Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2851497 A1 2015/03/23

(21) 2 851 497

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(22) Date de dépôt/Filing Date: 2014/05/07

(41) Mise à la disp. pub./Open to Public Insp.: 2015/03/23

(30) Priorité/Priority: 2013/09/23 (US14/034,456)

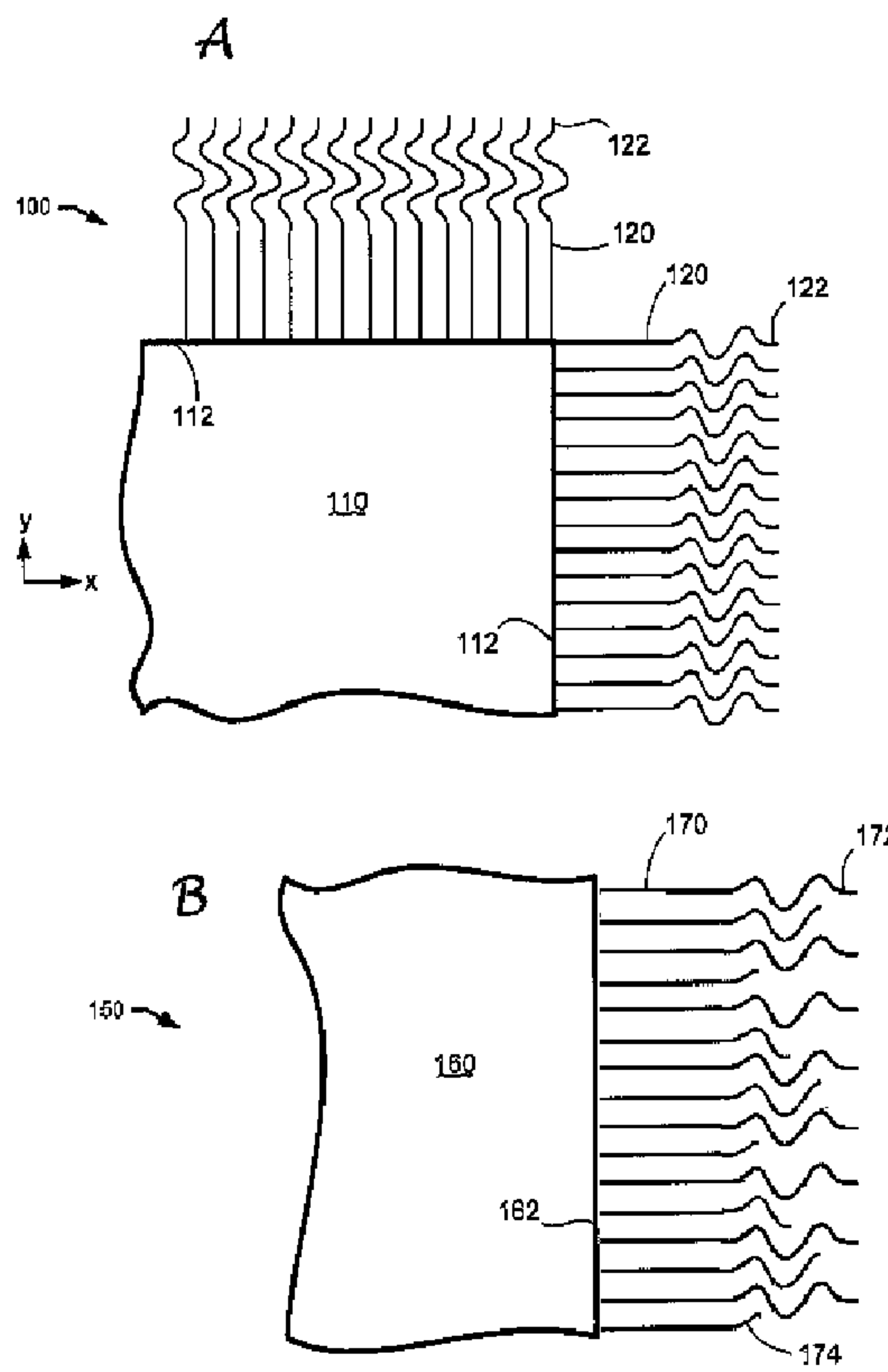
(51) Cl.Int./Int.Cl. *B29C 70/16* (2006.01), *C08J 5/04* (2006.01)

(71) Demandeur/Applicant:
THE BOEING COMPANY, US

(72) Inventeurs/Inventors:
GRIESS, KENNETH H., US;
ESPOSITO, JACK J., US;
GEORGESON, GARY E., US

(74) Agent: SMART & BIGGAR

(54) Titre : TEXTILES COMPOSITES COMPRENANT DES FILAMENTS DEPLOYES
(54) Title: COMPOSITE TEXTILES INCLUDING SPREAD FILAMENTS



(57) Abrégé/Abstract:
An article comprises a multi-directional textile of first reinforcing fiber tows extending in a first direction and second reinforcing fiber tows extending in a second direction. Filaments in the first fiber tows extend past a boundary of the textile and are spread. The tows are embedded in resin.

ABSTRACT

An article comprises a multi-directional textile of first reinforcing fiber tows extending in a first direction and second reinforcing fiber tows extending in a second direction. Filaments in the first fiber tows extend past a boundary of the textile and are spread. The tows are embedded in resin.

COMPOSITE TEXTILES INCLUDING SPREAD FILAMENTS

BACKGROUND

Fiber reinforced plastic (FRP) composites are attractive for aerospace structural applications. They have better specific strength and stiffness than metal, which translates into weight savings, fuel savings, and lower operating costs.

FRP structural elements such as skins, stiffeners, frames and spars may be joined together to form major components such as wings, fuselage and empennage. Disbonds of these FRP elements are undesirable.

SUMMARY

According to an embodiment herein, an article comprises a multi-directional textile of first reinforcing fiber tows extending in a first direction and second reinforcing fiber tows extending in a second direction. Filaments in the first fiber tows extend past a boundary of the textile and are spread. The tows are embedded in resin.

According to another embodiment herein, a structure comprises first and second parts joined together. The first part includes multiple layers of reinforcing fibers. An outer one of the layers includes a multi-dimensional textile of tows having spread filaments joined to a surface of the second part.

According to another embodiment herein, a method of fabricating a composite structure comprises mating first and second parts. The first part includes an outer layer having a weave of first tows extending in a first direction and second tows extending in a second direction. The method further comprises spreading ends of the tows into individual filaments, and joining the spread filaments to the surface of the second part.

These features and functions may be achieved independently in various embodiments or may be combined in other embodiments. Further details of the embodiments can be seen with reference to the following description and drawings.

Further, the disclosure comprises embodiments according to the following clauses:

Clause **1**: A structure comprising first and second parts joined together, the first part including multiple layers of reinforcing fibers, an outer one of the layers including a multi-dimensional textile of reinforcing of tows having spread filaments that are joined to a surface of the second part.

Clause **2**: The structure of clause **1**, wherein the first and second parts are discrete parts.

Clause **3**: The structure of clause **2**, wherein the discrete parts are aircraft structural elements.

Clause **4**: The structure of clause **1**, wherein the first part is a patch for the second part.

Clause **5**: The structure of clause **4**, wherein the second part is located at an area of an aircraft that is susceptible to impact damage.

Clause **6**: The structure of clause **1**, wherein ends of the filaments are wavy.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**A and **1**B are illustration of multi-directional composite textiles having spread filaments.

FIG. **2**A and **2**B are illustrations of tow filaments before and after they are spread.

FIG. **3** is an illustration of adjacent tows having filaments that are spread.

FIG. **4** is an illustration of a ply stack including a composite textile of tows having spread filaments.

FIG. **5** is an illustration of a part including the ply stack of FIG. **4**, the part joined to another part.

FIG. **6** is an illustration of a patch for a carbon fiber reinforced plastic panel.

FIGS. **7** and **8** are illustrations of composite textiles having spread filaments.

FIG. **9** is an illustration of filaments with wavy ends.

FIG. **10** is an illustration of a general method of using a composite textile having spread filaments.

FIG. **11** is an illustration of an aircraft.

DETAILED DESCRIPTION

Reference is made to FIG. **1**A, which illustrates an article **100** comprising a multi-directional composite textile **110** of first reinforcing fiber tows extending in a first direction and second reinforcing fiber tows extending in a second direction. In some embodiments, the multi-directional textile **110** may be a weave of tows extending in the x-direction and tows extending in the y-direction. In the embodiment illustrated in FIG. **1**A, the x- and y-directions are orthogonal. The multi-directional textile **110** has a boundary **112**. Within the boundary **112** of the textile **110**, the tows provide structural strength along the x- and y-directions.

A typical fiber tow may include thousands (e.g., **1**K, **3**K **12**K, **24**K) of fibers. Individual fibers or filaments of each tow may be bundled into a number (N) of rows. The bundled filaments in a tow are typically held together (that is, supported) by cross-fibers. The cross-fibers are typically orthogonal to the filaments **120**.

Filaments **120** of the tows extend past the boundary **112**. These filaments **120** only provide structural strength in the direction in which they extend. The filaments **120** have relaxed to no support in the orthogonal direction. Support may be relaxed, for instance, by using only a small percentage (e.g., **10**% to **30**%) of cross-fibers that would normally be used in a tow. In the example of FIG. **1**A, consider the tows extending in the x-direction and their filaments **120** extending past the boundary **112**. The filaments **120** provide structural strength in the x-direction. No cross-fibers are used to support these filaments **120**. Similarly, the filaments **120** extending past the boundary **112** in the y-direction provide strength only in the y-direction. No cross-fibers are used to support these filaments **120**.

This relaxed or lack of structural support in the orthogonal direction enables the filaments **120** to be “spread.” When compressed, the filaments **120** are redistributed such that the number (N) of rows is reduced. In the textile **110** of FIG. **1**A, the filaments **120** extending past the boundary **112** are spread.

FIGS. **2**A and **2**B illustrate a tow **210** in a textile before and after its filaments **220** have been spread. FIG. **2**A illustrates the tow **210** having N=**5** rows of filaments

220 prior to the filaments **210** being spread. When a compressive force (F) is applied to the unsupported or loosely supported portion of the tow **210** in the z-direction, the compressive force causes the filaments **220** to spread in an orthogonal (y) direction. FIG. **2**B shows the filaments **220** after having been spread. In the example of FIG. **2**B, the number rows of spread filaments **220** is reduced from five to two. Width of the spread filaments **220** may be greater than width of the fully supported filaments in the tow **210**.

Reference is once again made to FIG. **1**A. Reducing or eliminating the cross-fibers also reduces the axial stiffness of the filaments **120** extending past the boundary **112**. That is, the textile **110** is softer outside the boundary **112** than within the boundary **112**.

Stiffness of the filaments **120** outside the boundary **112** may be further reduced by making some or all of the filaments ends **122** wavy. FIG. **1**A illustrates filaments **120** having straight portions that terminate in wavy ends **122**. The wavy ends **122** lie in the x-y plane. Since the filaments **120** also lay in the same plane, the waviness is said to be "in-plane."

Thus, the textile **110** has a variable stiffness. Stiffness is highest within the boundary **112**, it is reduced outside the boundary **112**, and may be further reduced at the wavy ends **122**. Filaments **120** picking up loads at their ends will undergo less strain than filaments within the boundary **112**.

For the textile **110** illustrated in FIG. **1**A, the straight portions of the filaments outside the boundary **112** will transmit loads. Wavy ends **122** of the filaments will not transmit loads.

Reference is now made to FIG. **1**B, which illustrates another example of an article **150** including a composite textile **160** of tows. Filaments **170** extend beyond a boundary **162** of the tows. Load transition may be tailored by varying the length of the filaments **170** so that the filaments pick up the loads at different locations. Load transition may be further tailored by making some ends **172** of the filaments **120** wavy and some ends **174** straight.

The articles **100** and **150** of FIGS. **1**A and **1**B further include resin (not shown). The textiles **110** and **160** are embedded in the resin. As a first example, the tows and spread filaments are infused with resin matrix just prior to curing. As a second example, the tows are pre-impregnated with resin matrix prior to layup. As a third example, the tows are tacked together with a partially cross-linked resin to facilitate storage and transport before final processing.

Reference is made to FIG. **3**, which illustrates an example of first and second tows **310** and **320** that are separated by a distance d. As filaments **312** in the first tow **310** are spread, the width of the spread fibers may exceed the width of the first tow **310**. The same may be true for filaments **322** of the second tow **320**. Consequently, some filaments **312** extending from the first tow **310** may be intermixed with some filaments **322** extending from the second tow **320** (FIG. **3** shows only two intermixed filaments **312** and **322** to illustrate this aspect).

Reference is now made to FIG. **4**, which illustrates a ply stack **410**. The ply stack **410** includes multiple layers **420**. One or more of the outermost layers **420** of the ply stack **410** may includes a multi-dimensional textile herein (FIG. **4** shows a textile herein at only one outer layer). The remaining layers **410** may include conventional tows.

The ply stack **410** is not limited to any particular part or structure. Two examples will now be provided.

Reference is now made to FIG. **5**, which illustrates a first example in which a first part **510** is joined to a second part **520**. As but one example, the first part **510** may be a beam and the second part **520** may be a panel. The first part **510** includes the ply stack **410**. Filaments **412** extending from an outer layer of the ply stack **410** are located on a surface of the second part **520**. The parts **510** and **520** may be joined by bonding, co-bonding, or co-curing. Co-curing refers to joining the parts **510** and **520** while both parts **510** and **520** are green (that is, uncured). Co-bonding refers to joining the parts **510** and **520** while one of the parts is green and the other has already been cured or otherwise formed. Bonding refers to joining of the two parts **510** and **520** after the two parts **510** and **520** have already been cured.

The filaments **412** improve the joining of the two parts **510** and **520**. Having thousands of filaments **412** individually joined to the second part **520** greatly reduces the potential for disbonds. Since each filament **412** is independent of the others, disbonds of hundreds or thousands of filaments would have to occur to amount to anything of significance.

In-plane waviness of the filament ends offers added benefits. The waviness pick up little to no load.

Reference is made to FIG. **6**, which illustrates the second example: patching a panel **610** that includes multiple layers of carbon reinforcing fibers embedded in a plastic matrix. In each layer, the carbon fibers extend unidirectionally at a specific angle (e.g., **0** degrees, +**45** degrees, -**45** degrees and **90** degrees).

A damaged region of the panel **610** is scarfed out. In the example of FIG. **6**, the scarfed region **612** is seven layers deep and scarfed at an angle.

A patch **620** for the panel **610** includes a ply stack. The plies of the stack correspond to the layers of the panel **610** that were removed. Thus, each ply of the patch **620** is sized and shaped to replace a panel layer that was removed. In addition, each ply may have the same fiber orientation as the panel layer that was removed. A boundary of the top ply roughly coincides with the opening in the upper layer of the panel **610**.

In the patch **620** of FIG. **6**, the top ply includes a multi-directional weave of tows. Spread filaments (not shown) extend beyond the boundary of the weave. For example, spread filaments extend across four edges. Ends of the filaments may have in-plane waviness. The remaining plies of the patch **620** may include traditional weaves or unidirectional fibers tows.

A layer of adhesive **630** may be placed on the scarfed region **612** of the panel **610**. The patch **620** is placed in the scarfed region **612**. The filaments extending beyond the boundary of the weave are located on and joined to the upper surface of the panel **610**.

Thousands of spread filaments extend from the patch **620**, across a joint formed between the patch **620** and the panel **610**, and onto the panel **610**. The spread filaments create thousands of individual bonds to the panel **610**, which prevents peeling of the patch **620** from the panel **610**. The wavy ends of the filaments may pick up loads, but they do not transmit the loads to the rest of the patch, which further prevents peeling of the patch **620** from the panel **610**.

A textile herein is not limited to the joining of a first composite part to a second composite part. The second part may be made of metal or another non-composite material. Spread filaments extending past a joint between the two parts may be adhesively bonded to the metal part.

A textile herein is not even limited to the joining of one composite part to a non-composite part. Consider the example of FIG. **6**, except that both panel and patch are made of metal instead of a fiber reinforced plastic. The metal patch may be bonded within a damaged region of the metal panel, and a textile herein may cover the metal patch, with its spread filaments extending past the joint and onto a surface of the metal panel. In addition to retaining the metal patch in the panel, the textile may provide a barrier to moisture ingress.

A textile herein is not limited to the patterns illustrated in FIGS. **1**A and **1**B. A textile herein is not limited to filaments extending in first and second directions that are orthogonal.

FIG. **7** illustrates a textile **710** including a triaxial braid of tows extending in three directions (w, x and y). A central portion **720** of the textile **710** is formed from overlapping tows extending in all three directions. Peripheral portions **730** of the textile **710** are formed from tows extending in two of the three directions. For instance, the lower right peripheral portion **730** of the textile **710** is formed from tows extending in the w and y directions. Filaments extending past a boundary of the textile **710** are spread.

FIG. **8** illustrates a textile **810** having a circular boundary **830** and filaments **820** extending past the circular boundary **830**. This textile **810** may be formed by cutting a multi-dimensional weave into a circular shape, pulling out individual filaments at the boundary, and arranging those individual filaments orthogonal to the boundary **830**.

A multi-directional textile herein is not limited to a weave or braid. In other embodiments, the multi-directional textile **110** includes a laminate of multiple layers of tows, with the tows of each layer being unidirectional. For example, a first layer includes tows extending in the x-direction and a second layer includes tows extending in the y-direction. Strength is provided in the x and y-directions by those portions of the layers that overlap.

A textile herein is not limited to all filaments extending past a boundary. In some embodiments, only some filaments may extend past a boundary, while other filaments extending in the same direction are terminated at the boundary. An advantage of terminating some of the filaments at the boundary is that it is easier to spread the fibers extending past the boundary.

In a textile herein, all filaments may have the same modulus and same coefficient of thermal expansion. However, a textile herein is not so limited.

In a textile herein, all filaments may have the same composition. For example, a textile herein may have only carbon filaments. However, a textile herein is not so limited, and some embodiments may have filaments of different composition. For example, a textile herein may have a combination of glass filaments and carbon filaments. The use of glass filaments may result in a higher strain at load. Consider the example of FIG. **1**B. Carbon filaments having wavy ends may be replaced by glass fibers having straight ends.

A textile herein is not limited to tows of any particular width, or any particular number of filaments. Tows may include thousands of filaments.

In a textile herein, the filaments are not limited to wavy ends having sinusoidal shapes. In some embodiments, the filaments **920** of a textile **910** may have wavy ends **922** that are bent parallel to the textile's boundary **912**, as illustrated in FIG. **9**.

Reference is now made to FIG. **10**, which illustrates a general method of using a textile herein. At block **1010**, first and second parts are mated. The first part includes an outer layer having a weave of first tows extending in a first direction and second tows extending in a second direction. End portions of the first tows extend onto a surface of the second part. Adhesive may be placed on faying surfaces of the first and second parts.

At block **1020**, the end portions of the tows are spread into individual filaments. Pressure may be applied (e.g., by a roller) to the end portions to cause the filaments to spread. The filaments may be combed to further ensure that the filaments are spread. Adhesive may also placed on the spread filaments.

At block **1030**, the first part is joined to the second part, whereby faying surfaces of the parts are joined together, and the spread filaments are joined to the surface of the second part. Depending on the composition and the degree of cure of the parts, the joining may be performed by co-curing, co-bonding, or bonding. Heat and pressure during curing or bonding may be applied by an autoclave. If the first part is a patch, heat and pressure may be applied by a heat blanket.

Reference is made to Figure **11**, which illustrates an aircraft **1100** including a fuselage **1110**, wing assemblies **1120**, and empennage **1130**. A propulsion system **1140** including one or more propulsion units are coupled to the fuselage **1110**, wing assemblies **1120** or other portions of the aircraft **1100**. FRP structural elements such as skins, stiffeners, frames and spars may be joined together to form the fuselage **1110**, wing assemblies **1120** and empennage **1130**. Textiles herein may be used in these FRP structural elements. Consider the example of beam having an FRP flange that is bonded and/or fastened to a skin panel. The beam may be used to stiffen the skin panel. A textile herein is used in the outer layer of the flange. Individual filaments extending from the textile are joined to the skin panel. The filaments may extend lengthwise from the flange and/or transversely from the flange.

Textiles herein may also be used to patch damaged portions of the fuselage **1110**, wing assemblies **1120** and empennage. Certain areas of the aircraft **1100** may be vulnerable to erosion damage and/or impact damage. A textile herein may be used to patch the damage as described above. The individual filaments of the textile prevent the patch from peeling. Wavy ends of the filaments further prevent the patch from peeling.

The patch also reduces damage after impact. If a patched area is once again impacted by debris, the wavy ends of the filaments pick up the impact loads, but do not transmit the impact loads to the rest of the patch.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. An article comprising a multi-directional textile of first reinforcing fiber tows extending in a first direction and second reinforcing fiber tows extending in a second direction, portions of filaments in the first fiber tows extending past a boundary of the textile and spread, the tows embedded in resin.

2. The article of claim **1**, wherein filaments in the second tows also extend past the boundary of the textile and are spread.

3. The article of any preceding claim , wherein the filaments within the boundary of the textile provide structural strength along the first and second directions, and wherein those filaments extending past the boundary provide structural strength in only the first direction.

4. The article of any preceding claim, wherein the textile includes a number of rows of bundled filaments, and wherein the spread filaments are in a lesser number of rows.

5. The article of any preceding claim, wherein the textile includes a weave of the tows.

6. The article of claim **5**, wherein the filaments extending past the boundary have sparse to no support by cross-fibers.

7. The article of any preceding claim, wherein the textile includes a braid of tows extending in first, second and third directions.

8. The article of any preceding claim, wherein the textile has a circular boundary and wherein the filaments extending past the boundary are normal to the boundary.

9. The article of any preceding claim, wherein ends of the spread filaments have in-plane waviness.

10. The article of any preceding claim, wherein the filaments extending past the boundary are terminated at different lengths.

11. A layup comprising a plurality of layers of reinforcing fibers and an outer layer including the article of any preceding claim.

12. A method of fabricating a composite structure, comprising:

mating first and second parts, wherein the first part includes an outer layer having a weave of first tows extending in a first direction and second tows extending in a second direction;

spreading ends of the tows into individual filaments; and

joining the spread filaments to a surface of the second part.

13. The method of claim **12**, wherein the first and second parts are aircraft structural elements.

14. The method of claim **12**, wherein the first part is a patch for the second part, which is an aircraft structural element.

FIG. 1A

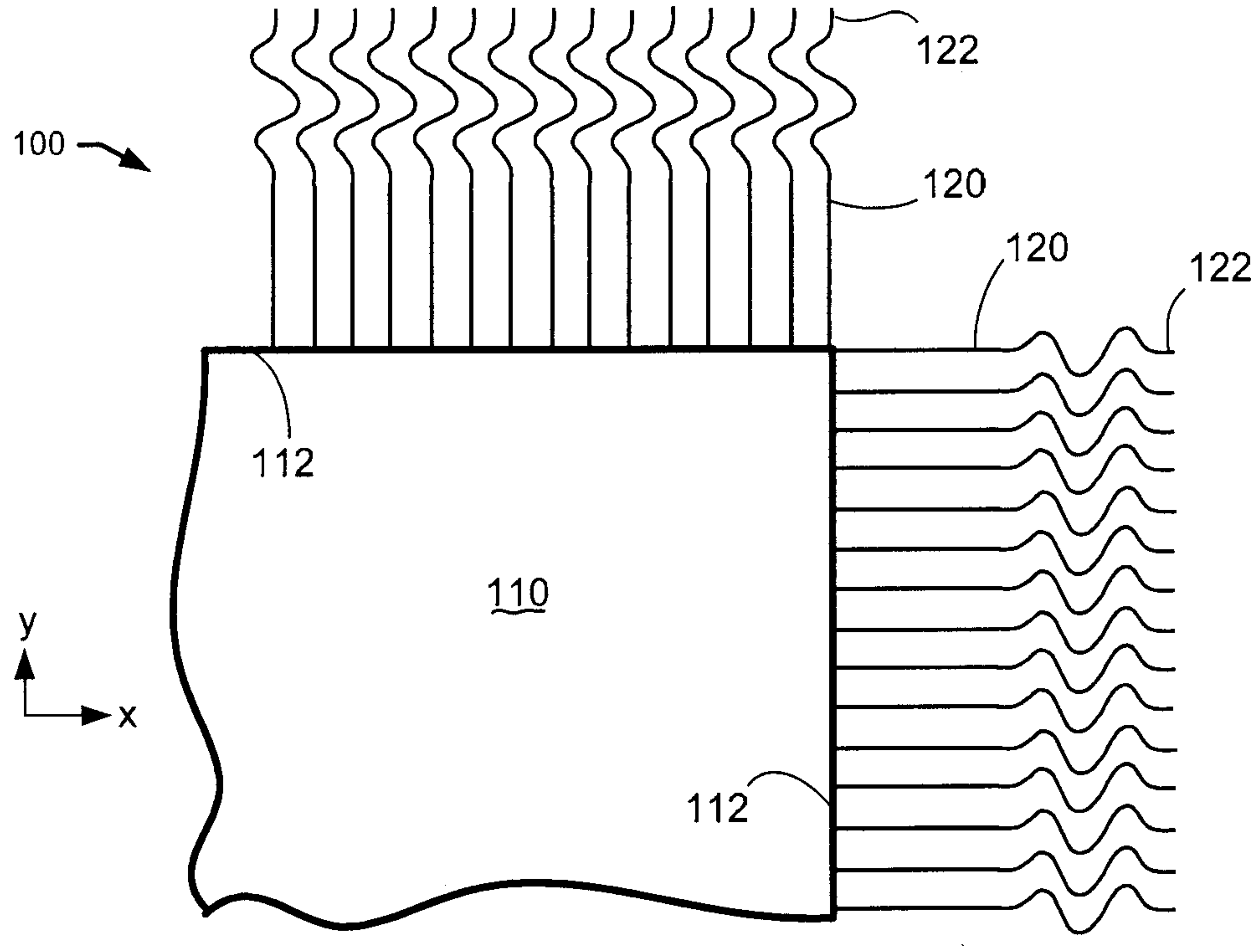


FIG. 1B

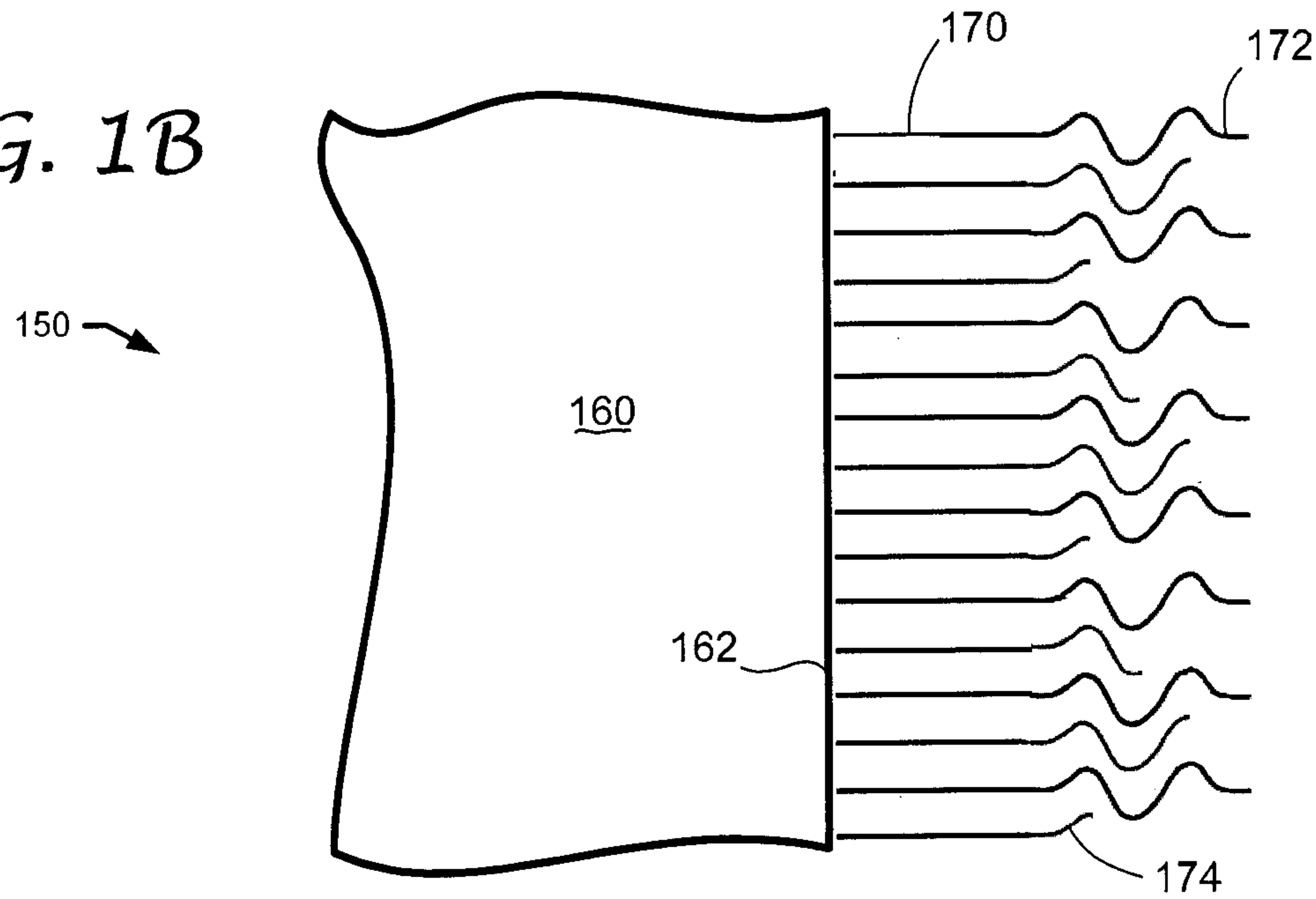


FIG. 2A

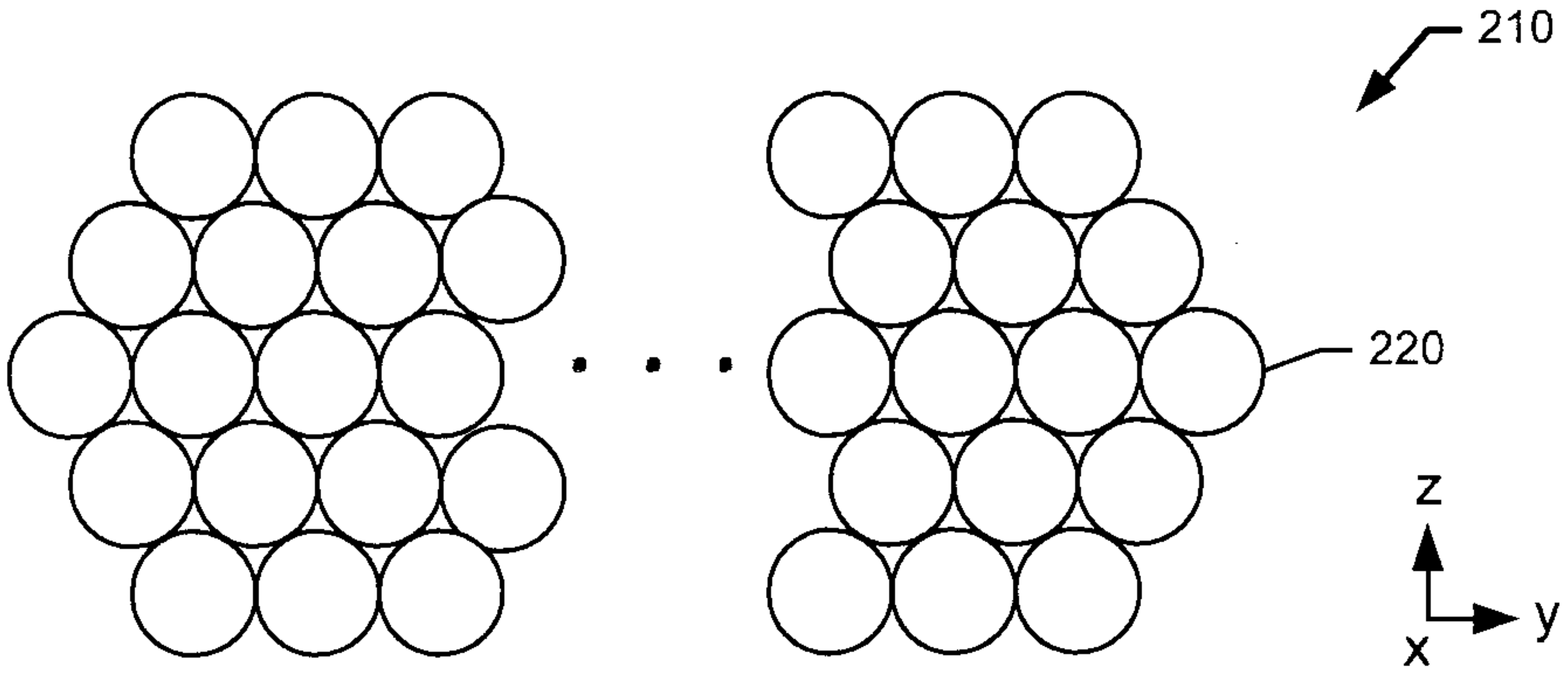


FIG. 2B

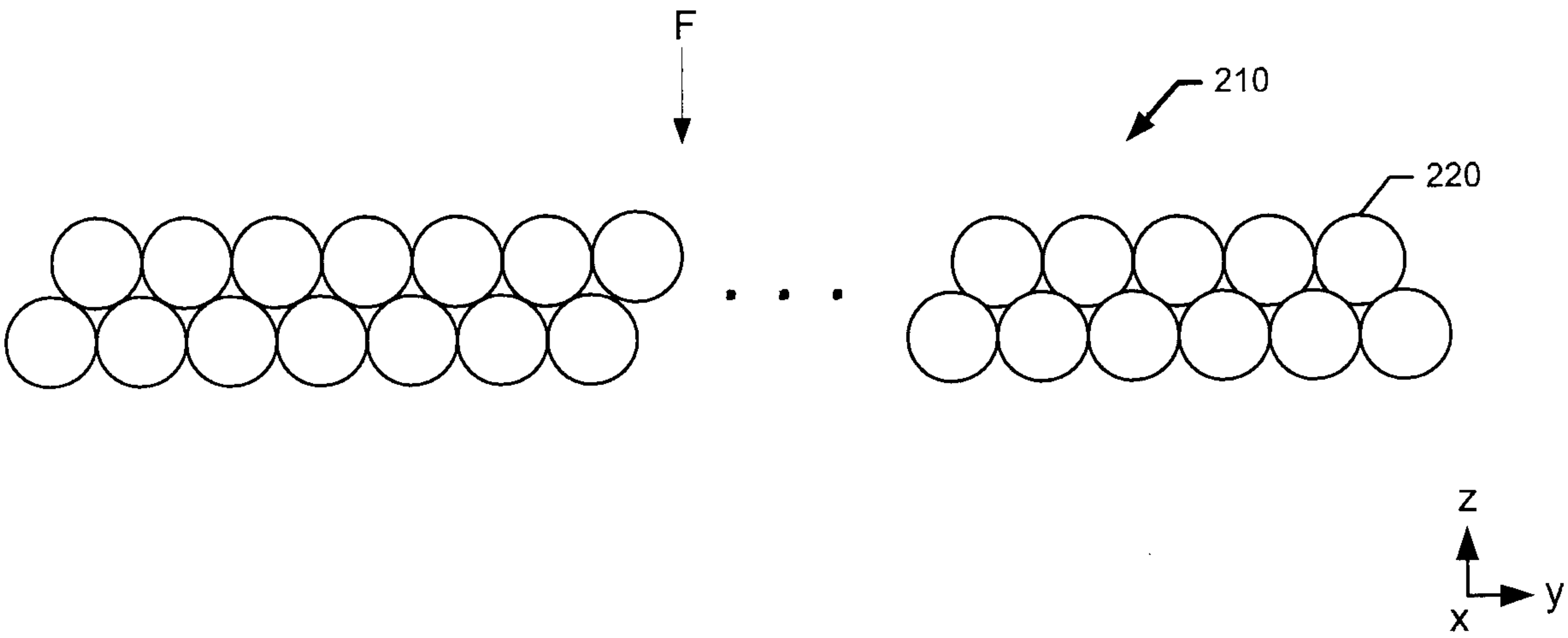


FIG. 3

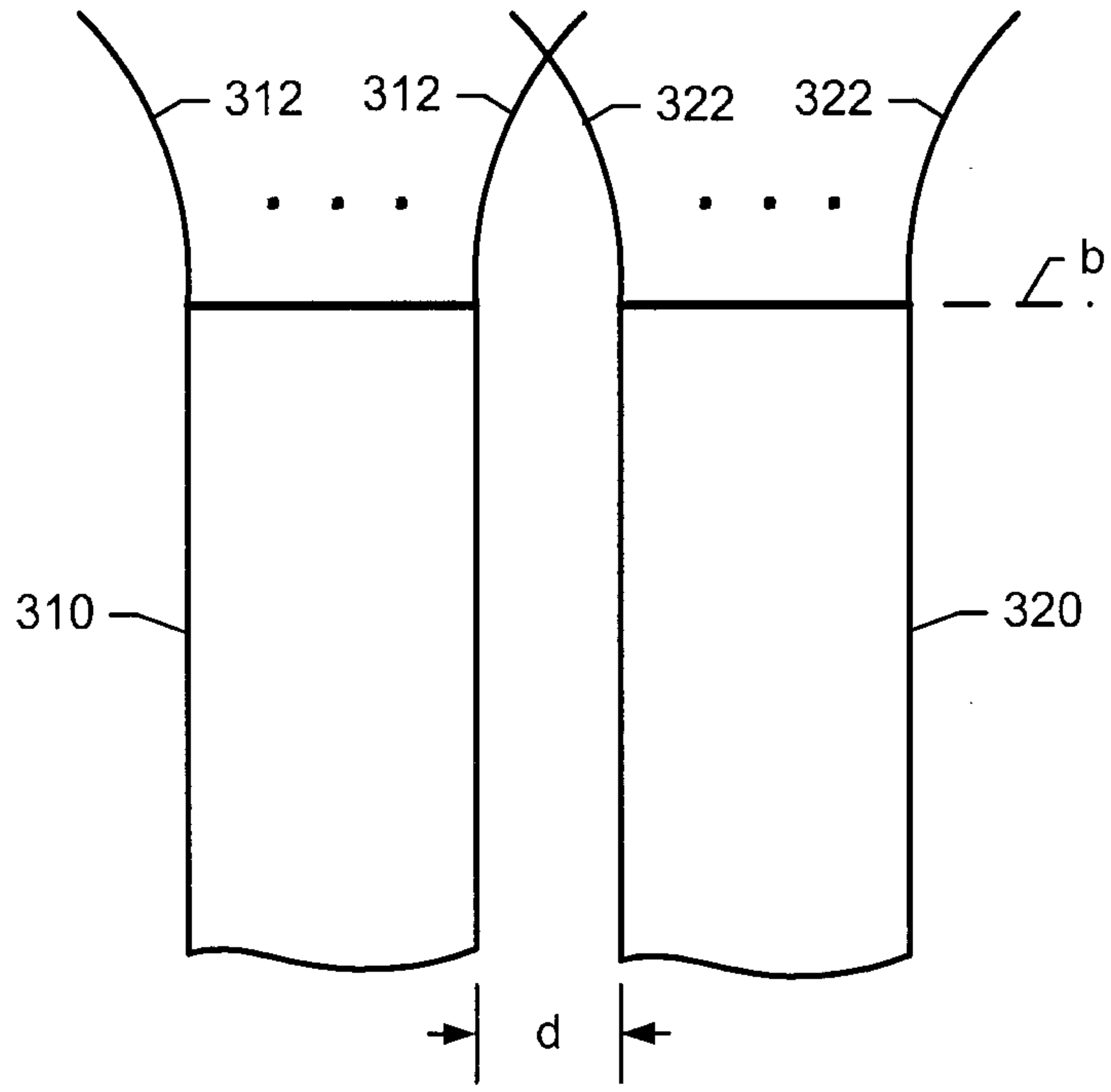


FIG. 4

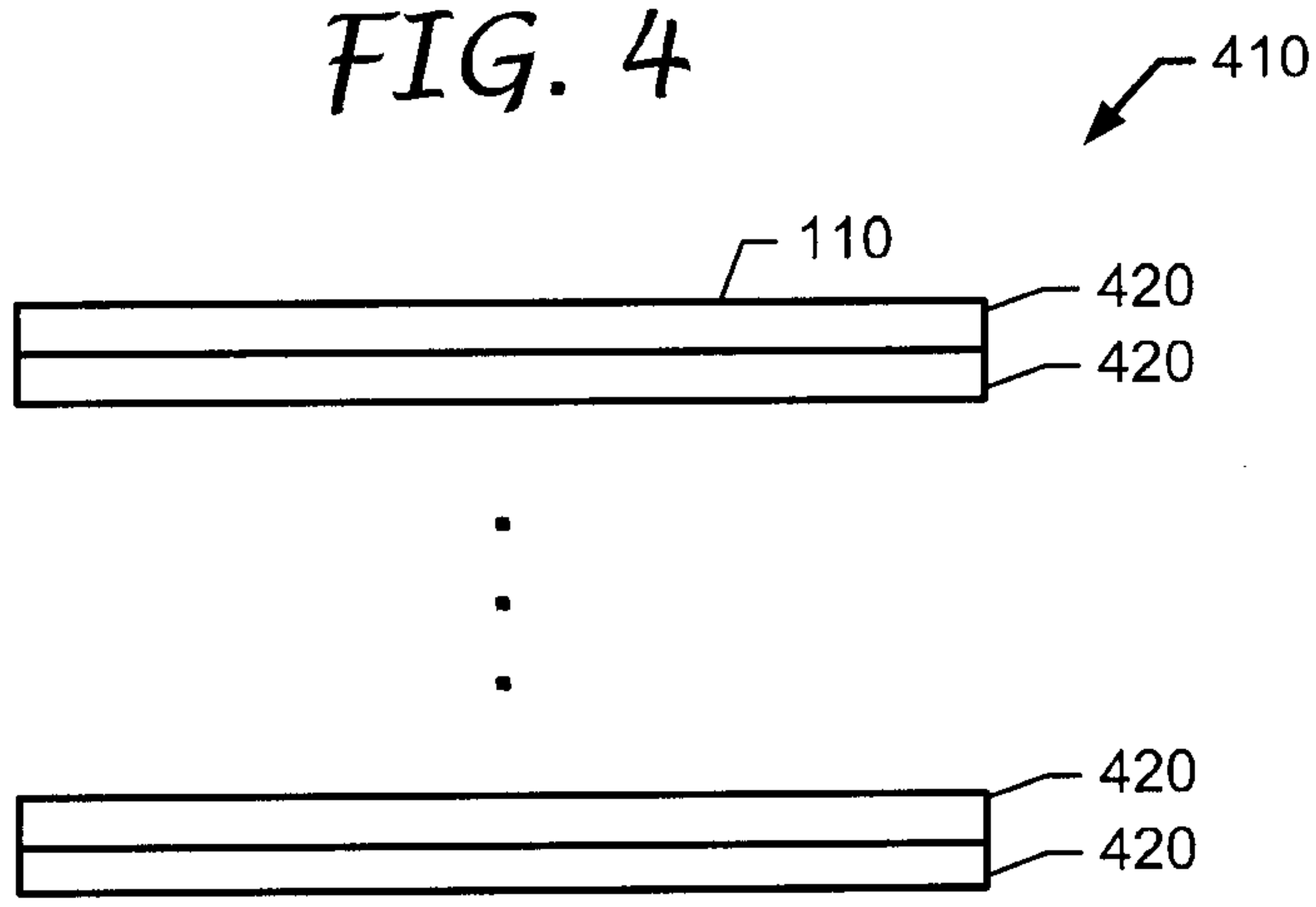


FIG. 5

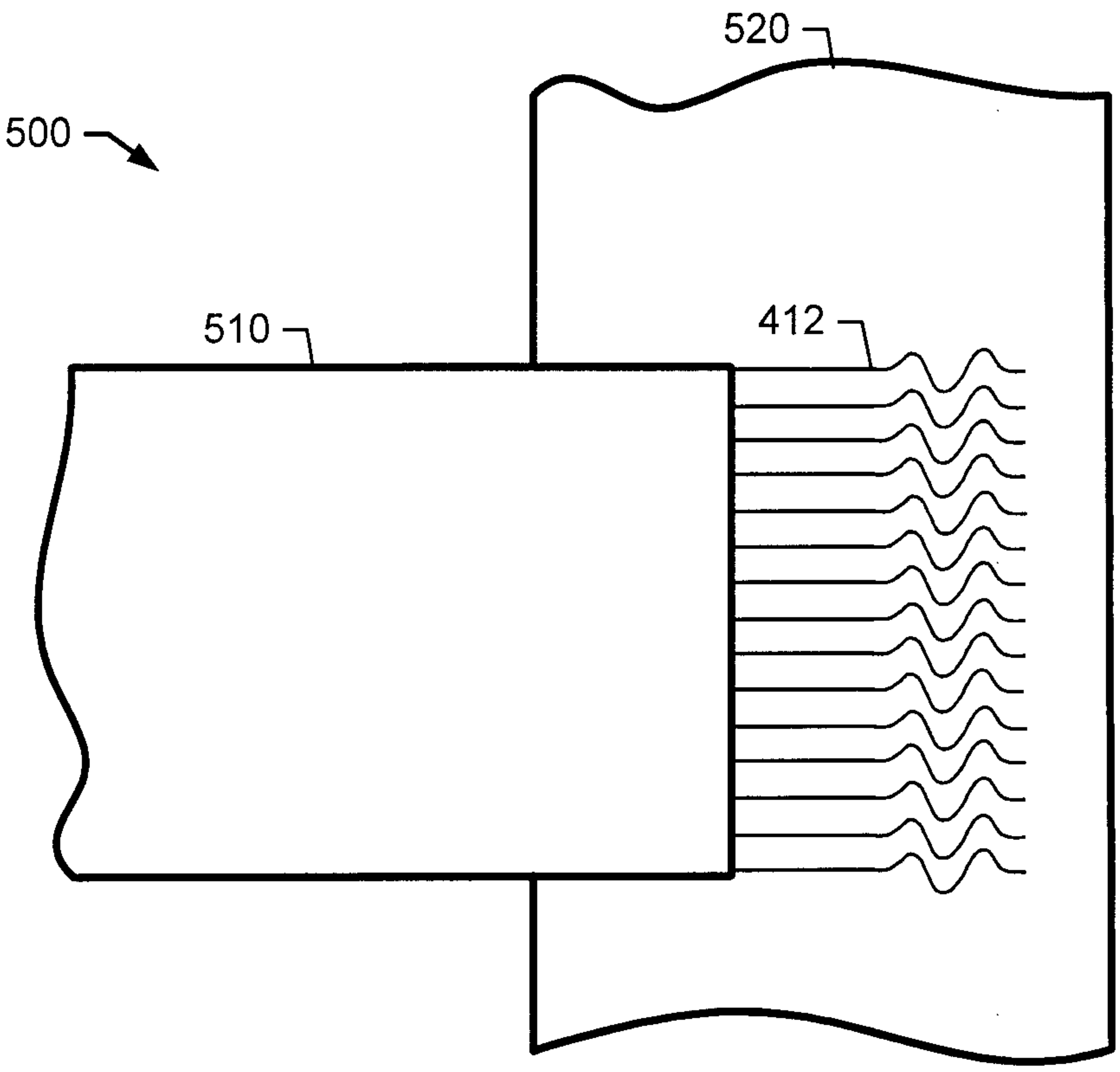


FIG. 6

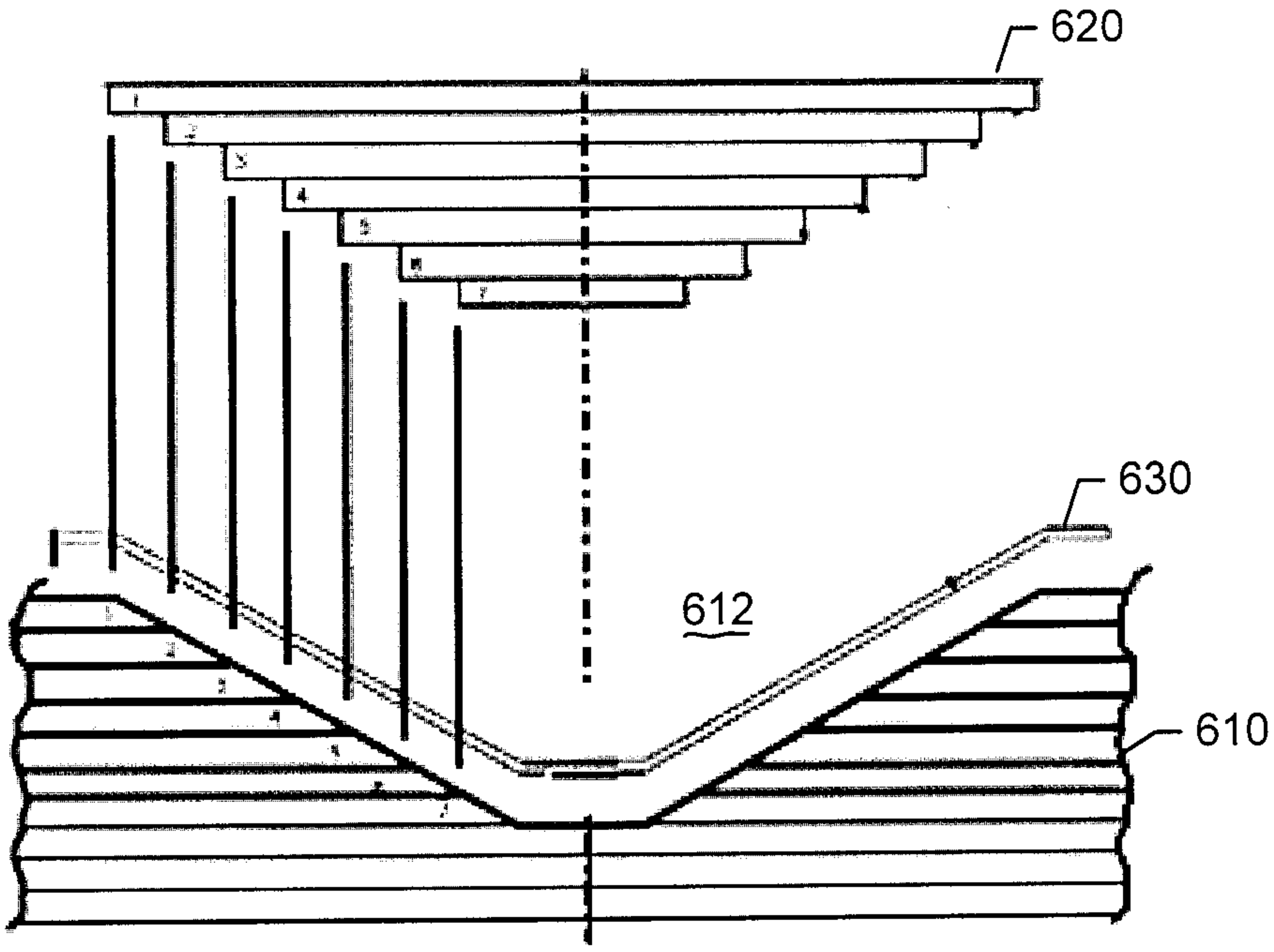


FIG. 7

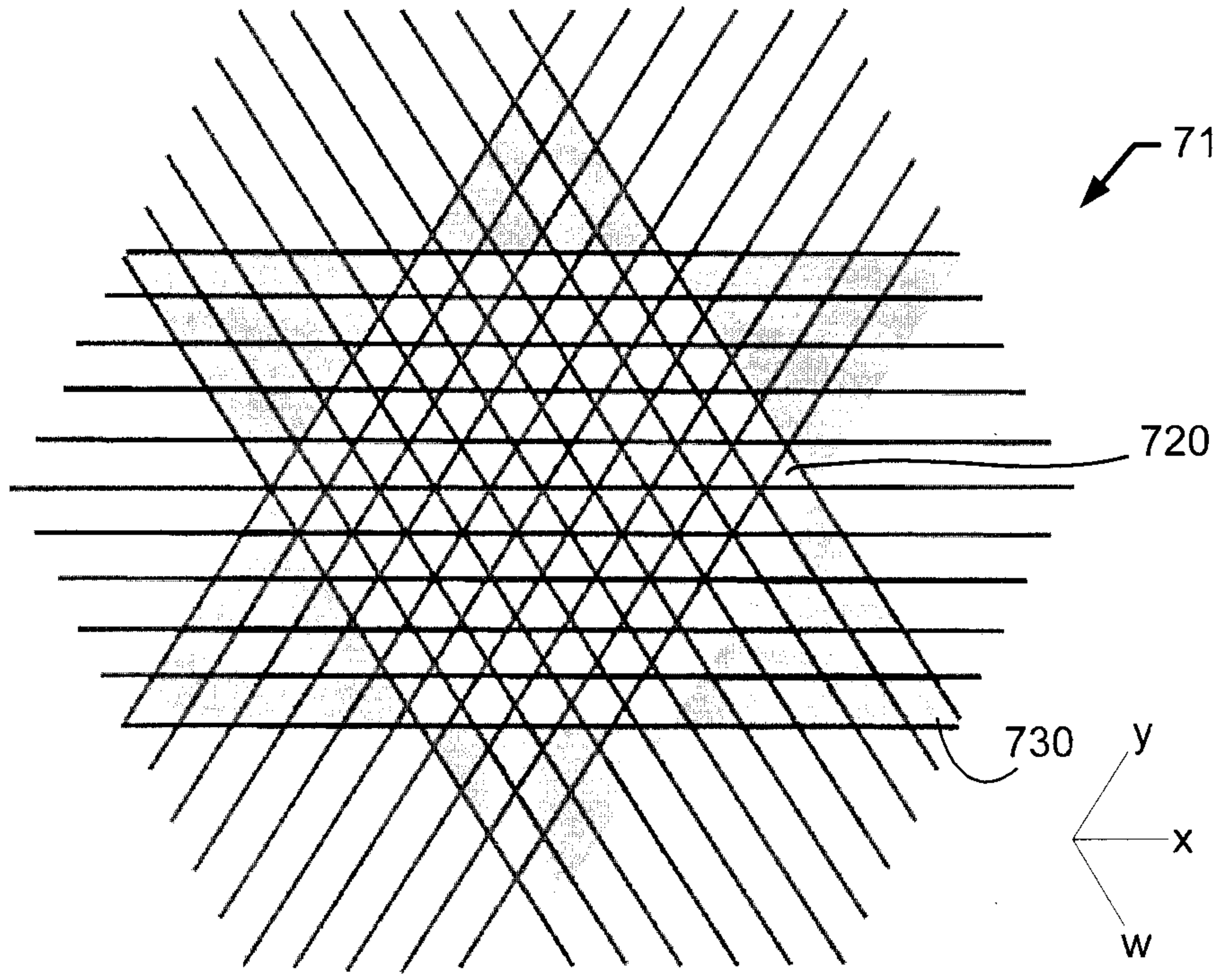


FIG. 8

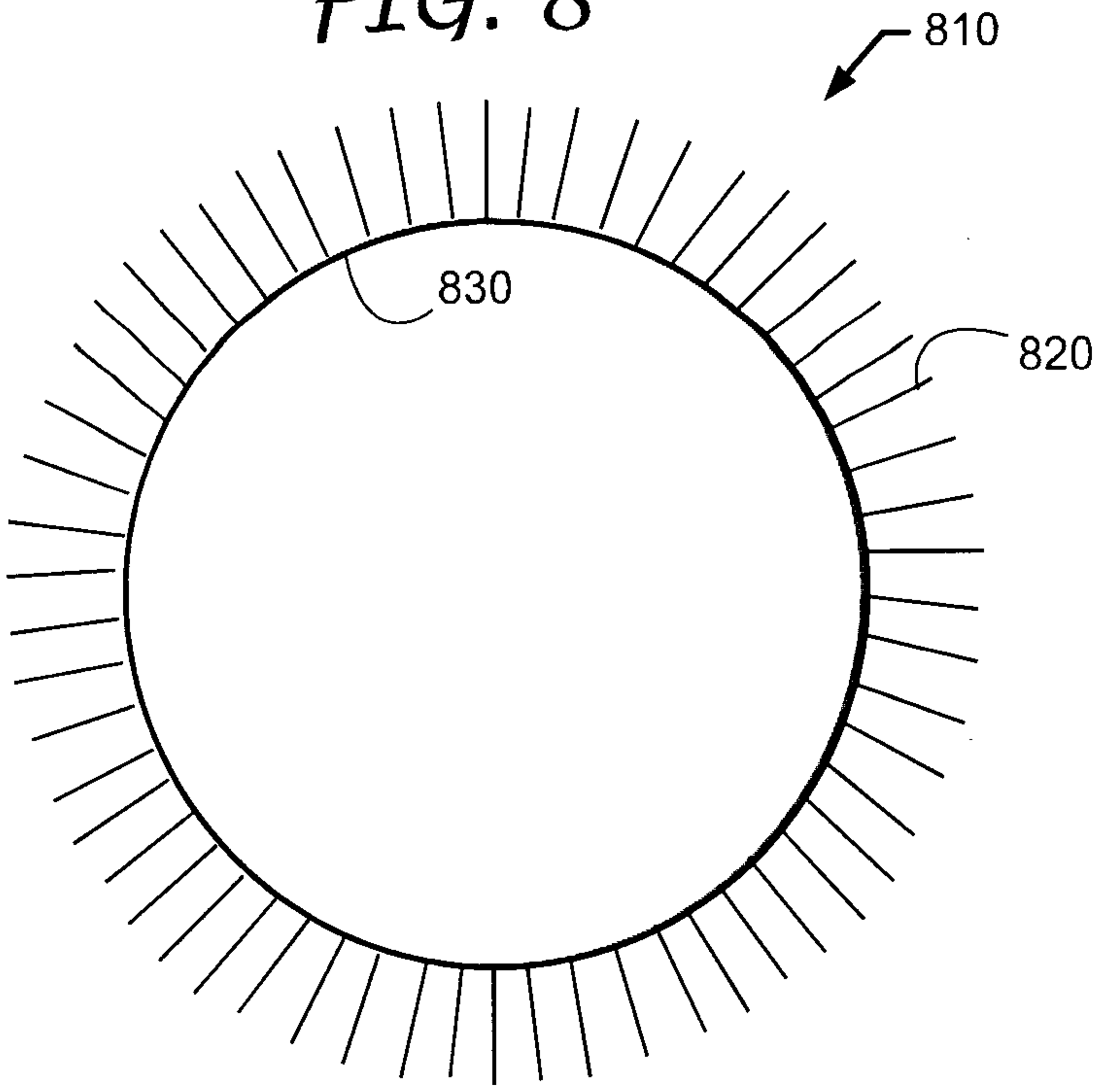


FIG. 9

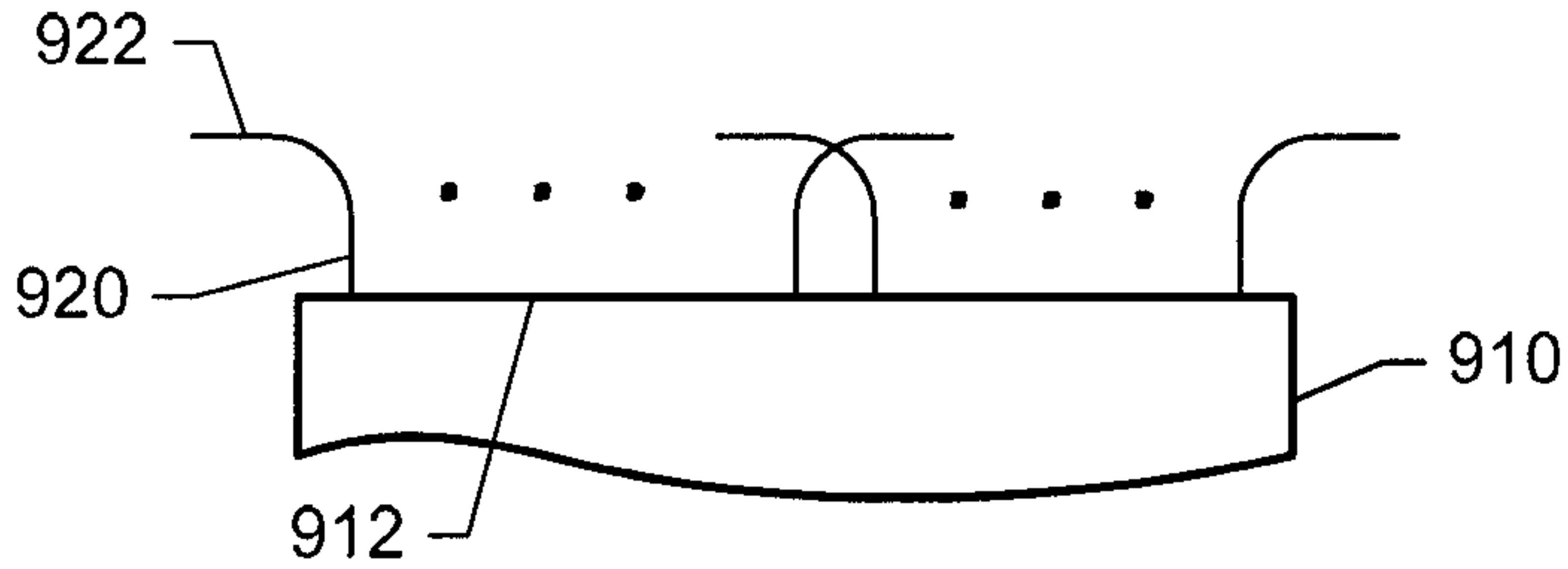


FIG. 10

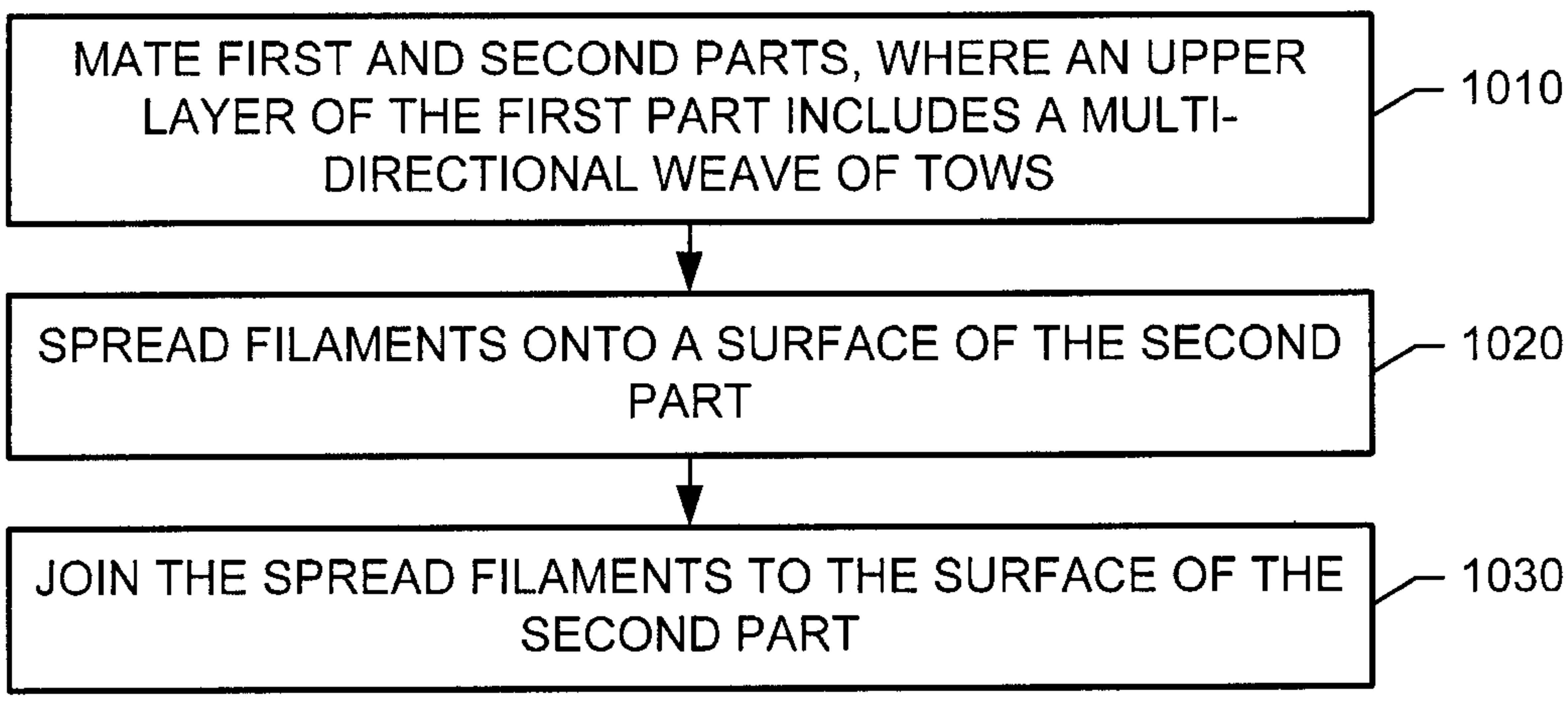
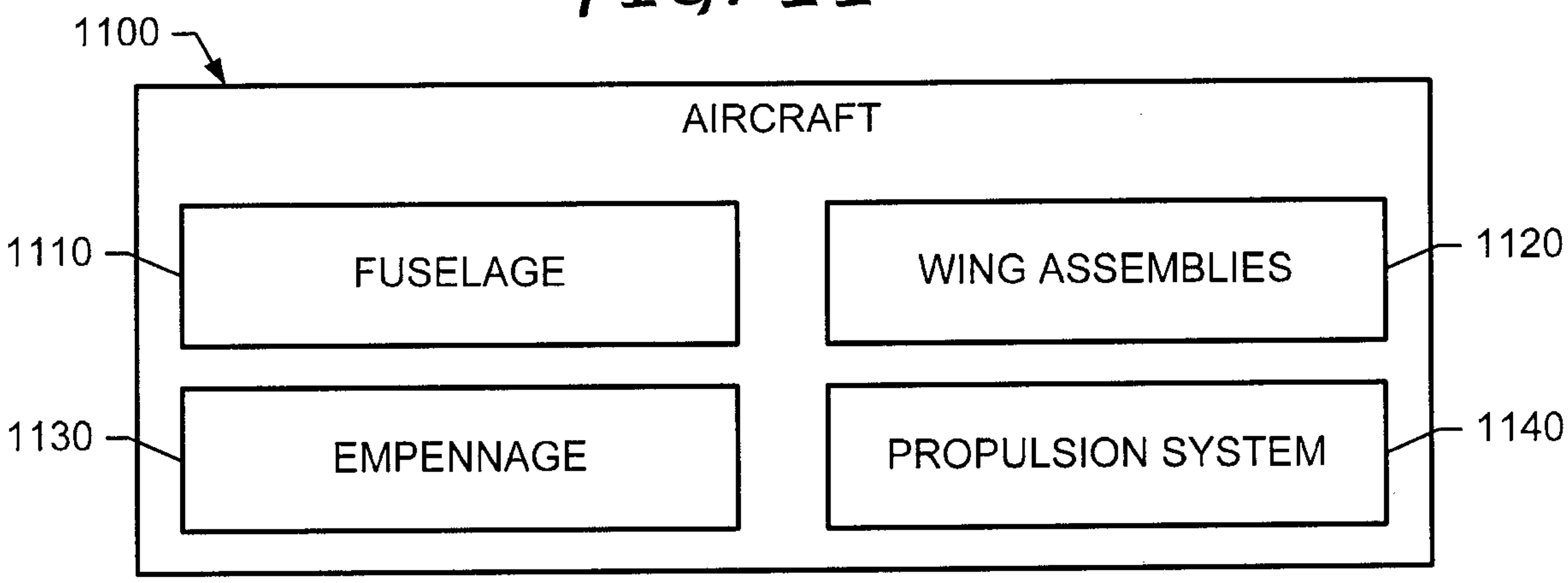
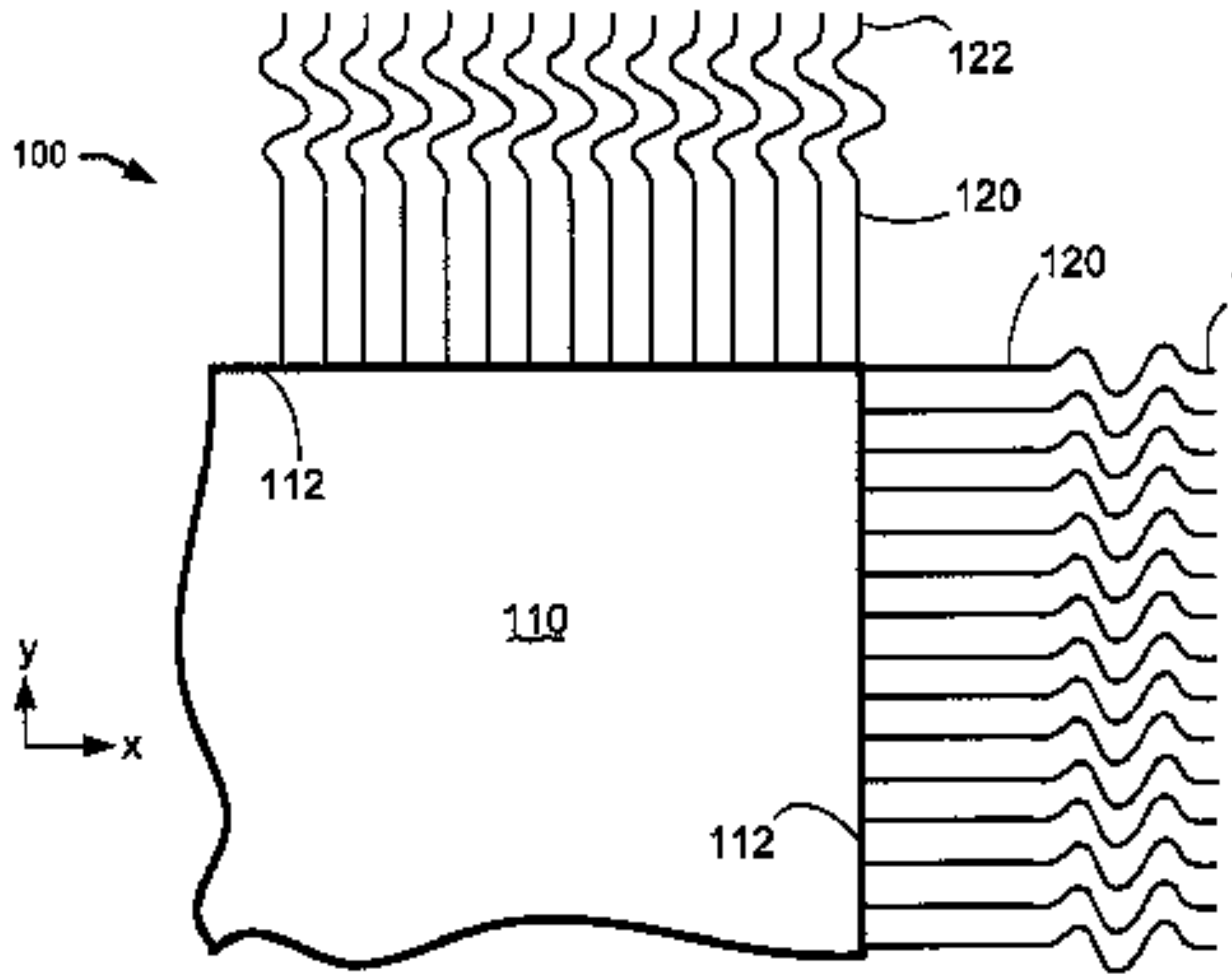


FIG. 11



A



B