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(54) Title: METHOD AND APPARATUS FOR REDUCING PLY WRINKLING OF COMPOSITE LAMINATES DURING FORMING

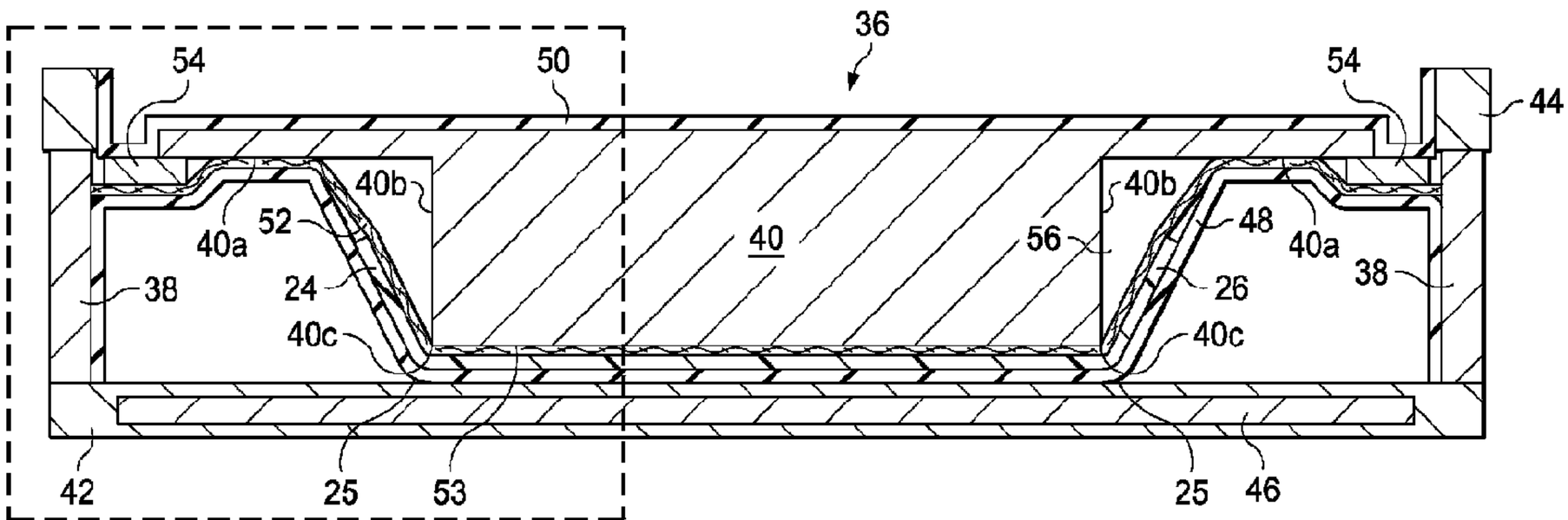

FIG. 10

(57) Abrégé/Abstract:
Ply wrinkling during hot drape forming of a composite laminate (28) is reduced at corner radii(25). A tensioning material (52) placed over an uncured composite laminate charge (28) maintains a compressive force on the laminate charge (28) as the charge is formed over a tool (40).

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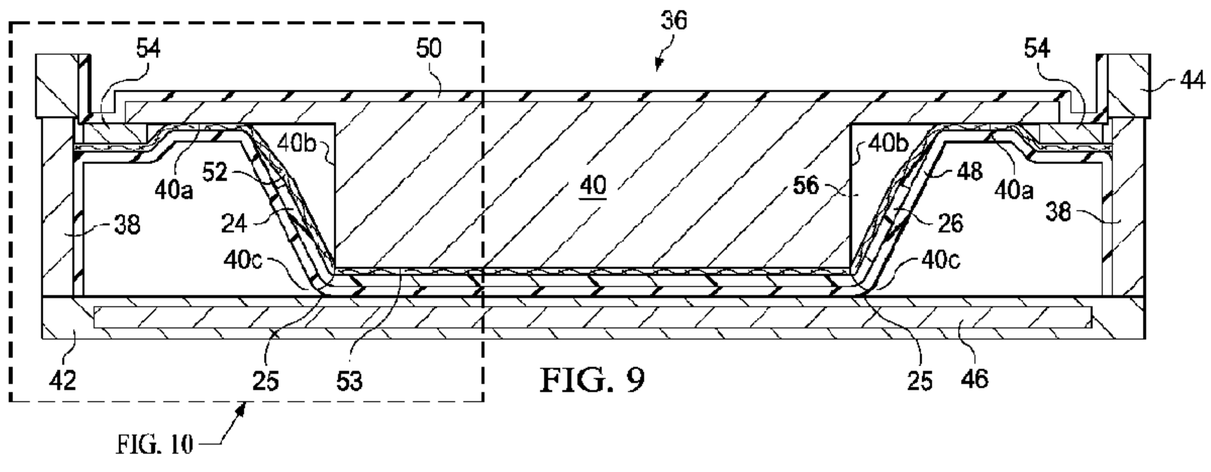

FIG. 9

(57) Abstract: Ply wrinkling during hot drape forming of a composite laminate (28) is reduced at corner radii(25). A tensioning material (52) placed over an uncured composite laminate charge (28) maintains a compressive force on the laminate charge (28) as the charge (28) is formed over a tool (40).

METHOD AND APPARATUS FOR REDUCING PLY WRINKLING OF COMPOSITE LAMINATES DURING FORMING

Background:

Hot drape forming may be used to form features such as flanges of a composite laminate part such as a stiffener. Hot drape forming is carried out by clamping and stretching a laminate charge in a frame, and heating it until soft enough to form. A pressure differential is then applied to the charge to form it over a shaped male tool. In one version of the process, known as top down forming, a compacted laminate charge is heated and formed down over a mandrel-like male tool. In another version of the process, referred to as inverted forming, the laminate charge is placed on a forming table, and a male tool is inverted and placed on top of the laminate charge. After the laminate charge is heated to forming temperature, a vacuum bladder beneath the laminate charge forms the charge upwardly onto and over the male tool.

Using either version of hot drape forming process described above, problems may be encountered when forming part features having relatively sharp radius corners. For example, when forming a composite angle stiffener having an inside radius corner between a flange and a web, the ply material closest to the male tool has a tendency to bunch, gather and form creases or wrinkles that may affect the mechanical performance of the stiffener. In some cases, the completed stiffener may be reworked to reduce creasing/wrinkling, while in other cases the stiffener must be scrapped. In either case, the problem of ply material creasing/wrinkling increases labor and/or material costs.

Accordingly, there is a need for a method and apparatus which substantially reduces or eliminates ply material creasing/wrinkling during hot drape forming of composite laminate parts having radius features. There is also a need for a method and apparatus of the type mentioned above which is cost-effective, easily implemented and which may reduce material and/or labor costs.

SUMMARY

The disclosed embodiments provide a method and apparatus for hot drape forming composite laminates which may reduce or eliminate ply wrinkling along radius features, such as inside corners. Ply wrinkling is reduced by maintaining plies in compression that are closest to a forming tool over which a composite laminate charge is formed. A compressive force is maintained on the plies by placing a tensioning material over the charge and maintaining tension on the tensioning material as the radius features being formed. The tensioning material applies a compressive force to the plies in the area of the radius features which prevents these plies from bunching or gathering. The reduction or elimination of ply wrinkling may reduce the need for reworking composite laminate parts, thereby reducing labor costs. Part scrap may also be reduced, thereby reducing material costs. The method and apparatus may be easily implemented without additional tooling, using simple, low-cost materials.

According to one disclosed embodiment, a method is provided of reducing ply wrinkling during hot drape forming of a composite laminate. The method comprises placing a tensioning material over an uncured composite laminate charge, hot drape forming the laminate charge over a forming tool, and using the tensioning material to compress the laminate charge as the laminate charge is being formed over the forming tool. The method may further comprise indexing the laminate charge on a table, and placing the tensioning material over the laminate charge may include overlapping peripheral edges of the tensioning material onto the table and loading the peripheral edges of the tensioning material against the table. Loading the peripheral edges of the tensioning material is performed by placing weights on the peripheral edges of the tensioning material. Hot drape forming may include sealing a flexible forming membrane over the laminate charge, drawing a vacuum between the forming membrane and the tool, and using the forming membrane to form the laminate charge over surfaces of the tool. Using the tensioning material to compress the laminate charge may include compressing the charge against the forming

membrane as the forming membrane forms the charge over surfaces of the tool. Placing the tensioning material over the laminate charge may include placing a plurality of sheets of fiberglass on the laminate charge which collectively cover substantially the entire area of the laminate charge, wherein each of the sheets extends beyond peripheral edges of the laminate charge. The method may also comprise retaining the peripheral edges of each of the sheets as the laminate charge is being hot drape formed over the tool.

According to another embodiment, a method is provided of hot drape forming a composite laminate part that reduces ply wrinkling along an inside corner of the composite laminate part, comprising placing at least one sheet of tensioning material over an uncured composite laminate charge, and retaining edges of the tensioning material, The method also includes hot drape forming the combination of the laminate charge and the tensioning material over an outside corner of a forming tool, and using the tensioning material to maintain a compressive force on the laminate charge at the inside corner of the laminate charge as the laminate charge is being hot drape formed over the outside corner of the forming tool. Placing the at least one sheet of tensioning material over the laminate charge includes placing the sheet of tensioning material in face-to-face, overlying contact with the laminate charge. The hot drape forming is performed using a flexible membrane to force the laminate charge around the outside corner of the forming tool as a compressive force on the laminate charge is being maintained by the tensioning material. Retaining the edges of the tensioning material against movement is performed by placing weights on the edges of the tensioning material. The method may further comprise placing and indexing the laminate charge on a table, and placing the sheet of tensioning material over the laminate charge may include placing the at least one sheet of tensioning material on the table, overlying the laminate charge and in face-to-face contact therewith.

According to still another embodiment, a method is provided of preventing ply wrinkling during hot drape forming of a composite laminate part having at least one flange, comprising placing an uncured composite laminate charge on a supporting

surface, and covering the laminate charge with a layer of tensioning material, including extending peripheral edges of the tensioning material outwardly beyond the laminate charge. The method also includes weighting the peripheral edges of the tensioning material against the supporting surface, forming the laminate charge over a tool, including forming the at least one flange by forming a portion of the laminate charge over a radiused tool corner, and using the layer of tensioning material to apply a compression force to the laminate charge along the radiused tool corner. The method also comprises unweighting the peripheral edges of the tensioning material, and removing the layer of tensioning material after the laminate charge has been formed. The method may also include removing the compressive force on the laminate charge during forming of the laminate charge over the tool after the portion of a laminate charge is formed over the radiused tool corner. Weighting of the peripheral edge may be performed by placing weights on the peripheral edge at substantially uniformly distributed locations around the peripheral edge. The method may further comprise allowing the tensioning material to tear as the portion of the laminate charge is being formed over the tool.

According to still another embodiment, apparatus is provided for hot drape forming a composite laminate part, comprising a tool over which a composite laminate charge may be formed, the tool including at least one corner feature for forming a radius on the part, a forming membrane adapted to form the laminate charge over the tool, and tensioning material between the forming membrane and the laminate charge for applying a compression force on the laminate charge at the corner to reduce wrinkling of the laminate charge at the radius during the forming. The tensioning material may include at least one sheet disposed in face-to-face contact with the laminate charge and having an outer periphery extending beyond outer edges of the laminate charge. The tensioning material has a tensile strength allowing the tensioning material to tear as the laminate charge is being formed over the tool. The apparatus may further include weights distributed around and loaded onto the outer periphery of the sheet for retaining the sheet around the outer

periphery thereof. The tensioning material may include a sheet having surface tack adherence to the laminate charge.

According to another embodiment, there is provided a method of reducing ply wrinkling during hot drape forming of a composite laminate, the method comprising: placing a tensioning material between an uncured composite laminate charge and a forming tool; hot drape forming the laminate charge over the forming tool, wherein hot drape forming comprises using a forming membrane to form the laminate charge over the forming tool; and using the tensioning material to compress the laminate charge against the forming membrane as the forming membrane forms the laminate charge over the forming tool.

According to another embodiment, there is provided an apparatus for hot drape forming a composite laminate part, the apparatus comprising: a tool over which a composite laminate charge may be formed, the tool including at least one corner feature for forming a radius on the part; a forming membrane adapted to form the laminate charge over the tool; and tensioning material between the tool and the laminate charge for compressing the laminate charge against the forming membrane at the corner feature to reduce wrinkling of the laminate charge at the radius during the forming.

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.

Figure **6**B is an illustration of a plan view similar to Figure **6**A, but showing several sheets of the tensioning material having been placed on the forming table, overlying the laminate charge.

Figure **6**C is an illustration of a plan view similar to Figure **6**B, but showing the remainder of the tensioning material sheets having been placed on the forming table, with tensioning weights having been placed partially around the perimeter of the tensioning material.

Figure **6**D is an illustration of a plan view similar to Figure **6**C, but showing the remainder of the tensioning weights placed around the perimeter of the tensioning material.

Figure **7** is an illustration of a cross-sectional view taken along the line **7**-**7** in Figure **6**D.

Figure **8** is an illustration of a cross-sectional view of the forming table, a male forming tool and an upper membrane having been installed.

Figure **9** is an illustration similar to Figure **8** but showing flanges of the channel stiffener partially formed.

Figure **10** is an illustration of the area designated as FIG. **10** in Figure **9**.

Figure **11** is an illustration similar to Figure **9**, but showing the flanges having been fully formed and the tensioning material partially torn.

Figure **12** is an illustration of a flow diagram of a method of hot drape forming a composite laminate charge.

Figure **13** is an illustration of a flow diagram of aircraft production and service methodology.

Figure **14** is illustration of a block diagram of an aircraft.

DETAILED DESCRIPTION

Referring first to Figures **1** and **2**, a multi-ply, composite laminate charge **28** may be formed into a laminate part such as a U-shaped channel stiffener **20** using a hot drape forming (HDF) process. The laminate charge **28** may comprise, without limitation, a carbon fiber reinforced plastic (CFRP). The composite laminate stiffener

20 may have a wide variety of applications. For example, two of the stiffeners **20** may be joined together back-to-back as shown in Figure **3** to form an I-beam that may be used for example and without limitation, in the aircraft industry as a wing spar **30**. The stiffener **20** comprises a web **22** and a pair of flanges **24**, **26** that transition outwardly from the web **22** along an inside corner radius **25**. The U-shaped channel stiffener **20** described above is merely exemplary of a wide variety of composite laminate structures having features such as the inside corner radius **25** that may result in gathering or bunching of the plies during the HDF process.

Referring now to Figure **4**, the stiffener **20** shown in Figures **2–3** may be formed in an HDF machine **32**. The HDF machine **32** broadly comprises a former **34**, a forming table **36** having a peripheral lower frame **38**, and a mandrel-like, male forming tool **40** over which a composite laminate charge **28** (Figure **1**) is formed after being heated to forming temperature. As shown in Figure **5**, the forming table **36** includes a support base **42** having an integrated heating element **46** for heating the laminate charge **28** to forming temperature. Although not shown in the Figures, indexing devices may be provided for indexing the location of a laminate charge **28** placed on the support base **42**.

Referring to Figures **5**, **6** and **6**A, a forming membrane **48** comprising a flexible, stretchable material such as, without limitation, a silicone, is stretched over the support base **42** within the lower frame **38**. In preparation for carrying out an HDF operation, a substantially flat composite laminate charge **28** is placed on the forming table **36**, in face-to-face, overlying contact with the forming membrane **48**. The support base **42** provides a surface for supporting the laminate charge **28** thereon. As previously mentioned, indexing devices may be used to locate the laminate charge **28** in a desired position of the support base **42**. Next, as shown in Figure **6**B, tensioning material **52** is placed over the laminate charge **28**. The tensioning material **52** extends outwardly beyond the outer periphery **55** of the laminate charge **28** to the lower frame **38**, and overlaps forming membrane **48**.

Depending upon the application as well as the size/geometry of the laminate charge **28**, the tensioning material **52** may comprise a plurality of individual

tensioning sheets **52**a which, in the illustrated example, are generally rectangular in shape and extend transversely across the width of the laminate charge **28**. The adjacent edges of the sheets **52**a may abut or overlap each other. The tensioning material **52** comprises a stretchable material having a preselected tensile strength which, when exceeded may result in the tensioning material **52** tearing or separating. The tensioning material **52** also possesses tack which allows it to adhere to the underlying the forming membrane **48**. In one embodiment, the tensioning material **52** may comprise a resin impregnated cloth such as, without limitation, an epoxy impregnated fiberglass woven cloth.

Referring now to Figure **6**C, with the tensioning material **52** installed over the laminate charge **28**, the outer perimeter **65** of the tensioning material **52** is retained during the forming process. In one embodiment, the tensioning material **52** is retained by placing a plurality of individual weights **54** on the tensioning material **52**, which load the perimeter **65** of the tensioning material **52** against the forming membrane **48** and support base **42**. The weights **54** may comprise, for example and without limitation, bags filled with a relatively heavy material such as lead shot. Other techniques for retaining the outer perimeter **65** of the tensioning material **52** are possible. Depending upon the application, the entire perimeter **65** of the tensioning material **52** is loaded using individual weights **54**, as shown in Figure **6**D. As best seen in Figure **7**, the loading provided by the weights **54** places the tensioning material **52** in tension, drawing it down against the laminate charge **28**.

Attention is now directed to Figures **8**–**11** which sequentially illustrate a process of hot drape forming the laminate charge **28** into the U-shaped channel stiffener **20** (Figure **2**) using the HDF machine **32** shown in Figure **4**. As illustrated in Figure **8**, a forming tool **40** is moved onto the forming table **36** and placed on top of the laminate charge **28**, thereby sandwiching the tensioning material **52** between the bottom face **53** of the tool **40**, and the laminate charge **28**. The forming tool **40** also includes oppositely facing sides **40**b, and a pair of laterally extending flanges **40**a. With the forming tool **40** on top of the laminate charge **28**, an upper frame **44** is then lowered onto and sealed against the lower frame **38**. A membrane **50** stretched

across and sealed to the upper frame **44**, creates, together with the forming membrane **48**, a substantially vacuum tight cavity **56**. Although not shown in the Figures, the hot drape forming machine **32** (Figure **4**) includes a system for evacuating the cavity **56**.

In preparation for an HDF operation, the heating element **46** is activated in order to heat the laminate charge **28** to a desired forming temperature. Next, a vacuum is drawn within cavity **56**. Referring particularly to Figure **9**, the vacuum within cavity **56** draws the membrane **50** down against the forming tool **40**, while the forming membrane **48** is drawn upwardly against the outer flanges **40**a. The forming membrane **48** also begins forming the flanges **24**, **26** of the laminate charge **28**, rotating them about corners **40**c of the tool **40** to form the corner radii **25**. The forming membrane **48** stretches and moves upwardly and outwardly, conforming to the lower frame **38**, while both the tensioning material **52** and the weights **54** move upwardly. This upward movement of the tensioning material **52** presses the tensioning material **52** against the tool flanges **40**a.

Referring particularly to Figures **9** and **10**, as the forming membrane **48** stretches and moves upwardly, folding the flanges **24**, **26**, it tensions **60** the material **52**, and, to some degree, may slightly stretch the material **52**. The tension **60** in the tensioning material **52** comprises and loads **62** the flanges **24**, **26** against the forming membrane **48**. The compression loading **62** of the flanges **24**, **26** against the forming membrane **48** maintains the plies of the flanges **24**, **26** (particularly those plies closest to the tool **40**) substantially flat, thereby reducing or eliminating any tendency of these plies to bunch, gather, collect or otherwise move out of plane as forming of the flanges **24**, **26** continues.

Referring now to Figure **11**, the tensioning material **52** maintains a compression load **62** on the flanges **24**, **26** to prevent ply wrinkling until each of the corner radii **25** is substantially fully formed. As the vacuum in the cavity **56** continues to increase and forming membrane **48** continues forming the flanges **24**, **26** toward the sides **40**b (Figure **9**) of the forming tool **40**, the force applied by the forming membrane **48** to the tensioning material **52** increases until the tension **60** exceeds

the tensile strength of the tensioning material **52**, resulting in the tensioning material **52** tearing or separating **66** in the area of the tool flanges **40**a. These tears or separations **66** in the tensioning material **52** release the tension **60** in the tensioning material **52**, thereby eliminating resistance to the continued inward forming movement of forming membrane **48** toward the tool **40**, allowing continued forming of the flanges **24**, **26** toward the sides of **40**b of the forming tool **40**.

Attention is now directed to Figure **12** which illustrates additional details of one embodiment of a method of hot drape forming a composite laminate part that reduces or eliminates ply wrinkling in radius areas. Beginning at step **70**, a suitable multi-ply composite laminate charge is placed and indexed in suitable forming equipment, such as an HDF machine **32**. At **72**, tensioning material **52** is cut into individual sheets **52**a of a desired length. The number of tensioning sheets **52**a that are cut is sufficient to provide complete coverage of the laminate charge **28** and the forming membrane **48** on each side of the charge **28**. At step **74**, each sheet **52**a is placed and centered on the laminate charge **28**, extending outwardly beyond the periphery of the charge **28** to the forming frame. At **76**, additional sheets **52**a of the tensioning material **52** are placed in order to provide full coverage of the laminate charge **28** with a desired overlap of the sheets **52**a. At **78**, tensioning weights **54**, such as shot bags, are positioned and placed end-to-end, near the frame **38** in order to retain the sheets **52**a of tensioning material **52** along their full length.

At step **80**, a laminate heating and forming cycle is initiated, beginning with heating of the laminate charge. At **82**, a desired level of vacuum is drawn in the cavity **56**, the HDF machine **32** is vented, and the tensioning weights **54** are removed. At step **84**, a forming cycle is initiated and held for a desired time interval. At **86**, the HDF machine **32** is vented, releasing the vacuum in the cavity **56**, and the forming tool **40** is removed. Then, at **88**, the sheets **52**a of tensioning material **52** are removed. Finally, at step **90**, the formed laminate part may be inspected for wrinkles.

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

laminate parts are fabricated by hot drape forming or by similar processes. Thus, referring now to Figures **13** and **14**, embodiments of the disclosure may be used in the context of an aircraft manufacturing and service method **94** as shown in Figure **13** and an aircraft **96** as shown in Figure **14**. Aircraft applications of the disclosed embodiments may include, for example, without limitation, spars, stringers, floor beams and similar stiffeners, to name only a few. During pre-production, exemplary method **94** may include specification and design **98** of the aircraft **96** and material procurement **100**. During production, component and subassembly manufacturing **102** and system integration **104** of the aircraft **96** takes place. Thereafter, the aircraft **96** may go through certification and delivery **106** in order to be placed in service **108**. While in service by a customer, the aircraft **96** is scheduled for routine maintenance and service **110**, which may also include modification, reconfiguration, refurbishment, and so on.

Each of the processes of method **94** 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 **14**, the aircraft **96** produced by exemplary method **94** may include an airframe **112** with a plurality of systems **114** and an interior **116**. Examples of high-level systems **114** include one or more of a propulsion system **118**, an electrical system **120**, a hydraulic system **122**, and an environmental system **124**. 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 **94**. For example, components or subassemblies corresponding to production process **102** may be

fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **96** is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages **102** and **104**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **96**. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **96** is in service, for example and without limitation, to maintenance and service **110**.

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 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. Further, the disclosure comprises embodiments below:

In accordance with one embodiment there is provided a method of reducing ply wrinkling during hot drape forming of a composite laminate. The method involves placing a tensioning material over an uncured composite laminate charge, hot drape forming the laminate charge over a forming tool, and using the tensioning

material to compress the laminate charge as the laminate charge is being formed over the forming tool.

The method may further involve indexing the laminate charge on a table, and placing the tensioning material over the laminate charge may include overlapping peripheral edges of the tensioning material onto the table and loading the peripheral edges of the tensioning material against the table.

Loading the peripheral edges of the tensioning material may be performed by placing weights on the peripheral edges of the tensioning material.

The hot drape forming may involve sealing a flexible forming membrane over the laminate charge, drawing a vacuum between the forming membrane and the tool, and using the forming membrane to form the laminate charge over surfaces of the tool.

Using the tensioning material to compress the laminate charge may involve compressing the charge against the forming membrane as the forming membrane forms the charge over surfaces of the tool.

Using the tensioning material over the laminate charge may involve placing a plurality of sheets of fiberglass on the laminate charge which collectively cover substantially the entire area of the laminate charge, wherein each of the sheets extends beyond peripheral edges of the laminate charge.

The method may further involve retaining the peripheral edges of each of the sheets as the laminate charge is being hot drape formed over the tool.

In accordance with another embodiment there is provided a method of hot drape forming a composite laminate part that reduces ply wrinkling along an inside corner of the composite laminate part. The method involves placing at least one sheet of tensioning material over an uncured composite laminate charge, retaining edges of the tensioning material, hot drape forming the combination of the laminate charge and the tensioning material over an outside corner of a forming tool, and using the tensioning material to compress the laminate charge at the inside corner of the laminate charge as the laminate charge is being hot drape formed over the outside corner of the forming tool.

Placing the at least one sheet of tensioning material over the laminate charge may involve placing the sheet of tensioning material in face-to-face, overlying contact with the laminate charge.

The hot drape forming may be performed using a flexible membrane to force the laminate charge around the outside corner of the forming tool as the laminate charge is being compressed by the tensioning material.

Retaining the edges of the tensioning material against movement may be performed by placing weights of the edges of the tensioning material.

The method may further involve placing and indexing the laminate charge on a table, and placing the at least one sheet of tensioning material over the laminate charge may include placing the at least one sheet of tensioning material on the table, overlying the laminate charge and in face-to-face contact therewith.

In accordance with another embodiment, there is provided a method of preventing ply wrinkling during hot drape forming of a composite laminate part having at least one flange. The method involves placing an uncured composite laminate charge on a supporting surface, covering the laminate charge with a layer of tensioning material, including extending peripheral edges of the tensioning material outwardly beyond the laminate charge, weighting the peripheral edges of the tensioning material against the supporting surface, forming the laminate charge over a tool, including forming the at least one flange by forming a portion of the laminate charge over a radiused tool corner, using the layer of tensioning material to apply a compressive force to the laminate charge along the radiused tool corner, unweighting the peripheral edges of the tensioning material, and removing the layer of tensioning material after the laminate charge has been formed.

The method may further involve removing the tension on the laminate charge during forming of the laminate charge over the tool after the portion of a laminate charge is formed over the radiused tool corner.

The weighting of the peripheral edge may be performed by placing weights on the peripheral edge at substantially uniformly distributed locations around the peripheral edge.

The method may further involve allowing the tensioning material to tear as the portion of the laminate charge is being formed over the tool.

In accordance with another embodiment, there is provided an apparatus for hot drape forming a composite laminate part. The apparatus includes a tool over which a composite laminate charge may be formed, the tool including at least one corner feature for forming a radius on the part, a forming membrane adapted to form the laminate charge over the tool, and tensioning material between the forming membrane and the laminate charge for applying a compressive force on the laminate charge at the corner feature to reduce wrinkling of the laminate charge at the radius during the forming.

The tensioning material may include at least one sheet disposed in face-to-face contact with the laminate charge and having an outer periphery extending beyond outer edges of the laminate charge, and the tensioning material may have a tensile strength allowing the tensioning material to tear as the laminate charge is being formed over the tool.

The apparatus may further include weights distributed around and loaded onto the outer periphery of the sheet for retaining the sheet around the outer periphery thereof.

The tensioning material may include a sheet having surface tack adherence to the laminate charge.

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

1. A method of reducing ply wrinkling during hot drape forming of a composite laminate, the method comprising:

placing a tensioning material between an uncured composite laminate charge and a forming tool;

hot drape forming the laminate charge over the forming tool, wherein hot drape forming comprises using a forming membrane to form the laminate charge over the forming tool; and

using the tensioning material to compress the laminate charge against the forming membrane as the forming membrane forms the laminate charge over the forming tool.

2. The method of claim **1**, further comprising:

indexing the laminate charge on a table; and

wherein placing the tensioning material between the laminate charge and the forming tool comprises overlapping peripheral edges of the tensioning material onto the table and loading the peripheral edges of the tensioning material against the table.

3. The method of claim **2**, wherein loading the peripheral edges of the tensioning material is performed by placing weights on the peripheral edges of the tensioning material.

4. The method of claim **3**, wherein the weights are placed at substantially uniformly distributed locations around the peripheral edge.

5. The method of any one of claims **1**-**4**, wherein placing the tensioning material between the laminate charge and the forming tool comprises placing a plurality of sheets of fiberglass on the laminate charge which collectively cover substantially the entire area of the laminate charge, wherein each of the sheets extends beyond peripheral edges of the laminate charge.

6. The method of claim **5**, wherein placing the plurality of sheets comprises placing the sheets in face-to-face, overlying contact with the laminate charge.

7. The method of claim **5** or **6**, further comprising:

retaining the peripheral edges of each of the sheets as the laminate charge is being hot drape formed over the forming tool.

8. The method of any one of claims **1**-**7**, wherein the hot drape forming further comprises:

sealing the forming membrane over the laminate charge; and

drawing a vacuum between the forming membrane and the forming tool.

9. The method of any one of claims **1**-**8**, wherein:

using the forming membrane to form the laminate charge over the forming tool comprises using the forming membrane to form the laminate charge over surfaces of the forming tool.

10. The method of any one of claims **1**-**8**, wherein:

using the forming membrane to form the laminate charge over the forming tool comprises using the forming membrane to form the laminate charge around an outside corner of the forming tool; and

using the tensioning material to compress the laminate charge against the forming membrane comprises using the tensioning material to compress the laminate charge at the inside corner of the laminate charge as the laminate charge is being hot drape formed over the outside corner of the forming tool.

11. The method of any one of claims **1**-**8**, wherein:

using the forming membrane to form the laminate charge over the forming tool comprises using the forming membrane to form the laminate charge over a radiused corner of the forming tool to form at least one flange in the laminate charge; and

using the tensioning material to compress the laminate charge against the forming membrane comprises using the tensioning material to compress the laminate charge along the radiused corner of the forming tool.

12. The method of any one of claims **1**-**11**, further comprising:

removing the tensioning material after the laminate charge has been formed.

13. The method of any one of claims **1-12**, further comprising:

allowing the tensioning material to tear as the laminate charge is being formed over the tool.

14. The method of any one of claims **1-13**, wherein placing the tensioning material between the laminate charge and the forming tool comprises sandwiching the tensioning material between the laminate charge and the forming tool.

15. An apparatus for hot drape forming a composite laminate part, the apparatus comprising:

a tool over which a composite laminate charge may be formed, the tool including at least one corner feature for forming a radius on the part;

a forming membrane adapted to form the laminate charge over the tool; and

tensioning material between the tool and the laminate charge for compressing the laminate charge against the forming membrane at the corner feature to reduce wrinkling of the laminate charge at the radius during the forming.

16. The apparatus of claim **15**, wherein:

the tensioning material comprises at least one sheet disposed in face-to-face contact with the laminate charge and having an outer periphery extending beyond outer edges of the laminate charge, and

the tensioning material has a tensile strength allowing the tensioning material to tear as the laminate charge is being formed over the tool.

17. The apparatus of claim **16**, further comprising:

weights distributed around and loaded onto the outer periphery of the at least one sheet for retaining the at least one sheet around the outer periphery thereof.

18. The apparatus of claim **15**, wherein the tensioning material comprises a sheet having surface tack adherence to the laminate charge.

19. The apparatus of any one of claims **15**-**18**, wherein the tensioning material is sandwiched between the tool and the laminate charge.

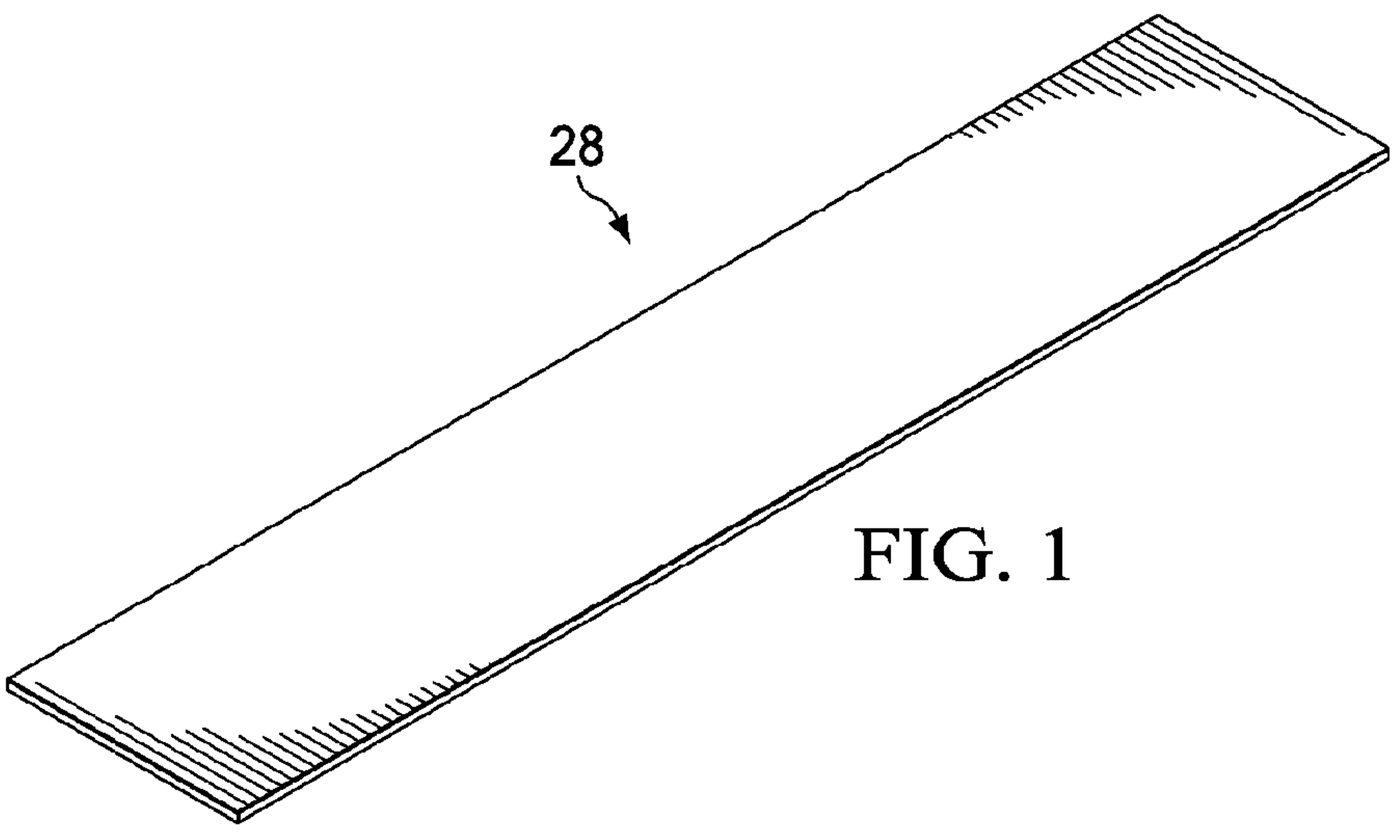

FIG. 1

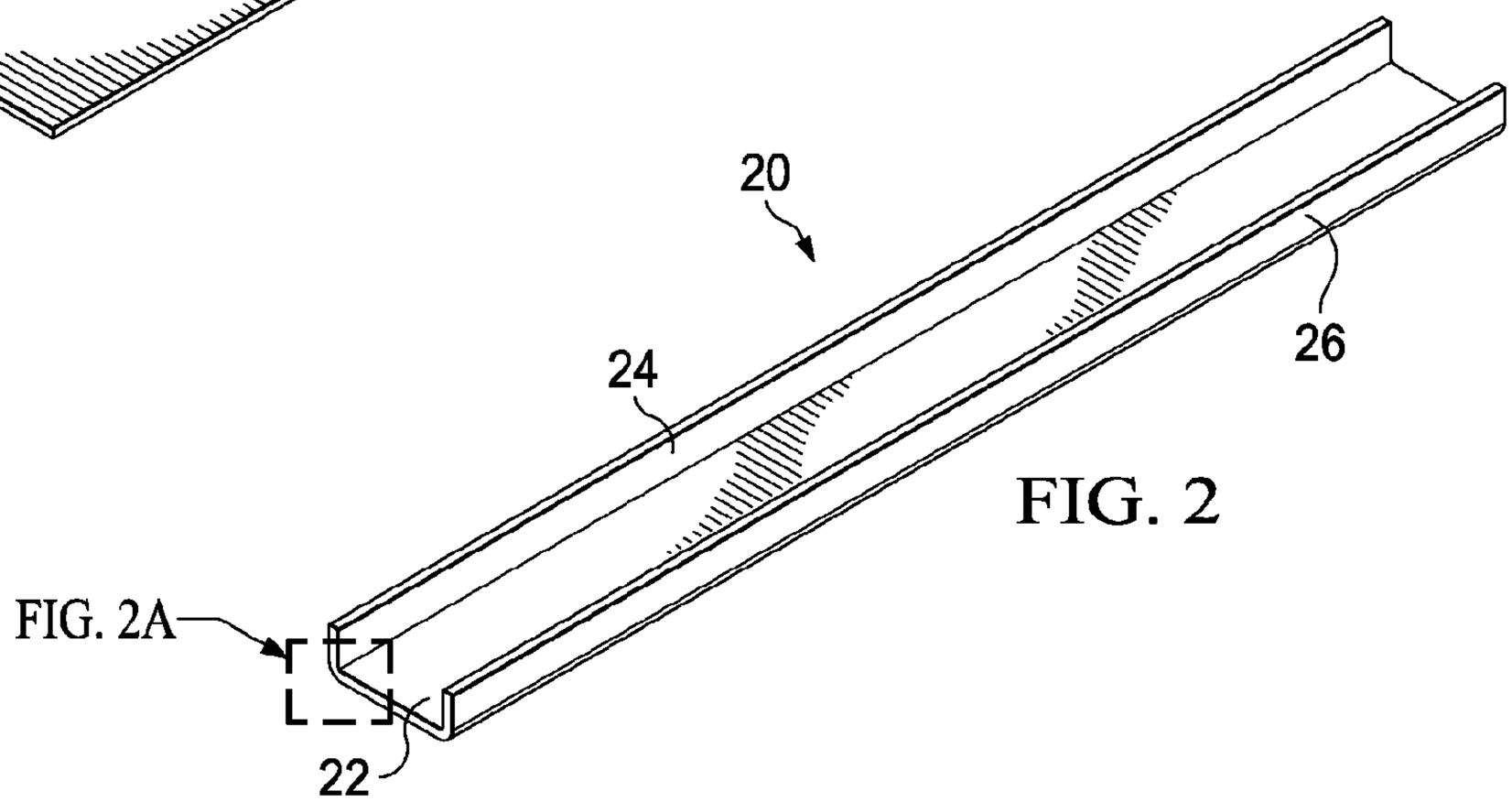

FIG. 2

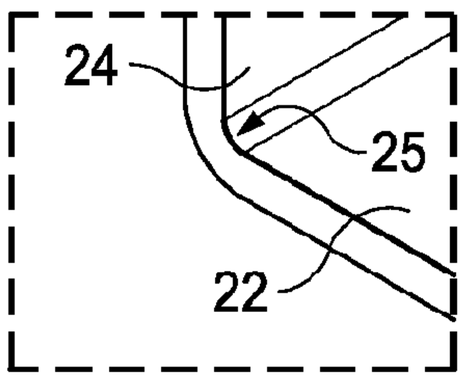

FIG. 2A

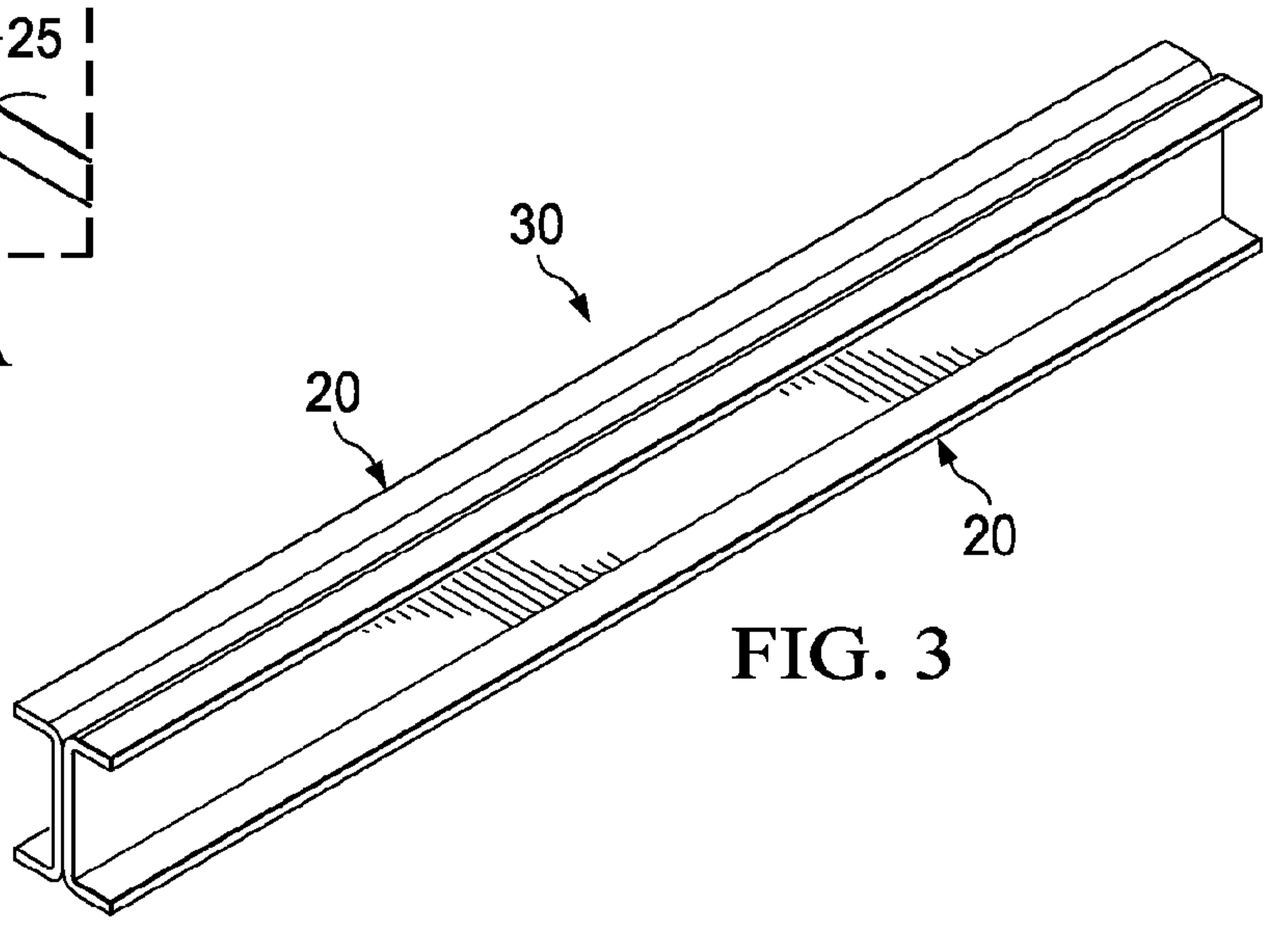

FIG. 3

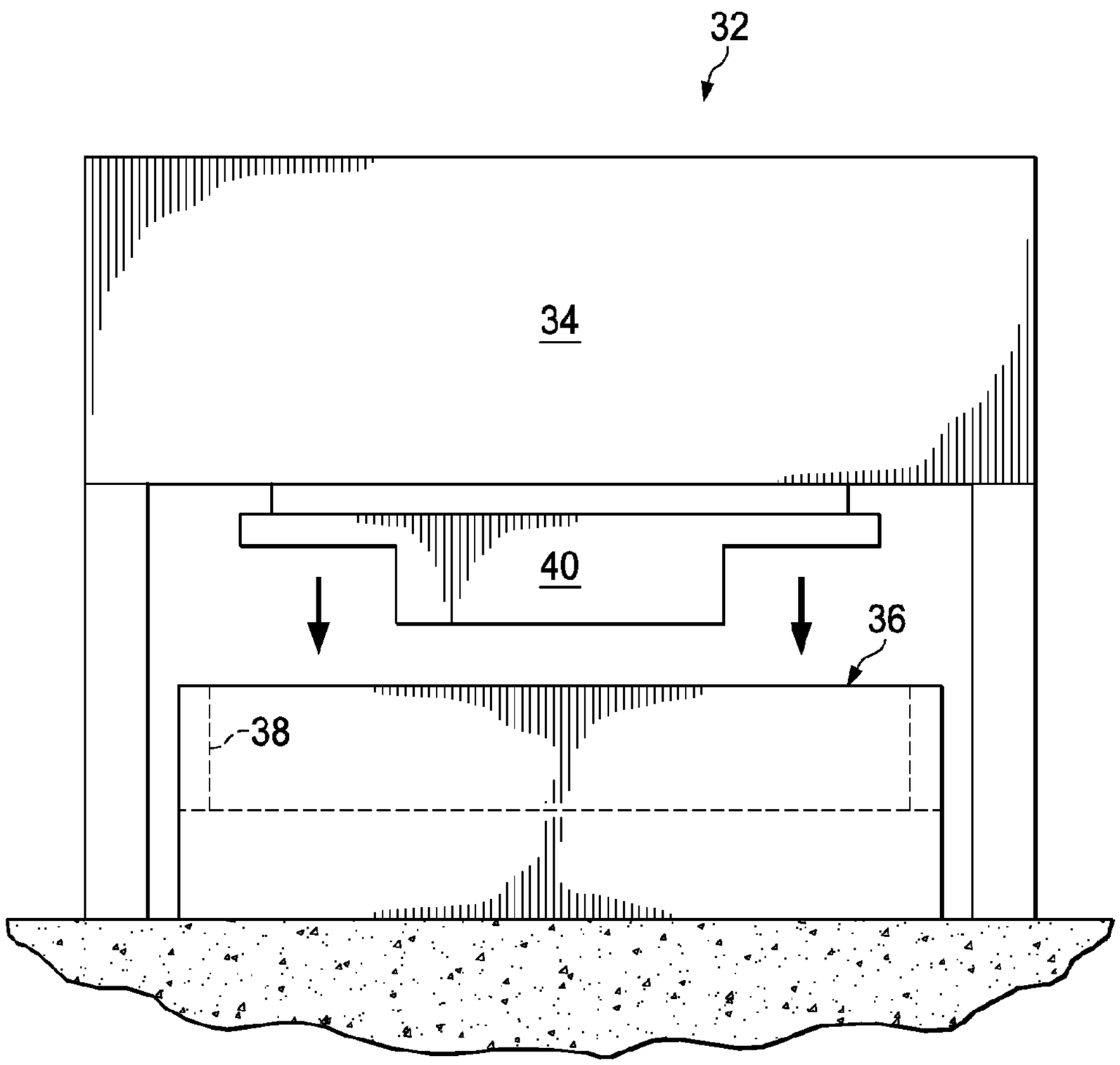

FIG. 4

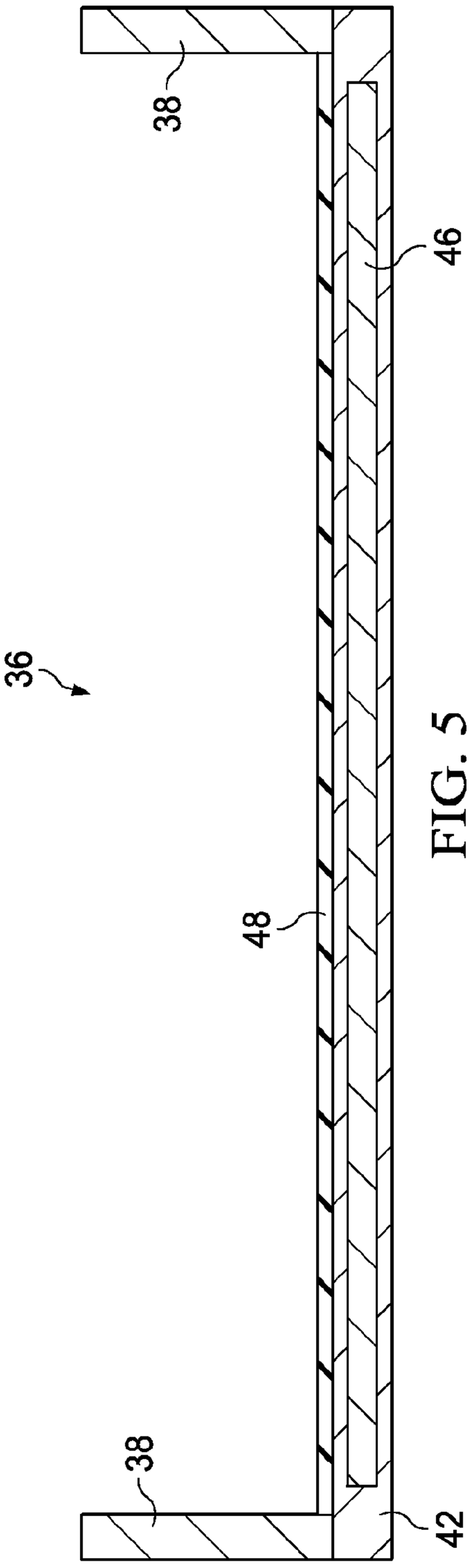

FIG. 5

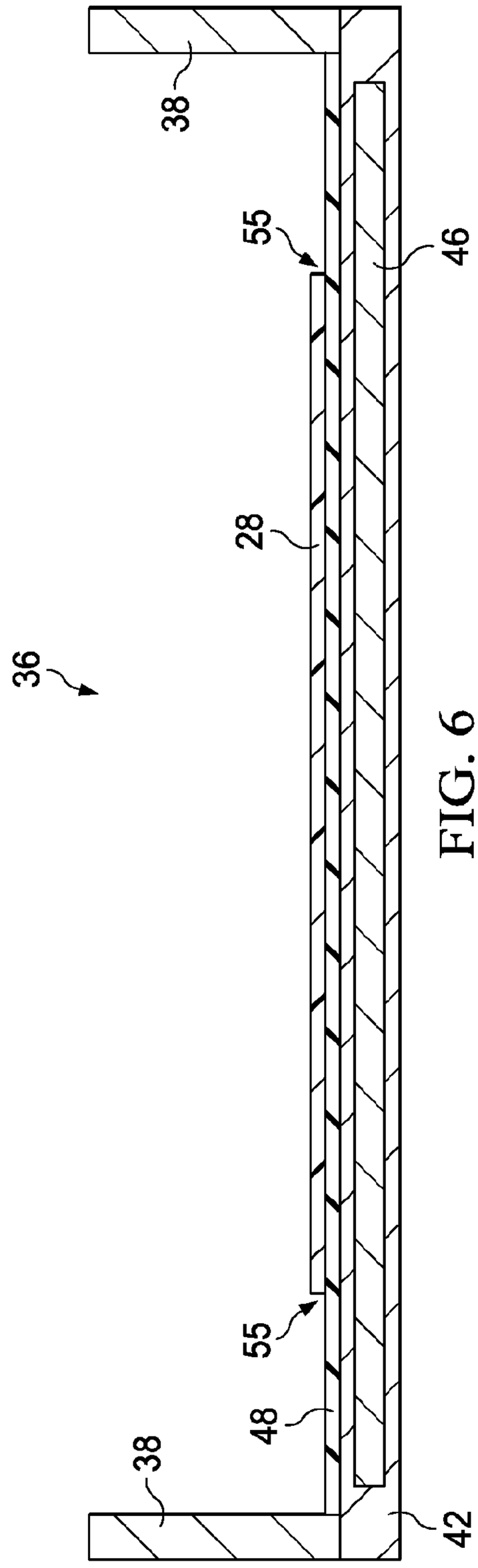

FIG. 6

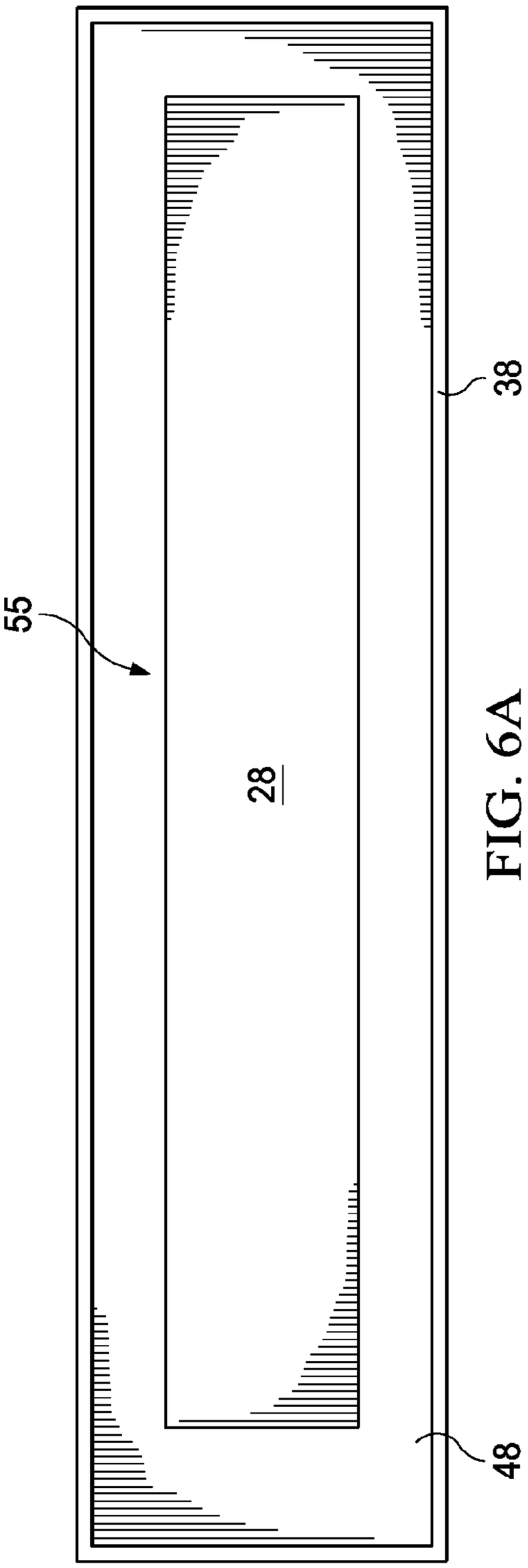

FIG. 6A

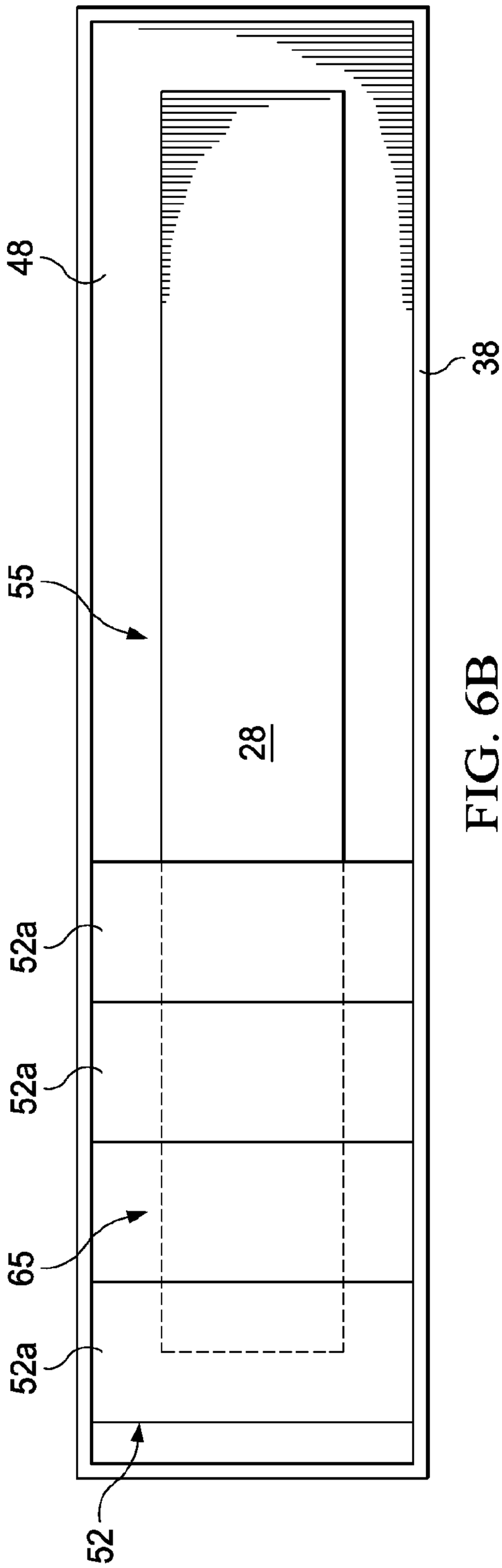

FIG. 6B

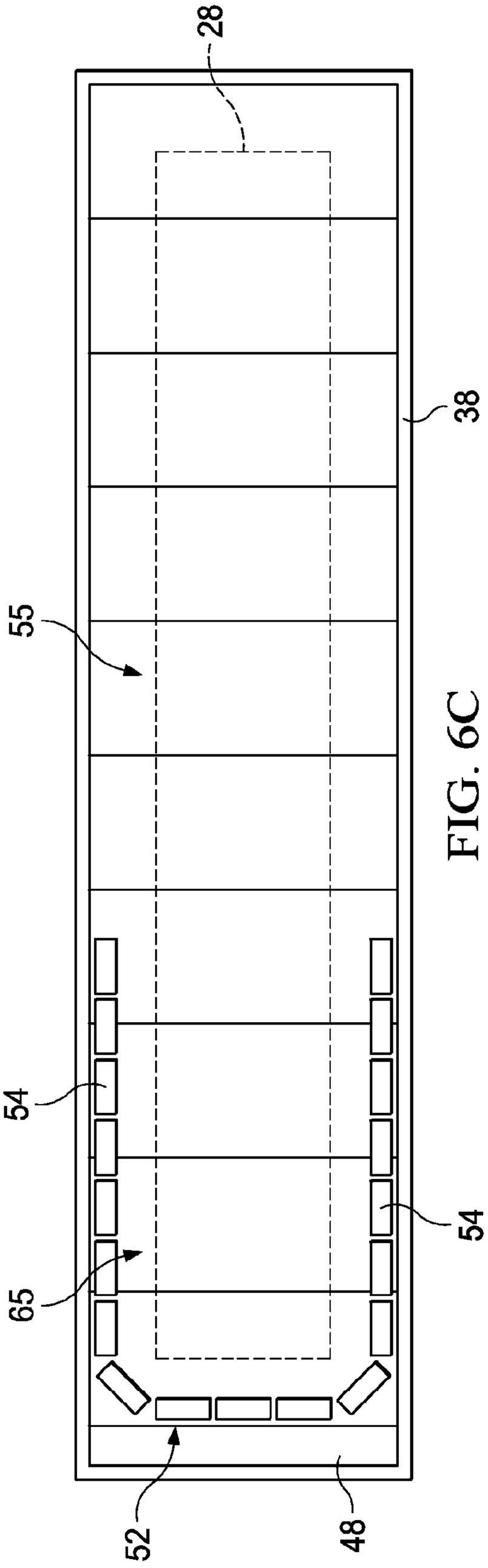

FIG. 6C

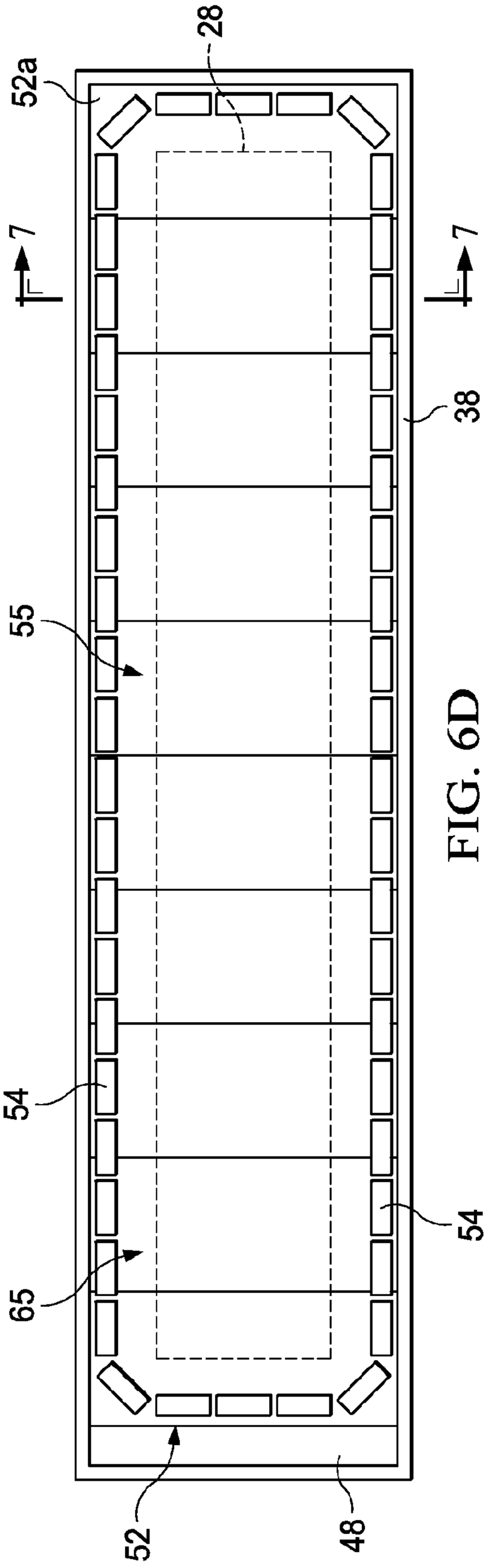

FIG. 6D

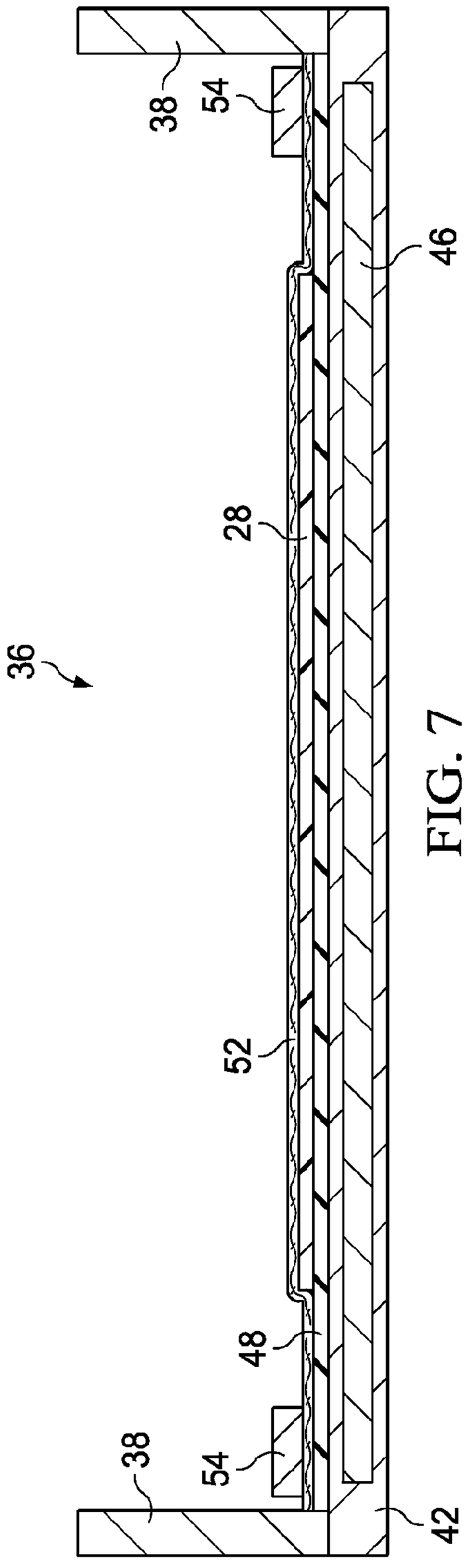
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FIG. 7

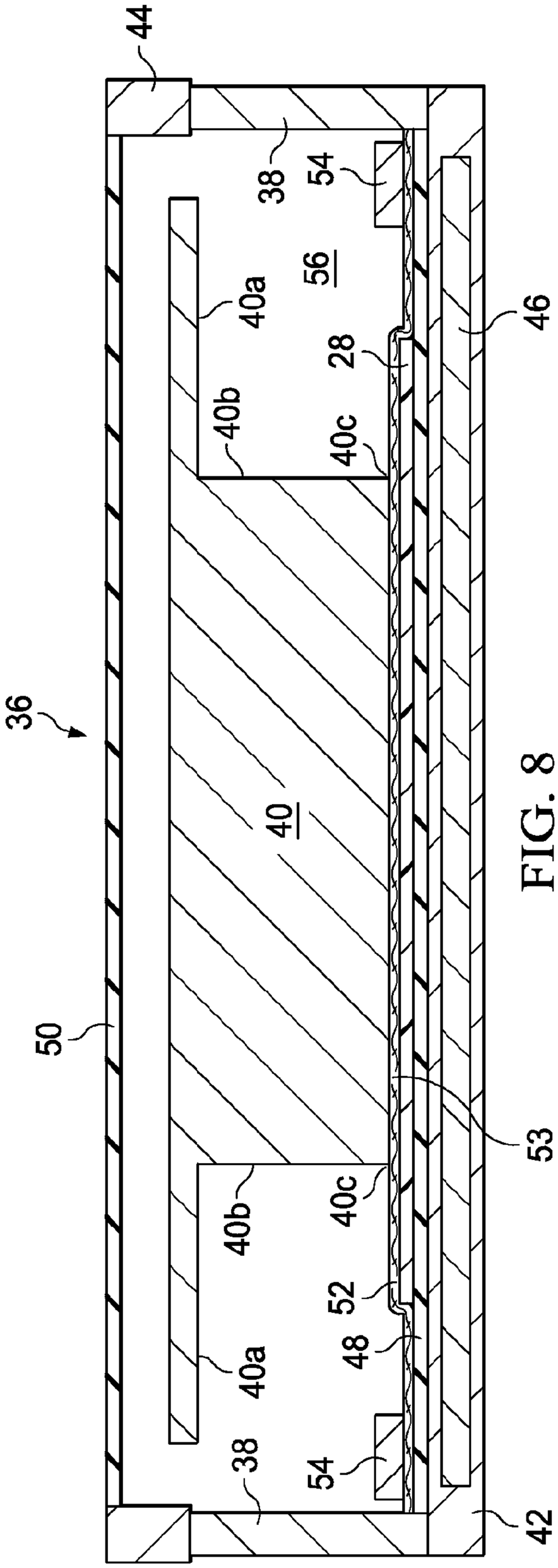
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FIG. 8

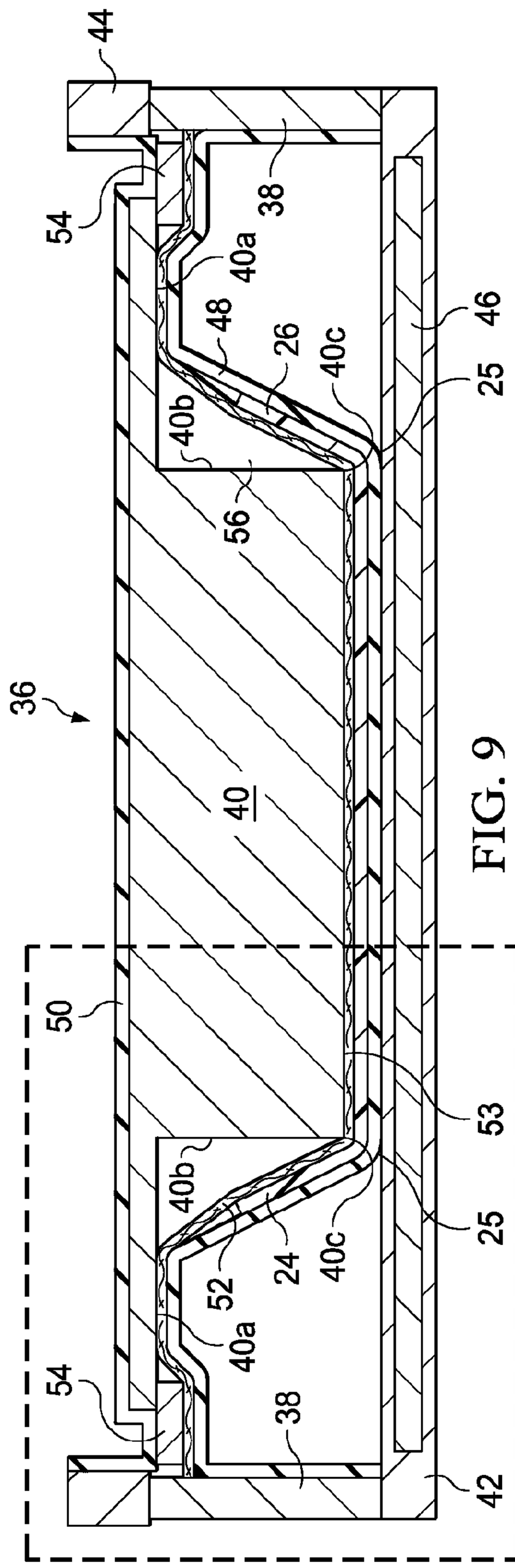
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FIG. 9

FIG. 10

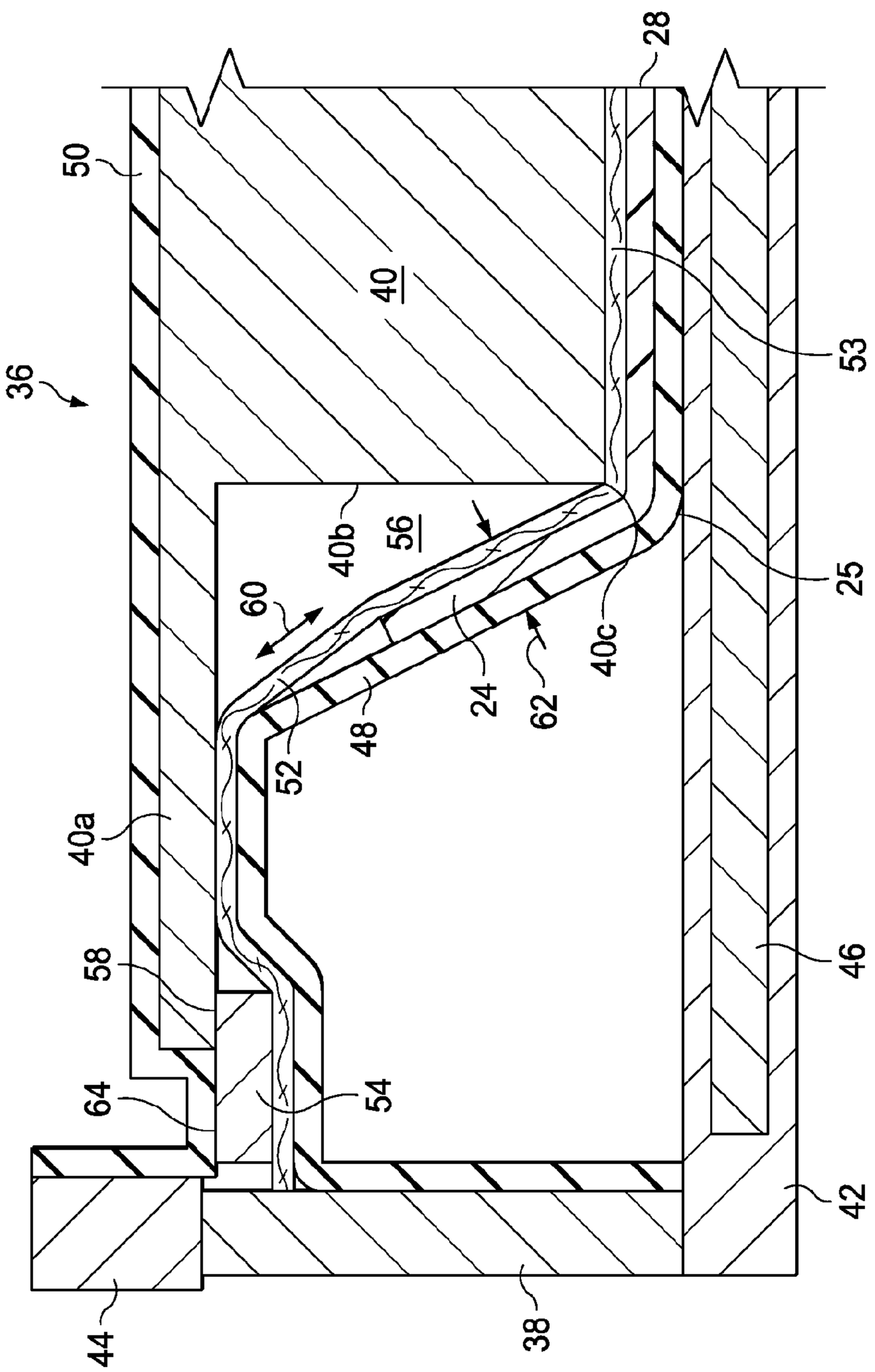

FIG. 10

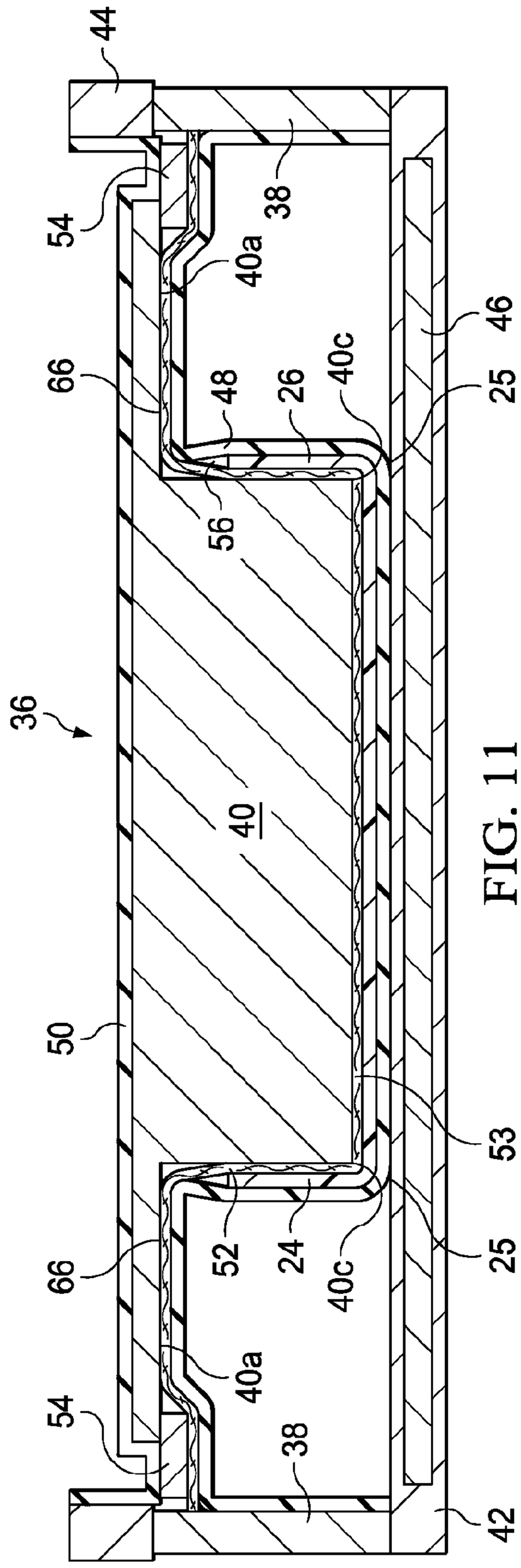
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FIG. 11

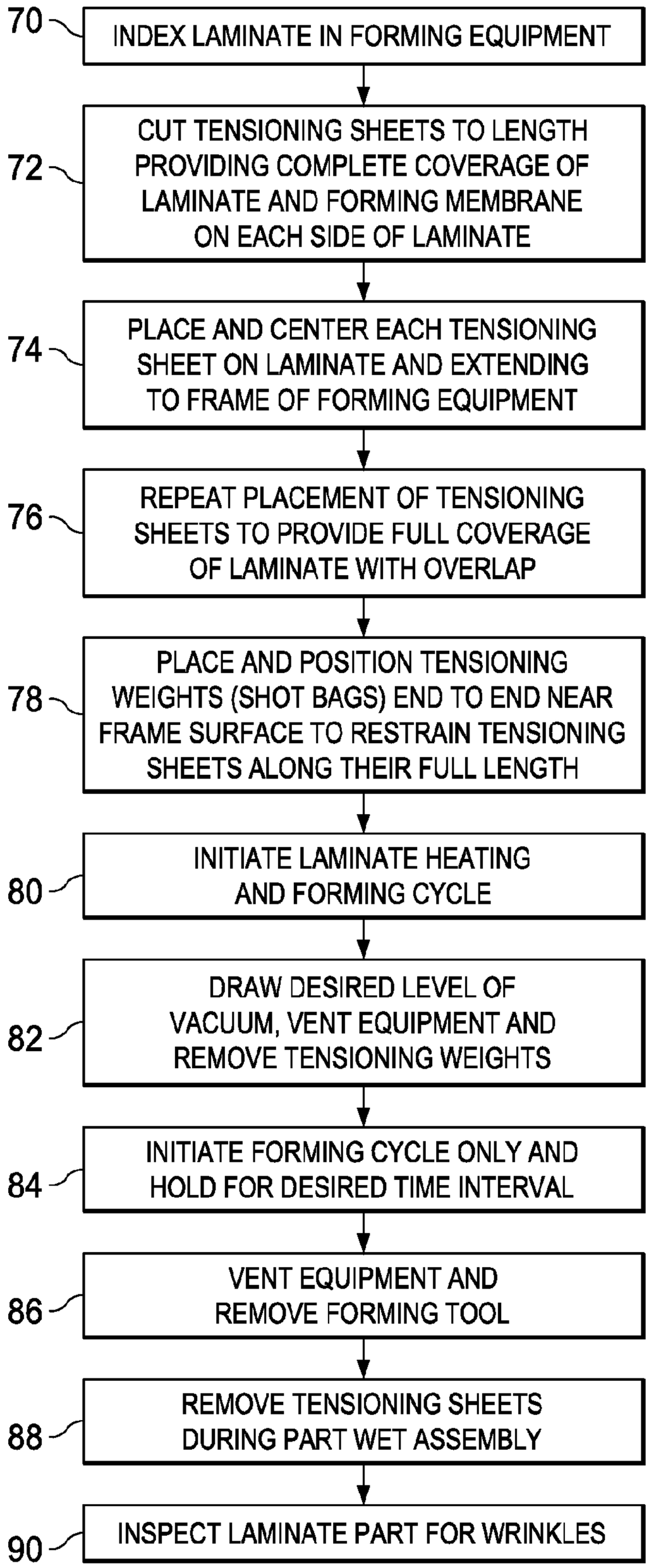
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FIG. 12

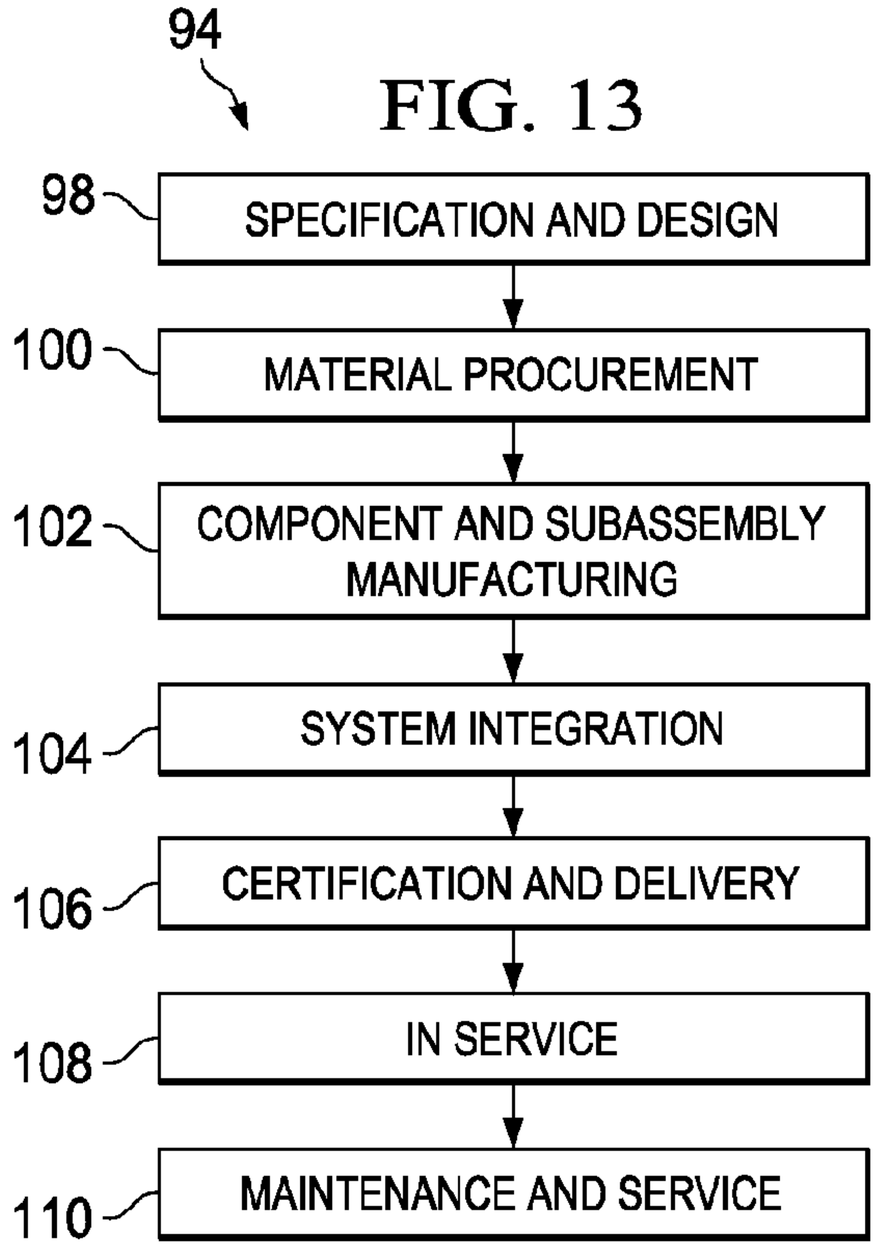
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FIG. 13

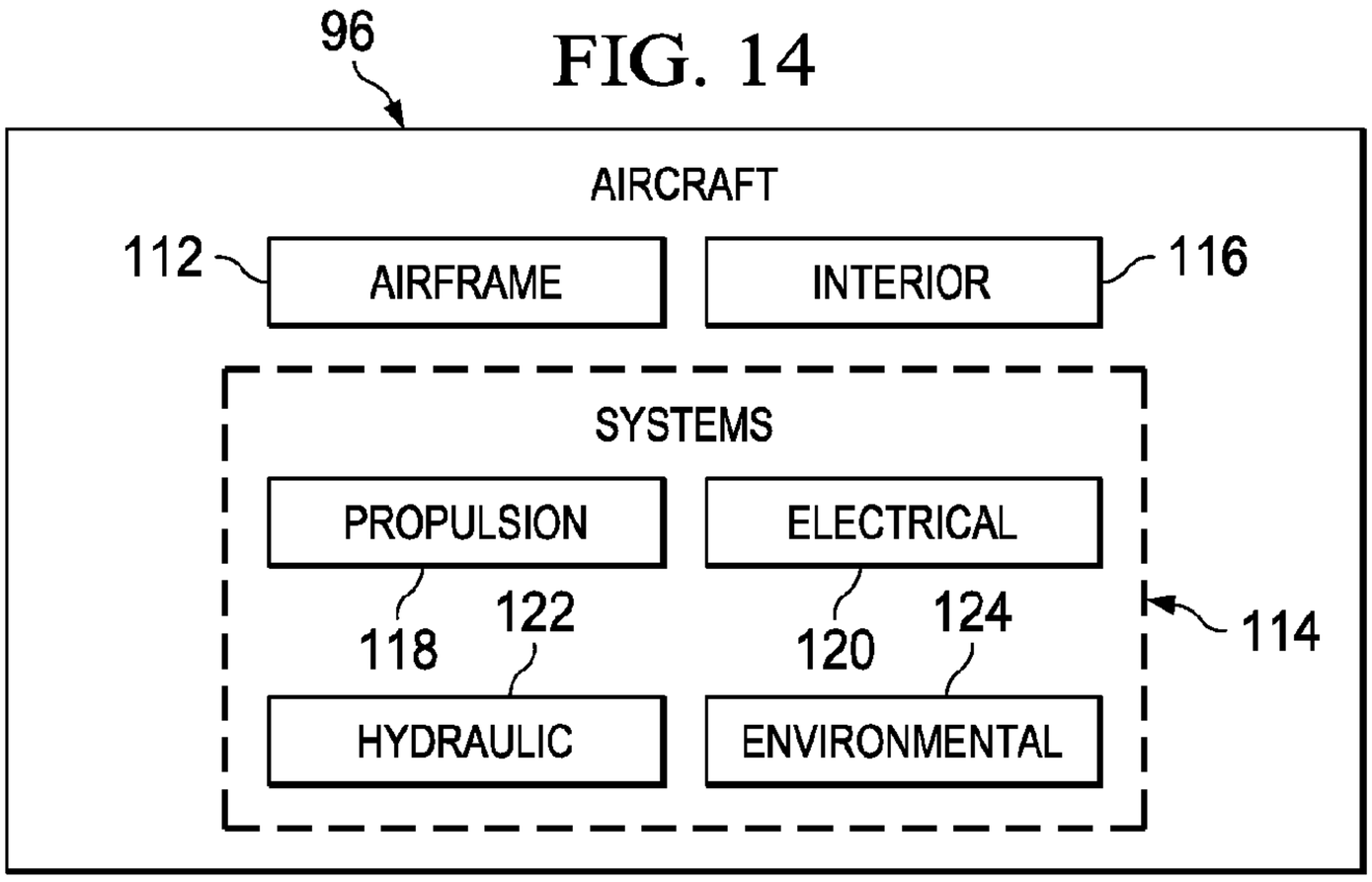
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FIG. 14

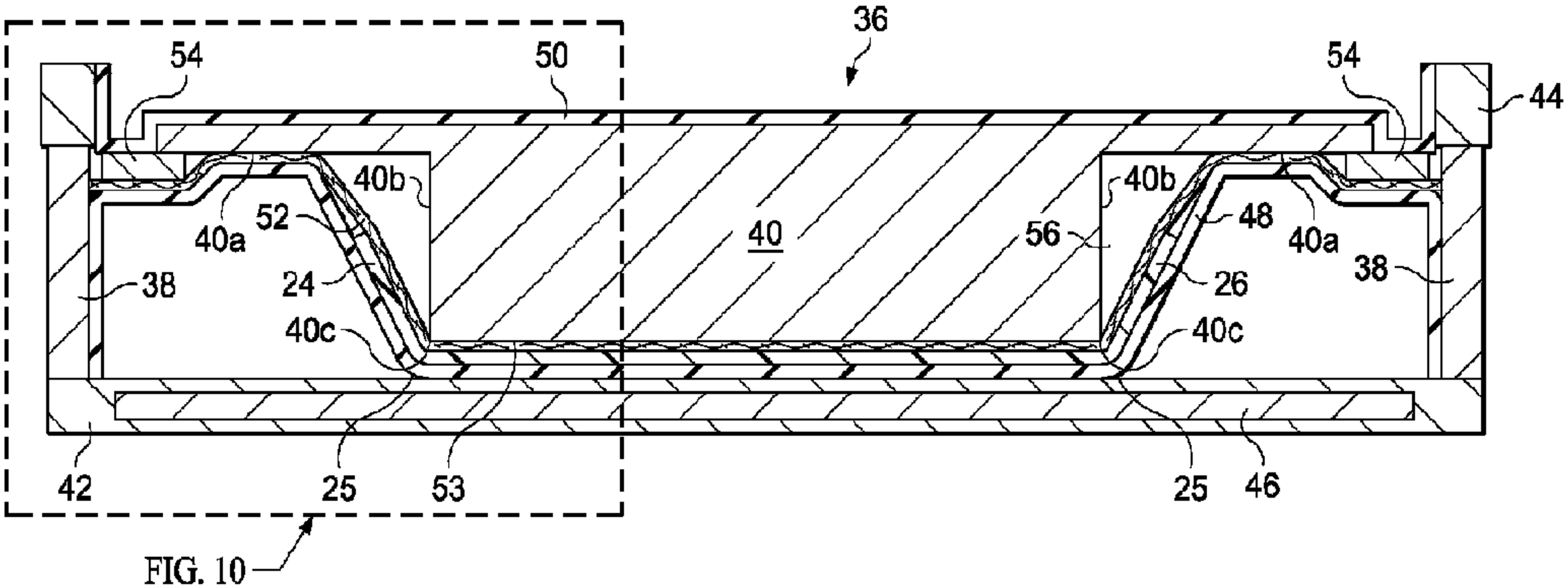
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FIG. 10