

Jan. 28, 1964

A. GOETZBERGER

3,119,947

SEMICONDUCTIVE ELECTRON EMISSIVE DEVICE

Filed Feb. 20, 1961

2 Sheets-Sheet 1

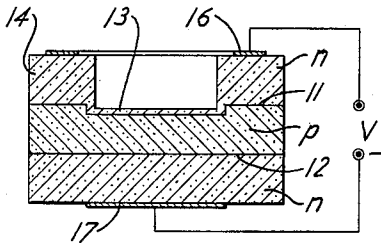


FIG. 1.

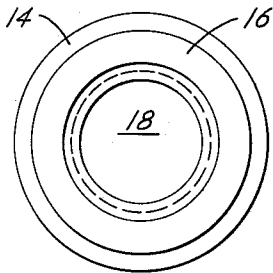


FIG. 2.

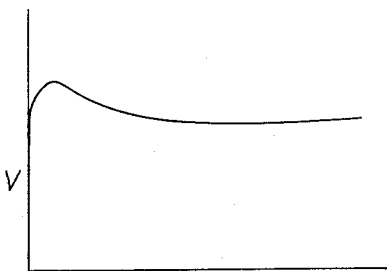
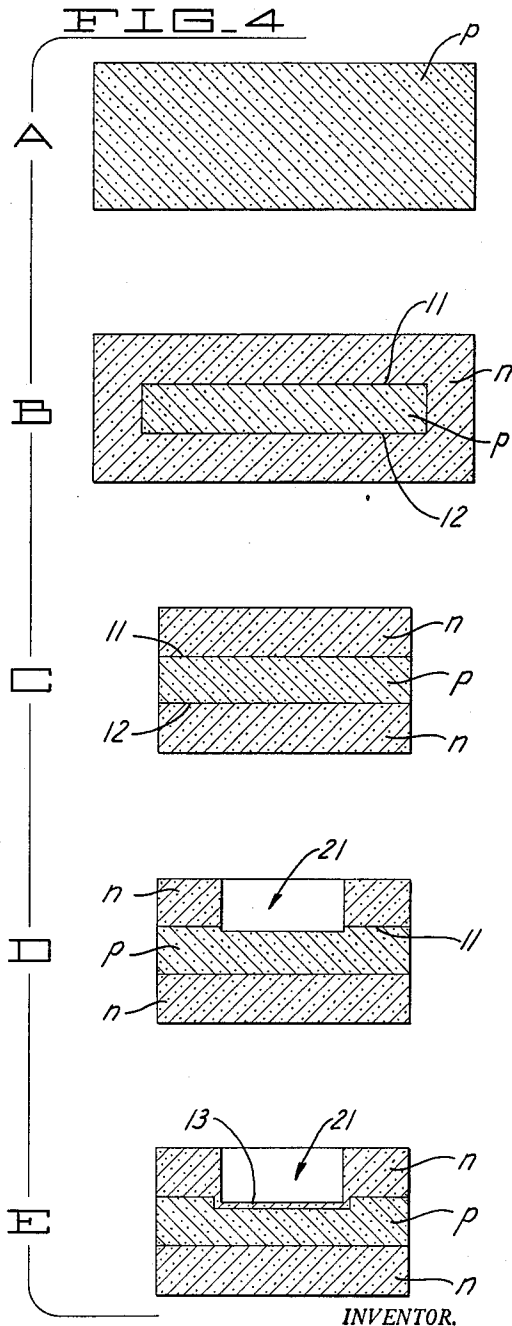


FIG. 3.



INVENTOR.
Adolf Goetzberger.
BY

Flehm and Schmitt
ATTORNEYS.

Jan. 28, 1964

A. GOETZBERGER

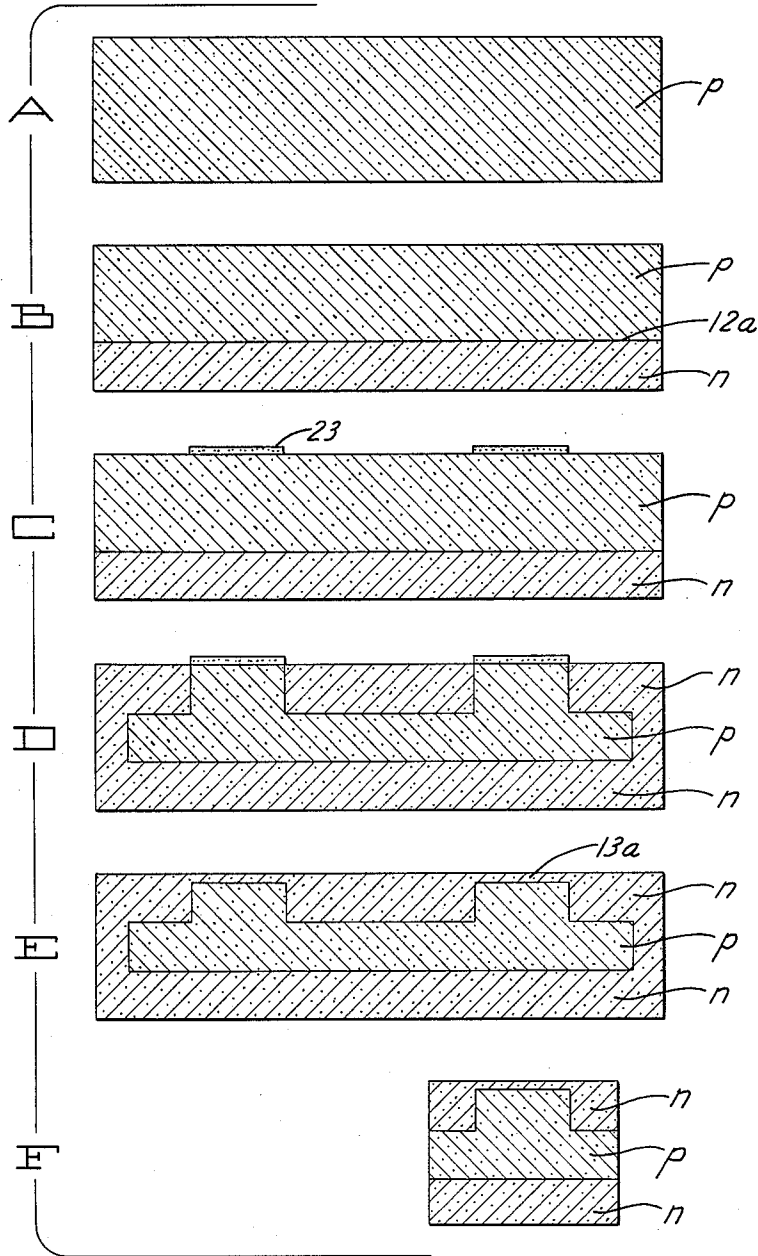
3,119,947

SEMICONDUCTIVE ELECTRON EMISSIVE DEVICE

Filed Feb. 20, 1961

2 Sheets-Sheet 2

FIG. 5



INVENTOR.
Adolf Goetzberger
BY

F. Lehmann and Sonin.
ATTORNEYS

1

3,119,947

SEMICONDUCTIVE ELECTRON EMISSIVE DEVICE

Adolf Goetzberger, Palo Alto, Calif., assignor to Clevite Corporation, Cleveland, Ohio, a corporation of Ohio
Filed Feb. 20, 1961, Ser. No. 90,292
1 Claim. (Cl. 313-346)

This invention relates generally to a semiconductor device and method for operation of the same and more particularly to a device and method for uniform avalanche breakdown over a relatively large area of a p-n junction.

Avalanche breakdown in p-n junctions is generally not uniform due to small variations of breakdown voltage from point to point. Certain surface conditions, dislocations and other crystal imperfections can lower the breakdown voltage at a localized region, an effect which can be studied by observation of light emission from thin diffused junctions at breakdown. There are also theoretical indications that complete uniformity of breakdown is impossible because statistical fluctuations of donors and acceptors will produce at least one small area of localized breakdown at a voltage slightly below the average breakdown voltage for the complete junction.

Uniform avalanche breakdown may provide a means for giving large area plasma where the energy of the electrons in the plasma is such as to overcome the work function and to, therefore, permit escape of the electrons from the surface. Such a device may then be used as a cold source of electrons in vacuum tube and the like devices.

It is a general object of the present invention to provide a semiconductor device and method for producing uniform avalanche breakdown.

It is still another object of the present invention to provide a uniform semiconductor electron emissive source.

It is still a further object of the present invention to provide a three layer semiconductor device and method of operating the same to provide uniform avalanche breakdown over a relatively large area of a p-n junction.

These and other objects of the invention will become more clearly apparent from the following description when taken in conjunction with the accompanying drawing.

Referring to the drawing:

FIGURE 1 shows a three layer semiconductor device in accordance with the invention;

FIGURE 2 is a top view of the device of FIGURE 1;

FIGURE 3 shows the current voltage characteristics of a device in accordance with the invention;

FIGURES 4A-4E show the steps in one possible method of constructing a device in accordance with the invention; and

FIGURES 5A-5F show the steps in another method of constructing a device in accordance with the invention.

Referring to FIGURES 1 and 2, the device shown includes three contiguous layers of semiconductive material with adjacent layers being of opposite conductivity type, in the illustrative example n-p-n, forming two rectifying junctions 11 and 12. The upper n-type layer includes a relatively thin portion 13 and a relatively thick surrounding or annular guard portion 14 to which ohmic contact 16 is made. The guard portion provides a convenient means for making ohmic contact and minimizes surface leakage. Ohmic contact 17 is made to the n-type lower layer. The relatively thin portion 13 serves to emit electrons uniformly when a plasma is set up in the same. The complete surface 18 of the recessed portion acts as a large area electron emissive source.

To operate the device in accordance with the invention, a voltage is applied to the device which serves to forward bias the junction 12 and to reverse bias the junction

2

11. The junction 12 then acts as an emitter junction emitting electrons into the p-type region and the junction 11 acts as a collector junction having a relatively high voltage applied across the same. The relatively high voltage applied to the junction 11 and the current gain through the device will cause avalanche to occur at the junction 11.

In three layer diodes, the relationship $M\alpha=1$ is true for current levels which are high in comparison to the collector saturation current. In the above expression, M is the multiplication factor and α the current amplification.

In silicon devices, α increases with increasing current, means are well known for achieving an α which increases with current in devices made from other types of semiconductive material; M, therefore, has to decrease.

According to the relationship

$$1/M=1-(V/V_B)^n$$

The voltage V across the junction decreases. In the above expression the voltage V_B is equal to the breakdown voltage and n is equal to a constant.

The current voltage characteristics of the device, therefore, show a negative resistance such as illustrated in FIGURE 3.

Uniformity of current over the area occur if V_B-V is relatively large compared to the variations of V_B over the junction area.

This can best be illustrated by a numerical example. Assume that n equals 2.8; it has been found that a junction of 30 v. breakdown voltage has localized areas of, as low as, 29 v. breakdown. When 28.9 volts are applied to this hypothetical junction, the current density to the 29 volt area is more than ten times higher than to the 30 volt area. However, the ratio is 1.05 for an applied voltage of 23 volts across the same junction. This smaller voltage drop for avalanche to set in occurs easily in a three-layer device in which current multiplication is present. Another effect that aids uniformity of current distribution is uniform injection from the emitter layer.

A device of the foregoing character was constructed and operated. Light emission which is an indication of uniform avalanche breakdown or plasma was observed. A typical light pattern showed that the flow was uniform over the entire area thereby providing uniform avalanche breakdown and a large area plasma emitting source.

By making the portion 13 in the neighborhood of .6 microns or less in thickness, the high energy avalanche breakdown or plasma at the junction will cause electrons to be emitted uniformly over the area of the surface. Thus, there is provided an improved cold electron source.

It is also to be observed that with uniform breakdown occurring over a substantial area, relatively high currents can be carried by the device. One possible use for the device would be as an over-voltage protector. Referring to FIGURE 3, it is seen that the device acts as a regulating element. Thus, if a high voltage surge should occur, the device will continue to regulate but pass the relatively high currents momentarily without being destroyed.

The steps in forming a device of the type shown in FIGURE 1 might be as illustrated in FIGURE 4 wherein a wafer of p-type material is subjected to a diffusion of donors to thereby form a n-type layer. The ends of the wafer are suitably removed, as for example, by etching to provide a three-layer structure of the type shown in FIGURE 4C. The structure of FIGURE 4C is masked and etched to form a recess 21 which extends beyond the junction 11. The device of FIGURE 4D is then subjected to a diffusion operation to form a relatively thin diffusion region. The diffusion region merges with the

3

n-type ring and forms a rectifying junction at the bottom of the recess. Typical dimensions for a device which serve to give uniform emission are a thickness on the order of .6 micron for the relatively thin layer at the base of the dimple, and 100 microns for the thickness of the base layer adjacent this region.

FIGURE 5 illustrates the steps in forming a device having a planar configuration. A starting wafer of semiconductive material, for example, p-type, FIGURE 5A, is operated upon to form a first p-n junction 12a, FIGURE 5B. The n-type layer may be formed by diffusion or epitaxial growth. The wafer is subsequently masked 10 23, FIGURE 5C, and diffused to form an n-type layer, FIGURE 5D. The wafer is subsequently cleaned, and a thin layer 13a is formed either by diffusion or epitaxial growth, FIGURE 5E. The wafer is then diced to form devices, FIGURE 5F.

Thus, there is provided a three-layer semiconductor emissive device in which a plasma is set up in a relatively thin layer forming a rectifying junction with an underlying layer at a voltage which is substantially below the avalanche voltage for the junction. This provides a means for achieving a uniform plasma or breakdown.

I claim:

In a semiconductor device having first, second, and third layers of semiconductive material, said first and third layers respectively forming first and second recti-

4

fying junctions with said second layer, means forming ohmic contact with at least said first and third layers, means serving to provide a substantially uniform plasma over a relatively large area of said first junction at a voltage substantially below the reverse breakdown voltage of said first junction, the last said means comprising a relatively broad, thin surface portion surrounded by a relatively thick portion of said first layer, said surface portion being adjacent to said second layer to form said first junction, said means forming an ohmic contact with the first layer ohmically contacting the layer solely at said relatively thick portion of the same, whereby application of a voltage, substantially below the reverse breakdown voltage for the first junction, between said ohmic contacts to forward bias the second junction and reverse bias the first junction serves to provide said uniform plasma.

References Cited in the file of this patent

UNITED STATES PATENTS

2,960,659 Burton ----- Nov. 15, 1960

OTHER REFERENCES

The Bell System Technical Journal, "Alloyed Junction Avalanche Transistors," by S. L. Miller and J. J. Ebers, September 1955, vol. 34, No. 5, page 883.