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(54) Raised microstructures

(57) Multiple embodiments of solid state microstructures, such as a condenser microphone, are disclosed. According to one embodiment, the transducer includes a fixed perforated member, a freely movable diaphragm spaced from the perforated member; a support ring in the perforated member maintaining the proper spacing between the diaphragm and the perforated member near the perimeter; and compliant suspension springs allowing the diaphragm to rest freely on the support ring and yet mechanically decouples the diaphragm from the perforated member. According to another embodiment, a raised micro-structure is disclosed for use in a silicon based device. The raised micro-structure comprises a generally planar film having a ribbed sidewall supporting the film.

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Description

TECHNICAL FIELD

[0001] The present invention relates to raised microstructures for silicon based devices.

BACKGROUND OF THE INVENTION

[0002] The use of silicon based capacitive transducers as microphones is well known in the art. Typically, such microphones consist of four elements: a fixed backplate; a highly compliant, moveable diaphragm (which together form the two plates of a variable air-gap capacitor); a voltage bias source and a buffer.

[0003] The batch fabrication of acoustic transducers using similar processes as those known from the integrated circuit technology offers interesting features with regard to production cost, repeatability and size reduction. Futhermore, the technology offers the unique possibility of constructing a single transducer having a wide bandwidth of operation with a uniform high sensitivity. This provides for a transducer that, with or no modification, can be used in such diverse applications as communications, audio, and ultrasonic ranging, imaging and motion detection systems.

[0004] The key to achieve wide bandwidth and high sensitivity lies in creating a structure having a small and extremely sensitive diaphragm. Designs have previously been suggested in U.S. Patent No. 5,146,435 to Bernstein, and in U.S. Patent No. 5,452,268 to Bernstein. In these structures, the diaphragm is suspended on a number of very flexible movable springs. However, the implementation of the springs leads to an inherent problem of controlling the acoustic leakage in the structure, which in turn affects the low frequency roll-off of the transducer. Another approach is to suspend the diaphragm in a single point, which also provides an extremely sensitive structure. See U.S. Patent No. 5,490,220 to Loeppert. Unfortunately, in this case the properties of the diaphragm material become critical, especially the intrinsic stress gradient which causes a free film to curl. Eventually, this leads to a similar problem for this structure concerning the reproducibility of the low frequency roll-off of the transducer.

[0005] The two mechanical elements, the backplate and diaphragm, are typically formed on a single silicon substrate using a combination of surface and bulk micromachining well known in the art. One of these two elements is generally formed to be planar with the surface of the supporting silicon wafer. The other element, while itself generally planar, is supported several microns above the first element by posts or sidewalls, hence the term "raised microstructure."

[0006] In general, the positioning of the two elements with respect to each other affects the performance of the entire device. Intrinsic stresses in the thin films comprising the raised microstructure cause the structure to deflect out of the design position. In a microphone in particular, variations in the gap between the diaphragm and backplate affect the microphone sensitivity, noise, and over pressure response.

[0007] Many other factors also affect the manufacture, structure, composition and overall design of the microphone. Such problems are more fully discussed and addressed in U.S. Patent No. 5,408,73 to Berggvist; U. S. Patent No. 5,490, 220 to Loeppert, and U.S. Patent No. 5,870,482 to Loeppert.

[0008] In the specific example of the design of a microphone backplate as a raised microstructure, the goal is to create a stiff element at a precise position relative to the diaphragm. One method to achieve this is to form the backplate using a silicon nitride thin film deposited over a shaped silicon oxide sacrificial layer which serves to establish the desired separation. This sacrificial layer is later removed through well known etch processes, leaving the raised backplate. Intrinsic tensile stress in the silicon nitride backplate will cause it to deflect out of position. Compressive stress is always avoided as it causes the structure to buckle.

[0009] FIG. 12 depicts one such raised microstructure 110 of the prior art. After the oxide is removed leaving the raised microstructure 110, an intrinsic tension will be present within the plate 112. This tension T results from the manufacturing process as well as from the difference between the coefficient of expansion of the material of the raised microstructure 110 and the supporting wafer 116. As shown, the tension T is directed radially outwards. The tension T intrinsic in the plate 112 will result in a moment as shown by arrow M about the base 118 of sidewall 114. This moment M results in a tendency of the plate 112 to deflect towards the wafer 116 in the direction of arrow D. This deflection of plate 112 results in a negative effect on the sensitivity and performance of the microphone.

[0010] A number of undesirable means to negate the effects of this intrinsic tension within a thin-film raised microstructure are known in the prior art. Among them are that the composition of the thin film can be adjusted by making it silicon rich to reduce its intrinsic stress levels. However, this technique has its disadvantages. It results in making the thin film less etch resistant to HF acid, increasing the difficulty and expense of manufacture. An additional solution known in the prior art would be to increase the thickness of the sidewall supporting the raised backplate thereby increasing the sidewall's ability to resist the intrinsic tendency of the thin film to deflect. While this sounds acceptable from a geometry point of view, manufacture of a thick sidewall when the raised microstructure is made using thin film deposition is impractical.

[0011] The object of the present invention is to solve these and other problems.

SUMMARY OF THE INVENTION

[0012] One aspect of the present invention results from a realization that a diaphragm has the highest mechanical sensitivity if it is free to move in its own plane. Furthermore, if the diaphragm is resting on a support ring attached to the perforated member, a tight acoustical seal can be achieved leading to a well controlled frequency roll-off of the transducer. Additionally, if a suspension method is chosen such that the suspension only allows the diaphragm to move in its own plane and does not take part in the deflection of the diaphragm to an incident sound pressure wave, complete decoupling from the perforated member can be achieved which reduces the sensitivity to external stresses on the transducer.

[0013] The present invention consists in a raised microstructure for use in a silicon based device, the raised microstructure comprising:

a generally planar thin-film;
a sidewall supporting the film;

wherein the sidewall has at least one rib formed therein.

[0014] The rib may be of generally arcuate, triangular or rectangular cross section.

BRIEF DESCRIPTION OF THE DRAWINGS:

[0015]

FIG. 1 is an enlarged schematic cross-sectional view taken along the line 1-1 in FIG. 2 of an acoustic transducer with clamped suspension in accordance with the present invention;
FIG. 2 is a top plan view, partially in phantom, of the acoustic transducer of FIG. 1;
FIG. 3 is a cross-sectional perspective view of the acoustic transducer of FIG. 2 taken along line 3-3 of FIG. 2;
FIG. 4 is an enlarged partial top view, partially in phantom, of an acoustic transducer similar to FIG. 2 wherein the perforated member includes an optionally shaped attach perimeter;
FIG. 5 is an enlarged schematic cross-sectional view taking along the plane 5-5 in FIG. 6 of an acoustic transducer with high compliance spring suspension in accordance with the present invention;
FIG. 6 is a top plan view, partially in phantom, of the acoustic transducer of FIG. 5;
FIG. 7 is a cross-sectional perspective view of the acoustic transducer of FIG. 6 taken along plane 7-7;
FIG. 8 is a greatly enlarged partial top view, partially in phantom, of an acoustic transducer similar to FIG. 5 wherein the perforated member includes an optionally shaped attach perimeter;
FIG. 9 is an electrical circuit for the detection of the change of the microphone capacitance whilst maintaining a constant electrical charge on the microphone;
FIG. 10 is an electrical circuit for the detection of the change of the microphone capacitance while maintaining a constant electrical potential on the microphone;
FIG. 11 is a cross-sectional perspective view of the acoustic transducer of FIG. 4;
FIG. 12 is a cross sectional schematic of a raised microstructure known in the prior art;
FIG. 13 is a cross sectional perspective view of a raised microstructure embodying the present invention;
FIG. 14 is a cross section of the raised microstructure of FIG. 13; and
FIG. 15 is a plan view of FIG. 13, taken along line 11-11.

DETAILED DESCRIPTION OF THE INVENTION:

[0016] While this invention is susceptible of embodiment in many different forms, there is shown in the drawings and will herein be described in detail preferred embodiments of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspect of the invention to the embodiments illustrated.

[0017] Referring now to the drawings, and particularly to FIGS. 1-3, an acoustic transducer in accordance with the present invention is disclosed. The acoustic transducer 10 includes a conductive diaphragm 12 and a perforated member 40 supported by a substrate 30 and separated by an air gap 20. A very narrow air gap or width 22 exists between the diaphragm 12 and substrate 30 allowing the diaphragm to move freely in its plane, thereby relieving any intrinsic stress in the diaphragm material and decoupling the diaphragm from the substrate. A number of small indentations 13 are made in the diaphragm to prevent stiction in the narrow gap between the diaphragm and substrate. The lateral motion of the diaphragm 12 is restricted by a support structure 41 in the perforated member 40, which also serves to maintain the proper initial spacing between diaphragm and perforated member. The support structure 41 may either be a continuous ring or a plurality of bumps. If the support structure 41 is a continuous ring, then diaphragm 12 resting on the support structure 41 forms tight acoustical seal, leading to a well controlled low frequency roll-off of the transducer. If the support structure 41 is a plurality of bumps, then the acoustical seal can be formed either by limiting the spacing between the bumps, by the narrow air gap 22, or a combination thereof.

[0018] The conducting diaphragm 12 is electrically insulated from the substrate 30 by a dielectric layer 31. A conducting electrode 42 is attached to the non-conductive perforated member 40. The perforated member contains a number of openings 21 through which a sacrificial layer (not shown) between the diaphragm and perforated member is etched during fabrication to form the air gap 20 and which later serve to reduce the acoustic damping of the air in the air gap to provide sufficient bandwidth of the transducer. A number of openings are also made in the diaphragm **12** and the perforated member **40** to form a leakage path **14** which together with the compliance of the back chamber (not shown), on which the transducer will be mounted, forms a high-pass filter resulting in a roll-off frequency low enough not to impede the acoustic function of the transducer and high enough to remove the influence of barometric pressure variations. The openings **14** are defined by photo lithographic methods and can therefore be tightly controlled, leading to a well defined low frequency behavior of the transducer. The attachment of the perforated member **40** along the perimeter **43** can be varied to reduce the curvature of the perforated member due to intrinsic internal bending moments. The perimeter can be a continuous curved surface (FIGS. 1-3) or discontinuous, such as corrugated (FIG. 4). A discontinuous perimeter **43** provides additional rigidity of the perforated member **40** thereby reducing the curvature due to intrinsic bending moments in the perforated member **40**.

[0019] Turning to FIGS. 5-7, an alternative embodiment of an acoustic transducer in accordance with the present invention is depicted. The transducer **50** includes a conductive diaphragm **12** and a perforated member **40** supported by a substrate **30** and separated by an air gap **20**. The diaphragm **12** is attached to the substrate through a number of springs **11**, which serve to mechanically decouple the diaphragm from the substrate, thereby relieving any intrinsic stress in the diaphragm. Moreover, the diaphragm is released for stress in the substrate and device package.

[0020] The lateral motion of the diaphragm **12** is restricted by a support structure **41** in the perforated member **40**, which also serves to maintain the proper initial spacing between diaphragm and perforated member **40**. The support structure **41** may either be a continuous ring or a plurality of bumps. If the support structure **41** is a continuous ring, then diaphragm **12** resting on the support structure **41** forms tight acoustical seal, leading to a well controlled low frequency roll-off of the transducer. If the support structure **41** is a plurality of bumps, then the acoustical seal can be formed by limiting the spacing between the bumps, or by providing a sufficiently long path around the diaphragm and through the perforations **21.**

[0021] The conducting diaphragm **12** is electrically insulated from the substrate **30** by a dielectric layer **31**. A conducting electrode **42** is attached to the non-conductive perforated member **40**. The perforated member contains a number of openings **21** through which a sacrificial layer (not shown) between the diaphragm **12** and the perforated member is etched during fabrication to form the air gap **20** and which later serves to reduce the acoustic damping of the air in the air gap to provide sufficient bandwidth of the transducer. A number of openings are made in the support structure **41** to form a leakage path **14** (FIG. 6) which together with the compliance of the back chamber (not shown) on which the transducer can be mounted forms a high-pass filter resulting in a roll-off frequency low enough not to impede the acoustic function of the transducer and high enough to remove the influence of barometric pressure variations. The openings **14** are preferably defined by photo lithographic methods and can therefore be tightly controlled, leading to a well defined low frequency behavior of the transducer. The attachment of the perforated member along the perimeter **43** can be varied to reduce the curvature of the perforated member due to intrinsic internal bending moments. The perimeter **43** can be smooth (FIGS. 5-7) or corrugated (FIGS. 8 and 11). A corrugated perimeter provides additional rigidity of the perforated member thereby reducing the curvature due to intrinsic bending moments in the perforated member.

[0022] In operation, an electrical potential is applied between the conductive diaphragm **12** and the electrode **42** on the perforated member. The electrical potential and associated charging of the conductors produces an electrostatic attraction force between the diaphragm and the perforated member. As a result, the free diaphragm **12** moves toward the perforated member **40** until it rests upon the support structure **41**, which sets the initial operating point of the transducer with a well defined air gap **20** and acoustic leakage through path **14**. When subjected to acoustical energy, a pressure difference appears across the diaphragm **12** causing it to deflect towards or away from the perforated member **40**. The deflection of the diaphragm **12** causes a change of the electrical field, and consequently capacitance, between the diaphragm **12** and the perforated member **40**. As a result the electrical capacitance of the transducer is modulated by the acoustical energy.

[0023] A method to detect the modulation of capacitance is shown in FIG. 9. In the detection circuit **100**, the transducer **102** is connected to a DC voltage source **101** and a unity-gain amplifier **104** with very high input impedance. A bias resistor **103** ties the DC potential of the amplifier input to ground whereby the DC potential "Vbias" is applied across the transducer. Assuming in this circuit a constant electrical charge on the transducer, a change of transducer capacitance results in a change of electrical potential across the transducer, which is measured by the unity-gain amplifier.

[0024] Another method to detect the modulation of capacitance is shown in FIG. 10. In the detection circuit **200**, the transducer **202** is connected to a DC voltage source **201** and a charge amplifier configuration **205** with a feedback resistor **203** and capacitor **204**. The feedback resistor ensures DC stability of the circuit and maintains the DC level of the input of the amplifier, whereby the DC potential "Vbias-Vb" is applied across the transducer. Assuming in this circuit a constant potential across the transducer, due to the virtual ground principle of the amplifier, a change of capacitance causes a change of charge on the transducer and consequently on the input side of the feedback capacitor leading to an offset between the negative and positive input on the amplifier. The amplifier supplies a mirror charge on output side of the feedback capacitor to remove the offset, resulting in a change of output voltage "Vout." The charge gain in this circuit is set by the ratio between the initial transducer capacitance and the capacitance of the feedback capacitor. An advantage of this detection circuit is that the virtual ground principle of the amplifier eliminates any parasitic capacitance to electrical ground in the transducer, which otherwise attenuate the effect of the dynamic change of the microphone capacitance. However, care should be taken to reduce parasitic capacitances to minimize the of gain of any noise on the signal "Vb" and the inherent amplifier noise.

[0025] An embodiment of the raised microstructure **110** of the present invention is shown in FIGS. 13 and 14. The raised microstructure **110** comprises a generally circular thin-film plate or backplate **112** supported by a sidewall **114**.

[0026] The raised microstructure **110** is comprised of a thin film plate **112** of silicon nitride deposited on top of a sacrificial silicon oxide layer on a silicon wafer **116** using deposition and etching techniques readily and commonly known to those of ordinary skill in the relevant arts. The sacrificial silicon oxide layer has already been removed from the figure for clarity. The sidewall **114** of the raised microstructure **110** is attached at its base **118** to the silicon wafer **116** and attached at its opposite end to the plate **112**. The sidewall **114** is generally perpendicular to plate **112**, but it is noted other angles may be utilized between the sidewall **114** and the plate **112**.

[0027] FIG. 15 shows a plan view of the assembly of FIG. 13 with a surface of the sidewall **114** of the present invention shown in phantom. It can be seen that the sidewall **114** of the present invention as shown in FIGS. 13-15 is ribbed, forming a plurality of periodic ridges **120** and grooves **122.** In the preferred embodiment, the ridges **120** and grooves **122** are parallel and equally spaced, forming a corrugated structure. Furthermore, the preferred embodiment utilizes ridges **120** and grooves **122** of a squared cross section. The effect of corrugating the side wall in this manner is to create segments **124** of the sidewall **114** that are radial, as is the intrinsic tension **T** of the plate **112.** By making portions of the sidewall **114** radial, as is the tension **T**, the sidewall **114** is stiffened. It has been found that the sidewall **114** of the prior art, which is tangential to plate **112**, is easily bent as compared to the radial segments **124** of the present invention.

[0028] Other geometries than that shown in FIGS. 13-15 of the corrugations or ridges **120** and grooves **122** can be imagined and used effectively to increase the sidewall's **114** ability to resist moment **M** and the geometry depicted in the FIGS. 13-15 is not intended to limit the scope of the present invention.

[0029] For example, a generally annular geometry, generally triangular geometry or any combination or variation of these geometries or others could be utilized for the ridges **122** and grooves **124**.

[0030] In the preferred embodiment, the corrugations are radial and hence the sidewalls **114** are parallel to the tension in the backplate **112**. Furthermore, the sacrificial material is etched in such a way that the sidewalls **114** are sloped with respect to the substrate to allow good step coverage as the thin film backplate **112** is deposited.

[0031] While the specific embodiments have been illustrated and described, numerous modifications come to mind without significantly departing from the spirit of the invention and the scope of protection is only limited by the scope of the accompanying Claims.

Claims

1. A raised microstructure (110) for use in a silicon based device, the raised microstructure (110) comprising:

a generally planar thin-film;
a sidewall (114) supporting the film;

wherein the sidewall has at least one rib (120) formed therein.

2. The raised microstructure of Claim 1 wherein the sidewall (114) is corrugated.

3. The raised microstructure of Claim 1 wherein the rib (120) has a generally arcuate cross section.

4. The raised microstructure of Claim 1 wherein the rib (120) has a generally triangular cross section.

5. The raised microstructure of Claim 1 wherein the rib (120) has a generally rectangular cross section.

6. The raised microstructure of Claim 1 wherein the thin-film (112) comprises one plate of a silicon based capacitive transducer.

7. The raised microstructure of Claim 1 wherein the thin-film (112) comprises a rigid backplate of a silicon based microphone.

FIG. 1

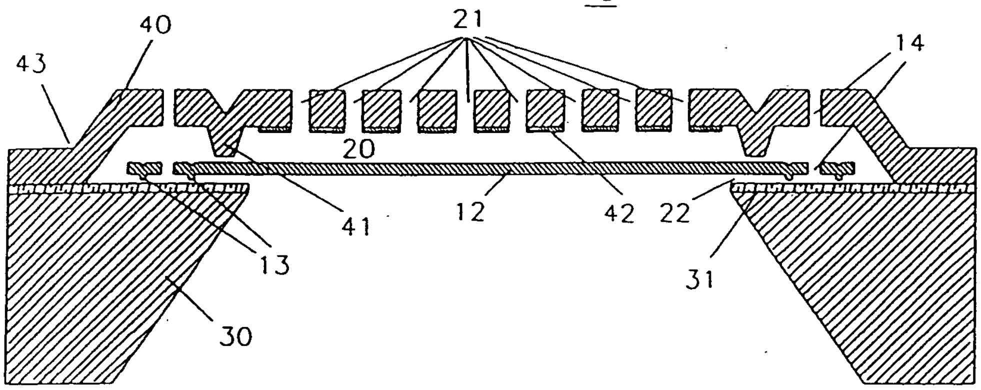


FIG. 2

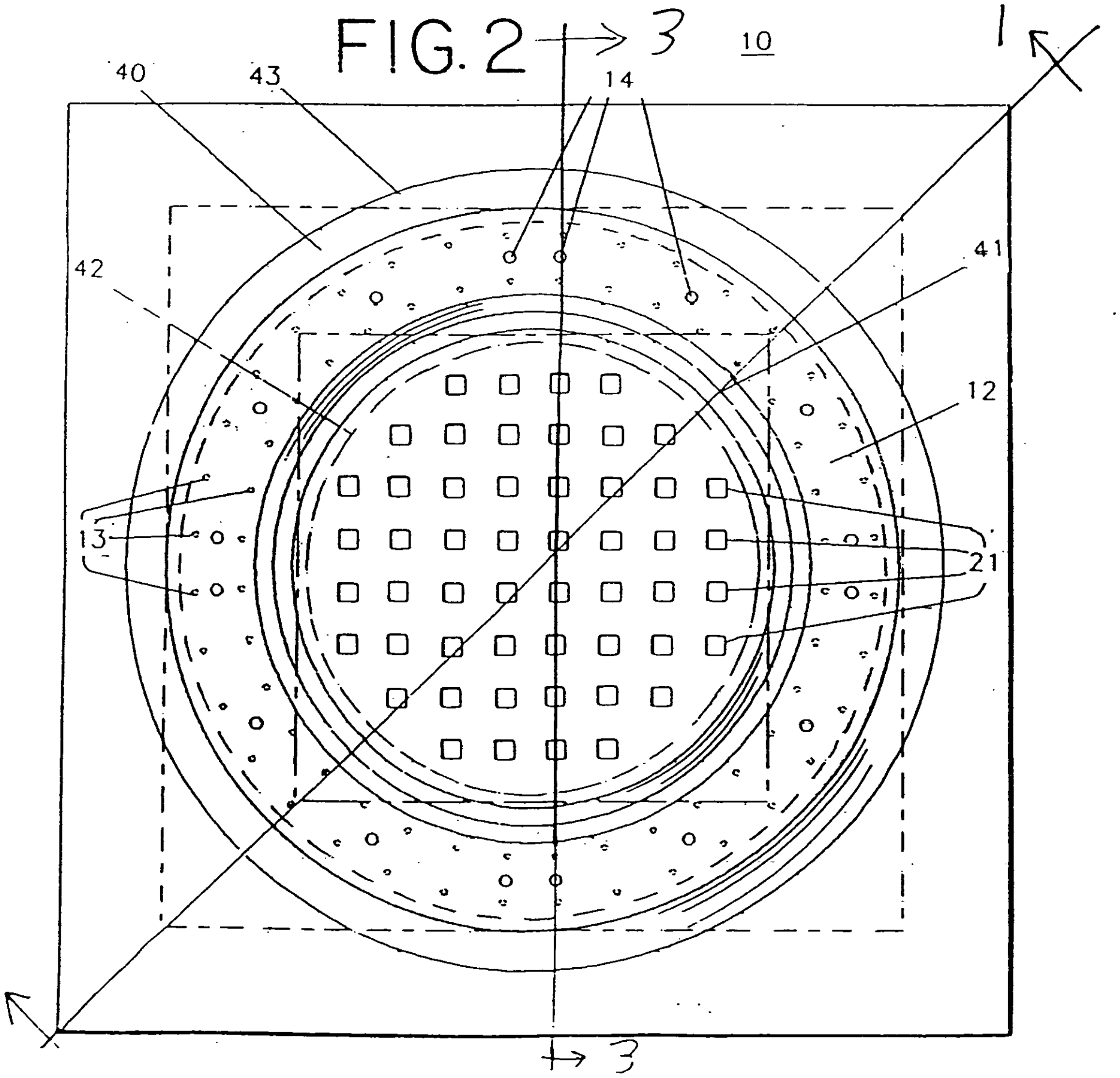


FIG. 3

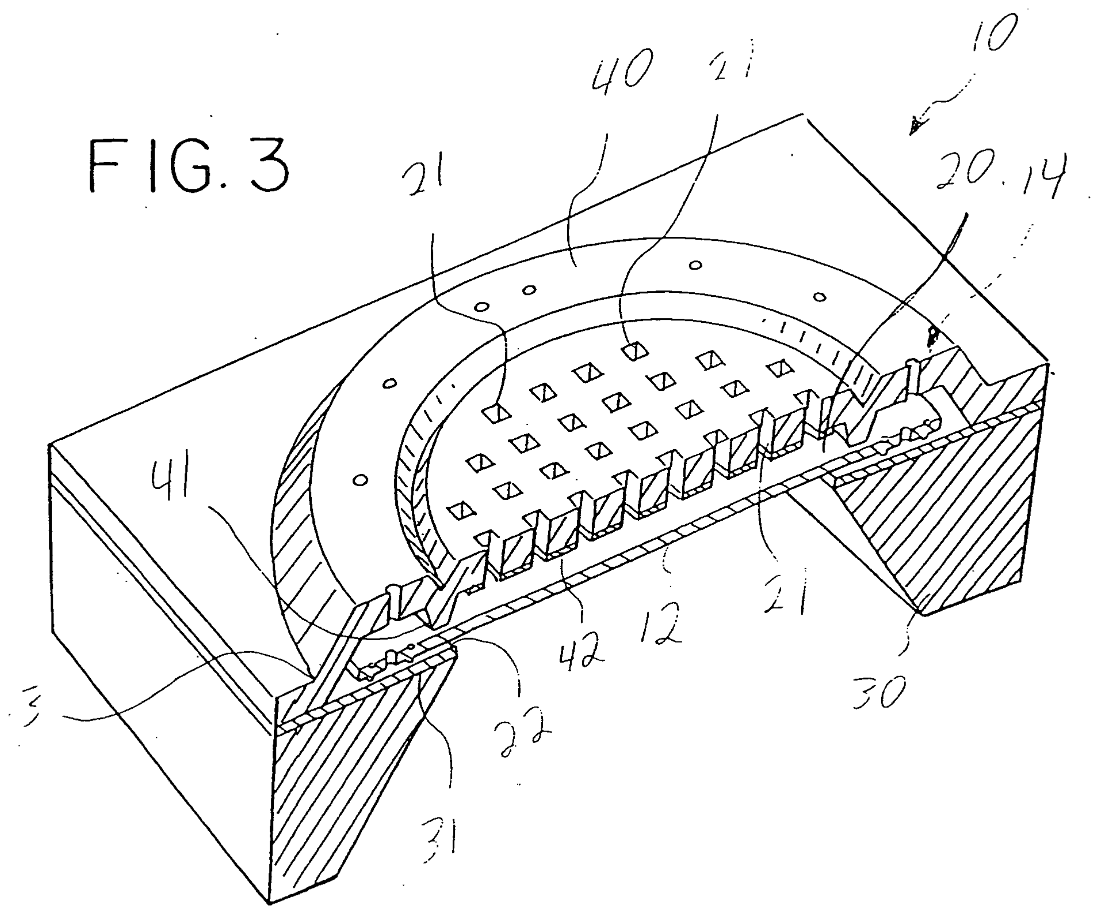


FIG. 4

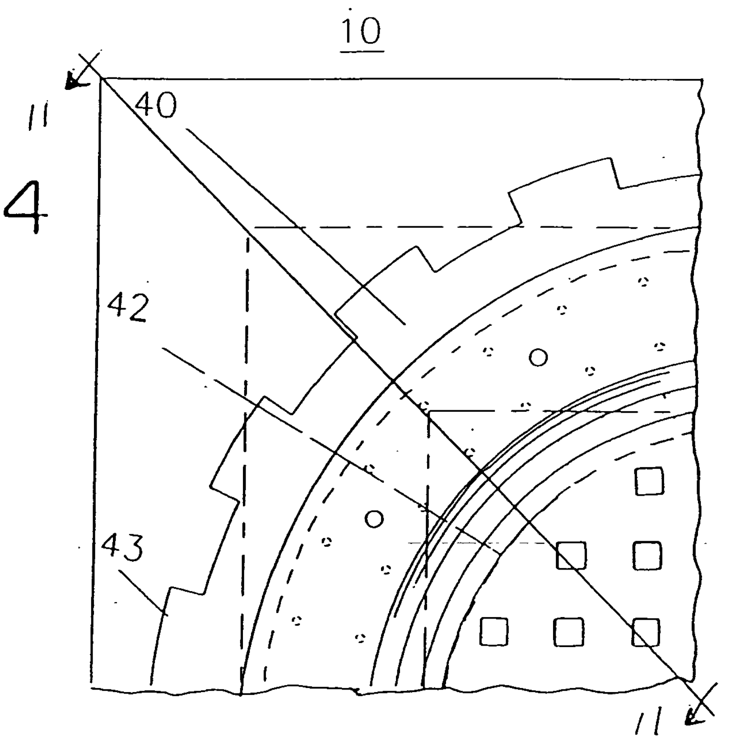


FIG. 5

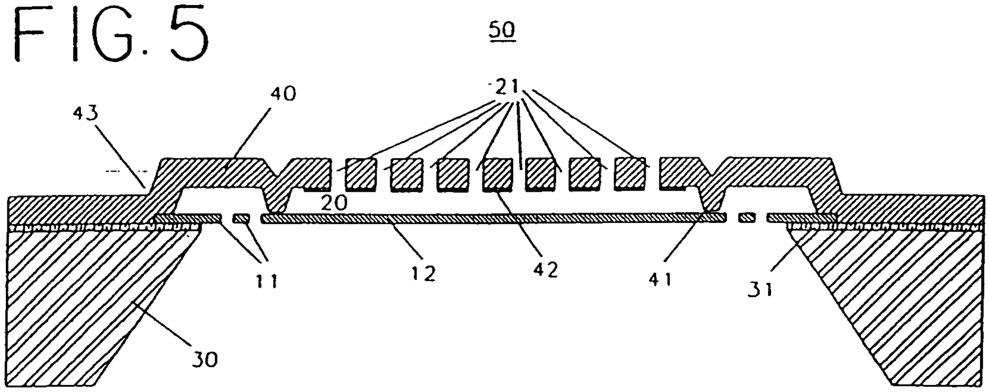


FIG. 6

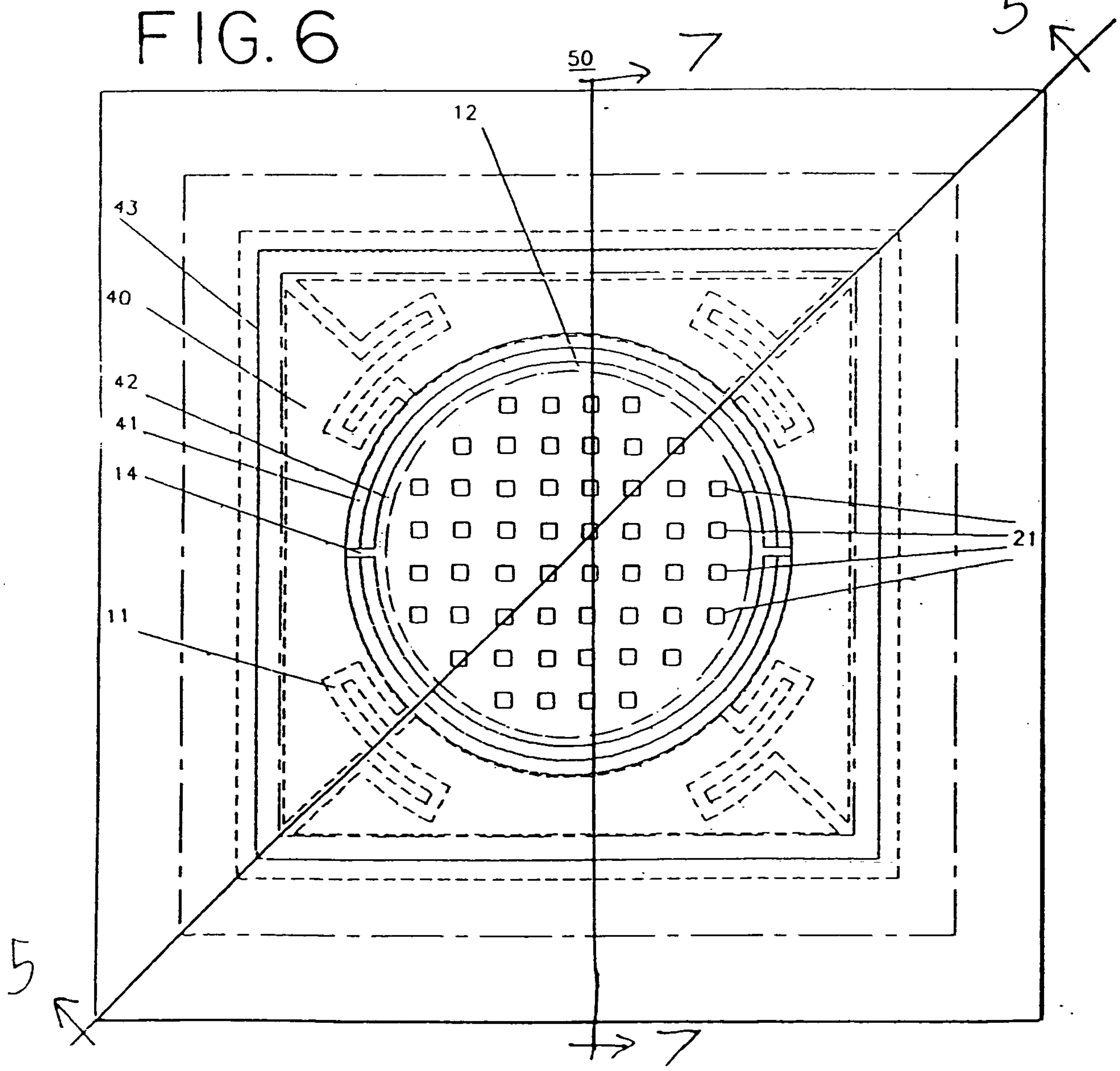


FIG. 7

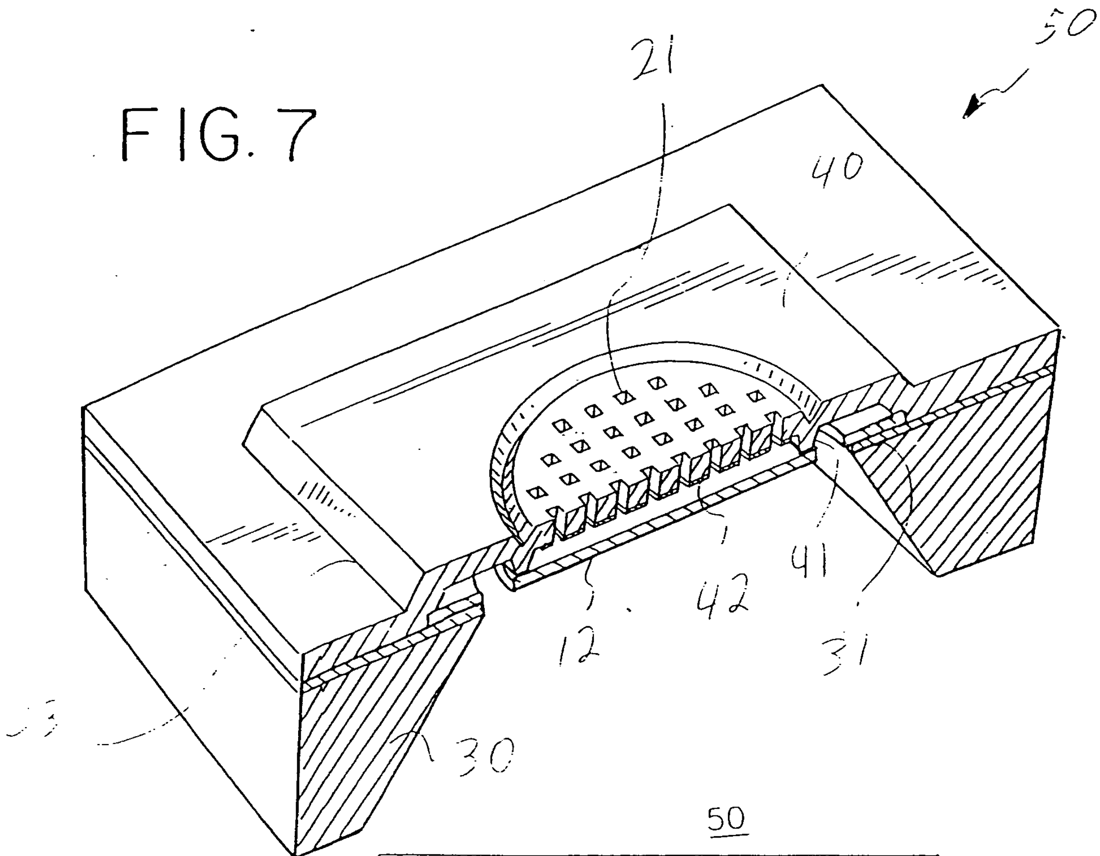
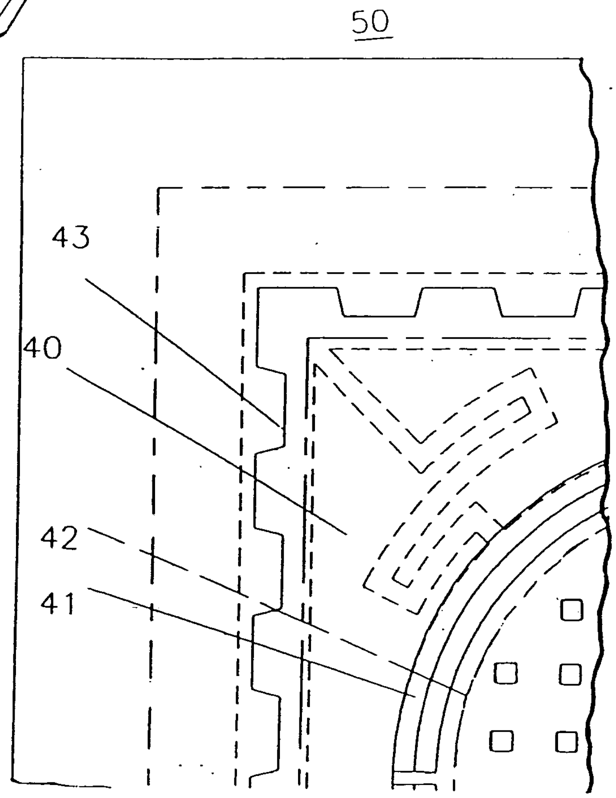


FIG. 8



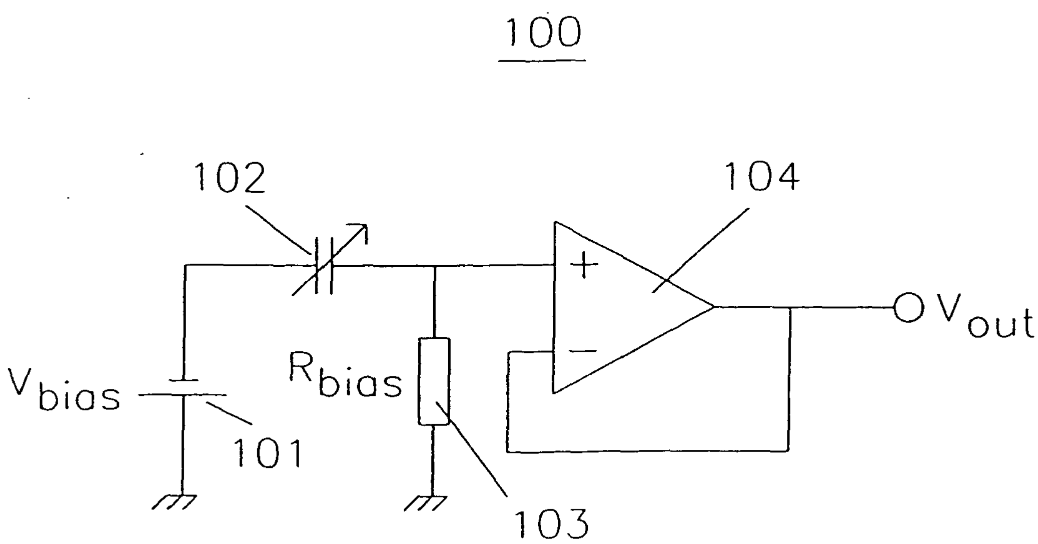


FIG. 9

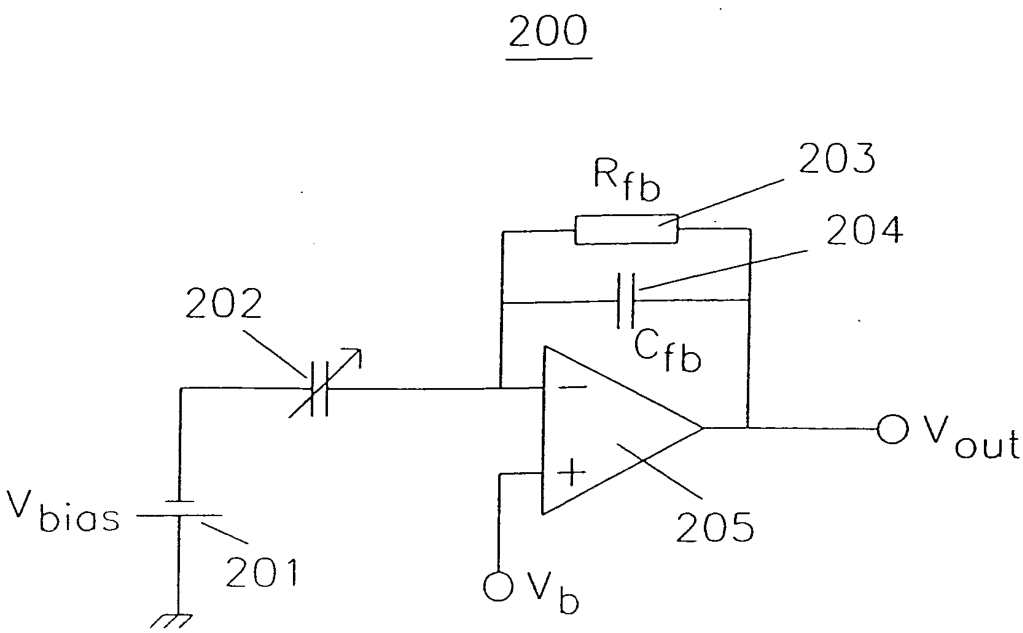


FIG. 10

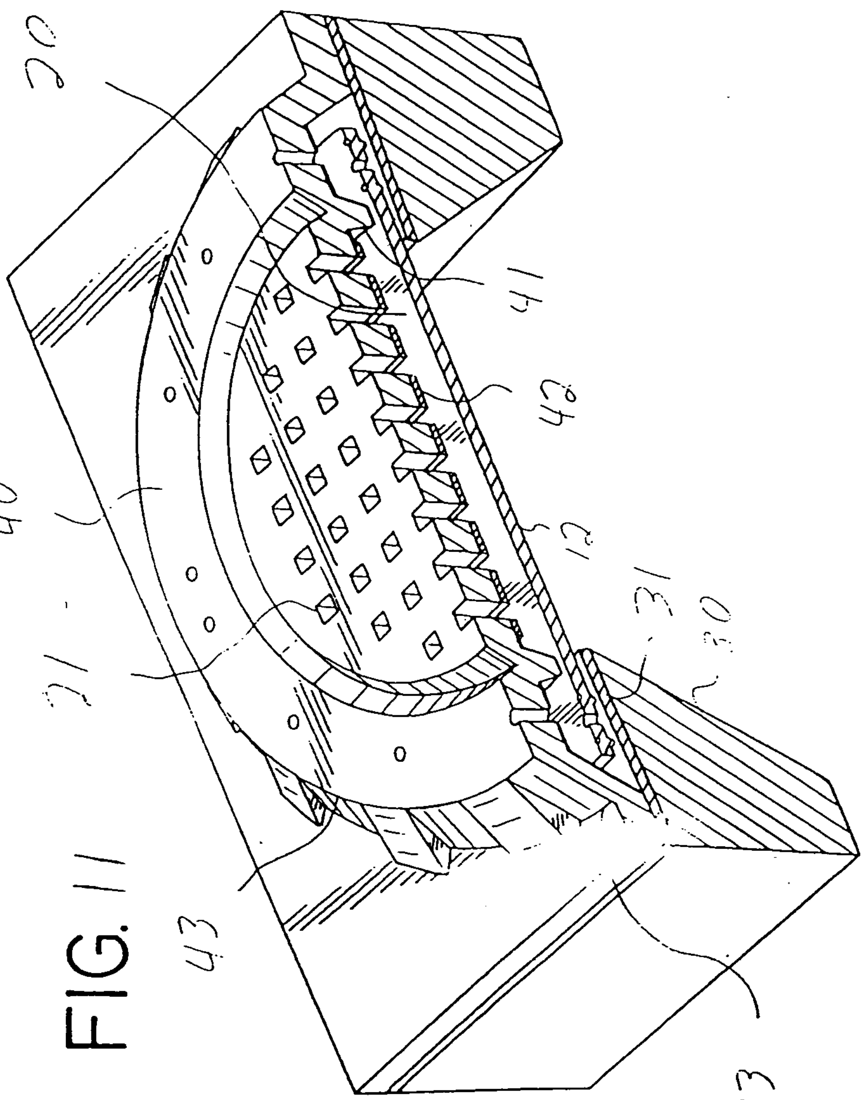
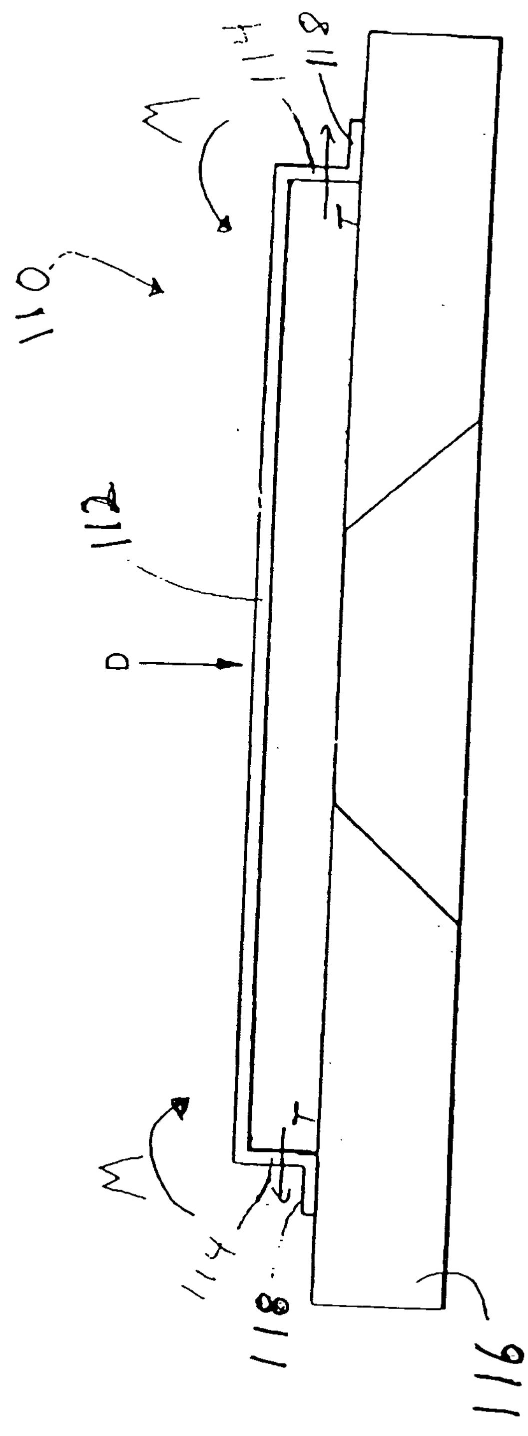


FIG. 11

FIG. 12



PRIOR ART

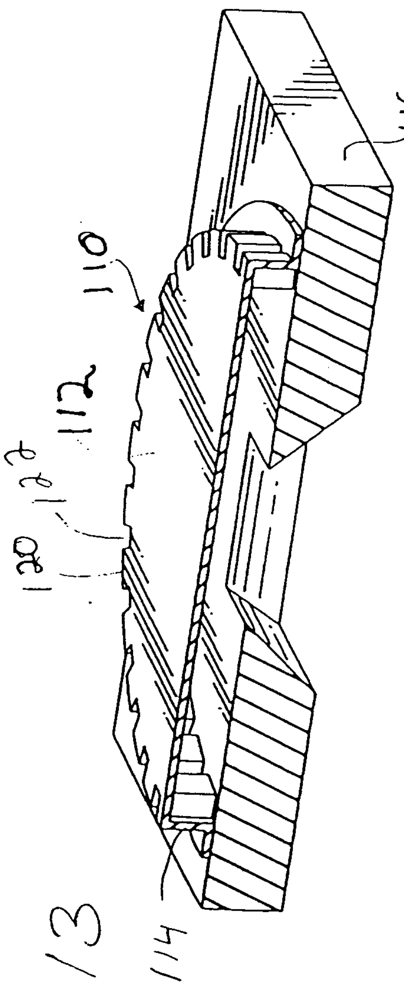


FIG. 13

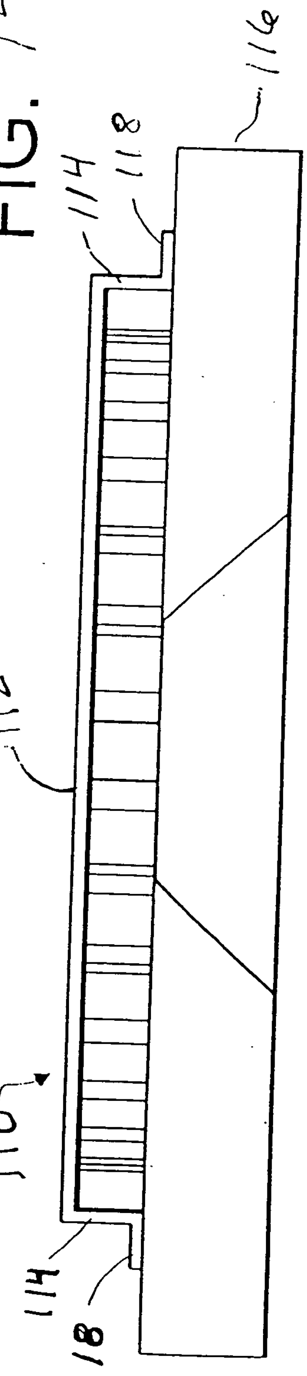


FIG. 14

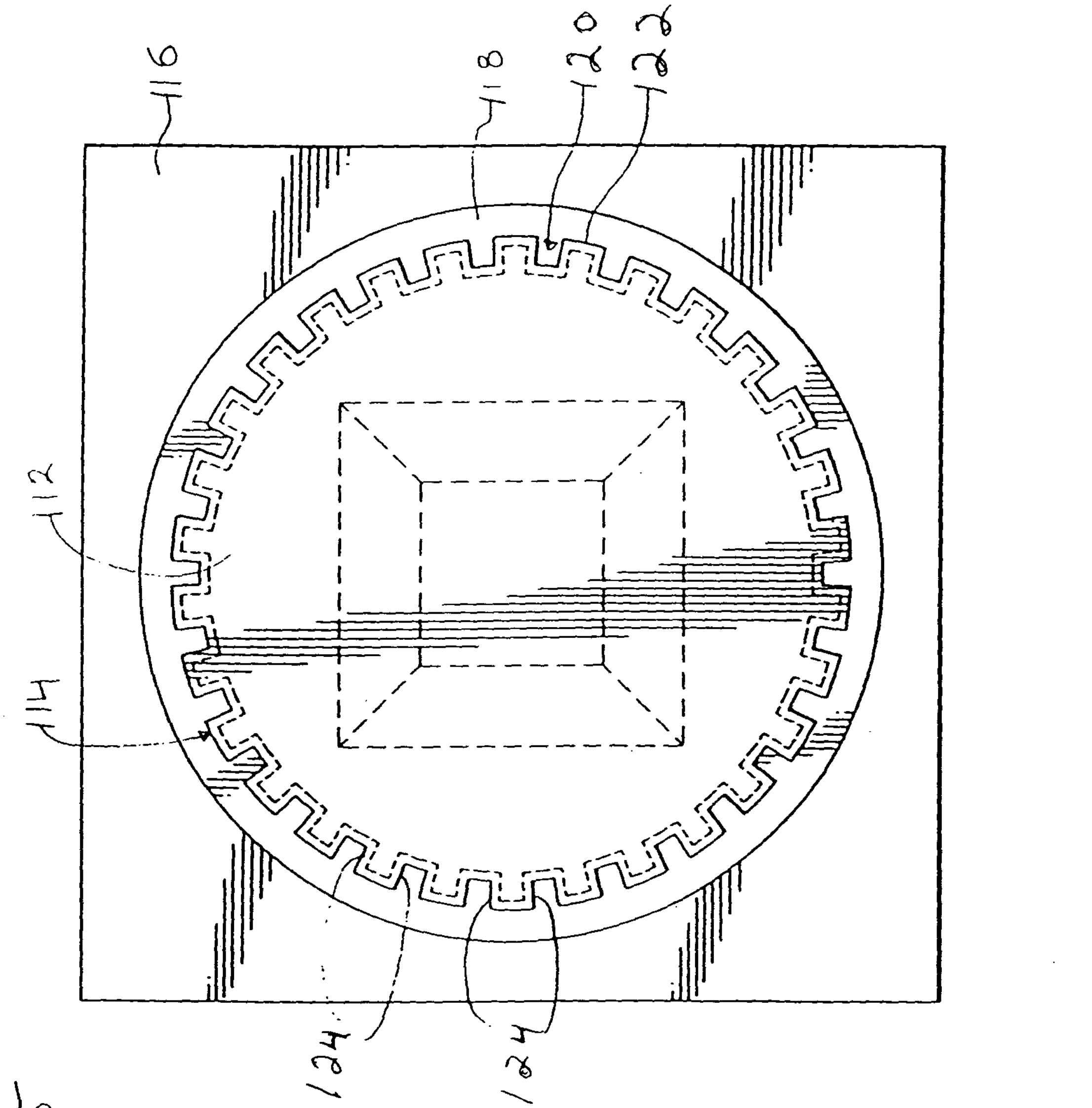


FIG. 15