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**Bhandari et al.**

(54) **SOLAR REFLECTING MIRROR HAVING A PROTECTIVE COATING AND METHOD OF MAKING SAME**

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**ONE PPG PLACE**
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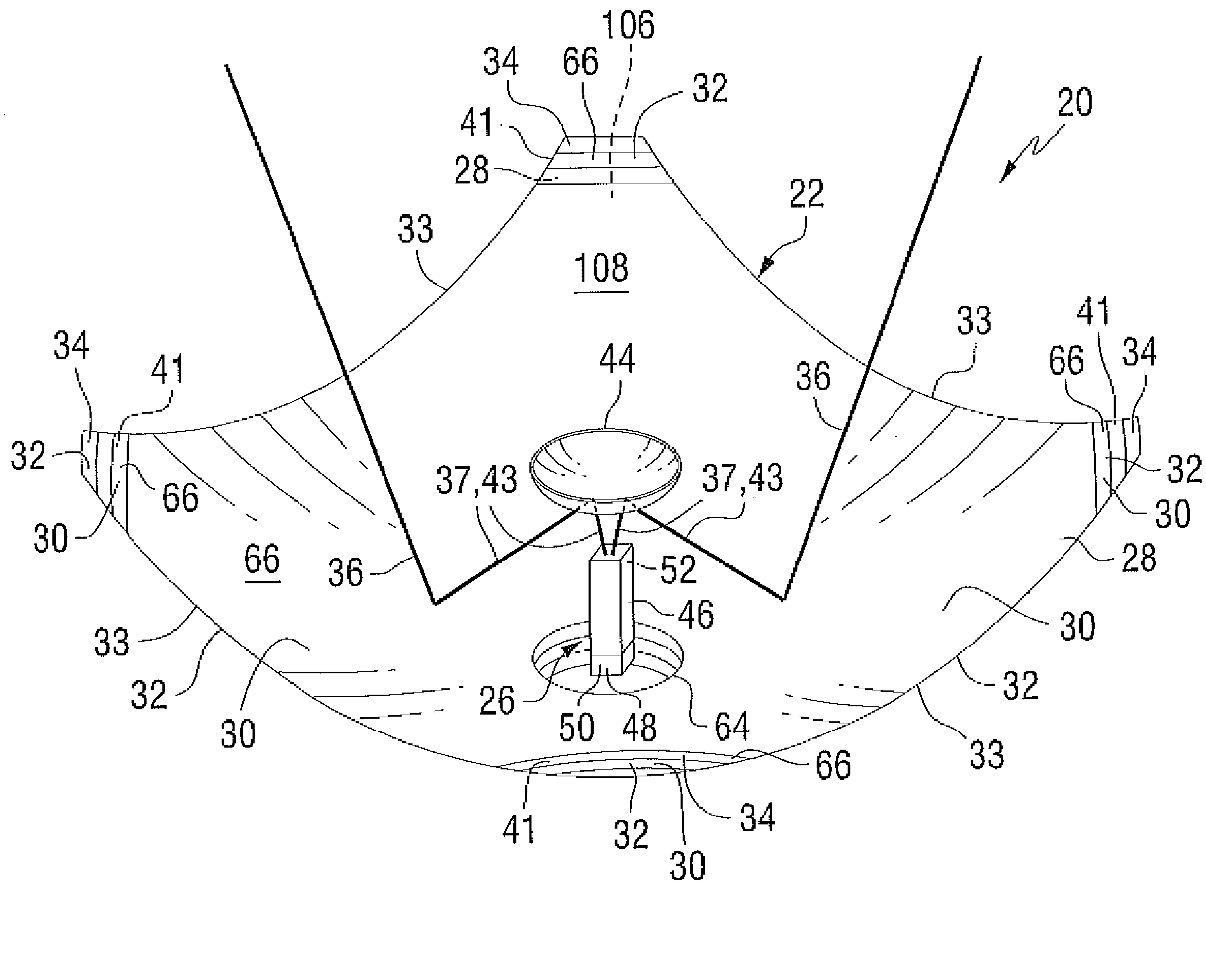
(52) **U.S. Cl.** .......................................... **126/684**; 29/592

(57) **ABSTRACT**

A solar reflecting mirror includes a shaped glass substrate having a focal area, a reflective coating over its convex surface and a sodium ion barrier layer over its concave surface. The shaped substrate has a strain pattern having a radial tension strain at the bottom area, and circumferential compression strain at the periphery of the substrate. As the distance from the periphery of the shaped substrate increases, the circumferential compression strain decreases to a "transition line" where circumferential tension strain begins. As the distance from the transition line in a direction toward the bottom area of the glass substrate increases, the circumferential tension increases. To compensate for the strain pattern in the shaped glass substrate to avoid buckling of, and surface cracks of, the barrier layer, the barrier layer including an oxide of silicon and aluminum thickness, among other things is varied on. A method of making the solar mirror from shaped sections is also discussed.



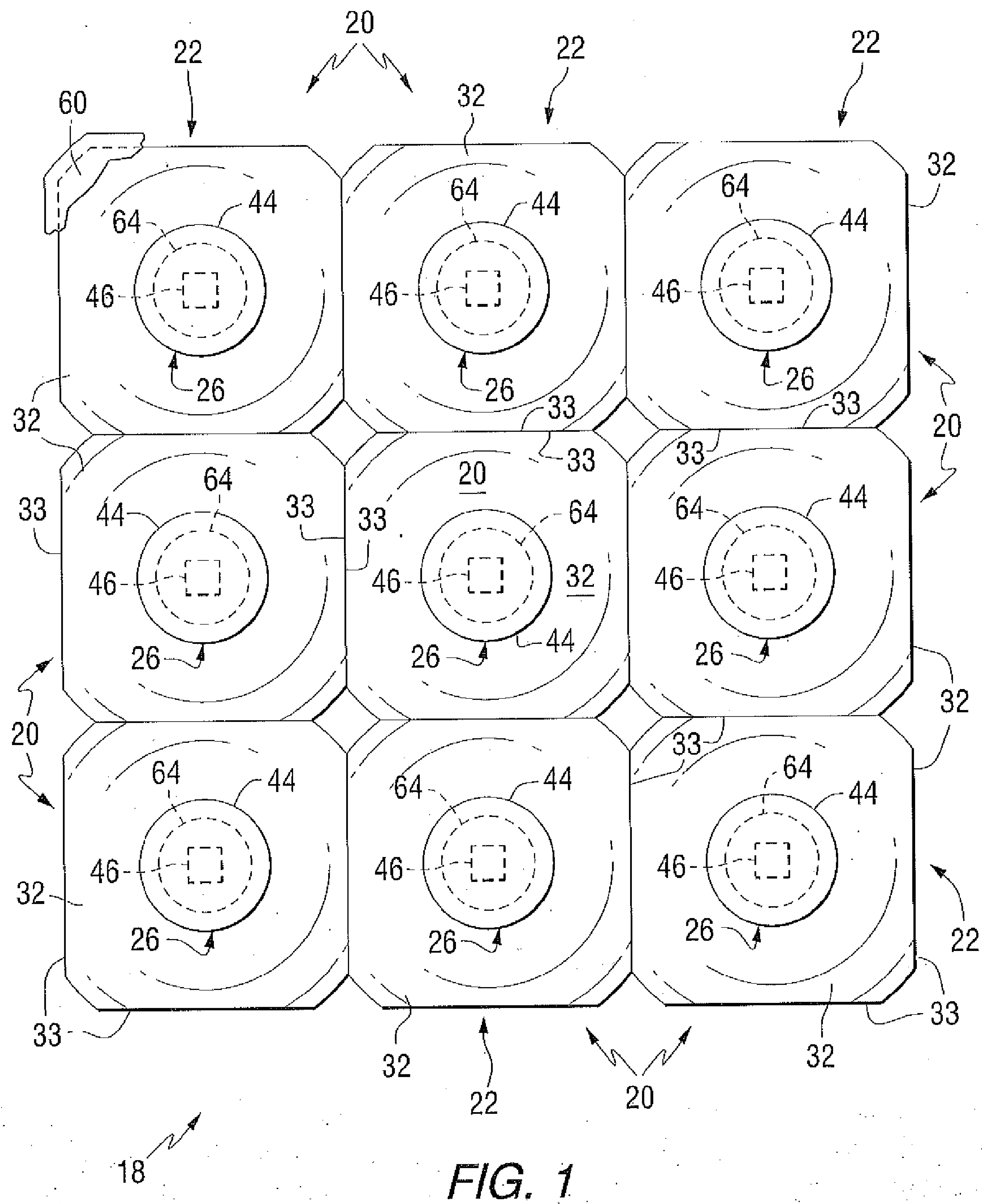



FIG. 1
PRIOR ART

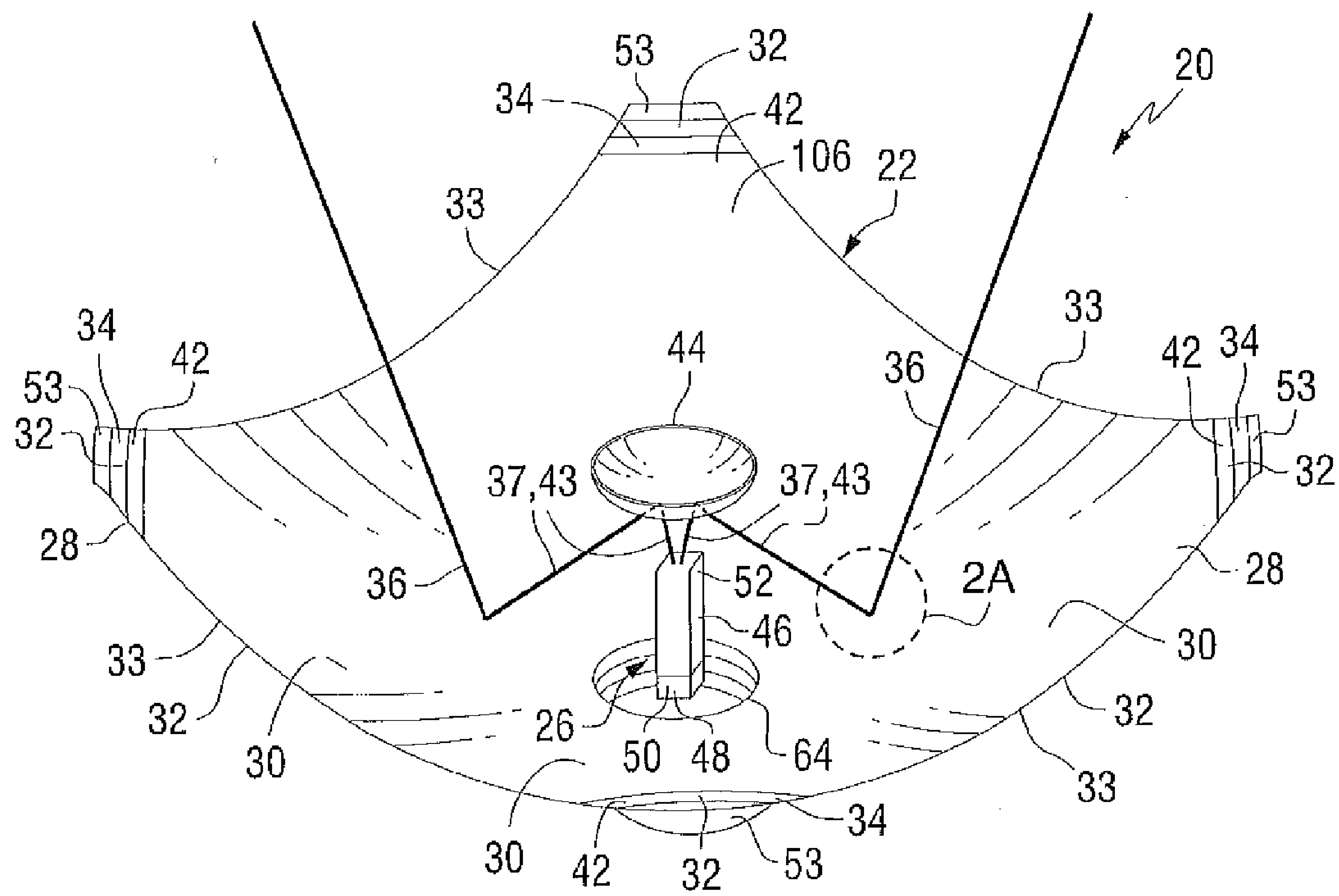



FIG. 2
PRIOR ART

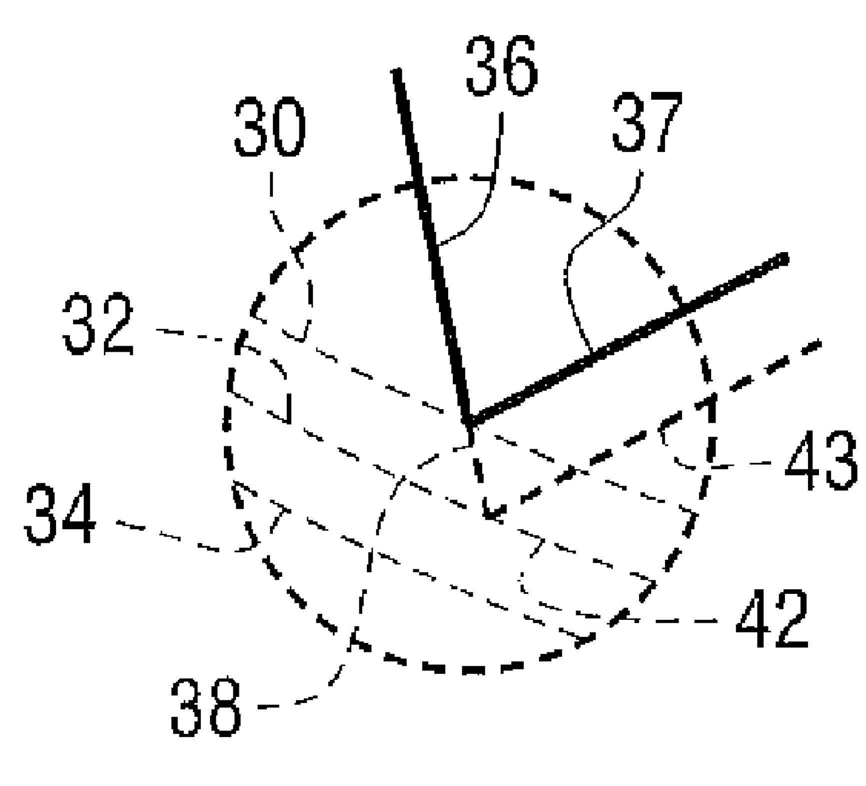



FIG. 2A

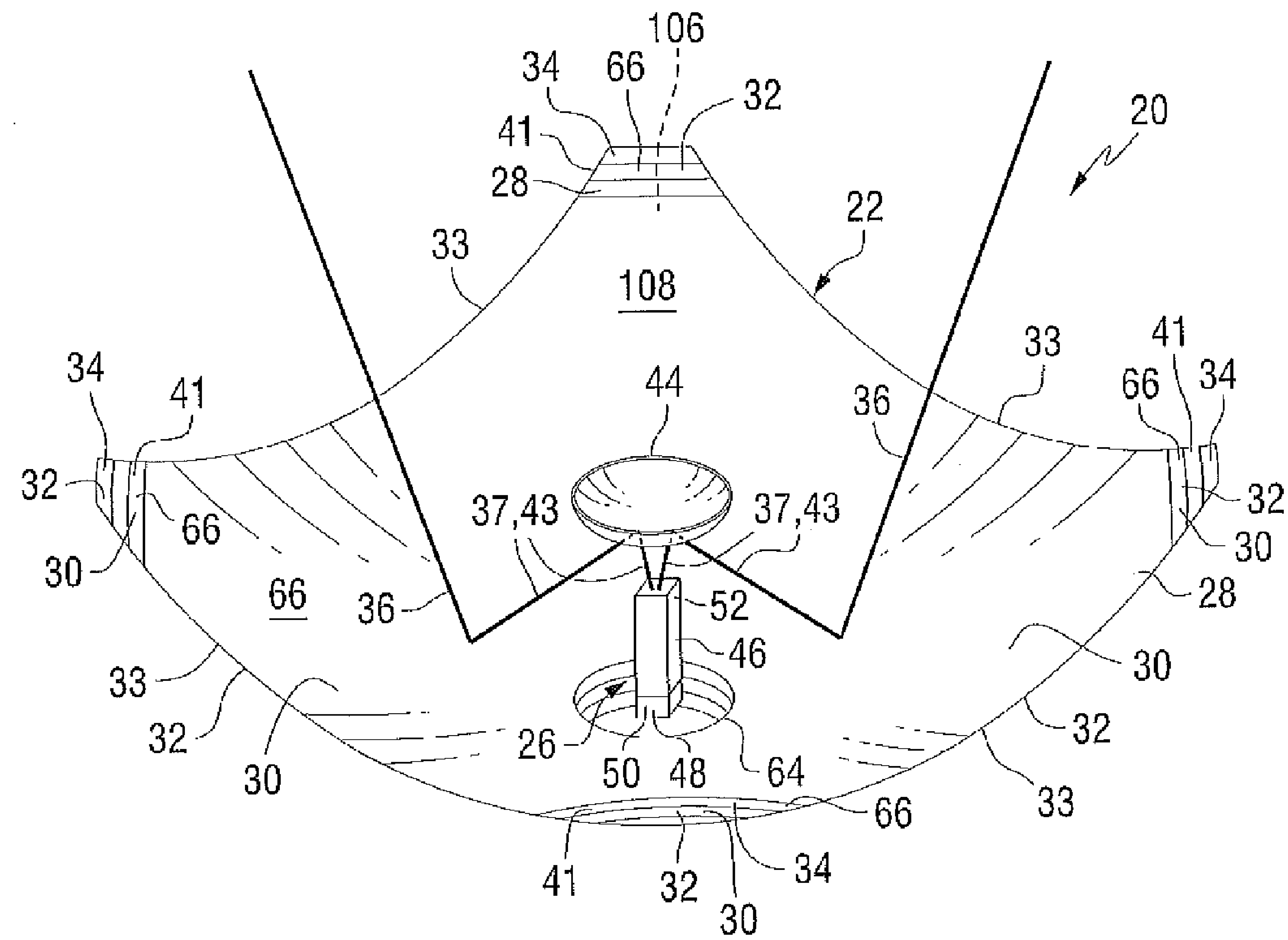

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FIG. 3

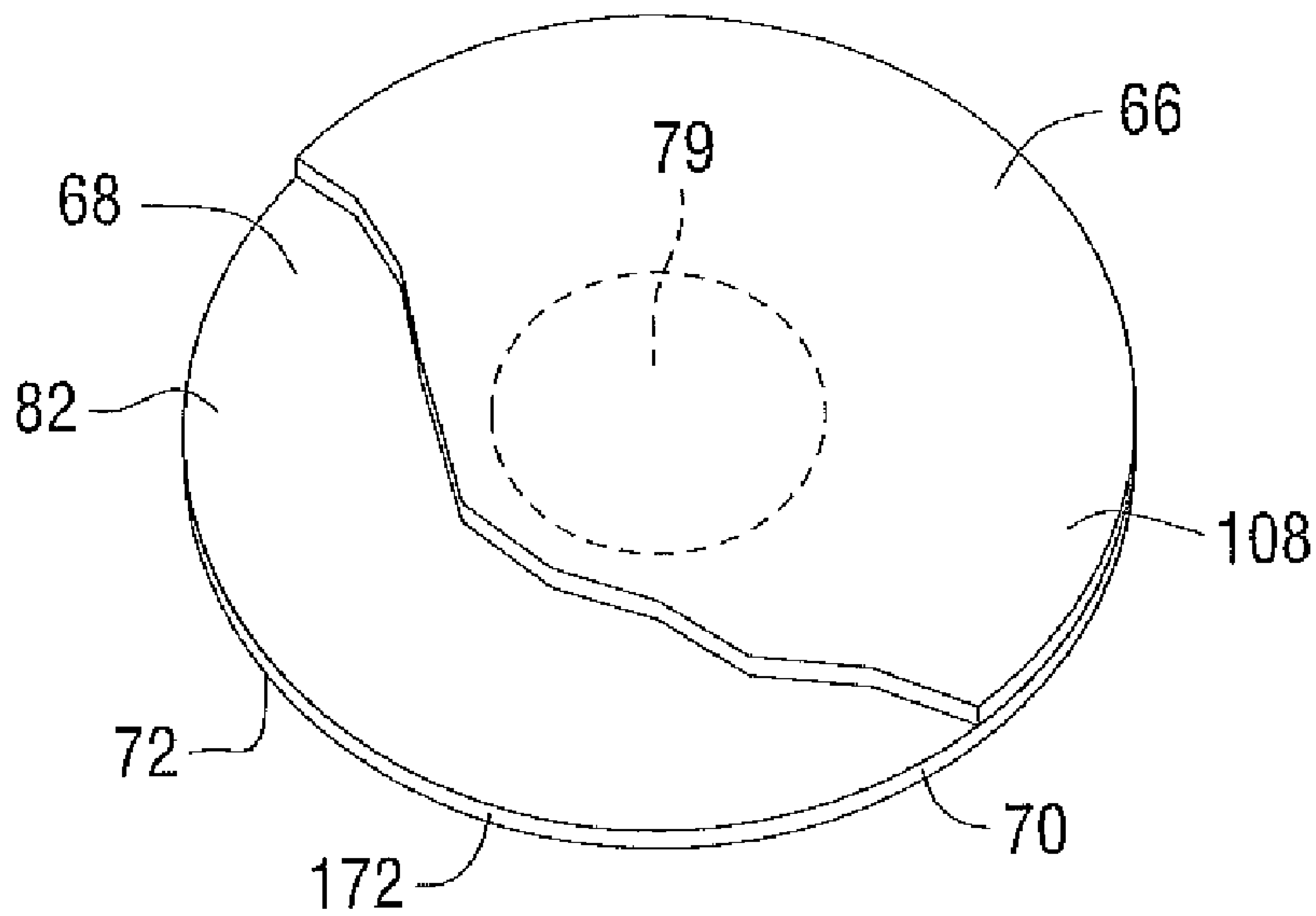


FIG. 4

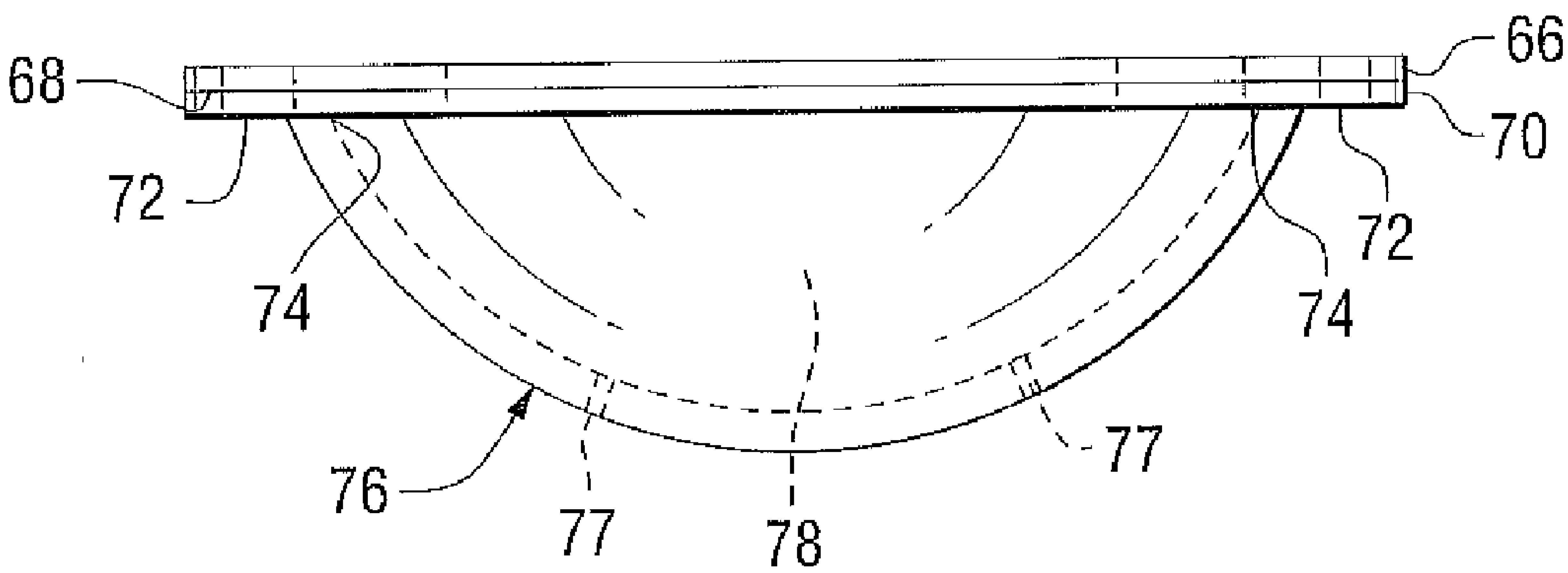


FIG. 5A

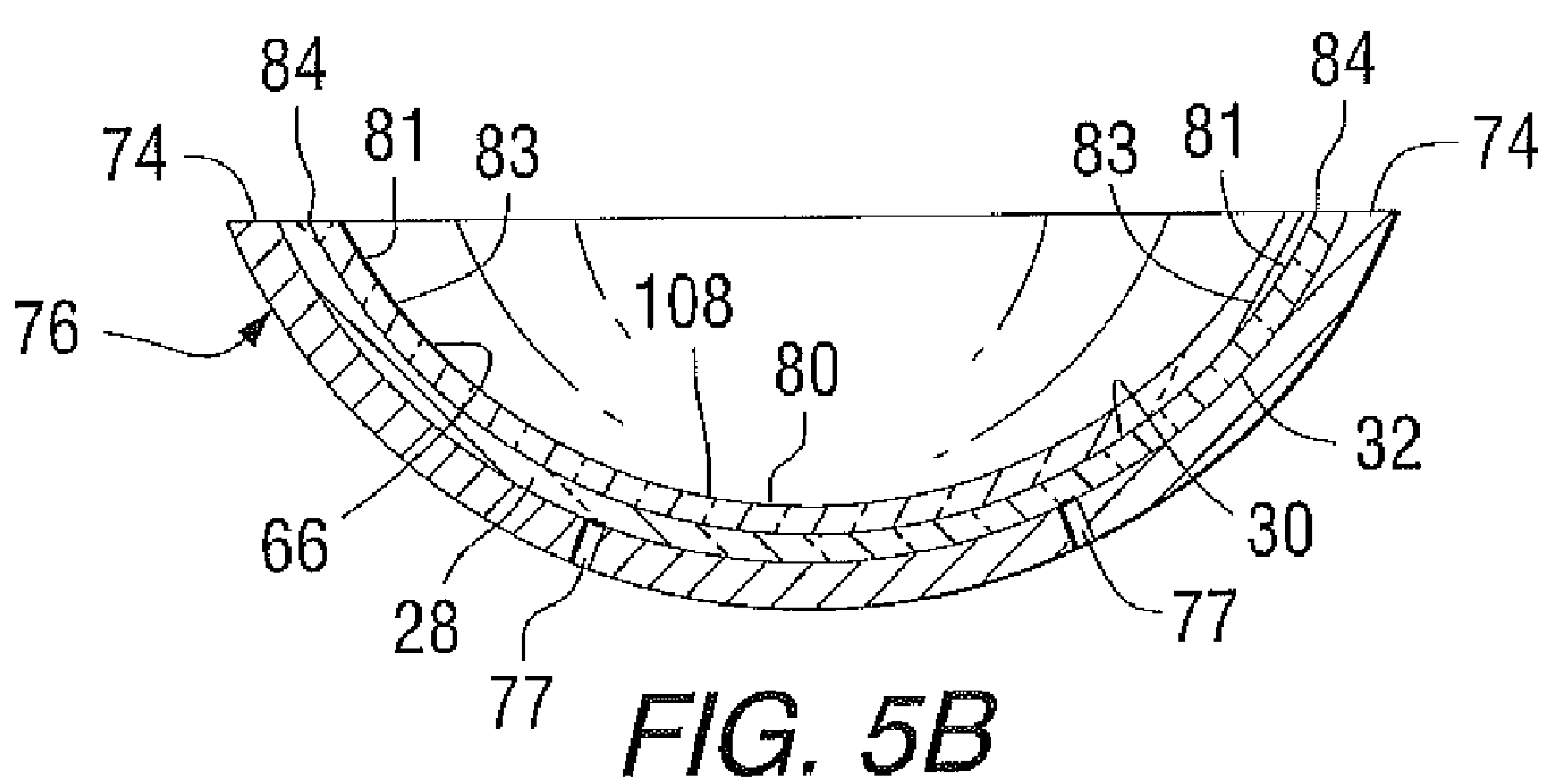


FIG. 5B

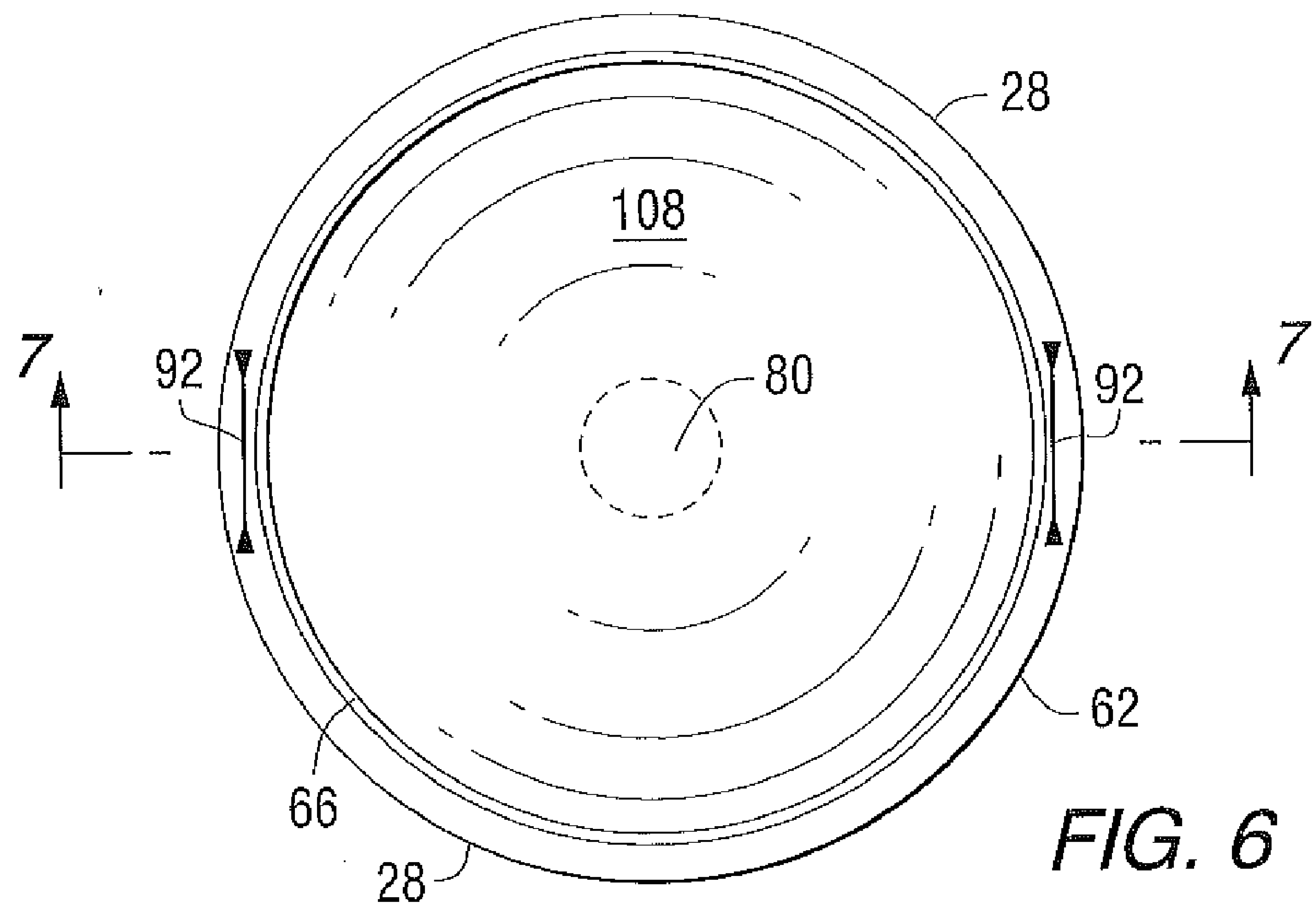


FIG. 6

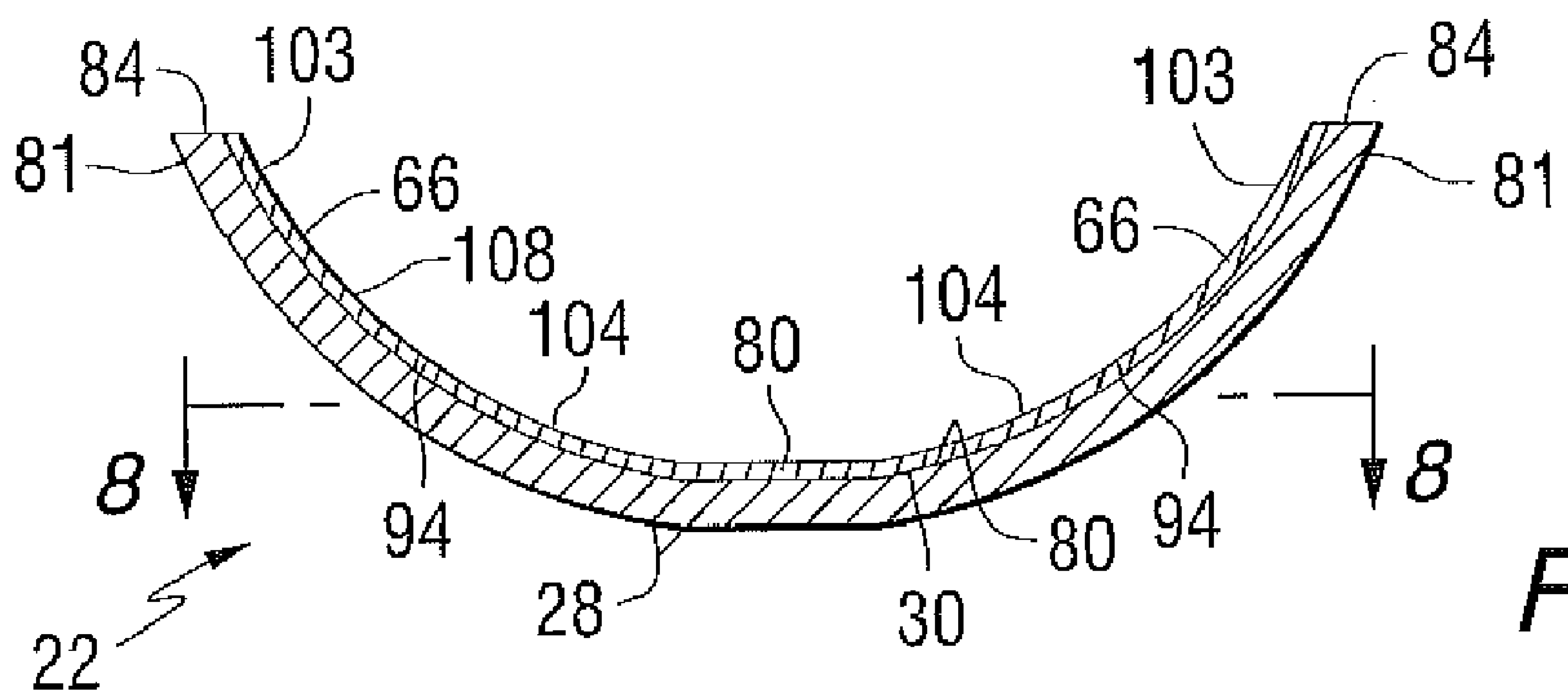


FIG. 7

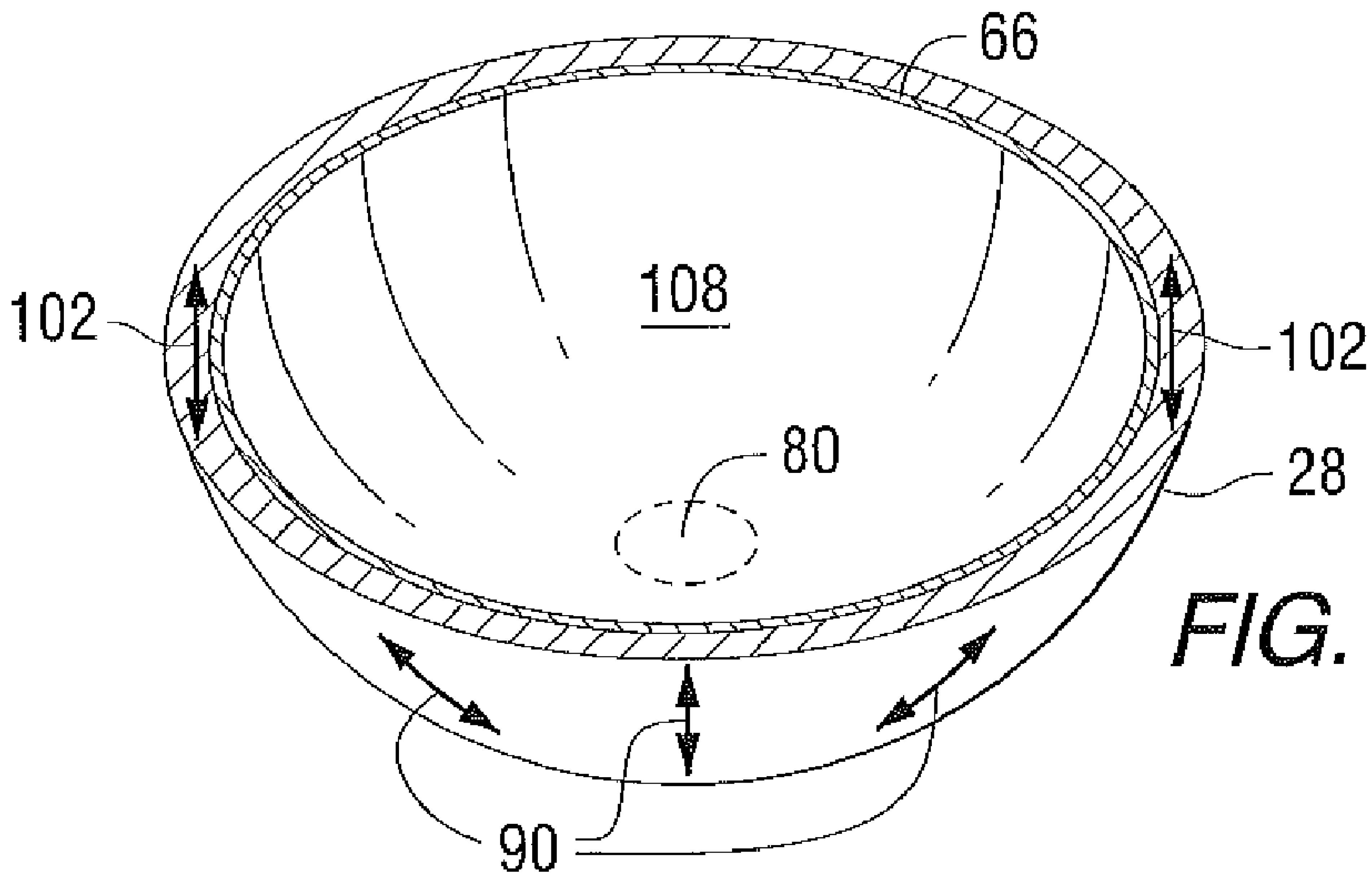


FIG. 8

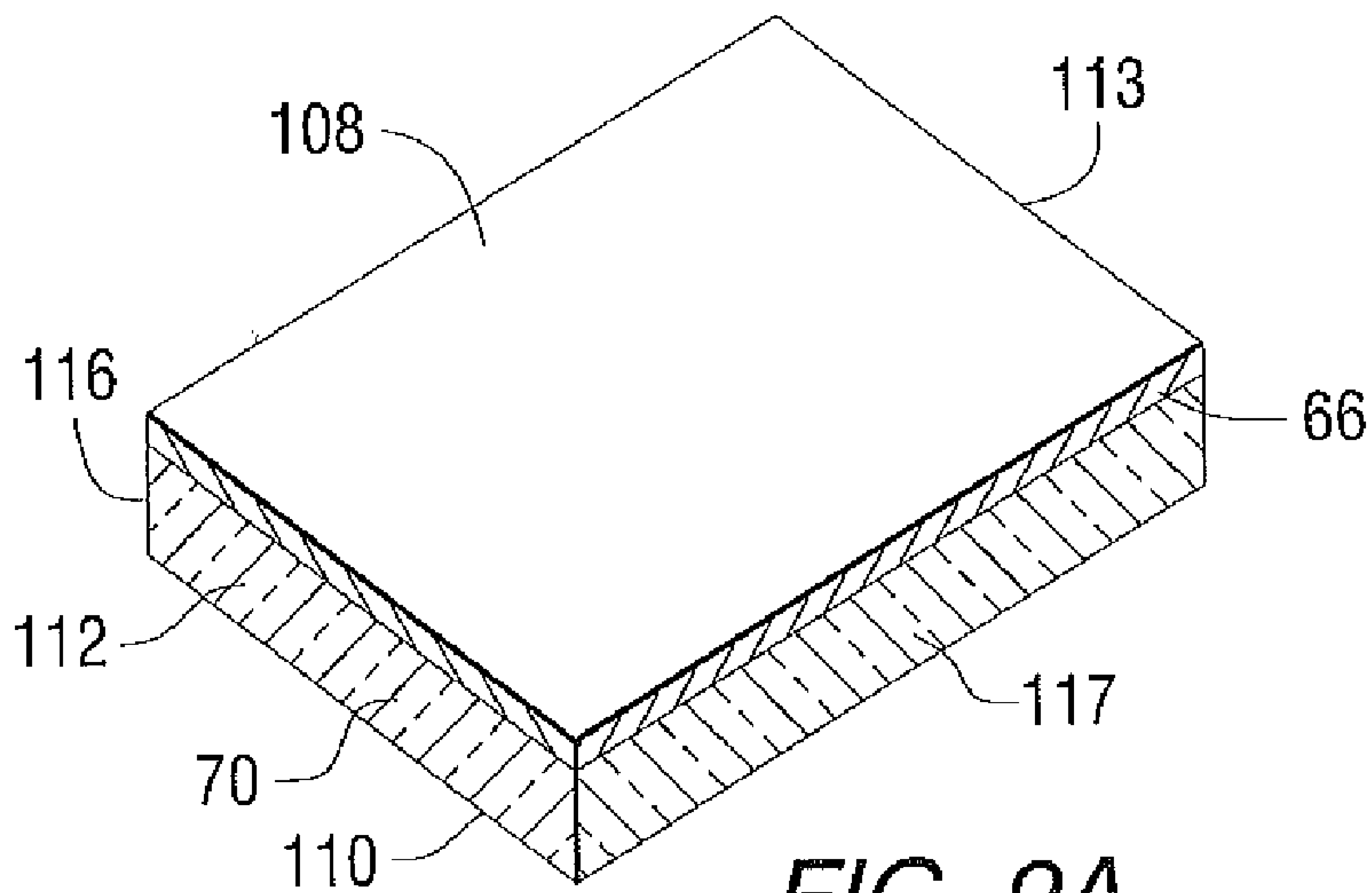


FIG. 9A

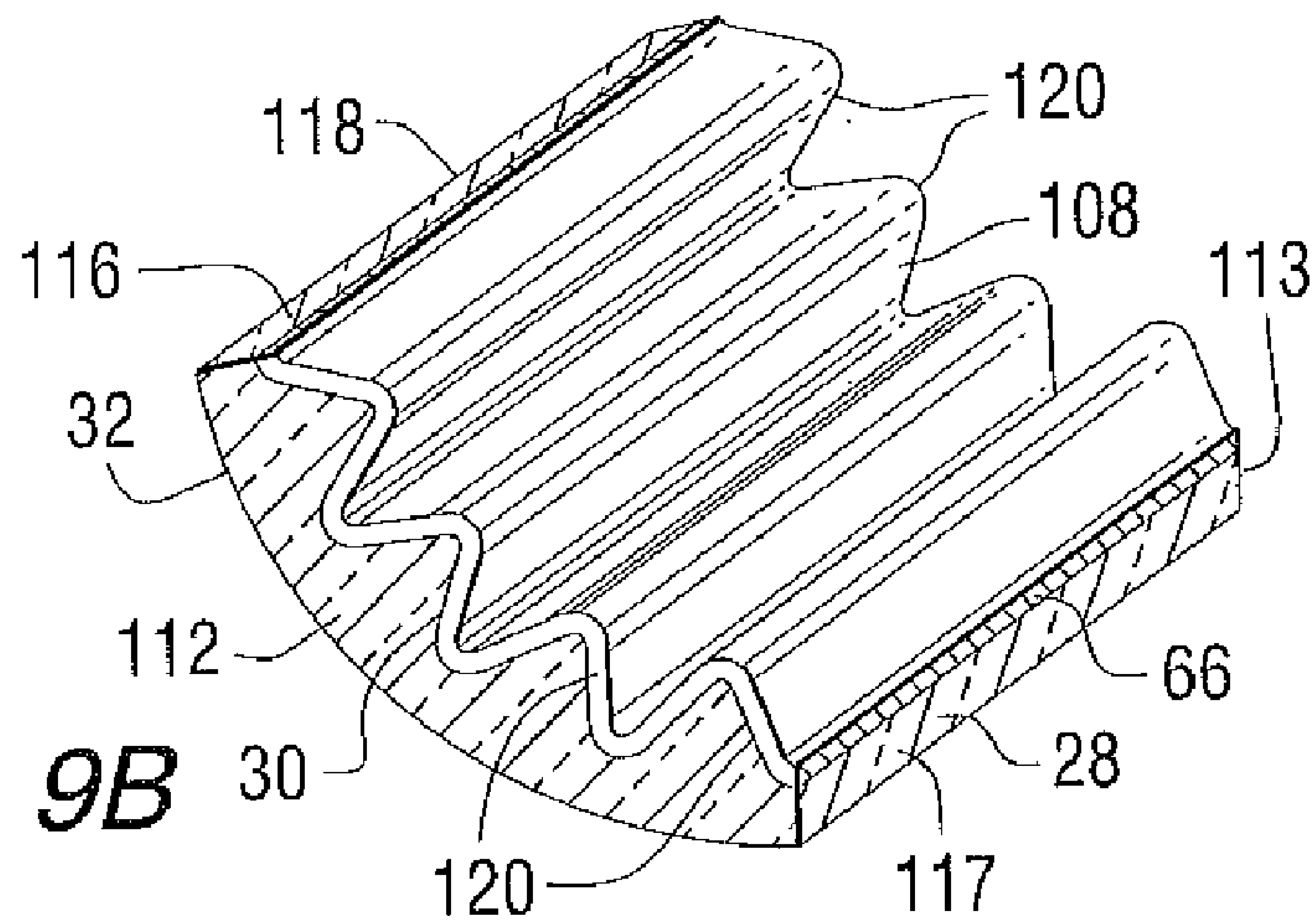


FIG. 9B

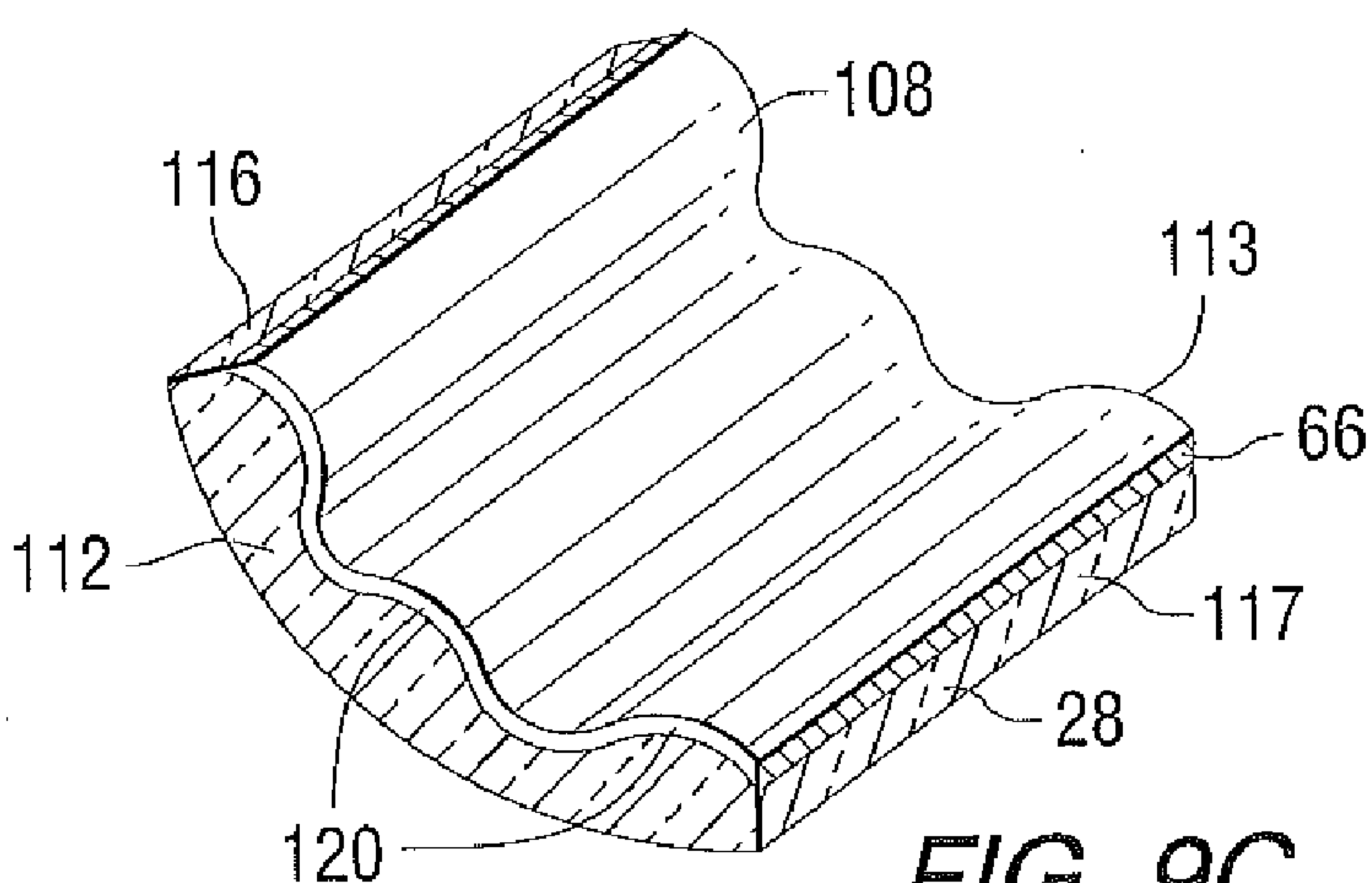


FIG. 9C

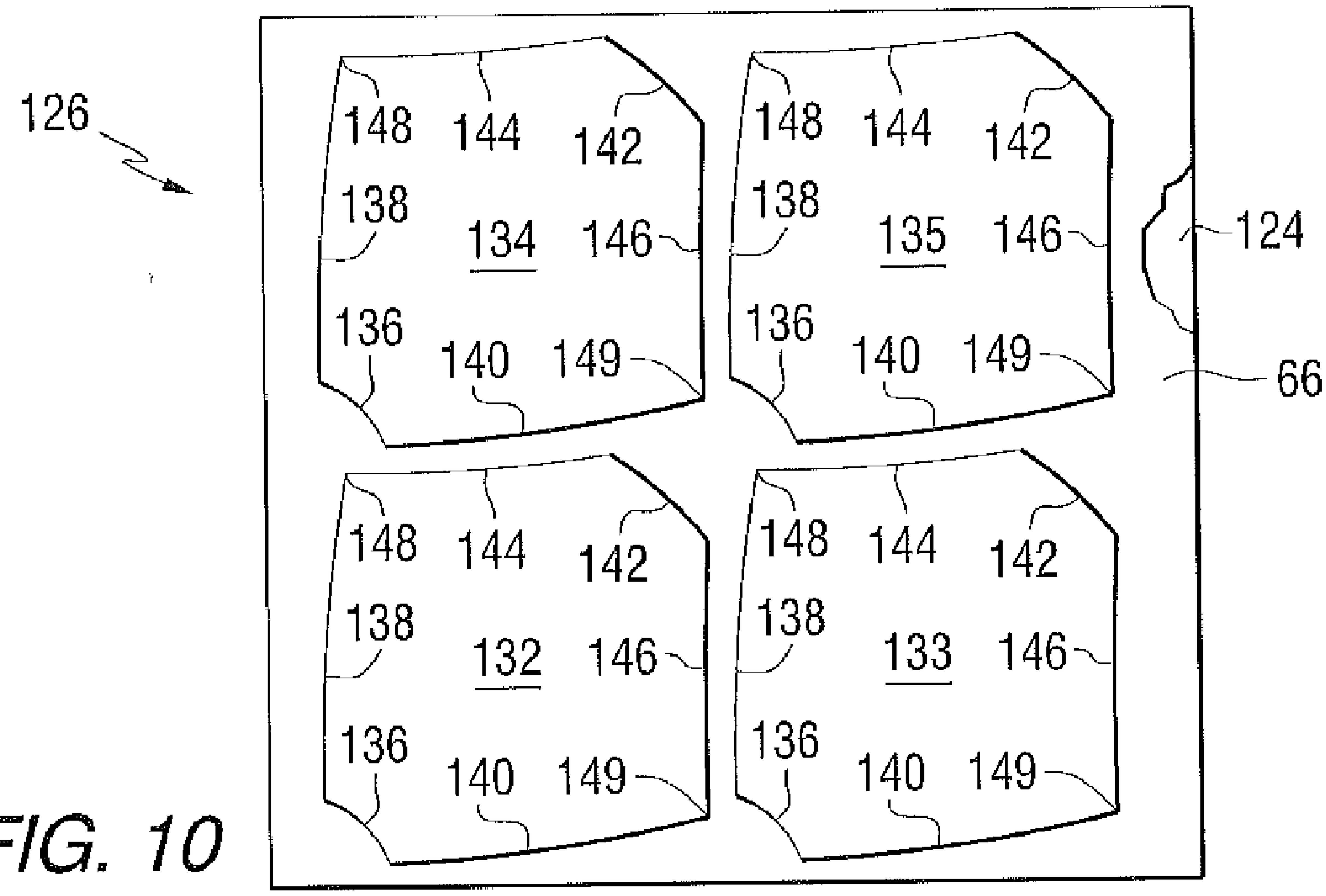
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FIG. 10

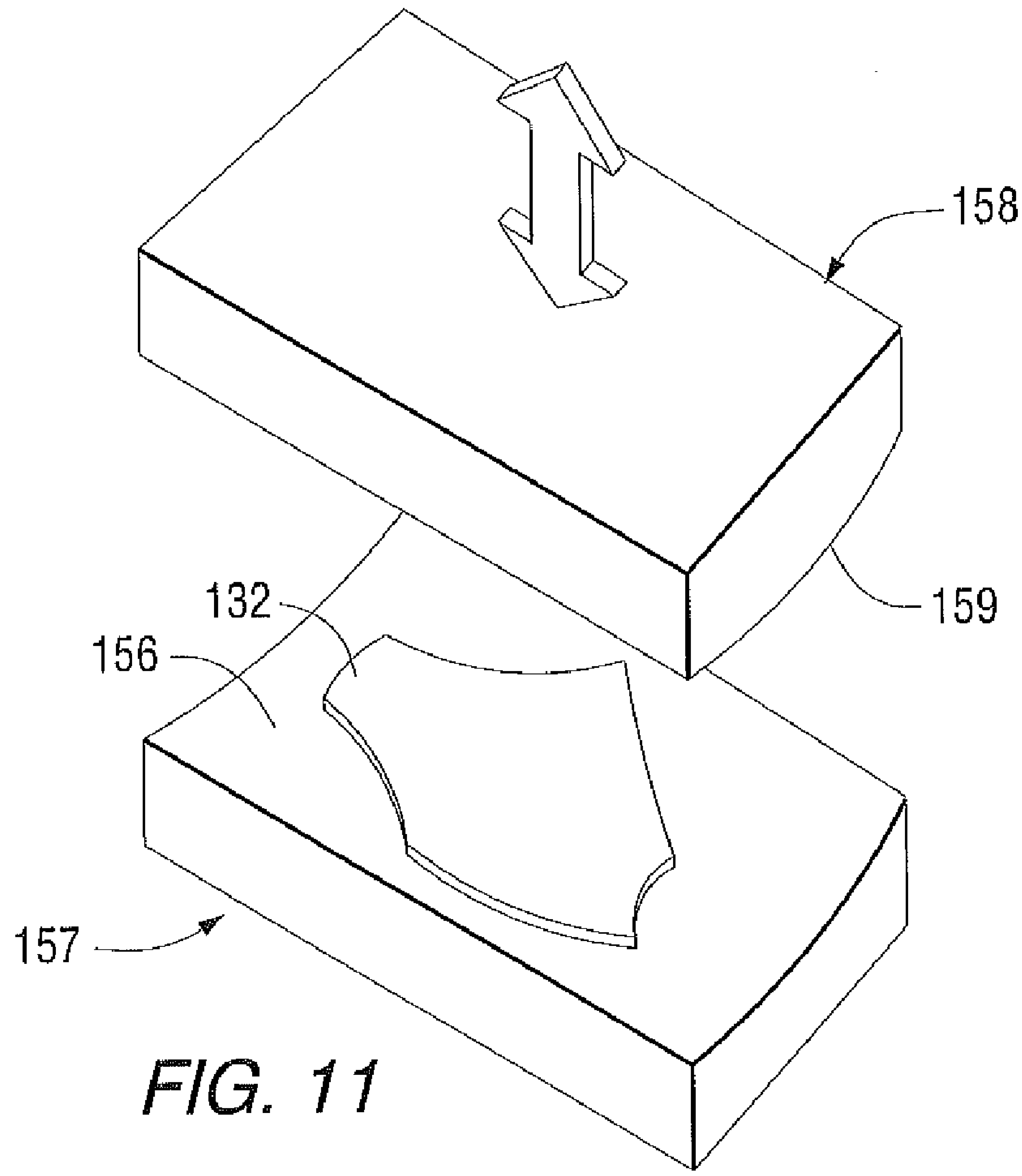
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FIG. 11

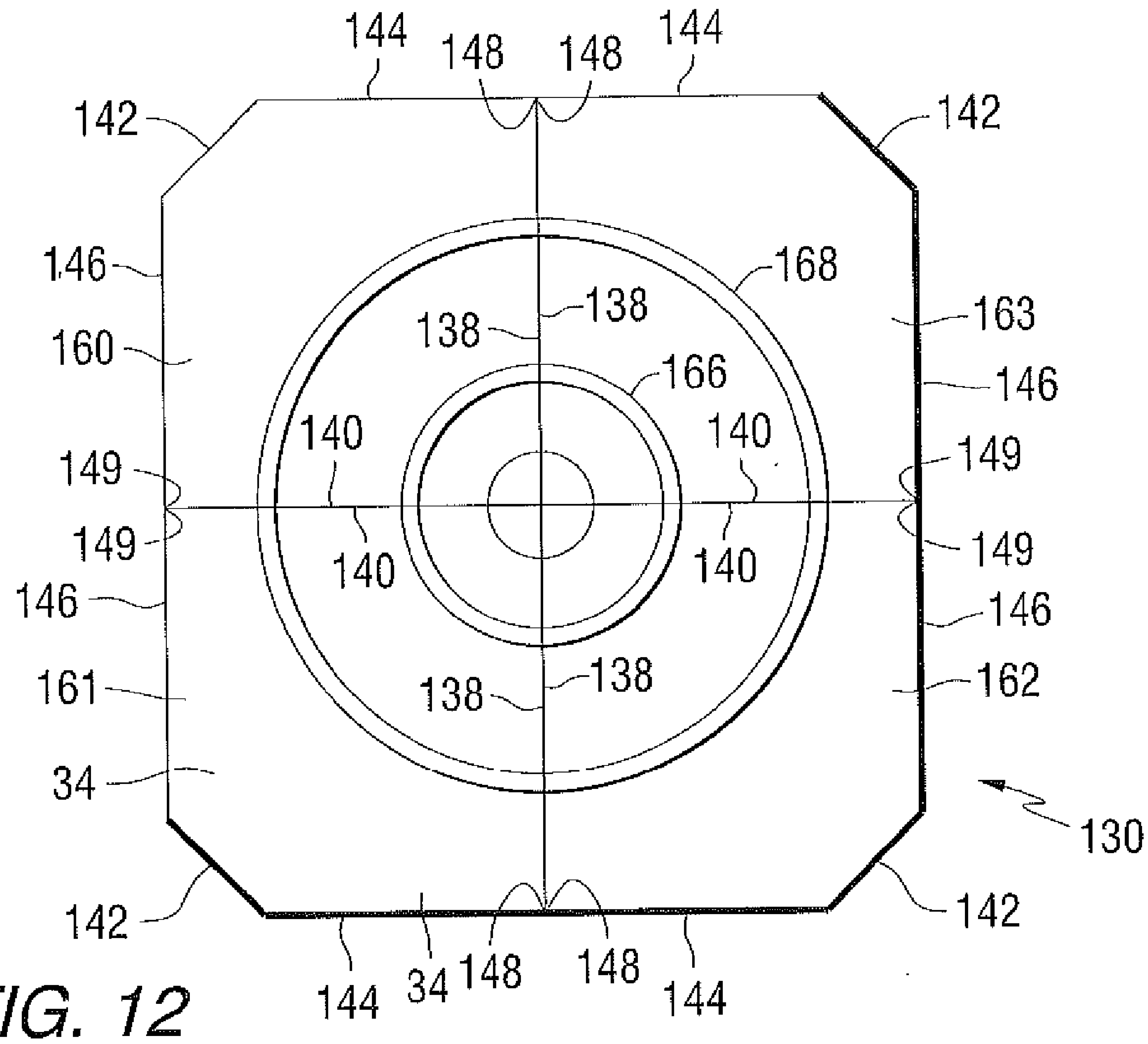
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FIG. 12

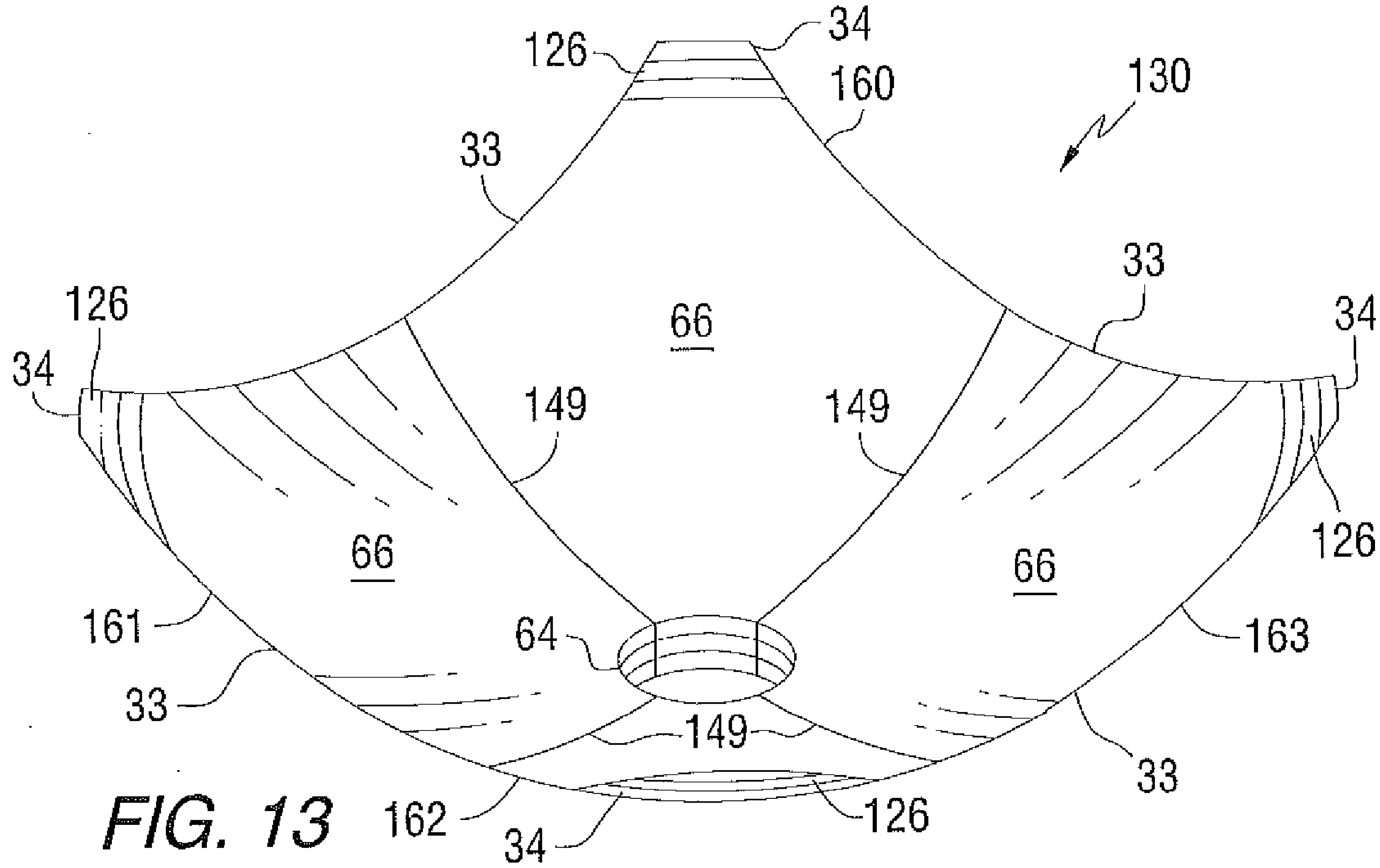
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FIG. 13

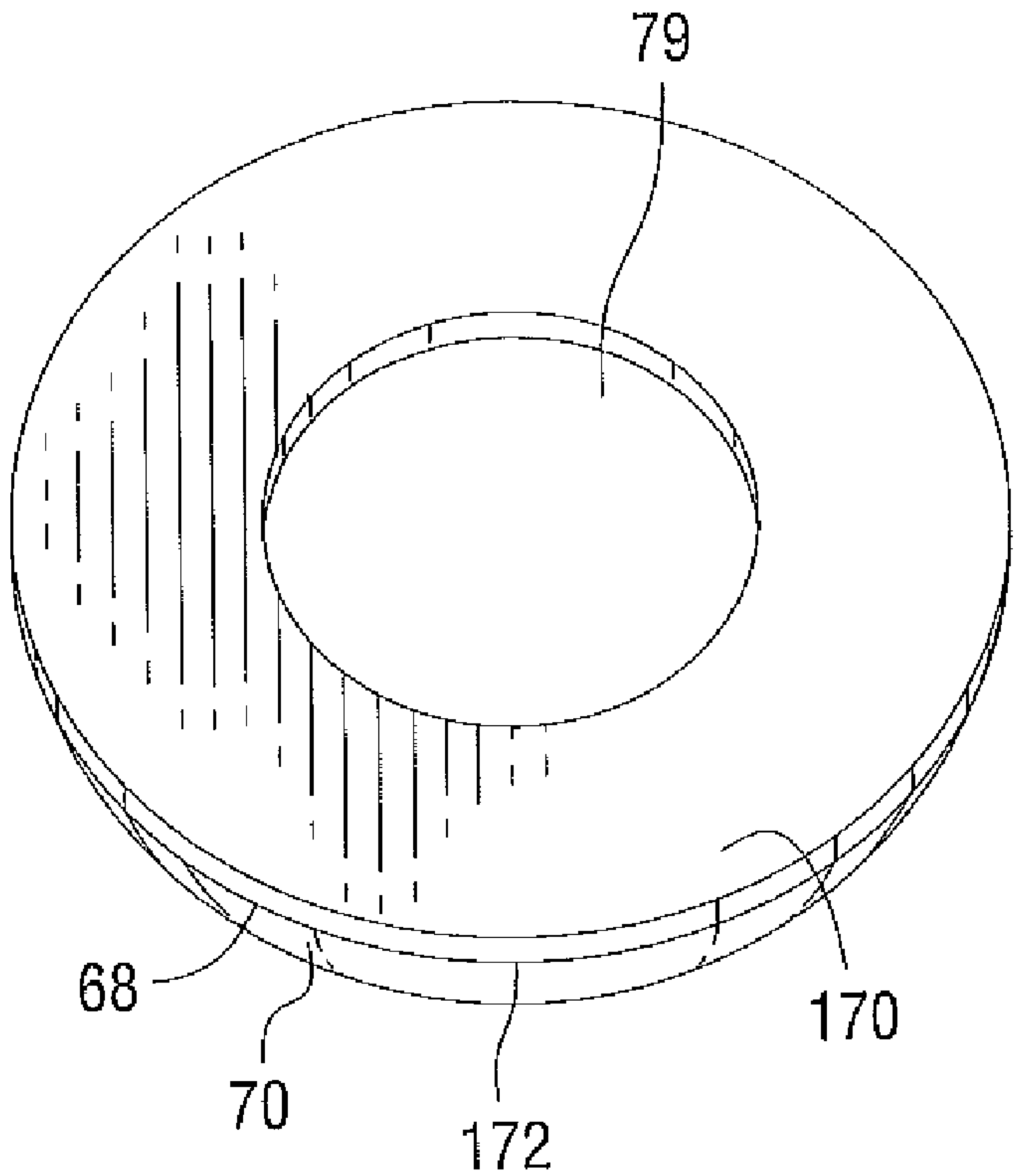


*FIG. 14*

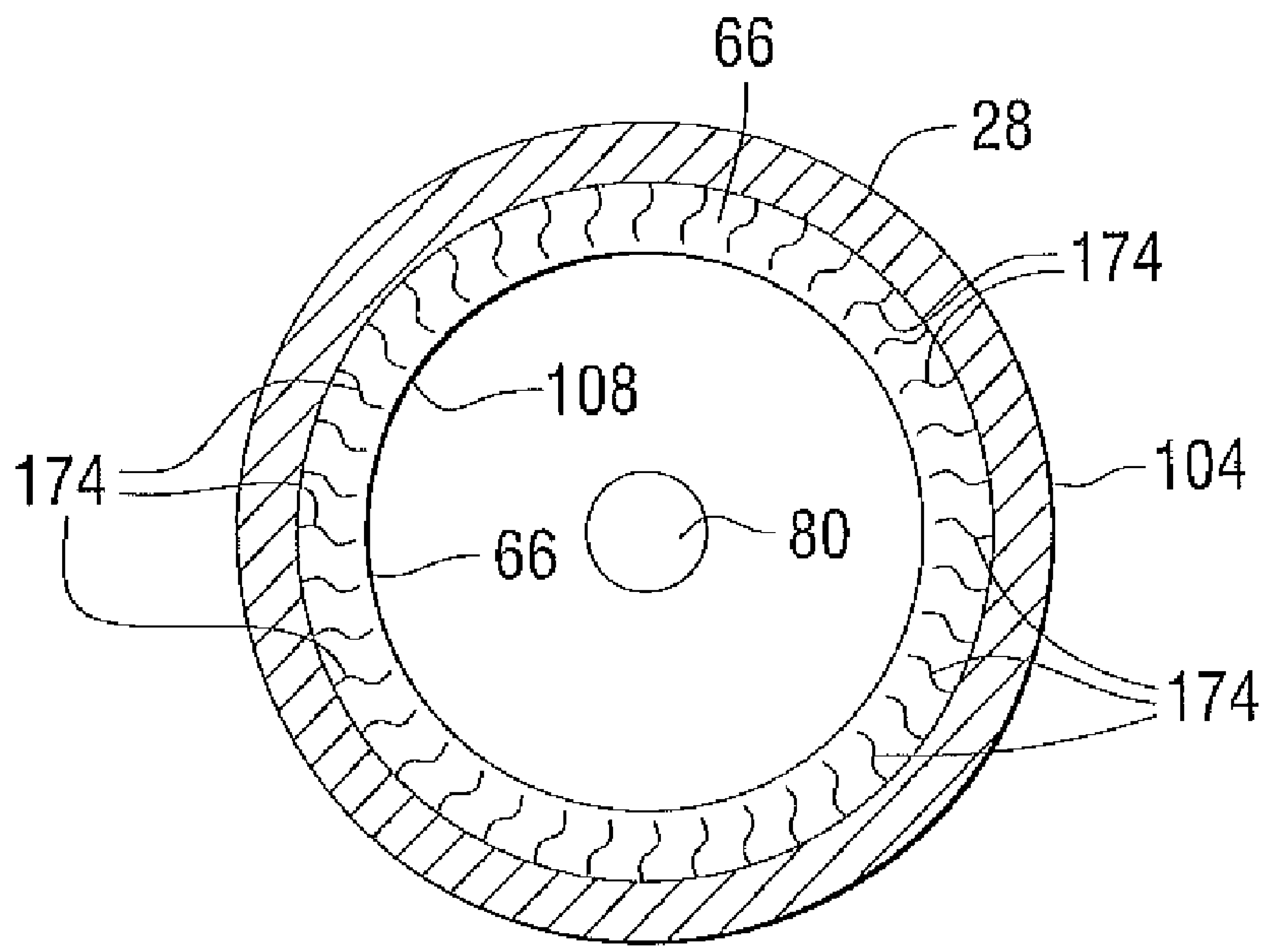


*FIG. 15*

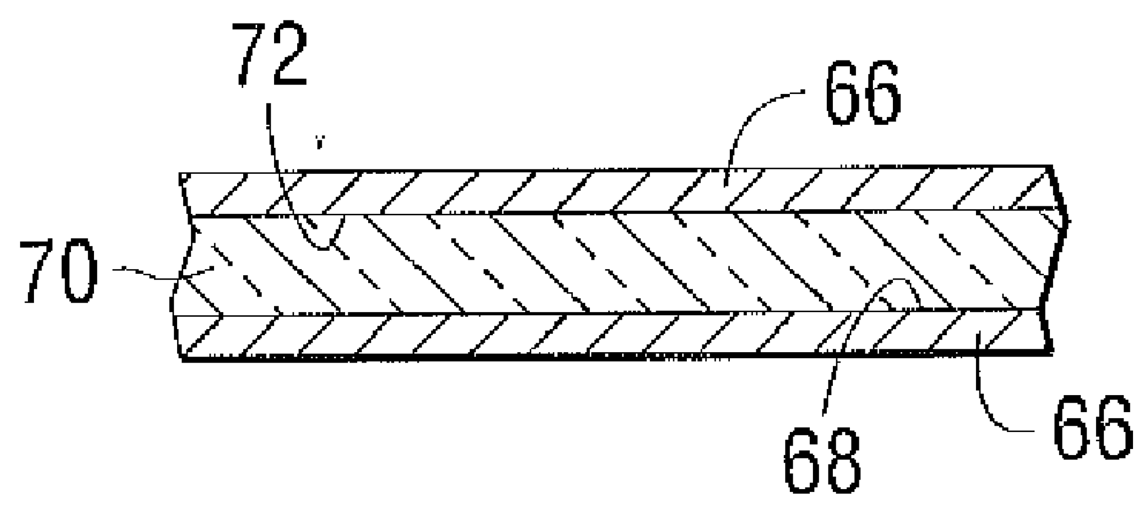


FIG. 16

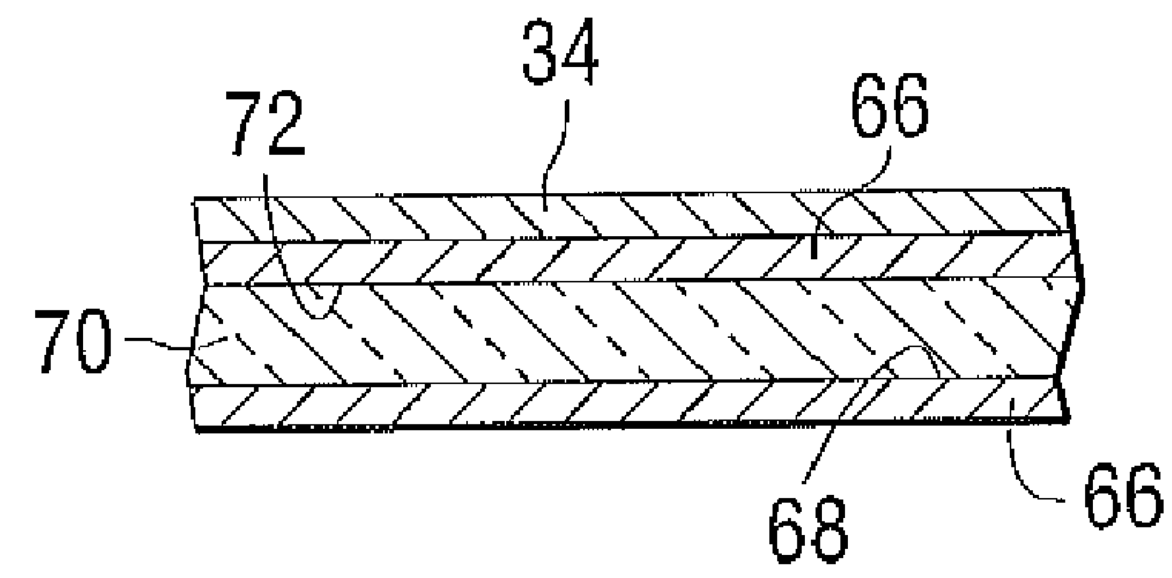


FIG. 17

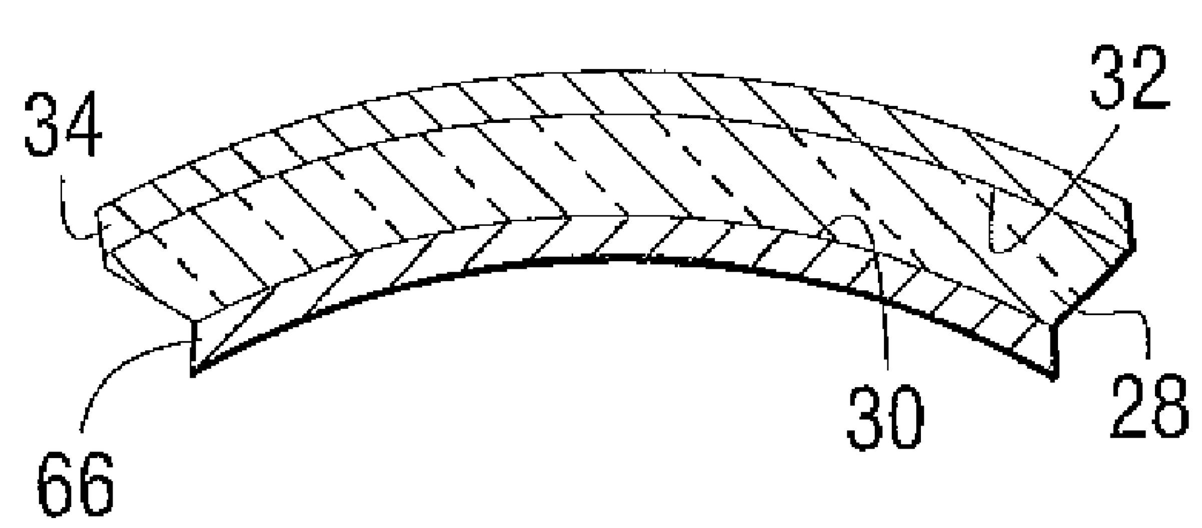


FIG. 18

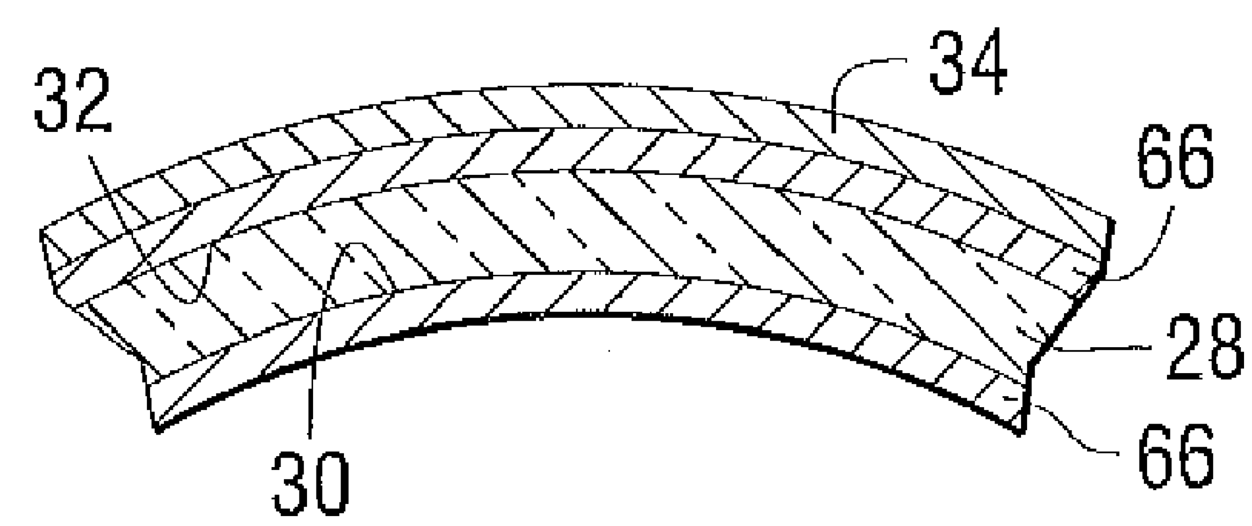


FIG. 19

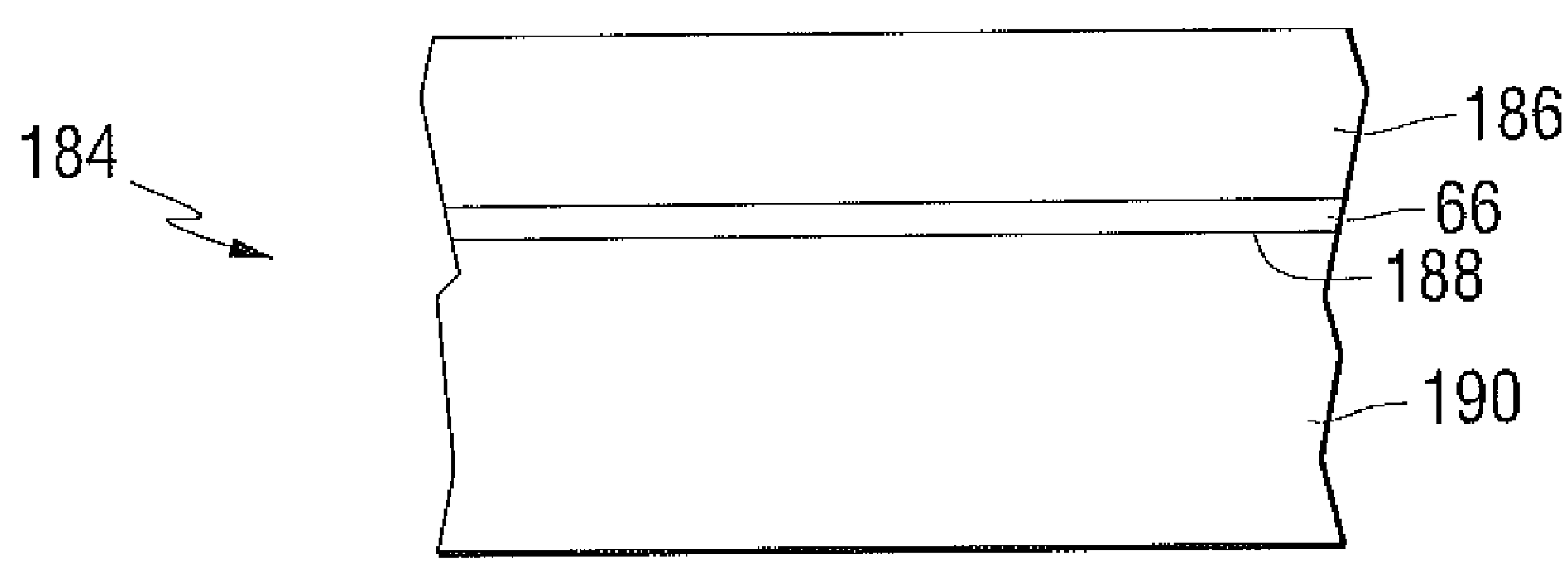


FIG. 20

# SOLAR REFLECTING MIRROR HAVING A PROTECTIVE COATING AND METHOD OF MAKING SAME

## CROSS REFERENCE TO RELATED APPLICATION

**[0001]** This application claims the benefits of U.S. Provisional Patent Application Ser. No. 61/164,047 filed Mar. 27, 2009 and titled "ALKALI BARRIER LAYER." Application Ser. No. 61/164,047 in its entirety is incorporated herein by reference.

**[0002]** This application is related to U.S. patent application Ser. No. ______ filed even date in the name of James P. Thiel and titled A SOLAR REFLECTING MIRROR AND METHOD OF MAKING SAME. Application Ser. No. ______ in its entirety is incorporated herein by reference.

## BACKGROUND OF THE INVENTION

**[0003]** 1. Field of the Invention

**[0004]** This invention relates to a solar reflecting mirror, e.g. a parabolic shaped solar reflecting glass mirror having a protective coating, e.g. an alkali barrier layer and method of making same, and more particularly, to an alkali barrier layer on the concave surface of the mirror to prevent alkali ions, e.g. sodium ions from precipitating on the concave surface of the mirror. The preferred alkali barrier layer of the invention has scratch resistant and chemical resistant properties to prevent abrasive damage to the concave surface of the mirror.

**[0005]** 2. Description of the Available Technology

**[0006]** At the present time, there is interest to increase the efficiency of solar collectors, e.g. and not limiting to the discussion, improve the efficiency of solar mirrors, e.g. parabolic shaped mirrors, used to reflect the sun's rays to a device located at the focal point of the parabolic mirror. The device is usually of the type known in the art to convert the sun's energy to another form of useable energy, e.g. electric energy. In another embodiment of the prior art, the parabolic mirror is a primary mirror reflecting the sun's rays to a secondary mirror positioned relative to the focal point of the primary mirror to reflect the sun's rays to the converting device.

**[0007]** In general, the parabolic shaped mirror includes a parabolic shaped substrate having a reflective surface, e.g. a silver coating on the convex surface of the shaped substrate. The preferred material of the shaped substrate is soda-lime-silica glass because of the high yield in shaping a flat glass sheet to a parabolic sheet or substrate; the low cost of making flat glass sheets, and the high yield and low cost of applying a solar reflective coating on a surface of the shaped glass substrate.

**[0008]** Although soda-lime-silica glass is an acceptable material for the substrate for solar reflecting mirrors, there are limitations to the use of glass. More particularly, in the shaping process, a flat glass sheet is heated to temperatures above 1200° Fahrenheit (hereinafter also referred to as "F") and shaped into the parabolic shape. During the heating and shaping of the glass sheet, the alkali ions, e.g. the sodium ions in the glass sheet diffuse, or leech, out of the glass sheet. Further, during exposure of the parabolic shaped glass substrate to solar energy, e.g. long-term environmental exposure, additional sodium ions leech out of the glass substrate. As is appreciated by those skilled in the art, the leeching or diffusion of the sodium ions from the glass is an expected occurrence, and at low temperatures is a slow process. However, heating the glass and/or the long term environmental exposure of the glass to solar energy accelerates the leeching or diffusion of sodium ions out of the glass, and increases the amount of sodium ions that leech out of the glass. The sodium ions leeching out of the glass react with moisture in the atmosphere, and convert from sodium ions to sodium compounds, e.g. sodium hydroxide and sodium carbonate. The sodium compounds can etch the surface of the glass and can deposit as a precipitate on the surface of the glass. The sodium compound precipitates decrease the transmission of visible light through the glass, e.g. in the case of the parabolic shaped glass substrate, decrease transmission of solar energy to the reflective coating on the convex surface of the shaped glass substrate, and decrease the transmission of the solar energy reflected from the reflective coating through the shaped glass substrate to the concave surface of the shaped glass substrate.

**[0009]** Further as is appreciated by those skilled in the art, the surface of the shaped glass substrates is a specular surface, and the solar energy is incident on the concave surface of the glass substrate as parallel light rays. The parallel light rays are reflected from the concave surface, and reflected from the reflective coating, as convergent light rays. The sodium compound precipitate on the concave glass surfaces converts the specular surface to a non-specular or diffusing surface directing the light rays reflected from, and passing through, the precipitate away from the focal point of the primary mirror. The term "specular surface" as used herein means a light reflective surface where a light ray incident on the reflective surface has an angle of incidence equal to the angle of reflection. The term "non-specular or diffusing surface" as used herein means a reflective surface where a light ray incident on the reflective surface has an angle of incidence different from the angle of reflection.

**[0010]** Another limitation of glass is that care has to be exercised to avoid scratching the glass surfaces. Scratches on the glass surfaces can also change a specular surface to a non-specular or diffusing surface. As is appreciated by those skilled in the art, as the reflective concave surface changes from a specular surface to a non-specular or diffusing surface, the percent of reflective solar light rays incident on the focal point of the parabolic shaped mirror are reduced, lowering the efficiency of the solar reflective mirror.

**[0011]** Present techniques to remove and/or to eliminate the sodium compound precipitate from the concave surface of a parabolic mirror include cleaning the surfaces and/or enclosing the concave surface of the mirror in a sealed chamber having an inert gas to prevent the sodium ions from forming the precipitate. Present techniques for removing scratches include buffing the surfaces of the glass sheet having the scratches. All of these techniques to ensure the surfaces of the solar mirror remain a specular surface are expensive.

**[0012]** Barrier layers are known in the art, e.g. disclosed in U.S. Pat. Nos. 4,238,276; 5,270,615; 5,830,252 and 6,027,766, and U.S. patent application Ser. No. 08/597543, and U.S. Publication 200710275253A1. One of the limitations of the presently available alkali barrier layers and/or scratch resistant layers is that they are efficient for use on flat or shaped surfaces of glass substrates, but are not efficient for use on a flat surface that is subsequently shaped to a curved surface, e.g. a concave surface of a parabolic mirror. There is little, if any, recognition or discussion in the prior art of the problems that have to be solved when a substrate coated with a barrier layer and/or a scratch resistant layer is shaped from a flat-coated substrate to a parabolic shaped coated substrate. More particularly, there is little, if any, discussion in the prior art of eliminating the cracks in, and/or the buckling of, the coating as the contour of the coated glass is changed from a glass piece having flat surface to a shaped glass substrate having a concave surface. As is recognized by the instant application, when the barrier coating is stressed, the coating cracks and the sodium ions are exposed to the atmosphere and form the sodium compound precipitate on the surfaces of the glass substrate, and/or when the barrier coating and/or the scratch resistant coating buckles the surface changes from a specular surface to a non-specular or diffusing surface.

**[0013]** As can now be appreciated by those skilled in the art, it would be advantages to provide an alkali barrier coating or layer, e.g. a sodium ion barrier coating that has scratch resistant properties to prevent the concave surfaces of the primary and secondary mirrors from changing from a specular surface to a non-specular or diffusing surface.

## SUMMARY OF THE INVENTION

**[0014]** This invention relates to a solar reflecting mirror having a curved reflective surface, including, among other things, a transparent substrate having a convex surface and an opposite concave surface, and a reflective coating over the convex surface and an alkali barrier layer or coating over the concave surface. The reflective coating reflects selected wavelengths of the electromagnetic spectrum.

**[0015]** Further, the invention relates to a method of making the solar reflecting mirror having a curved reflective surface by, among other things, providing a flat transparent sheet; shaping the sheet to provide a shaped transparent substrate having a convex surface and an opposite concave surface and a focal area; applying a reflective coating over the convex surface of the substrate, and providing an alkali barrier layer over the concave surface of the substrate.

**[0016]** Still further, the invention relates to an alkali barrier coating including, among other things, an oxide of silicon and aluminum.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0017]** FIG. **1** is an elevated plan view of a prior art array of solar collectors.

**[0018]** FIG. **2** is an isometric view of a prior art solar collector, and FIG. **2**A is an enlarged view of a sun's ray incident on the concave surface of the solar collector.

**[0019]** FIG. **3** is a view similar to the view of FIG. **2** showing a solar mirror of the invention.

**[0020]** FIG. **4** is an isometric view of a piece of glass having a coating of the invention, the coating in FIG. **4** having portions removed for purposes of clarity.

**[0021]** FIG. **5**A is a side elevated view of a vacuum mold having the piece of glass of FIG. **4** mounted on the open end of the vacuum mold, and FIG. **5**B is a cross sectional view of the vacuum mold having the shaped glass substrate of the invention in the interior of the vacuum mold.

**[0022]** FIG. **6** is an elevated top view of the shaped glass substrate of the invention showing the pattern of circumferential compressive strains at the periphery of the shaped glass substrate.

**[0023]** FIG. **7** is a view taken along line **7-7** of FIG. **6** showing, among other things, the transition strain line of the shaped glass substrate.

**[0024]** FIG. **8** is a view taken along line **8-8** of FIG. **7** showing the circumferential tensile strain and the radial tensile strain of the shaped glass substrate.

**[0025]** FIG. **9**A is an isometric view of a segment of the glass piece shown in FIG. **4**; FIG. **9**B is an isometric view of the segment shown in FIG. **9**A after the glass piece is shaped into the shaped glass substrate, the coating having peaks and valleys, and FIG. **9**C is a view similar to the view of FIG. **9**B showing a segment of the shaped glass substrate made according to the teachings of the invention, the coating having reduced number of peaks and valleys, reduced heights of peaks and reduced depths of valleys.

**[0026]** FIG. **10** is a view similar to the view of FIG. **4** showing another embodiment of the invention to make the shaped solar mirror of the invention that includes cutting a coated glass into segments.

**[0027]** FIG. **11** is an isometric top view of a glass sheet pressing arrangement that can be used in the practice of the invention to shape the segments cut from the coated glass of FIG. **10**.

**[0028]** FIG. **12** is a top view of a shaped solar mirror of the invention made by joining shaped glass segments.

**[0029]** FIG. **13** is a view similar to the view of FIG. **3** showing the shaped solar mirror of the invention made with the shaped glass segments

**[0030]** FIG. **14** is view similar to view of FIG. **4** showing a coating shield over a circular glass piece.

**[0031]** FIG. **15** is an elevated cross sectional top view of the shaped glass substrate at a position between the transition strain line and the bottom of the shaped glass substrate, the view showing fissures in the circumferential tension and radial tension areas of the shaped glass substrate, the cross hatching of the coating is not shown for purposes of clarity.

**[0032]** FIGS. **16-19** are cross sectional side views of sections of flat glass pieces of the type shown in FIG. **4** having a barrier coating and/or a scratch resistant coating of the invention on one or both surfaces of the glass pieces, and optionally a reflective surface over one surface of the glass pieces.

**[0033]** FIG. **20** is a side view of a section of a photovoltaic cell having the barrier layer of the invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

**[0034]** In the following discussion, spatial or directional terms, such as "inner", "outer", "left", "right", "up", "down", "horizontal", "vertical", and the like, relate to the invention as it is shown in the drawing figures. However, it is to be understood that the invention can assume various alternative orientations and, accordingly, such terms are not to be considered as limiting. Further, all numbers expressing dimensions, physical characteristics, and so forth, used in the specification and claims are to be understood as being modified in all instances by the term "about." Accordingly, unless indicated to the contrary, the numerical values set forth in the following specification and claims can vary depending upon the desired properties sought to be obtained by the present invention. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Moreover, all ranges disclosed herein are to be understood to encompass any and all sub-ranges subsumed therein. For example, a stated range of "1 to 10" should be considered to include any and all sub-ranges between (and inclusive of) the minimum value of 1 and the maximum value of 10; that is, all sub-ranges beginning with a minimum value of 1 or more and ending with a maximum value of 10 or less, e.g., 1 to 6.7, or 3.2 to 8.1, or 5.5 to 10. Also, as used herein, the terms "applied over", or "provided over" mean applied, or provided on but not necessarily in surface contact. For example, a material "applied over" a substrate or a substrate surface does not preclude the presence of one or more other materials of the same or different composition located between the deposited material and the substrate or substrate surface.

**[0035]** Before discussing several non-limiting embodiments of the invention, it is understood that the invention is not limited in its application to the details of the particular non-limiting embodiments shown and discussed herein since the invention is capable of other embodiments. Further, the terminology used herein to discuss the invention is for the purpose of description and is not of limitation. Still further, unless indicated otherwise, in the following discussion like numbers refer to like elements.

**[0036]** The barrier coating or layer of the invention is a silicon-aluminum oxide coating discussed in detail below. The silicon-aluminum oxide coating of the invention also provides protection against mechanical damage, e.g. scratches, and chemical damage, e.g. chemical etching from materials having a pH in the range of 7-14, and in particular in the range of 9-14. The following discussions relating to the barrier properties of the coating of the invention are applicable to the scratch resistant properties of the coating of the invention unless indicated otherwise. In this regard, at coating thickness below 50 nanometers (hereinafter also referred to as "nm"), the silicon-aluminum oxide coating of the invention loses resistance to mechanical damage and chemical damage.

**[0037]** For clarity of discussion, the terms "alkali barrier layer or coating" and "sodium ion barrier layer or coating" means a layer or coating that acts as a barrier to prevent, or limit the formation of alkali or sodium precipitates on, and optionally has a resistance to prevent or limit mechanical and/or chemical damage to, the surface over which, or on which, the layer or coating is applied. "Protective layer or coating" means a layer or coating that has a resistance to prevent or limit mechanical and/or chemical damage to, and/or can limit the formation of alkali or sodium precipitates on, the surface over which, or on which, the layer or coating is applied.

**[0038]** Non-limiting embodiments of the invention will be discussed using magnetron sputtering vacuum deposition (hereinafter also referred to as "MSVD") coating process to apply a coating or layer or film over, or on, a substrate surface that is a barrier to alkali ions, e.g. prevents the sodium ions from reacting with moisture in the atmosphere and converting the sodium ions to sodium compounds, e.g. sodium hydroxide and sodium carbonate, which compounds precipitate on the surface of the glass as discussed above. As is appreciated, the invention is not limited to the coating process, and the coating process can be any coating process that applies or coats an alkali ion, e.g. a sodium ion, barrier film or layer on, or over, a glass surface.

**[0039]** The following discussion is directed to non-limiting embodiments of applying an alkali ion barrier coating or layer. Unless indicated otherwise, the discussion is applicable to scratch resistant coatings or layers.

**[0040]** As is appreciated, the glass substrate or piece is not limiting to the invention, and the glass can be a glass of any composition; the glass can be clear or colored glass, and/or the glass can be annealed, heat strengthened or tempered glass. The glass piece or substrate can have any shape, thickness and size. The non-limiting embodiments of the invention are presented as the embodiments relate to solar reflecting mirrors. The invention, however, is not limited thereto, and the invention can be practiced in the manufacture of commercial and residential windows; glass shower doors; transparencies for air, space, land and water vehicles; coated bottles; coated glass for thin film photovoltaic applications; electrically heated glass for anti-fog commercial refrigerators, and glass for furniture use.

**[0041]** In the following discussion, the shaped solar reflecting mirror is referred to as a parabolic shaped reflecting mirror, however, the invention is not limited thereto, and the invention, unless indicated other wise can be practiced with any mirror having a curved reflective surface and a focal point or focal area, e.g. but not limited to the invention, a parabolic shaped mirror, and spherical shaped mirror. A "focal point" and "focal area" is defined as a position where more than 80% of the solar rays reflected from the mirror converge. The size and the location of the "focal area" is not limiting to the invention, and in one non-limiting embodiment of the invention, the focal area is less than one fifth (1/5) of the reflecting area of the mirror.

**[0042]** Shown in FIG. **1** is an array **18** of shaped solar collectors **20** (see FIG. **2**) of the prior art to convert solar energy to electric energy. The invention is not limited to the manner of joining the solar collectors **20** in the array **18** and any techniques known in the art can be used to join the solar collectors **20** in the array **18**. Further, the invention is not limited to the number of solar collectors **20** in the array **18**, e.g. the invention can be practiced on one solar collector **20** and an of array of 2, 3, 4, 5, 10, 20, greater than 50 and any number combination of solar collectors. Still further, the invention contemplates an array **18** of solar collectors **20** mounted in any convenient manner in a stationary position, or an array **18** of solar collectors **20** mounted in any convenient manner to follow the path of the sun to maximize exposure of the solar collectors to solar energy. Each of the solar collectors **20** can have the same or have different designs to direct the solar energy to a particular area where the solar energy is converted to an alternative energy source, e.g. electric energy or heat.

**[0043]** With reference to FIG. **2**, each of the solar collectors **20** includes a shaped reflective mirror, e.g. a parabolic shaped mirror **22** (also referred to herein as a "primary mirror") to focus the solar energy on device **26** to convert the solar energy to electric energy. The parabolic shaped mirror **22** includes a parabolic shaped glass substrate **28**. The glass substrate **28** preferably has a total iron content of less than 0.020 weight percent, a 90% transmission in the visible range, e.g. 350 to 770 nanometers ("nm"), of the electromagnetic spectrum, and in the infrared ("IR") range, e.g. greater than 770 nm to 2150 nm of the electromagnetic spectrum, and a low absorption, e.g. below 2% in the visible range and the IR range. Glasses having the preceding optical properties are disclosed in U.S. patent application Ser. No. 12/275,264 filed Nov. 21, 2008 and U.S. Pat. No. 5,030,594, which documents in their entirety are incorporated herein by reference. PPG Industries, Inc. sells glasses having the above properties under the trademarks STARPHIRE and SOLARPHIRE PV. The shaped glass substrate **28** has a concave surface **30** and an opposite convex surface **32**. The periphery of shaped glass substrate **28**

is shaped to provide sides **33**. As shown in FIG. **1**, the sides **33** of adjacent solar collectors **20** contact one another to maximize coverage of a given area with reflective surfaces. A reflective coating, layer or film **34** (clearly shown in FIG. **2**) is over and preferably on the convex surface **32** of the shaped glass substrate **28**. The reflective film **34** can be metal, e.g. but not limited to silver, aluminum, nickel, stainless steel or gold. Usually the reflective film **34** is silver.

**[0044]** With continued reference to FIG. **2**, the parallel solar energy rays represented by rays **36** are incident on the concave surface **30**. A portion **37** of the rays **36** is reflected from the concave surface **30** to the converting device **26**, and a portion **38** passes through the concave surface **30**, and through the shaped glass substrate **28**, and is reflected from surface **42** of the reflective film **34** back through the shaped glass substrate **28** as reflected ray **43** (see FIG. **2**A) to the converting device **26**. The solar energy rays are shown in FIG. **2** as two rays **36** for purpose of clarity and simplicity instead of the infinite number of parallel solar energy rays incident on the concave surface **30**. Further, as is appreciated by those skilled in the art, there is reflection of the solar rays between the concave surface **30** and the convex surface **32** of the shaped glass substrate **28**; however, a detailed discussion of the transmission, absorption and reflection of the solar energy rays incident on, and passing through a transparent substrate is well known in the art and no further discussion is deemed necessary.

**[0045]** In the embodiment shown in FIGS. **1** and **2**, the converting device **26** includes a shaped secondary mirror **44** positioned relative to the focal point of the parabolic shaped mirror or primary mirror **22**, and an optical rod or light bar **46** (clearly shown in FIG. **2**) at the focal area of the primary mirror **44**. Multi-junction solar cells **48** are positioned at end **50** of the light bar **46**. With this arrangement the reflected rays **37** and **43** (see FIG. **2**A) are incident on the secondary mirror **44**; the secondary mirror reflects the rays **37** and **43** to end **52** of the light bar **46** (clearly shown in FIG. **2**). The rays **37** and **43** pass through the light bar **46** and out of the end **50** of the light bar **46**, and are incident on the solar cells **48** to convert the solar energy to electric energy. As is appreciated by those skilled in the art, the solar cells **48** can be positioned at the focal point of the primary mirror **22** to eliminate the secondary mirror **44**.

**[0046]** The invention is not limiting to the shape of the secondary mirror **44**. More particularly, the secondary mirror in the practice of the invention preferably has a flat reflective surface. In the practice of the invention, the secondary mirror was a circular piece of flat glass having a solar reflecting coated surface, e.g. a silver coated surface. The invention, however, can be practiced using a shaped secondary mirror having concave and convex surfaces and a reflective coating on at least one of the surfaces, e.g. the convex surface.

**[0047]** With reference to FIG. **1**, a cover **60** (partially shown in upper left hand corner of FIG. **1**) is supported over the array of solar collectors to prevent dust and water from depositing on the concave surface **30** of the parabolic shaped mirror **22** of the solar collectors **20**. As is known in the art, the cover **60** is transparent to the visible and IR wavelength ranges of the electromagnetic scale. Optionally the shaped glass substrate **28** of the primary mirror **22** has a cut out **64** (clearly shown in FIG. **2**) at the bottom of the glass shaped substrate **28** to provide access to the light bar **46** and the solar cells **48**.

**[0048]** As discussed above in the section titled "Description of The Available Technology," a limitation of the presently available solar collectors is the use of soda-lime-silica glass substrates for the primary mirror **22** and for the secondary mirror **44**. The glass substrates are usually cut glass pieces cut from a continuous glass ribbon made by the float glass process, e.g. the glass making process disclosed in U.S. Pat. Nos. 3,333,936 and 4,402,722, which patents in their entirety are hereby incorporated by reference. As is well known in the art, the soda-lime silica glass contains sodium ions. The long term environment exposure, e.g. to the solar rays **36** impinging on the primary mirror **22** heats the shaped glass substrate **28**, and the heating of the glass to form the parabolic shaped substrate **28**, provides energy for sodium ions to diffuse or leech out of the shaped glass substrate **28**. The sodium ions leeching out of the shaped glass substrate **28** at the surfaces **30** and **32** react with the moisture in the atmosphere, and convert the sodium ions to sodium compounds, e.g. sodium hydroxide and sodium carbonate. The sodium compounds deposit as a precipitate on the surfaces of the shaped glass substrate **28**. The sodium compound precipitate on the concave surface **30** of the shaped glass substrate **28** decreases the visible light transmission of the shaped glass substrate **28** and makes portions of the concave surface **30** having the sodium compound precipitate a non-specular or diffusing surface directing the reflected rays **37** and **43** away from the focal point of the primary mirror **22**, or away from the secondary mirror **44**. There is minimal, if any, sodium compound precipitate on the convex surface **32** of the primary mirror **22** because the convex surface has the reflective coating **34** and a protective plastic coating or film **53** (shown only in FIG. **2**) over the reflective coating. As is known in the art, the protective coating **53** protects the reflective coating **34** from the environment, and in the practice of the invention, the protective coating **53** limits sodium ions at the convex surface **32** of the glass substrate **28** from reacting with the environment to form the sodium precipitates. Although the protective coating **53** for the reflective coating **34** prevents the formation of sodium compound precipitates, the invention contemplates the practice of the invention on the convex surface **32** of the glass substrate **28**. As can now be appreciated, the secondary mirror **44**, which is made of soda-lime silica glass, can have the same drawbacks as the primary mirror **22** except that the sodium compound precipitate on the secondary mirror directs the reflected rays from the primary mirror **22** away from the light rod **46**.

**[0049]** With reference to FIG. **3**, in one non-limited embodiment of the invention, the concave surface **30** of the shaped glass substrate **28** of the primary mirror **22** has a sodium barrier coating or layer or film **66**.

**[0050]** With reference to FIG. **4**, the sodium barrier coating **66** is applied over and preferably on surface **68** of a circular shaped flat glass piece **70**. The surface **68** of the glass piece **70** is designated to be the concave surface **30** of the shaped glass substrate **28**. In the practice of the invention the barrier layer **66** preferably transmits greater than 90%, more preferably greater than 95% and most preferably 100% of the visible and IR spectrum of the electromagnetic wavelength. The barrier layer **66** preferably can withstand temperatures greater than the shaping or bending temperature of the glass, e.g. temperatures greater than 1220° Fahrenheit ("F") for soda-lime silica glass. Further, the barrier layer **66** preferably does not crack and/or buckle during shaping of the glass piece **70** to the extent that alkali ions, e.g. sodium ions, can not move through the cracks in the barrier coating **66**, and the buckling does not significantly deflect the rays **37** and **43** away from the focal point of the parabolic shaped mirror **22**. A discussion of cracks in the barrier coating **66** and buckling of the barrier coating **66** is presented in more detail below.

**[0051]** In one non-limiting embodiment of the invention, the circular flat glass piece **70** had a diameter of 18 inches (45.72 centimeters ("cm")) and a thickness of 0.083 inch (2.1 millimeters ("mm")). An 800 angstrom thick barrier coating **66** of an oxide of 85 atomic percent silicon and 15 atomic percent aluminum was deposited on the surface **68** of the glass piece **70** (designated to be the concave surface **30** of the shaped glass substrate **28**) by the MSVD coating process. The surface **72** of the coating glass piece designated to be the convex surface **32** of the shaped glass substrate **28** was placed on open end **74** of a vacuum-shaping mold **76** (see FIG. **5**A). The glass piece **70** and the mold **76** were heated in a furnace (not shown) to heat the glass piece to a temperature of 1220° F. (660° centigrade ("C")). The coated glass piece **70** and the vacuum-mold **76** were uniformly heated in any usual manner. After the coated glass piece **70** and the vacuum-mold **76** were heated to 1220° F. (660° C.), air was evacuated from the interior **78** of the mold **76** by way of spaced holes **77** to force the heated glass piece **70** into the interior **78** of the vacuum mold **76** to provide the shaped glass substrate **28** having the coating **66** (see FIG. **5**B). The heated shaped glass substrate was controllable cooled to anneal the shaped glass substrate. As can be appreciated, the invention contemplates heating the glass piece **70** and the vacuum mold **76** separately, and thereafter placing the glass piece **70** on the open end **74** of the vacuum mold **76**, and shaping the glass piece **70** as described above. Processes and equipment for heating glass, shaping glass in vacuum molds, for annealing glass and coated glass are well known in the art and no detailed discussion is deemed necessary.

**[0052]** During the shaping process, as the flat glass piece **70** (see FIG. **4**) is biased or pulled into the interior **78** of the vacuum mold **76**, center portion **79** of the flat glass piece **70** is stretched. As a result of the stretching, the thickness at bottom area **80** of the shaped glass substrate **28** (see FIG. **5**B) (corresponding to the center portion **79** of the glass piece **70** in FIG. **4** and the hole **64** in FIG. **3**) is 80% of the thickness of the center portion **79** of the flat glass piece **70** (see FIG. **4**), and the thickness of the marginal edge **81** of the shaped glass substrate **28** (see FIG. **5**B) is 105% of the thickness of marginal edge **82** of the flat glass piece **70** (see FIG. **4**). As can be appreciated, the marginal edge **81** of the shaped glass substrate **28** is highly strained and has optical distortion. In the practice of the invention, but not limited thereto, a segment **83** of the shaped glass substrate **28** (see FIG. **5**B) was cut off to remove portions of the highly strained and optically distorted glass and to position the sides **33** of adjacent ones of the shaped solar mirror **20** against one another as shown in the array **18** (see FIG. **1**). In the practice of the invention, but not limiting to the invention, a section of about 2 inches measured from peripheral edge **84** toward the bottom **80** (see FIG. **5**B) of the shaped glass substrate **28** was cut off. Additional portions of the peripheral edge of the shaped glass substrate were removed to provide the sides **33** (see FIG. **3**) of the shaped glass substrate **28**. The cut out or hole **64** (see FIG. **3**) was cut in the bottom area **80** (see FIG. **5**B) of the shaped glass substrate **28**. Thereafter, the reflective coating, e.g. a silver layer **34** was applied over the convex surface **32** of the shaped glass substrate **28** (see FIG. **3**), and the protective film **53** (see FIG. **2**) was applied on the reflective coating **34**.

**[0053]** As is appreciated, the invention is not limited to the process of cutting the hole **64** in the bottom area **80** (see FIG. **5**B) of the shaped glass substrate **28**, cutting the peripheral edge **24** of the shaped glass substrate, or to the coating process to apply the reflective coating **34** and the protective coating **53** over the convex surface **32** of the shaped glass substrate **28**, and any cutting and/or coating techniques known in the art can be used in the practice of the invention.

**[0054]** At a temperature in the range of 1200°-1300° F. (649°-704° C.), the glass piece **70** is heat softened or viscous; on the other hand, the barrier coating **66** of the invention, e.g. the oxide of aluminum and silicon is a refractory material and remains dimensionally stable at a temperature in the range of 1200°-1300° F. (649°-704° C.). As used herein, the term "dimensionally stable" means that the physical dimensions of the coating during and/or after heating of the glass piece does not change more than ±5% and preferably not more than ±2%. During the shaping of the flat glass piece **70** to the shaped glass substrate **28**, the strain pattern shown in FIGS. **6-8** develops in the shaped glass substrate **28**. With reference to FIGS. **6-8**, as needed, radial tension strain shown by number **90** are present at the bottom portion of the shaped glass substrate (see FIG. **8**), and circumferential compression strain shown by the number **92** are present at the periphery **84** of the shaped glass substrate **28**. The barrier coating **66** experiences the stresses due to being adhered to the concave surface of the glass substrate. As the distance from the periphery **84** of the shaped glass substrate **28** increases in a direction toward the bottom area **80** of the shaped glass substrate **28** (see FIG. **7**), the radial tension strain **90** generally remains the same, and the circumferential compression strain **92** decreases to a location designated as the "transition line" and identified by the number **94** in FIG. **7** where circumferential tension strain designated by the number **102** (see FIG. **8**) begins in the glass and the radial tension strain **90** (see FIG. **8**) is present in the glass. For the shaped glass substrate **28** under discussion, e.g. the shaped glass substrate **28** made from the flat glass piece **70** having a diameter of 18 inches (45.72 cm) and a thickness of 0.083 inch (2.1 mm), the transition line **94** is at a position on the shaped glass substrate **28** that corresponds to a position on the flat glass piece **70** about 3 inches (7.62 cm) from the center, i.e. from the center of the center portion **79**, of the flat glass piece **70**. As the distance from the transition line **94** in a direction toward the bottom area **80** of the shaped glass substrate **28** increases, the shaped glass substrate has increasing circumferential tension strain designated by the number **102** and has the radial tension strain **90** (see FIG. **8**).

**[0055]** As is appreciated by those skilled in the art, the strains in the shaped glass substrate **28** can be measured in any convenient manner. In the practice of the invention, the strains of the shaped glass piece **28** under discussion were calculated using the ANSYS finite element computer program.

**[0056]** The sodium barrier coating **66** in the circumferential compression area **103** of the shaped glass substrate **28**, i.e. the area between the periphery **84** and the transition line **94** of the shaped glass substrate **28** (see FIG. **7**) was observed to have buckling in the radial direction perpendicular to the compressive strain in the glass. In the location of the transition line **94**, the barrier coating **66** was observed to have an area of radial cracks. In the circumferential tension area **104** of the shaped glass substrate **28**, i.e. the area between the transition line **94** and the bottom area **80** of the shaped glass substrate **28** (see FIG. **7**), the barrier coating **66** was observed to have small random fissures or cracks.

**[0057]** As discussed above, the maximum compressive stresses are at the marginal edge portions **81** of the shaped glass substrate **28** (see FIGS. **5**B and **7**), and it is expected that maximum buckling of the barrier coating **66** will be present at the marginal edge portions **81**. It has also been observed that very few of the suns rays impinging on the marginal edge portions **81** of the initially shaped glass substrate **28** are directed to the focal point or focal area of the shaped glass substrate **28**. In view of the foregoing, the marginal edge portion **81** of the initially shaped glass substrate **28** extending a distance from the peripheral edge **84** of the shaped glass substrate **28** equal to 10-15% of the distance measured from the peripheral edge **84** to the center of the bottom area **80** of the initially shaped glass substrate was removed. In one non-limiting embodiment of the invention, for a shaped glass substrate **28** shaped from a flat glass piece **70** having a diameter of 18 inches (45.72 cm), a section of about 2 inches (5.08 cm) measured from peripheral edge **84** toward the bottom **80** (see FIG. **5**B) of the shaped glass substrate was cut off to remove portions of the highly strained and optically distorted glass. Additional portions of the peripheral edge of the shaped glass substrate were removed to provide the sides **33** (see FIG. **3**) of the shaped glass substrate **28**,

**[0058]** The discussion is now directed to the observed and/or expected defects caused by the fissures and/or cracks in the barrier coating **66**, and the observed and/or expected defects caused by buckling of the barrier coating. It is expected that cracks or fissures that extend through the thickness of the barrier coating **66** will provide passageways for moisture in the atmosphere and the sodium ions leeching out of the glass to interact with one another to form sodium compound precipitates which can deposit on surface **108** of the barrier coating **66** (see FIG. **7**) and/or between the barrier coating **66** and the concave surface **30** of the shaped glass substrate **28**. The sodium compounds on the surface **108** of the barrier coating **66** can change the specular surface of the barrier coating **66** to a non-specular or diffusing surface, and the sodium compound precipitates between the barrier coating **66** and the convex surface **30** can cause separation of the barrier coating **66**.

**[0059]** The defect of buckling can change the surface **108** of the barrier coating **66** from a specular surface to a non-specular or diffusing surface, and severe cases of buckling can, in addition, cause cracks in the barrier coating. The following discussion is directed to the barrier coating **66**, and the discussion, unless indicated otherwise, is applicable to the scratch resistant properties (discussed above) of the barrier coating.

**[0060]** With reference to FIGS. **9**A-**9**C as needed, the barrier coating **66** on a segment **110** of the glass piece **70** (FIG. **9**A) expected to be in the area of circumferential compression **103** (see FIG. **7**) has a length measured between sides **112** and **113**, and a width measured between sides **116** and **117**. After the glass piece **70** is shaped into the shaped glass substrate **28**, the segment **110** of the flat glass piece **70** corresponds to segment **118** of the shaped glass substrate **28**. The convex surface **32** of the segment **118** of the shaped glass substrate **28** has a length as measured between the sides **112** and **113** of the segment **118** that is slightly greater than the length measured between sides **112** and **113** of the segment **110** of the flat glass piece **70**, and the convex surface **32** of the segment **118** of the shaped glass substrate **28** has a width as measured between sides **116** and **117** of the segment **118** that is less than the width of the segment **110** of the flat glass piece **70** as measured between sides **116** and **117** of the segment **118**. The concave surface **30** of the segment **110** of the shaped glass substrate **28** has a length as measured between sides **112** and **113** of the segment **118** that is slightly greater than the length measured between sides **112** and **113** of the segment **110** of the flat glass piece **70**, and the concave surface **30** of the segment **118** of the shaped glass substrate **28** has a width as measured between sides **116** and **117** of the segment **118** that is less than the width of the flat glass piece **70** as measured between sides **116** and **117** of the segment **118**.

**[0061]** The difference in the increase between the length of the convex surface **32** and the length of the concave surface **30** as measured between the sides **112** and **113** of the segment **118** is small. The difference in the decrease between the width of the concave surface **30** as measured between the sides **116** and **117** of the segment **118** is greater than the difference between the length of the concave side and convex side of the segment **118**. By way of illustration and not limiting to the invention, a measured expansion between the sides **112** and **113** of the segment **110** and the sides **112** and **113** of the segment **118** was 2-6% for both the concave side and the convex side. The contraction between the sides **116** and **118** of the segment **110** and the sides **116** and **118** of the segment **118** measured at the perimeter of the shaped glass substrate **28** was 14% with the concave side **30** having a contraction of 14% and the convex side **32** having a contraction of 13%. At the bottom **80** of the shaped glass substrate **28**, the elongation for the convex and concave sides was 5% and 4%, respectively.

**[0062]** The length and width of the barrier coating **66**, on the other hand, remains the same and buckles because of the reduction of the width of the concave and convex surfaces of the shaped glass substrate **28** compared to the corresponding width of the flat glass piece **70** commonly referred to as strain. More particularly, the glass is viscous during the shaping process, and the buckling of the barrier coating **66** changes the contour of the concave surface **30** of the shaped glass substrate **28** to a surface having folds **120**, e.g. a corrugated surface (see FIG. **9**B) to accommodate the decrease in the width of the surface **72** of the flat glass piece **70**. The folds **120** change the surface **108** of the barrier coating **66** and the concave surface **30** of the shaped glass substrate **28** from a specular surface in FIG. **9**A to a non-specular or diffusing surface in FIG. **9**B. In the first instance (FIG. **9**B), as the thickness of the barrier coating **66** increases, e.g. the barrier coating increases to a thickness of 160 nanometers ("nm"), while the amount of shrinkage of the width of the flat glass piece remains the same, the number of folds **120** and the height of the folds **120** increases, increasing the percentage of diffused reflected sun rays **37** and **43** (see FIGS. **2** and **2**A). In the second instance (FIG. **9**C) as the thickness of the barrier coating **66** decreases, e.g. the barrier coating **66** decreases to a thickness of 60 nm, while the amount of shrinkage of the flat glass piece **70** remains the same, the number of folds **120** and the height of the folds in the second instance (FIG. **9**C) is less than the number of folds **120** and the height of the folds **120** in the first instance (see FIG. **9**B), decreasing the percentage of diffused reflected sun rays **37** and **43** (see FIGS. **2** and **2**A). As mentioned above, the area **103** of the circumferential compression (see FIG. **7**) decreases as the distance from the periphery **84** of the shaped glass substrate **28** increases (see FIGS. **6**-**8**); therefore the percent shrinkage of the circumferential width of the concave surface **30** of the shaped glass substrate **28** decreases as the distance from the periphery **84**

of the shaped glass substrate **28** increases, and the thickness of the barrier coating **66** can be increased without increasing the number of folds **120** and the amplitudes of the folds **120** (see FIGS. **9**B and **9**C).

**[0063]** In one non-limiting embodiment of the invention, the thickness of the barrier coating **66** is selected to have sodium barrier properties and to minimize buckling. More particularly, the minimum thickness of the barrier coating **66** is selected to prevent the sodium ions from reacting with moisture in the atmosphere to convert the sodium ions to sodium compound precipitates and to minimize buckling. As is appreciated by those skilled in the art, the mechanism of sodium ions moving out of the glass is a diffusion process and for purposes of this invention the parameter of interest is the amount of sodium ions present in the glass. The diffusion rate, size of the alkali ion, e.g. the sodium ion, and the energy to drive the sodium ion to the surface of the shaped glass substrate **28** is not considered relevant to the present discussion because the use of the solar mirror is a long term use, e.g. 30 years.

**[0064]** Based on the forgoing, the amount of alkali ions or sodium ions in glass is a function of the glass composition and the thickness of the glass piece, e.g. as the thickness of the glass piece **70** or of the shaped glass substrate **28** increases, the number of sodium ions in the glass piece increases, and the thickness and/or density of the barrier coating is preferably increased. For a soda-lime-silica glass the sodium concentration is generally 14 weight percent. In one non-limiting embodiment of the invention the parabolic shaped mirror **22** is made of a glass substrate having a thickness of 0.083 inch (2.1 millimeter). In this non-limiting embodiment of the invention, the barrier coating is an MSVD coating of an oxide of 85 atomic percent silicon and 15 atomic percent aluminum. The minimum coating thickness to prevent sodium ions from reacting with moisture in the environment to convert the sodium ion to sodium compound precipitates is 40 nm. As is appreciated, any thickness above the minimum thickness prevents sodium ions from reacting with moisture in the environment; however, as the thickness of the barrier coating **66** increases, the severity of the buckling increases. In the practice of the invention, the barrier coating **66** in the circumferential tension area **104** (see FIG. **7**) is preferably in the range of 40-100 nm, more preferable in the range of 60-100 nm, and most preferably in the range of 60-80 nm. The same coating composition having coating thicknesses in the range of 40-100 nm provides a protective coating against mechanical and chemical attack and/or damage.

**[0065]** As discussed above, the flat glass piece **70** is shaped using the vacuum mold **76** (see FIGS. **5**A and **5**B). After the flat glass piece **70** is shaped, the shaped glass substrate is removed from the mold **76** when the glass is dimensionally stable and is annealed. For purposes of the invention, the glass is considered to be dimensionally stable when the shaped glass can support its own weight without changing its shape. For the glass disclosed in U.S. patent application Ser. No. 12/275,264 filed Nov. 21, 2008 and U.S. Pat. No. 5,030,594, the glass is dimensionally stable at a temperature of 1050° F. The annealing process reduces the intrinsic stresses in the barrier coating **66** and in the shaped glass substrate **28** to minimize residual stresses so that the barrier coating and the shaped glass substrate **28** can be cut without shattering the substrate **28** or fracturing the barrier coating. The annealing equipment and rate at which the flat glass substrate **28** is annealed is not limiting to the invention, and any equipment for, and method of, and rate of, annealing known in the art can be used in the practice of the invention. Annealing coated and uncoated glass articles is well known in the art and no further discussion is deemed necessary.

**[0066]** The invention is not limited to the thickness of the glass piece **70**, and the glass piece can be any thickness. In the preferred practice of the invention, the glass piece **70** is preferably thin to provide a light-weight shaped glass substrates **28**. Although thin glass is preferred, the glass thickness should be sufficient thick to have structural stability. As used herein the term "structural stability" means the glass has to be processed from the flat glass piece **70** (see FIG. **4**) to the parabolic shaped mirror **22** (see **3**) using a vacuum mold or a pressing mold with minimal glass breakage. In the practice of the invention, the glass thickness is preferably in the range of 0.075-0.126 inch (1.9-3.2 mm), more preferably in the range of 0.078-0.110 inch (2.0-2.8 mm), and most preferably in the range of 0.083-0.091 inch (2.1-2.3 mm).

**[0067]** In the preferred practice of the invention, the barrier coating **66** is an oxide of 15 atomic percent aluminum and 85 atomic percent silicon. Increasing the atomic percent of aluminum makes the coating stiffer. Although a stiffer coating reduces buckling, it is prone to cracking. The cracks in the coating can result in moisture in the atmosphere reacting with the sodium ions converting the sodium ions to sodium compounds. For barrier coatings of an oxide of aluminum and silicon, the coatings preferably include 30-100 atomic percent silicon and 0-70 atomic percent aluminum, more preferably 50-95 atomic percent silicon and 5-50 atomic percent aluminum, e.g. 30 to less than 100 atomic percent silicon and greater than 0 to 70 atomic percent aluminum, and most preferably includes 60-90 atomic percent silicon and 10-40 atomic percent aluminum. As can be appreciated, the invention is not limited to a barrier coating or film of an oxide of aluminum and silicon, and any sodium barrier film of the type known in the art can be used in the practice of the invention. Types of barrier coatings that can be used in the practice of the invention include, but are not limited to, the coatings or films disclosed in United States Publication 2007/0275253A1, which document in its entirety are hereby incorporated by reference.

**[0068]** As is appreciated by those skilled in the art of MSVD coating, the deposition parameters can be altered to reduce intrinsic stresses in the coated barrier film; however, as discussed above, the barrier film and the shaped glass substrate are annealed at the same time to minimize residual stresses so that the shaped glass substrate **28** can be cut without shattering the substrate **28**. Therefore reducing the intrinsic stress in the barrier coating during the deposition of the coating is optional and not limiting to the invention.

**[0069]** The invention contemplates reducing the strain in the shaped glass substrate **28** by reducing the time to shape the glass piece **70** (see FIG. **4**) into the shaped glass substrate **28** (see FIG. **5**B). As can be appreciated as the temperature of the glass piece **70** increases, the viscosity of the glass decreases, and the amplitude of the buckling of the barrier coating **66** increases because the coating has time to buckle to its full extent, and the glass has time to flow in the plane of the coating, e.g. the glass has time to flow into the folds of the barrier coating **60** or **120** (see FIG. **9**C). Further, increasing the shaping time, i.e. the time it takes to pull the glass piece **70** into the cavity of the shaping mold **76**, increases the amplitude of the buckling of the barrier coating **66** because the coating **66** has time to buckle to its full extent, and the glass has time to flow into the folds of the barrier coating **66** (see FIG. **4**) or **120** (see FIG. **9**C).

**[0070]** In the practice of the invention, the glass piece **70** at the time of forming preferably has a viscosity in the range of $1.00\times10^{7.8}$ poise to $5.36\times10^{9}$ poise, when the glass piece is pulled into the vacuum mold **76**. At this viscosity range, minimum buckling of the barrier coating **66** was found to occur when the shaping time is three seconds, and maximum buckling of the barrier coating **66** was found to occur when the shaping time is 25 seconds. Based on the forgoing, it is expected that minimum buckling of the barrier coating **66** is greater than zero to five seconds and preferably three seconds, and maximum buckling of the barrier coating **66** is 25 or more seconds for glass in the viscosity range of $1.00\times10^{7.6}$ poise to $5.36\times10^{9}$ poise.

**[0071]** As is appreciated by those skilled in the art the temperature versus viscosity curve for glass depends on the glass composition. It has been determined that soda-lime-silica glass of the type sold by PPG Industries, Inc. under the registered trademark STARPHIRE has a viscosity in the range of $1.00\times10^{7.8}$ poise to $5.36\times10^{9}$ poise at temperatures in the range of 1200° to 1300° F. In the practice of the invention, the piece **70** of STARPHIRE glass was heated in a furnace set at 1300° F. to heat the glass piece **70** to an expected temperature of 1220° F. The glass had a viscosity of $2.60\times10^{9}$ poise, and minimum buckling of the barrier coating **66** was found to occur when the shaping time is three seconds, and maximum buckling of the barrier coating **66** was found to occur when the shaping time is 25 seconds.

**[0072]** As can now be appreciated by those skilled in the art, the strain patterns for the convex side of the shaped glass piece **28** are similar to the strain patterns for the concave side of the shaped glass piece **28**.

**[0073]** With reference to FIGS. **10-13**, as needed, the invention also contemplates reducing the strain in the shaped glass substrate **28** by cutting segments from a flat glass sheet, shaping the segments and joining the shaped segments together to provide a shaped glass substrate similar in shape to the shaped glass substrate **28** (see FIG. **3**). In one non-limiting embodiment of the invention, surface **124** of a flat glass sheet **126** is coated with the barrier coating **66** (see FIG. **10**). The surface **124** of the glass sheet **126** is expected to be the concave surface **128** of the shaped glass substrate **130** (see FIGS. **12** and **13**). Four flat segments **132-135** are cut from the glass sheet **126**. Each of the flat segments **132-135** includes a radiused corner **136** joining sides **138** and **140**; a flat end **142** joining sides **144** and **146**; side **138** is joined to side **144** at corner **148**, and side **140** is joined to side **146** at corner **149**.

**[0074]** Each of the segments **132-135** are sized such that shaping the segments **132-135** as discussed below provides ¼ of the shaped glass substrate **130** (see FIGS. **12** and **13**) such that joining the shaped segments **132-135** together in a manner discussed below forms the shaped glass substrate **130**, which is similar to the shaped glass substrate **28** (see FIG. **3**).

**[0075]** The invention is not limited to the manner in which the segments **132-135** are cut from the glass sheet **126**, and any of the cutting or scoring techniques known in the art can be used in the practice of the invention. The edges of the segments **132-135** can be seamed as is known in the art for purposes of safety. Each of the flat segments **132-135** are shaped in any convenient manner using any of the pressing methods and equipment known in the art, e.g. but not limited to press bending using a solid upper mold having a shaping surface and a lower mold having a flexible supporting surface; a solid upper mold having a shaping surface and a lower ring mold, and a vacuum upper mold having a shaping surface, e.g. as disclosed in U.S. Pat. Nos. 7,240,519 and 7,437,892 which patents in their entirety are hereby incorporated by reference.

**[0076]** In the preferred practice of the invention, the segments **132-135** are shaped using an upper vacuum mold having a shaping surface. With reference to FIG. **11**, one of the segments **132-135**, e.g. the segment **132** is heated to a viscosity in the range of $1.00\times10^{7.8}$ poise to $5.36\times10^{9}$ poise and provided on curved surface **156** of lower support member **157**. Upper vacuum shaping mold **158** having a shaped surface and the support member **157** are moved relative to one another, e.g. the upper mold **158** moved toward the lower support member **157** to bring the segment **132** into contact with the shaping surface **159**. Vacuum is pulled through the shaping surfaces **159** of the upper mold **158** to shape the segment **132**. The process is repeated to shape the remaining three segments **133-135** to provide four shape segments **160-163**. Optionally, the four segments can be shaped simultaneously by providing a shaping mold with four shaping areas.

**[0077]** The reflective coating **34** and the protective coating **53** (see FIG. **2**) is applied to the convex surface of the shaped segments **160-163**.

**[0078]** In the preferred practice of the invention, the barrier coating **66** is applied to the surface **124** of the flat glass sheet **126** before the segments **132-135** are cut from the glass sheet **126**. The invention, however, contemplates applying the barrier coating **66** to the flat segments **132-135** or the shaped segments **160-163**. In the practice of the invention, the reflective coating **34** and the protective coating **54** are applied to the convex surface of the shaped segments **160-163**; the invention, however, contemplates applying the reflective coating **34** and the protective coating **53** to the surface of the glass sheet **126** opposite to the surface **124** of the glass sheet. As can be appreciated, if the reflective coating **34** and the protective coating **54** are applied before the segments **132-135** are shaped, the reflective coating **34** and the protective coating **54** have to withstand the temperatures at which the glass segments **132-135** are shaped. Optionally the protective coating **54** can be applied after the segments are shaped.

**[0079]** The invention is not limited to the number of segments **132-135** joined to make the shaped glass substrate **130**, and the shaped glass substrate **130** can be formed by joining 2, 3, 4, 5 or more segments. As can now be appreciated, the greater the number of shaped segments joined to form the shaped glass substrate **130**, the greater will be the reduction in the strain in the shaped glass substrate **28** or **130**.

**[0080]** With reference to FIGS. **12** and **13**, the shaped glass segments **160-163** are joined together in any convenient manner. In one non-limited embodiment of the invention, the segments **160-163** are positioned together to form the shaped glass substrate **130**, and a pair of rings **166** and **168** (shown only in FIG. **12**) are secured to the reflective coating **34** by an adhesive. In another non-limiting embodiment of the invention, the rings **166** and **168** are joined to the convex surface **32** of the shaped glass substrate. Thereafter, the convex surface of the joined shaped segments **160-163** and the rings **166** and **168** are coated in any convenient manner with the reflective coating **34** and the protective coating **53**. In still another non-limiting embodiment of the invention, the sides of the shaped segments are joined together by an adhesive, e.g. an adhesive joins the sides **140** of adjacent ones of the shaped segments together, and the sides **138** of adjacent ones of the shaped segments together as shown in FIG. **12**. As viewed in FIGS. **10** and **13**, the radiused corners **136** form the cut out **64** of the shaped substrate **130**.

**[0081]** The invention is not limited to manner in which the dimensions of the flat segments **132-135** are derived. For example and not limiting to the invention, the dimensions of the flat segments can be derived from a computer program, and from constructing the shaped parabolic substrate, cutting the shaped substrate into the desired number of segments, and measuring the sides of the segments.

**[0082]** As can now be appreciated, employing the above techniques will reduce the strain in the glass and will reduce the buckling and fracturing of the barrier coating **66**; however, as long as strains remain in the glass the barrier coating **66** will have degrees of buckling and cracking. In view of the forgoing, the invention contemplates further reducing the fracturing and buckling of the barrier coating **66** by providing barrier coatings **66** of different thickness over selectively surface portions of the flat glass piece **70** designated to be the concave surface **30** of the shaped glass substrates **28** (see FIG. **3**) and the shaped glass substrate **126** (see FIG. **13**), In the following discussion, the embodiments of the invention are practiced on the flat glass piece **70** to provide the shaped glass substrate **28** shaped from the flat glass piece **70**. The discussion, however unless indicated otherwise is applicable to applying the barrier coating **66** to the glass segments **132-135**, or the shaped glass segments **160-163**.

**[0083]** In a first non-limiting embodiment of the invention, the barrier coating **66** has a constant thickness over the surface **68** of the flat glass piece **70** (see FIG. **4**) designated to be the concave surface **30** of the shaped glass substrate **28** (hereinafter referred to as "Coating Technique No. 1"). In a second non-limiting embodiment of the invention, the changing of the circumferential strains in the concave surface **30** of the shaped glass substrate **28** is compensated for by applying or depositing a barrier coating or layer **66** that has varying thickness, e.g. a thickness that increases as the distance from perimeter **150** of the circular flat glass piece **70** (see FIG. **4**) increases in a direction toward the center portion **79** of the flat glass piece **70** (hereinafter referred to as "Coating Technique No. 2"). In a third non-limiting embodiment, the changing of the circumferential strains in the concave surface **30** of the shaped glass substrate **28** is compensated for by applying or depositing the barrier layer **66** to have a first constant thickness from the perimeter **170** of the flat glass piece **70** to the expected position of the transition line **94** (see FIG. **7**), and a second constant thickness from the transition line **94** to the center portion **79** of the flat glass piece **70**, with the second thickness of the barrier coating thicker than the first thickness of the barrier coating (hereinafter referred to as "Coating technique No. 3").

**[0084]** The variation of coating thickness for making the shaped glass substrate **28** (see FIGS. **3** and **5B**) can be accomplished by masking areas of the flat piece **70** to have a thin coating, e.g. using a shield **170** to cover the surface of the glass piece **70** (see FIG. **14**) expected to be in the circumferential compression area **103** (see FIG. **7**) as the center portion **79** of the flat glass piece **70** is coated.

**[0085]** Coating Technique No. 1 is practiced to provide the segments **160-163** by coating the surface **124** of the flat glass sheet **126** before, or after, cutting the outline of the segments **132-136** in the sheet. Coating technique No. 2 is practiced to provide the segments **160-163** by coating the segments after the segments **132-136** are outlined in the flat glass sheet **126** by cut lines, or after the segments **132-136** are removed from the glass sheet. The thickness of the coating **66** for Coating Technique No. 2 increases as the distance from the flat end **142** (see FIG. **10**) increases in a direction toward the radiused corner **136**. Coating technique No. 3 is practiced to provide the segments **160-163** by coating the segments after the segments **132-136** are outlined in the flat glass sheet **126** by cut lines, or after the segments **132-136** are removed from the glass sheet. The coating **66** for Coating Technique No. 3 is applied to the segments **132-135** to have a first constant thickness from the sides **144** and **146** of the flat segments **132-136** to the expected position of the transition line **94** (see FIG. **7**), and a second constant thickness from the transition line **94** to the radiused end **136** of the segments **132-136**.

**[0086]** The barrier coating **66** for Coating Technique No. 1 has a constant thickness in the range of 40-100 nm, or in the range of 80-100 nm. In one non-limiting embodiment of the invention, the barrier coating **66** included an oxide of 85 atomic percent silicon and 15 atomic percent aluminum. The barrier coating **66** having a thickness of 80 nm was deposited by the MSVD on the surface **72** of the flat piece glass **70**. The glass was of the type disclosed in U.S. patent application Ser. No. 12/275,264 filed Nov. 21, 2008 or U.S. Pat. No. 5,030,594. The flat glass piece 70 was a circular piece of glass having a diameter of 17.75 inches; a total iron content of less than 0.020 weight percent, a 90% transmission in the visible range, and the IR range, of the electromagnetic spectrum, and below 2% absorption in the visible range and the IR range. The flat glass piece **70** was shaped in a vacuum mold to provide the shaped glass substrate **28**, e.g. a bending time of less than 25 seconds. After the shaped glass substrate cooled, the periphery of the shaped glass substrate **28** was shaped as discussed above to provide the shaped glass substrate **28** with the sides **33** and the center hole **28** (see FIG. **3**). A reflective silver coating **34** was applied over the convex surface **32** of the shaped glass substrate **28** to provide the parabolic shaped mirror **22**.

**[0087]** The Coating Technique No. 2 provides a barrier coating **66** that increases in thickness as the distance from the periphery of the flat glass piece **70** toward the center portion **79** increases, e.g. the barrier coating **66** increases, preferably, but not limiting to the invention, from a thickness of 40 nm at the periphery **172** of the flat glass piece **70** to a thickness of 80 nm at the center portion **79** of the flat glass piece **70**. In this manner the thickness of the barrier coating **66** increases as the circumferential strains in the glass decrease and the % width shrinkage of the concave surface **30** of the shaped glass substrate **28** decreases to reduce the buckling. Passing the transition line **94** toward the center portion **80** of the shaped glass substrate **28**, the thickness of the barrier coating **66** increases as the circumferential tension increases. With reference to FIG. **15**, there is shown a cross section of the shaped glass substrate **28** in the circumferential tension area **104**, which is between the transition line **94** and the center area **80** (see FIGS. **7** and **15**). The barrier coating **66** has fissures **174**, however the barrier coating **66** is thick enough, e.g. 80 nm such that the fissures **154** do not extend to the surface **108** of the barrier coating **66**.

**[0088]** The barrier coating **66** for Coating Technique No. 3 has a first constant thickness from the periphery **172** of the flat glass piece **70** to the expected position of the transition line **94** of the shaped glass substrate **28**, and a second constant thickness from the transition line **94** to the center portion **79** of the flat glass piece **70**, with the first thickness of the barrier coating **66** thinner than the second thickness of the barrier coating **66**. In one non-limiting embodiment of the invention, the first constant thickness of the barrier coating **66** is in the range of 40-60 nm, more preferably 40 to 50 nm, and the second constant thickness is in the range of greater than 60 to 100 nm, more preferably in the range of greater than 60 to 80 nm. With this arrangement, the buckling of the barrier coating **66** is minimized in the circumferential compression area **103**, and the thickness of the barrier coating **66** is thick enough in the circumferential tension area **104** such that the fissures **174** do not extend to the surface **108** of the barrier coating **66**. Further, with this arrangement, the thickness of the barrier coating **66** is thinner between the peripheral edge **84** and the transition line **94**, i.e. in the area of increased glass thickness to reduce buckling of the barrier coating **66**, and the thickness of the barrier coat **66** is thicker between the transition line **94** and the bottom area **80** of the shaped glass substrate **28**, i.e. in the area of the thinner glass where buckling is not as severe as in the circumferential compression area **103** and the fissures **174** are a concern. As can be appreciated, the invention is not limited to the coating thickness change in the area of the transition line **94**, and the coating thickness change can be a gradual change, or a step change.

**[0089]** As can now be appreciated, in the instance when the secondary mirror **44** includes a shaped substrate, the technique of preventing buckling of the barrier coating **66** can be practiced to make a shaped secondary mirror.

**[0090]** Additional embodiments of the invention include, but are not limited to:

**[0091]** 1. applying the barrier layer **66** and/or the scratch resistant coating over the surface **68** of the flat glass piece **70** designated to be the concave surface **30** of the shaped glass substrate **28** and the barrier layer **66** over the surface **72** of the flat glass piece **70** (see FIG. **16**) designated to be the convex surface, and shaping the flat glass sheet **70** to the shaped glass substrate **28**. Thereafter the reflective layer **34** and optionally the protective coating **53** are applied over the barrier layer **66** on the convex surface **32** of the shaped glass substrate **28**;

**[0092]** 2. applying the barrier layer **66** and/or the scratch resistant coating over the surface **68** of the flat glass piece **70** designated to be the concave surface of the shaped glass substrate **28**, and the barrier layer **66** over the surface **72** of the flat glass piece **70** designated to be the convex surface of the flat glass piece **70**, and applying the reflective coating layer **34** over the barrier layer **66** on the surface **72** (see FIG. **17**), and thereafter shaping the flat glass sheet **70** to the shaped glass substrate **28**;

**[0093]** 3. shaping the flat glass piece **70** to a parabolic shaped glass substrate **28**, and applying the barrier layer **66** and/or the scratch resistant coating over the concave surface **30**, and the reflective coating **34** over the convex surface **32** of the parabolic shaped glass substrate **28** (see FIG. **18**), and

**[0094]** 4. shaping the flat glass piece **70** to the shaped glass substrate **28**, and applying the barrier layer **66** over the convex surface **32**, and the barrier layer and/or the scratch resistant coating over the concave surface **30** of the shaped glass substrate **28**, and applying the reflective coating **34** over or on the barrier layer **66** over or on the convex surface **32** (see FIG. **19**).

**[0095]** As can be appreciated, when the reflective layer **34** and/or the barrier layer **66** and/or the scratch resistant coating are applied to the flat glass piece **70**, and the coated flat glass is heated and shaped in the practice of a non-limiting embodiment of the invention, e.g. as discussed above, the reflective layer **34** and the barrier layer **66** and/or the scratch resistant coating have to be able to withstand the elevated temperatures of shaping, e.g. above 1200° F. Reflective coatings that can withstand elevated temperatures are known in the art, e.g. see U.S. Pat. No. 7,329,433 which patent in its entirety is hereby incorporated by reference. The patent discloses primer films that are deposited on a reflective layer to protect the reflective layer during high temperature processing.

**[0096]** In the preferred practice of the invention, the barrier layer **66** is applied using MSVD equipment. As is appreciated by those skilled in the art, the cathodes for MSVD coating have to be electrically conductive. To provide a silicon cathode that is electrically conductive, aluminum is added to the silicon, e.g. greater than 5 weight percent. The invention, however, is not limited to MSVD application of the barrier layer, and any known coating process for applying the barrier layer can be used in the practice of the invention. Further, the invention is not limited to having a homogenous barrier layer, and the invention contemplates a barrier layer having varying compositions of oxides of silicon and aluminum. For example in one non-limiting embodiment of the invention, a first barrier layer of an oxide of 60 atomic weight percent of aluminum and 40 atomic weight percent of silicon is applied to the surface of the glass and a second barrier layer of an oxide of 85 atomic weight percent of aluminum and 15 atomic weight percent of silicon is applied on the first barrier layer.

**[0097]** As can now be appreciated the barrier layer **66** of the invention can be used to prevent sodium ions from damaging conductive layers of photovoltaic devices. More particularly, and with reference to FIG. **20**, there is shown a photovoltaic device **184** having a conductive coating **186** over the barrier layer **66** of the invention. The barrier layer **66** is applied to surface **188** of glass sheet **190**. The barrier layer **66** prevents the sodium ions forming sodium compound precipitates that attack and damage the conductive coating **186** of the photovoltaic cell **184**.

**[0098]** As discussed in detail above, the barrier layer of an oxide of silicon and aluminum in addition to providing a barrier to prevent sodium ions from moving out of the glass, also provides a protective layer for the glass to prevent mechanical and chemical damage to the glass surface.

**[0099]** It will be readily appreciated by those skilled in the art that modifications can be made to the non-limiting embodiments of the invention without departing from the concepts disclosed in the foregoing description. Accordingly, the particular non-limiting embodiments of the invention described in detail herein are illustrative only and are not limiting to the scope of the invention, which is to be given the full breadth of the appended claims and any and all equivalents thereof.

What is claimed is:

**1**. A solar reflecting mirror having a curved reflective surface, comprising:

a transparent substrate having a convex surface and an opposite concave surface, and

a reflective coating over the convex surface and an alkali barrier layer over the concave surface wherein the reflective coating reflects selected wavelengths of the electromagnetic spectrum.

**2**. The solar mirror according to claim **1** wherein the alkali barrier layer has mechanical and chemical protective properties.

**3**. The solar mirror according to claim **1** wherein the barrier layer is on the concave surface of the substrate and comprises an oxide of silicon and aluminum.

**4**. The solar mirror according to claim **3** wherein the barrier layer has a weight percent of silicon greater than a weight percent of aluminum.

**5**. The solar mirror according to claim **4** wherein the barrier layer comprises 15 atomic percent aluminum and 85 atomic percent silicon, and the film is deposited by magnetron sputtering vacuum deposition.

**6**. The solar mirror according to claim **5** wherein the barrier layer has a thickness in the range of 700-950 nanometers.

**7**. The solar mirror according to claim **1** wherein the transparent substrate is a soda-lime-silica shaped glass substrate having a focal area and the barrier layer is a sodium ion barrier layer.

**8**. The solar mirror according to claim **7** wherein the barrier layer has a first surface and an opposite second surface, and the first surface of the barrier layer is in surface contact with the concave surface of the shaped glass substrate and the second surface of the barrier layer is facing away from the concave surface of the shaped glass substrate.

**9**. The solar mirror according to claim **8** wherein the barrier layer comprises an oxide of silicon and aluminum, and the first surface of the barrier layer has a first weight percent of silicon and the second surface of the barrier layer has a second weight percent of silicon, wherein the first weight percent of silicon is different than the second weight percent of silicon.

**10**. The solar mirror according to claim **7** wherein the shaped glass substrate comprises at least two shaped glass segments maintained together to provide the shaped glass substrate.

**11**. The solar mirror according to claim **10** wherein each segment comprises (1/(total segments of the parabolic shaped glass substrate)) part of the parabolic shaped glass substrate.

**12**. The solar mirror according to claim **7** wherein perimeter of the shaped glass substrate comprises four corners and four sides.

**13**. The solar mirror according to claim **7** wherein the shaped glass substrate has a strain pattern comprising a radial tension strain at a bottom area of the shaped glass substrate, and circumferential compression strain at a periphery of the shaped glass substrate; wherein as the distance from the periphery of the shaped glass substrate increases in a direction toward the bottom area of the shaped glass substrate, the circumferential compression strain decreases to an area designated as a “transition line” where circumferential tension strain and the radial tension strain are present in the glass, and as the distance from the transition line in a direction toward the bottom area of the shaped glass substrate increases, the circumferential tension strain increases.

**14**. The solar mirror according to claim **13** wherein the barrier coating covers the concave surface of the glass shaped substrate and has a constant thickness.

**15**. The solar mirror according to claim **14** wherein the barrier layer has a thickness in the range of 60 to 100 nanometers, and a composition comprising an oxide of silicon and aluminum, and the reflective coating is a silver coating.

**16**. The solar mirror according to claim **13** wherein the barrier coating increases in thickness as the distance from the periphery of the shaped glass substrate toward the bottom area of the shaped glass substrate increases

**17**. The solar mirror according to claim **16** wherein the barrier coating is in the thickness range of 40 to 100 nanometers.

**18**. The solar mirror according to claim **13** wherein the barrier coating has a first constant thickness from the perimeter of the shaped glass substrate to the transition line of the shaped glass substrate, and a second constant thickness from the transition line of the shaped glass substrate to the bottom area of the shaped glass substrate, wherein the first constant thickness is different from the second constant thickness.

**19**. The solar mirror according to claim **18** wherein the first constant thickness of the barrier coating is in the range of 40 to 60 nanometers, and the second constant thickness is in the range of greater than 60 to100 nanometers.

**20**. A method of making a solar reflecting mirror having a curved reflective surface, comprising:

providing a flat transparent sheet;

shaping the sheet to provide a shaped transparent substrate having a convex surface and an opposite concave surface and a focal area;

applying a reflective coating over the convex surface of the substrate, and

providing an alkali barrier layer over the concave surface of the substrate.

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