United States Patent

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[32] Priority **Sept. 22, 1967**
[33] **Japan**
[31] **42/60956, 42/60958, 42/60957 and 42/60959**

[54] **TRANSISTOR HAVING CONCAVE COLLECTOR CONTACT AND METHOD OF MAKING SAME**
9 Claims, 16 Drawing Figs.

[52] **U.S. Cl.** **317/235,** 148/175, 148/177
[51] **Int. Cl.** **H01l 11/06**
[50] **Field of Search** 317/235/40.1, 22.1, 40.13, 48.1, 47, 237/5.4, 235

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Primary Examiner—Jerry D. Craig
Attorney—Darby and Darby

ABSTRACT: A switching transistor element of the concave collector contact structure and having excellent second breakdown characteristics and a method of making such a transistor by forming the concave collector contact by the alloying method using a jig comprising a projection, by the diffusion method which employs two kinds of impurities having different diffusion constants or by the epitaxial growth method using a substrate to which a concave part is provided in advance.

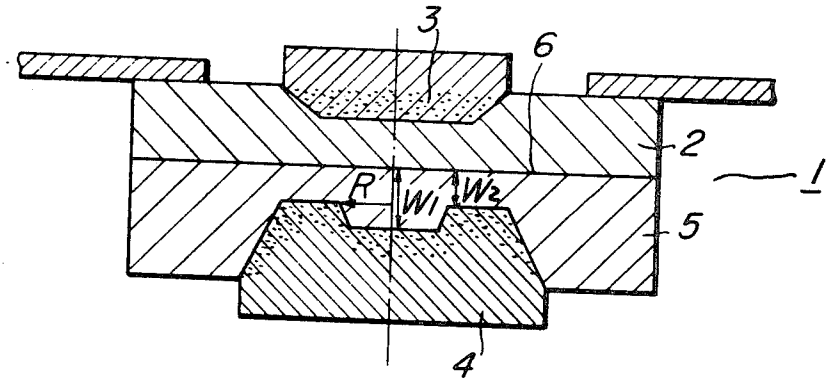


FIG. 1

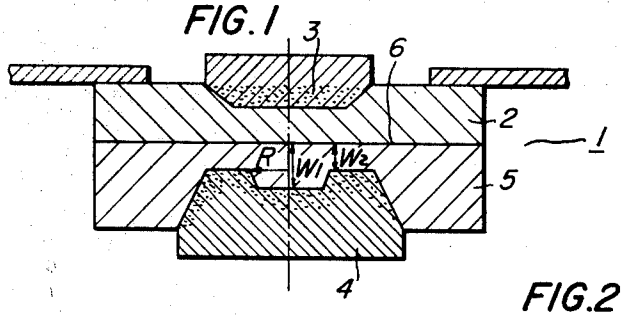


FIG. 2

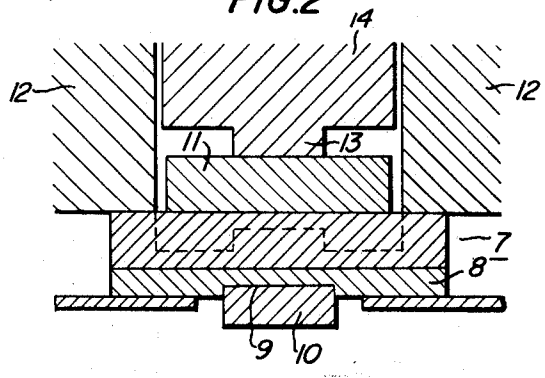


FIG. 5a

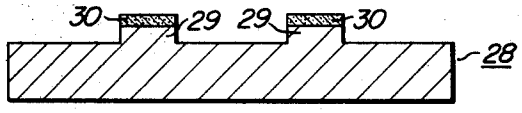


FIG. 5b

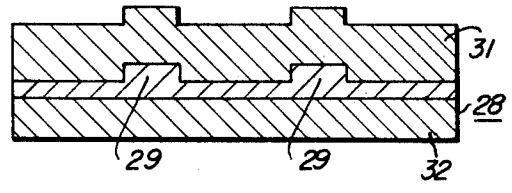


FIG. 5c

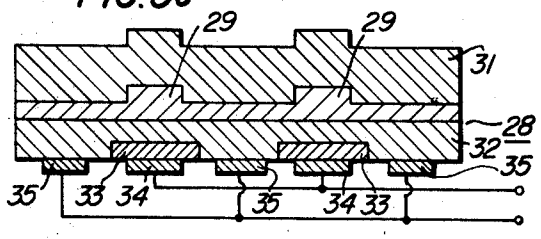


FIG. 3a

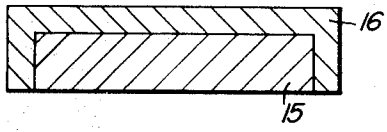


FIG. 3b

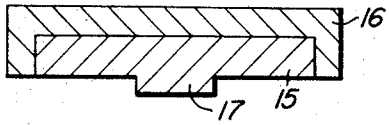


FIG. 3c

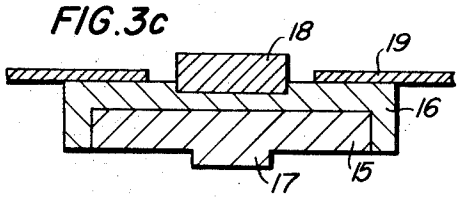


FIG. 3d

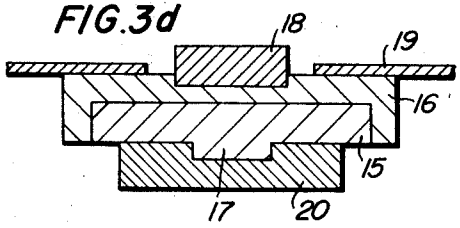


FIG. 3e

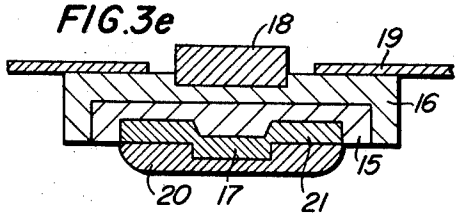


FIG. 3f

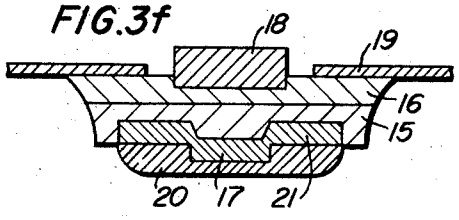


FIG. 4a

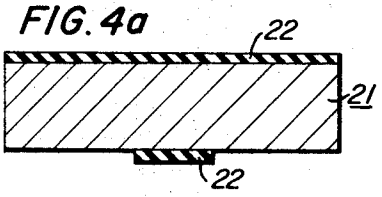


FIG. 4b

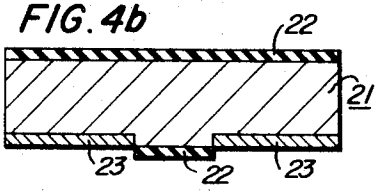


FIG. 4c

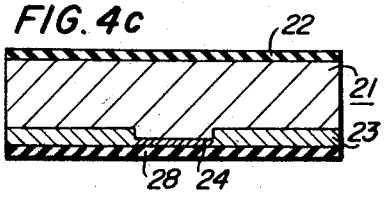


FIG. 4d

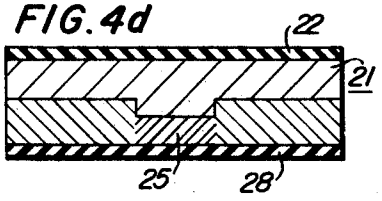
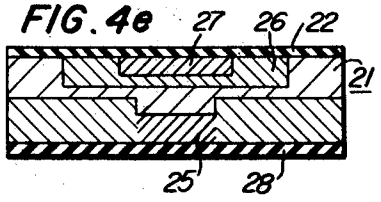


FIG. 4e



TRANSISTOR HAVING CONCAVE COLLECTOR CONTACT AND METHOD OF MAKING SAME

BACKGROUND OF THE INVENTION

1. **Field of the Invention**

This invention relates to a transistor, and more particularly to the structure of a switching transistor comprising a high resistivity substantial collector layer and a low resistivity collector contact, wherein the second breakdown characteristics thereof are improved by changing the thickness of the collector layer facing the emitter layer or forming a concave collector contact.

2. Description of the Prior Art

When a reverse bias is applied between the emitter and the base of a conventional switching transistor to operate it as a circuit element, a second breakdown, which causes a rapid lowering of the collector-emitter breakdown voltage, takes place when the current running between the collector and the base exceeds a certain value.

The cause of this second breakdown has not yet been clarified, but it is considered that the center portion of the emitter layer locally turns into the state of the forward bias due to the potential drop of the base layer and the local concentration of current takes place. Then, the local heating of the reverse-biased junction, i.e. the local rise of temperature of the junction occurs and it diminishes the barrier characteristics of the junction.

Accordingly, conventional switching transistors suffer from the inconvenience that they must be used in a low potential region.

SUMMARY OF THE INVENTION

A primary object of this invention is to provide a reliable switching transistor having a high breakdown voltage by forming a concave collector contact to change the thickness of an active collector layer facing an emitter layer.

Another object of this invention is to provide a method of forming said collector contact simply by use of conventional techniques to obtain the transistor comprising said collector contact.

A further object of this invention is to provide a method of forming said concave collector contact by two deposition processes and one diffusion process.

A still further object of this invention is to provide a method of forming said concave collector contact simply by employing the alloying method or the epitaxial growth method after the etching process.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a cross section of a transistor structure embodying this invention;

FIG. **2** is a diagram illustrating the method of making the transistor of this invention by use of the alloying technique;

FIGS. **3***a* to **3***f* are diagrams illustrating the method of making a transistor of this invention by use of the other alloying technique;

FIGS. **4***a* to **4***e* are diagrams illustrating the method of making a transistor of this invention by two deposition processes and one diffusion process; and

FIG. **5***a* to **5***c* are diagrams illustrating a method of making a concave collector contact by the epitaxial growth method.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1**, the structure of a transistor of this invention will be described in detail in conjunction with a theoretical analysis of its characteristics. As shown in FIG. **1**, the transistor of this invention comprises an N conductivity-type base layer **2** provided by diffusion in a P conductivity-type Ge substrate **1**, a P conductivity-type emitter layer **3**, and a P conductivity-type collector contact **4** formed in a lightly doped region which becomes a collector layer.

It is characteristic of this invention that the collector contact has a concave shape. Namely, the substantial collector layer **5** has a convex shape.

The deficiencies described hereinabove can be obviated by the transistor having such a structure. The theoretical basis will be described as follows with reference to FIG. **1**. Namely, when the distance between the concave collector contact **4** and the base-collector junction **6** is denoted by W_1 and W_2 as shown in the figure, the condition $W_1 > W_2$ must be fulfilled. Further, it is necessary that the concave portion is provided opposite to the emitter layer **3** and $R > 0$.

Comparison is made in Table **1** between four kinds of transistors satisfying said requirements and a transistor with $R=0$.

TABLE 1

R(mm)	0	0.7	0.85	1.2	1.65
$W_1(\mu)$	27	27	41	42	41
$W_2(\mu)$	27	20	25	21	21
$I_{S/B}$(A)	6.2	17.2	18.7	20.2	23.0

As is evident from Table **1**, the transistor having a concave collector contact can withstand a very large current even when the resistivity and the collector width are the same as those of the transistor with $R=0$. The transistors described above have substantially the same collector-base avalanche breakdown voltage.

The circuit used in this experiment was formed by connecting a load inductance L and a power source V_{cc} for feeding the collector voltage in series between the emitter and the collector, and by providing a power source V_{EB} for supplying the reverse bias between the base and the emitter and a pulse generator for supplying a forward bias connected in parallel with said power source V_{EB}. The values shown in Table **1** were obtained by measuring the collector current $I_{S/B}$ when the second breakdown was initiated by successively supplying forward bias pulse voltage and, at the same time, by increasing said V_{cc}.

The reason why the above-mentioned current $I_{S/B}$ increases in the transistor having said collector contact structure is as follows according to the investigation by the inventors.

As is described in the Proceedings of the IEEE, vol. 56, No. 1, 1968, pp. 123—124, when a reverse bias is applied between the emitter and the base, the value of the generated voltage due to a decrease in the current running through the load inductance reaches the collector-base breakdown voltage and the avalanche breakdown current flows between the collector and the base until the transistor acquires a cutoff state. However, the current path differs from transistor to transistor and, in a transistor with $R>0$, the avalanche breakdown occurs initially in a part corresponding to the narrow collector region. Therefore, the transverse potential drop in the base layer is relatively small in the transistor of this invention which comprises the concave collector contact. On the other hand, in a transistor with $R=0$ or having a plane collector contact, the transverse potential drop is large on account of the breakdown current flowing into the base layer. This difference between the two types of transistors is considered to cause the difference to occur in the second breakdown characteristics.

As has become apparent from the foregoing explanation, the second breakdown voltage due to the emitter-collector reverse bias can be remarkably enhanced in the transistor of this invention only by making the collector contact into a concave shape.

The methods of fabricating the transistor of this invention which comprises the concave collector contact will be described concretely with reference to FIGS. **2** to **5**.

EXAMPLE 1

The first example will be explained with reference to FIG. **2**. A donor impurity is diffused by the powder method into a P conductivity-type germanium substrate **7** having a thickness of

200μ and a resistivity of 15ohm-cm. Then the thickness is made to be 140μ by selectively etching one of the surfaces. In this process, the layer formed by the diffusion is the base layer **8** and it has a surface impurity concentration of 3.5×10^{17} atoms/cm.^{3} and a width of about 60μ.

After forming the base layer, the emitter layer is formed. An alloy ball of 1.85 mm. in diameter which includes 80 percent by weight of Pb and 20 percent by weight of In is mounted on the Ge substrate and heated at 560° C. for 7 minutes to alloy with the Ge substrate. According to this process, an emitter layer **10** is provided and an emitter-base junction **9** is formed at a depth of 17μ. The emitter layer **10** has a diameter of about 3 mm. Namely, the alloy ball becomes large in its extension when alloying.

The most characteristic process in this method is one of forming the concave collector contact in the collector layer. In this process, an In plate **11** of 0.4 mm. in thickness and 3.9 mm. in diameter is disposed at a position in the desired region which satisfies the conditions $0<R$ and $W_1>W_2$. Said plate is heated at 450° C. for 7 minutes for alloying. In this case, a jig **12** which limits the spatial spread of the In plate **11** is used and a weight **14** having a projection **13** is mounted on the In plate as shown in FIG. **2**. When the weight **14** having the projection **13** is used, the part of the In plate in contact with projection **13** is pressed by the projection after fusing and a thin fused layer surrounded by a layer higher by the height of the projection is formed. When heat alloying was performed at 450° C. and for 7 minutes by using a weight of 3.85 mm. in diameter and 1.8 g. in weight which had a projection of 1.85 mm. in diameter and 0.3 mm. in height as said weight **14**, the concave collector contact became 4 mm. in diameter, the deeply alloyed region was 65μ, the shallowly alloyed region was 48μ and the radius of the narrow collector layer, i.e. the distance corresponding to R in FIG. **1** was 0.85 mm.

Since the collector contact formed by this method is not plane, heat treatment is performed again to facilitate the setting to the header. This time, the heat treatment is performed at 450° C. and for 7 minutes by using a plane weight not having the projection. The concave part of the In plate is removed by this treatment and a plane surface is formed. During this treatment, In hardly alloys into Ge and merely the In plate melts to become flat at its surface.

This method differs from the conventional alloying method only in providing a projection at the desired part of the weight and the established conventional alloying techniques can be utilized without modification. Further, in this method, the concave collector contact can be formed by single alloying treatment.

Further, even in an overlayed type transistor wherein a plurality of emitter layers exist independently in a base layer, the concave collector contact can be formed simply by working the end part of the jig weight.

EXAMPLE 2

The second method will be explained with reference to FIGS. **3***a* to **3***f*, which show respective steps.

In the first step, as described in Example **1**, a donor impurity is diffused by the powder method into a P type germanium body 15 of 200μ in thickness and 15 ohm-cm in resistivity. Then one of the surfaces of the body is coated with wax, while the other surface is selectively etched. As a result, a base layer **16** of 60μ in diffusion depth and 3.5×10^{17} atoms/cm^3 in surface impurity concentration is formed in the Ge body **15** of 140μ in thickness as shown in FIG. **3***a*. The second step which is the most characteristic of this method is shown in FIG. **3***b*. In this method, the position of the emitter layer is determined first and then a circular protrusion **17** having a selected radius $R>0$ is formed on the germanium body **15**. The protrusion **17** is 1.9 mm. in diameter and 20μ in height, for example. The manufacturing process of the protrusion **17** has an important meaning for the shape of the concave collector contact described hereinbelow. In an experiment made by the inventors, a stamped Ni plate of 1.9 mm. in diameter is adhered in place with wax to form an etching mask.

As has been described hereinabove, an emitter layer **18** is provided by the alloying method in the third step as shown in FIG. **3***c* in the same way as in said first method after the protrusion **17** is formed. Then the base tab **19** for deriving the base layer **16** is attached thereto. Next, as a fourth step, a concave collector contact **21** characteristic of this invention is formed as shown in FIGS. **3***d* and **3***e*.

The collector contact **21** is formed by turning the C. **15** upside down, placing an In plate **20** on the protrusion **17**, placing a weight having a flat end surface on the In plate **20**, and heating the assembly by employing a spatial spread limiting jig as in Example **1**. The heating condition is 540° C. and 7 minutes.

The difference between W_1 and W_2 shown in FIG. **1** or the depth of the narrow collector region substantially coincides with the height of the protrusion formed by the second step. For example, when the protrusion was 20μ in height as described hereinabove, a depth difference of 22μ appeared.

In this method, in order to passivate the junctions exposed at the surface of the semiconductor body, a part of each junction exposed at the surface is etched with a mixed etchant of HF and HNO_3, CH_3COOH, etc., as shown in FIG. **3***f* as a final step. Since, according to this method, the collector contact having a concave shape is naturally formed by first providing a protrusion on a semiconductor body by etching, it is not necessary to worry about the shape of an impurity metal plate for forming the contact but any shape will be accepted.

Further, since the height of the protrusion can be made accurate by etching, the position of the narrow collector layer can be chosen accurately. Therefore, this method has the advantage that the influence due to the shift of the concave collector contact can be minimized.

EXAMPLE 3

This method relates particularly to a method of making a transistor having a concave collector contact of a silicon body and will be explained in conjunction with FIGS. **4***a* to **4***e*. First, as shown in FIG. **4***a*, silicon oxide films **22** are formed by oxidizing both surfaces of an N type silocon body of 10 ohm-cm. in resistivity. Then, the silicon oxide film **22** on one surface is removed except the portion corresponding to a narrow collector layer where a concave collector contact is to be formed (i.e. the collector layer having a width of W_1 in FIG. **1**). The remaining portion serves as a deposition mask. Then, phosphorus is deposited on the exposed surface to form a first deposition layer **23** as shown in FIG. **4***b*. At this time an oxide layer is formed again on the exposed surface.

Usually this deposition step is done at 1200° C. and for 40 minutes. The deposited impurity, phosphorus, diffuses into the semiconductor body, though gradually.

After said phosphorus deposition step, the oxide film **22** used as a mask in the foregoing step is etched off as shown in FIG. **4***c* and a second impurity deposition is performed again in an atmosphere including water vapor to form a second deposition layer **24** and an oxide film **28**. Antimony is used as the second impurity.

In this method, it is important to use impurities giving the same conductivity type, but having different diffusion constants like phosphorous and antimony.

When phosphorus is diffused into the silicon body at 1300° C., its diffusion constant is about 10^{-12} cm^2/sec., while that of antimony is about 3×10^{-13} cm^2/sec. under the same condition. Thus the diffusion constant of phosphorus is about three times larger. This method makes the most of the difference in the diffusion constant. After the deposition process is completed, the body is carried into a furnace to perform diffusion as shown in FIG. **4***d* and the diffusion is performed at 1300° C.

Since the diffusion constants of the first and second diffusion layers differ by a factor of about three, phosphorus is diffused to 30μ and antimony is diffused to 10μ by the diffusion process for 5 hours. In this way, a concave collector contact **25** having a difference of 20μ is formed. After said step, a base layer **26** and an emitter layer **27** are formed in the silicon body

21 by the same techniques as used in forming conventional planar or mesa type transistors to obtain a transistor as shown in FIG. 4*e*.

It is a feature of this method that the impurities for making the concave collector contact are deposited before the emitter and base layers are formed. It is also important that the first impurity for forming the first deposition layer has a larger diffusion constant than the second impurity for forming the second deposition layer. An important advantage of this method is that the contact is formed by a single diffusion step. Namely, no care need be taken of contamination after the diffusion process is initiated and only time and temperature have to be controlled. Thus this method is suitable for mass production.

EXAMPLE 4

This method relates to a method of making the concave collector contact easily and with good reproducibility by using the etching and epitaxial growth techniques no mater how complicated the pattern of the emitter layer is. This method will be described with reference to FIGS. 5*a* to 5*c*.

Though Ge as well as Si may be used as semiconductor material in this method, the case where a silicon body **38** is employed will be described.

The first step of this method, is to provide protrusions **29** in the region facing the emitter region as in Example **2**. As shown in FIG. 5*a*, the protrusions **29** are provided by etching the body **38** through a photoresist film **30** in a mixture etchant of HF, HNO_3, CH_3COOH, etc. after the photoresist film is selectively applied when the photoetching technique is used. Though the photoresist film is used in the above description, it is also possible in this method to first form a silicon oxide film by thermal oxidation and to employ it as an etching mask. It is characteristic of this method to provide the protrusions **29**.

Then, as shown in FIG. 5*b*, an epitaxial growth layer **31** of less than 0.02 ohm-cm. in resistivity and having an N conductivity-type is grown on the N conductivity type body **38** which serves as the collector layer of the transistor, so that the collector contact **31** has the designed shape. Next, an impurity is diffused from the surface of the body **38** opposite to said epitaxial layer **31** to form a base layer **32** as in Examples 1 and 2.

The epitaxial growth layer **31** formed by said process becomes a collector contact.

As has become apparent from the foregoing description, the collector contact completely forms the desired concave collector contact due to the protrusions **29** and the epitaxial growth layer **31** grown substantially in parallel with said protrusions.

Then, as shown in FIG. 3*c*, emitter layers **33** are formed in the base layer **32** by selective diffusion. The positions of the emitter layers **33** must be adjusted to the positions corresponding to the protrusions **29** formed in the first step.

Subsequently, emitter electrodes **34** and base electrodes **35** are formed of a suitable material like Au, Al, etc. to complete a transistor.

According to this method, since no novel techniques are employed, the work can be done quite efficiently so long as the positioning in the first etching step is done carefully. The inventors have found that it is advisable to provide a silicon epitaxial growth layer when the semiconductor body is silicon and a germanium epitaxial layer when it is germanium because the formation of a heterojunction can thereby be prevented. According to this method, since the concave collector contact is formed by the epitaxial growth method, it is possible to form the concave portions corresponding to the protrusions under a substantially uniform condition. Further, since the protrusions are formed by the photoetching technique, they can be formed quite accurately.

In all of the above-described embodiments the collector contact was made of concave shape. However, according to experiments made by the inventors, also the following modifications can attain the objects of the invention although the collector contact having the concave shape is preferable.

That is, even if the collector contact has not a continuous closed annular protrusion, if the collector contact has, at its peripheral portion, a continuous protrusion the area of which is 10 percent or more of that of the collector contact or discrete protrusions the total area of which is 10 percent or more of the area of the collector contact, the objects of the invention can be attained. The value of 10 percent is an empirical value. If the area of the protrusion or protrusions is less than 10 of that of the collector contact, a concentration of current called a hot spot takes place, and the transistor is apt to undergo the second breakdown.

The manufacturing methods hereinabove described can easily be modified so as to manufacture such protrusion or protrusions. In Example **1**, the peripheral of the projection **13** provided to the weight **14** has only percent be modified. In Example **2**, the circular portion **17** provided in the second step as shown in FIG. 3*b* has only to be cut into an appropriate shape. In Example **3**, the areas of the first and second deposition layers percent and **24** shown in FIGS. 4*b* and 4*c* have only to be modified, for example the area of the first deposition layer **23** has only to be made 40 percent of the area of Example **3**. In Example **4**, the shape of the protrusion **29** has only to be modified as in Example **2**.

From the above description, it is to be noted that the shape of the collector contact of the invention includes perfect as well as imperfect concave shapes.

Further, according to experiments made by the inventors it was found that the preferably ratio of W_1 to W_2 shown in FIG. **1** was $W_1/W_2 \geqq 1.2$.

Though the method has been described with reference to Si or Ge in the above Examples 1 to 4, the same effect is evidently obtained in the case of compound semiconductors such as GaAs, InAs, AlP, SiC, etc.

We claim:

1. A transistor comprising an emitter layer of a material of one conductivity-type, a base layer of a material having a conductivity-type opposite to said one conductivity-type forming a junction on one surface thereof with said emitter layer, a collector layer of material of said one conductivity-type forming a junction on one surface with the other surface of said base layer, said collector layer having on the other surface thereof a protruding portion which opposes at least a portion of said emitter layer, and a collector contact having a recessed portion which is generally complementary to and in electrical contact with said protruding portion of said collector layer.

2. A transistor as in claim **1** wherein said protruding portion of said collector layer is annular in shape.

3. A transistor as in claim **1** wherein said collector contact is of a material having a resistivity which is lower than the resistivity of the material forming the collector layer.

4. A transistor as in claim **1** wherein the area of the recess of said collector contact is at least 10 percent of the area of the collector contact which is in electrical contact with the collector layer.

5. A transistor as in claim **1** wherein the height from the top of said protrusion of said collector layer to said junction of said base and collector layers (ω_1) and the height from the portion of the collector contact adjacent said other surface of said collector layer surrounding said protruding portion to said junction of said base and collector layers has a (ω_2) ratio equal to at least 1.2.

6. A transistor as in claim **1** wherein the collector layer is formed with a recessed area at least partially around said protruding portion, said collector contact also being located in said recessed area.

7. A transistor as in claim **1** wherein the remainder of said other surface of said collector layer below said protruding portion is generally planar.

8. A transistor as in claim **1** wherein said protruding portion of said collector layer has a height of at least 10μ.

9. A transistor as in claim **1** wherein said collector contact makes electrical contact with the protruding portion of said collector layer over substantially the entire exposed surface of said protruding portion.