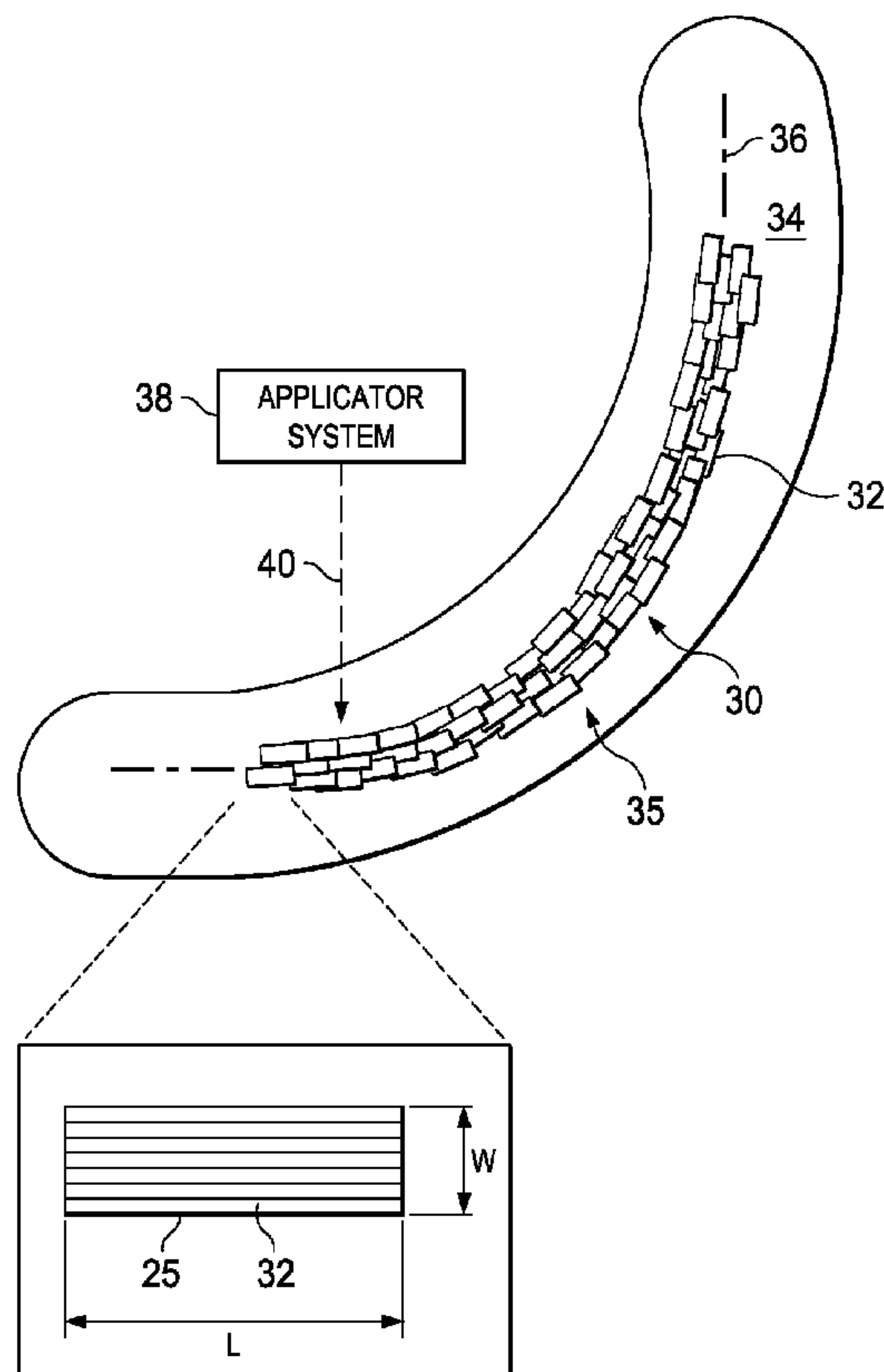




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(54) **Titre : FORMATION D'ELEMENTS COMPOSITES A L'AIDE D'UN PRE-IMPREGNE A FIBRES DISCONTINUES ORIENTEES**
(54) **Title: FORMING COMPOSITE FEATURES USING STEERED DISCONTINUOUS FIBER PRE-PREG**



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Interlaminar features of a composite structure are laid up by placing and steering individual chopped fiber pre-preg segments onto a substrate.

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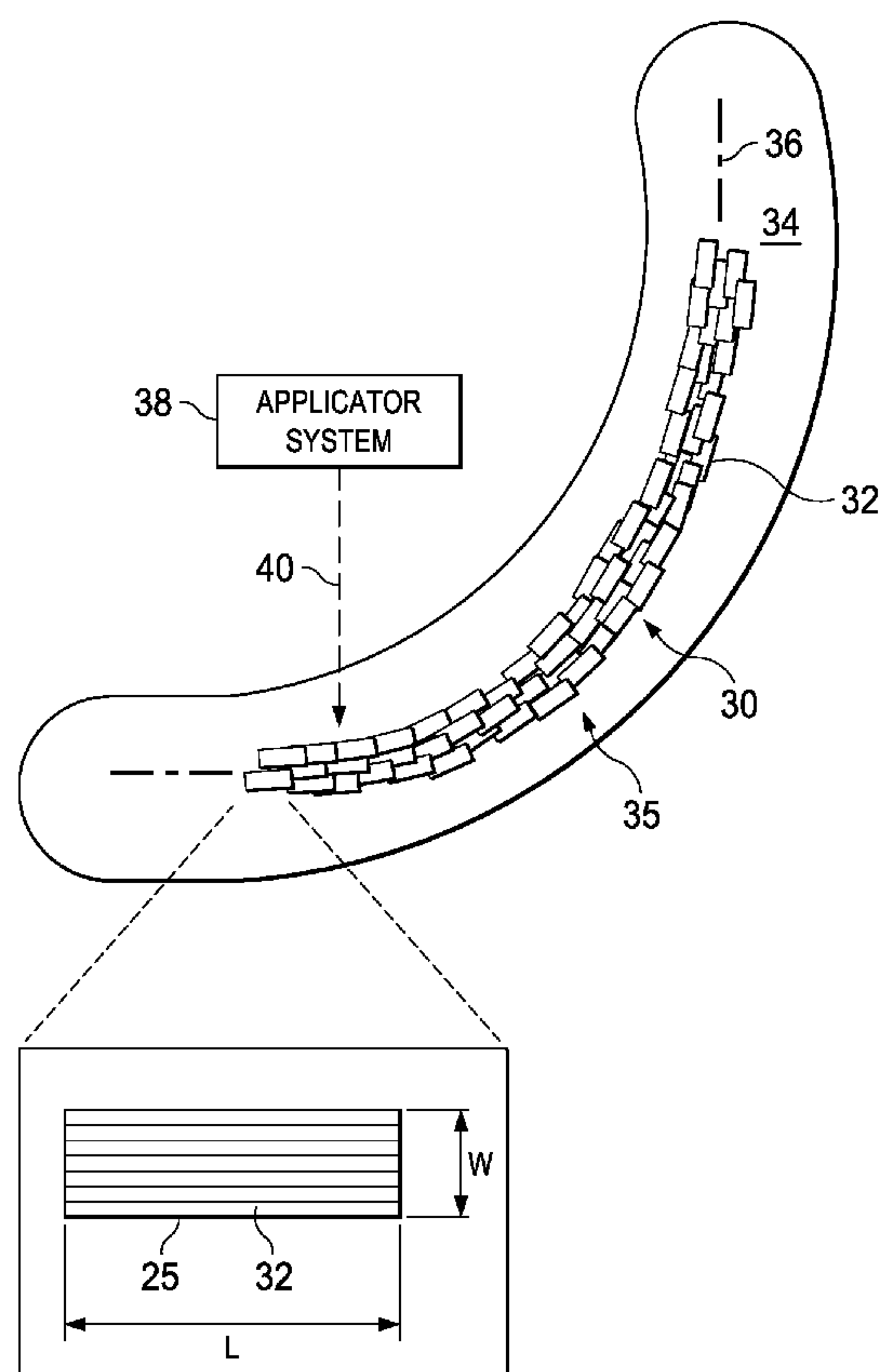


FIG. 1

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FORMING COMPOSITE FEATURES USING STEERED DISCONTINUOUS FIBER PRE-PREG

5

BACKGROUND INFORMATION

1. Field:

The present disclosure generally relates to fabrication of composite laminate structures using fiber pre-preg, and deals more particularly with a method and apparatus for forming composite structural features by steering
10 discontinuous fiber pre-preg onto a substrate with desired fiber orientations.

2. Background:

The strength, stiffness and load transfer characteristics of a composite laminate structure may be optimized through control of fiber orientation during the
15 layup process. Conventional composite laminates may be laid up using pre-preg tapes, tows or broad goods, employing either automated fiber placement equipment or hand placement techniques to layup the material. Generally, the resulting composite structure exhibits substantially consistent structural properties throughout. In some cases, however, it may be necessary or desirable
20 to control the thickness and/or fiber orientation in local areas of a composite laminate in order to optimize its structural properties and/or account for higher local stresses.

The ability to control local thickness/fiber orientation is limited using current fabrication processes. For example, automated fiber placement
25 equipment may be used to steer continuous tows onto the substrate, but the radius of curvature that can be achieved is limited, thus making control of fiber orientation difficult in local areas having tight contours. Achieving close control over thickness and/or fiber orientation in local areas of laminate may also be costly and time-consuming.

30 Accordingly, there is a need for a method and apparatus for controlling composite laminate thickness and/or fiber orientation in local areas of a laminate in order to optimize the laminate's structural properties. There is also a need for a

method and apparatus of the type mentioned above which is efficient, highly controllable and which may reduce labor and material costs.

SUMMARY

5 The disclosed embodiments provide a method and apparatus for fabricating composite features of laminates which provide increased control over feature thickness and/or fiber orientation in local areas of a laminate structure, such as in tight contours and/or within transitions in laminate thickness. Composite material may be laid up such that fiber orientations are substantially
10 continuously aligned with load vectors in selected local areas of a laminate, thereby optimizing the laminate's structural properties.

 The amount of composite material required to provide local areas of a laminate structure with desired structural properties may be reduced by forming the composite features using scrap pre-preg derived from other
15 products/processes. Recycling of scrap pre-preg for use in the disclosed method may reduce material costs, thus optimizing the buy-to-fly ratio (the ratio of materials weight procured to the weight of the finished product) for aircraft applications of the embodiments. The embodiments allow composite material in the form of discontinuous fiber pre-preg to be "steered" onto a substrate in order
20 to achieve desired fiber orientations.

 The use of discontinuous fiber pre-preg allows greater control over laminate thickness variations in local areas of the laminate, while allowing local tailoring of laminate thickness in three dimensions to provide smooth transitions between differing features of a laminate structure. Moreover, the use of
25 discontinuous fiber pre-preg permits the formation of doublers or other pad-ups having tight contours and/or tapered edges to achieve smooth load transitions within a structure. Also, the use of discontinuous fiber pre-preg may result in composite features having a higher fiber content.

 According to one disclosed embodiment, a method is provided of forming
30 a composite feature having discontinuous reinforcement fibers. The method comprises producing a plurality of resin infused fiber segments each having unidirectional reinforcing fibers, placing the resin infused fiber segments on a substrate, and arranging the resin infused fiber segments such that the

reinforcing fibers of resin infused fiber segments placed on the substrate are substantially aligned relative to a desired reference orientation. Producing the resin infused fiber segments includes chopping scrap fiber pre-preg into individual pieces, which may be performed by breaking or splitting fiber pre-preg along and between the reinforcing fibers into individual pieces. Placing the resin infused fiber segments on the substrate includes moving an applicator over the substrate, and dispensing the resin infused fiber segments from the applicator onto the substrate as the applicator moves over the substrate. Arranging the resin infused fiber segments includes aligning the resin infused fiber segments as they are being dispensed from the applicator onto the substrate. Producing the resin infused fiber segments is performed by drawing continuous fiber pre-preg tape from the applicator, and chopping the pre-preg tape into the resin infused fiber segments as the resin infused fiber segments are being dispensed from the applicator onto the substrate. Dispensing the resin infused segments from the applicator includes dispensing a bandwidth of the resin infused fiber segments onto the substrate. Placing the resin infused fiber segments on the substrate is formed of by streaming the resin infused fiber segments from an applicator head onto the substrate. Streaming the resin infused fiber segments is performed by introducing the resin infused fiber segments into an airstream, and using the airstream to project the resin infused fiber segments onto the substrate. The resin infused fiber segments is performed after the resin infused fiber segments have been placed on the substrate. The method may further comprise applying resin to the substrate before the resin infused segments are placed on the substrate. The method may also comprise applying a resin on at least one end of each of the resin infused fiber segments before they are placed on the substrate.

According to another disclosed embodiment, a method is provided of laying up composite material on a substrate the method comprises placing individual chopped fiber pre-preg segments on the substrate, and controlling the orientation of the pre-preg segments on the substrate. Placing the pre-preg segments on the substrate is performed by moving an applicator head over the substrate along a desired path, and dispensing the pre-preg segments from the applicator head onto the substrate as the applicator moves over the substrate. Controlling the orientation of the pre-preg segments is performed by aligning the

pre-preg segments being dispensed from the applicator head. Controlling the orientation of the pre-preg segments includes changing the orientation of the pre-preg segments after the pre-preg segments have been placed on the substrate.

According to still another embodiment, a composite laminate structure
5 layup is provided comprising a plurality of layers of composite material, each of the layers including a plurality individual chopped fiber pre-preg segments having aligned fiber orientations. The fiber orientations of the chopped fiber pre-preg segments are substantially aligned with a non-linear load path through the composite laminate structure. Each of the individual chopped fiber pre-preg
10 segments may have an aspect ratio of approximately 6:1. The plurality of layers of composite material have a tailored cross-sectional shape and is contoured along a length of the layup.

According to still another disclosed embodiment, apparatus is provided for laying up a composite structure. The apparatus comprises an applicator
15 adapted to move over the surface of a substrate, and dispense at least one stream of substantially aligned chopped, resin infused fiber segments onto the surface of a substrate. The apparatus may also comprise a computer controlled manipulator for moving the applicator along a preselected path over the substrate. The applicator includes a supply of continuous resin infused fiber, and
20 a chopper for chopping the continuous resin infused fiber into individual resin infused fiber segments. Applicator may further include an airstream generator for carrying the resin infused fiber segments from the applicator onto the substrate. The applicator may be adapted to simultaneously dispense multiple streams of substantially aligned chopped, resin infused fiber segments onto the substrate.
25 The features, functions, and advantages can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

In one embodiment there is provided a method of forming a composite
30 feature having discontinuous reinforcement fibers, including producing a plurality of resin infused fiber segments each having unidirectional reinforcing fibers; placing the resin infused fiber segments on a substrate; and, arranging the resin infused fiber segments such that the reinforcing fibers of resin infused fiber

segments placed on the substrate are substantially aligned relative to a desired reference orientation.

Producing the resin infused fiber segments may include chopping scrap fiber pre-preg into individual pieces.

5 Producing the resin infused fiber segments may be performed by splitting fiber pre-preg along and between the reinforcing fibers into individual pieces.

Placing the resin infused fiber segments on the substrate may include moving a applicator over the substrate, and dispensing the resin infused fiber segments from the applicator onto the substrate as the applicator moves over the
10 substrate.

Arranging the resin infused fiber segments may include aligning the resin infused fiber segments as they are being dispensed from the applicator onto the substrate.

Producing the resin infused fiber segments may be performed by drawing
15 continuous fiber pre-preg tape from the applicator, and chopping the pre-preg tape into the resin infused fiber segments as the resin infused fiber segments are being dispensed from the applicator onto the substrate.

Dispensing the resin infused fiber segments from the applicator may include dispensing a bandwidth of the resin infused fiber segments onto the
20 substrate.

Placing the resin infused fiber segments on the substrate may be performed by introducing the resin infused fiber segments into an airstream, and using the airstream to stream the resin infused fiber segments from an applicator head onto the substrate.

25 Streaming the resin infused fiber segments may be performed by introducing the resin infused fiber segments into an airstream, and using the airstream to project the resin infused fiber segments onto the substrate.

Arranging the resin infused fiber segments may be performed after the resin infused fiber segments have been placed on the substrate.

30 The method may further include applying resin to the substrate before the resin infused fiber segments are placed on the substrate.

The method may further include applying a resin on at least one end of each of the resin infused fiber segments before they are placed on the substrate.

In another embodiment there is provided a method of laying up composite material on a substrate, including placing individual chopped fiber pre-preg segments on the substrate; and, controlling an orientation of the pre-preg segments on the substrate.

5 Placing the pre-preg segments on the substrate may be performed by moving an applicator head over the substrate along a desired path, and dispensing the pre-preg segments from the applicator head onto the substrate as the applicator moves over the substrate.

10 Controlling an orientation of the pre-preg segments may be performed by substantially aligning the pre-preg segments being dispensed from the applicator head relative to a desired orientation.

Controlling an orientation of the pre-preg segments may include changing the orientation of the pre-preg segments after the pre-preg segments have been placed on the substrate.

15 In another embodiment there is provided a composite laminate structure layup, including a plurality of layers of composite material, each of the layers including a plurality individual chopped fiber pre-preg segments having substantially aligned fiber orientations.

20 The fiber orientations of the chopped fiber pre-preg segments may be substantially aligned with a non-linear load path through the composite laminate structure.

Each of the individual chopped fiber pre-preg segments may have an aspect ratio of approximately 6:1.

25 The plurality of layers of composite material may have a tailored cross-sectional shape and may be contoured along a length of the layup.

According to another embodiment there is provided an apparatus for laying up a composite structure, including an applicator adapted to move over a substrate, and dispense at least one stream of substantially aligned chopped, resin infused fiber segments onto the substrate.

30 The apparatus may further comprise a computer controlled manipulator for moving the applicator along a preselected path over the substrate.

The applicator may include a supply of continuous resin infused fiber, and a chopper for chopping the continuous resin infused fiber into individual resin infused fiber segments.

5 The applicator may include an airstream generator for streaming the resin infused fiber segments from the applicator onto the substrate.

The applicator may be adapted to simultaneously dispense multiple streams of substantially aligned chopped, resin infused fiber segments onto the substrate.

10 According to another embodiment, a method of forming a composite feature having discontinuous reinforcement fibers is disclosed. The method involves producing a plurality of resin infused fiber segments each having unidirectional reinforcing fibers; placing the plurality of resin infused fiber segments on a substrate; and arranging the plurality of resin infused fiber segments such that the reinforcing fibers of the resin infused fiber segments placed on the substrate are substantially aligned relative to a desired reference orientation.

15 Producing the plurality of resin infused fiber segments may involve chopping scrap fiber pre-preg into individual pieces.

Producing the plurality of resin infused fiber segments may involve splitting fiber pre-preg along and between the reinforcing fibers into individual pieces.

20 Placing the plurality of resin infused fiber segments on the substrate may involve moving an applicator over the substrate, and dispensing the plurality of resin infused fiber segments from the applicator head onto the substrate as the applicator moves over the substrate.

25 Arranging the plurality of resin infused fiber segments may involve aligning the plurality of resin infused fiber segments as they are being dispensed from the applicator onto the substrate.

Producing the plurality of resin infused fiber segments may involve drawing continuous fiber pre-preg tape from the applicator, and chopping the pre-preg tape into the plurality of resin infused fiber segments as the plurality of resin infused fiber segments are being dispensed from the applicator onto the substrate.

30

Dispensing the plurality of resin infused fiber segments from the applicator may involve dispensing a bandwidth of the plurality of resin infused fiber segments onto the substrate.

5 Placing the plurality of resin infused fiber segments on the substrate may involve introducing the plurality of resin infused fiber segments into an airstream, and using the airstream to stream the plurality of resin infused fiber segments from an applicator head onto the substrate.

10 Streaming the plurality of resin infused fiber segments may involve introducing the plurality of resin infused fiber segments into an airstream, and using the airstream to project the plurality of resin infused fiber segments onto the substrate.

Arranging the plurality of resin infused fiber segments may be performed after the plurality of resin infused fiber segments have been placed on the substrate.

15 The method may further involve applying resin to the substrate before the plurality of resin infused fiber segments are placed on the substrate.

The method may further involve applying a resin on at least one end of each of the plurality of resin infused fiber segments before they are placed on the substrate.

20 Producing the plurality of resin infused fiber segments each having unidirectional reinforcing fibers may involve causing the plurality of resin infused fiber segments to be aligned such that the unidirectional reinforcing fibers of each fibre segment are substantially parallel to each other.

25 Arranging the plurality of resin infused fiber segments may involve placing the resin infused fiber segments into a shaker tray having a series of parallel channels and vibrating the shaker from side-to-side.

According to another disclosed embodiment, a method of forming a composite feature having discontinuous reinforcement fibers involves placing a pre-preg tape into an applicator head, thereafter chopping the pre-preg tape into a plurality of distinct resin infused fiber segments, each having unidirectional reinforcing fibers and each chopped to have a desired aspect ratio, wherein an

aspect ratio comprises a length of an individual segment divided by a width of the individual segment; moving the applicator head over a substrate, dispensing the plurality of distinct resin infused fiber segments from the applicator head onto the substrate as the applicator head moves over the substrate, and steering, using the applicator head, the plurality of distinct resin infused fiber segments such that the unidirectional reinforcing fibers of substantially all of the plurality of distinct resin infused fiber segments placed on the substrate are substantially aligned relative to a desired reference orientation.

Chopping the plurality of distinct resin infused fiber segments may involve splitting the pre-preg tape along and between reinforcing fibers into individual pieces.

Steering the plurality of distinct resin infused fiber segments may involve aligning the plurality of chopped resin infused fiber segments as they are being dispensed from the applicator head onto the substrate.

Chopping the plurality of distinct resin infused fiber segments may involve drawing the pre-preg tape from a pre-preg tape supply in the applicator head, and chopping the pre-preg tape into the plurality of distinct resin infused fiber segments as the plurality of distinct resin infused fiber segments are being dispensed from the applicator head onto the substrate.

Steering the plurality of distinct resin infused fiber segments from the applicator head may involve dispensing a bandwidth of the plurality of resin infused fiber segments onto the substrate.

Steering the plurality of distinct resin infused fiber segments involves introducing the plurality of distinct resin infused fiber segments into an airstream, and using the airstream to stream the plurality of distinct resin infused fiber segments from the applicator head onto the substrate.

Streaming the plurality of distinct resin infused fiber segments may involve using the airstream to project the plurality of distinct resin infused fiber segments onto the substrate.

The method may further involve applying resin to the substrate before the plurality of distinct resin infused fiber segments are placed on the substrate.

The method may further involve applying resin on at least one end of each of the plurality of distinct resin infused fiber segments before they are placed on the
5 substrate.

According to still another disclosed embodiment, an apparatus is provided for laying up a composite structure. The apparatus includes an applicator adapted to move over a substrate, and dispense at least one stream of substantially aligned chopped, resin infused fiber segments onto the substrate, wherein the applicator
10 includes a supply of continuous resin infused fiber, a chopper for chopping the continuous resin infused fiber into individual resin infused fiber segments, and an airstream generator for streaming the resin infused fiber segments from the applicator onto the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

Figure 1 is an illustration of a combined block and diagrammatic of discontinuous fiber pre-preg being applied to a substrate along a tight contour.

Figure 1A is an illustration of a plan view showing one shape of the pre-preg segments.

Figure 1B is an illustration of a plan view showing another shape of the pre-preg segments.

Figure 1C is an illustration of a plan view showing a further shape of the pre-preg segments.

Figure 2 is an illustration of a perspective view of a barrel section of an aircraft fuselage showing loads applied to the fuselage.

Figure 3 is an illustration of a diagrammatic view of one of the window openings in the fuselage of Figure 2, also showing load vectors around the window opening.

Figure 4 is an illustration of an elevational view of one of the window openings in the fuselage shown in Figure 2, also showing a surrounding doubler formed of discontinuous fiber pre-preg.

Figure 5 is an illustration of the area designated as "FIG. 5" in Figure 4.

Figure 6 is an illustration of a sectional view taken along the line 6-6 in Figure 5.

Figure 7 is an illustration of a cross-sectional view of a composite structure showing a discontinuous interlaminar fiber filler and transition in a gap within the thickness of a composite laminate structure.

Figure 8 is an illustration of a flow diagram of a method of laying up interlaminar composite features using the disclosed method.

Figure 9 is an illustration of a perspective view of a portion of an aircraft fuselage frame section, broken lines indicating areas where interlaminar structural features may be formed using the disclosed method.

Figure 10 is an illustration of a sectional view taken along the line 10-10 in Figure 9 showing an interlaminar structural feature formed using the disclosed method.

Figure 11 is an illustration of a sectional view taken along the line 11-11 in Figure 9.

Figure 12 is an illustration of a combined block and diagrammatic view of a system for placing discontinuous fiber pre-preg.

Figure 13 is an illustration of a combined block and diagrammatic view of an alternate embodiment of the system for placing discontinuous fiber pre-preg.

Figure 14 is an illustration of a flow diagram of a method of laying up composite laminates using discontinuous fiber pre-preg derived from pre-preg scrap.

Figure 15 is an illustration of a plan view showing various shapes of pre-preg scrap that may be used in the method shown in Figure 14.

Figure 16 is an illustration of a plan view showing randomly oriented, fiber pre-preg segments formed by chopping the scrap shown in Figure 15.

Figure 17 is an illustration of a plan view similar to Figure 16, but showing the fiber orientations of the fiber pre-preg segments having been aligned in preparation for application to a substrate.

Figure 18 is an illustration of a diagrammatic view of a method of converting fiber pre-preg scrap into segments and readying it for application to a substrate.

Figures **19A** is an illustration of a diagrammatic side view of an applicator applying resin onto a substrate.

Figure **19B** is an illustration of a plan view of the resin applied to the substrate shown in Figure **19A**.

5 Figure **20A** is an illustration of a diagrammatic side view showing chopped fiber pre-preg segments being applied over the resin shown in Figure **19B**.

Figure **20B** is an illustration of a plan view of the substrate in Figure **20A**, showing the random orientation of the chopped fiber pre-preg segments.

10 Figure **21A** is an illustration of a diagrammatic side view showing the fiber segment aligner aligning the chopped fiber pre-preg segments.

Figure **21B** is an illustration of a plan view showing the chopped fiber pre-preg segments of Figure **21A** having been aligned by the fiber segment aligner.

Figure **22A** is an illustration of a side view of a chopped fiber pre-preg segment with a drop of resin having been placed on one end thereof.

15 Figure **22B** is an illustration of a bottom view of the chopped fiber pre-preg segment shown in Figure **22A**.

Figure **23A** is an illustration of a side view of the chopped fiber pre-preg segment of Figure **22A** having been placed on a substrate, but prior to rotation thereof.

20 Figure **23B** is an illustration of a plan view of the chopped fiber pre-preg segment shown in Figure **23A**.

Figure **24A** is an illustration of a side view, similar to Figure **23A**, but after the chopped fiber pre-preg segment has been rotated.

25 Figure **24B** is an illustration similar to Figure **23B**, but showing the fiber pre-preg segment having been rotated, the position of the chopped fiber pre-preg segment before rotation being indicated in the phantom.

Figure **25** is an illustration of a flow diagram of aircraft production and service methodology.

Figure **26** is illustration of a block diagram of an aircraft.

30

DETAILED DESCRIPTION

The disclosed embodiments provide a method and apparatus for fabricating fiber reinforced resin laminates which provide increased control over

laminate thickness, contour, width, cross-sectional profile and/or fiber orientation in local areas of a laminate structure. Referring to Figure 1, a composite feature **30** comprises discontinuous, resin infused fibers which may be in the form of chopped fiber pre-preg segments **32** having unidirectional reinforcing fibers **25**.

5 Each of the fiber pre-preg segments **32** is elongate, having a length L that is greater than its width W . Each of the fiber pre-preg segments **32** may have an aspect ratio (L/W) in the range of approximately **6:1**, however this particular ratio is merely illustrative. The fiber pre-preg segments **32** may have other aspect ratios that are selected and/or optimized for the application, including structural

10 requirements and the equipment used to position or place the segments **32**. In some embodiments, the fiber pre-preg segments **32** may have a length that is equal to or less than its width. For convenience and ease of description, the illustrative examples of composite features **30** that will be discussed below utilize unidirectional fiber pre-preg. However, it should be noted here that the principals

15 of the disclosed embodiments may be employed to form composite features **30** using other types of pre-preg segments **32**, including resins that are reinforced with fibers having multiple fiber orientations, such as, for example and without limitation, bidirectional fibers that are woven (cloth pre-preg) or otherwise combined in a manner to suit the particular application.

20 The disclosed embodiments are particularly well-suited for forming any of a variety of interlaminate features **30**, i.e. features **30** that are located between two continuous plies. However, the embodiments may also be employed to form composite features **30** that are partially or fully exposed, such as external features. . In some applications, it may be useful or desirable to employ pre-preg

25 segments **32** having fibers of differing lengths. Differing fiber lengths in a segment **32** may be achieved by, for example and without limitation, shaping the segment **32**, such as by chopping, in a manner that results in some of the fibers being longer or shorter than other fibers. Three illustrative examples of pre-preg segments **32** having shapes configured to produce reinforcing fibers of differing

30 lengths are respectively shown in Figures 1A–1C. Other segment shapes resulting in differing fiber lengths are possible. As previously mentioned, while the pre-preg segments **32** shown in Figures 1A–1C employ unidirectional reinforcing

fibers, other fiber arrangements are possible, such as a woven fibers (not shown).

The reinforcing fibers **25** may comprise high-strength fibers, such as glass or carbon fibers, graphite, aromatic polyamide fiber, fiberglass, or another suitable reinforcement material. The resin matrix in which the fibers **25** are held may comprise thermoplastic or thermoset polymeric resins. Exemplary thermosetting resins may include allyls, alkyd polyesters, bismaleimides (BMI), epoxies, phenolic resins, polyesters, polyurethanes (PUR), polyurea-formaldehyde, cyanate ester, and vinyl ester resin. Exemplary thermoplastic resins may include liquid-crystal polymers (LCP); fluoroplastics, including polytetrafluoroethylene (PTFE), fluorinated ethylene propylene (FEP), perfluoroalkoxy resin (PFA), polychlorotrifluoroethylene (PCTFE), and polytetrafluoroethylene-perfluoromethylvinylether (MFA); ketone-based resins, including polyetheretherketone; polyamides such as nylon-6/6, **30%** glass fiber; polyethersulfones (PES); polyamideimides (PAIS), polyethylenes (PE); polyester thermoplastics, including polybutylene terephthalate (PBT), polyethylene terephthalate (PET), and poly(phenylene terephthalates); polysulfones (PSU); or poly(phenylene sulfides) (PPS).

As used herein, "pre-preg" means fibers that have been impregnated with an uncured or partially cured resin which acts as a matrix to hold the fibers and which is flexible enough to be formed into a desired shape. The resin is then "cured," e.g., by the application of heat in an oven or an autoclave, to harden the resin into a strong, rigid, fiber-reinforced structure. In the case of pre-preg segments **32** having unidirectional fibers, the fibers extend substantially parallel to each other and, for purposes of this description, have a **0°** axial orientation, referred to hereinafter as the fiber direction or orientation of the pre-preg segments **32**. Where pre-preg segments **32** are used that have multiple sets of fiber orientations, typically the fiber orientations one or more of these sets will be used in aligning and orienting the segments **32** as they are being placed on a substrate **34** during the layup process.

The fiber pre-preg segments **32** may be laid up on a substrate **34** that may comprise a tool or an underlying continuous composite ply, using a suitable applicator system **38** which "steers" the fiber pre-preg segments **32** onto the

substrate **34**. The applicator system **38** dispenses, places and aligns the fiber pre-preg segments **32** on the substrate **34** such that the direction of the fibers **25** in each of the fiber pre-preg segments **32** is substantially aligned in a desired orientation. For example, in the example shown in Figure **1**, the fiber orientations of the fiber pre-preg segments **32** are substantially aligned with a curved center axis **36** forming a relatively tight contour **35**, with the fiber orientations of the segments **32** changing in direction along the contour **35** to remain substantially aligned in a desired orientation relative to the center axis **36**. The degree to which a chosen set of the fiber orientations of the pre-preg segments **32** are aligned with respect to a desired orientation, direction, or axis will depend upon the application. In some applications, the orientations of the pre-preg segments **32** may vary to some extent at one or more locations of a composite feature **30**. In fact, in some applications, some degree of variation of pre-preg segment orientation relative to a desired, reference orientation may be useful or desirable within a specified tolerance of variation.

In one embodiment, the applicator system **38** dispenses a serial stream **40** of pre-aligned fiber pre-preg segments **32**, which are then steered and placed onto substrate **34** by moving an applicator head (not shown) forming part of the applicator system **38** in a desired path over the substrate **34**, which in the illustrated example, is along, or parallel to the center axis **36**. Repeated passes of the applicator head over the substrate **34** result in successive layers or plies being laid up, each comprising aligned fiber pre-preg segments **32**. Thus, the composite feature **30** comprises multiple layers or plies of discontinuous fibers infused with resin.

Although not shown in Figure **1**, as will become apparent later in the description, the disclosed embodiments may also be employed to fill voids or gaps (not shown) in composite structures as well as to form transitions (not shown) in laminate thicknesses by steering resin infused, discontinuous fibers such as chopped fiber pre-preg onto a substrate. By continuously steering the orientation of the fiber pre-preg segments **32** as they are being placed, structural properties of the laminate may be closely controlled on a local basis and therefore optimized. These void or gap fillers, as well as features such as bulk doubler areas that include transitions in laminate thicknesses will typically be

interlaminar features (located between continuous plies), however in some applications as previously mentioned, it is possible that they may be exposed, external features.

Attention is now directed to Figures 2–6 which illustrate use of the disclosed method and apparatus in connection with the fabrication of an aircraft fuselage 44 (Figure 2). The fuselage 44 comprises an outer skin 46 supported on internal framework 45 which includes barrel shaped frames 65 and longitudinally extending stringers 47. The skin 46 may include one or more discontinuities, such as window openings 42, cargo doors (not shown), etc. Fuselage pressure 49 results in a hoop load 50 being applied to the circumference 55 of the fuselage 44, passing through the window openings 42 or other openings in the skin 46. Further, during flight, the crown 54 of the fuselage 44 is placed under tension 75, while the belly 56 of the fuselage 44 is placed under compression 77, resulting in shear loads 52 (Figure 3) that must traverse the window openings 42. As shown in Figure 3, the hoop loads 50 and shear loads 52 are transferred around the perimeter of the window openings 42. Consequently, the corners 58 around the window openings 42 are more highly stressed 59 because they must transfer both the hoop loads 50 and the shear loads 52. As will be discussed below, the disclosed method and apparatus may be employed to layup composite doublers forming an interlaminar pad-up feature 30 around the window openings 42 that stiffens and strengthens the fuselage 44 around the window opening 42, enabling the skin 46 to transfer the required loads through the corners 58.

Referring particularly to Figure 5, the pad-up feature 30 is formed of a discontinuous fiber pre-preg comprising a plurality of steered fiber pre-preg segments 32 similar to the fiber pre-preg segments 32 previously discussed in connection with Figure 1. The fiber pre-preg segments 32 are steered as they are being placed on a tool (not shown) or underlying ply (not shown) so that their respective fiber orientations are substantially aligned with structural load paths, which in this example, is along or parallel to a contoured axis 36 at the corners 58. The number of layers or plies of fiber pre-preg segments 32 that are steered onto the substrate 34 will vary with the application, and the desired thickness of the pad-up feature 30. In some applications, it may be desirable to tailor the cross-sectional area of the pad-up feature 30 formed by steering the fiber pre-

preg segments **30** onto the substrate **34**. For example, referring to Figure **6**, the pad-up feature **30** shown in Figures **4** and **5** may be laid up on one or more underlying full plies **60** and may be covered by one or more overlying full plies **62**. The pad-up feature **30** comprises a double taper **64** that is formed by laying down
 5 layers of the fiber pre-preg segments **32** that are successively narrower in width “**W**”. Tapering of the pad-up feature **30** allows the resulting doubler to better conform to the full plies **60**, **62**.

For example, referring to Figure **7**, the fiber pre-preg segments **32** may be steered and layered to form cross-sectional shapes that are suitable for filling
 10 gaps or voids **82** in a composite laminate, such as gaps **82** that may be formed in transitions in the thickness of a laminate structure **85**. In the example shown in Figure **7**, the composite sandwich laminate structure **85** comprises a core **86** sandwiched between two composite plies **60**, **62**. A gap **82** is formed as the laminate structure **85** as it transitions from the core **86** to a solid laminate **87**. The
 15 gap **82** forms a structural discontinuity that may require strengthening and reinforcement in order to carry the required loads. The gap **82** may be filled with layers of the fiber pre-preg segments **32** to form a discontinuous fiber pre-preg filler feature **30**, which in this example, has a single taper **84**.

Figure **8** illustrates the overall steps of a method of making a
 20 discontinuous fiber composite feature **30** by steering fiber pre-preg segments **32** onto a substrate **34**. Beginning at **66**, fiber pre-preg segments **32** are produced, as by, for example, chopping the fiber pre-preg to a desired dimensions and a desired aspect ratio. At **68**, discontinuous fiber plies are laid up by placing the fiber pre-preg segments **32** on a substrate **34** at step **70**, and at **72**, arranging the
 25 fiber pre-preg segments **32** such that the fiber orientations of the reinforcing fibers are aligned in a desired direction. As will be discussed below in more detail, the fiber pre-preg segments **32** may be placed on the substrate **34** using an applicator head which may also be used to steer the fiber pre-preg segments **32** and align them along load paths through a structure.

30 Attention is now directed to Figures **9–11** which illustrate a portion of a frame section **74** having a generally Z-shaped cross-section. The frame section **74** may form a portion of a barrel shaped frame **65** such that used in the fuselage **44** shown in Figure **1**. The frame section **74** includes upper and lower, oppositely

extending flanges **76**, **78** connected by a web **80**. "Mousehole" openings **82** may be provided in the web **80** and flange **76** in order to provide clearance for longitudinally extending stringers **47** (Figure **2**) in the fuselage **44**. The disclosed method and apparatus may be employed to form discontinuous resin infused
5 fiber features **30** selectively reinforce portions of the frame section **74**, particularly in local areas that may experience higher stresses. Thus, one side of a central portion of the web **80** may be provided with a longitudinally extending, contoured, pad-up feature **30a** formed by multiple layers of discontinuous fiber pre-preg comprising fiber pre-preg segments **32** that are steered onto the web **80** as the
10 frame section **74** is being laid up.

In the illustrated embodiment, as is apparent from Figures **10** and **11**, the pad-up feature **30a** varies in cross-sectional shape along its length, however in other embodiments the cross-sectional shape of the pad-up feature **30a** may be constant along its length. Similarly, pad-up features **30b**, **30c** comprising layers of
15 fiber pre-preg segments **32**, such as chopped pre-preg, may be steered onto the web **80** in contoured patterns surrounding the mouseholes **82**. The pad-up features **30a**, **30b**, **30c** may have any desired cross-sectional geometry selected to optimize local structural properties of the frame section **74**. Any of the pad-up features **30b**, **30c** may vary in cross-sectional size and/or shape along its length.

20 Attention is now directed to Figure **12** which illustrates one embodiment of a system **88** that may be employed to form discontinuous, resin infused fiber features **30** of the type previously described, including local features of a structure that may require strengthening, stiffening and/or reinforcement. The system **88** broadly comprises an applicator head **90** that is adapted to place fiber
25 pre-preg segments **32**, such as chopped pre-preg **32**, onto a substrate **34**, forming multiple layers or plies **96**. Applicator head **90** is displaced in X, Y and Z directions over the substrate **34** by an automated manipulator **92** which may comprise, for example and without limitation, a robot.

The manipulator **92** as well as the applicator head **90** are operated by a
30 programmed CNC (computer numerically controlled) controller **94**. The applicator head **90** includes a pre-preg tape supply **98** which supplies unidirectional fiber pre-preg tape **100** through guides **102** to a chopper **103**. The chopper **103** may comprise a conventional cutter mechanism (not shown) operated in

synchronization with the movement the applicator head **90** to chop the pre-preg fiber tape **100** into fiber pre-preg segments of the desired size and shape. The chopped fiber pre-preg segments **32** are fed **40** into an airstream **104** generated by airstream generators **106** on the applicator head **90**. The airstream **104** propels and places the pre-aligned fiber pre-preg segments **32** through a nozzle **108** onto the substrate **34** as the applicator head **90** over the substrate **34**. The pre-preg segments **32** are applied to the substrate **34** in the desired orientation as they contact and adhere to the substrate **34**. Orienting the segments **32** as they are being placed on the substrate **34** may eliminate the need to subsequently adjust the orientation of the segments **32**. A heater **105** may be provided on the applicator head **90** in order to heat the pre-preg fiber segments **32** and thereby increase their tackiness. This increased tack may assist in adhering and holding the pre-preg fiber segments **32** in a desired orientation on the substrate **34**. The heater **105** may comprise any of a variety of devices suitable for the application, including but not limited to a hot air blower, a conduction rod, a focused infrared heater or a laser, to name only a few. The heater **105** may generally heat the entire area of the segments **32**, or may produce a focused beam (not shown), such as a laser beam, that heats only a portion of a segment **32** until it is "sticky" enough to adhere to the substrate when it is placed.

The applicator head **90** may move from side-to-side (in the Y direction) in order to apply a width of the chopped pre-preg segments **32** in a desired orientation, while in other embodiments, the applicator head **90** may be used to make multiple linear passes over the substrate **34** in the X direction, in order to cover a desired width of the substrate **34** with the chopped fiber pre-preg segments **32** for each layer or ply **96**. While the applicator head **90** has been illustrated with airstream generators **106** to place the fiber pre-preg segments **32**, other means such as mechanical mechanisms may be employed to dispense, place and align the fiber pre-preg segments **32**, as the applicator head **90** moves across, and steers the fiber pre-preg segments **32** onto the substrate **34**. It should be particularly noted here that the system **88**, including the applicator head **90** discussed above are merely illustrative of a wide variety of equipment may be used to place and position the pre-preg segments **32**. The particular form

of the system **88** that is used will depend upon the application, including specific structural requirements and the layup techniques that are employed. Moreover, the fabrication of the pre-preg segments **32** and equipment used to place and position the segments **32** on a substrate **34** may be implemented using a single
 5 machine, or several different machines.

Figure **13** illustrates an alternate embodiment of the applicator head **90** shown in Figure **12**, in which multiple rows of individual chopped fiber pre-preg segments **32** may be simultaneously dispensed, aligned in a desired orientation and placed by the applicator head **90** to form a bandwidth **110** of segments **32**
 10 with each pass of the applicator head **90** across the substrate **34**.

Referring now to Figures of **14–17**, the disclosed embodiments may be employed to layup layers or plies of discontinuous fiber pre-preg using scrap pre-preg **124** (Figure **15**). Referring to Figure **14**, as shown at step **112**, the scrap pre-preg **124** may be obtained from non-conforming/scrap parts or from scrap
 15 pre-preg resulting from other production processes. The scrap pre-preg **124** may have any of various shapes, as shown in Figure **15**. At step **116** shown in Figure **14**, the scrap pre-preg **124** is chopped into individual fiber pre-preg segments **32**, and following this chopping process, the segments **32** may have a random fiber orientation **126**, as shown in Figure **16** and/or may have fibers of differing
 20 lengths. At step **118**, the chopped fiber pre-preg segments **32** are substantially aligned **128** with a desired fiber orientation as shown in Figure **17**. At step **120**, the aligned fiber pre-preg segments **32** are fed to an applicator. At step **122** the applicator is used to dispense, steer and place the fiber pre-preg segments **32** on the substrate **34**, such that fiber orientations of the fiber pre-preg segments **32**
 25 are aligned in a desired direction.

The chopped fiber pre-preg **32** derived from scrap that is used in the disclosed method may be produced using any of several processes. For example, referring to Figure **18**, scrap pre-preg **124** may be introduced into a chopper device **130** which may be similar to a blender, having rotating blades
 30 **132** inside an open vessel **135**. The blades **132** chop and break the scrap fiber pre-preg **124** into individual fiber pre-preg segments **32**, breaking or splitting the pre-preg along the lines of, and between the reinforcing fibers, resulting in the fiber pre-preg segments that have a random orientation **126**. With the scrap pre-

preg having been chopped into individual fiber pre-preg segments **32**, the randomly oriented **126** fiber pre-preg segments **32** are aligned, for example by placing them in a shaker tray **134** having a series of parallel channels **136**. The shaker tray **134** is vibrated side-to-side **138**, causing the randomly oriented **126** fiber pre-preg segments **32** that have been loaded onto the tray **134** to fall into and align themselves within the channels **136**, resulting in rows **140** of aligned, fiber pre-preg segments **32**. The aligned rows **140** of the fiber pre-preg segments **32** may be fed to an applicator head **90** which dispenses, places and steers the fiber pre-preg segments **32** on the substrate **34** with desired fiber orientations.

Figures **19A–21B** illustrate another embodiment of a method of steering chopped fiber pre-preg segments **32** onto a substrate **34**. As shown in Figures **19A-19B**, an applicator **140** is used to apply **142** a suitable resin **144** onto the substrate **34**, as the applicator **140** moves **150** across the substrate **34**. The resin **144** may be applied by spraying the resin **144** onto the substrate **34**, rolling the resin **144** onto the substrate **34** or using other application techniques. Next, as shown in Figures **20A-20B**, chopped fiber pre-preg segments **32** are applied to the substrate **34** by a suitable applicator **146** that moves **150** over the substrate **34**. When initially applied in this manner, the fiber pre-preg segments **32** may have random orientations, as shown in Figure **20B**. Then, as shown in Figures **21A and 21B**, a fiber segment aligner **148** is moved **150** over the substrate **34** to align the fiber pre-preg segments **32** in a desired direction, which in this case, is along axis **36**. The fiber segment aligner **148** may use one or more mechanical devices to contact and realign the fiber pre-preg segments **32**, or alternatively may use noncontact techniques, such as an airstream (not shown) to achieve the desired segment alignment. As previously discussed, however, orienting the segments **32** as they are being initially placed on the substrate **34** may be desirable in some applications, since this technique may eliminate the need for the additional step of repositioning the segments **32** to the desired fiber orientations.

Figures **22A–24B** illustrate an alternate technique for placing and aligning the fiber pre-preg segments **32** on the substrate **34**. Referring to Figures **22A and 22B**, a small quantity, such as a drop, of resin **152** is placed on one end **154** of each of the fiber pre-preg segments **32**. Then, as shown in Figures **23A-23B**, the

fiber segment **32** is placed on the substrate **34**. At this point, the fibers of the fiber segment **32** may not be aligned with the desired orientation, such as axis **36**. As shown in Figures **24A-24B**, the fiber segment **32** is then rotated **156** so that the fiber orientation of the fiber segment **32** is aligned with the axis **36**. The orientation process may be performed using mechanical devices **49**, or using noncontact techniques such as streaming air over the substrate **34**.

Embodiments of the disclosure may find use in a variety of potential applications, particularly in the transportation industry, including for example, aerospace, marine, automotive applications and other application where composite structures may require local features requiring tight contours, thickness control and/or cross-sectional tailoring. Thus, referring now to Figures **25** and **26**, embodiments of the disclosure may be used in the context of an aircraft manufacturing and service method **158** as shown in Figure **25** and an aircraft **160** as shown in Figure **26**. Aircraft applications of the disclosed embodiments may include, for example, without limitation, various parts of the airframe **176** such as frames, beams, spars, and stringers to name only a few. During pre-production, exemplary method **158** may include specification and design **162** of the aircraft **160** and material procurement **164**. During production, component and subassembly manufacturing **166** and system integration **168** of the aircraft **160** takes place. Thereafter, the aircraft **160** may go through certification and delivery **170** in order to be placed in service **172**. While in service by a customer, the aircraft **160** is scheduled for routine maintenance and service **174**, which may also include modification, reconfiguration, refurbishment, repair and so on.

Each of the processes of method **158** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in Figure **26**, the aircraft **160** produced by exemplary method **158** may include an airframe **176** with a plurality of systems **178** and an interior

180. Examples of high-level systems **178** include one or more of a propulsion system **182**, an electrical system **184**, a hydraulic system **188**, and an environmental system **190**. Any number of other systems may be included. Although an aerospace example is shown, the principles of the disclosure may be applied to other industries, such as the marine and automotive industries.

Systems and methods embodied herein may be employed during any one or more of the stages of the production and service method **158**. For example, components or subassemblies corresponding to production process **166** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **160** is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages **166** and **168**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **160**. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **160** is in service, for example and without limitation, to perform maintenance and service **174**, or to carry out repair or refurbishment of structures at any time during the service life of the aircraft **160**.

As used herein, the phrase “at least one of”, when used with a list of items, means different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, “at least one of item A, item B, and item C” may include, without limitation, item A, item A and item B, or item B. This example also may include item A, item B, and item C or item B and item C. The item may be a particular object, thing, or a category. In other words, at least one of means any combination of items and number of items may be used from the list but not all of the items in the list are required.

The description of the different illustrative embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different advantages as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in

the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVELEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method of forming a composite feature having discontinuous reinforcement fibers, comprising:
 - 5 producing a plurality of resin infused fiber segments each having unidirectional reinforcing fibers;
 - placing the plurality of resin infused fiber segments on a substrate; and
 - arranging the plurality of resin infused fiber segments such that the reinforcing fibers of the resin infused fiber segments placed on the
10 substrate are substantially aligned relative to a desired reference orientation.
2. The method of claim 1, wherein producing the plurality of resin infused fiber segments comprises chopping scrap fiber pre-preg into individual pieces.
3. The method of claim 1, wherein producing the plurality of resin infused fiber
15 segments comprises splitting fiber pre-preg along and between the reinforcing fibers into individual pieces.
4. The method of any one of claims 1 to 3, wherein placing the plurality of resin infused fiber segments on the substrate comprises:
 - moving an applicator over the substrate; and
 - 20 dispensing the plurality of resin infused fiber segments from the applicator head onto the substrate as the applicator moves over the substrate.

5. The method of claim 4, wherein arranging the plurality of resin infused fiber segments comprises aligning the plurality of resin infused fiber segments as they are being dispensed from the applicator onto the substrate.
6. The method of claim 4 or 5, wherein producing the plurality of resin infused fiber segments comprises:
- drawing continuous fiber pre-preg tape from the applicator; and
- chopping the pre-preg tape into the plurality of resin infused fiber segments as the plurality of resin infused fiber segments are being dispensed from the applicator onto the substrate.
7. The method of any one of claims 4 to 6, wherein dispensing the plurality of resin infused fiber segments from the applicator comprises dispensing a bandwidth of the plurality of resin infused fiber segments onto the substrate.
8. The method of any one of claims 1 to 3, wherein placing the plurality of resin infused fiber segments on the substrate comprises introducing the plurality of resin infused fiber segments into an airstream, and using the airstream to stream the plurality of resin infused fiber segments from an applicator head onto the substrate.
9. The method of claim 8, wherein streaming the plurality of resin infused fiber segments comprises:
- introducing the plurality of resin infused fiber segments into an airstream; and
- using the airstream to project the plurality of resin infused fiber segments onto the substrate.

- 10.** The method of any one of claims **1** to **9**, wherein arranging the plurality of resin infused fiber segments is performed after the plurality of resin infused fiber segments have been placed on the substrate.
- 11.** The method of any one of claims **1** to **10**, further comprising:
- 5 applying resin to the substrate before the plurality of resin infused fiber segments are placed on the substrate.
- 12.** The method of any one of claims **1** to **11**, further comprising applying resin on at least one end of each of the plurality of resin infused fiber segments before they are placed on the substrate.
- 10 **13.** The method of any one of claims **1** to **12**, wherein producing the plurality of resin infused fiber segments each having unidirectional reinforcing fibers comprises causing the plurality of resin infused fiber segments to be aligned such that the unidirectional reinforcing fibers of each fiber segment are substantially parallel to each other.
- 15 **14.** The method of any one of claims **1** to **4**, wherein arranging the plurality of resin infused fiber segments comprises placing the resin infused fiber segments into a shaker tray having a series of parallel channels and vibrating the shaker from side-to-side.
- 20 **15.** A method of forming a composite feature having discontinuous reinforcement fibers, comprising:
- placing a pre-preg tape into an applicator head;
- thereafter chopping the pre-preg tape into a plurality of distinct resin infused fiber
- 25 segments, each having unidirectional reinforcing fibers and each chopped to have a desired

aspect ratio, wherein an aspect ratio comprises a length of an individual segment divided by a width of the individual segment;

moving the applicator head over a substrate;

5 dispensing the plurality of distinct resin infused fiber segments from the applicator head onto the substrate as the applicator head moves over the substrate; and

10 steering, using the applicator head, the plurality of distinct resin infused fiber segments such that the unidirectional reinforcing fibers of substantially all of the plurality of distinct resin infused fiber segments placed on the substrate are substantially aligned relative to a desired reference orientation.

16. The method of claim **15**, wherein chopping the plurality of distinct resin infused fiber segments comprises splitting the pre-preg tape along and between reinforcing fibers into individual pieces.

15 **17.** The method of claim **15** or **16**, wherein steering the plurality of distinct resin infused fiber segments comprises aligning the plurality of chopped resin infused fiber segments as they are being dispensed from the applicator head onto the substrate.

20 **18.** The method of any one of claims **15** to **17**, wherein chopping the plurality of distinct resin infused fiber segments comprises:

drawing the pre-preg tape from a pre-preg tape supply in the applicator head; and

25 chopping the pre-preg tape into the plurality of distinct resin infused fiber segments as the plurality of distinct resin infused fiber segments are being dispensed from the applicator head onto the substrate.

19. The method of any one of claims **15** to **18**, wherein steering the plurality of distinct resin infused fiber segments from the applicator head comprises dispensing a bandwidth of the resin infused fiber segments onto the substrate.
- 5 20. The method of any one of claims **15** to **19**, wherein steering the plurality of distinct resin infused fiber segments comprises introducing the plurality of distinct resin infused fiber segments into an airstream, and using the airstream to stream the plurality of distinct resin infused fiber segments from the applicator head onto the substrate.
- 10 21. The method of claim **20**, wherein streaming the plurality of distinct resin infused fiber segments comprises:
- using the airstream to project the plurality of distinct resin infused fiber segments onto the substrate.
- 15 22. The method of any one of claims **15** to **21**, further comprising:
- applying resin to the substrate before the plurality of distinct resin infused fiber segments are placed on the substrate.
23. The method of any one of claims **15** to **22**, further comprising applying resin on at least one end of each of the plurality of distinct resin infused fiber segments before they are placed on the substrate.
- 20 24. An apparatus for laying up a composite structure, comprising:
- an applicator adapted to move over a substrate, and dispense at least one stream of substantially aligned chopped, resin infused fiber segments onto the substrate, wherein the applicator includes:
- a supply of continuous resin infused fiber;

a chopper for chopping the continuous resin infused fiber into individual resin infused fiber segments; and

an airstream generator for streaming the resin infused fiber segments from the applicator onto the substrate.

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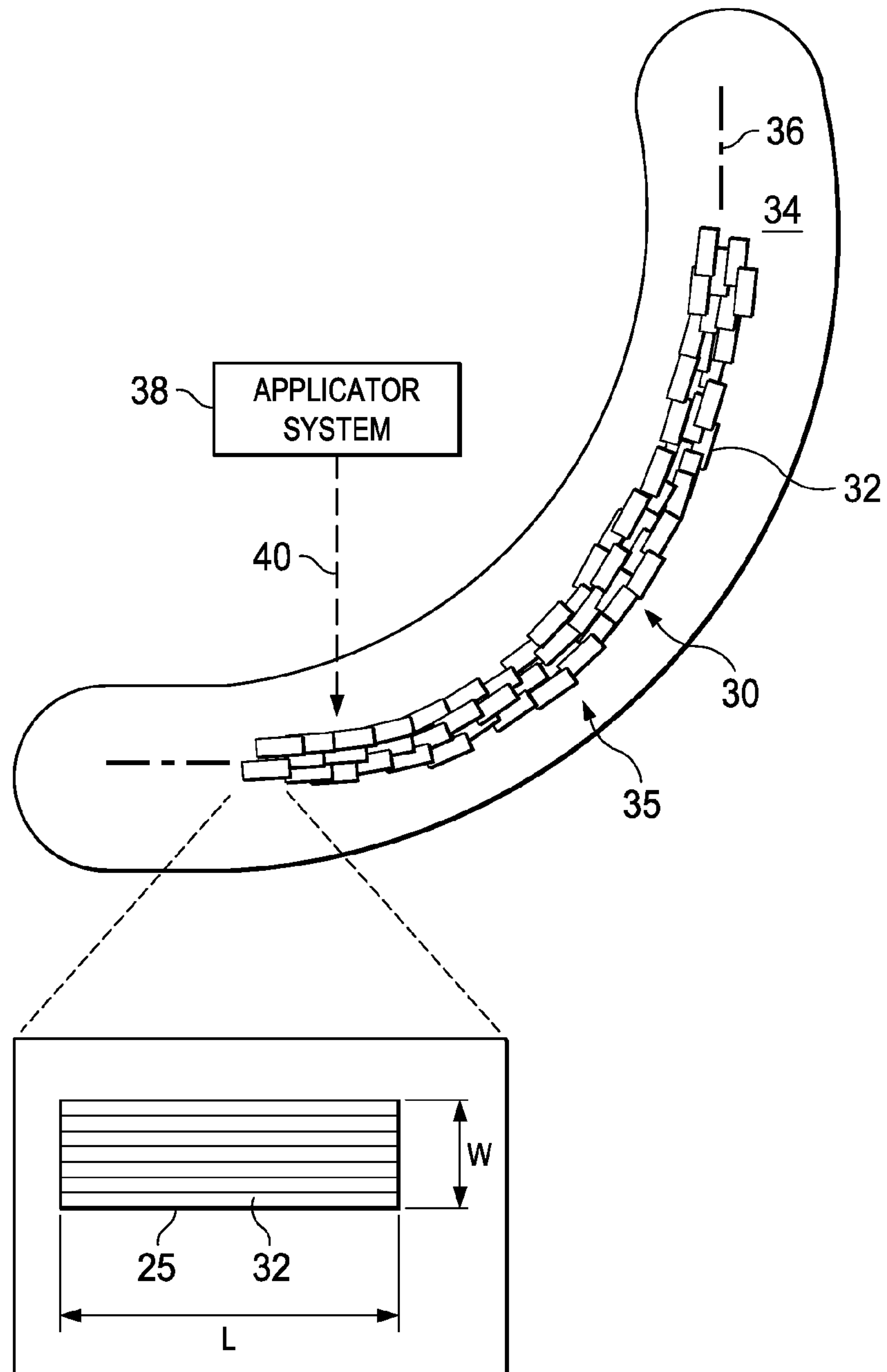


FIG. 1

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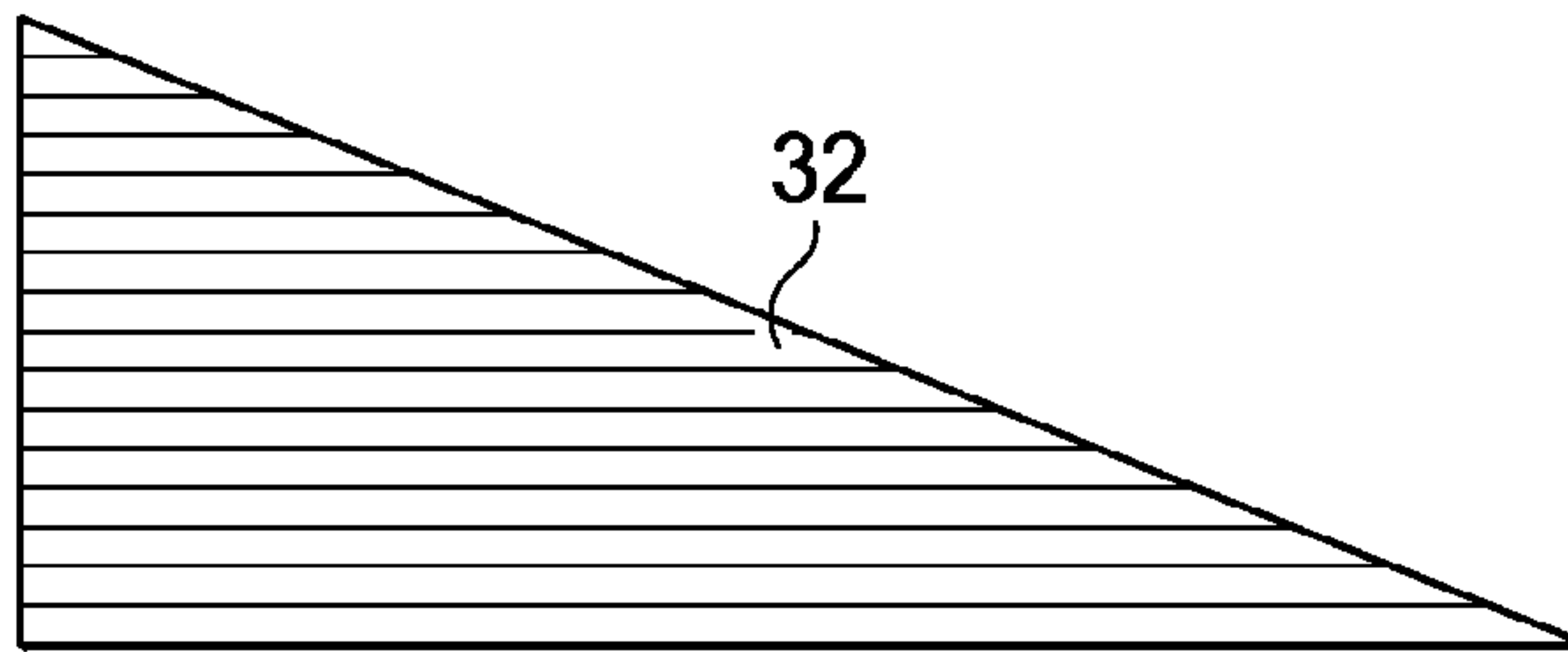


FIG. 1A

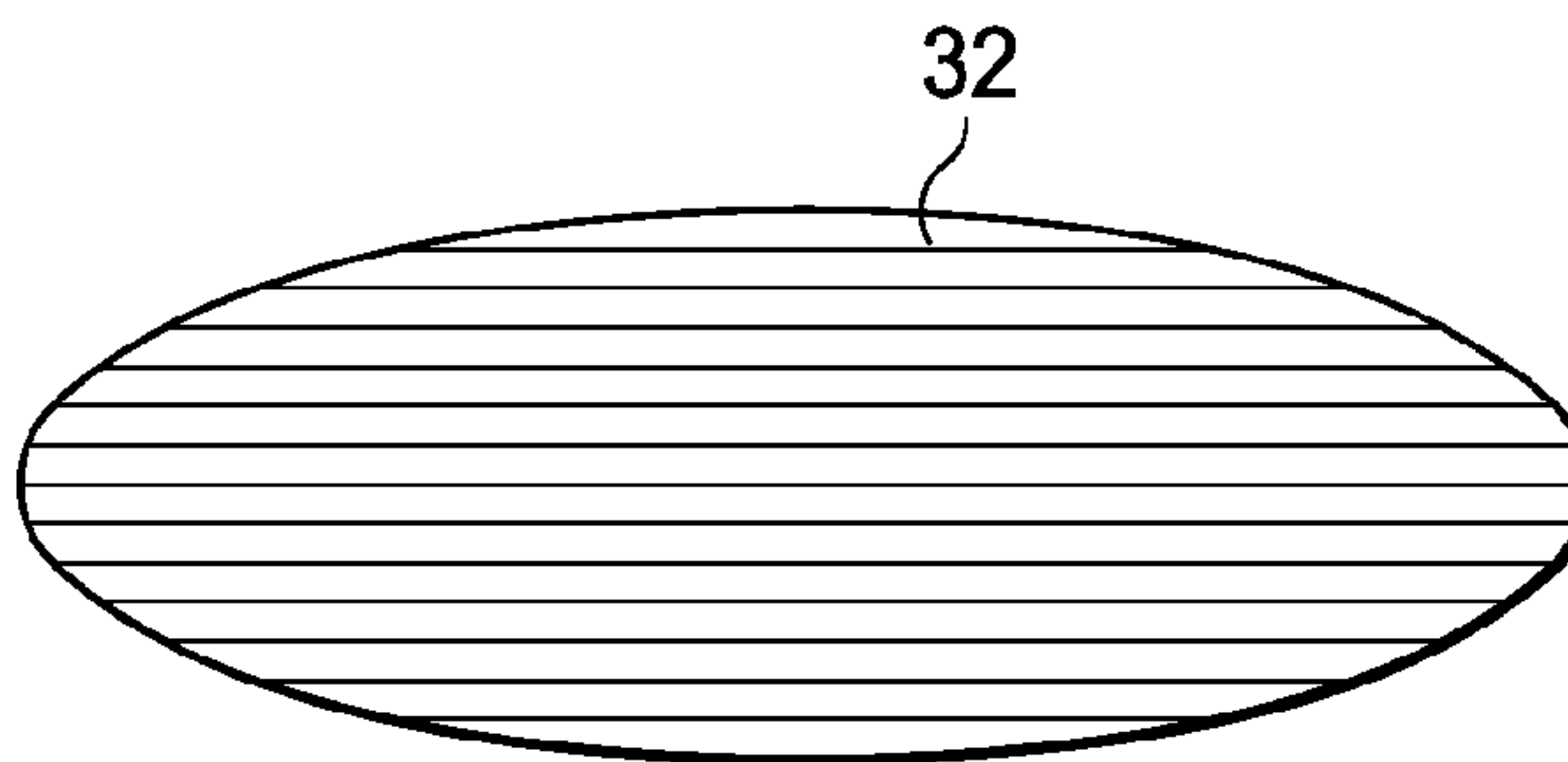


FIG. 1B

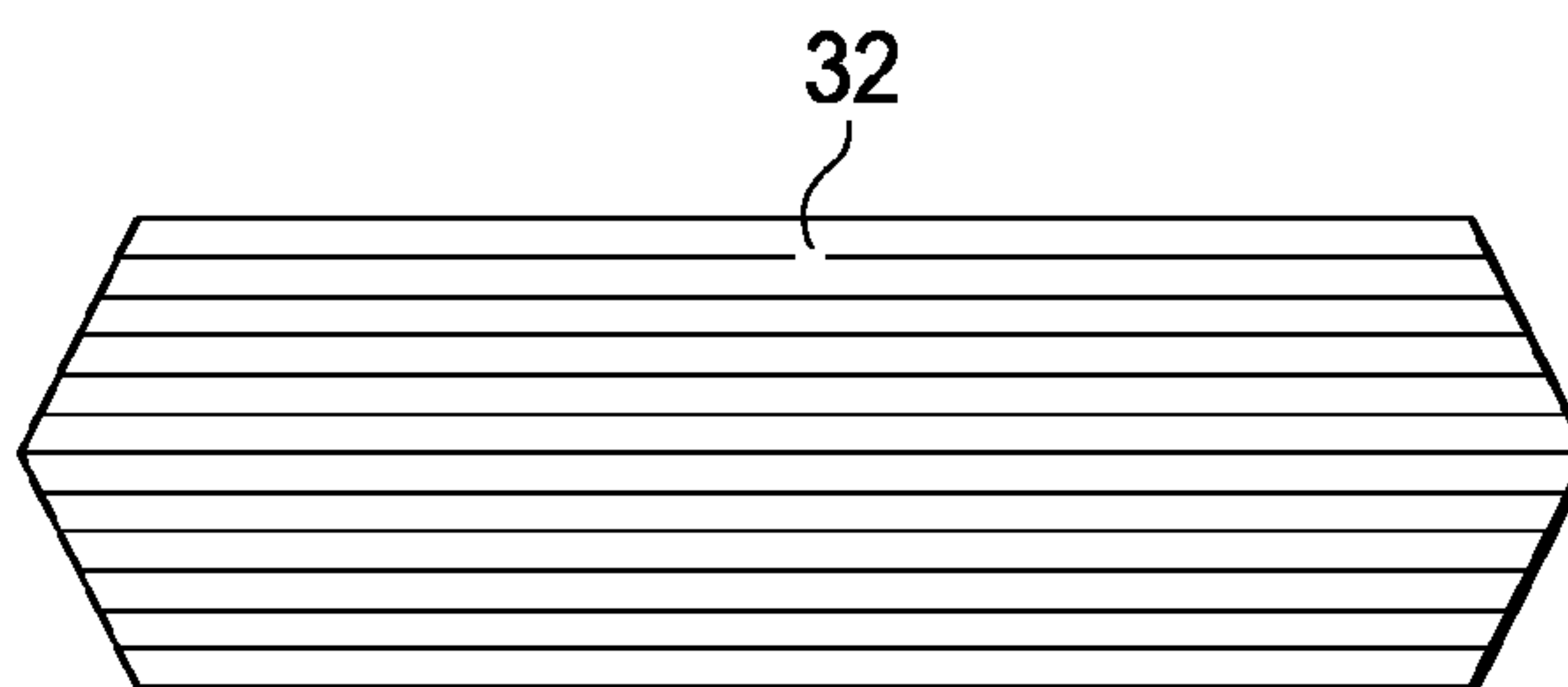
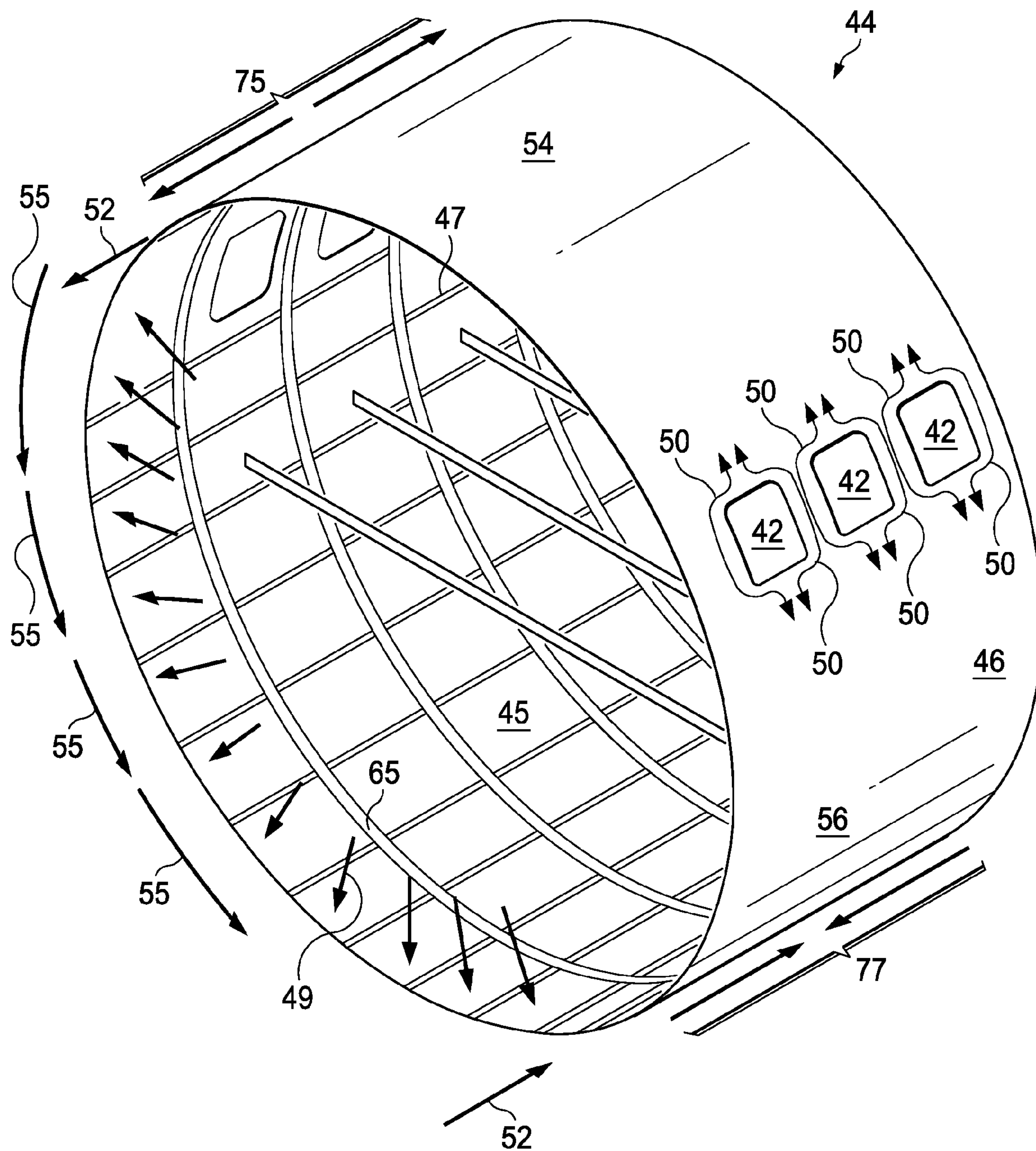


FIG. 1C

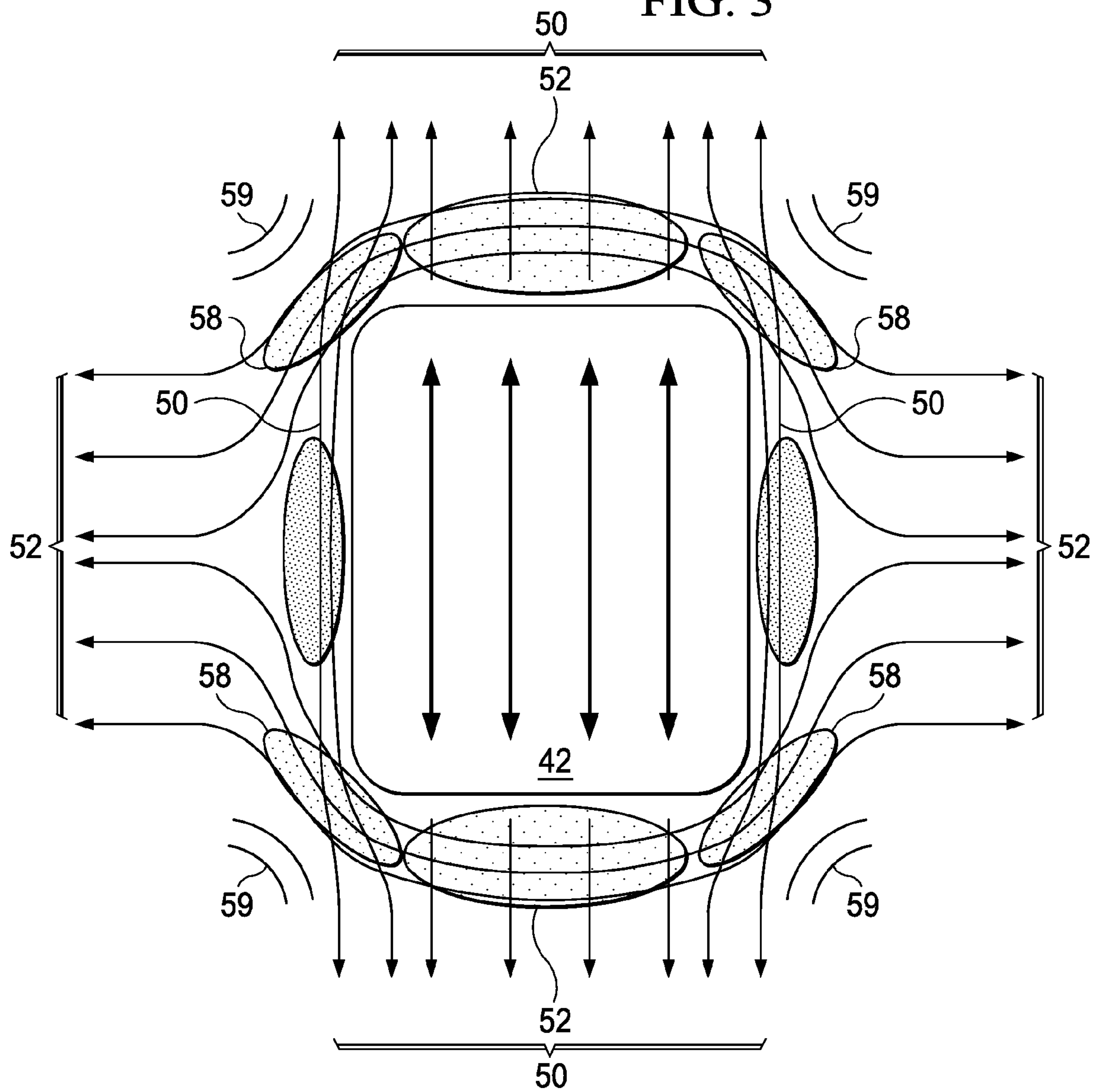
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FIG. 2



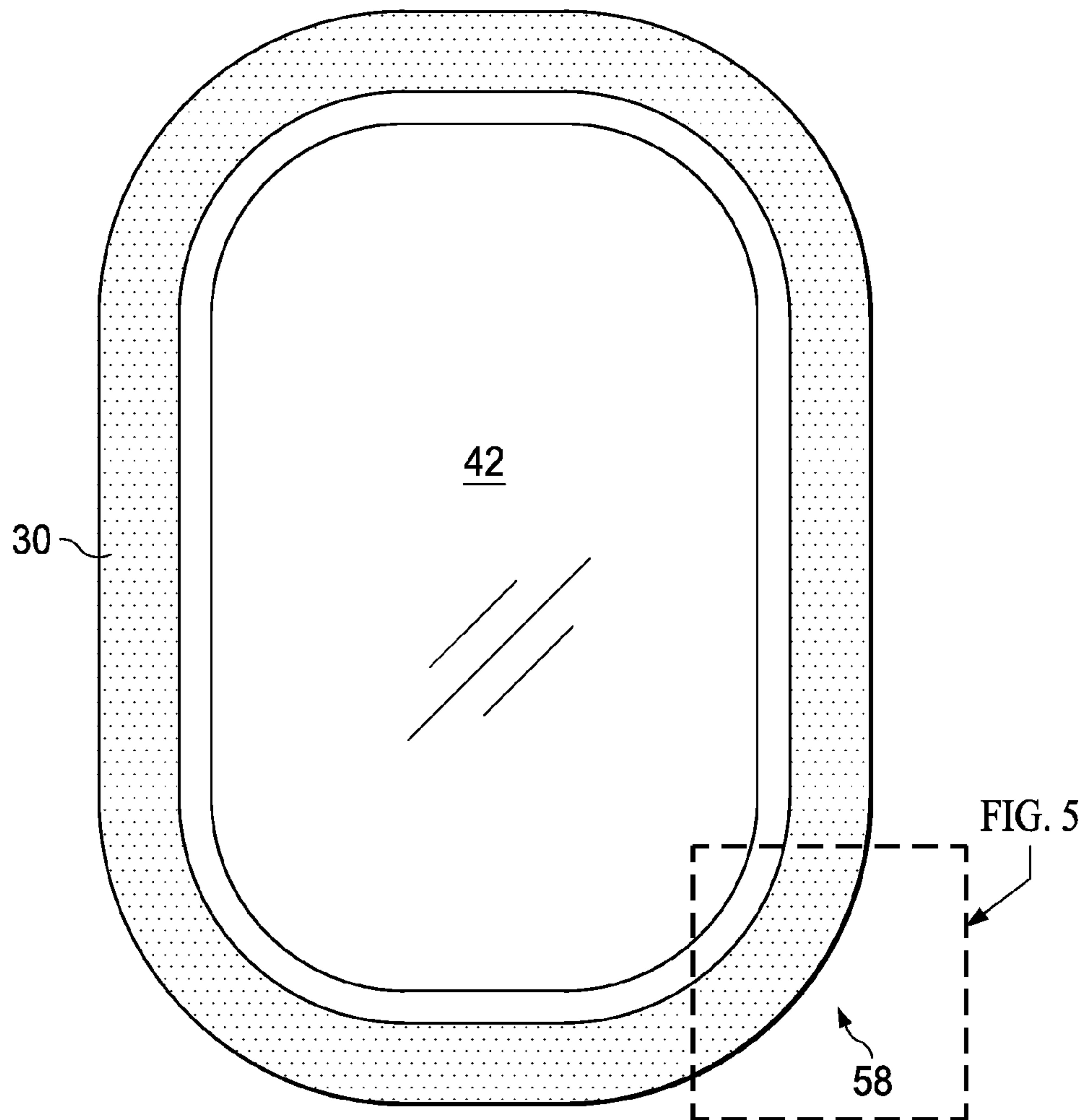
4/18

FIG. 3



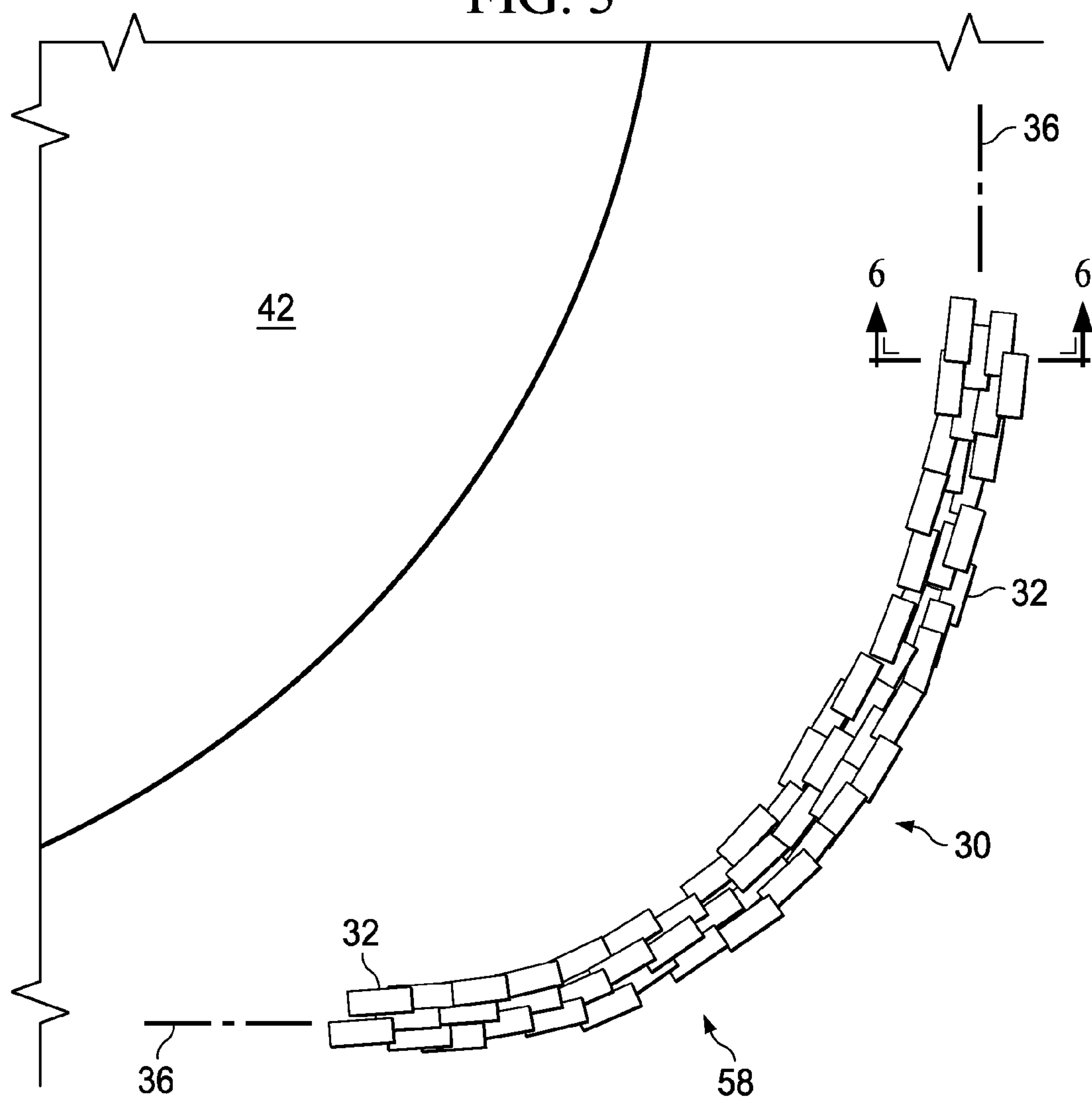
5/18

FIG. 4

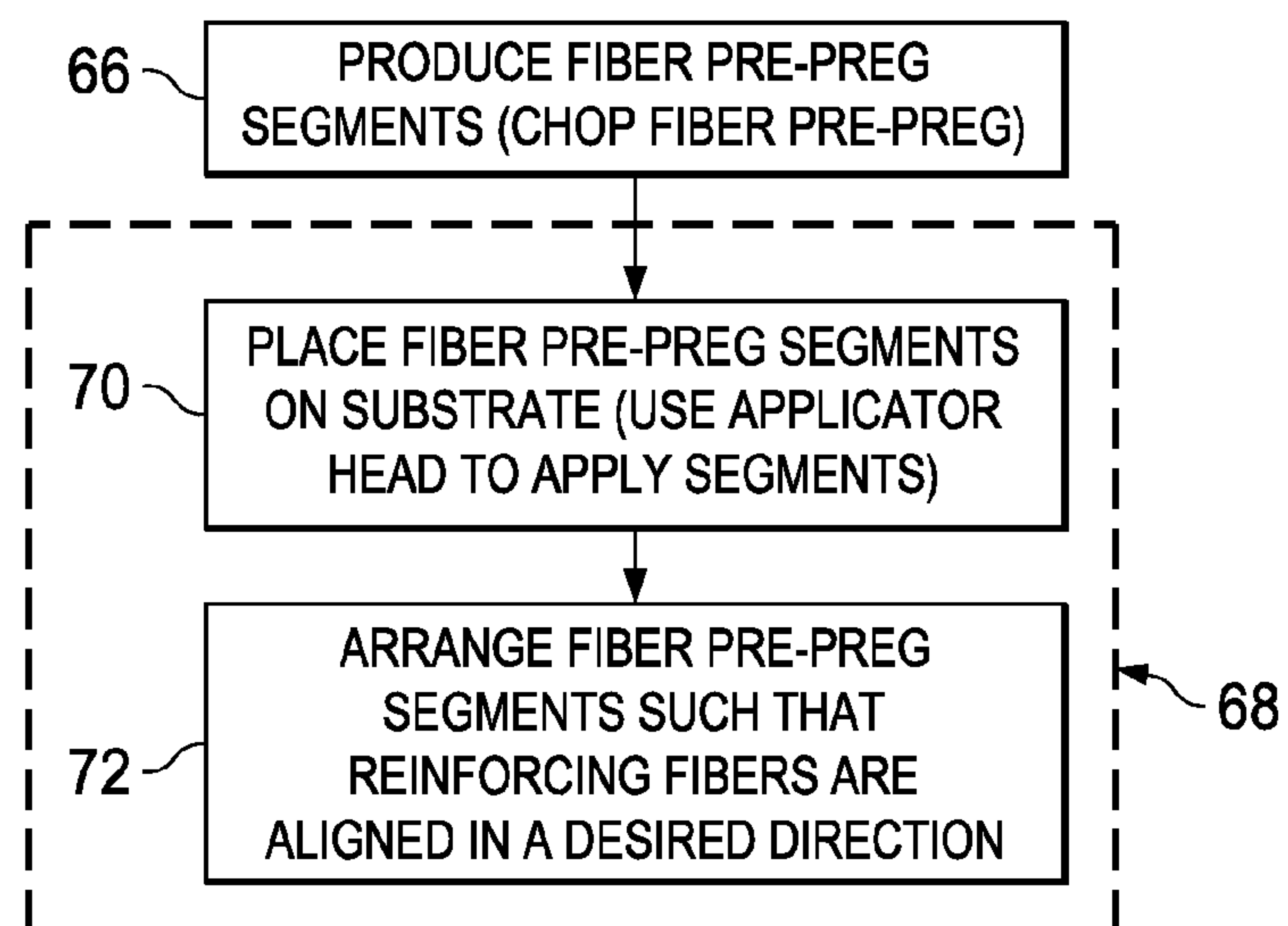
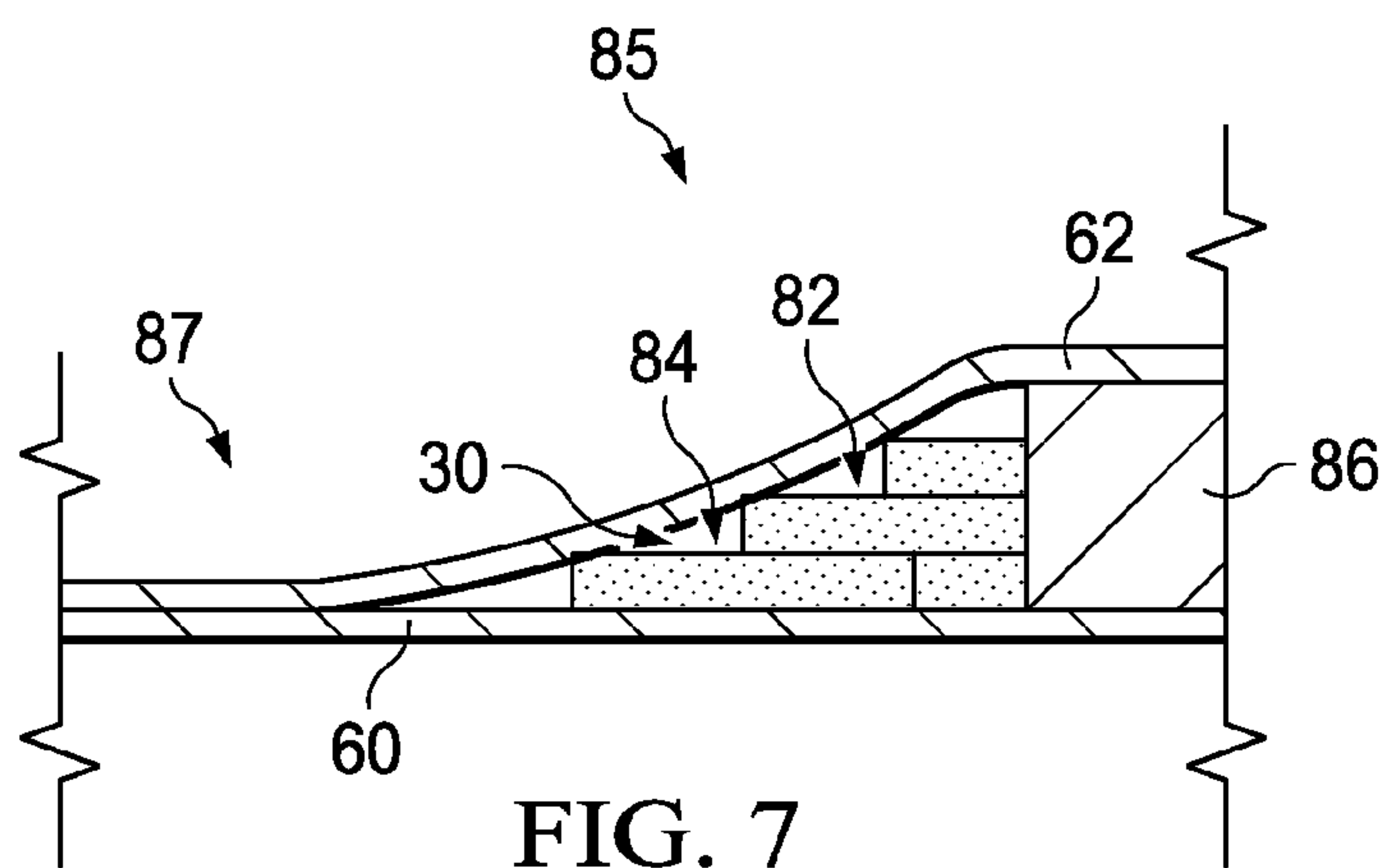
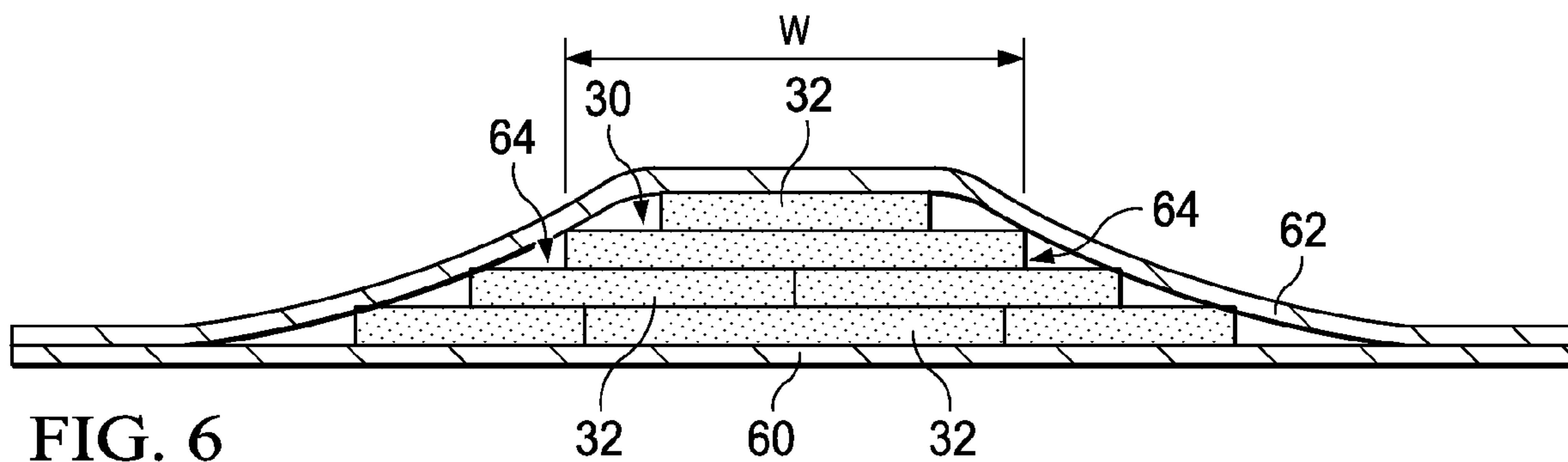


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FIG. 5



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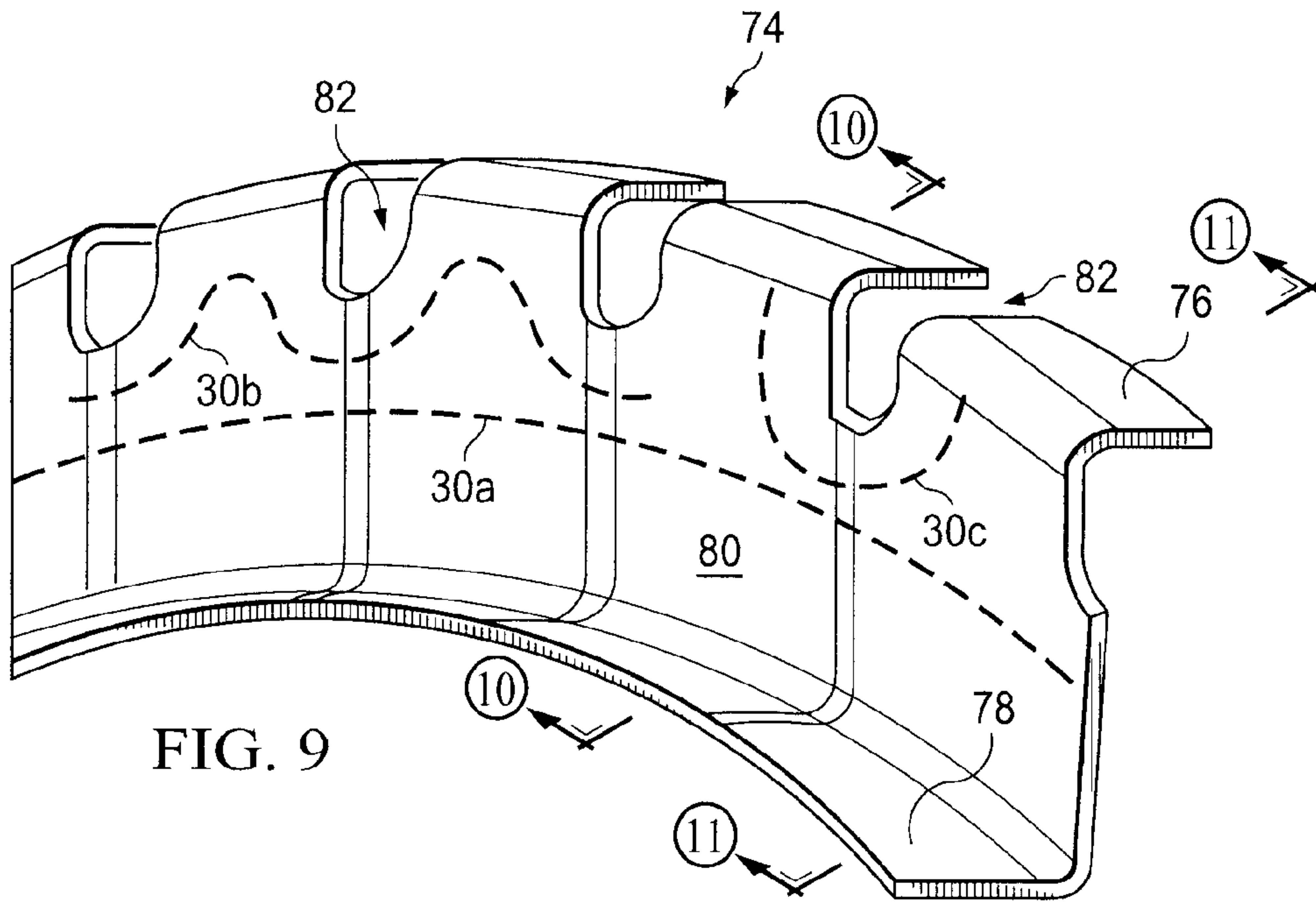


FIG. 9

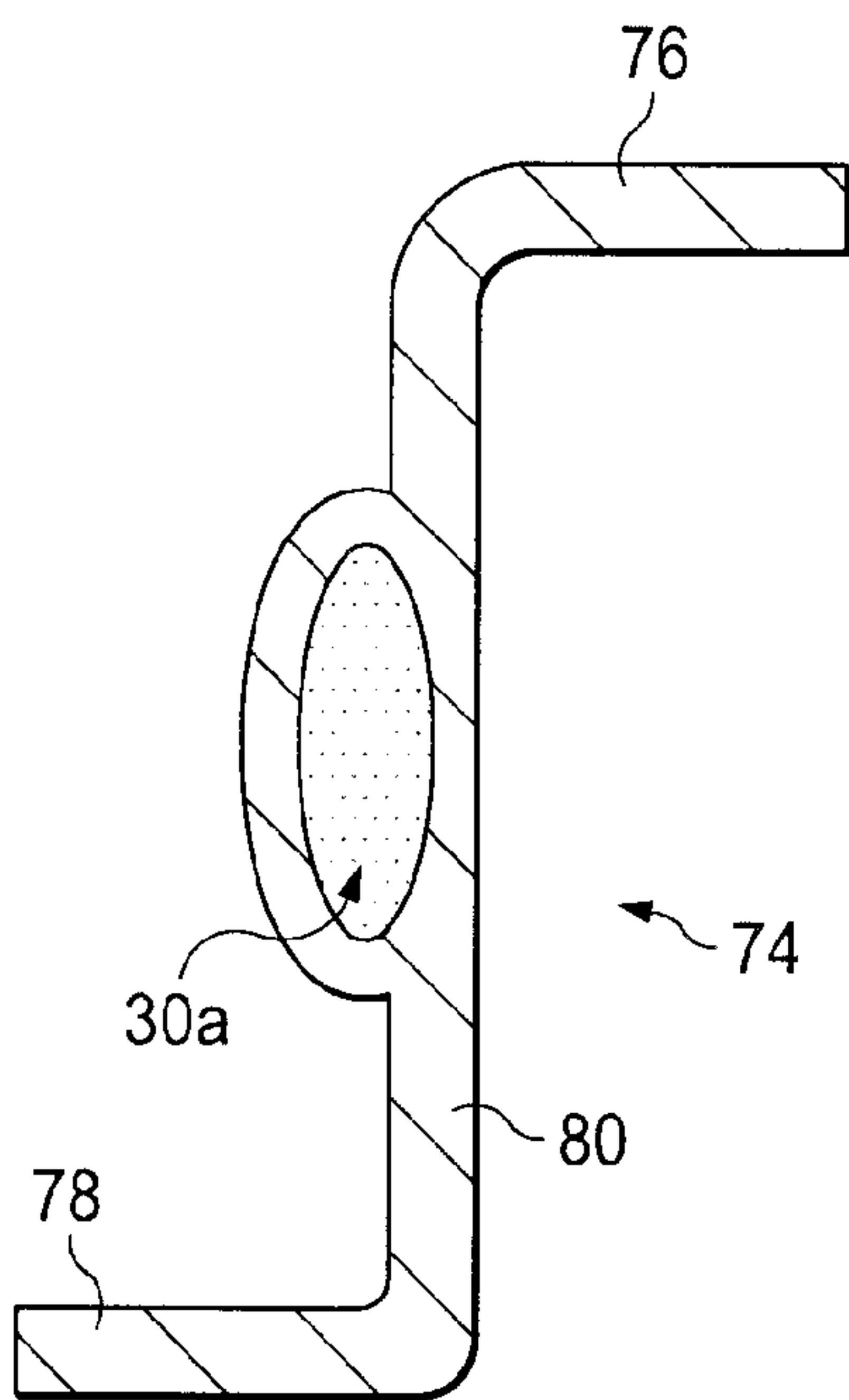


FIG. 10

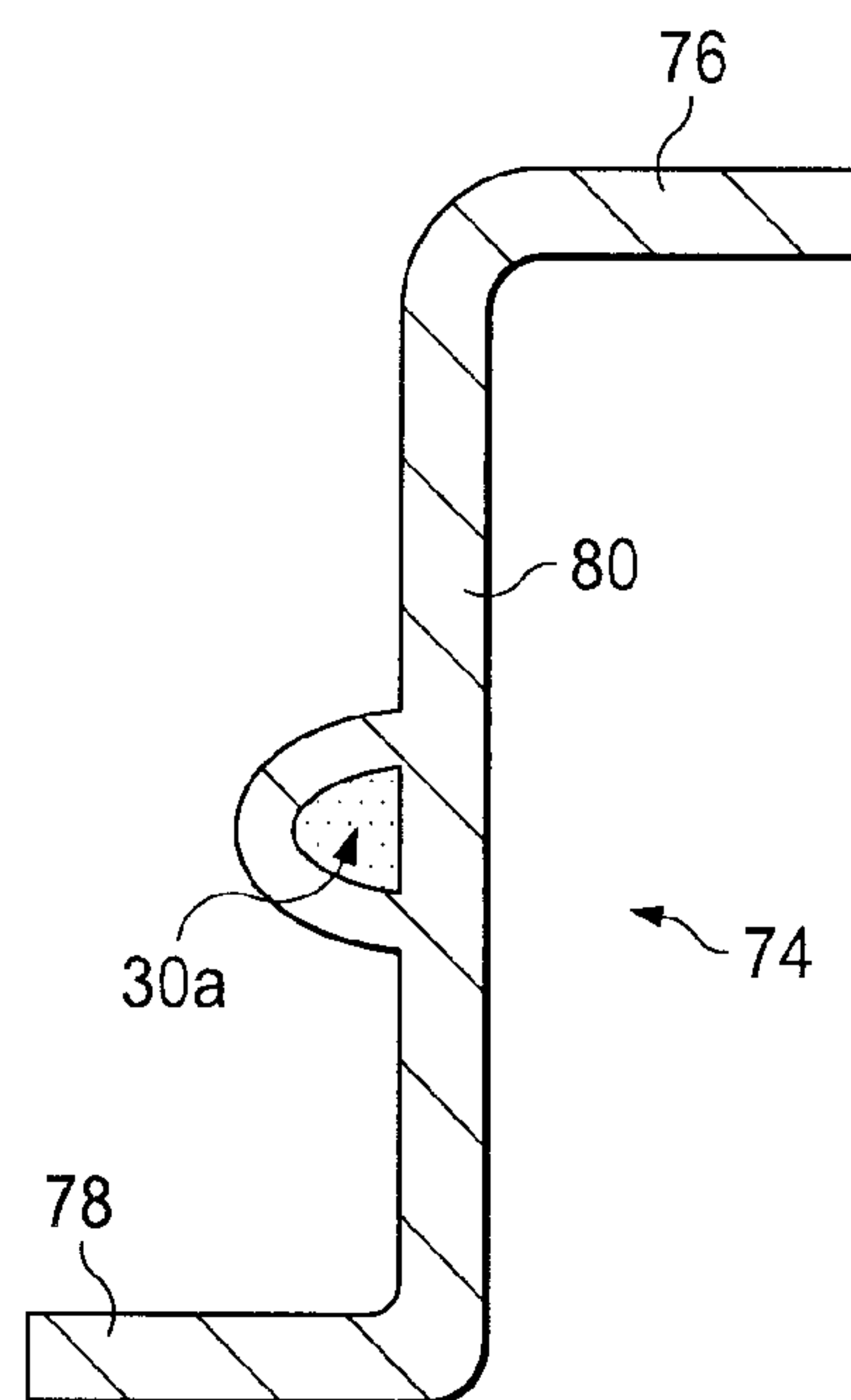
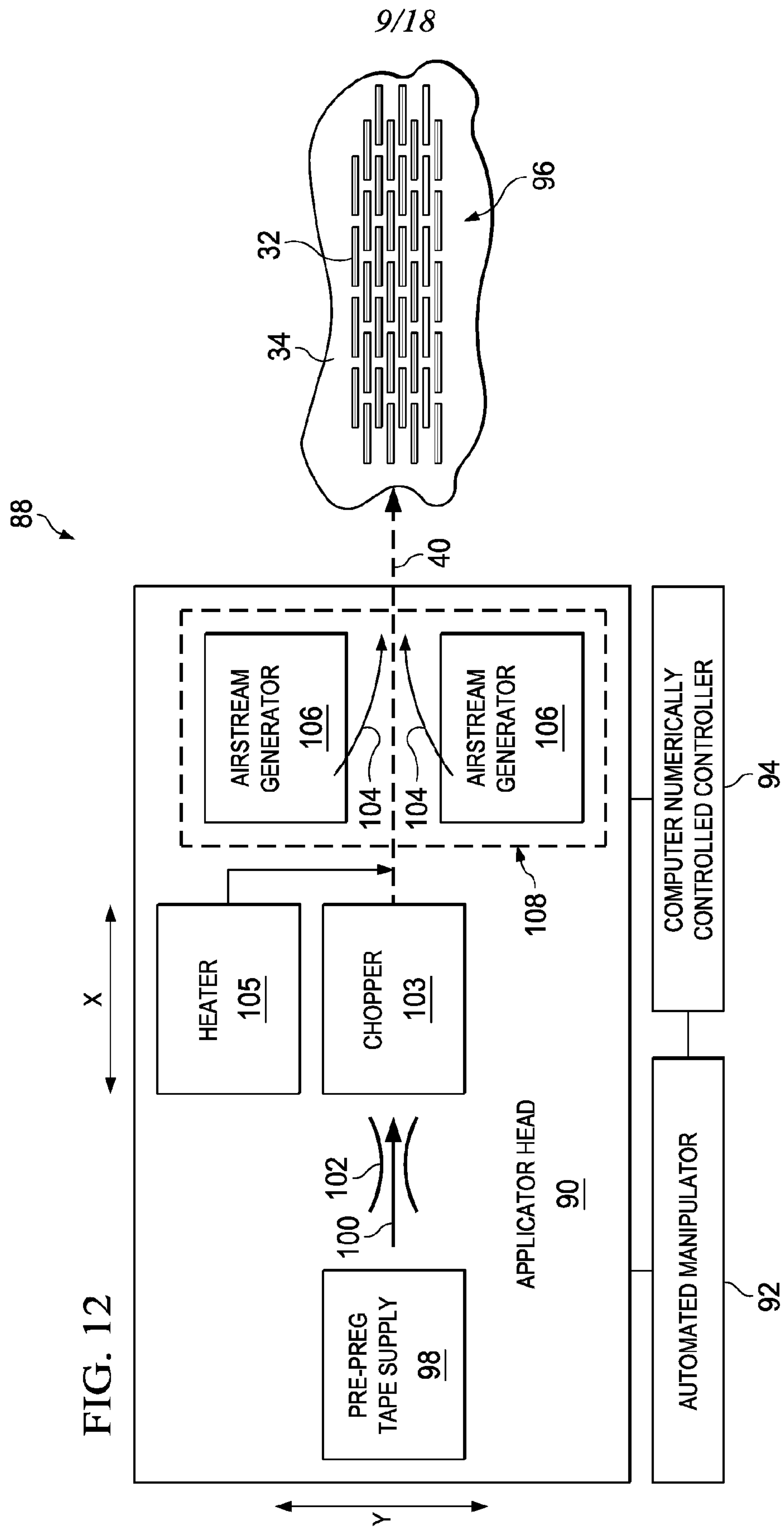


FIG. 11

FIG. 12



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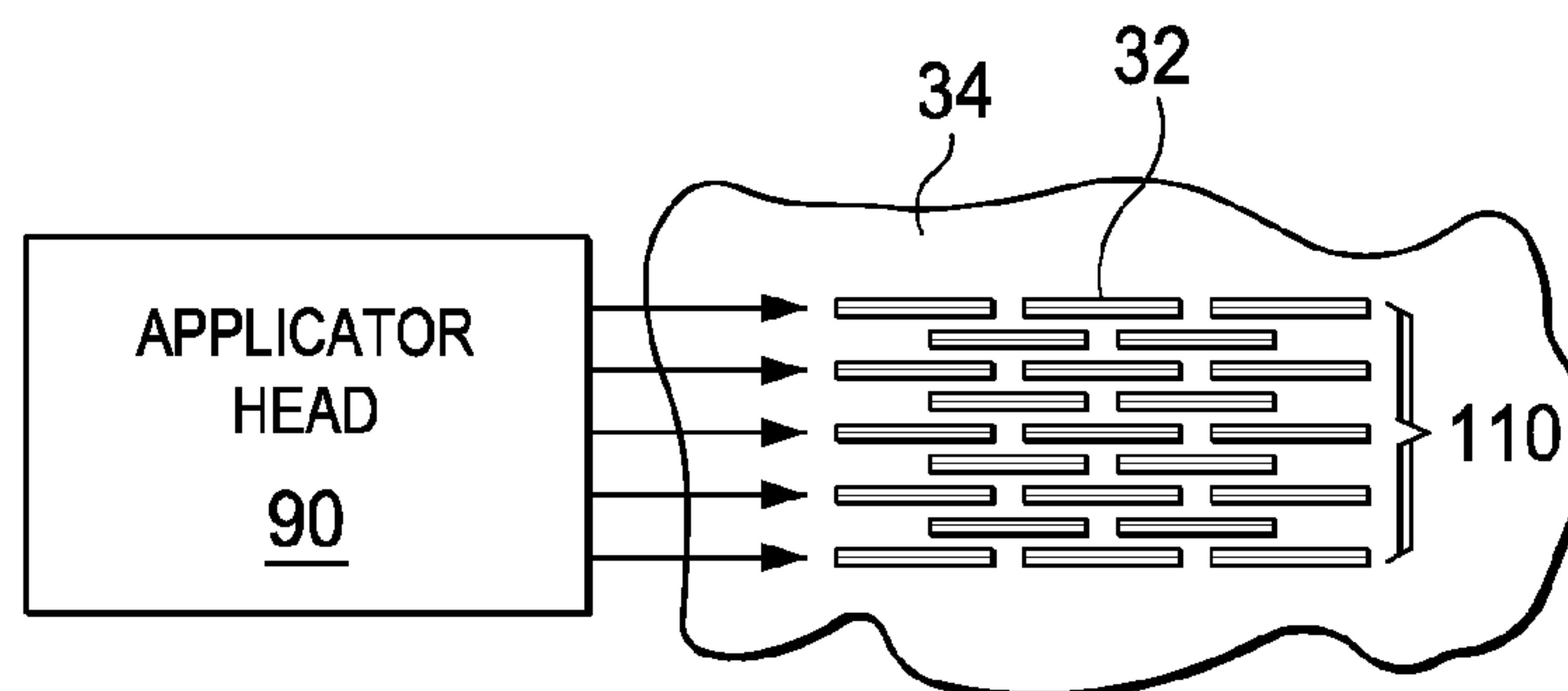


FIG. 13

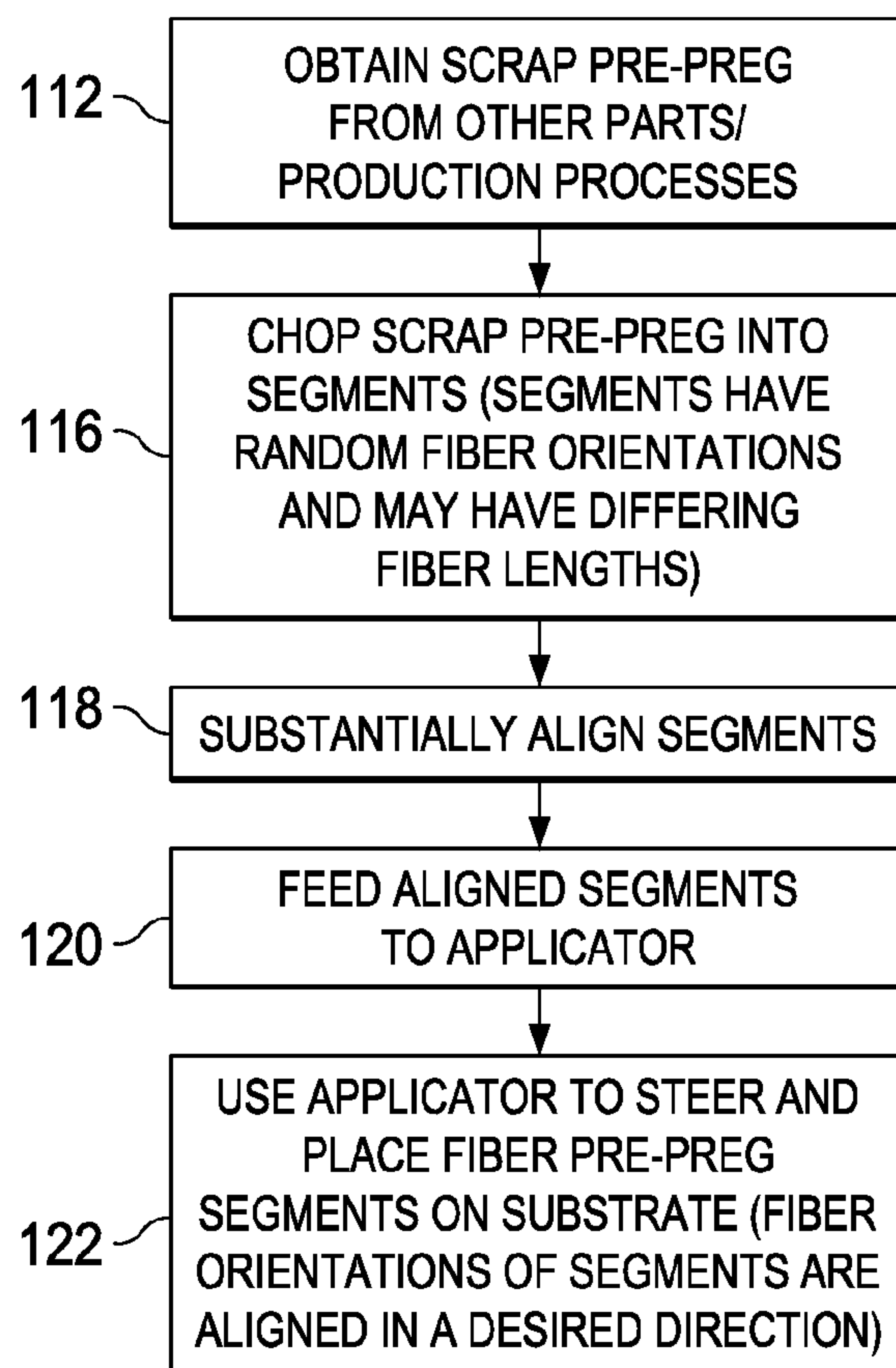


FIG. 14

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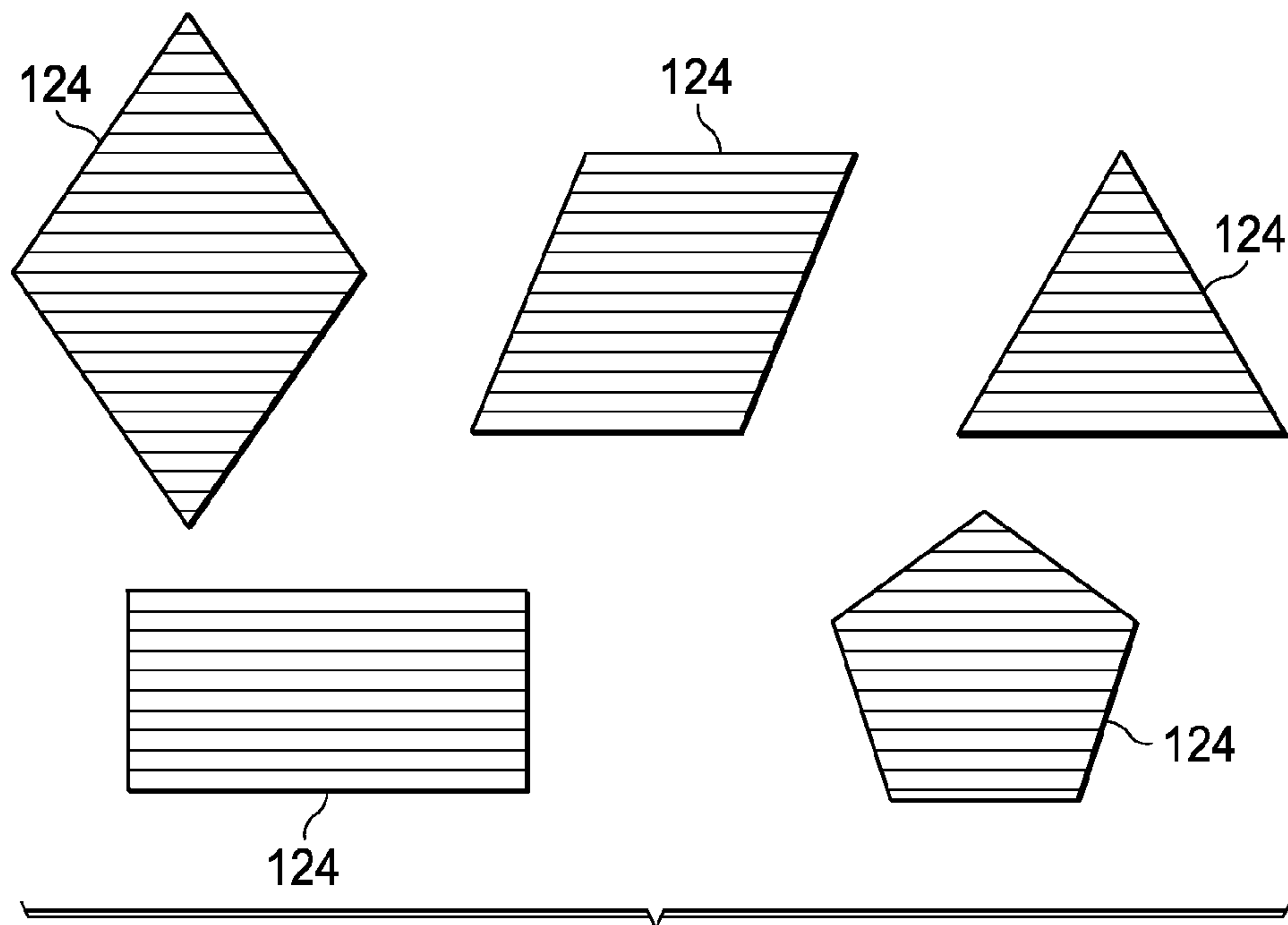


FIG. 15

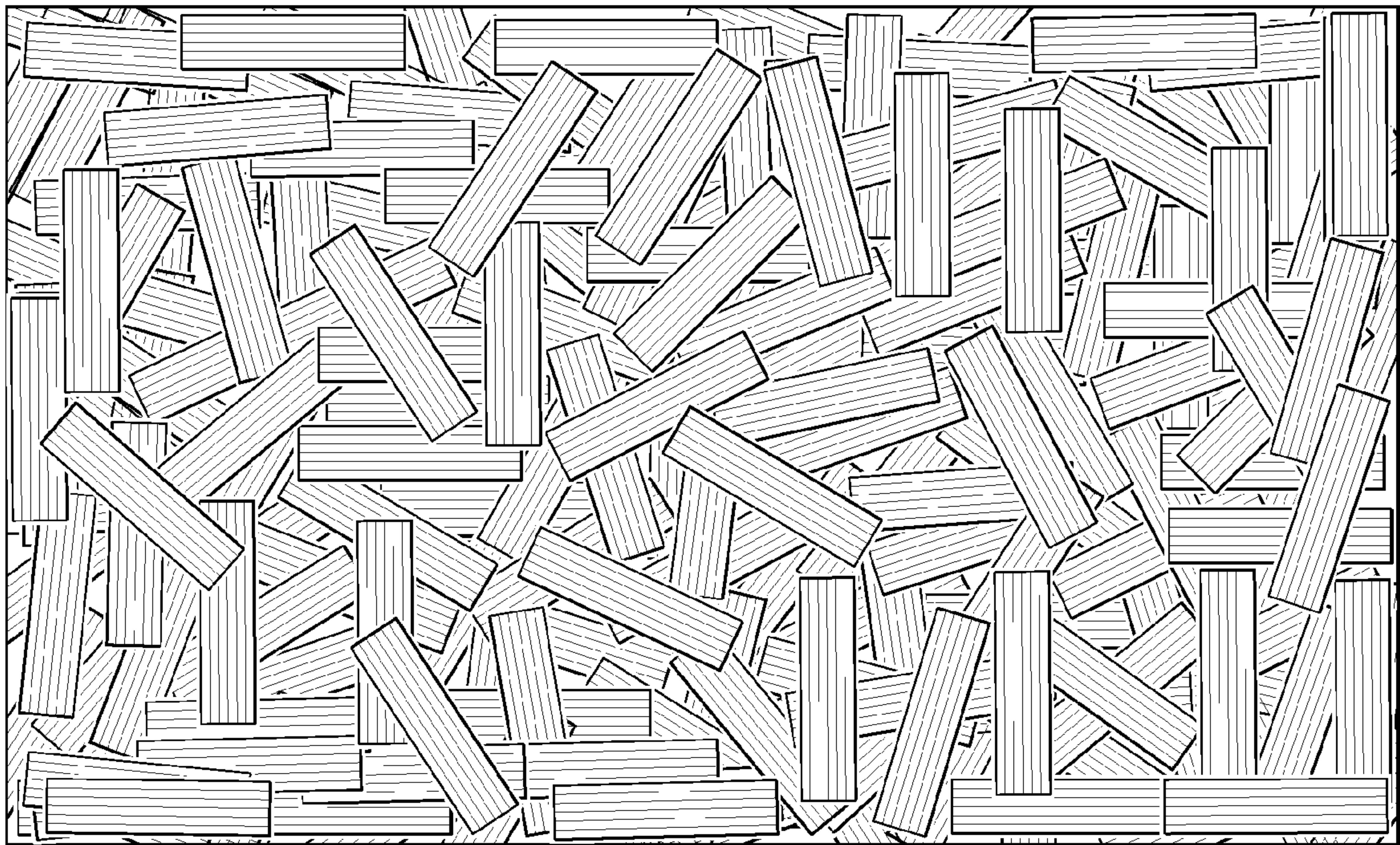
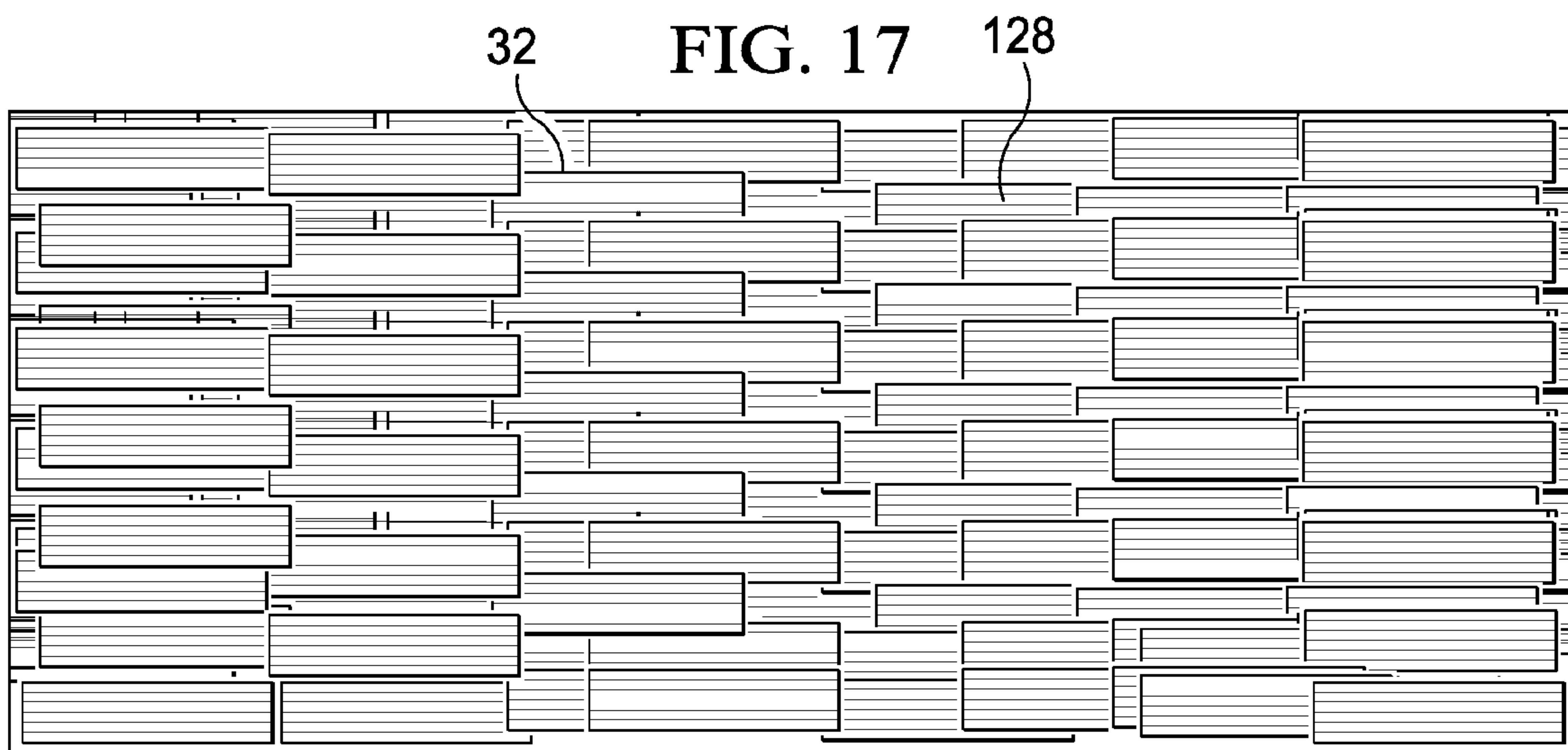
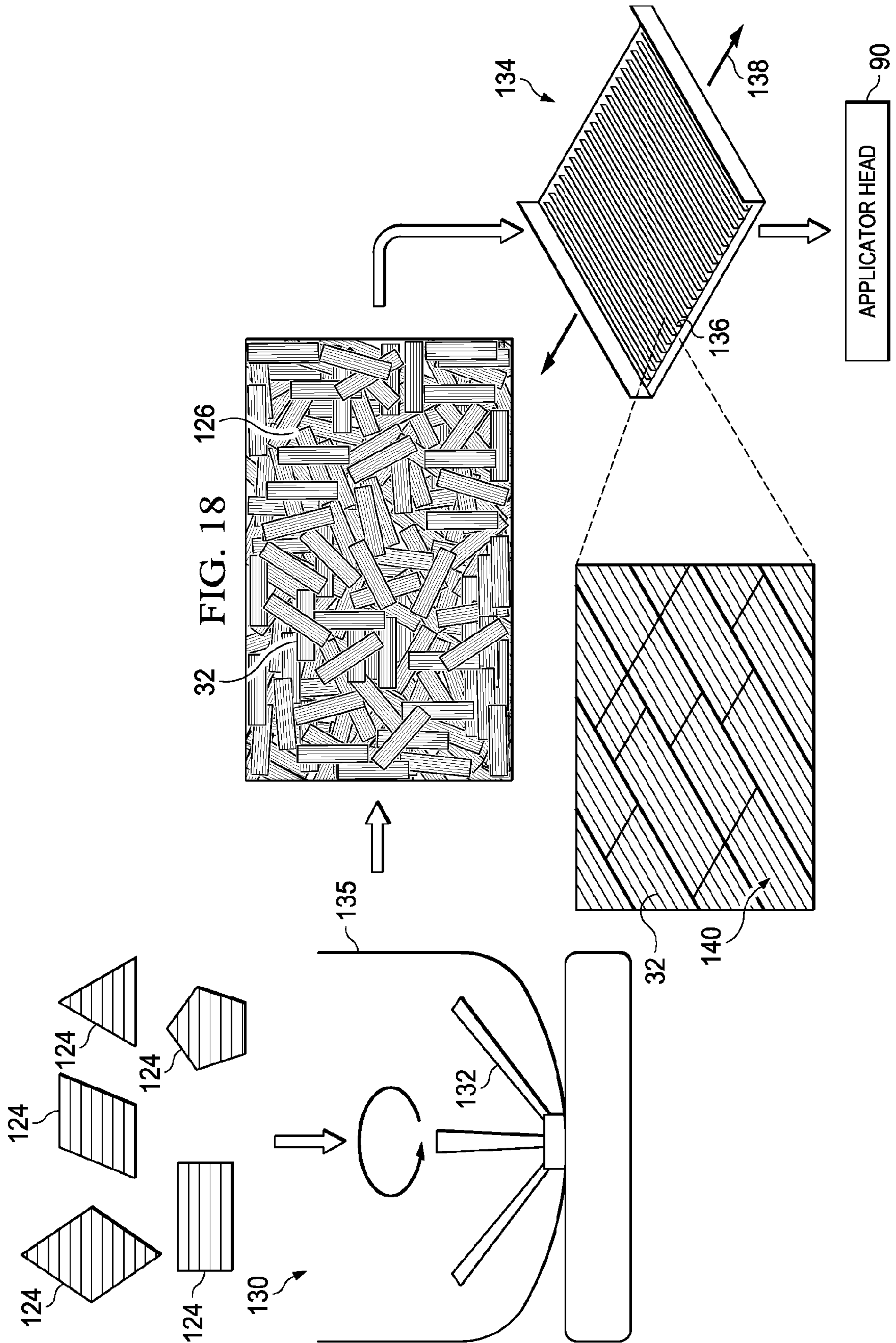


FIG. 16

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FIG. 19A

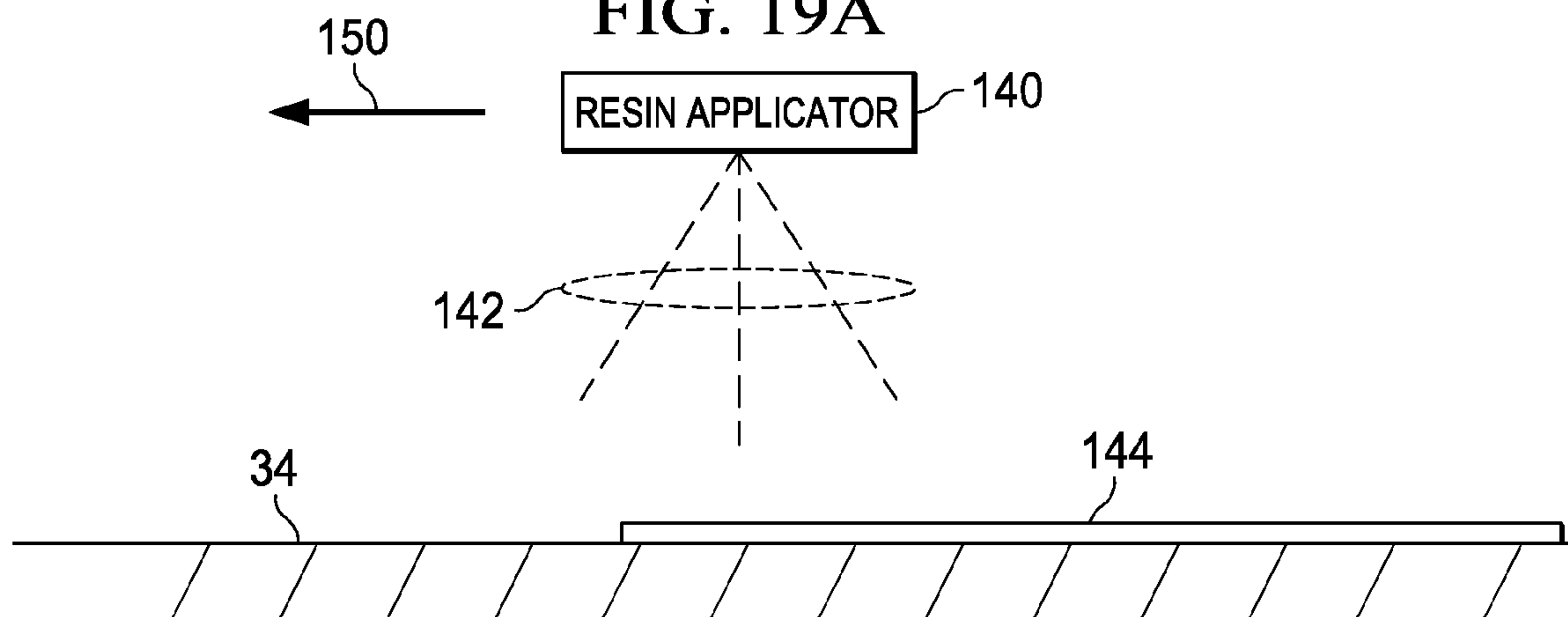


FIG. 19B

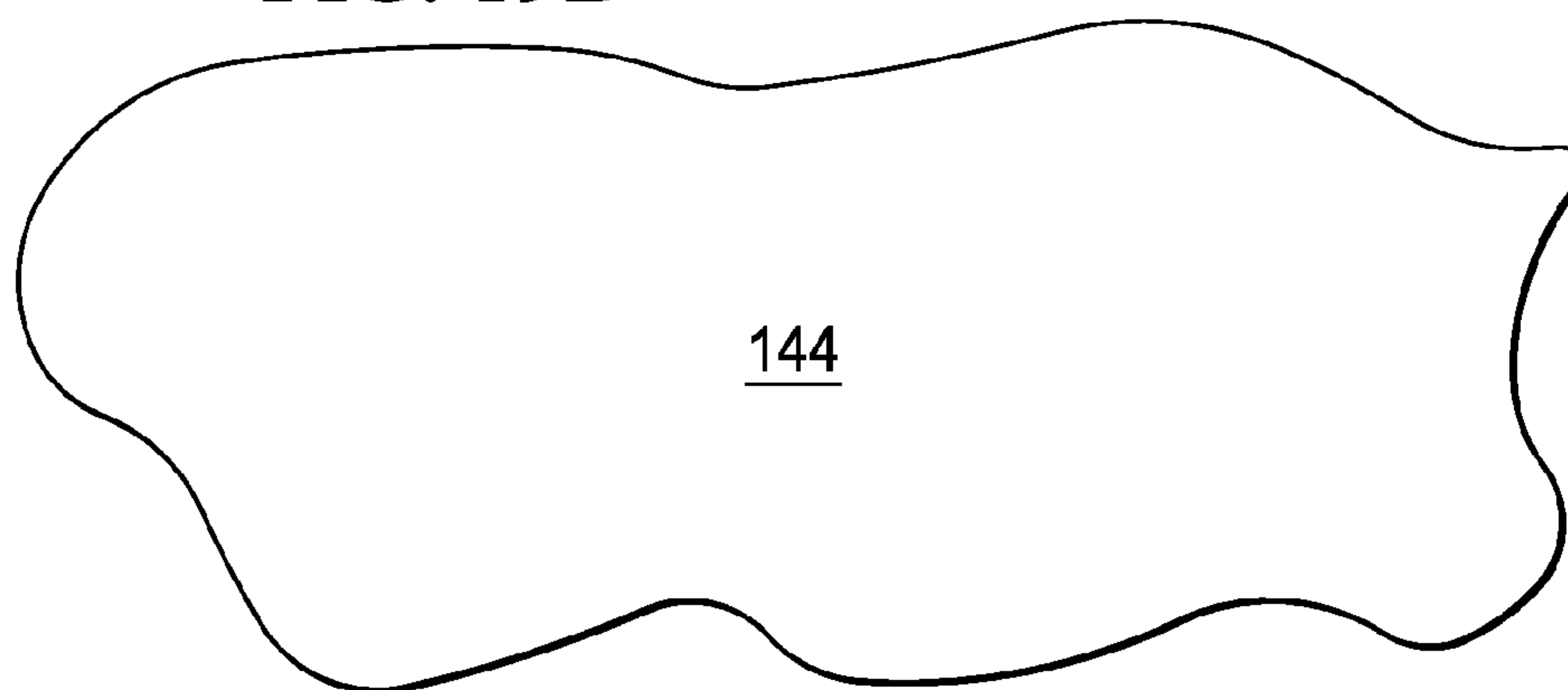
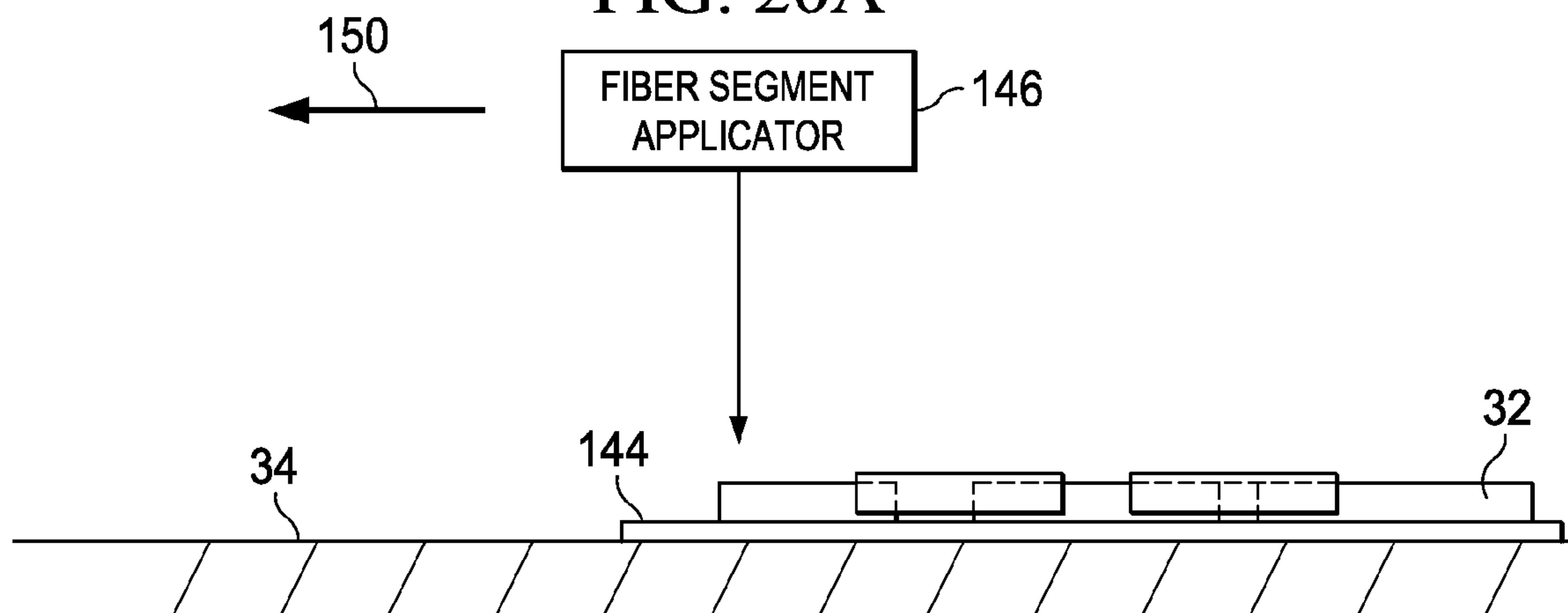


FIG. 20A



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FIG. 20B

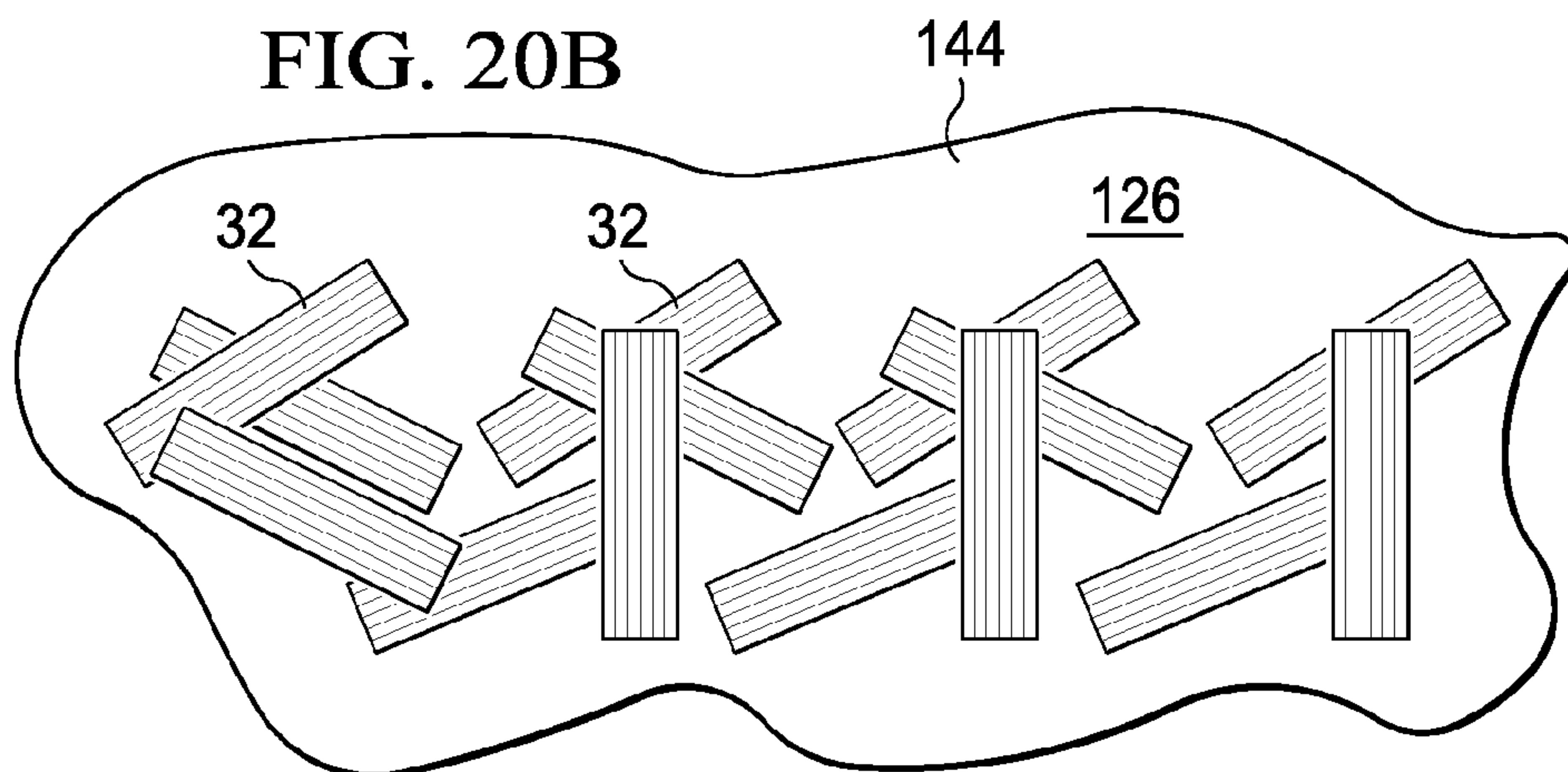


FIG. 21A

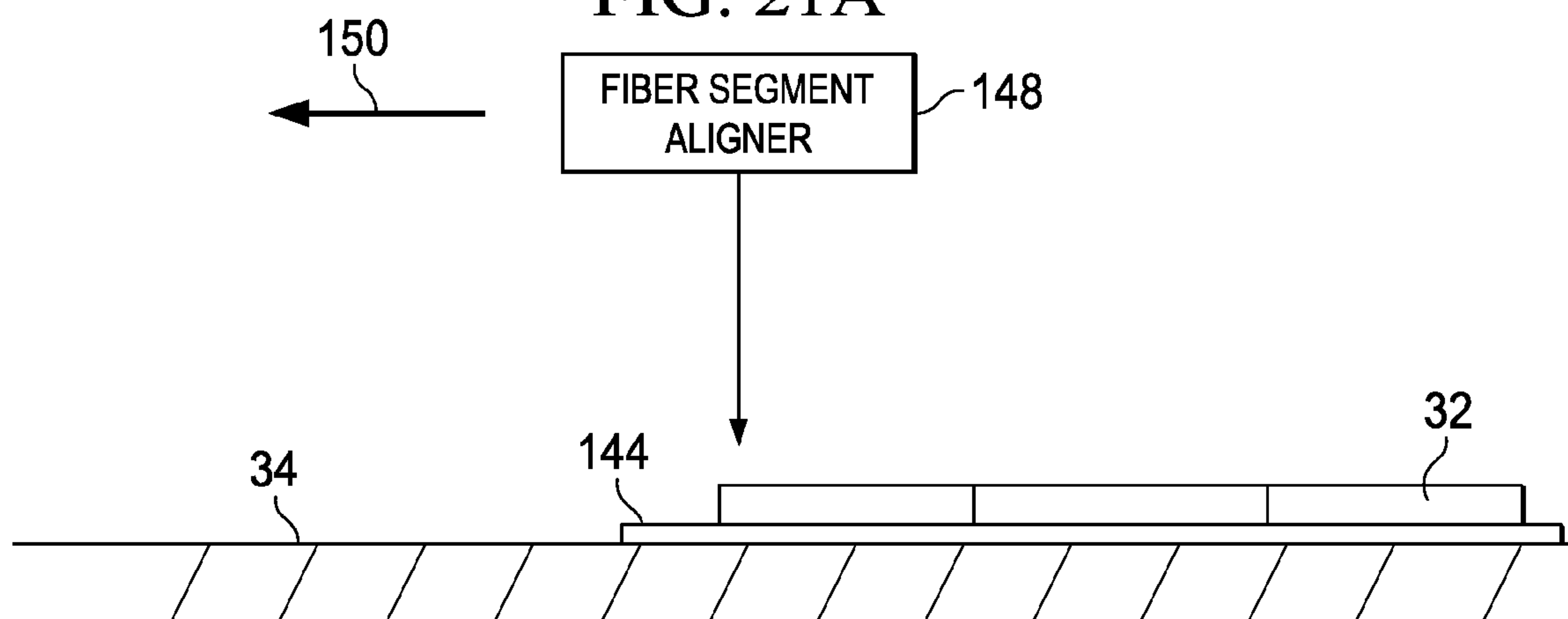
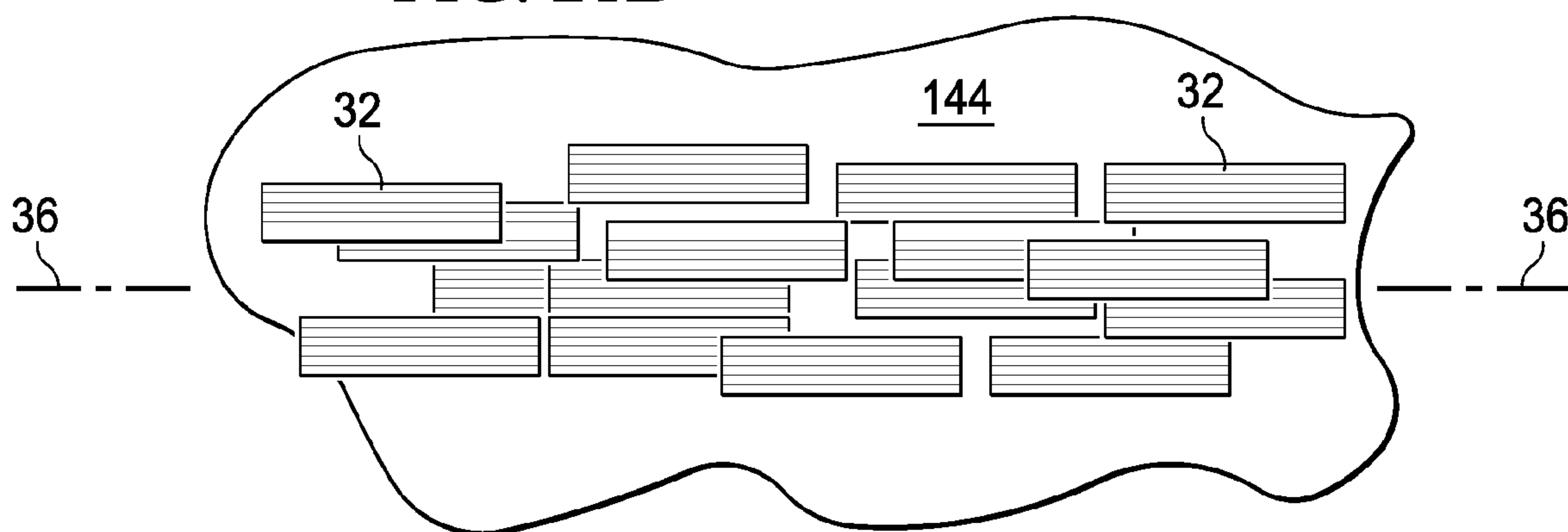
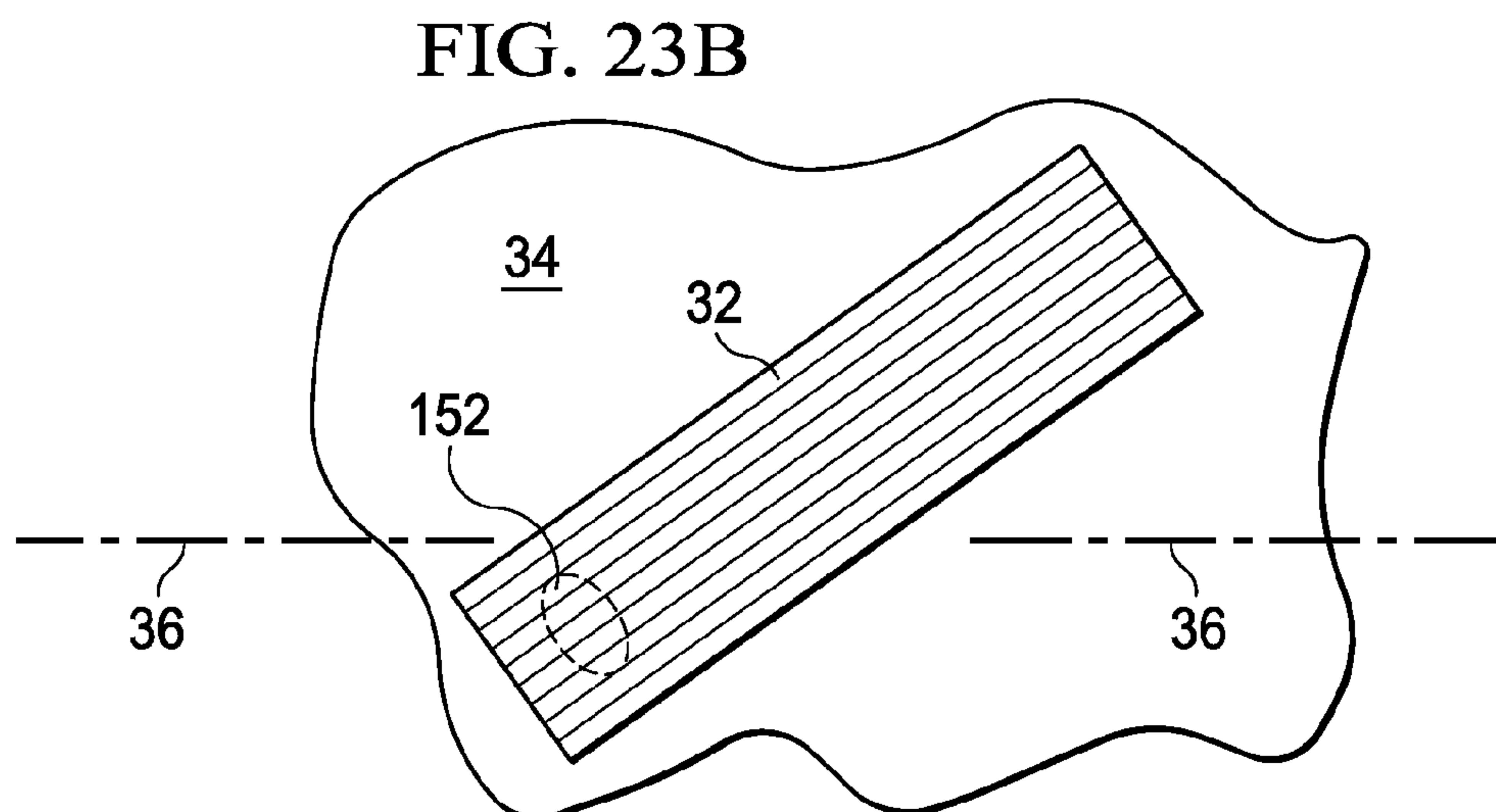
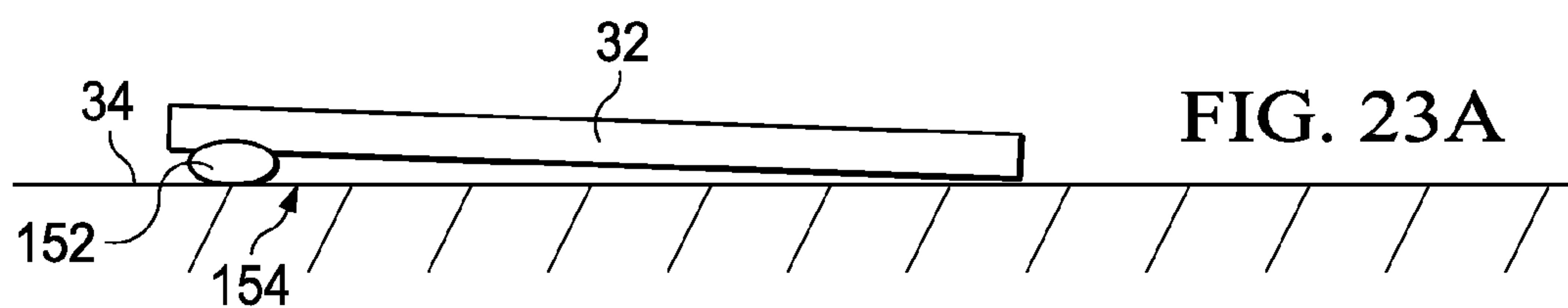
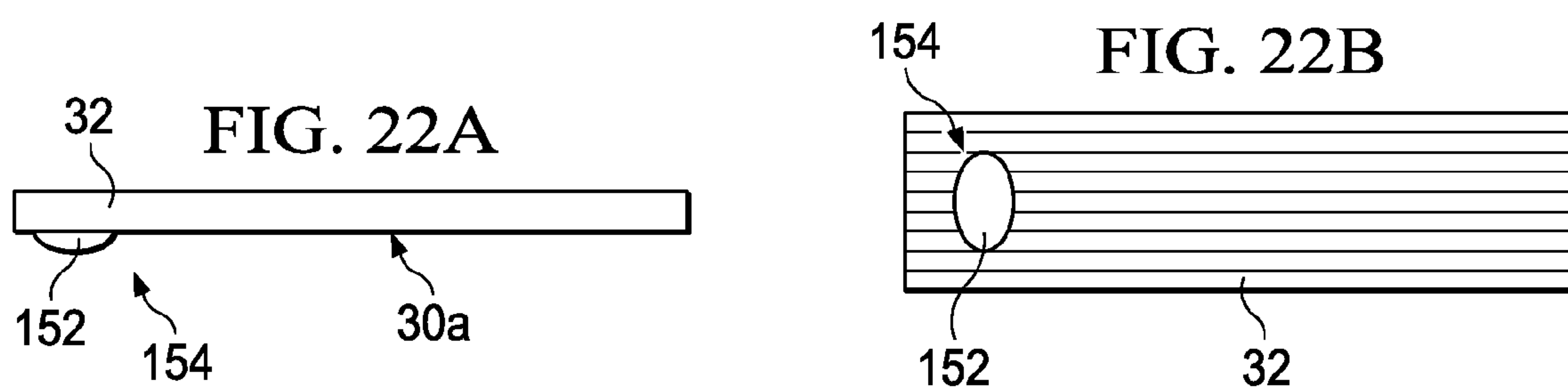


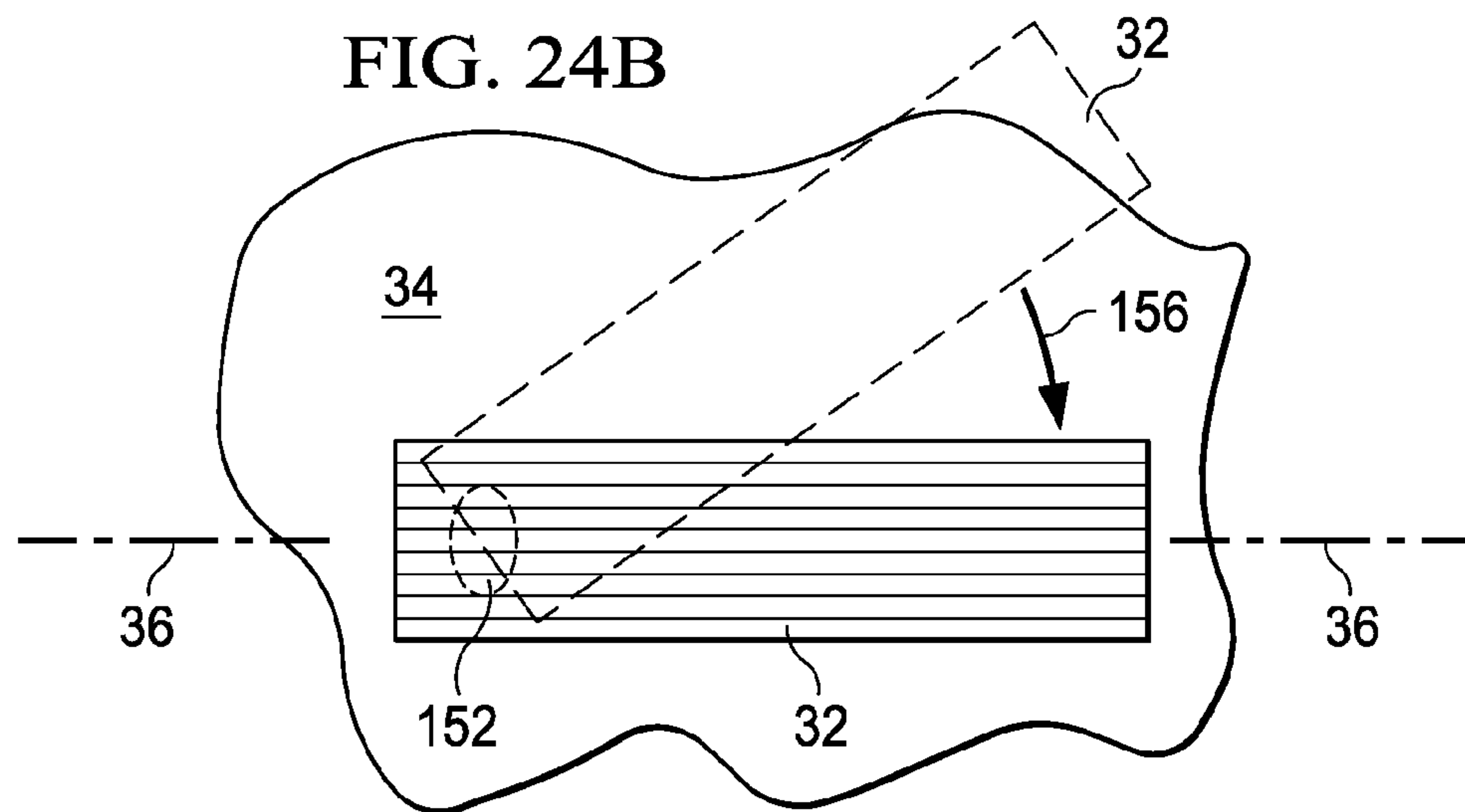
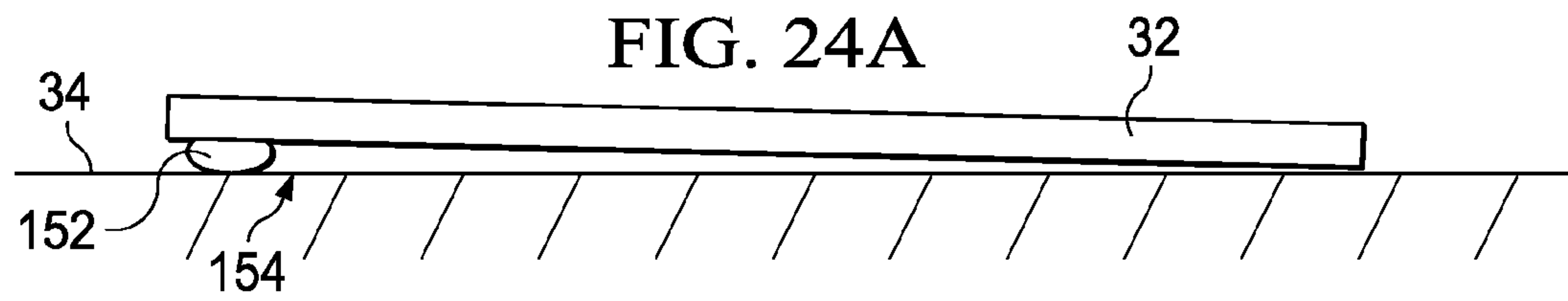
FIG. 21B



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