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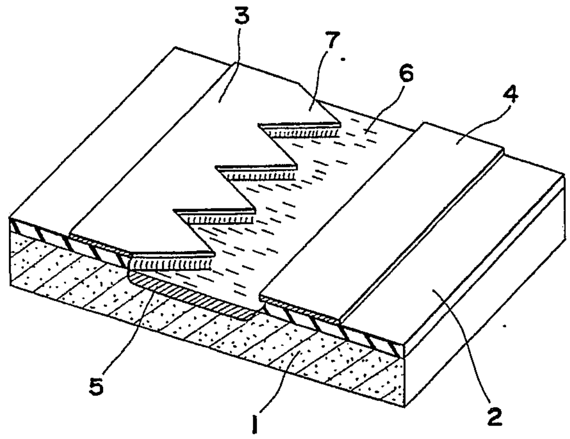
(54) Field-emission type switching device and method of manufacturing it.

(57) A field-emission type switching device includes a substrate (1, 2; 11) formed with a recess (6; 15) having a straight edge and serrated edge opposite to the straight edge. A gate electrode (5; 14) is formed at the bottom of the recess (6; 15). An emitter electrode (3, 12) is provided over the substrate (1, 2; 11) and formed with a serrated edge which is slightly off alignment with the serrate edge of the recess (6; 15) so as to provide an emitter overhanging portion (3a) overhanging the recess (6;15). Similarly, a collector electrode (4, 13) is provided over the substrate means (1, 2; 11) and formed with a straight edge which is slightly off alignment with the straight edge of the recess (6; 15) so as to provide a collector overhanging portion (4a) overhanging the recess (6; 15).

Fig. 2



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FIELD-EMISSION TYPE SWITCHING DEVICE AND METHOD OF MANUFACTURING IT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a super-high-speed switching device using field-emission type cold cathode.

2. Description of the Prior Art

Research and development have been made recently on super-high-speed switching devices using thin-film field-emission type cold cathode having the structure shown in Fig. 1 or on super-high-speed transistors. Insulation layer 22 is formed on the surface of silicon substrate 21, while gate electrode 24 having a hole 26 of 1-1.5 micrometer diameter and adjacent collector electrode 25 are formed on the insulation layer 22. During the making of hole 26, insulation layer 22 is partly remained in a shape of cone, and thereafter, a cone-shaped field-emission type cold cathode (hereinafter referred to as emitter electrode) 23 is formed on the surface of silicon substrate 21. Accordingly, the emitter electrode 23 and the silicon substrate 21 are electrically connected. There are 0.5-1 micrometer and 10-20 micrometers of spacings provided between the tip of emitter electrode 23 and the gate electrode 24 and between emitter electrode 23 and collector electrode 25, respectively.

When the switching device is placed in vacuum and 80-100V is fed to the gate electrode 24 with respect to the voltage of emitter electrode 23, more than 10^7V/cm of high electric field is generated at the tip of the emitter electrode, thereby emitting electrons from emitter electrode 23, as shown by dotted lines. The emitted electron beam enters into the collector electrode 25 so that the collector electrode 25 generates electric signal relative to the emitted electron beam. Electron beam containing several-tens electron volt of energy runs through vacuum at 5-10 X 10^8 cm/second of speed. This is faster than 5 X 10^7 cm/second of the maximum moving speed of electron inside of semiconductor by more than one digit place. Accordingly, it is possible to provide a super-high-speed switching device having a switching speed faster than the switching speed of semiconductor devices, such as FET, by more than one digit place.

Although the switching device according to the prior art is capable of operating at a speed faster than that of the semiconductor switching device by more than one digit place, there is a limit in shortening of the operation time, because the prior art switching device has such a structure that the gate electrode 24 is inserted between emitter electrode 23 and collector electrode 25. In other words, it is quite difficult according to the prior art switching device to make the spacing between the emitter electrode and the collector electrode less than 10 micrometers to shorten the electron-running time.

Also, the rate of electron entering into the collector electrode is not always sufficient. Also, there is such defect that electron beam flows into other neighboring switching devices to cause a crosstalk.

Furthermore, after forming the gate electrode and the collector electrode, it is necessary according to the prior art switching devices to go through complicated manufacturing processes such as making of a hole through the insulation layer 22 in order to form cone-shaped emitter electrode by obliquely adhering vaporized high-melt-point metal like tungsten for example while rotating the entire substrate.

SUMMARY OF THE INVENTION

The object of the present invention is therefore to provide an imaging device which solves these problems.

The present invention has been developed with a view to substantially solving the above described disadvantages and has for its essential object to provide an improved electrophotographic imaging device.

In order to achieve the aforementioned objective, a field-emission type switching device according to the present invention comprises: a substrate means formed with a recess having a straight edge and serrated edge opposite to said straight edge; a gate electrode formed at the bottom of said recess; an emitter electrode provided over said substrate means and having a serrated edge which is slightly off alignment with the serrate edge of said recess so as to provide an emitter overhanging portion overhanging said recess; a collector electrode provided over said substrate means and having a straight edge which is slightly off alignment with the straight edge of said recess so as to provide a collector overhanging portion overhanging said recess.

Furthermore, a method for making a field-emission type switching device according to the present invention comprises steps of: (a) forming an insulation layer on a semiconductor substrate layer; (b) forming an electric conductive layer over said insulation layer; (c) etching said electric conductive layer to form an emitter electrode having a serrated edge and a collector electrode having a straight edge; (d) etching said insulation layer through a space between said emitter electrode and collector electrode so as to form a recess in said insulation layer such that an emitter overhanging portion is formed overhanging said recess and, at the same time, a collector overhanging portion is formed overhanging said recess; (e) ion injecting at the bottom of said recess into said semiconductor substrate so as to form a gate electrode; and (f) etching said overhanging portions to provide tapered edges.

When 50 through 80V of voltage is fed to the gate electrode adjacent to the emitter electrode, more than 10^7 V/cm of high electric field is generated at the tip of the emitter electrode, and then electron is emitted. Part of the emitted electron enters into the gate electrode, whereas majority of electron enters into the collector electrode provided in opposition from the emitter electrode, and thus, electric signal added to the gate electrode can be modulated and transmitted to the collector electrode. The spacing between the emitter electrode and the collector electrode can be set less than one micron, and therefore, extremely fast switching operation can be achieved.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other objects and features of the present invention will become clear from the following description taken in conjunction with the preferred embodiments thereof with reference to the accompanying drawings throughout which like parts are designated by like reference numerals, and in which:

Fig. 1 illustrates a cross-sectional view of the thin-film field-emission type switching device according to a prior art;

Fig. 2 illustrates a perspective view of the structure of essential electrodes of the field-emission type switching device according to a first embodiment of the present invention;

Fig. 3 illustrates a perspective view of the structure of essential electrodes of the switching device according to a second embodiment of the present invention; and

Fig. 4 illustrates steps for forming the field-emission type switching device shown in Fig. 2.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

First Embodiment

Referring to Fig. 2, a field-emission type switching device according to a first embodiment of the present invention is shown. The field-emission type switching device comprises a P-type silicon substrate 1 having a thickness of 300 micrometer and an insulation layer 2 made of silicon oxide film having a thickness of 0.5 micrometer formed on the P-type silicon substrate 1. The insulation layer 2 is partly removed to provide a recess 6. One edge of the recess 6 is straight and other edge opposite to the one edge is serrated. An emitter electrode 3 and a collector electrode 4 which are formed by a tungsten silicide (WSi_2) film with a thickness of 0.2 micrometer are provided on insulation layer 2 such that emitter electrode 3 has a serrated edge 7 which is slightly off alignment towards the collector electrode 4 with the serrate edge of the recess 6, and collector electrode 4 has a straight edge which is slightly off alignment towards the emitter electrode 3 with the straight edge of the recess 6. Thus, peripheral edge portion of the serrated edge 7 of emitter 3 and peripheral edge portion of collector 4 extend over groove 6.

The bottom of groove 6, which is the surface of the silicon substrate 1 is formed with an n+ region by an ion-injection process, thereby defining a gate electrode 5.

Referring to Figs. 4a-4e, steps for forming the field-emission type switching device of Fig. 2 are shown. First, as shown in Fig. 4a, the insulation layer 2 made of silicon oxide film having 0.3-0.6 micrometer is formed on the surface of P-type silicon substrate 1, and then WSi_2 film 9 having a thickness of 0.2 micrometer is formed on the surface of the insulation layer.

Then, as shown in Fig. 4b, the emitter electrode 3 and the collector electrode 4 are formed by the step of photolithographic etching, providing 1-3 micrometers, preferably 1.5 micrometers, of spacing between the tip of the serrated edge of emitter electrode 3 and the straight edge of collector electrode 4.

Then, as shown in Fig. 4c, the insulation layer 2 between electrodes 3 and 4 is removed by etching process using buffer etching solution, resulting in a formation of recess 6. A peripheral edge portion 3a of emitter electrode 3 and a peripheral edge portion 4a of collector electrode 4 extend over the recess 6 as in eaves.

Then, as shown in Fig. 4d, by applying ion-injection process, low-resistance n+ layer is formed on the surface of the silicon substrate between both electrodes for making gate electrode 5. A low-resistance p+ layer is formed when an N-type substrate is used.

Then, as shown in Fig. 4e, overhanging portions 3a and 4a are etched so as to provide a tapered edge.

From a microscopic viewpoint, as shown in Fig. 5, each pointed tip of the serrated edge 7 is rounded with a curvature radius R of 0.5-1 micrometer, and has a tapered edge thickness T of 0.02-0.04 micrometer. A sharp edge is particularly suitable for the intense and concentrated electrode emission from emitter electrode 3. Since it is very difficult to obtain a sharp edge by reducing the curvature radius R, the sharp edge is obtained by making the tapered edge thickness T very thin.

In one operation mode, emitter electrode 3 is connected to earth and collector electrode 4 is applied with 60V. At this condition, no electron emits from emitter electrode 3. Then, when gate electrode 5 is provided with 50V pulse, emission of electrons from emitter electrode 3 occurs during the pulse period. Thus, a negative pulse signal is generated at collector electrode 4.

According to another operation mode, emitter electrode 3 is connected to earth and when collector electrode 4 is applied with 80V, emitter electrode 3 emits electrons to cause electron current to flow to collector electrode 4. During such a electron current flow, when gate electrode 5 is applied with -30V pulse voltage, the electron current is cut off during the pulse period.

In this way, current flowing between the emitter and collector electrodes can be turned ON and OFF in accordance with voltage change at gate electrode 5, thus providing switching operation. Furthermore, amplification of voltage and current can also be achieved. Thus, the field-emission type switching device according to the present invention can be used in the same way as the field-effect transistor formed by a semiconductor. The switching device of the present invention can provide less than 0.2 pico-second of the limit of the switching speed as determined by the running time of electron between the emitter and collector electrodes.

According to the first embodiment, film made from silicon oxide is used for forming the insulation layer 2. Alternatively, insulation layer 2 may be formed by such materials as Si_3N_4, Ta_2O_3, or Al_2O_3 having a high insulation property. As the thickness of insulation layer 2 is made thinner, the operation becomes more sensitive to the change of voltage in gate electrode 5. Thus, the drive voltage can be lowered. Furthermore, material for forming the emitter electrode is not limited to WSi_2, but such material as W, Ta, Mo having high melting point, or carbide such as WC, TaC, ZrC, or SiC, or carbon, may also be used.

Second Embodiment

Referring to Fig. 3 a field-emission type switching device according to a second embodiment of the present invention is shown. Emitter electrode 12 and collector electrode 13 are formed on the surface of glass substrate 11. A recess 15 is formed in the glass substrate 11 between electrodes 12 and 13. A gate electrode 14 is disposed in recess 15. A distance D1 measured between the tip of emitter electrode 12 and gate electrode 14 is 0.5-1.0 micrometer, a distance D2 between the edge of gate electrode 14 and collector electrode 13 is 1-2 micrometers, and a width W of gate electrode 14 is 0.5-1.0 micrometer. The switching device of the second embodiment operates in the same manner as that of the first embodiment, and similar high speed and stable operation as that observed in the first embodiment is obtained. Furthermore, a level difference between emitter and gate electrodes is 0.5-1.0 micrometer.

In the second embodiment, when distance D1 is made shorter than distance D2, it is possible to improved the effect of the gate electrode. Furthermore, by making the distance D2 great, it is possible to increase the dielectric breakdown voltage between both gate and collector electrodes, thus making it possible to provide a switching device having high amplification rate.

The switching device according to the present invention may be encapsulated by a suitable casing to provide the switching device in a vacuum condition, or in a non-active gas.

According to the field-emission type switching device of the present invention, since the distance between the emitter electrode and the collector electrode can be reduced to less than one-tenth the prior art switching device, the switching speed can be shortened more than one-tenth. Furthermore, no crosstalk occurs between adjacent devices, and yet, the invented switching device can be manufactured at inexpensive cost.

Although the present invention has been fully described in connection with the preferred embodiments thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications are apparent to those skilled in the art. Such changes and modifications are to be understood as included within the scope of the present invention as defined by the appended claims unless they depart therefrom.

Claims

1. A field-emission type switching device comprising:
a substrate means (1, 2; 11) formed with an elongated recess (6; 15);
a gate electrode (5; 14) formed at the bottom of

said recess (6; 15);
an emitter electrode (3, 12) provided over said substrate means (1, 2; 11) adjacent one side of said elongated recess (6; 15);
a collector electrode (4, 13) provided over said substrate means (1, 2; 11) adjacent other side opposite to said one side of said elongated recess (6; 15).

2. A field-emission type switching device comprising:
a substrate means (1, 2; 11) formed with a recess (6; 15) having a straight edge and serrated edge opposite to said straight edge;
a gate electrode (5; 14) formed at the bottom of said recess (6; 15);
an emitter electrode (3, 12) provided over said substrate means (1, 2; 11) and having a serrated edge which is slightly off alignment with the serrate edge of said recess (6; 15) so as to provide an emitter overhanging portion (3a) overhanging said recess (6;15);
a collector electrode (4, 13) provided over said substrate means (1, 2; 11) and having a straight edge which is slightly off alignment with the straight edge of said recess (6; 15) so as to provide a collector overhanging portion (4a) overhanging said recess (6; 15).

3. A field-emission type switching device as claimed in Claim 2, wherein said substrate means (1, 2) comprises a substrate layer (1) made of semiconductor material and an insulation layer (2) made of electrically insulation material.

4. A field-emission type switching device as claimed in Claim 3, wherein said gate electrode (5) is formed by an ion-injection process.

5. A field-emission type switching device as claimed in Claim 2, wherein said gate electrode (14) is formed by a metallic film.

6. A field-emission type switching device as claimed in Claim 2, wherein said emitter overhanging portion (3a) is tapered towards the end thereof.

7. A field-emission type switching device as claimed in Claim 6, wherein said tapered edge has a curvature radius of 0.5-1.0 micrometer.

8. A field-emission type switching device as claimed in Claim 6, wherein said tapered edge has a thickness of 0.02-0.04 micrometer.

9. A field-emission type switching device as claimed in Claim 2, wherein a distance between emitter electrode (3, 12) and collector electrode (4, 13) is 1-3 micrometers.

10. A field-emission type switching device as claimed in Claim 3, wherein said insulation layer (2) has a thickness of 0.3-0.6 micrometer.

11. A field-emission type switching device as claimed in Claim 5, wherein said collector electrode (13) and said gate electrode (14) are spaced greater than a spacing between emitter electrode (12) and said gate electrode (14).

12. A field-emission type switching device as claimed in Claim 5, wherein said emitter electrode (12) and said gate electrode (14) are spaced 0.5-1.0 micrometer.

13. A field-emission type switching device as claimed in Claim 5, wherein said collector electrode (13) and said gate electrode (14) are spaced 1-2 micrometers.

14. A field-emission type switching device as claimed in Claim 5, wherein said emitter electrode (12) and said gate electrode (14) are in different levels with a level difference of 0.5-1.0 micrometer.

15. A method for making a field-emission type switching device comprising the steps of:
(a) forming an insulation layer (2) on a semiconductor substrate layer (1);
(b) forming an electric conductive layer (9) over said insulation layer (2);
(c) etching said electric conductive layer (9) to form an emitter electrode (3) having a serrated edge and a collector electrode (4) having a straight edge;
(d) etching said insulation layer (2) through a space between said emitter electrode (3) and collector electrode (4) so as to form a recess in said insulation layer (2) such that an emitter overhanging portion (3a) is formed overhanging said recess (6;15) and, at the same time, a collector overhanging portion (4a) is formed overhanging said recess (6; 15);
(e) ion injecting at the bottom of said recess (6) into said semiconductor substrate (1) so as to form a gate electrode (5); and
(f) etching said overhanging portions (3a, 4a) to provide tapered edges.

Fig. 1 PRIOR ART

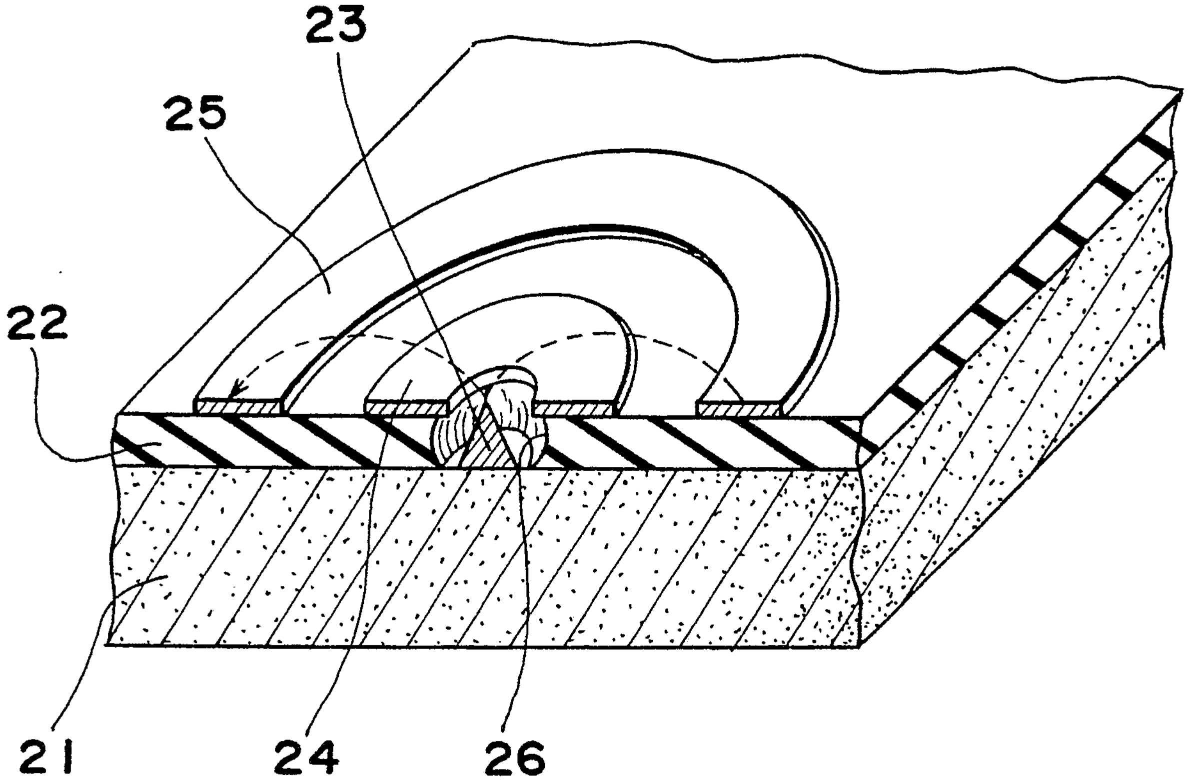

Fig. 5

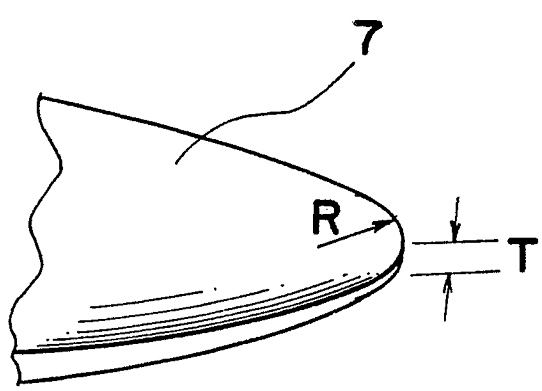

Fig. 2

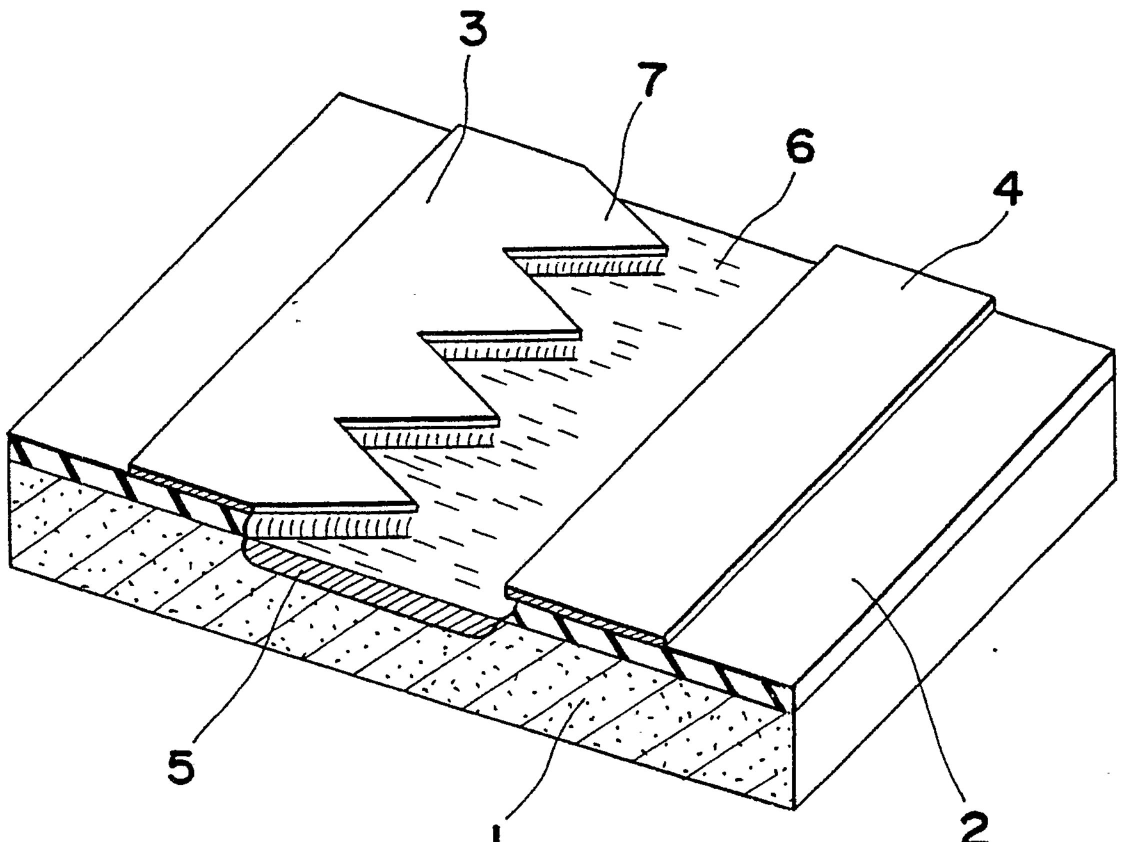

Fig. 3

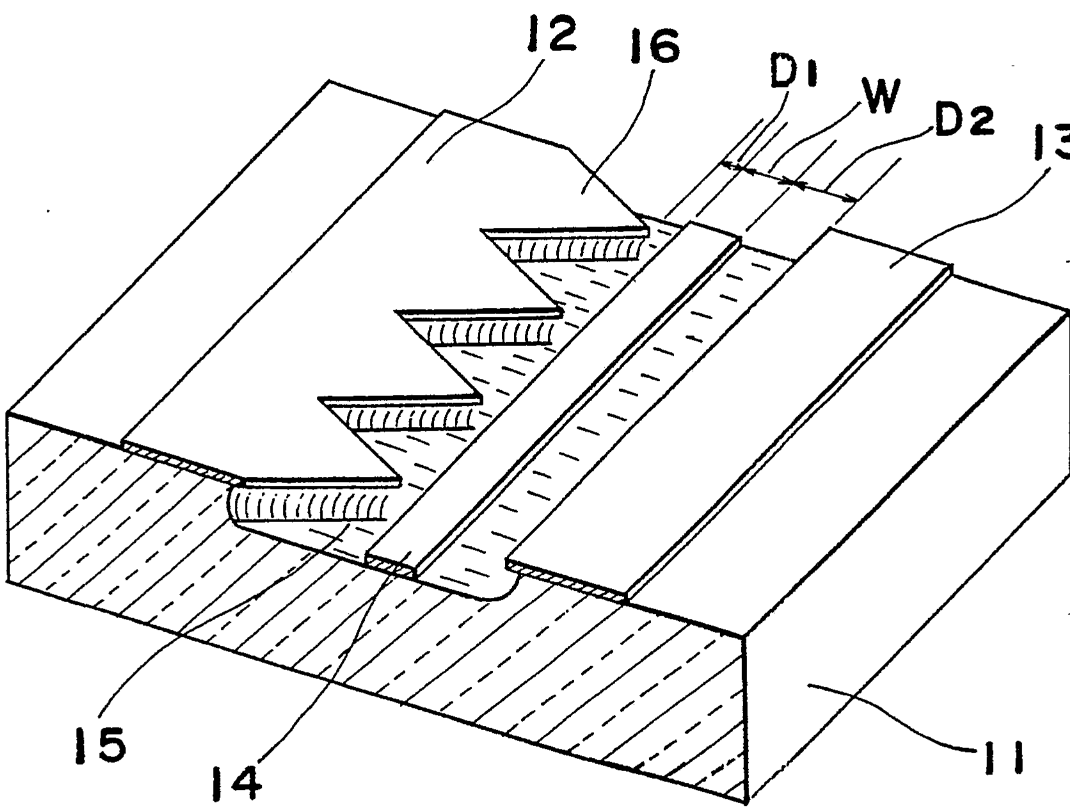

Fig. 4a

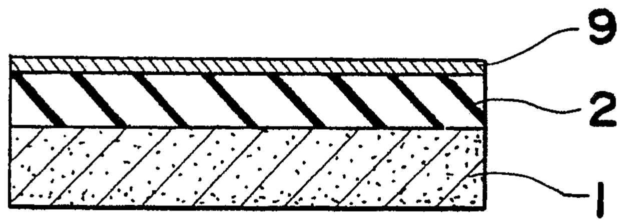

Fig. 4b

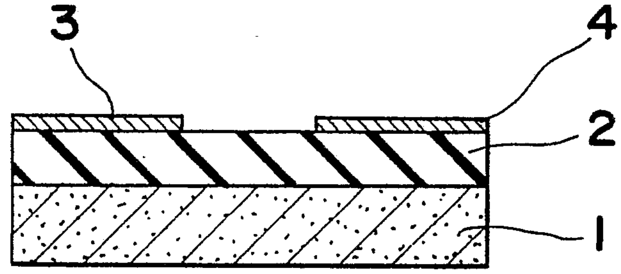

Fig. 4c

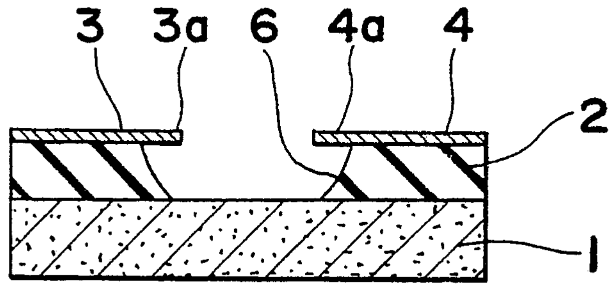

Fig. 4d

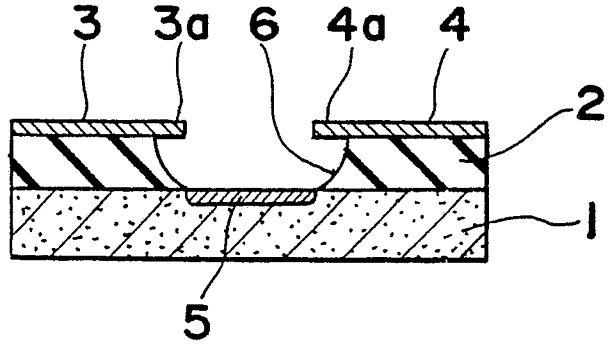

Fig. 4e