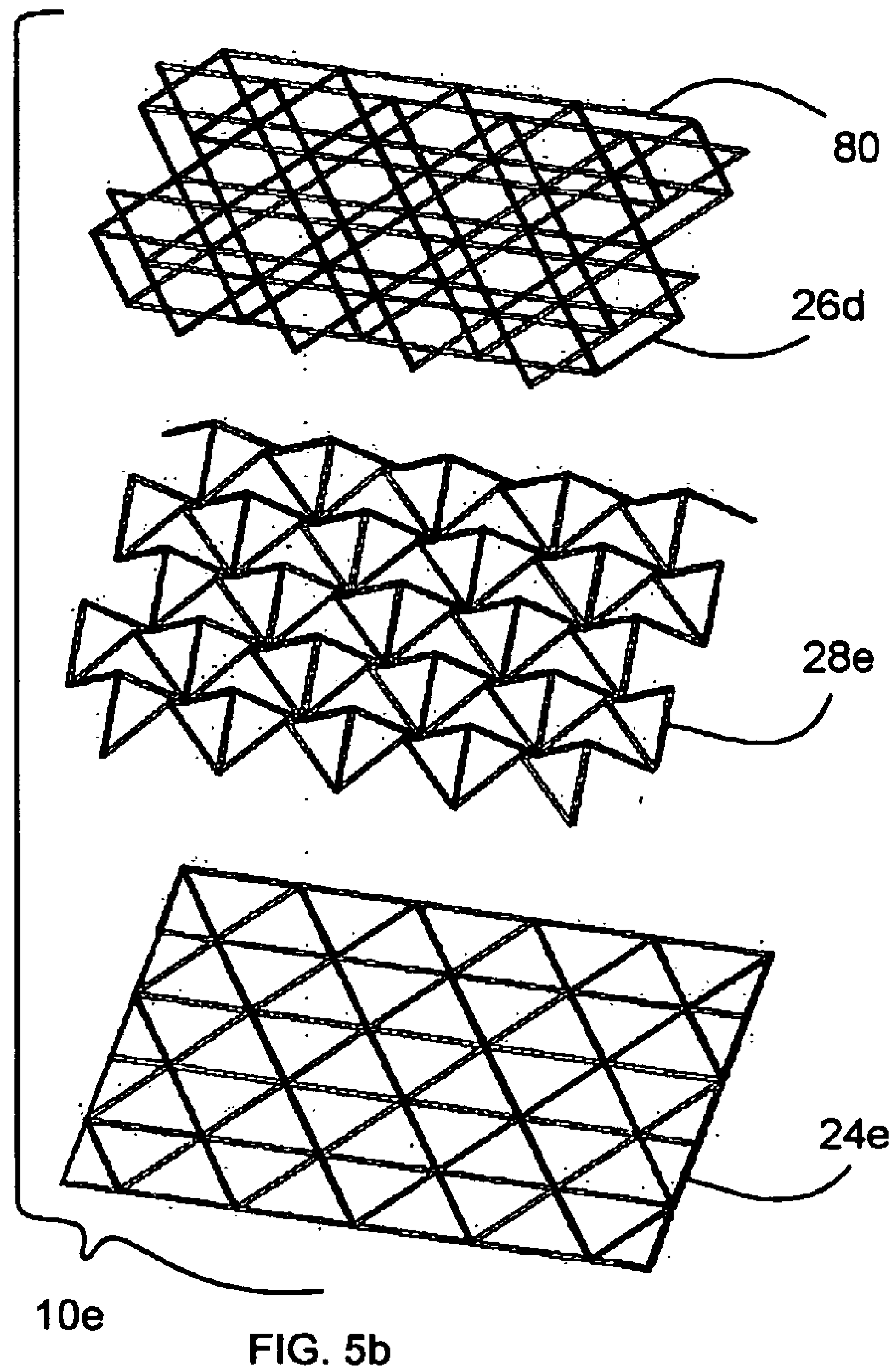


FIG. 5b

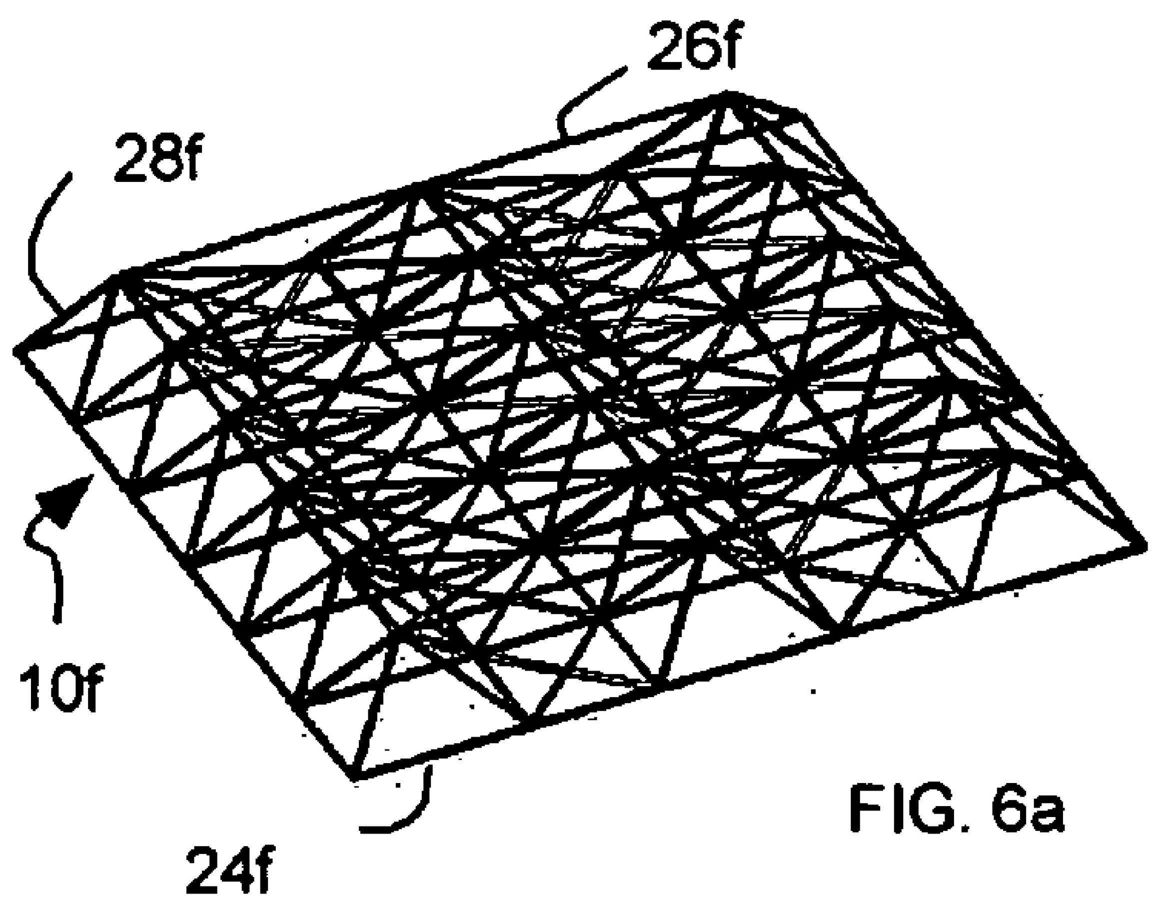


FIG. 6a

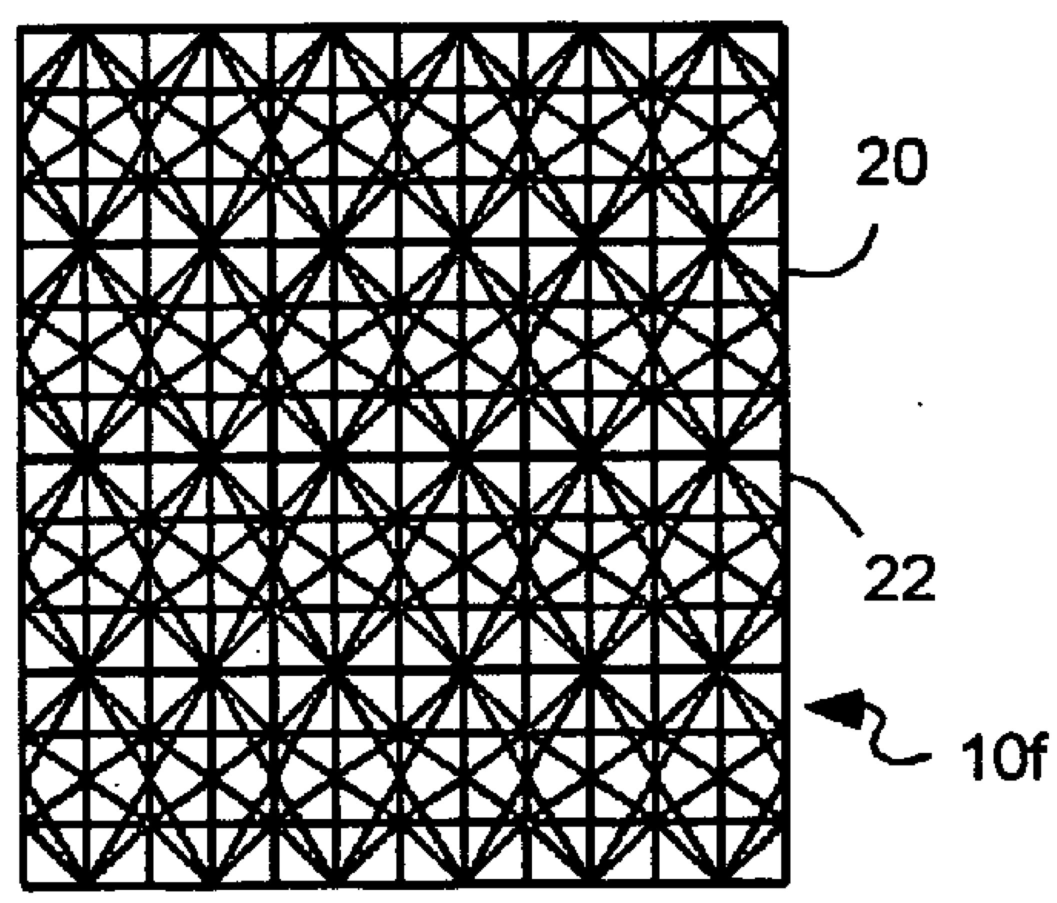


FIG. 6b

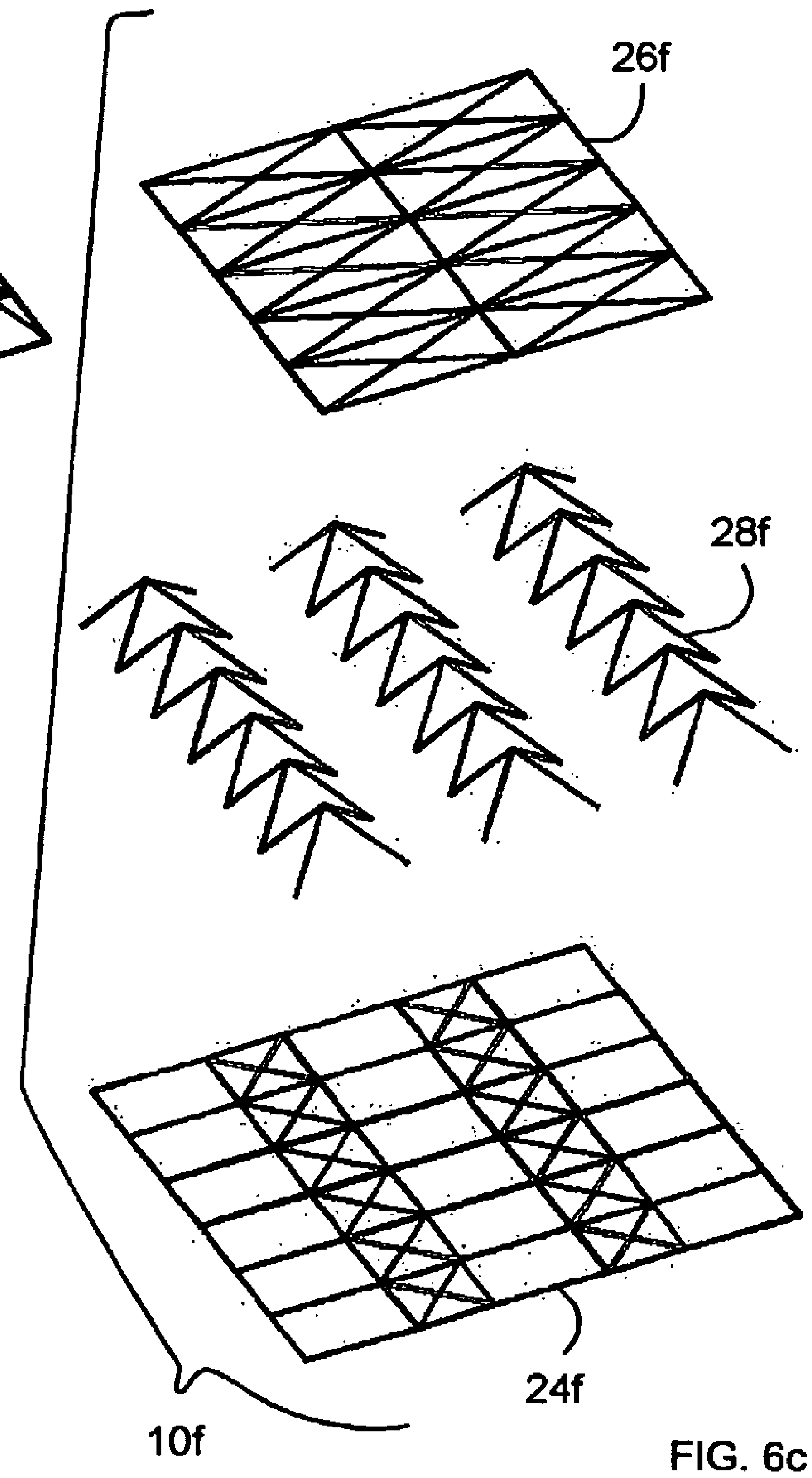


FIG. 6c

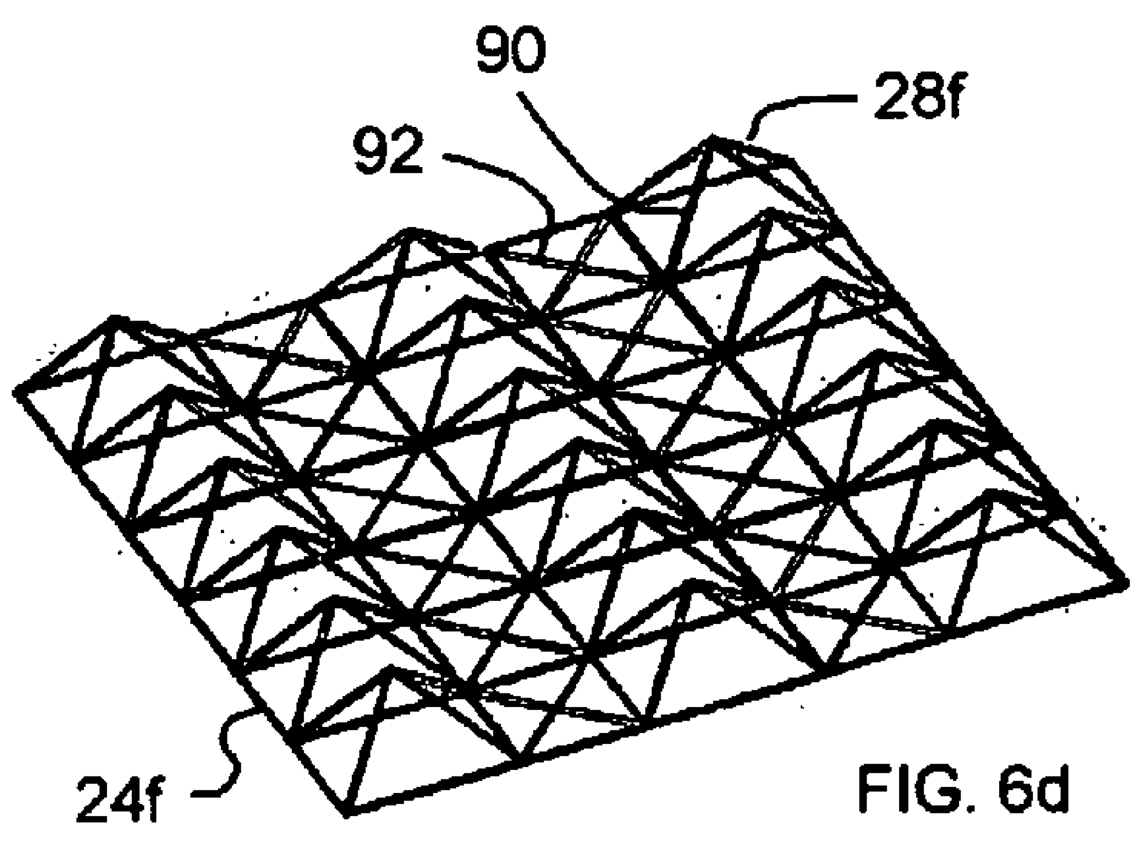


FIG. 6d

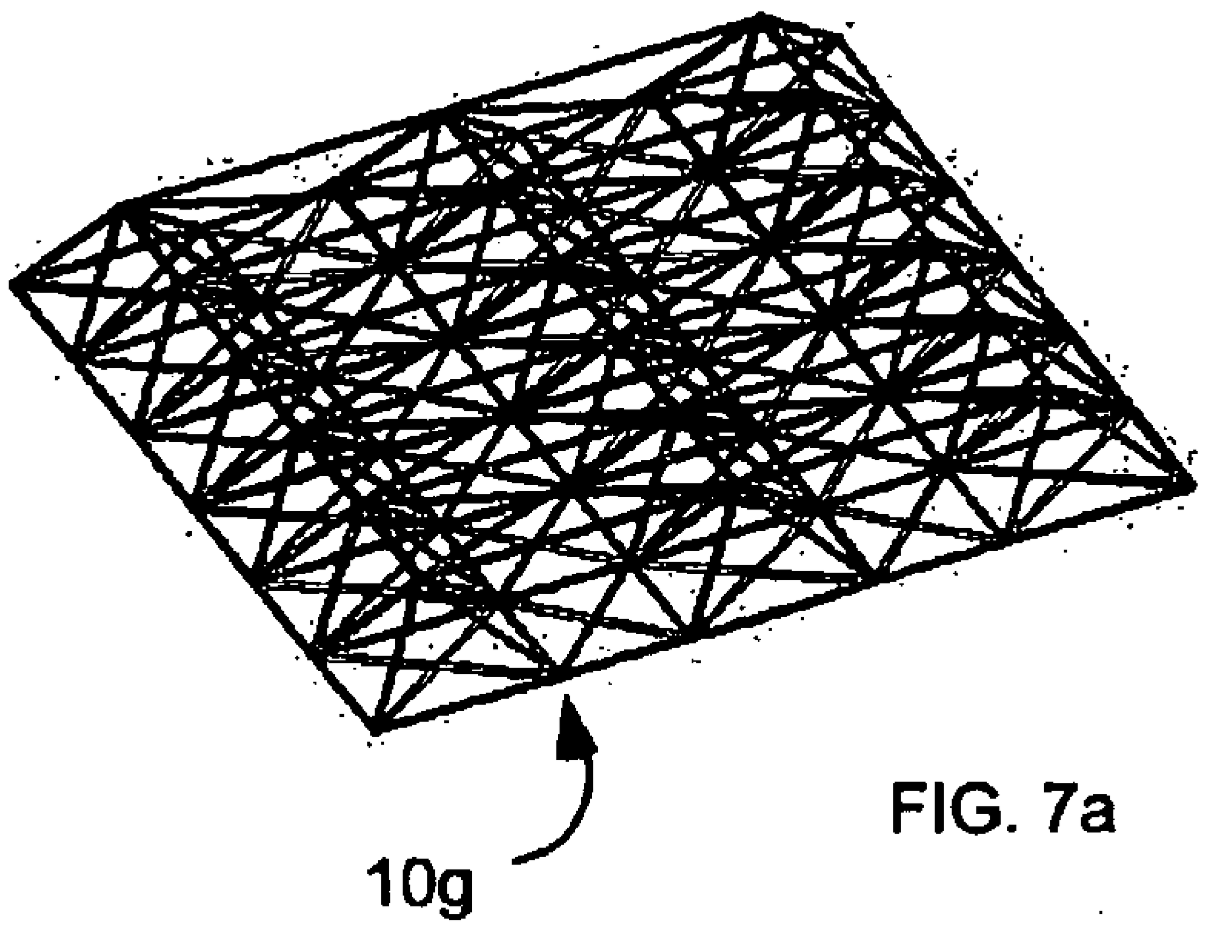


FIG. 7a

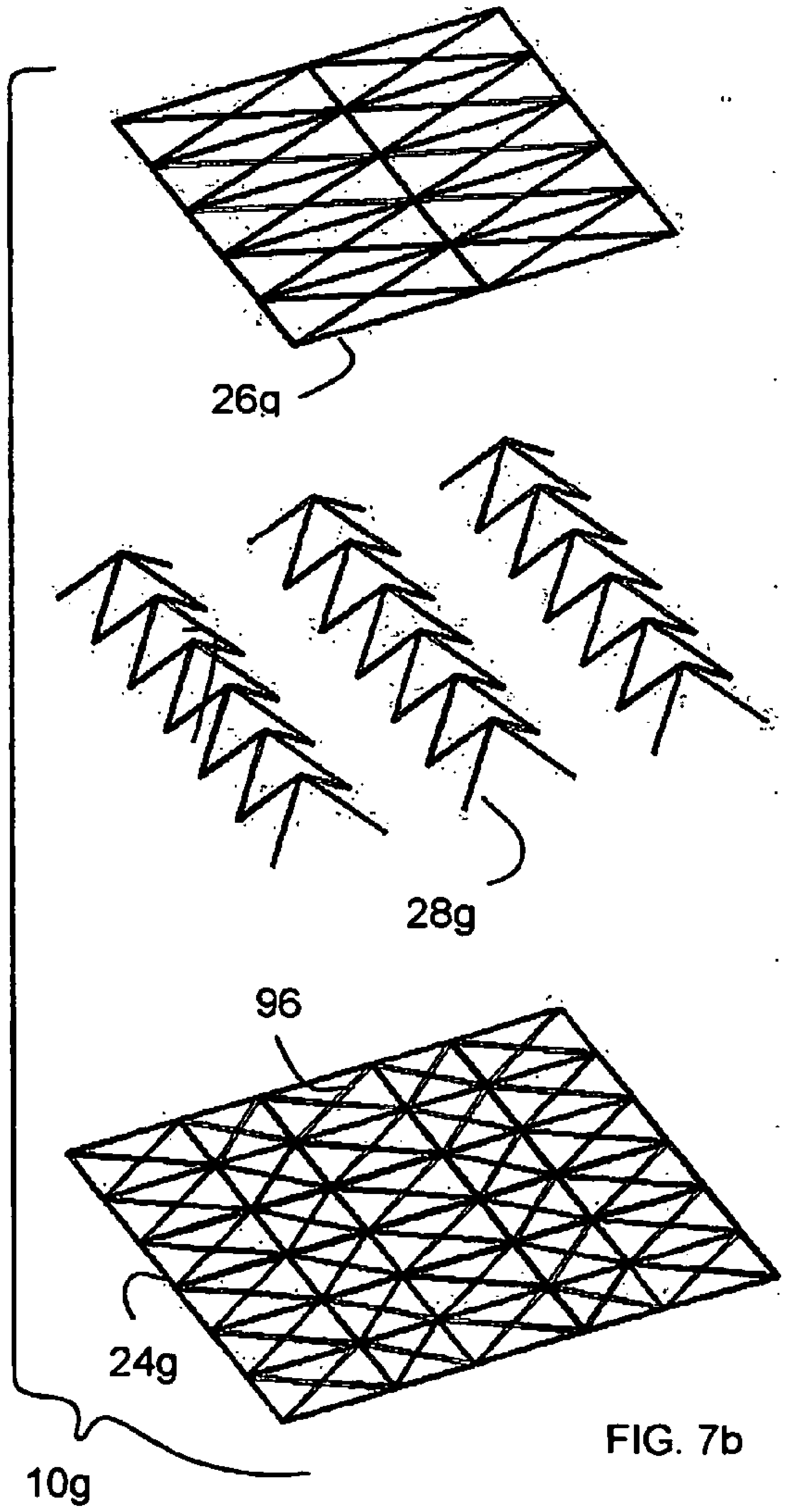


FIG. 7b

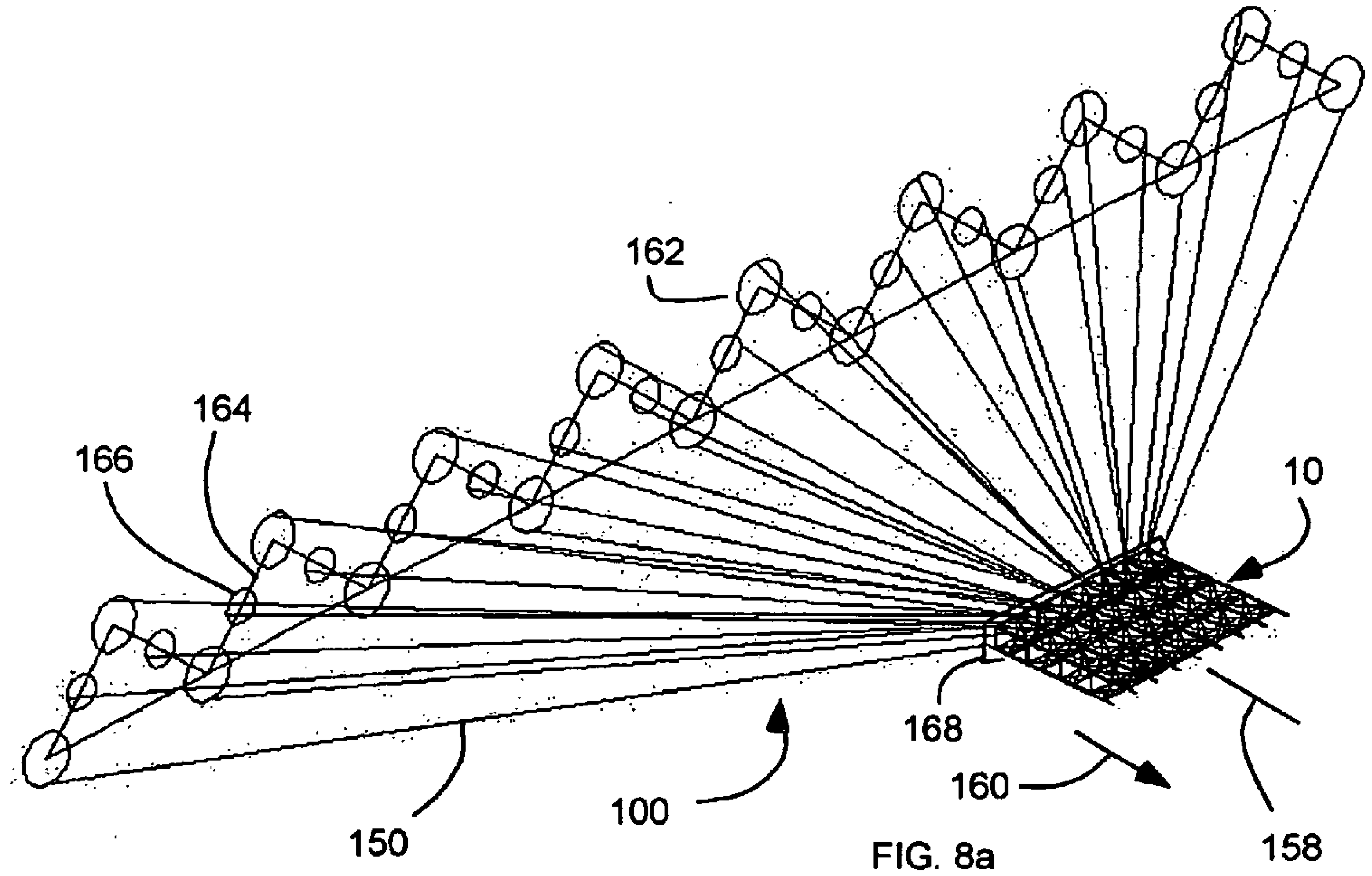


FIG. 8a

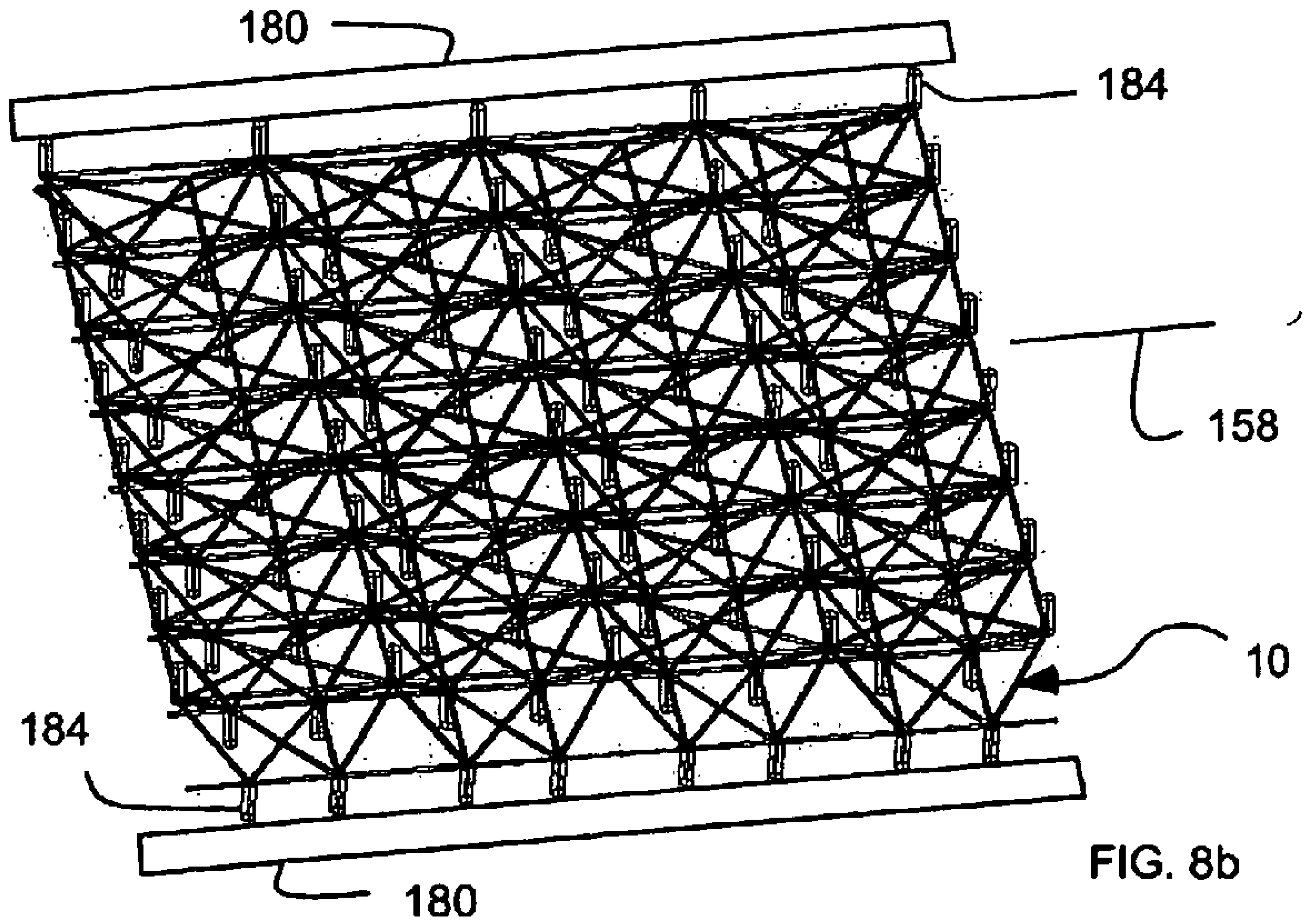


FIG. 8b

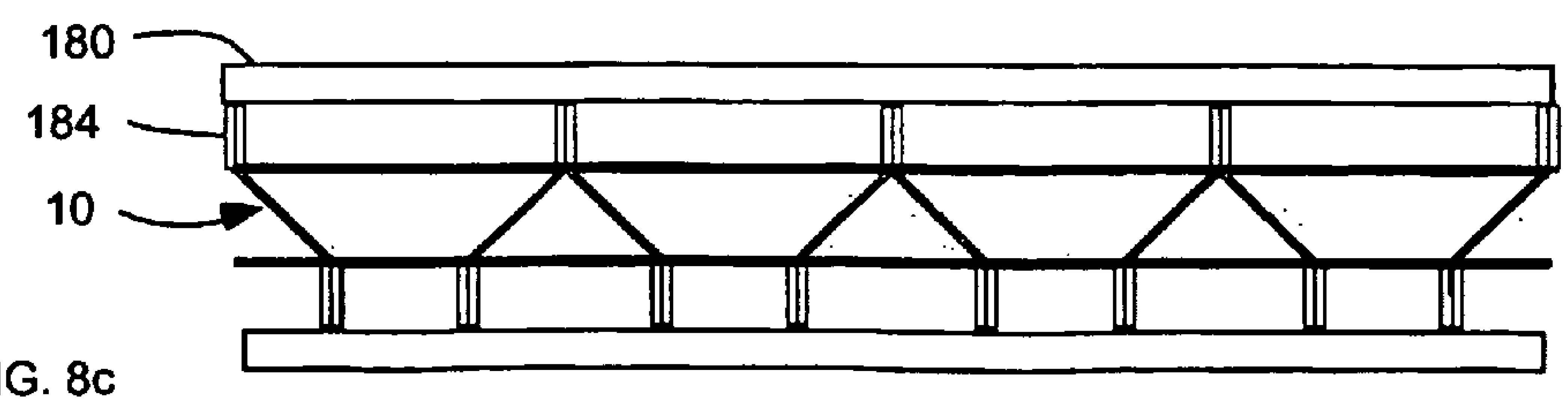


FIG. 8c

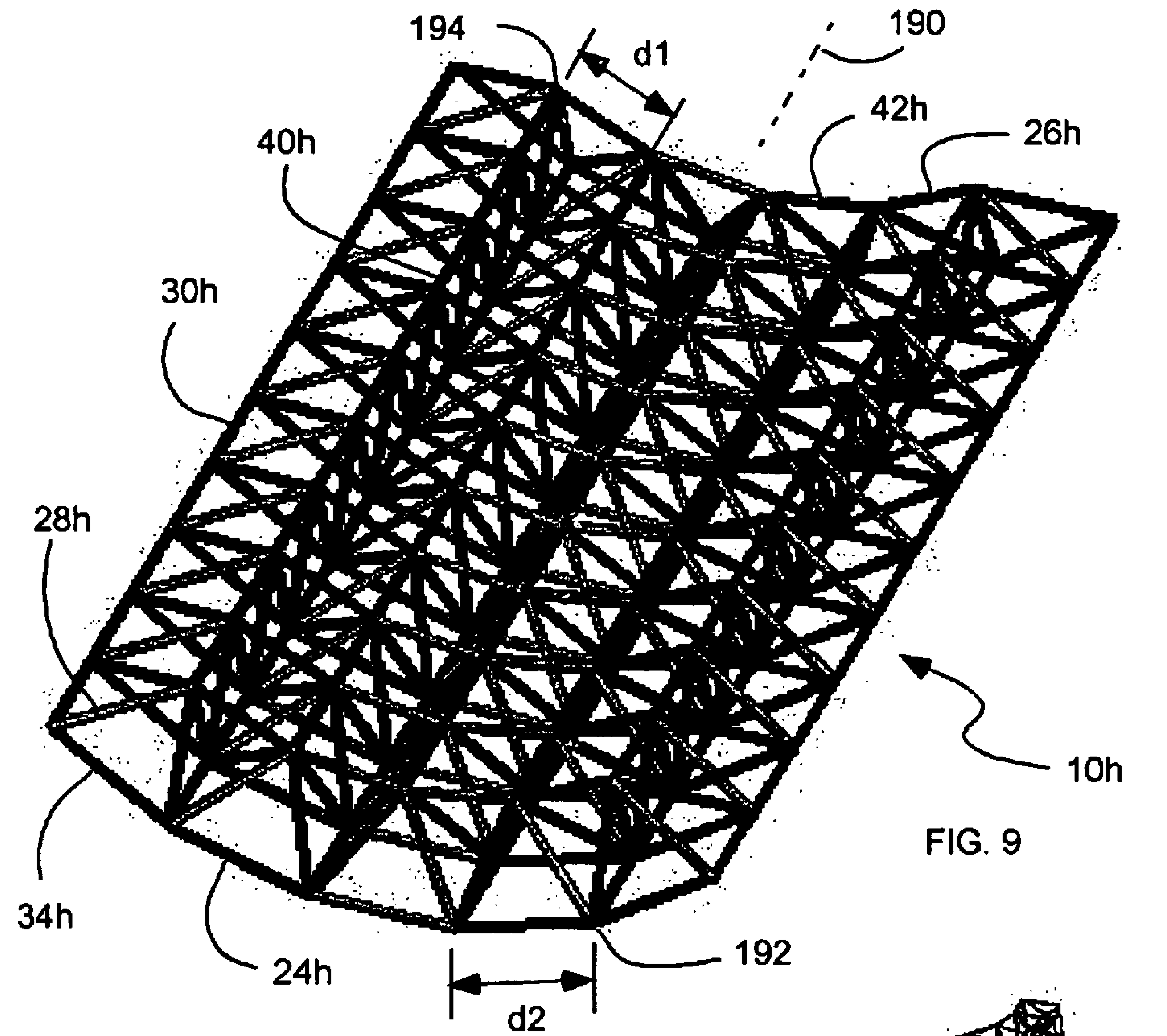


FIG. 9

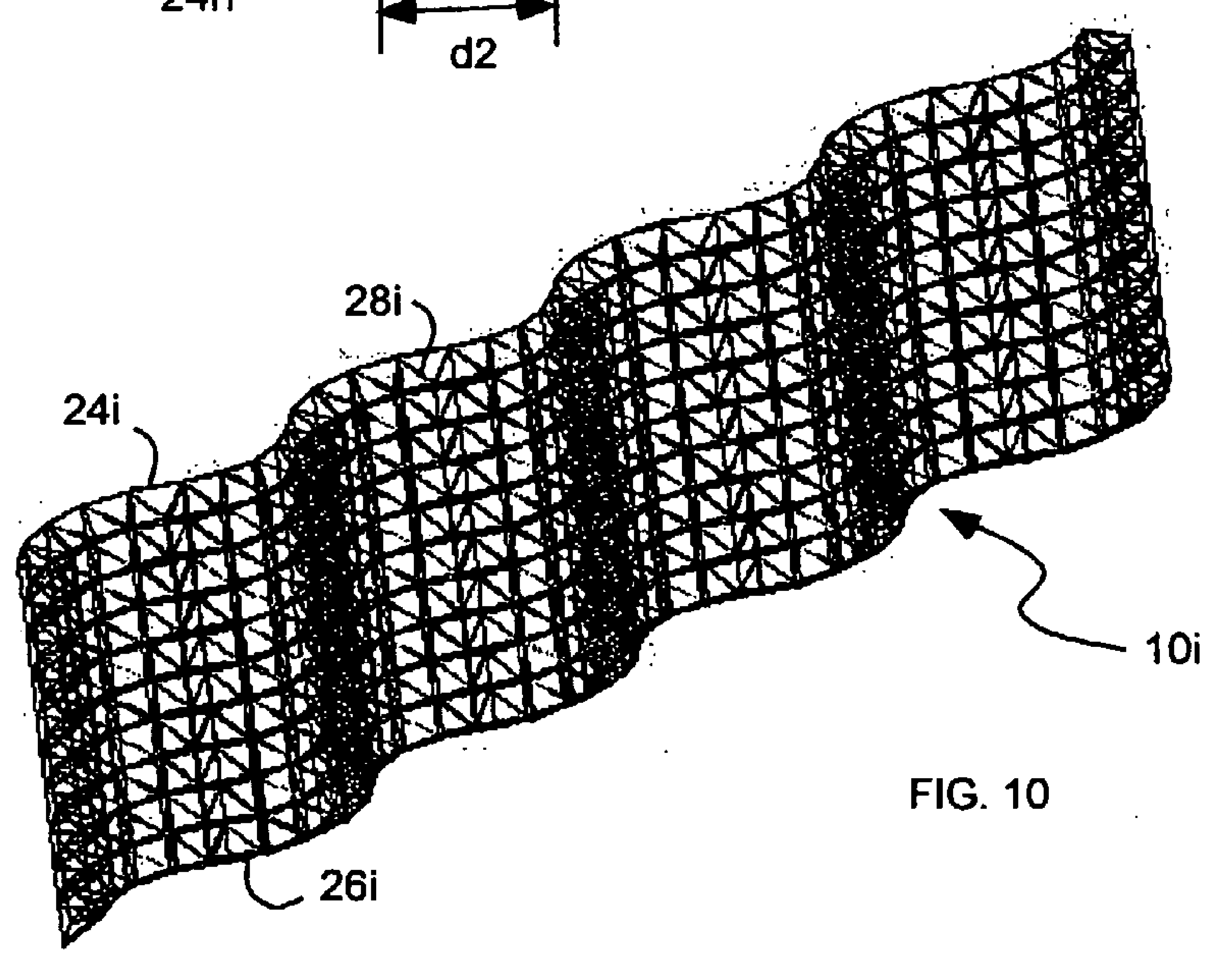


FIG. 10

THREE-DIMENSIONAL GRID PANEL

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates generally to a three-dimensional grid structure or panel. More particularly, the present invention relates to a grid structure or panel with enhanced stiffness and/or strength.

[0003] 2. Related Art

[0004] The pursuit of structurally efficient structures in the civil, mechanical, aerospace and sports arenas is an ongoing quest. An efficient truss structure is one that has a high strength to weight ratio and/or a high stiffness to weight ratio. An efficient truss structure can also be described as one that is relatively inexpensive, easy to fabricate and assemble, and does not waste material.

[0005] Trusses are typically stationary, fully constrained structures designed to support loads. They consist of straight members connected at joints at the end of each member. The members are two-force members with forces directed along the member. Two-force members can only produce axial forces such as tension and compression forces in the member. Trusses are often used in the construction of bridges and buildings. Trusses are designed to carry loads which act in the plane of the truss. Therefore, trusses are often treated, and analyzed, as two-dimensional structures. The simplest two-dimensional truss consists of three members joined at their ends to form a triangle. By consecutively adding two members to the simple structure and a new joint, larger structures may be obtained.

[0006] The simplest three-dimensional truss consists of six members joined at their ends to form a tetrahedron. By consecutively adding three members to the tetrahedron and a new joint, larger structures may be obtained. This three dimensional structure is known as a space truss.

[0007] Frames, as opposed to trusses, are also typically stationary, fully constrained structures, but have at least one multi-force member with a force that is not directed along the member. Machines are structures containing moving parts and are designed to transmit and modify forces. Machines, like frames, contain at least one multi-force member. A multi-force member can produce not only tension and compression forces, but shear and bending as well.

[0008] Traditional structural designs have been limited to one or two-dimensional analysis resisting a single load type. For example, I-beams are optimized to resist bending and tubes are optimized to resist torsion. Limiting the design analysis to two dimensions simplifies the design process but neglects combined loading. Three-dimensional analysis is difficult because of the difficulty in conceptualizing and calculating three-dimensional loads and structures. In reality, many structures must be able to resist multiple loadings. Computers are now being utilized to model more complex structures.

[0009] Complex three-dimensional structures or structural members have been developed with enhanced performance characteristics, such as increased strength, increased rigidity, reduced weight, etc. Such structures are described in U.S. Pat. No. 5,921,048, issued Jul. 13, 1999. Such structures can include two overlapping, off-set, tube-like structures. The first structure can include at least two, spaced-apart, helical components, and at least one reverse helical component attached to the at least two helical components. The helical and reverse helical components have a common longitudinal axis, but opposing angular orientations about the axis. In addition, each helical and reverse helical component can include at least three elongated, straight segments rigidly connected end-to-end in a helical configuration forming a single, complete rotation about the axis. Thus, the helical and reverse helical components form a first triangular-shaped cross section. In one aspect, the structure includes three helical components and three reverse helical components. In addition, the second structure can include rotated helical components and rotated reverse helical components, similar to, but rotated with respect to the helical and reverse helical components described above. Thus, the rotated helical and rotated reverse helical components form a second triangular-shaped cross section, rotated with respect to the first. In one aspect, the structure includes three rotated helical components and three rotated reverse helical components, for a total of twelve helical components. Together, the helical, reverse helical, rotated helical, and rotated reverse helical components appear as an imaginary tubular member-having a six-pointed star cross section when viewed along the axis. The various helical components intersect at external nodes and internal nodes. The components form six internal and six external nodes. Longitudinal or axial components may extend parallel to the axis and intersect the internal and/or external nodes.

[0010] Such three dimensional structures have shown great promise for various applications, such as trusses, poles, posts, etc. Such truss or pole configurations, however, can be difficult to use in other configurations due to the generally round configuration.

SUMMARY OF THE INVENTION

[0011] It has been recognized that it would be advantageous to develop a three-dimensional structure or panel with a flatter and thinner configuration, and with enhanced stiffness and strength.

[0012] The invention provides a three-dimensional grid panel with an intermediate grid disposed between and interconnecting two spaced-apart grids. The two spaced-apart grids each include: a) a first plurality of spaced-apart, elongated components; and 2) a second plurality of spaced-apart, elongated components, oriented transverse to the first plurality of components and intersecting the first plurality of components at nodes. The intermediate grid includes: 1) a first plurality of intermediate components, each extending between nodes of the two spaced-apart grids; and 2) a second plurality of intermediate components, oriented transverse to the first plurality of intermediate components and intersecting the first plurality of intermediate components at nodes, each of the second plurality of intermediate components extending between nodes of the two spaced-apart grids.

[0013] In accordance with a more detailed aspect of the invention, the components of the two spaced-apart grids and the intermediate grid can include continuous strands of fiber intersecting at the nodes. A plurality of continuous strands of fiber can be disposed in a repeating geometric pattern with the strands crossing and attaching to one another at nodes positioned at an outer perimeter of the grid panel. The strands can form discrete segments arranged sequentially with one another along the respective strands, and extending between the nodes

[0014] Additional features and advantages of the invention will be apparent from the detailed description which follows, taken in conjunction with the accompanying drawings, which together illustrate, by way of example, features of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] **FIG. 1***a* is a perspective view of a grid panel in accordance with an embodiment of the present invention;

[0016] **FIG. 1***b* is a partial perspective view of the grid panel in **FIG. 1***a;*

[0017] **FIG. 1***c* is a top view of the grid panel in **FIG. 1***a;*

[0018] **FIG. 1***d* is a front view of the grid panel in **FIG. 1***a;*

[0019] **FIG. 1***e* is a side view of the grid panel in **FIG. 1***a;*

[0020] **FIG. 1***f* is an exploded view of the grid panel of **FIG. 1***a;*

[0021] **FIG. 2***a* is a perspective view of another grid panel in accordance with an embodiment of the present invention;

[0022] **FIG. 2***b* is an exploded view of the grid panel of **FIG. 2***a;*

[0023] **FIG. 3***a* is a perspective view of a grid panel in accordance with an embodiment of the present invention;

[0024] **FIG. 3***b* is an exploded view of the grid panel of **FIG. 3***a;*

[0025] **FIG. 4***a* is a perspective view of a grid panel in accordance with an embodiment of the present invention;

[0026] **FIG. 4***b* is an exploded view of the grid panel of **FIG. 4***a;*

[0027] **FIG. 5***a* is a perspective view of a grid panel in accordance with an embodiment of the present invention;

[0028] **FIG. 5***b* is an exploded view of the grid panel of **FIG. 5***a;*

[0029] **FIG. 6***a* perspective view of a grid panel in accordance with an embodiment of the present invention;

[0030] **FIG. 6***b* is a top view of the grid panel in **FIG. 6***a;*

[0031] **FIG. 6***c* is an exploded view of the grid panel of **FIG. 6***a;*

[0032] **FIG. 6***d* is a partial perspective view of the grid panel in **FIG. 6***a* showing the lower or left grid and the intermediate grid;

[0033] **FIG. 7***a* is a perspective view of another grid panel in accordance with the present invention;

[0034] **FIG. 7***b* is an exploded view of the grid panel of **FIG. 7***a;*

[0035] **FIG. 8** is a schematic view of an apparatus and method for forming a grid panel in accordance with the present invention;

[0036] **FIG. 8***b* is a partial schematic view of an apparatus and method for forming a grid panel in accordance with the present invention;

[0037] **FIG. 8***c* is a partial schematic view of an apparatus and method for forming a grid panel in accordance with the present invention;

[0038] **FIG. 9** is a perspective view of another grid panel in accordance with an embodiment of the present invention; and

[0039] **FIG. 10** is a perspective view of another grid panel in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0040] Reference will now be made to the exemplary embodiments illustrated in the drawings, and specific language will be used herein to describe the same. It will nevertheless be understood that no limitation of the scope of the invention is thereby intended. Alterations and further modifications of the inventive features illustrated herein, and additional applications of the principles of the inventions as illustrated herein, which would occur to one skilled in the relevant art and having possession of this disclosure, are to be considered within the scope of the invention.

[0041] Some aspects of three-dimensional structures are described in U.S. Pat. No. 5,921,048, issued Jul. 13, 1999, which is herein incorporated by reference. As illustrated in **FIGS. 1***a-f,* a three-dimensional grid structure or panel, indicated generally at **10**, in accordance with the present invention is shown. As described above, other truss or pole structures have been developed that have generally tubular or pole-like shapes. The grid panel **10** of the present invention has a flatter configuration suitable for use in situations that can require a panel structure. The flat configuration is relatively broad in two dimensions (such as longitudinally and laterally), and relatively thin in a third dimension (such as thickness). In one aspect, the grid panel **10** can be disposed in a planar layer, as shown. In another aspect, the grid panel **10** can be disposed in an open curvilinear or arcuate layer.

[0042] The structure and geometry of the grid panel **10** may be described in numerous ways. The grid panel **10** can include a plurality of elements or members **12** arranged in a repeating pattern along the grid panel **10**. The elements or members **12** can be relatively straight, and can be combined together to form the repeating patterns in the panel. The grid panel **10** may be conceptualized and described as a plurality of elongated components **20** extending along and through the grid panel. The components **20** can be elongated, and can extend across the panel **10**. The components **20** can be straight, or can alternate back and forth, as described below. The components can be formed or conceptualized as a plurality of sequential members **12** coupled end-to-end. The components **20** can have various different angular orientations with respect to one another. In addition, the components **20** can be provided in groups or arrays of components with similar orientations, with the components **20** of each group being spaced-part from one another in an array. Furthermore, groups of components **20** can be combined into grids or sub-grids of the grid panel, with the grids including groups of components with different orientations so that the components **20** from one group intersect and/or transverse the components **20** of another group. Each component **20** also can include a plurality of sequential discrete or straight segments **22** connected end-to-end in straight and/or angled configurations. As described in greater detail below, each component **20** can be formed by a tow or strand of continuous fibers that extend through and along the grid panel, and intersect or connect with other tows or strands at nodes, to form a grid panel that has enhanced rigidity and strength, and reduced weight.

[**0043**] The grid panel **10** can include two spaced-apart grids, such as first and second, left and right, or lower and upper grids **24** and **26**, that are sub-grids or sub-structures of the grid panel **10**. The two grids **24** and **26** are spaced-apart from one another, and can be oriented substantially parallel with one another. In addition, the two grids. **24** and **26** are formed by components **20**, and can have a thickness defined by, or substantially equal to, a thickness of the components **20** that form the individual grids **24** and **26**, or the strands of fiber that form the components. An intermediate grid **28** is disposed between, and extends between the two spaced-apart grids **24** and **26**, and joins or attaches the two grids **24** and **26** together. The intermediate grid **28** also is formed in part by components **20**, but has a thickness defined by the spacing or distance between the spaced-apart grids **24** and **26**. The grid panel **10** has a thickness that is substantially less than a width and a height of the grid panel **10**, or a width and a length of the grid panel. The thickness is measured across the two grids **24** and **26**, while the width and height (or length) are measured along the two grids.

[**0044**] Referring to **FIG. 1***f*, a first or lower grid **24** can include a plurality of elongated and spaced-apart longitudinal components **30**, and a plurality of elongated and spaced apart lateral components **34**. The longitudinal components **30** have a similar orientation, are disposed in a common layer, and are arrayed in a spaced-apart relationship. Similarly, the lateral components **34** have a similar orientation, are disposed in a common layer, and are arrayed in a spaced-apart relationship. The longitudinal components **30** and lateral components **34** have transverse orientations with respect to one another, such that the longitudinal and lateral components **30** and **34** can cross or intersect one another at nodes or primary nodes **36**. The components **30** and **34** of the first grid **24** can be disposed in a planar layer and can be oriented orthogonal to one another, as shown. Thus, the components **30** and **34** can outline square or rectangular shapes. The elongated components **30** and **34** can be substantially straight, as shown.

[**0045**] The second or upper grid **26** can be similar in many respects to the first or lower grid **24** with a plurality of longitudinal components **40** intersecting or crossing a plurality of lateral components **42** at nodes **36**, and oriented transverse to the lateral components **42**. The first and second grids **24** and **26** can be off-set with respect to one another, or so that the nodes **36** of each grid are off-set with respect to one another. Thus, the nodes **36** of the first grid **24** are positioned across from the square or rectangular spaces of the second grid **26**, while the nodes **36** of the second grid **26** are similarly positioned across from the square or rectangular spaces of the first grid **24**. The nodes **36** can be disposed about a perimeter or exterior of the grid panel **10**.

[**0046**] The intermediate grid **28** can include a plurality of elongated, spaced-apart intermediate components, including a first plurality of first intermediate components **46**, and a second plurality of second intermediate components **48**. The first intermediate components **46** have a similar orientation, and are arrayed in a spaced-apart relationship. Similarly, the second intermediate components **48** have a similar orientation, and are arrayed in a spaced-apart relationship. The first and second intermediate components **46** and **48** have transverse orientations with respect to one another such that the intermediate components **46** and **48** can cross or intersect one another at the nodes **36**. The intermediate components **46** and **48** of the intermediate grid **28** can be oriented orthogonal to one another, as shown. In addition, the intermediate components **46** and **48** can extend back and forth between the first and second grids **24** and **26**. The intermediate components **46** can include sequential segments **22** that alternate back and forth between the two grids **24** and **26**, and thus alternate orientations. Thus, the various components **30**, **34**, **46** and **48** (or **40**, **42**, **46** and **48**), or members **12** thereof, can outline pyramid-shaped spaces with five sides, including four triangular sides and one square or rectangular side.

[**0047**] As described above, the first and second grids **24** and **26**, or nodes **36** thereof, can be off-set with respect to one another. Thus, the intermediate components **46** and **48** extend from nodes in one grid on a diagonal to the nodes in the other grid. The intermediate components **46** and **48** can extend diagonally or transverse to both the grids **24** and **26**, and to the longitudinal and lateral components **30** and **34** (and **40** and **42**). While the longitudinal and lateral components **30** and **34** can extend longitudinally and laterally along the grid panel **10**, the intermediate components **46** and **48** can extend both diagonally across the grid panel **10**, and back and forth through the thickness of the grid panel **10**.

[**0048**] The grid panel **10** defines a layer that contains the grid panel. Similarly, the first and second grids **24** and **26**, and the intermediate grid **28**, also define layers within the layer of the grid panel **10**. The first and second grids **24** and **26** define first and second layers. The first layer is defined by and contains the plurality of lateral and longitudinal components **30** and **34**. Similarly, the second layer is defined by and contains the plurality of lateral and longitudinal components **40** and **42**. The first and second layers can have a thickness equal to a diameter of the components **30**, **34**, **40** and **42**, or strands of fiber. An intermediate layer is defined by and contains the diagonal components **46** and **48**. The first and second layers can be relatively thin with respect to the intermediate layer, while the intermediate layer can be relatively thick with respect to the first and second layers. In addition, the layers can be planer or flat, as shown. Alternatively, the layers can be curved.

[**0049**] Referring to **FIGS. 2***a-b*, another grid panel **10***b* is shown that is similar in many aspects to the grid panel described above. The first and second spaced-apart grids **24***b* and **26***b* additionally include a plurality of diagonal components, including a first plurality of first diagonal components **50** and **54** (for respective first and second grids **24***a* and **24***b*), and a second plurality of second diagonal components **52** and **56** (for respective first and second grids **24***a* and **24***b*). The first and second diagonal components **50** and **52**, and **54** and **56**, are oriented transverse both to each other, and to the longitudinal and lateral components **30** and **32**, and **40** and **42**. The first and second diagonal components **50** and **52**, and **54** and **56**, intersect each other at secondary nodes **58**, and intersect the longitudinal and lateral components **30** and **32**, and **40** and **42**, at primary nodes **36**.

[**0050**] Referring to **FIGS. 3***a-b,* another grid panel **10***c* is shown that is similar in many respects to those described above. Each of the first and second spaced-apart grids **24***c* and **26***c* includes three different groups of similar components, with the components of each group having a different angular orientation with respect to one another, such as at sixty degree angles with respect to one another. The first grid **24***c* can include a first group of first components **60**, a second group of second components **62**, and a third groups of third components **64**. As described above, the components of each group can have a common orientation and a common plane, and can be arrayed or spaced-apart from one another. The first, second and third components **60**, **62** and **64** can transverse each other, and intersect each other at nodes **36**. Thus, the components form triangle-shaped spaces therebetween. The second grid **26***c* similarly can include first, second and third groups of first, second and third components **66**, **68** and **70**. The spaced-apart grids **24***c* and **26***c* can be positioned or oriented with respect with one another to match, as opposed to being off-set, so that the nodes **36** of each grid align with the nodes of the other grid.

[**0051**] The intermediate grid **28***c* also includes three different groups of similar components, namely a first group of first components **72**, a second group of second components **74**, and a third groups of third components **76**. The components of each group can have similar orientations, and can be arrayed in a spaced-apart relationship. The first, second and third intermediate components **72**, **74** and **76** have transverse orientations with respect to one another such that the intermediate components can cross or intersect one another at the nodes **36**. As described above, the intermediate components can extend back and forth between the first and second grids **24***c* and **26***c*. Thus, the various components can outline pyramid-shaped spaces with seven sides, including six triangular sides and one hexagon-shaped side.

[**0052**] Referring to **FIGS. 4***a-b,* another grid panel **10***d* is shown that is similar in many respects to those described above. Unlike the grid panel **10***c* shown in **FIGS. 3***a-b,* however, the grid panel **10***d* in **FIGS. 4***ab* include first and second spaced-apart grids **24***c* and **26***c* that are off-set with respect to one another, or whose nodes are off-set with respect to one another. In addition, the off-set of the spaced-apart grids **24***c* and **26***c* changes the configuration of the intermediate grid **28***d.* The intermediate grid **28***d* includes different groups of intermediate members **78** configured to form pyramid-shaped spaces with four triangular sides.

[**0053**] Referring to **FIGS. 5***a-b,* another grid panel **10***e* is shown that is similar in many respects to those described above. The second or upper grid **26***e* includes different groups of diagonal members **80**, where the diagonal members in each group are spaced-apart, but with different intervals or at different distances. For example, the spaces between the diagonal members **80** can include larger and smaller alternating spaces.

[**0054**] Referring to **FIGS. 6***a-d,* another grid panel **10***f* is shown that is similar in many respects to those described above. First or lower grid **24***f* includes lateral and longitudinal components **30** and **34**, where the lateral components **34** are spaced-apart, but with different intervals or at different distances. For example, the spaces between the lateral **34** can include larger and smaller alternating spaces. The first grid **24***f* can include diagonal components, as shown in **FIG. 6***c.* The intermediate grid **28***f* can include intermediate components **90** that both 1) traverse the space between the first and second grids, as described above, and 2) extend along the first and second grids, indicated at **92** in **FIG. 6***d.*

[**0055**] Referring to **FIGS. 7***a-b,* another grid panel **10***g* is shown that is similar in many respects to those described above. The first or lower grid **24***g* can include diagonal components **96** that are non-linear, or that are not straight. The diagonal components **96** can include sequential segments with alternating and different angular orientations with respect to one another.

[**0056**] In one aspect, the first and second grids can have similar configurations, as shown in **FIGS. 1***a*-**4***b.* In another aspect, the first and second grids can have different configurations, as shown in **FIGS. 5***a*-**7***b.*

[**0057**] The various components can define an interior space in the grid panel that is substantially void except for the intersecting components of the intermediate grid. Alternatively, the interior space can be filed with another material, such as foam, to add additional structural or functional aspects to the panel, such as thermal or noise insulation. In addition, the grids themselves can define an interior space between the components that is substantially void. Alternatively, these interior spaces can also be filled with another material. In addition, a skin or panel can be disposed on one or both of the first and second grids. The nodes can be positioned at a perimeter of the grid panel. The nodes can be regularly and evenly spaced, or can be irregularly spaced.

[**0058**] Although the above grid panels have been described with respect to various different configurations, it will be appreciated that other configurations are possible and are within the scope of the invention.

[**0059**] As stated above, the grid panel can be formed of composite material, such as fiber in a resin matrix. The fibers preferably are continuous, and can be carbon, glass, basalt, aramid, Kevlar, polyethylene, nylon, bamboo, or other natural or man-made fibers. The resin can be any type, such as a thermoplastic resin, like PCV, or thermoset resin, like epoxy or vinyl ester. The repeating geometric shapes of the grid panel can be formed from a plurality of continuous strands or tows of fiber extending along the grids. Each component of the grid panel can include a plurality of continuous fibers. The strands of fiber can cross and attach to one another at the nodes. The strands, tows or fibers of the various components can be twisted, wrapped, and/or braided together to reduce gaps, particularly at intersections or nodes. The various components can be formed of a group of outer fibers wrapped or braided around a core of inner fibers. For example, a braided sleeve can encapsulate a core of straight or twisted fibers.

[**0060**] The fibers of the various components can be interwoven or overlap at the intersections or nodes. For example, the fibers of the longitudinal components can pass between the fibers of the lateral components. It is of course understood that the fibers of all the components can pass between or intersect the fibers of other components. For example, the fibers of the one component can be maintained in a single tow or strand with the fibers of another component surrounding the one component. In addition, it is understood that the components can merely pass by one another, without interweaving, overlapping or intersecting. The overlaying or intersecting fibers, however, can form gaps between the fibers. As previously mentioned, such gaps can reduce the strength of the structure by as much as 90%. It will be appreciated that the strength of the grid panel is derived from the synergy of the collective fibers as a bundle. Thus, isolating or separating fibers can have a detrimental effect on the strength of the structure. Therefore, as described above, the fibers, strands or tows can be twisted, wrapped, braided, or wrapped with a braid to condense the fibers and reduce any gaps, and increase the strength of the fibers, and the grid panel.

[**0061**] In addition, the various components can intersect at a single node at a single location or position, as described above. It will be appreciated that the intersection of many fibers can create a bulky node, and may introduce gaps. In addition, the intersection of the many fibers can create nonlinearities in the fibers that also degrade their structural performance. In one aspect, the nodes or intersections can be off-set with respect to one another. Thus, the nodes or intersections can be off-set, or spaced apart, forming a grouping of different nodes or intersections in close proximity to one another. Thus, a single node or point of intersection can be separated into two or more nodes or intersections to reduce the bulk of the intersections and to reduce gaps.

[**0062**] In one aspect, the grid panel can be configured with a taper along one or more directions. In another aspect, the grid panel can be configured with an arcuate shape, and can thus be curved. The nodes on one side can be located closer together than those on another side. Similarly, the segments on one side can be longer than those on another side. It will be appreciated that the grid panel can be non-symmetrical.

[**0063**] In another aspect, the grid panel can have tapering components. For example, the longitudinal components can taper. The tapering components can be formed by strands or tows of fiber that are thicker and stronger at one end or portion of the structure, and thinner and lighter at another end or portion. The number of fibers in the strands or tows can be increased or reduced to form the taper.

[**0064**] The panels of the present invention can be fabricated or cast in free-space from a method referred to as tensioned fiber placement or casting. The method involves interlacing one or more rotating or alternating strands of transverse fibers with an array of tensioned, longitudinal fibers to form a support skeleton suitable for further interlacing or over-wrapping of other fiber strands at varying orientations. These collective, interwoven, fibers are coated with resin and cured in this tensioned, skeletal configuration to form a sturdy structure with very high load capacity and stiffness, but very low weight.

[**0065**] A plurality of continuous fibers can be pulled from a feed source along a processing path about a longitudinal axis. At least some of the fibers can be wound around the longitudinal axis in opposite directions to form the various components that intersect at nodes. The fibers can be engaged along the processing path substantially only at locations localized at select nodes without substantially engaging the components. The select nodes can be maintained radially outwardly from the longitudinal axis to create sequential discrete segments in the intermediate components. The select nodes can be engaged from outside the components or panel. Thus, the structure can be formed without a traditional internal mandrel.

[**0066**] Referring to **FIGS. 8***a-c,* an apparatus **100** and method are shown for fabricating such a grid panel from continuous fibers or tows **150** or strands of fibers. The apparatus **100** can be configured to fabricate the various grid panels having various different configurations.

[**0067**] The apparatus **100** can include a frame or base support member with a processing path **158** along which the continuous fibers **150** are arranged into the grid panel **10**. The processing path **158** can have a longitudinal axis that is concentric with the grid panel. The continuous fibers **150**, and resulting grid panel **10**, are drawn or pulled through the processing path **158** of the apparatus **100**, as indicated by arrow **160**. A puller can pull the continuous fibers **150** and/or grid panel **10** through the processing path **158** and maintain the fibers **150** in a taut condition. The fibers **150** are disposed in the processing path **158**, and pulled taut, to provide an axial support configuration which forms an operating skeleton for assembly of the grid panel **10**. This skeletal structure enables formation of complex open structures without dependence upon a traditional internal mandrel, die, or other internal shaping device configured to support the entire surface of an object. A plurality of fiber feed sources **162** can be associated with or coupled to the frame or base support member to provide the continuous fibers **150**. Thus, the continuous fibers **150** can be drawn from the fiber feed sources **162** and through the apparatus **100** or processing path **158**. The fiber feed sources **162** can include center feed coils or outer feed spools about which the continuous fibers **150** are wound. Any fiber source that facilitates continuous release of a tensioned fiber can be utilized in this apparatus.

[**0068**] The apparatus **100** can include a separate fiber feed source **162** for each component. It is of course understood that the number of fiber feed sources **162** depends on the number of components, which can vary depending on the configuration and size of the grid panel to be fabricated.

[**0069**] In addition, each fiber feed source **162** can provide a plurality of fibers or tows **150** that are grouped together in the strands to form the individual components of the grid panels **10**. For example, a single tow can be formed of several thousand individual fibers. The plurality of fibers or tows **150** from each fiber feed source **162** can be twisted or rotated together, wrapped, braided, or overwrapped with a braid to form the strands.

[**0070**] A rotational or displacement element(s) can be associated with the fiber feed sources **162** and frame or base support member **154** to displace the fibers **150** or fiber feed sources **162** around the processing path **158**. The displacement element(s) can wind the continuous fibers **150** in opposite directions to form the transverse diagonal components. The displacement element(s) can include tracks on the paths along which the fiber feed sources **162** travel. The displacement element(s) can include displacement frames to which the fiber feed sources **162** are coupled so that the fiber feed sources also travel along the paths as the displacement frames displace.

[**0071**] For example, the plurality of fiber feed sources can include stationary fiber feed sources from which longitudinal components are pulled straight through the processing path. Other fiber feed sources can extend back and forth with respect to the processing path to form the lateral components. Other fiber feed sources can travel back and forth along the path **164** to form the intermediate components. Because the intermediate components transverse one another, the path **164** can include passing locations **166** where the fiber feed sources can pass one onother.

[**0072**] An orientation guide member **168** can be associated with the frame or base support member, and positioned between the fiber feed sources **162** and the processing path **158**, to receive the continuous fibers **150** from the plurality of fiber feed sources **162** for angularly reorienting the continuous fibers **150** to a desired pre-processing configuration. The orientation guide member **168** can be a ring for guiding the fibers **150** from the fiber feed sources **162** to the processing path **158**. The preprocessing configuration represents the reorientation of the fibers **150** from the feed sources **162** to a longitudinally stressed skeletal structure along the processing path **158**.

[**0073**] An intermediate support element or member **180** can be disposed at the processing path **158** and associated with the frame or base support member. The intermediate support element **180** can include a plurality of engagement members **184** disposed around the processing path **158** to engage the nodes **36** of the components, and to direct and maintain the nodes of the components outwardly. Thus, the intermediate support element **180** and/or engagement members **184** form the sequential discrete or straight segments **22** in the components. The intermediate support element **180** and/or engagement members **184** support the fibers **150** in the configuration of the grid panel **10**. As discussed in greater detail below, the engagement members **184** can travel with the grid panel **10** as the fibers **150** are drawn through the processing path **158**. The engagement members **184** and/or intermediate support element **180** also can be a puller or traction member to pull the fibers through the processing path. The intermediate support element **180** can be disposed around the grid panel **10** with the engagement members **184** engaging the nodes **36** from the exterior of the grid panel **10**, as shown. The engagement members **184** can include hooks, notches, or grooved heads around which the fibers **150** are wound. The engagement members **184** and/or intermediate support element **180** form an external support structure for the fibers, as opposed to a traditional internal mandrel configured to support the entire inner surface of the grid panel.

[**0074**] The engagement members **184** can engage or contact the grid panel substantially only at the nodes. The engagement or contact can be localized at or along the nodes. The engagement members **184** can bias the nodes outwardly. Thus, the engagement members **184** can exert an outward force on the grid panel at the nodes. The engagement members **184** form the straight segments in the grid panel. The engagement members **184** can establish free space points intermittently which operate to support the nodes of the grid panel without a traditional internal mandrel that is continuous.

[**0075**] The intermediate support element **180** and/or engagement members **184** can be outwardly displacable and operable with respect to the fibers **150** to intermitently draw or displace fibers **150** outwardly and along a path to a stable, extended position representing the grid panel. Thus, the configuration of the grid panel or operating skeleton can be maintained without the aid of an internal mandrel or cavity die.

[**0076**] The intermediate support element **180** and/or engagement members **184** can be located outwardly to correspond to the desired size and shape of the grid panel. In one aspect, the engagement members **184** are adjustably positioned so that a grid panel of any desired size or shape can be formed. The intermediate support element **180** and/or the engagement members **184** can be displaced outwardly during processing so that changes in size or thickness can be accomplished during processing.

[**0077**] The engagement members **184** can be provided in sets or groups corresponding to the number of nodes. In another aspect, numerous sets can be provided, with only some being used depending on the number of desired nodes.

[**0078**] The adjustable nature of the engagement members **184** and/or support element **180** can provide for easier manufacture of structural components typically made of geometry specific tooling. It will be appreciated that minor changes made to traditional structures requires that a new mandrel be machined.

[**0079**] As described above, the intermediate support element **180** and/or engagement members **184** can support and maintain the fibers from outside the structure. Thus, the intermediate support element **180** and/or engagement members **184** do not interfere with the various segments that cross or intersect the interior of the grid panel. As discussed above, a traditional, internal, continuous mandrel can be difficult to withdraw from the interior of the grid panel because of the segments that cross or intersect the interior.

[**0080**] A resin applicator can be associated with the frame or base support member to apply resin to the continuous fibers **150**, as is known in the art. The resin applicator can include a nozzle to spray or drip resin onto the fibers. The resin can be applied to the fibers **150** while the fibers **150** are supported by the engagement members **184**. In addition, the resin can be applied to the fibers **150** prior to engagement by the engagement members **184** so that the engagement members do not block the application of the resin. A nozzle or spraying is one example of means for applying resin to the fibers. Other means for applying resin to the fibers include, for example, a resin bath through which the fibers are drawn, multiple spray nozzles, prepreg (pre-impregnated) fibers, etc. Applying the resin to the fibers creates a liquid resin/fiber composite.

[**0081**] An oven, heat source, or other curing device can be associated with the frame or base support member to help cure the resin, as is known in the art. The resin can be cured while the fibers **150** are supported by the engagement members **184**. An oven or heat source is one example of means for curing the resin or the liquid fiber/resin composite. Other means for curing the resin include, for example, heat, forced air, UV radiation, microwaves, electron beam, laser beam, etc. Curing the resin or liquid resin/fiber composite creates a sturdy, rigid, three-dimensional truss structure capable of bearing multidirectional loading.

[**0082**] A puller or traction member can be associated with the frame or the base support member to apply axial tension and pull the continuous fibers **150** and/or the grid panel through the processing path **158**. The puller also can engage the cured resin/fiber composite structure, such as with the use of a gear-like device with teeth that intermesh with the cured structure. The puller also can engage the structure with graspers that grasp the structure or components, such as the axial components. The graspers can be pneumatically, hydraulically, electrically or mechanically actuated. As stated above, as the grid panel and fibers are pulled through the processing path, the engagement members **184** and/or intermediate support element **180** can move with the grid panel. In one aspect, the engagement members **184** can move along the intermediate support element **180**. In another aspect, the engagement members **184** also can be used as the puller or traction member. Thus, the grid panel **10** can be fabricated with any desired length, while at the same time having variable thickness.

[**0083**] A cutter also can be associated with the frame or base support member to cut the grid panel **10** to a desired length. The cutter can include a blade to cut through the various components and/or segments. In addition, the cutter can include a high-pressure fluid jet, water jet, laser beam, or any other cutting mechanism.

[**0084**] Further explanation and example of such a method and apparatus for fabricating complex, composite structures can be found in International Application No. PCT/US02/26178, published Feb. 27, 2003 (International Publication No. WO 03/016036), which is herein incorporated by reference.

[**0085**] Alternatively, the panels described above can be made by other methods and tools, such as internal mandrels. The mandrel can be configured with heads or other fiber holder to hold the fibers at the locations of the nodes. The fibers can be wrapped around a mandrel to form the desired configuration of the panel. The mandrel can be dissolved or collapsed to remove the mandrel from the fibers, after the resin has cured. Examples of other methods for fabricating such structures can be found in U.S. patent application Ser. No. 10/343,133, and International Application No. PCT/US01/23636 published Feb. 7, 2002 (International Publication No. WO 02/10535), which are herein incorporated by reference.

[**0086**] Referring to **FIG. 9**, another grid panel **10***h* is shown that is similar in many respects to those described above. The grid panel **10***h* has an arcuate or curved shape, so that the grid panel and components are disposed in an acruate or curved layer. The grid panel **10***h* can have an axis **190**. Unlike the grid panel described above, however, the grid panel **10***h* in **FIG. 9** includes first and second spaced-apart grids **24***h* and **26***h* that are curved. The curvature of the grids **24***h* and **26***h* can be concentric, as shown. The grids **24***h* and **26***h* can include respective longitudinal components **30***h* and **40***h* that can be parallel with the axis **190**. In addition, the grids **24***h* and **26***h* can include respective lateral components **34***h* and **42***h* that curve about the axis **190**. The longitudinal and lateral components **30***h* and **34***h* of the first grid **24***h* can intersect one another at outer nodes **192**, while the longitudinal and lateral components **40***h* and **42***h* of the second grid **26***h* can intersect at inner nodes **194**. The outer nodes **192** can be spaced-apart a distance d**1** greater than a distance d**2** of the inner nodes **194**. Thus, the nodes on one side can be located closer together than the nodes on the opposite side. An intermediate grid **28***h* can extend between the nodes **192** and **194** of the grids **24***h* and **26***h*.

[**0087**] Referring to **FIG. 10**, another grid panel **10***i* is shown that has a wavy profile or cross-section. Thus, the first and second grids **24***i* and **26***i*, and the intermediate grid **28***i*, can have multiple curvatures.

[**0088**] In addition, a panel can have a bowl, partially spherical or spherical shape, or with curves in two dimensions.

[**0089**] It is to be understood that the above-referenced arrangements are only illustrative of the application for the principles of the present invention. Numerous modifications and alternative arrangements can be devised without departing from the scope of the present invention while the present invention has been shown in the drawings and fully described above with particularity and detail in connection with what is presently deemed to be the most practical and preferred embodiments(s) of the invention, it will be apparent to those of ordinary skill in the art that numerous modifications can be made without departing from the principles and concepts of the invention.

What is claimed is:

1. A three-dimensional grid panel, comprising:

a) a plurality of continuous strands of fiber disposed in a repeating geometric pattern;

b) the strands crossing and attaching to one another at nodes positioned at an outer perimeter of the grid panel;

c) the strands forming discrete segments arranged sequentially with one another along the respective strands and extending between the nodes; and

d) the plurality of continuous strands of fiber being disposed in groups, including at least:

i) a first layer having at least two groups of spaced-apart strands oriented to transverse one another at the nodes;

ii) a second layer, spaced-apart from the first layer, having at least two groups of spaced-apart strands oriented to transverse one another at the nodes; and

iii) an intermediate layer, disposed between the first and second layers, having at least two groups of spaced-apart diagonal strands oriented to transverse one another at the nodes and extending transverse between the first and second layers and attaching the first and second layers together.

2. A panel in accordance with claim 1, wherein the first and second layers are substantially parallel.

3. A panel in accordance with claim 1, wherein the strands of fiber in the intermediate layer extend back and forth between the first and second layers.

4. A panel in accordance with claim 1, wherein the nodes of the first layer are off-set with respect to the nodes of the second layer.

5. A panel in accordance with claim 1, wherein the nodes of the first layer are aligned with respect to the nodes of the second layer.

6. A panel in accordance with claim 1, wherein the first and second layers each further include at least three groups of spaced-apart strands oriented to transverse one another at the nodes.

7. A panel in accordance with claim 1, wherein the first and second layers have a thickness substantially the same as a thickness of the strands.

8. A panel in accordance with claim 1, wherein the intermediate layer has a thickness greater than a thickness of either of the first and second layers.

9. A three-dimensional grid panel, comprising:

a) two spaced-apart grids, each having:

i) a first plurality of spaced-apart, elongated components including continuous strands of fiber;

ii) a second plurality of spaced-apart, elongated components, oriented transverse to the first plurality of components, and including continuous strands of fiber intersecting the continuous strands of fiber of the first plurality of components at nodes; and

b) an intermediate grid, disposed between and interconnecting the two spaced-apart grids, the intermediate grid having:

i) a first plurality of intermediate components, each extending between nodes of the two spaced-apart grids, and including continuous strands of fiber; and

ii) a second plurality of intermediate components, oriented transverse to the first plurality of intermediate components, and including continuous strands of fiber intersecting the continuous strands of fiber of the first plurality of intermediate components at nodes, each of the second plurality of intermediate components extending between nodes of the two spaced-apart grids.

10. A panel in accordance with claim 9, wherein the first and second plurality of intermediate components can include a plurality of sequential segments that alternate back and forth between the two spaced-apart grids.

11. A panel in accordance with claim 9, wherein the two spaced-apart grids are substantially parallel.

12. A panel in accordance with claim 9, wherein the nodes of the two spaced-apart grids are off-set with respect each other.

13. A panel in accordance with claim 9, wherein the nodes of the two spaced-apart grids are aligned with respect each other.

14. A panel in accordance with claim 9, wherein the two spaced-apart grids each further include a third plurality of spaced-apart, elongated components, oriented transverse to the first and second plurality of components, and intersecting the first and second plurality of components at nodes.

15. A panel in accordance with claim 9, wherein the two spaced-apart grids have a thickness substantially the same as a thickness of the plurality of components.

16. A panel in accordance with claim 9, wherein the intermediate grid has a thickness greater than a thickness of either of the two spaced-apart grids.

17. A panel in accordance with claim 9, wherein the first plurality of spaced-apart, elongated components are longitudinal components; wherein the second plurality of spaced-apart elongated components are lateral components with respect to the longitudinal components; and wherein the two spaced-apart grids each further have:

a first plurality of diagonal components oriented transverse to both the longitudinal and lateral components and intersecting the longitudinal and lateral components at the nodes; and

a second plurality of diagonal components oriented transverse to the first plurality of diagonal components, and the longitudinal and lateral components, and intersecting the longitudinal and lateral components.

18. A three-dimensional grid panel, comprising:

a) two spaced-apart grids, each having:

i) a first plurality of spaced-apart elongated components including continuous strands of fiber; and

ii) a second plurality of spaced-apart elongated components oriented transverse to the first plurality of components, and including continuous strands of fiber intersecting the continuous strands of fiber of the first plurality of components at nodes; and

iii) the nodes of the two spaced-apart grids are off-set with respect each other; and

iv) the first and second plurality of components being disposed in a layer having a thickness substantially the same as a thickness of the components; and

b) an intermediate grid, disposed between and interconnecting the two spaced apart grids, the intermediate grid having at least:

i) a first plurality of intermediate components, each extending between nodes of the two spaced-apart grids, and including continuous strands of fiber; and

ii) a second plurality of intermediate components, oriented transverse to the first plurality of intermediate components, and including continuous strands of fiber intersecting the continuous strands of fiber of the first plurality of intermediate components at nodes, each of the second plurality of inetermediate components extending between nodes of the two spaced-apart grids

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