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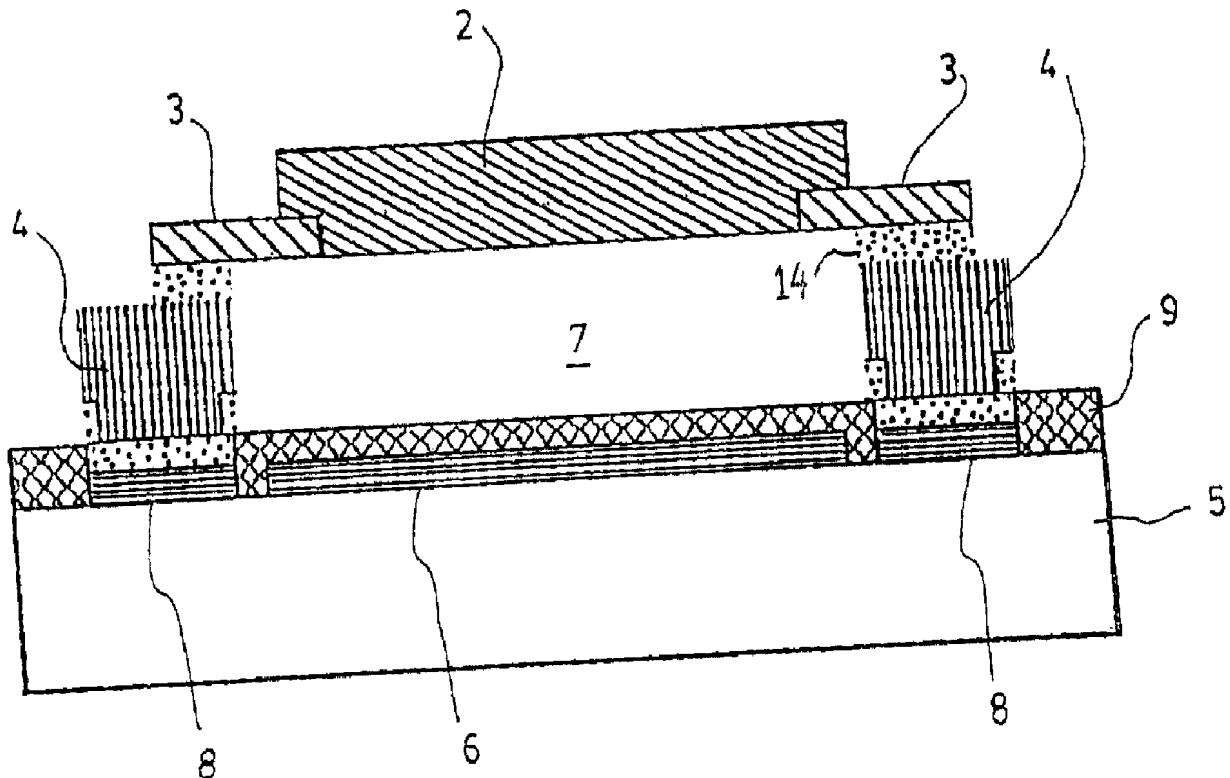
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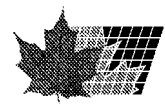
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(54) Title: MICRODEVICE WITH MOVABLE MICROPLATFORM AND PROCESS FOR MAKING THEREOF



(57) Abrégé/Abstract:

A process for making a microdevice that includes the steps of providing a base member and selectively electroforming a support member for supporting a microplatform with respect to the base member. The process also includes the steps of selectively electroforming the microplatform and forming a flexible hinge member for hingedly connecting the microplatform to the support member and allowing relative movement of the microplatform with respect to the support member. This microdevice, when compared to prior art devices, can have improved mechanical strength, rigidity, low deformation, and high planarity.



ABSTRACT

A process for making a microdevice that includes the steps of providing a base member and selectively electroforming a support member for supporting a microplatform with respect to the base member. The process also includes the steps of selectively electroforming the microplatform and forming a flexible hinge member for hingedly connecting the microplatform to the support member and allowing relative movement of the microplatform with respect to the support member. This microdevice, when compared to prior art devices, can have improved mechanical strength, rigidity, low deformation, and high planarity.

MICRODEVICE WITH MOVABLE MICROPLATFORM AND PROCESS FOR MAKING THEREOF

FIELD OF THE INVENTION

- 5 The present invention relates to a microdevice and a process for making thereof, but more particularly, to a microdevice equipped with a movable microplatform and a process for making thereof.

BACKGROUND OF THE INVENTION

- 10 There are several examples of miniature electromechanical devices equipped with movable microplatforms with lateral dimensions from a few micrometers to several thousands of micrometers. The pivoting along one or multiple axis, and vertical or horizontal displacement of these microplatforms is possible due to various types of hinge members including torsional and flexure hinge types.
- 15 The movement of the microplatforms is induced typically via electrostatic, magnetic or thermal mechanisms.

The functions performed by these microdevices equipped with movable microplatforms include phase and amplitude modulation of visible, UV or IR radiation beams as well as mechanical protection with open and close functions of specialty microsystems. In particular, the microdevices used for radiation beam manipulation are often called micromirror devices and find multiple applications in telecom for laser beam attenuation and switching as well as in projection imagers as the spatial light modulators.

25 In optical applications in particular, it is extremely important to provide movable microplatforms that are free of mechanical deformations and defects, with a residual radius of curvature of many meters and surface roughness better than $\lambda/10$, where λ is the wavelength of radiation used.

30 There are typically two methods used for manufacturing individual and arrays of microdevices equipped with movable microplatforms. The first most

devices making use of a stress-free semiconductor layer of silicon. The epitaxial silicon layer with a thickness ranging from less than one to tens of micrometers is grown on the etch stop layer deposited on the Si wafer.

- 5 Also known in the art, there are US Patent Application 2001/0044165 A1 by S.B. Lee et al. and US Patent 6,353,492 B2 by R.W. McClelland, which disclose pivoting microplatform devices made entirely from monocrystalline silicon wafers by the deep etching technique.
- 10 Application of silicon in the form of polished wafers or epitaxial layers deposited on silicon wafers allows to alleviate some limitations associated with the thin film technology. Silicon in this form is light, strong and stiff, yielding rigid microplatforms with low moment of inertia. It also yields a wide range of microplatform thicknesses from tens to hundreds of micrometers.
- 15 Silicon wafers can be polished to provide excellent surface quality (i.e. very low roughness) and flatness. They will reflect radiation effectively when covered with appropriate coatings. On the other hand, patterning of silicon wafers may be a limiting factor in terms of minimum feature size or geometrical form especially if the anisotropic wet etching technique is applied.
- 20 Moreover, the microdevices equipped with movable monocrystalline silicon microplatforms are typically of hybrid construction. They consist of at least two different parts, one comprising the microplatform and the other one performing a function of the supporting base equipped with electrodes and contact pads for actuation of the microplatform. Fully monolithic devices are difficult to
- 25 implement and are mostly formed by the competing thin film technology.

The following United States Patents disclose other devices suffering from the same drawbacks as described above: 5,083,857 (L.J. Hornbeck); 5,212,582 (W.E. Nelson); 5,233,456 (W.E. Nelson); 5,312,513 (J.M. Florence et al.); and

30 5,789,264 (J.H. Chung).

SUMMARY OF THE INVENTION

An object of the present invention is to provide a process for making a microdevice equipped with a movable microplatform that overcomes the above-identified drawbacks of the prior art devices. In particular, a preferred
5 microdevice according to the present invention can have improved mechanical strength, rigidity, low deformation, and high planarity. The microdevice may also be fully monolithic.

According to the present invention, there is provided a process for making a
10 microdevice, comprising the steps of:

- a) providing a base member;
- b) selectively electroforming at least one support member for supporting a microplatform with respect to the base member;
- c) selectively electroforming the microplatform; and
- 15 d) forming at least one flexible hinge member for hingedly connecting the microplatform to said at least one support member and allowing relative movement of the microplatform with respect to said at least one support member.

20 According to another aspect of the present invention, there is provided a microdevice comprising:

- a base member;
- at least one support member mountably connected to the base member, said at least one support member being selectively electroformed
25 according to a selective electroforming process;
- at least one hinge member mountably connected to said at least one support member; and
- a microplatform hingedly connected to said at least one hinge member for allowing relative movement of the microplatform with respect to said at
30 least one support member, the microplatform being selectively electroformed according to a selective electroforming process.

Figure 2 is a perspective view of the microdevice shown in Figure 1A.

Figures 3A to 3L are side section views of various layers showing the steps involved in a first preferred process of making a microdevice, according to a preferred embodiment of the present invention.

Figures 4A to 4L are side section views of various layers showing the steps involved in a second alternate process of making a microdevice according to a preferred embodiment of the present invention.

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DETAILED DESCRIPTION OF THE INVENTION

Referring to Figures 1A, 1B, 1C and 2, there are shown different types of preferred embodiments of microdevices 1 according to the present invention. Each of the illustrated microdevices 1 includes a base member and at least one support member 4 mountably connected to the base member. As will be explained below, the support member 4 is selectively electroformed according to a selective electroforming process and there are typically two support members 4 that are mounted on the base member. The microdevice 1 also includes at least one hinge member 3 mountably connected to the support member 4 and a microplatform 2 hingedly connected to the hinge member 3 for allowing relative movement of the microplatform 2 with respect to the support member 4. The microplatform 2 is also selectively electroformed according to a selective electroforming process.

25 Referring to Figures 3A to 4L, there is also illustrated a process for making the above microdevice 1. The process essentially involves the steps of:

- a) providing a base member;
- b) selectively electroforming at least one support member 4 for supporting a microplatform 2 with respect to the base member;
- 30 c) selectively electroforming the microplatform 2; and
- d) forming at least one flexible hinge member 3 for hingedly connecting the microplatform 2 to the at least one support member 4 and

allowing relative movement of the microplatform 2 with respect to the at least one support member 4.

Referring now to Figures 3A to 3L, the process according to the present invention is preferably realized according to a first embodiment, wherein:

step b) comprises the step of mountably connecting the at least one support member 4 to the base member;

step d) is performed after step b) and before step c) and comprises the step of mountably connecting the at least one hinge member 3 to the at least one support member 4; and

step c) comprises the step of mountably connecting the microplatform 2 to the at least one hinge member 3.

Referring to now Figures 4A to 4L, the process according to the present invention is preferably realized according to a second alternate embodiment, wherein:

step c) is performed before steps a), b) and d) and comprises the step of selectively electroforming the microplatform 2 on a sacrificial substrate 20;

step d) is performed before steps a) and b) and comprises the step of mountably connecting the at least one hinge member 3 to the microplatform 2;

step b) is performed before step a) and comprises the steps of mountably connecting the at least one support member 4 to the at least one hinge member 3 and removing the sacrificial substrate 20; and

step a) comprises the step of mountably connecting the at least one support member 4 to the base member.

The above first and second preferred processes will be explained in more details herein below. Of course, several modifications may be effected thereto as those skilled in the art will understand.

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As explained above, the process according the present invention is based on the selective electroforming technique (i.e. localized electroforming), which

thin (typically below 1 μm) protective layer 9 typically made of SiO_2 or Si_3N_4 . Openings 10 are provided in the protective layer 9 for accessing the metallic (typically Al, Au) contact pads 8.

5 Figure 3B shows the manufacturing step of covering the substrate 5 with a first metal seed layer 11. This seed layer 11 has typically a thickness of 0.1 to 0.15 μm and is made of metals such as Cu or Zn. This seed layer 11 is typically deposited by thermal evaporation, sputtering or electroforming. The seed layer 11 permits to apply electrical potential to the substrate 5 to start the
10 electroforming process. Additional layers made of Ti or Cr with a thickness below 0.1 μm may also be used with the other materials as the adherence increasing layers.

Figure 3C shows the step of covering the substrate 5 with the first photoresist
15 layer 12 and patterning of this layer 12 using the photolithographic technique. Various commercially available photoresist materials compatible with standard electroplating baths such as Shipley 1800 series, SU-8, AZ 4562 and BPR 100 can be used. Thickness of this photoresist layer 12 will define the height of cavity 7 underneath the microplatform 2, as shown in Figure 2. This height
20 may vary from 1 μm to hundreds of micrometers. In the photolithographic patterning process, openings 13 are produced in the first photoresist layer 12.

Figure 3D illustrates the selective electroforming of the support members 4 in the openings 13 of the first photoresist layer 12. These support members 4
25 are in electrical contact with the contact pads 8 of the substrate 5. The preferred materials for the support members 4 are typically Ni and Ni-Fe alloys. Typically, low internal stress and very uniform Ni deposits can be obtained from nickel sulfamate baths continuously agitated and filtered to less than 3 μm . Commercial wafer electroplating stations, known in the art,
30 equipped with stationary or rotating cathodes with proper baffle arrangements will allow to achieve such high quality nickel deposits. Typical applied

currents, bath temperatures and pH levels are in the range 0.5-30 Adm^{-2} , 32-60°C and 3.5-5 respectively.

In a typical selective electroforming operation, the substrate 5 or sacrificial substrate 20 are placed in a holder which allows electrical contact through the seed layers 11 or 21. This holder is then dipped in the electroplating bath so that the substrate faces the anode consisting of the metal to be plated or a platinized grid. A constant or pulsed current is then applied between the anode and stationary or rotating cathode so that the electrochemical reduction and consequently metal deposition can take place. The electroforming time is proportional to the thickness of deposited metal. The wafer is then rinsed and dried prior to subsequent processing steps.

Figure 3E shows deposition of a second metallic seed layer 14 similar to the first seed layer 11. The second seed layer 14 required for electroforming of the hinge members 3 material typically consist of the same material as the first seed layer 11, i.e. Cu, Zn or Al and it is deposited using the thermal evaporation and sputtering techniques. Its thickness is typically smaller than the thickness of the first seed layer 11, i.e. below 0.1 μm . Figure 3E also shows deposition usually by a spin coating method of a second photoresist layer 15 and the photolithographic patterning of this second photoresist layer 15 in order to define the shape of the hinge members 3. Openings 16 in this second photoresist layer 15 down to the second seed layer 14 will permit electroforming of the hinge members 3.

Figure 3F shows the electroforming of the hinge members 3. The hinge members 3 are typically made of materials having low Young's modulus and high yield strength and relatively low stiffness such as Au in order to allow free movements of the microplatform attached to them. For electrolytic gold plating, commercial cyanide-containing formulations used in the microelectronics industry can be employed. Typical applied currents, bath temperatures and pH levels are in the range 0.05-0.3 Adm^{-2} , 43-60°C and 5.5-7 respectively. It is preferable and most advantageous that the hinge

microplatforms are produced (over 50 μm) and the microdevice application requires efficient and low-loss reflection of electromagnetic radiation from the movable microplatform.

- 5 Figure 3J shows the step of removal of the third photoresist layer 17 by the wet stripping or oxygen plasma ashing techniques.

Figure 3K shows the step of selective removal of part of the second seed layer 14 not protected by the hinge member 3 material and the microplatform
10 2 material. A wet isotropic etching is typically performed and the etching solution should not attack the materials of the hinge members 3 and the microplatform 2. Figure 3K also shows, after removal of the second seed layer 14, the removal of the first photoresist layer 12. This processing step is carried out in a proper solution not attacking the other materials of the microdevice 1
15 or by the plasma ashing in the oxygen containing atmosphere.

Figure 3L shows the final step of removal of the first seed layer 11 from the surface of the substrate 5 as well as the residue of the second seed layer 14 from the microplatform 2 and the hinge members 3. This completes the
20 liberation of the microplatform 2, the hinge member 3, and the support members 4. The etching solution for removal of the seed layers 11 and 14 should not attack other materials of the microdevice 1. This final step also fully defines the height of the cavity 7 below the microplatform 2 allowing a free movement of this microplatform 2 supported by the hinges 3 and the support
25 members 4.

Referring to Figures 4A to 4L, there is shown a second preferred embodiment of a manufacturing process for making hybrid microdevices 1 equipped with movable microplatforms 2.

30

Figure 4A shows a temporary or sacrificial substrate 20 covered with the first seed layer 21 and the first photoresist layer 22. The preferred materials for the

sacrificial substrate 20 are glass and semiconductor wafers such as Si. The preferred materials for the first seed layer 21 are Cu, Zn, and Al layers typically having a thickness 0.1 – 0.5 μm . Additional layers made of Ti or Cr with a thickness below 0.1 μm may also be used with the other materials as the adherence increasing layers. All these layers are typically deposited by the thermal evaporation or sputtering techniques. The sacrificial substrate 20 is used to build a partial microdevice equipped with a movable microplatform 2 before transferring this partial microdevice and attaching it to a permanent substrate 5 so that it becomes the final microdevice 1. The first seed layer 21 is used to achieve the electroforming of the microplatform 2. It is also used as a sacrificial layer for attaching the partial microdevice during build-up to the temporary substrate 20. The first photoresist layer 22 is patterned to define the shape of the microplatform to be electroformed in the opening 23 in the first photoresist layer 22. Rugosity of the upper surface 24 of the temporary substrate 20 will define the surface quality of the microplatform 2 to be built on the temporary substrate 20. An optional step (not shown) of deposition and patterning of an additional highly reflective optical layer potentially having grating or other optical structures can be performed at this stage, on the first seed layer 21 and prior to deposition of the first photoresist layer 22.

20

Figure 4B shows the step of electroforming of the microplatform 2. This microplatform 2 may have the same specifications as the one described with reference to Figure 3H.

25 Figure 4C shows the deposition of the second seed layer 25 as well as deposition and patterning of the second photoresist layer 26. The openings 27 in the second photoresist layer 26 will define the shape of hinge members.

Figure 4D shows electroforming of the hinge members 3 which may have the same specifications as the hinge members 3 described with reference to
30 Figure 3F.

Figure 4H shows the removal of the third photoresist layer 28 by the wet stripping or oxygen plasma ashing down to the second seed layer 25.

- 5 Figure 4I shows the selective partial removal of the second seed layer 25 not protected by the support members 4 and the hinge members 3 materials.

Figure 4J shows the removal of the first photoresist layer 22 by the wet stripping or oxygen plasma ashing techniques.

10

- Figure 4K shows the separation by wet etching of the microdevice 1 from the sacrificial substrate 20. This separation is achieved by removal by wet etching of the first seed layer 21. At the same time the residue of the second seed layer 25 now exposed is also removed in the same etching solution. This precludes that the etching solution used is attacking both the second seed layer 25 and the first seed layer 21 but not attacking other materials present.
- 15

- Figure 4L shows the final step of attaching the freestanding partial microdevice to the permanent substrate 5 by making use, for example, of the soldering material 30. The soldering material 30 is subjected to a reflow and then brought in thermal and mechanical contact with the contact and soldering pads 8 of the substrate 5 covered with the protective layer 9. Surface tension of the molten soldering material 30 during the soldering of the partial microdevice to the substrate 5 will help to align the support members 4 with respect to the contact pads 8 of the substrate 5. Other methods for attachment of the microdevice 1 to the permanent substrate 5 can also be used including gluing or thermal bonding.
- 20
- 25

- There is a possibility that the separation step illustrated in Figure 4K can be performed after completion of the attachment step shown in Figure 4L. This may be quite suitable especially in the case when individual miniature devices or partial microdevices are being manipulated in order to perform their
- 30

attachment to the permanent substrate 5. This may not be the case when a large array of partial microdevices having a form of a substantial freestanding pellicle is being manipulated for attachment.

5 As mentioned above, the microdevices 1 that are formed according to the process of the present invention can provide mechanically solid support members 4 and microplatforms 2, with thicknesses up to tens and even hundreds of micrometers. These microdevices 1, when compared to the prior art devices, have improved mechanical strength, rigidity, low deformation, and
10 high planarity. This provides a unique opportunity for forming microdevices 1 with microplatforms 2 with lateral dimensions of hundreds or even thousands of micrometers and a wide range of tilt angles (up to 90°) and displacements (several micrometers). Moreover, the proposed forming processes make possible the manufacturing of microdevices 1 being integrated parts of
15 semiconductor substrates equipped with integrated electronic circuits or microdevices which can be in a hybrid fashion attached via soldering, gluing etc. to other substrates made of glass, ceramic or semiconductor. This offers an enormous flexibility in designing functional devices optimized for particular applications and operational environment.

20

Although preferred embodiments of the present invention have been described in the context of manufacturing a single microdevice equipped with a movable microplatform, the same embodiments can be applied to manufacturing in a single process of arrays of several microdevices at the
25 same time. Moreover, it is to be understood that the invention described in detail herein and illustrated in the accompanying drawings is not limited to these precise embodiments and that various changes and modifications may be effected therein without departing from the scope or spirit of the present invention.

ix) covering the second seed layer (14) with a second photoresist layer (15); and

x) photolithographically patterning the second photoresist layer (15) to produce at least one opening (16) on the second photoresist layer (15) that is aligned with said at least one support member (4), said at least one hinge member (3) being selectively electroformed in said at least one opening (16) of the second photoresist layer (15).

8. The process for making the microdevice (1) according to claim 7, wherein step c) comprises the steps of:

xi) removing, after step x), the second photoresist layer (15);
xii) covering, after step xi), said side with a third photoresist layer (17);
xiii) photolithographically patterning the third photoresist layer (17) to produce an opening (18) on the third photoresist layer (17), the microplatform (2) being selectively electroformed in the opening (18) of the third photoresist layer (17);

xiv) removing, after step xiii), the third photoresist layer (17);
xv) selectively removing, after step xiv), a part of the second seed layer (14) that is unprotected by said at least one hinge member (3);

xvi) removing, after step xv), the first photoresist layer (12); and
xvii) removing, after step xvi), the first seed layer (11) and another part of the second seed layer (14) unprotected by said at least one support member (4) for defining a cavity (7) between the microplatform (2) and the base member.

25

9. The process for making the microdevice (1) according to claim 8, wherein step c) further comprises the step of polishing an upper surface (19) of the microplatform (2) after step xiii).

10. The process for making the microdevice (1) according to claim 3, wherein step c) comprises the steps of:

30

xiii) removing, after step xii), a part of the second seed layer (25) unprotected by said at least one support member (4) and hinge member (3);

xiv) removing, after step xiii), the first photoresist layer (22); and

xv) removing, after step xiv), the first seed layer (21) for separating the
5 sacrificial substrate (20) from the microplatform (2).

13. The process for making the microdevice (1) according to claim 12, wherein step a) comprises the steps of:

xvi) providing a substrate (5) after step xv);

10 xvii) connecting, after step xvi), at least one electrode (6) and at least one contact pad (8) onto a side of the substrate (5);

xviii) covering the side of said substrate (5) with a protective layer (9);

xix) providing at least one opening (10) in the protective layer (9) for accessing said at least one contact pad (8); and

15 xx) soldering, after step xix), said at least one support member (4) onto the base member, via the soldering material (30) and said at least one contact pad (8).

14. A microdevice (1) comprising:

20 a base member;

at least one support member (4) mountably connected to the base member, said at least one support member (4) being selectively electroformed according to a selective electroforming process;

25 at least one hinge member (3) mountably connected to said at least one support member (4); and

a microplatform (2) hingedly connected to said at least one hinge member (3) for allowing relative movement of the microplatform (2) with respect to said at least one support member (4), the microplatform (2) being selectively electroformed according to a selective electroforming process.

30

15. The microdevice (1) according to claim 14, wherein the base comprises:

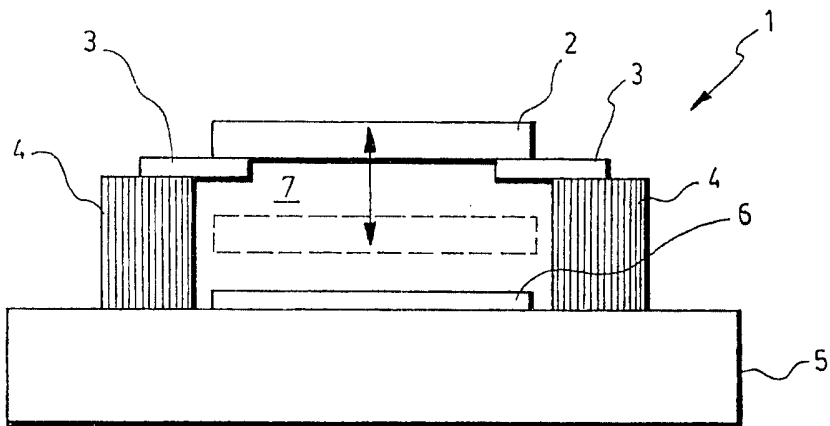


FIG. 1C

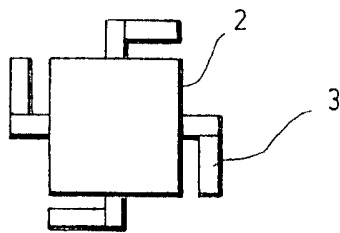


FIG. 1C1

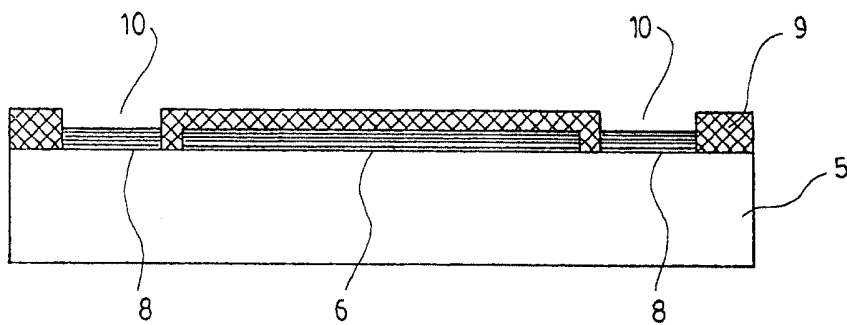


FIG. 3A

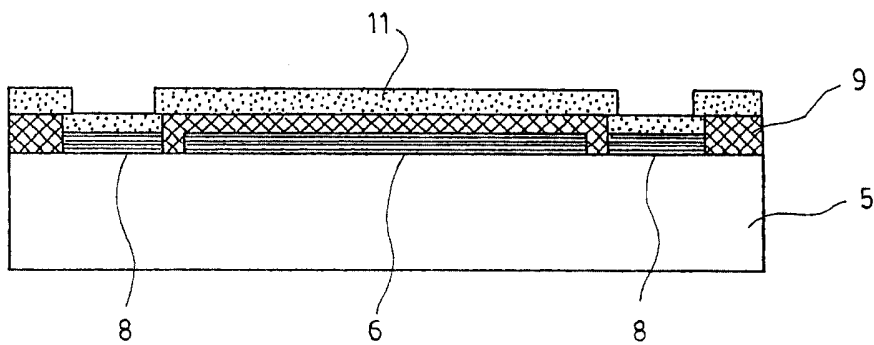


FIG. 3B

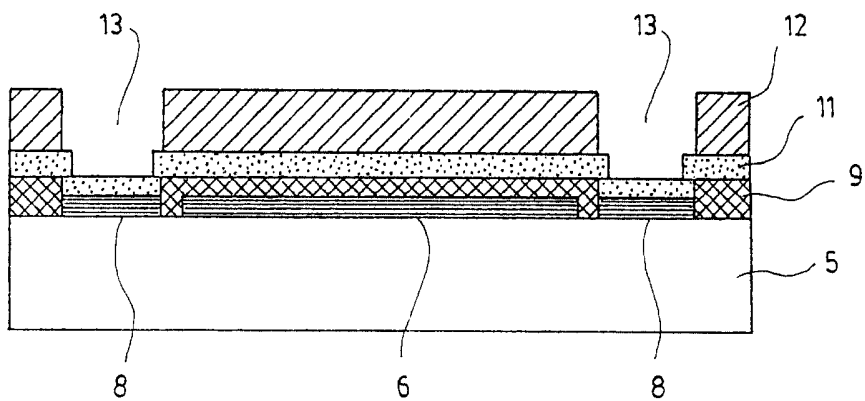


FIG. 3C

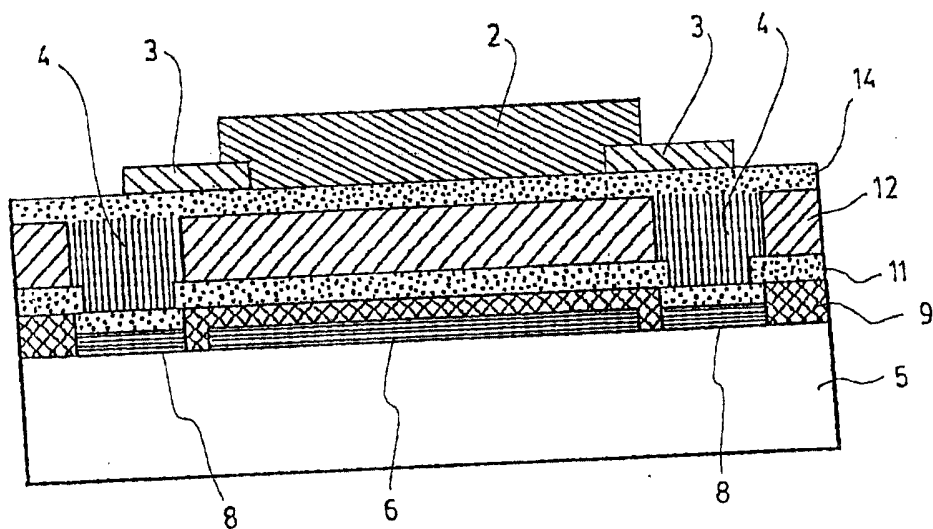


FIG. 3J

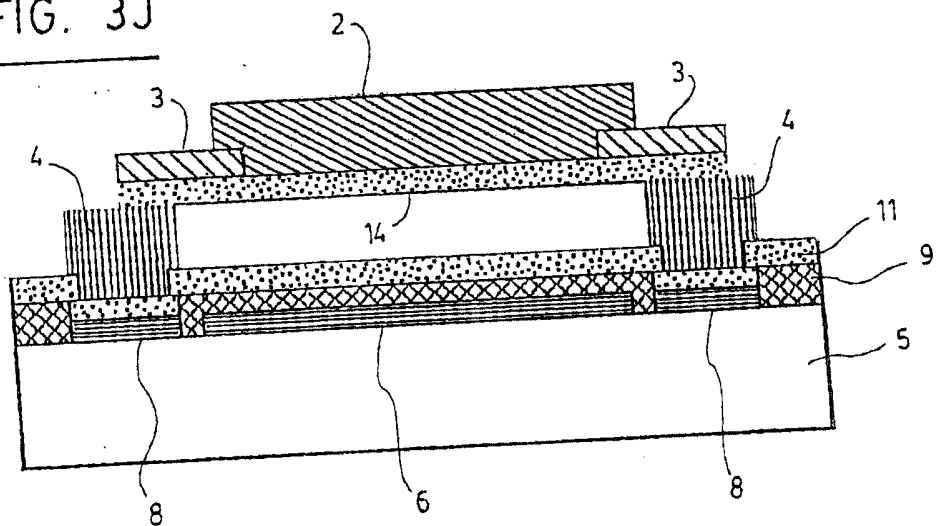


FIG. 3K

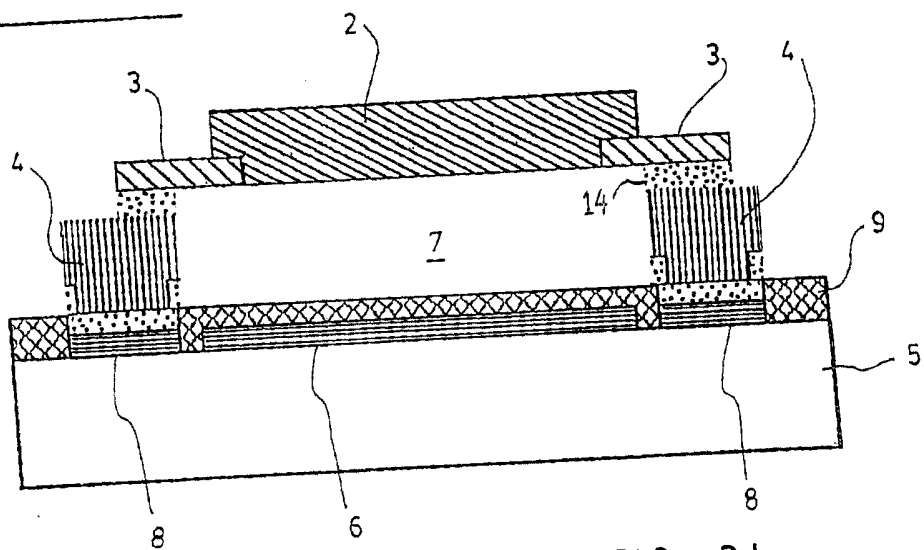


FIG. 3L

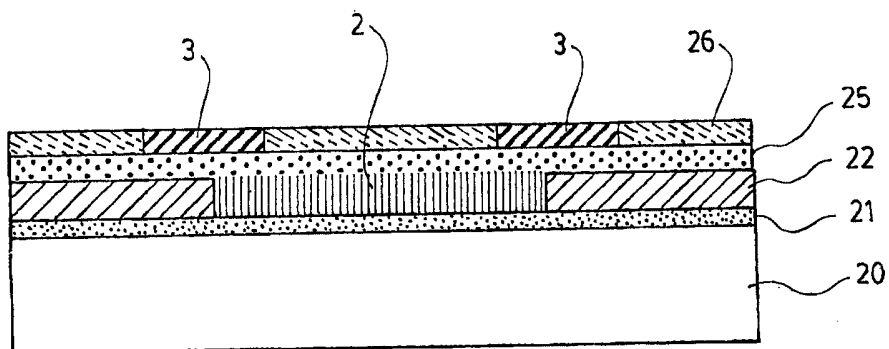


FIG. 4D

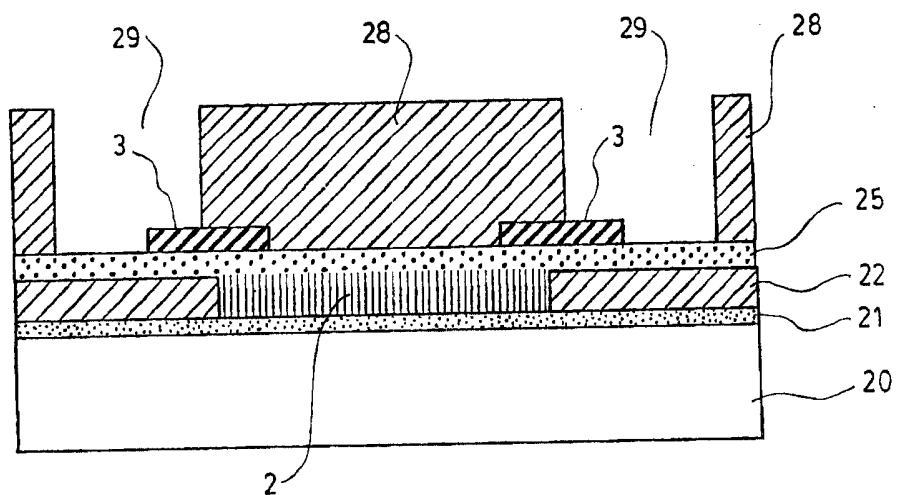


FIG. 4E

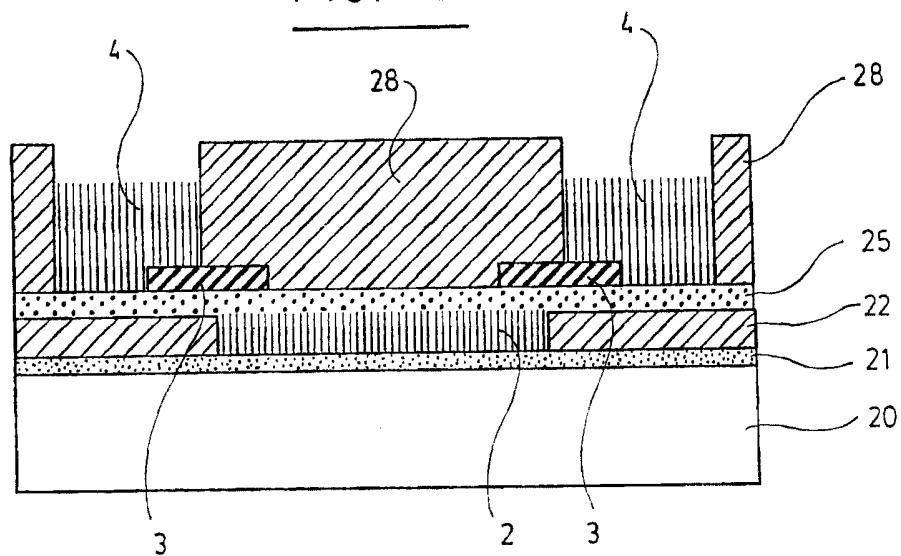


FIG. 4F

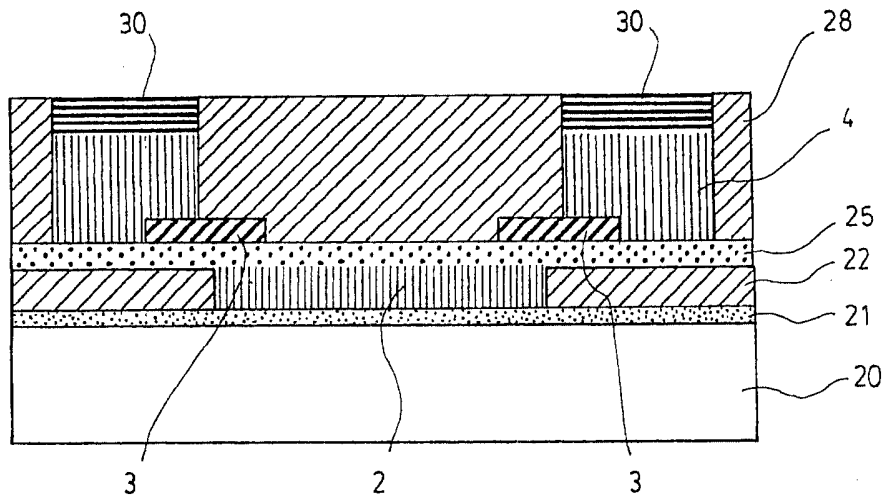


FIG. 4G

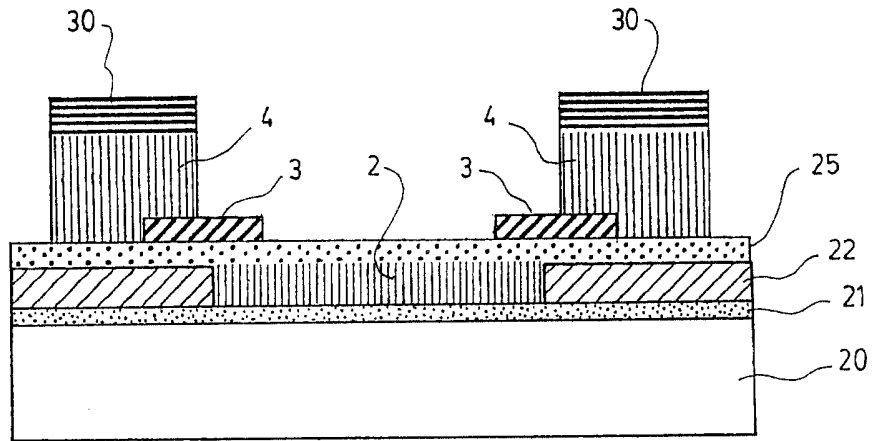


FIG. 4H

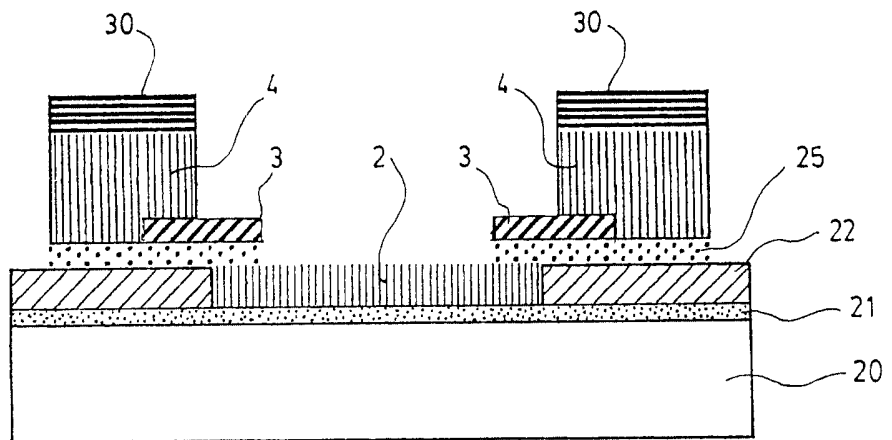


FIG. 4i

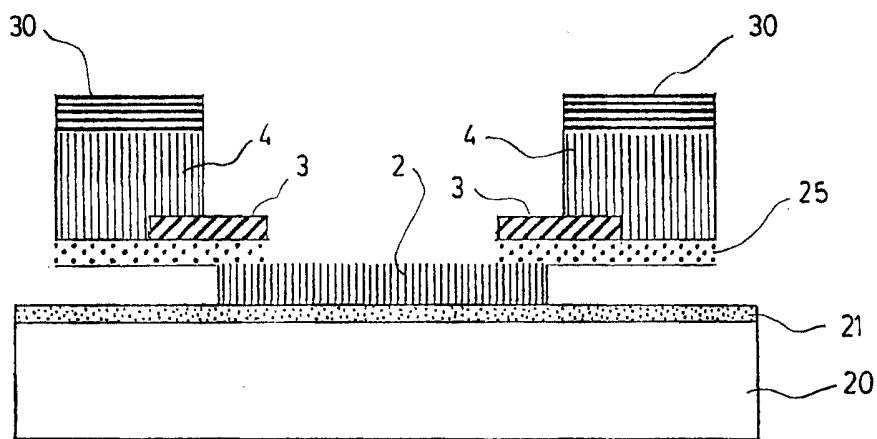


FIG. 4J

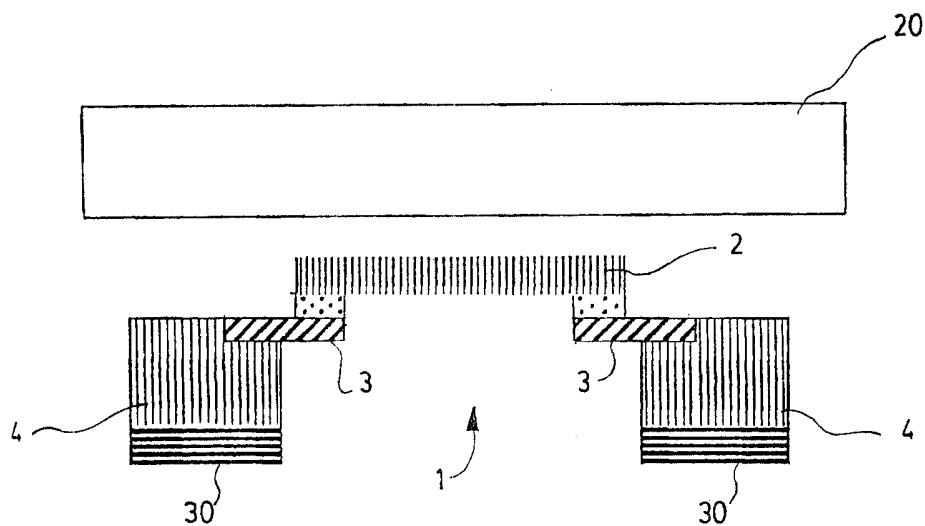


FIG. 4K

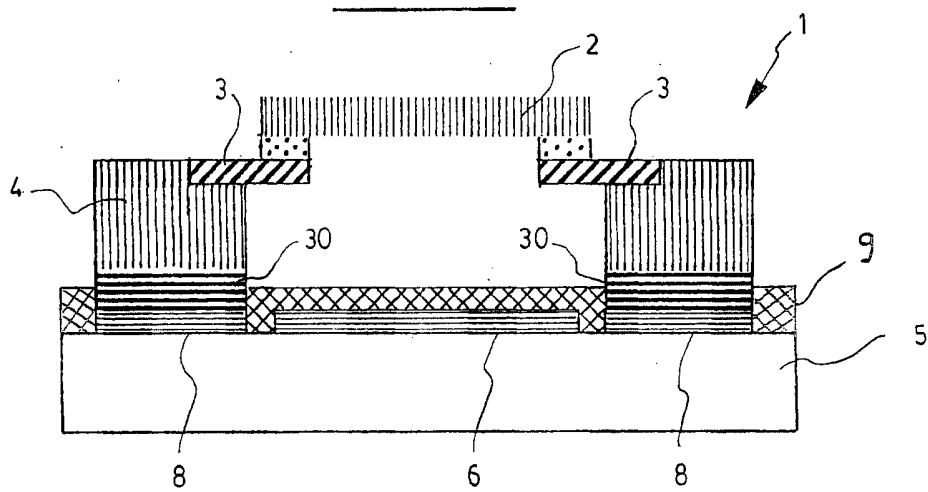


FIG. 4L

