PATENT SPECIFICATION

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COMPLETE SPECIFICATION

High Power Junction Transistor

We, CLEVITE CORPORATION, a Corporation organized and existing under the Laws of the State of Ohio, and having its principal place of business at 17000 St. Clair Avenue, Cleveland 10, Ohio, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a junction transistor for high power operation.

In the alloy junction transistor small discs of appropriate doping metal are alloyed to opposite major faces of a thin semiconductor wafer so as to form rectifying junctions therewith. For example, a P-N-P alloy junction transistor may be constructed by alloying indium discs to opposite major faces of an N-type germanium wafer, these discs serving as the emitter and collector respectively, and with a base electrode making ohmic contact with the N-type germanium wafer. In the conventional configuration of the alloy junction transistor the emitter is in the form of a circular disc and the base electrode is connected to the semiconductor wafer relatively distant from the emitter. This conventional configuration is not well suited for high power operation. Due to the finite resistivity of the material of the semiconductor wafer and its finite thickness between the emitter and collector junctions, the base current when the transistor is in operation causes a reduction of the bias on the portions of the emitter junction remote from the base electrode. This severely limits the amount of current which a transistor of this configuration can carry. In particular, this configuration results in a reduced injected current density at the portions of the emitter junction spaced from the peripheral portions of the emitter at this junction which are closest to the base electrode. For example, in a typical transistor of this conventional configuration including a germanium wafer .001 inch thick, an emitter efficiency of substantially 100%, a minority carrier lifetime in the semiconductor wafer of 100 microseconds, and an injected current density at the periphery of the emitter junction of 10 amps/sq.cm., the injected current density at this junction at a distance of 1 mm. inward from the emitter periphery is only about 4 amps/sq.cm. Any portions of the emitter further inward than this would be even more inefficient and thus it would be wasteful of materials to provide an emitter greater than about 2 mm. in diameter under these conditions. Such an emitter, under the typical conditions specified above, would have a total current capacity of only 300 milliamperes. Also, the concentration of current adjacent the periphery of the emitter tends to cause degradation of other operation characteristics of the transistor.

According to the invention there is provided a semiconductor device comprising a body of semiconductive material, an emitter of strip form making rectifying contact with one surface of said body, a base electrode making ohmic contact with said surface on opposite sides of said emitter and in close parallel relation to said emitter on at least one of said opposite sides, and a collector region making rectifying contact elsewhere on said body.

The term "strip form" is used herein to mean that the electrode to which it is applied is of elongated nature, that is to say it has substantially greater length than width. Thus a long narrow electrode of rectilinear or curvilinear form is considered to be of strip form. Substantially the whole of the emitter operates quite efficiently in injecting current into the semiconductor, and consequently the device is capable of passing much higher total currents without a dele-

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teriously high injected current density at any particular point on the emitter junction.

The various features and advantages of the present invention will be apparent from the following description of several preferred embodiments thereof, illustrated in the accompanying drawing.

In the drawings:—

Fig. 1 is a perspective view showing the general principle of the present invention;

Fig. 2 is a plan view of a transistor embodying the principles of this invention;

Fig. 3 is a section taken along the line 3—3 in Fig. 2;

Fig. 4 is a plan view of a second embodiment of this invention;

Fig. 5 is a section taken along the line 5—5 in Fig. 4;

Fig. 6 is a plan view showing a third transistor configuration according to the present invention;

Fig. 7 is a section taken along the line 7—7 in Fig. 6;

Fig. 8 is a plan view of a fourth transistor configuration in accordance with this invention;

Fig. 9 is a section taken along the line 9—9 in Fig. 8;

Fig. 10 is a plan view of a still further transistor configuration in accordance with this invention; and

Fig. 11 is a section taken along the line 11—11 in Fig. 10.

Referring to Fig. 1, illustrating the general principle of the present invention, a thin slab 10 of semiconductor material, such as germanium, is suitably doped with an appropriate impurity to make it of one conductivity type. For example, it may be doped with an extremely small amount of donor impurity, such as antimony or arsenic, to make it N-type. An emitter region 11 is bonded to one major face 12 on the semiconductor slab. This emitter region is formed by alloying or diffusing suitable acceptor material, such as indium, to that face of the semiconductor slab. The acceptor material penetrates into the semiconductor slab and adjacent the interface 13 between the emitter and the semiconductor slab the emitter presents a low resistivity region of semiconductive alloy of P-type conductivity, which makes a rectifying junction with the N-type semiconductor slab 10 at their interface 13. The emitter 11 is of strip form, i.e., it is elongated in the direction of the major dimension of that major face on the semiconductor slab.

A pair of base regions 14 and 15 are bonded to the same major face 12 on the semiconductor slab, making ohmic contact therewith along their entire lengths, respectively, on opposite sides of the emitter. These base regions are of highly electrically conductive material and are elongated in the same direction as the emitter, extending in parallel, close, equally spaced relationship to the opposite side edges of the emitter.

On the opposite major face 16 of the semiconductor slab is diffused or alloyed an elongated collector 17 of acceptor material, such as indium. The acceptor material penetrates into the semiconductor slab to provide a low resistivity region of conductivity type opposite to that of the semiconductor slab itself adjacent the junction interface 18 between the collector and the semiconductor slab. The collector makes rectifying contact with the semiconductor slab directly opposite the entire length of the emitter 11 and is slightly wider than the emitter.

In operation, the two base regions 14 and 15 are connected together electrically by suitable external means. It will be apparent that the base current flow in the semiconductor slab 10 is perpendicular to the direction of elongation of the emitter and base. Because of this direction of the base current and the elongation of the emitter and base regions, as well as the close spacing between the emitter and base regions, the total voltage drop in the device due to base current is minimized. The emitter current may be increased to any desired value without resulting in an increase in the current density simply by extending the length of the semiconductor slab and the electrode regions.

A practical form of transistor, which embodies the basic principles illustrated in Fig. 1, is shown in Figs. 2 and 3. In this configuration the elongated thin rectangular semiconductor slab 20 of one conductivity type has alloyed or diffused onto one of its major faces 21 an elongated strip form emitter 22 of material which provides a region of opposite conductivity type making rectifying contact with the semiconductor slab and elongated in the direction of elongation of the semiconductor slab itself. A lead-in wire 22*a* of copper or the like is soldered to the emitter 22 at any convenient location thereon. The base electrode is in the form of two elongated regions 23 and 24 of suitable material such as solder, which make ohmic contact with the semiconductor slab on opposite sides of the emitter 22 in close, equally spaced, parallel relation to the adjacent side edges of the emitter. The elongated base regions 23 and 24 are interconnected at their ends by further base regions 25 and 26 which extend across the ends of the emitter and make ohmic contact with the semiconductor slab. Thus, the several base regions form a rectangular base electrode which extends completely around the emitter 22 in closely spaced relation thereto. A lead-in wire 23*a* is soldered to any desired portion of the base electrode. The collector electrode 27 is alloyed or diffused to the opposite major face 28 on the semiconductor slab and provides a region of opposite conductivity type which makes rectifying contact with the semiconductor slab. The collector region extends across an area substantially equal to that bounded by the base electrode on the first-mentioned major face 21 of the semiconductor slab. Both the emitter region and collector region penetrate into the semiconductor slab, as in Fig. 1. The collector is soldered to a copper plate 29, to which external electrical connection is made.

In this embodiment, the operation is essentially as described above, with substantially all of the base current flow being in a direction perpendicular to the direction of elongation of the emitter electrode. The base electrode regions 25 and 26 serve essentially as a convenient means for electrically interconnecting the major, elongated base electrode regions 23 and 24. In a specific embodiment of this particular configuration the semiconducting body 20 is of N-type germanium of 1-5 ohm cm. resistivity, the dimensions of the semiconducting slab are 0.600″ x 0.200″ x .020″, the indium emitter region is 0.400″ x .070″ and the indium collector region 0.500″ x 0.150″. The closest spacing between the emitter and collector interfaces is 0.001″ and the spacing between the emitter and base electrodes is .030″. This transistor has a current capacity of several amperes.

A further modification is shown in Figs. 4 and 5. Here the thin semiconductor slab of one conductivity type has alloyed or diffused onto one of its major faces 121 a pair of spaced parallel elongated strip form emitter regions 122*a* and 122*b*, each of which makes rectifying contact with this face of the semiconductor slab. The base electrode comprises three elongated regions 123*a*, 123*b* and 123*c*, disposed respectively on opposite sides of the emitter regions and in close proximity thereto, substantially parallel to the emitter regions. These base electrode regions are interconnected by further base electrode regions 123*e* and 123*f*, which extend across the ends of the emitter regions. All of these base electrode regions are of high conductivity material making ohmic contact with the major face 121 of the semiconductor slab. The collector electrode 127 is alloyed or diffused onto the opposite major face 128 of the semiconductor slab and makes rectifying contact therewith across an area of said face slightly greater than that bounded by the base electrode regions 123*a*, 123*e*, 123*c* and 123*f* on the first major face 121 of the semiconductor slab and directly opposite that area bounded by these base electrode regions. Both emitters, as well as the collector, penetrate into the semiconductor slab and provide regions of conductivity type opposite to that of the semiconductor slab which make rectifying junctions with the semiconductor slab. The external electrical connections (not shown) preferably are similar to those shown in Figs. 2 and 3.

In this modification substantially all of the base current flows substantially perpendicular to the direction of elongation of the emitter regions, with a consequent increase in over-all current carrying capacity for the transistor.

A further embodiment of this invention is shown in Figs. 6 and 7. In this device the thin slab 30 of semiconductor material of one conductivity type is of rectangular shape. Alloyed or diffused to one major face 31 on the semiconductor body are a plurality of elongated strip form, spaced, parallel emitter regions 32, 33, 34, 35, 36 and 37, which may be interconnected at one end by an emitter region 38 to provide a comb-like configuration. Each of the emitter regions makes rectifying contact with the semiconductor slab. The base electrode comprises a plurality of elongated base regions 39, 40, 41, 42 and 43, making ohmic contact with the same face on the semiconductor slab and each of which is disposed between a pair of adjacent emitter regions in close, equally spaced, parallel relation therewith. The base regions 39-43 in this instance interconnected by an elongated base region 44, which forms one side of a rectangular base electrode configuration surrounding the entire emitter electrode region, the other sides of this square being formed by the elongated base regions 45, 46 and 47. The base regions 45 and 47 extend in closely spaced, parallel relation to the emitter regions 32 and 37, respectively. A collector region 48 is alloyed or diffused to the opposite major face 49 on the semiconductor slab and makes rectifying contact therewith. The collector region is rectangular in shape and extends slightly beyond the outline 44, 45, 46, 47 of the base electrode. The material of both the emitter and collector electrodes penetrates into the material of the semiconductor slab, as indicated in Fig. 7, and provide regions of conductivity type opposite to that of the semiconductor slab and which makes rectifying junctions therewith. The external electrical connections (not shown) may be made as illustrated in Figs. 2 and 3.

In the operation of this device, substantially all of the base current flows perpendicular to the elongated emitter regions 32-37, with a consequent decrease in current density variations and increase in the overall current carrying capacity of the device. In one specific embodiment, a transistor having the general configuration shown in Fig. 6 was fabricated with five parallel emitter portions on an N-type germanium slab 1.0″ x 1.0″ x .020″. A second embodiment of this type had two parallel emitter regions of an N-type germanium slab 0.6″ x 0.4″ x .020″. Both of these devices had current carrying capacities in tens of amperes.

In the embodiment of Figs. 8 and 9, the emitter is in the form of an annular strip 50 of low resistivity material diffused or alloyed to one major face 51 on the thin, circular semiconductor slab 52. The emitter provides a region of opposite conductivity type to that of the semiconductor slab in rectifying contact with the semiconductor slab throughout the annular extent of the emitter. An inner base electrode region in the form of a circular disc 53 surrounded by the emitter region 50 makes ohmic contact with the same major face 51 on the semiconductor slab, with its circular peripheral edge extending in closely spaced relation to the inner edge of the emitter region 50 and parallel thereto. An outer base electrode region in the form of a circlar annulus 54, which surrounds the emitter region 50, makes ohmic contact with the same major face on the semiconductor slab. This outer base electrode region extends in parallel, closely spaced relation to the outer edge of the emitter region. Preferably the spacings between the emitter region and the inner and outer base electrode regions are equal. A collector electrode 56 is diffused or alloyed to the opposite major face 55 of the semiconductor slab and provides a region of opposite conductivity type which makes rectifying contact with the semiconductor slab. In the illustrated embodiment the collector region 56 is circular and extends slightly beyond the outer peripheral edge of the outer peripheral edge of the outer base electrode 54. The external electrical connections to the various electrodes may be as shown in Figs. 2 and 3.

In operation, the inner and outer base electrode regions are interconnected through a suitable external connection. Base current flows through the semiconductor slab 52 radially inward and outward from the annular emitter region 50, substantially perpendicular to the emitter region and to both base regions.

A modification of the Fig. 8 embodiment is illustrated in Figs. 10 and 11, wherein there are provided two concentrically disposed circular emitter regions 60 and 61, and three concentrically disposed base regions 62, 63 and 64, the innermost base region 62 being in the form of a circular dot disposed concentrically within the inner emitter region 60, the intermediate base region 63 being in the form of a circular annulus positioned concentrically between the inner and outer emitter regions 60 and 61, and the outer base region 64 being in the form of a circular annulus which surrounds the outer emitter region 61 concentric therewith. The inner and outer emitter regions 60 and 61 are alloyed or diffused to one major face 65 of the thin circular semiconductor body 66 and provide regions of opposite conductivity type to that of the semiconductor body which make elongated rectifying contacts with the semiconductor body. The base electrodes are of high conductivity material and make ohmic contact with the semiconductor body. The collector electrode 67 is alloyed or diffused to the opposite major face 68 on the semiconductor body and provides a region of opposite conductivity type to that of the semiconductor body which makes rectifying contact with an area of the semiconductor body which extends slightly beyond that bounded by the outer base electrode 64.

The emitter regions 60 and 61 are connected together electrically through an external connection, and the base regions 62, 63 and 64 are similarly interconnected electrically. In operation, base current to the inner base region 62 flows radially inward through the semiconductor body from the inner emitter region 60, base current to the intermediate base region 63 flows through the semiconductor body radially outward from the inner emitter region 60 and radially inward from the outer emitter region 61, and base current to the outer base region 64 flows through the semiconductor body radially outward from the outer emitter region 61. Thus all of the base currents flow perpendicular to the lengths of the respective elongated emitter regions, as in the preceding embodiments of this invention.

Obviously, the principles of the present invention may be extended to provide any desired number of concentric emitter and base regions.

Furthermore, it is to be understood that various other modifications and refinements departing from the specific embodiments illustrated in the accompanying drawings may be adopted without departing from the spirit and scope of the present invention.

In each of the foregoing embodiments of the present invention for optimum performance certain design factors must be considered. From the viewpoint only of the bias cut-off effect the emitter electrode should be as narrow as possible since improved efficiency results. However, the number of minority carriers lost at the surface due to surface recombination is approximately proportional to the emitter periphery, so that with very thin emitters, having a large ratio of periphery to total area, this effect is proportionately more severe. Also, since the transistor is made by an alloying or diffusion process and the depth of penetration is finite, in order that the base region be as uniformly thin as possible the emitter width should be large compared to the alloying depth. Also, very narrow emitters will be mechanically weak and difficult to fabricate. The relative importance of these various factors depends upon many things—surface recombination velocity, which is closely dependent upon the etching technique used, being one of the most important. Therefore, experimentation and experience are necessary in order to arrive at the optimum emitter width for any particular type of fabrication technique used. For commonly available germanium within the resistivity range from 1 to 3 ohm-cm., with a base layer thickness of .001″ to .002″, and emitter current densities of 10 to 50 amps/sq.cm. an emitter width of about 2 mm. has been found to be approximately the optimum.

The base electrodes should be equally spaced from the emitter and as close to the emitter as possible, the closeness being dictated primarily by mechanical considerations.

From the viewpoint of collection efficiency, the collector electrode should be as large as possible, but on the other hand increasing the collector area increases the saturation current and also increases the likelihood that the collector region will contain some serious crystal imperfection. In practice, if the collector is made to extend one or two diffusion lengths sideways beyond the emitter, the collection will be sufficiently good.

WHAT WE CLAIM IS:—

1. A semiconductor device comprising a body of semiconductive material, an emitter of strip form making rectifying contact with one surface of the body, a base electrode making ohmic contact with said surface on opposite sides of said emitter and in close parallel relation to said emitter on at least one of said opposite sides, and a collector region making rectifying contact elsewhere on said body.

2. A device as claimed in Claim 1 in which said body has opposite major faces, said emitter and base make contact with one of said major faces, and said collector makes contact with the other of said major faces.

3. A device as claimed in Claim 1 or 2 in which said body of material is of one conductivity type and said emitter and collector are of opposite conductivity type

4. A device as claimed in Claim 1, 2 or 3 in which the base electrode extends in close parallel relation to said emitter on both sides thereof.

5. A device as claimed in Claim 4 in which the parts of the base electrode which extend parallel to the sides of the emitter are connected together by parts which extend across the ends of the emitter.

6. A device as claimed in Claims 2 and 5 in which the collector extends over an area at least as great as the area bounded by the base electrode parts.

7. A device as claimed in Claim 1, 2, 3 or 4 in which the emitter is of annular form and the base electrode is constituted by a circular part within the annulus of the emitter and an annular part extending around the emitter.

8. A device as claimed in any preceding claim having a plurality of emitters and a plurality of base electrodes extending along opposite sides of each emitter.

9. A device as claimed in Claim 8 in which the emitter electrodes are interconnected and the base electrodes are interconnected.

10. A semiconductor device substantially as herein described with reference to the accompanying drawings.

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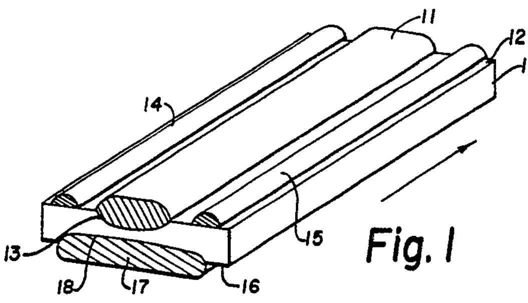

Fig. 1

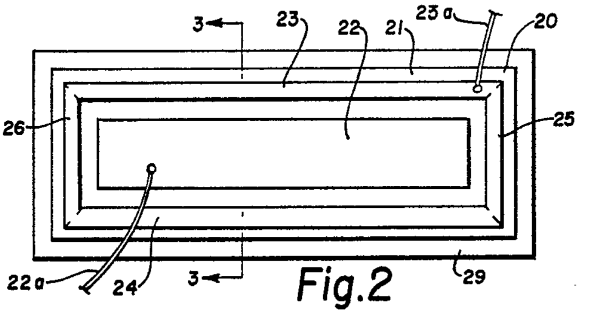

Fig.2

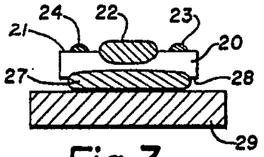

Fig.3

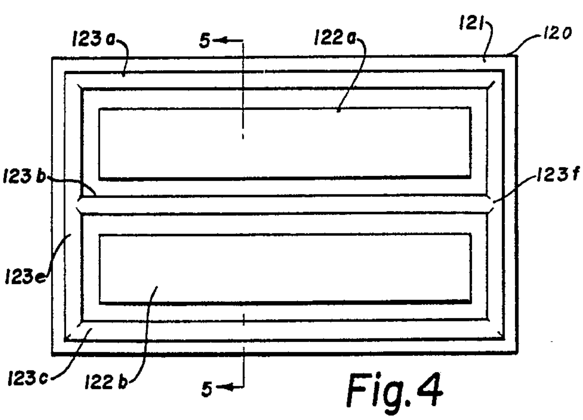

Fig.4

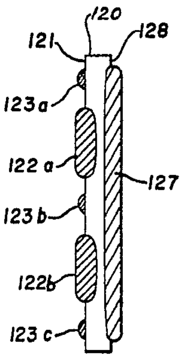

Fig.5

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Sheets 1 & 2

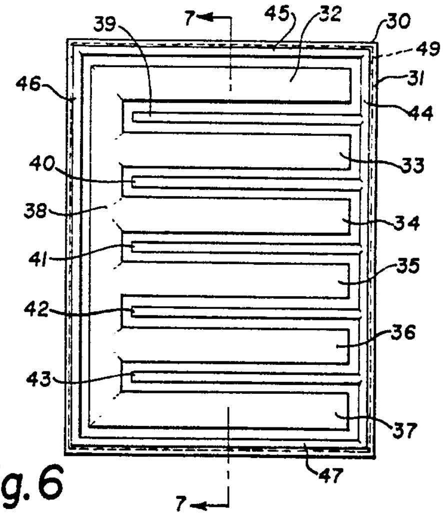

Fig.6

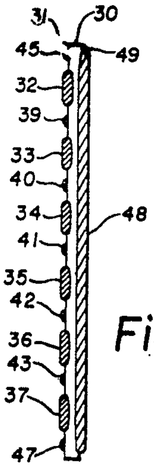

Fig.7

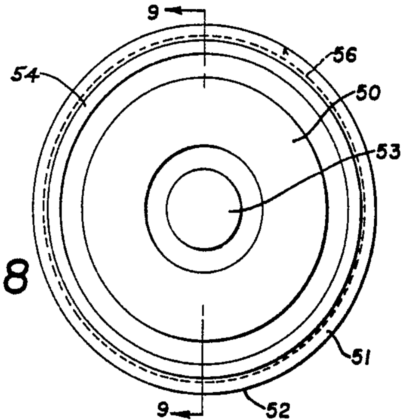

Fig.8

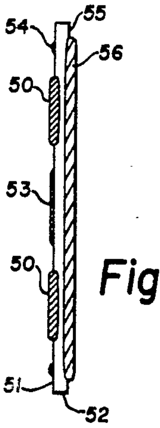

Fig.9

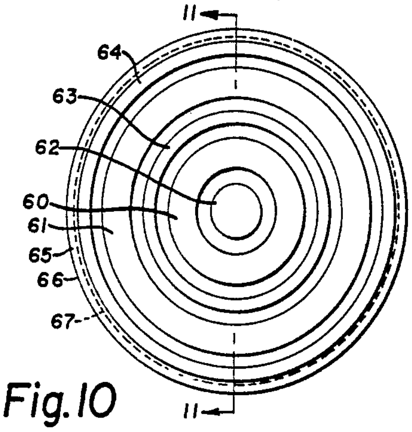

Fig.10

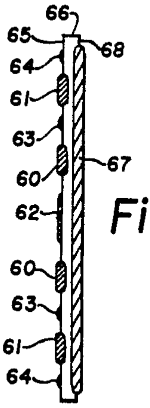

Fig.11

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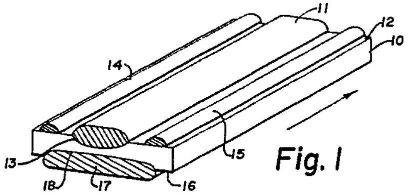

Fig. 1

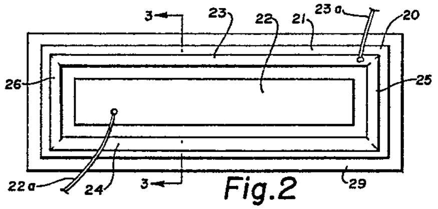

Fig. 2

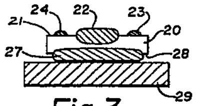

Fig. 3

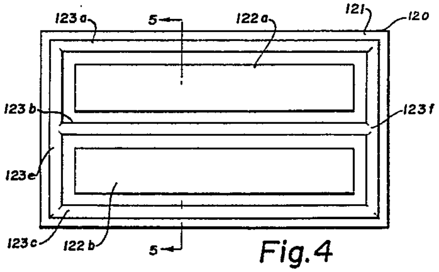

Fig. 4

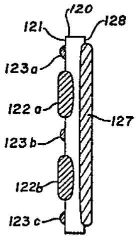

Fig. 5

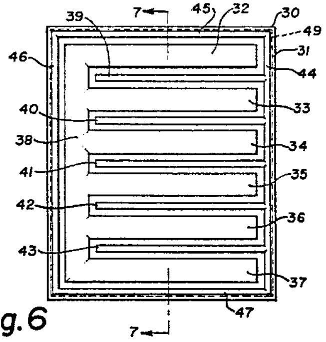

Fig. 6

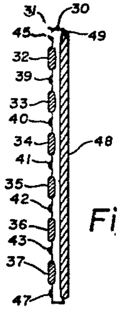

Fig. 7

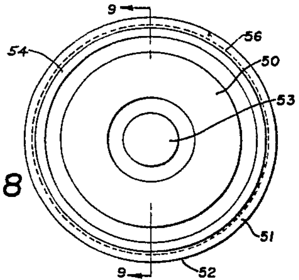

Fig. 8

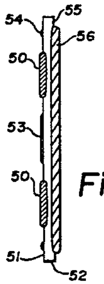

Fig. 9

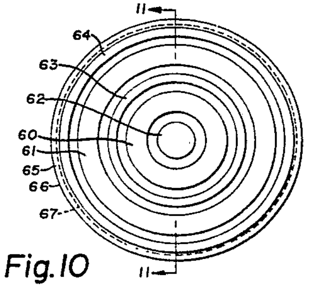

Fig. 10

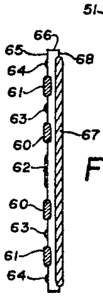

Fig. 11