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(54) Acceleration sensor and a method for its manufacture

Beschleunigungsmessaufnehmer sowie Verfahren zu seiner Herstellung

Capteur d'accélération et procédé pour sa fabrication

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(56) References cited:
GB-A- 1 300 367 **US-A- 4 848 157**

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Description

[0001] The present invention relates to devices for converting an acceleration into an electrical quantity and, more particularly, to an acceleration sensor and to a method for its manufacture.

[0002] Acceleration sensors are used in many fields of technology, for example in the motor vehicle industry where they are used to control various devices such as air bags, ABS braking systems, active suspensions, inertial orientation systems and several engine parts.

[0003] Various types of acceleration sensors are known which differ from each other in their construction and principle of operation, see e.g. US-A-4 848 157. In recent years, alongside conventional sensors made on the macroscopic scale and constituted essentially by mechanical switches sensitive to acceleration, miniaturised planar sensors have been devised and made available which are made using techniques typical for semiconductor devices such as the planar technology. In many cases, they are formed on a substrate of semiconductive material together with the circuits and electronic components necessary for the amplification and processing of the signal produced thereby. These latter sensors have many advantages over conventional ones, as well as the obvious one of smaller size: low cost, great reliability, improved signal-to-noise ratio, integrability with processing and memory devices, better reproducibility, etc.

[0004] The methods of manufacture of planar sensors are based on working a wafer of semiconductive material, typically silicon, on both of its faces, essentially by means of bulk micromachining, or working on only one face by deposition and selective removal of thin films and surface micromachining. This latter type of working is particularly suitable for integration of the structure of the sensor with the processing circuits.

[0005] With regard to the operation of planar sensors, this is based on the effect of the acceleration on a structure which has a so-called seismic mass, anchored to the substrate by a mechanical suspension element. The seismic mass, when subject to an inertial force due to an acceleration, moves relative to the substrate, possibly deforming and causing stress in the suspension means. The movement and/or deformation and/or stress are converted into an electrical signal which is then amplified and processed as necessary.

[0006] In a known sensor, the seismic mass constitutes one electrode of a capacitor, the second electrode of which is in the substrate. A movement of the seismic mass causes a variation in the capacitance of the capacitor which in turn is detected and processed by a suitable circuit.

[0007] An object of the invention is to provide a sensor of the type which can be made by surface micromachining, the operation of which is based on the effect of an inertial force on an element anchored to the substrate and which lends itself to being made easily by techniques compatible with the usual industrial processes for the manufacture of integrated circuits, and which is both very small and capable of producing an analogue signal.

[0008] Another object of the invention is to provide a method for the manufacture of a sensor of the type indicated above.

[0009] These objects are achieved by the acceleration sensor defined in Claim 1 and by putting into practice the method defined in Claim 6.

[0010] The invention will be better understood from the following detailed description of one embodiment thereof, given by way of non-limitative example, made in relation to the appended drawings, in which:

Figures 1 to 3 show schematically the structure of an acceleration sensor according to the invention, respectively, in plan, in section on the line II-II of Figure 1 and in section on the line III-III of Figure 1,

Figure 4 is a perspective, sectional view of part of an acceleration sensor according to the invention,

Figures 5 to 10 are sectional views of part of the acceleration sensor of Figure 4 in various stages of manufacture; and

Figures 11 to 16 are sectional views of another part of the acceleration sensor of Figure 4 in the same manufacturing stages as in Figures 5 to 10.

[0011] With reference firstly to Figures 1 to 3, the sensor according to the invention has a structure substantially like that of an integrated transformer made by planar technology on a substrate. The core of the transformer, indicated 11, is formed on the substrate, for example a silicon wafer indicated 10. The core is in the shape of a frame and has two parts, including two opposite sides, fixed to the substrate 10 but insulated therefrom by a layer of dielectric material 12, for example silicon dioxide. Two windings constituted by metal conductors are formed around the two opposite sides of the core and are insulated from the core and encapsulated in the dielectric layer 12. One of the two windings, indicated 13, which acts as the excitation coil, is adapted to be connected to an external power supply, for example a constant voltage supply 14, as shown in the drawing. The other winding, indicated 15, which serves as the reading coil, is adapted to be connected to measuring means shown in the drawing by a block 16, for measuring an electrical quantity induced therein.

[0012] The dielectric layer 12 has an opening 17 under part of the core whereby the other two opposite sides of the core each have a suspended portion, that is, a portion which is free to bend if appropriately stressed.

[0013] The operation of the sensor is based on the same operating principle as a transformer, that is, on the generation of an electromotive force as a result of a variation in magnetic flux. The excitation coil generates a magnetic flux in the core which, if it varies, induces an electrical voltage in the reading coil. While, however, in an ordinary transformer, the excitation coil is supplied with a voltage which varies with time, in the sensor according to the invention, the excitation coil 13 is supplied with a constant voltage and the variation in magnetic flux is caused by a geometric deformation of the core 11 due to the acceleration. More particularly, when the structure undergoes an acceleration perpendicular to the substrate, as shown by an arrow F in Figure 3, the suspended portions of the core 11 bend and thus lengthen as a result of the inertial forces which act thereon. The lengthening of the core 11 causes a variation in magnetic reluctance in the magnetic circuit constituted by the core and hence a variation in the magnetic flux which is detected by the reading coil 15 as a voltage across its terminals.

[0014] Analytically, the operation of the sensor may be described by consideration of the laws which link the magnetic flux in the core to the (constant) current I which passes through the coil (Hopkinson's Law):

$$N_1 I = R\Phi$$

where N_1 is the number of turns in the excitation coil 13 and R is the magnetic reluctance of the core 11, and the law of magnetic reluctance:

$$R = \frac{L}{\mu S}$$

where μ is the magnetic permeability of the material of which the core is made and L and S are the length and section of the magnetic circuit, respectively.

[0015] It can be shown that the absolute value of the voltage V induced in the reading coil is:

$$|V| = \frac{\partial \Phi}{\partial t} = N_2 \cdot N_1 \cdot I \cdot \frac{\mu \cdot S}{L^2} \cdot \frac{\partial L}{\partial A} \cdot \frac{\partial}{\partial t}(A)$$

where N_2 is the number of turns in the reading coil 15 and A is the acceleration. The measurement of the voltage V thus gives a measure of the acceleration A.

[0016] For the manufacture of an acceleration sensor according to the invention, one starts from a substrate 10 constituted by a single crystal of silicon in which the circuits necessary for the amplification and processing of the signal generated by the sensor have been formed by known techniques for the manufacture of monolithic integrated circuits.

[0017] Figure 4 shows a portion of the substrate 10 containing the acceleration sensor according to the invention in a final stage in the manufacturing process. The various steps in the process are described with reference to Figures 5 to 16. It is noted that Figures 5 to 10 show the structure in section along the line A-A of Figure 4 and Figures 11 to 16 show the structure in section along the line B-B of Figure 4.

[0018] Figures 5 and 11 show the substrate 10 as it appears in the manufacturing step immediately after the deposition of a dielectric layer which serves to insulate the circuit elements of polycrystalline silicon, for example the gate electrodes of the MOSFET transistors, from the metals which will be formed during a subsequent step in the process. While in conventional processes the dielectric is constituted solely by silicon dioxide, in the process of the invention it is constituted by a layer of silicon nitride 20 with a layer of silicon dioxide 21 superimposed thereon. It should be noted that the substrate has pads 23 of silicon dioxide (field oxide) partly encapsulated in the single silicon crystal which define a sunken zone (active area) of the substrate by surrounding it. This structure is manufactured by the known oxidation technique for localised growth at high temperature in an oxidising environment commonly used for the manufacture of MOS-type integrated circuits.

[0019] A metal layer, for example of aluminium, is deposited on the silicon dioxide layer 21 and from this there are formed, by known photolithographic techniques, metal segments 24 located in two adjacent series, like those indicated 30 in Figure 4, intended to constitute parts of the windings 13 and 15. The whole is then covered by a layer 25 of silicon nitride (Figures 6 and 12). A layer 26 of metal, for example a chromium-copper-chromium multi layer, is formed on the latter by vapour-phase deposition and serves to anchor the ferromagnetic core material firmly to the substrate and then a layer 27 of a polymer, for example a polyamide resin, is formed by spinning and baked in an oven. A recess in the form of a frame is formed in the polymer layer 27 by plasma etching through an aluminium mask. The recess formed is then filled with a ferromagnetic alloy, for example iron (19%) and nickel (81%) by electrolysis to form the core 28. The structure shown in Figures 7 and 13 is thus obtained.

[0020] The process continues with the removal of the remaining polymer layer 27 and the uncovered part of the nitride layer 25. A layer 29 of silicon dioxide is then formed (Figures 8 and 14) by deposition of tetraorthosilicate (TEOS) from the vapour phase at low pressure (LPCVD) and decomposition. Apertures are then formed in the layer 29 to form connection pathways between the metal segments 24 and similar segments which complete the turns of the windings 13 and 15. These segments, indicated 30, and the connection pathways, indicated 31, are formed by the usual photolithographic techniques by deposition and subsequent selective etching of a second metal, for example aluminium. A layer 32 of silicon dioxide doped with phosphorus is then deposited for insulation and passivation. At this point an aperture, in this case rectangular, is formed in the layers 32 and 29 of silicon dioxide by chemical etching (Figures 9 and 15) and then in the underlying layer 25 of silicon nitride in order to uncover two portions of two parallel sides of the frame-shaped core (Figure 1).

[0021] Finally the structure is subjected to isotropic chemical attack, for example by hydrofluoric acid, completely to remove the portion of the silicon dioxide accessible through the aperture, thus uncovering the nitride layer 20. The structure shown in Figures 10 and 16 is thus obtained.

[0022] This is subjected to operations to form the electrical connections with the exterior and then encapsulated hermetically by conventional methods in a metal casing. This operation may be carried out in air or in nitrogen, preferably at a pressure below atmospheric.

[0023] Although only a single embodiment of the invention has been described and illustrated, it is clear that numerous variations and modifications may be made thereto with the use of the same innovative concept. For example, the ferromagnetic core could be of a different shape, for example it could be open instead of closed and have one or more, cantilevered portions instead of the suspended portions being anchored at both ends.

Claims

1. An acceleration sensor formed by planar technology on a substrate (10), including a core (11) of ferromagnetic material and, coupled inductively together by this core, a first winding (13) adapted to be connected to a power supply (14) and a second winding (15) adapted to be connected to circuit means (16) for measuring an electrical quantity induced therein, the core (11) having at least one suspended portion which is free to bend as a result of an inertial force due to an accelerative movement of the sensor itself.

2. An acceleration sensor according to Claim 1, in which the core (11) is in the shape of a frame with two opposite sides fixed to the substrate (10) and in which the substrate (10) has a sunken area at least in correspondence with the other two opposite sides, thus leaving two portions of the core suspended.

3. A device for converting an acceleration into an electrical quantity comprising an acceleration sensor according to any one of the preceding claims and processing circuits formed in the same substrate as that in which the sensor is formed.

4. A device according to Claim 3, including a casing which hermetically seals the substrate with the sensor in an air atmosphere.

5. A device according to Claim 3, including a casing which hermetically seals the substrate with the sensor in a nitrogen atmosphere.

6. A method for the manufacture of an acceleration sensor according to Claim 1, including the following steps:

   subjecting a wafer comprising a single crystal of silicon (10) to oxidation for localised growth at high temperature in an oxidising environment so as to form raised pads of silicon dioxide (23) which bound a sunken area on the wafer,
   forming a first layer of silicon nitride (20) on the sunken area,
   forming a first layer of silicon dioxide (21) on the first layer of silicon nitride (20) and on the pads (23),
   forming a first series and a second series of adjacent metal segments (24) over the pads (23),
   forming a second layer of silicon nitride (25) over the sunken area and the pads (23) and covering the metal segments (24),
   forming a core (28) of ferromagnetic material over the metal segments (24),
   forming a second layer of silicon dioxide (27) over the sunken area and the pads (23) and encapsulating the core (28),
   forming a third series and a fourth series of adjacent metal segments (30) respectively over the first and the second series of adjacent metal segments (24) and a multiplicity of electrical connecting pathways (31) between the segments of the first (24) and third (30) series and between the segments of the second (24) and fourth (30) series so as to form the first winding (13) and the second winding (15) respectively,
   removing part of the second layer of silicon dioxide (27) so as to uncover at least a portion of the core (28),
   removing the second layer of silicon nitride (25) left uncovered by the removal of part of the second layer of silicon dioxide (27),
   subjecting the first layer of silicon dioxide (21) left uncovered by the removal of the second layer of silicon dioxide (27) to isotropic chemical attack so as to expose the first layer of silicon nitride (20) over the entire sunken area so that the said portion of the core (28) remains suspended and spaced from the sunken area of the wafer.

Patentansprüche

1. Ein Beschleunigungssensor, der durch Planartechnik auf einem Substrat (10) gebildet ist, der einen Kern (11) aus ferromagnetischem Material und, durch diesen Kern induktiv aneinandergekoppelt, eine erste Wicklung (13), die dazu konzipiert ist, mit einem Leistungsversorgungsgerät (14) verbunden zu sein, und eine zweite Wicklung (15), die dazu konzipiert ist, mit einer Schaltungseinrichtung (16)

zum Messen einer in derselben induzierten elektrischen Größe verbunden zu sein, umfaßt, wobei der Kern (11) mindestens einen Schwebeabschnitt aufweist, der sich infolge einer Trägheitskraft aufgrund einer Beschleunigungsbewegung des Sensors selbst frei biegen kann.

2. Ein Beschleunigungssensor gemäß Anspruch 1, bei dem der Kern (11) in Form eines Rahmens mit zwei gegenüberliegenden Seiten, die an dem Substrat (10) befestigt sind, vorliegt und bei dem das Substrat einen versenkten Bereich aufweist, der zumindest den anderen beiden gegenüberliegenden Seiten entspricht, wodurch zwei Abschnitte des Kerns schwebend bleiben.

3. Eine Vorrichtung zum Umwandeln einer Beschleunigung in eine elektrische Größe, die einen Beschleunigungssensor gemäß einem der vorhergehenden Ansprüche und Verarbeitungsschaltungen aufweist, die in demselben Substrat wie das, in dem der Sensor gebildet ist, gebildet sind.

4. Eine Vorrichtung gemäß Anspruch 3, die ein Gehäuse umfaßt, das das Substrat mit dem Sensor in einer Luftatmosphäre hermetisch abdichtet.

5. Eine Vorrichtung gemäß Anspruch 3, die ein Gehäuse umfaßt, das das Substrat mit dem Sensor in einer Stickstoffatmosphäre hermetisch abdichtet.

6. Ein Verfahren für die Herstellung eines Beschleunigungssensors gemäß Anspruch 1, das folgende Schritte umfaßt:

   Unterziehen eines Wafers, der ein Siliziumeinkristall (10) aufweist, einer Oxidierung für örtlich begrenztes Wachstum bei hoher Temperatur in einer oxidierenden Umgebung, um erhöhte Flächenstücke aus Siliziumdioxid (23) zu bilden, die einen versenkten Bereich auf dem Wafer begrenzen;

   Bilden einer ersten Schicht aus Siliziumnitrid (20) auf dem versenkten Bereich;

   Bilden einer ersten Schicht aus Siliziumdioxid (21) auf der ersten Schicht aus Siliziumnitrid (20) und auf den Flächenstücken (23);

   Bilden einer ersten Serie und einer zweiten Serie von benachbarten Metallsegmenten (24) über den Flächenstücken (23);

   Bilden einer zweiten Schicht aus Siliziumnitrid (25) über dem versenkten Bereich und den Flächenstücken (23) und Bedecken der Metallsegmente (24);

   Bilden eines Kerns (28) aus ferromagnetischem Material über den Metallsegmenten (24);

   Bilden einer zweiten Schicht aus Siliziumdioxid (27) über dem versenkten Bereich und den Flächenstücken (23) und Einkapseln des Kerns (28);

   Bilden einer dritten Serie und einer vierten Serie von benachbarten Metallsegmenten (30) über der ersten bzw. der zweiten Serie von benachbarten Metallsegmenten (24) und einer Vielzahl von elektrischen Verbindungsbahnen (31) zwischen den Segmenten der ersten (24) und dritten (30) Serie und zwischen den Segmenten der zweiten (24) und vierten (30) Serie, um die erste Wicklung (13) bzw. die zweite Wicklung (15) zu bilden;

   Entfernen eines Teils der zweiten Schicht aus Siliziumdioxid (27), um zumindest einen Abschnitt des Kerns (28) freizulegen;

   Entfernen der zweiten Schicht aus Siliziumnitrid (25), die durch das Entfernen eines Teils der zweiten Schicht aus Siliziumdioxid (27) freigelegt wurde;

   Unterziehen der ersten Schicht aus Siliziumdioxid (21), die durch das Entfernen der zweiten Schicht aus Siliziumdioxid (27) freigelegt wurde, einem isotropen chemischen Angriff, um so die erste Schicht aus Siliziumnitrid (20) über dem gesamten versenkten Bereich freizulegen, so daß der Abschnitt des Kerns (28) schwebend und von dem versenkten Bereich des Wafers beabstandet bleibt.

Revendications

1. Capteur d'accélération formé par technologie plane sur un substrat (10), incluant un noyau (11) en matériau ferromagnétique et, couplés de façon inductive ensemble par ce noyau, un premier enroulement (13) conçu pour être connecté à une alimentation électrique (14) et un second enroulement (15) conçu pour être connecté à des moyens à circuit (16) destinés à mesurer une quantité électrique qui y est induite, le noyau (11) comportant au moins une partie suspendue qui est libre de fléchir consécutivement à une force inertielle provoquée par un mouvement d'accélération du capteur lui-même.

2. Capteur d'accélération selon la revendication 1, dans lequel le noyau (11) se présente sous la forme d'un cadre avec deux côtés opposés fixés au subs-

trat (10) et dans lequel le substrat (10) présente une aire noyée au moins en correspondance avec les deux autres côtés, laissant ainsi deux parties du corps du noyau suspendues.

3. Dispositif destiné à convertir une accélération en une quantité électrique, comprenant un capteur d'accélération selon l'une quelconque des revendications précédentes et des circuits de traitement formés dans le même substrat que dans celui dans lequel le capteur est formé.

4. Dispositif selon la revendication 3, incluant un boîtier qui ferme de manière hermétique le substrat avec le capteur dans une atmosphère d'air.

5. Dispositif selon la revendication 3, incluant un boîtier qui ferme hermétiquement le substrat avec le capteur dans une atmosphère d'azote.

6. Procédé de fabrication d'un capteur d'accélération selon la revendication 1, incluant les étapes suivantes, qui consistent :

> à soumettre une plaquette se composant d'un monocristal de silicium (10) à l'oxydation pour une croissance localisée à haute température sous un environnement oxydant de manière à former des patins de dioxyde de silicium (23) qui lient une aire noyée sur la plaquette,
> à former une première couche de nitrure de silicium (20) sur l'aire noyée,
> à former une première couche de dioxyde de silicium (21) sur la première couche de nitrure de silicium (20) et sur les patins (23),
> à former une première série et une seconde série de segments métalliques adjacents (24) par dessus les patins (23),
> à former une seconde couche de nitrure de silicium (25) par dessus l'aire noyée et les patins (23) et à recouvrir les segments métalliques (24),
> à former un noyau (28) en matériau ferromagnétique par dessus les segments métalliques (24),
> à former une seconde couche de dioxyde de silicium (27) par dessus l'aire noyée et les patins (23) et à encapsuler le noyau (28),
> à former une troisième série et une quatrième série de segments métalliques adjacents (30) respectivement par dessus les première et seconde séries de segments métalliques adjacents (24) et une multiplicité de trajets de connexion électrique (31) entre les segments des première (24) et troisième (30) séries et entre les segments des seconde (24) et quatrième (30) séries de manière à former le premier enroulement (13) et le second enroulement (15), respectivement,
> à retirer une partie de la seconde couche de dioxyde de silicium (27) de manière à découvrir au moins une partie du noyau (28),
> à retirer la seconde couche de nitrure de silicium (25) laissée découverte par le retrait de la partie de la seconde couche de dioxyde de silicium (27),
> à soumettre la première couche de dioxyde de silicium (21) laissée découverte par le retrait de la seconde couche de dioxyde de silicium (27) à une attaque chimique isotropique de façon à exposer la première couche de nitrure de silicium (20) par dessus l'entière aire noyée de telle sorte que la dite partie du noyau (28) demeure suspendue et espacée de l'aire noyée de la plaquette.

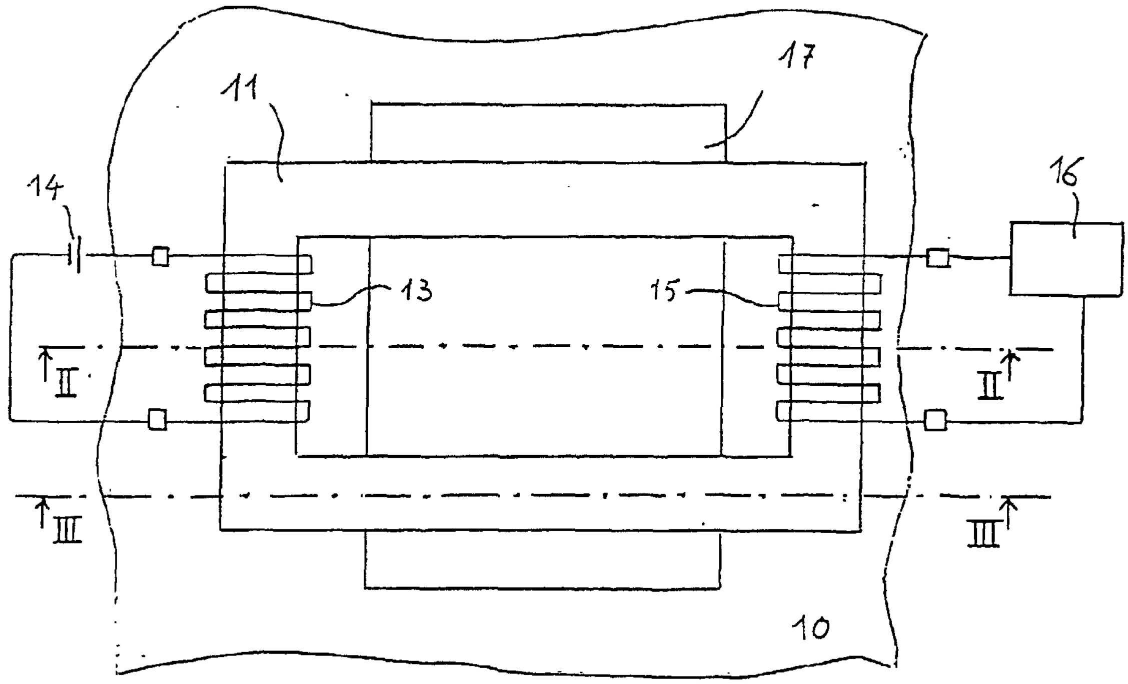

FIG. 1

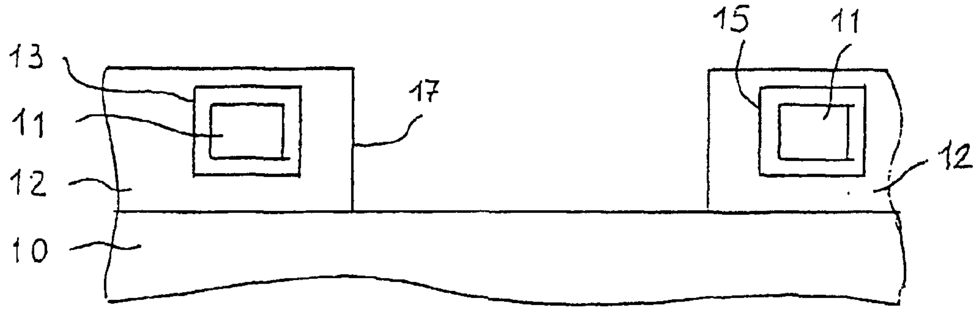

FIG. 2

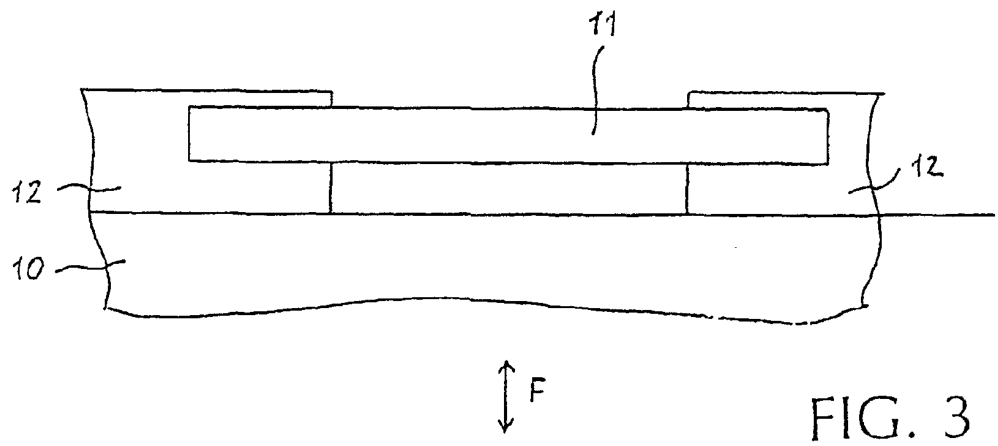

FIG. 3

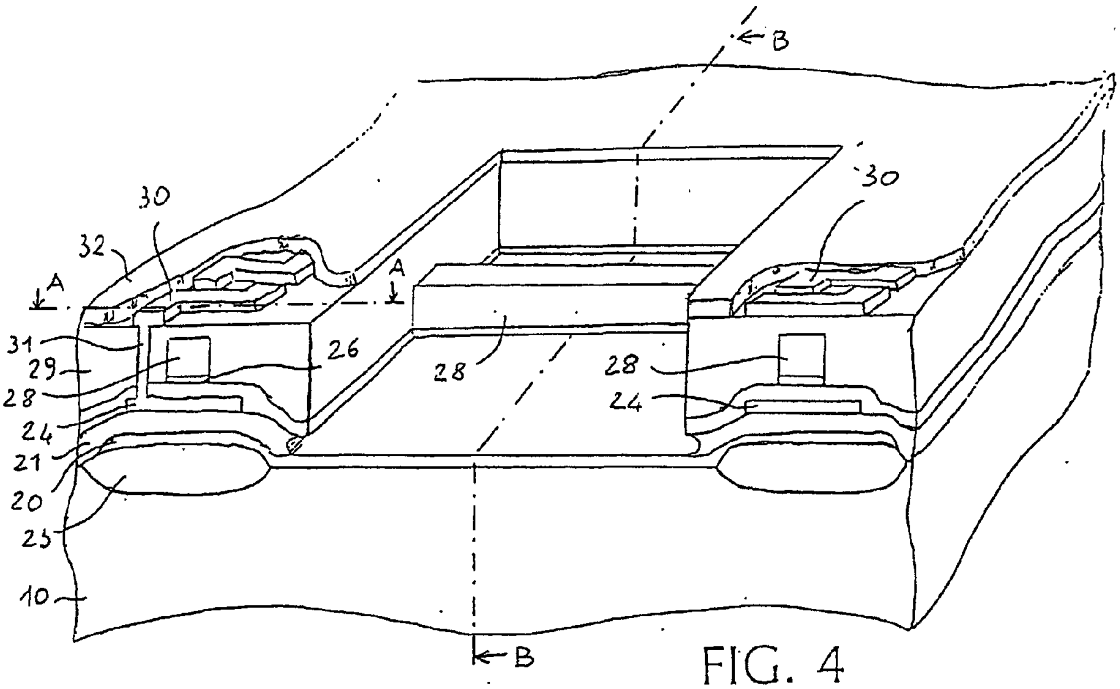

FIG. 4

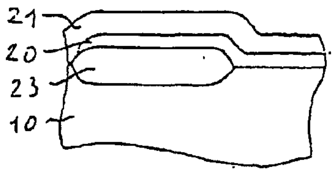

FIG. 5

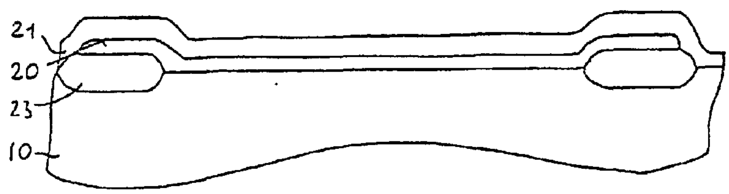

FIG. 11

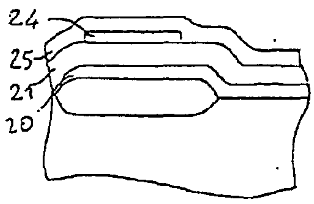

FIG. 6

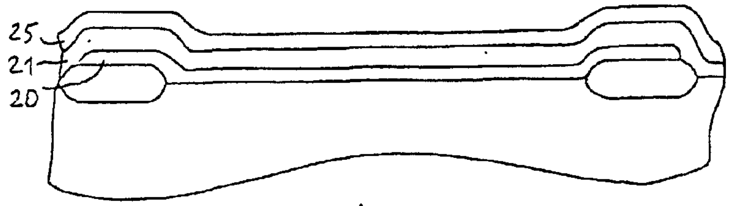

FIG. 12

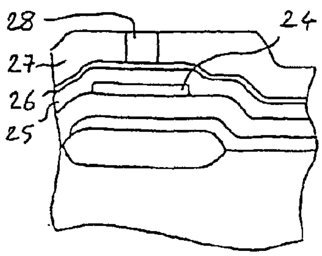

FIG. 7

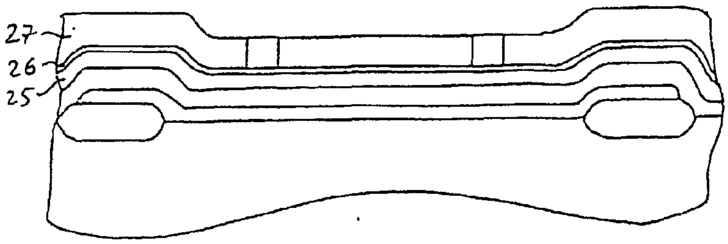

FIG. 13

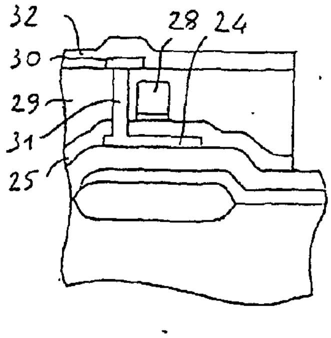

FIG. 8

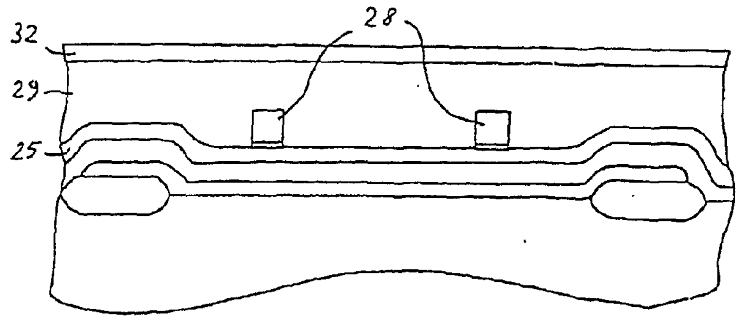

FIG. 14

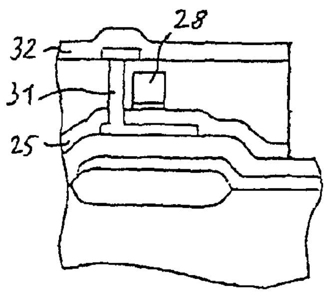

FIG. 9

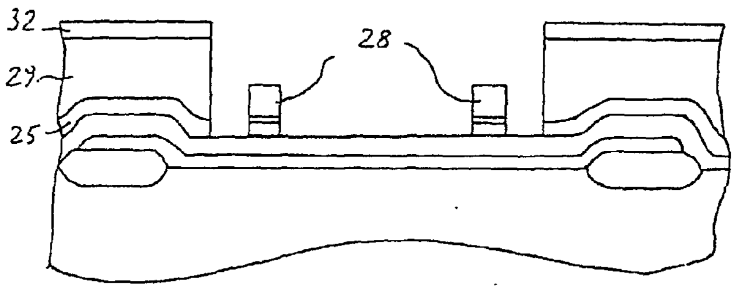

FIG. 15

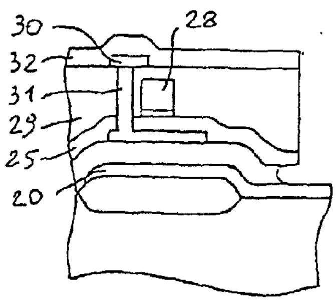

FIG. 10

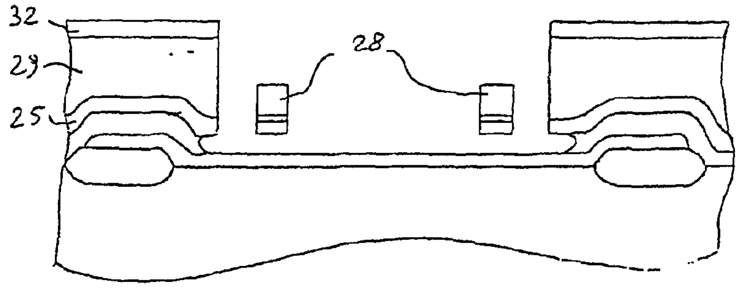

FIG. 16