



IR-1127 (2-)

- 1 -

IGBT WITH INTEGRATED CONTROLRELATED APPLICATIONS

This application is related to copending application Serial No. 08/121,288, filed September 14, 1993 in the name of Bruno C. Nadd (IR-1016) and to copending application Serial No. 08/298,383, filed August 30, 1994 in the names of Bruno C. Nadd and Talbott M. Houk (IR-1070), both of which are assigned to the assignee of the present invention.

BACKGROUND OF THE INVENTION

This invention relates to insulated gate bipolar transistors (IGBTs), and more specifically relates to a novel monolithic semiconductor chip structure having an IGBT and control circuits therefor which are integrated into a common monolithic chip (or die).

It is well known that control circuits can be integrated into the same chip as contains a discrete power MOSFET section. Such devices are sold by the International Rectifier Corporation, the assignee of the present invention, under its trademark SMARTFET. The structure of such devices is also shown in copending application Serial Nos. 08/121,288 (IR-1016) and 08/298,383 (IR-1070), referred to above.

Attempts to extend the above concept of a monolithically formed control circuit with a power IGBT (one which handles 1 watt or more of power) have not been successful. This is because the control circuits are contained in a "P well" or P-type diffusion in the same



- 2 -

N epitaxially formed layer (epi) as receives the junctions forming the IGBT. Thus, when the IGBT conducts in the forward direction, the P⁺ substrate is forward biased relative to the N epi so that a copious number of minority carriers (holes in the case of the N channel device being described) are injected into the N epi. Because the P well containing the control junctions is close to the IGBT power junctions, holes are also injected under the P well. This has several consequences:

1. The P well acts as the collector of a vertical PNP transistor (with the N epi and P⁺ substrate). As a result, high parasitic current is injected into the P well and to ground (since the P well is usually grounded).
2. The N⁺ source and drain diffusions in the P well act as the cathodes of vertical parasitic thyristors. The triggering of these parasitic thyristors can destroy the chip.
3. The injection of minority carriers into the P well can disturb the operation of sensitive, low power level analog circuits.

Therefore, a smart IGBT with junction-isolation has not been practical.

One attempt to overcome the problem produced by minority carrier injection has been to employ dielectric isolation of the control circuit from the main body of the chip. This structure, however, requires very expensive and very complex processing.

30 BRIEF DESCRIPTION OF THE INVENTION

In accordance with the present invention, a novel monolithically integrated power IGBT and control



- 3 -

section therefore are junction-isolated, but the effect of minority carrier injection from the IGBT section to under the control section is substantially reduced.

5 In the following description of the invention, an N channel IGBT having an N^+ lateral buffer layer is described. Thus reference will be made, for convenience, to the forward bias of the P^+ substrate, N epi junction. This language is intended to cover the junction to the N^+ buffer if such a buffer is used. Moreover, the invention
10 applies equally to P channel devices and, in general, to any MOS gated bipolar device.

In a first embodiment of the invention, the control section or P well is laterally spaced from the periphery of the active IGBT region by greater than about
15 three diffusion lengths of the minority carrier. As a result, the P^+ substrate to N epi junction will be effectively de-biased under the P well so that the concentration of minority carriers under the P well is very substantially reduced. Note, however, that the
20 implementation of the above concept requires added silicon chip area. Further, the low sheet resistivity N^+ buffer layer commonly used to reduce the β of the PNP portion of the IGBT interferes with the de-bias of the P^+ substrate, N^+ buffer junction.

25 In accordance with a second embodiment of the invention, a further P^+ diffusion is placed between the control P well and the IGBT active area. The further P^+ diffusion is connected to the source (or cathode) electrode of the IGBT section. Consequently, most hole
30 current outside of the active IGBT area will be diverted to the further P^+ diffusion and to the IGBT source



- 4 -

electrode. Note that with this approach some hole current can still flow to under the P well.

5 In a third embodiment of the invention, the region between the P⁺ substrate and N⁻ epi and surrounding the active area is, in effect, short-circuited so that the P⁺ substrate, N⁻ epi junction under the control P well is fully de-biased. A preferred way to carry out this embodiment employs an N⁺ diffusion on the upper surface of the chip and surrounding one or both
10 the control P well or active IGBT area and the connection of the N⁺ diffusion to the back or bottom of the chip and to the P⁺ substrate.

Consequently, the P⁺ substrate under the IGBT area is forward-biased relative to the N⁻ epi (or N⁺ buffer layer if one is used) during forward conduction.
15 Electrons will flow laterally through the N⁻ epi or the N⁺ buffer layer and outwardly of the active IGBT area and up to the novel N⁺ diffusion at the upper surface of the chip. This causes a lateral voltage drop in the N⁺ buffer layer (or N⁻ epi) so that the P⁺ substrate to N⁻ epi junction is progressively de-biased, moving laterally away from under the active area. By appropriately choosing the resistance R_s between the buffer layer and the new N⁺ diffusion and the lateral resistance of the
20 buffer layer R_b such that R_s is much less than R_b, the voltage across the N⁺/P⁺ junction under the control P well is almost zero and only negligible hole injection can occur.

30 In the preferred embodiment of the invention, a proper field termination is required on both sides of the N⁺ diffusion. However, interconnections must be made from the control circuit to the IGBT, for example source

THIS SHEET HAS BEEN
REPLACED



- 5 -

contacts, gates, Kelvin sources, current sense leads, and the like. In order to make these connections without crossing over the high voltage field termination, a novel topology is provided wherein the control section and IGBT section are enclosed by a common continuous field termination which is reentrantly bent around both sides of the N^+ diffusion, but leaves a narrow conductor-routing-channel spaced from the end of the N^+ diffusion. Control conductors of metal, polysilicon or the like can be disposed over and atop this narrow routing-channel.

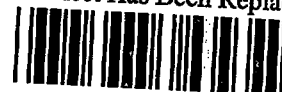
In the preferred embodiment of the invention, a parasitic diode is created between the main drain and source electrodes as a consequence of the use of the novel N^+ diffusion between control and IGBT sections. This diode prevents the use of the chip in applications requiring reverse voltage blocking, and cannot be used in applications requiring an external fast recovery diode. In accordance with another feature of the invention and to overcome the effect of this parasitic diode, a novel lateral PNP transistor is integrated into the IGBT section and is connected to and enables the operation of the N^+ diffusion only when the IGBT is forward biased. Thus, the parasitic diode is open-circuited during those times when it could interfere with the chip operation.

Other features and advantages of the present invention will become apparent from the following description of the invention which refers to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a cross-section of a portion of a SMARTFET structure of the prior art.

THIS SHEET HAS BEEN
REPLACED



- 6 -

Figure 2 shows a cross-section of a portion of an IGBT in which a P well is formed in the same chip and illustrates the problems created.

5 Figure 3 shows a cross-section of a portion of an IGBT in which a control circuit is formed in a well which is dielectrically insulated from the chip.

Figure 4 shows the topology of a chip employing a first embodiment of the invention.

10 Figure 5 shows a cross-section of Figure 4 taken across the section lines 5-5 in Figure 4.

Figure 6 shows a cross-sectional view of a portion of a SMART-IGBT chip having a P^+ region positioned between the active region and control region in accordance with the invention.

15 Figure 7 shows another embodiment of the invention, employing an N^+ diffusion between the active IGBT area and the control area and is a cross section of Figure 6 taken across the section lines 5-5 in Figure 6.

20 Figure 8 shows a preferred embodiment of the topology of the active and control areas of Figure 7.

Figure 9 shows a cross-section similar to that of Figure 7 to more realistic scale and shows certain circuit components defined by the junctions.

25 Figure 10 is an equivalent circuit diagram of Figure 9.

Figure 10A shows the current in the circuit of Figure 10 when the IGBT is forward biased.

30 Figure 10B shows the current paths in the circuit of Figure 10 under reverse voltage and illustrates a parasitic diode.

Figure 11 shows the addition of a PNP diode to the circuit of Figure 10 to eliminate the effect of the parasitic diode of Figure 10B under reverse voltage.



- 7 -

Figure 12 shows the structure of Figure 9 with the added PNP diode of Figure 11 implemented therein.

Figure 13 shows a preferred topology for the structure of Figure 12.

5 DETAILED DESCRIPTION OF THE DRAWINGS

Referring first to Figure 1, there is schematically shown a small portion of a MOSFET chip of silicon 20 in cross-section. Silicon chip 20 has an N⁺ substrate 21 and a layer 22 of epitaxial silicon which receives junctions which define the active MOSFET section 19 and its control circuit 30. Thus, the active power MOSFET section includes a plurality of P type MOSFET bases, such as bases 23 and 24, which are distributed over the active MOSFET area of chip 20 as shown in U.S. Patent 5,008,725. Each of bases 23 and 24 receive respective N⁺ annular sources 25 and 26, respectively. A conventional polysilicon gate structure 27 overlies a conventional gate diode which covers the channel regions formed in bases 23 and 24. A main power source electrode 28 and drain electrode 29 are provided as usual.

The control section 30 is monolithically integrated into the same chip 20 with the active power MOSFET 19. Thus, a P well 40 is diffused into layer 22 and is laterally spaced from active MOSFET area 19. P well 40 contains any desired control circuitry for turning on and off the active area 19, such as, for example, thermal sensors, current sensors, undervoltage sensors and the like, such as those described in co-pending application Serial No. 08/298,383 (IR-1070), described above. A lateral control transistor is schematically shown in Figure 1, comprised of N⁺ source diffusion 41, N⁺ drain diffusion 42, and gate 43, all



- 8 -

contained in P well 40 and junction isolated from active MOSFET area 19. The control transistor in P well 40 may then be suitably coupled to the gate 27 to effect a control of the active MOSFET in response to any desired sensed parameter. Thus, intelligence is monolithically integrated into the chip containing a power MOSFET device.

The concept of simply integrating a junction-isolated control section in an IGBT chip has created seemingly insurmountable problems. These problems are best understood from a consideration of Figure 2 which shows the simple addition of a P⁺ substrate 50 to the chip 20 of Figure 1 (in place of N⁺ substrate 21 of Figure 1), causing it to operate as an IGBT. Note that a conventional N⁺ buffer layer 51 may also be added in Figure 2 in order to reduce the β of the PNP portion of the IGBT. All other components having the same numerals as Figure 1 have the same function. Note that power section 19 will now operate in an IGBT mode due to the presence of P⁺ region 50.

The device of Figure 2 cannot operate satisfactorily because, during forward conduction in the IGBT mode, the junction 52 between the P⁺ substrate 50 and N⁺ buffer 51 (or the junction to N⁺ epi 22 if no buffer is used) is forward biased along its length. Therefore, a copious number of minority carriers (holes in the embodiment of Figure 2) are injected in the epi layer 22 and under P well 40. This hole injection is shown by the arrows in Figure 2, and causes several problems:

1. The P well 40, taken with N⁺ epi 22 and P⁺ substrate 50 forms a parasitic PNP transistor 60. Since the P well is commonly grounded (not shown), the minority



- 9 -

carriers in epi 22 turn the PNP transistor 60 on, causing a high parasitic current in the P well 40 to ground.

2. The N⁺ diffusions 41 and 42 in well 40 act as the cathodes of parasitic four-layer thyristor 61.

5 The triggering of this parasitic thyristor 61 can cause the destruction of the device.

3. The injection of minority carriers under P well 40 also will disturb the operation of the sensitive low level analog circuits which are integrated
10 into well 40.

As a consequence of the injection of minority carriers under a junction-isolated control well, this technology has not been used to create a "SMART IGBT" analog to the "SMARTFET" device.

15 One known structure which has avoided the minority carrier injection problem employs a dielectrically isolated P well 70, as shown in Figure 3, which is isolated from the N epi by a silicon dioxide liner 71. In Figure 3, parts similar to those of Figure
20 2 have similar identifying numerals. This solution, however, requires very expensive and complex fabrication procedures.

The present invention achieves results similar to those of Figure 3, but employs junction-isolation
25 techniques which can be carried out with cost-effective fabrication.

In a first embodiment of the invention, the boundary of the active IGBT area in Figure 2 is spaced by three diffusion lengths or more from the boundary of the
30 P well 40. Thus, Figures 4 and 5 show one possible arrangement for this embodiment, wherein components similar to those of Figure 2 are given similar identifying numerals. Figures 4 and 5 also show field



- 10 -

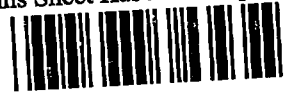
terminations 70 and 71 which surround the active IGBT area 19 and the control area 30, respectively. The dotted lines 75 indicate the connection of the control circuit 30 to the gate 27 and source (and other related terminals) of the active IGBT area 19. Note that other control areas and other IGBTs or other power devices can be integrated into epi layer 22 of Figures 4 and 5 at areas laterally removed from area 19.

In accordance with the invention, the distance between the periphery of the P well 40 and the periphery of the active IGBT junctions is greater than about three minority carrier lengths. As a result of this spacing, junction 52 is de-biased under control section 41 and the level of minority carrier injection under the control section 40 will be much lower. Note that the sheet resistivity of the N^+ buffer layer can also be increased to assist in de-biasing the junction 52 or 51 under the control region 30.

Figure 6 shows a second embodiment of the invention where components similar to those of Figure 2 have similar identifying numerals. Note that the buffer layer 21 is not shown in Figure 6, but can be used if desired. In Figure 6, a P^+ diffusion 80 is added as shown and is disposed between the control section 30 and the IGBT section 19. The P^+ region 80 is further connected to IGBT source electrode 28.

In operation, holes schematically shown in Figure 6 by arrows are injected into region 22. However, the holes outside of area 19 are preferably collected by diffusion 80, so that fewer holes can be collected by P well 40.

Figures 7 and 8 show a still further embodiment of the invention, wherein components similar to those of

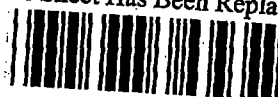


- 11 -

prior figures have the same identifying numerals. Figure 8 also shows a novel continuous field termination 90 which almost fully encloses each of IGBT area 19 and control area 30, leaving a narrow neck 90 over which control lead 75 can travel without crossing the high voltage field termination 90. The area between laterally spaced IGBT region 19 and control region 30 then receives an N^+ diffusion 95 (Figures 7 and 8) which is between and co-extensive with adjacent lengths of reentrantly folded termination 90. Diffusion 95 has a contact 96 which is connected to P^+ region 50 as shown by dotted line 97. In practice, connection 97 can be a wire-bond connection or the like. It is possible that the connection is automatically made simply by the action of a saw during wafer cutting.

The operation of the device of Figures 7 and 8 is as follows:

When the IGBT section 19 is conducting, junction 52 is forward biased. A lateral electron current, shown by the arrows, flows in the buffer layer 51 (or in the epi 22 if no buffer is used) and to the N^+ diffusion 95. This causes a lateral voltage drop along resistance R_b in the buffer layer. Therefore, the junction 52 is progressively de-biased from the edge of IGBT area 19, toward control area 30. By making the resistance R_s to diffusion 95 much lower than R_b , the voltage across junction 52 under P well 40 can be reduced to almost zero so that the level of minority carrier injection in that region is negligible. Making $R_s \ll R_b$ can be accomplished by appropriately fixing the width W_s of diffusion 95, relative to the epi layer 22 resistivity and the buffer layer 51 resistivity.



- 12 -

Since the control logic in control area 30 is normally referenced to the source 28 of the IGBT, a proper field termination is required on both sides of the N⁺ diffusion 95, previously described as terminations 70 and 71 in Figures 4 and 5, and 90 in Figures 7 and 8. The interconnections of these areas by conductors 75 must pass over and be insulated from terminations 70 and 71. In the embodiment of Figure 8, however, the IGBT 19 and control section 30 are both substantially fully enclosed by termination 90 except for the narrow surface channel or neck region 90a over which the connections 75 can be routed without crossing over termination 90. The neck region 90a is sufficiently narrow to prevent meaningful P⁺ carrier injection from under the IGBT section 19 to under the control section 30. As previously stated, interconnections 75 can be made of metal or conductive polysilicon traces or the like over the grounded P well 40.

The connection 97 of the N⁺ diffusion 95 to the backside of the wafer can be made with a wire bond to the lead frame (not shown) which may support the chip 20, or, if the chip is in a TO-220 type package, it can be made to the center pin, for example, of the package. In many cases, the connection will be made through the saw-damaged chip edge of the chip 20, created during wafer cutting.

Figure 9 shows the chip 20 of Figure 7 to a more realistic, but still schematic, scale. Parts of Figure 9, similar to those of Figure 7, have the same identifying numerals. Because of limitations of scale, the source and gate structures in well 40 and in bases 23 and 24 are not shown in Figure 9. Shown, however, is an active area termination cell 100 for IGBT 19 and an

THIS SHEET HAS BEEN
REPLACED



- 13 -

intentional isolation spacing of about 700 microns between active IGBT area 19 and P well 40.

Figure 9 next shows vertical PNP transistors Q1 and Q2 which are formed by the junctions of IGBT 19 and control area 30. It further shows the access resistance R1 between buffer layer 51 and N⁺ diffusion 95 and resistances R2 and R3 of the buffer layer between the bottom of resistance R1 to the approximate location of the bases of PNP transistors Q2 and Q1, respectively.

The equivalent circuit of Figure 9 is shown in Figure 10. Figure 10 also shows NPN parasitic transistors Q1' and Q2' which are the parasitic NPN transistors of the N source, P base and N⁺ epi 22 for the IGBT section 19 and the corresponding transistor of section 40, respectively. Also shown in Figure 10 are resistors RB1 and RB2 which are the effective resistances between the base and emitter of the NPN transistors Q1' and Q2', respectively.

Under normal circumstances, transistors Q1' and Q2' should not conduct to avoid latch up of its corresponding parasitic thyristor. This is avoided in transistor Q1' by designing a very low value for resistor RB1.

However, the implementation of lateral NMOS transistors in the control section results in a much higher value for RB2 and for the gain of transistor Q2. Consequently, the control section is much more latch-up sensitive than the IGBT section and hole injection by transistor Q2 should be avoided. This is the purpose of the N⁺ finger 95.

Figure 10A shows the currents in heavy line when the IGBT is forward biased. During forward bias, the base-emitter junction of transistor Q1 is forward

THIS SHEET HAS BEEN
REPLACED



- 14 -

biased. The base-emitter junction of transistor Q2 sees only $V_{be} (Q1) * R1 / (R3 + R1)$. By properly choosing the geometry (and thus the ratio $R1/R3$) it is possible to almost eliminate the current in transistor Q2 (see dotted line in Figure 10A) and the risk of latch-up in the control section.

This approach prevents the latch-up of the control section in the forward-biased mode. However, as shown in Figure 10B, there is a parasitic diode 110 between the drain 29 and source 28 under reverse bias. Diode 110 consists of the base collector junctions of transistors Q1' and Q2', in series with RB1 and RB2; and R2 and R3, respectively, and R1.

This parasitic diode 110 has two damaging consequences:

1. It prohibits applications where a reverse voltage capability is necessary (such as in electronic ignition).
2. It cannot be used in applications where there is an external fast recovery diode, since the internal parasitic diode 110 will carry a part of the current diode. Diode 110 is outwardly extremely slow and its recovery current induces latch-up in the control section 30. In other words, if one re-applies a positive voltage on the drain 29 while the base/collector junction of transistor Q2' is full of minority carriers, the Q2/Q2' thyristor will latch.

As a further feature of the invention, the effect of the parasitic diode 110 is eliminated by connecting R1 of Figures 9, 10, 10A and 10B to the drain 29 only when the IGBT is forward biased. Thus, as shown in Figures 11 and 12, a lateral PNP transistor Q3 is added outside of the field termination 90 of IGBT section



- 15 -

19, shown from edge cell 100 to edge cell 120 in Figure 12. The P diffusion which defines emitter 121 in Figure 12 is connected to drain 29 as by a wire bond, and the P diffusion which defines collector 122 is connected to contact 96 of N⁺ diffusion 95.

In operation, when the IGBT 19 is forward biased, Q1 conducts and so does Q3. This dynamically connects R1 to the drain 29. When the IGBT 19 is reverse biased, Q1 and Q3 are not conducting and R1 is floating. Therefore, no reverse current flows in the structure.

Q3 can be a low voltage transistor (the same as the reverse blocking rating as the IGBT 19 itself, usually 10 to 50V). Thus, it can be made with a narrow base (for example 10 microns) and have a high gain so that it is fully saturated when the IGBT 19 is forward biased.

Figure 13 schematically shows the implementation of transistor Q3 in the chip surface. Components similar to those of Figure 8 have the same reference numerals in Figure 13. Note that emitter and collector regions 121 and 122, respectively, are connected to a tap 125 of drain 29 and N⁺ finger 96, respectively.

Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein, but only by the appended claims.



This Sheet Has Been Replaced



- 16 -

WHAT IS CLAIMED IS:

1. An insulated gate bipolar transistor and a control circuit therefore integrated into a common semiconductor chip; said semiconductor chip having a P type silicon substrate and having a low concentration N type region formed on the top surface thereof and a P⁺ region formed on the bottom surface thereof; a first area of said low concentration region receiving diffusions defining the base, source and channel regions of an insulated gate bipolar transistor; a second area of said low concentration region being laterally spaced from said first area; said second area including a P well diffusion and control circuit diffusions in said P well; and coupling means coupling said insulated gate bipolar transistor in said first area to said control circuit diffusions; and means disposed between said first and second areas for limiting the injection of holes from said P⁺ region into said P well diffusion during the injection of holes to produce the operation of said insulated gate bipolar transistor in said first area.

2. The device of claim 1 wherein said means disposed between said first and second areas includes a relatively large lateral spacing between said areas, which is at least about three diffusion lengths of holes in said low concentration N type region.

3. The device of claim 1 wherein said means disposed between said first and second areas includes a second P⁺ diffusion into the top surface of said low concentration N type region, and means connecting said second P⁺ diffusion to said source of said insulated gate

THIS SHEET HAS BEEN
REPLACED



This Sheet Has Been Replaced



- 17 -

bipolar transistor, whereby said second P⁺ diffusion will collect holes which would otherwise be collected by said P well in said second area.

4. The device of claim 1, wherein said means disposed between said first and second areas includes an N⁺ diffusion into the top surface of said low concentration N type region; and means electrically
5 connecting said N⁺ diffusion to said P type substrate.

5. The device of claim 1 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

6. The device of claim 1 which further includes field termination means disposed on the upper surface of said device, and which at least partially surrounds said first and second areas.

7. The device of claim 6 wherein said field termination means encloses the opposite sides of said narrow neck region, and the full remaining peripheries of each of said first and second areas.

8. The device of claim 1 wherein said low concentration N type region is an epitaxially grown region.

9. The device of claim 1 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a gate electrode disposed above said channel regions and
THIS SHEET AND BEING
REPLACED



This Sheet Has Been Replaced



- 18 -

5 drain electrode connected to the bottom of said P⁺ region at said bottom surface.

10. The device of claim 2 wherein said low concentration N type region is an epitaxially grown region.

11. The device of claim 3 wherein said low concentration N type region is an epitaxially grown region.

12. The device of claim 4 wherein said low concentration N type region is an epitaxially grown region.

13. The device of claim 5 wherein said low concentration N type region is an epitaxially grown region.

14. The device of claim 6 wherein said low concentration N type region is an epitaxially grown region.

5 15. The device of claim 10 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a gate electrode disposed above said channel regions; and a drain electrode connected to the bottom of said P⁺ region at said bottom surface.

16. The device of claim 11 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a



This Sheet Has Been Replaced



- 19 -

5 gate electrode disposed above said channel regions; and a
drain electrode connected to the bottom of said P⁺ region
at said bottom surface.

17. The device of claim 12 which further
includes a source electrode connected to said source and
base regions of said insulated gate bipolar transistor, a
gate electrode disposed above said channel regions; and a
5 drain electrode connected to the bottom of said P⁺ region
at said bottom surface.

18. The device of claim 13 which further
includes a source electrode connected to said source and
base regions of said insulated gate bipolar transistor, a
gate electrode disposed above said channel regions; and a
5 drain electrode connected to the bottom of said P⁺ region
at said bottom surface.

19. The device of claim 14 which further
includes a source electrode connected to said source and
base regions of said insulated gate bipolar transistor, a
gate electrode disposed above said channel regions; and a
5 drain electrode connected to the bottom of said P⁺ region
at said bottom surface.

20. The device of claim 6, wherein said means
disposed between said first and second areas includes an
N⁺ diffusion into the top surface of said low
concentration N type region; and means electrically
5 connecting said N⁺ diffusion to said P⁺ region; said N⁺
region being disposed between and spaced from said field
termination means at locations where said field

THIS SHEET HAS BEEN
REPLACED



This Sheet Has Been Replaced



- 20 -

termination extends along coextensive portions of said first and second areas.

21. The device of claim 20 wherein the upper surfaces of said first and second areas are joined at a narrow neck regions; said coupling means comprising conductors disposed atop and across said neck region.

22. The device of claim 21 wherein said field termination encloses the opposite sides of said narrow neck region, and the full remaining peripheries of each of said first and second areas.

23. The device of claim 22 wherein said low concentration N type region is an epitaxially grown region.

24. The device of claim 23 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a gate electrode disposed above said channel regions; and a drain electrode connected to the bottom of said P⁺ region at said bottom surface.

25. The device of claim 4 which further includes a lateral PNP transistor integrated into said first area and having its collector connected to said N⁺ region, its base region being the said N type region and its emitter region being connected to said P⁺ region such that it conducts only when said insulated gate bipolar transistor is forward biased whereby said N⁺ region is connected to said P⁺ type substrate only when said IGBT is forward biased.

THIS SHEET HAS BEEN
REPLACED



This Sheet Has Been Replaced



- 21 -

26. The device of claim 20 which further includes a lateral PNP transistor integrated into said first area and having a source region connected to said N⁺ region, and being biased to conduct only when said insulated gate bipolar transistor is forward biased whereby said N⁺ region is connected to said N type substrate only when said IGBT is forward biased.

27. The device of claim 24 which further includes a lateral PNP transistor integrated into said first area and having a source region connected to said N⁺ region, and being biased to conduct only when said insulated gate bipolar transistor is forward biased whereby said N⁺ region is connected to said N type substrate only when said IGBT is forward biased.

28. An IGBT and a control circuit therefore monolithically integrated into a common semiconductor chip; said semiconductor chip having a bottom P type layer and a substantially coextensive N type layer atop said P type layer; a first area of the surface of said N type layer receiving diffusions which define an IGBT; a second area of the surface of said N type layer receiving a P well which contains control device diffusions therein which are junction isolated from said first area; the junction between said N type layer and said P type layer extending continuously from under said first area to under said second area; and means for at least partly de-biasing said junction in the area under said control area when said IGBT area is in conduction and minority carriers are being injected from said P type layer and into said N type layer.



This Sheet Has Been Replaced



- 22 -

29. The device of claim 28 wherein said means for de-biasing comprises the lateral spacing of said first and second areas by more than about three diffusion lengths of minority carriers injected from said P layer into said N layer during the forward conduction of said IGBT area.

30. The device of claim 28 wherein said first area has an IGBT source, and wherein said means comprises a P⁺ diffusion disposed into the surface of said N layer and between said first and second areas and connected to said IGBT source.

31. The device of claim 28 which further includes an N⁺ diffusion into the surface of said N layer and disposed between said first and second areas, and being connected to said P layer.

32. The device of claim 28 which further includes coupling means for coupling said control device diffusions to said diffusions which define an IGBT whereby said IGBT is operated in response to control signals from said control device diffusions.

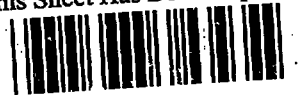
33. The device of claim 29 which further includes coupling means for coupling said control device diffusions to said diffusions which define an IGBT whereby said IGBT is operated in response to control signals from said control device diffusions.

34. The device of claim 30 which further includes coupling means for coupling said control device diffusions to said diffusions which define an IGBT

THIS SHEET HAS BEEN
REPLACED



This Sheet Has Been Replaced



- 23 -

5 whereby said IGBT is operated in response to control signals from said control device diffusions.

5 35. The device of claim 31 which further includes coupling means for coupling said control device diffusions to said diffusions which define an IGBT whereby said IGBT is operated in response to control signals from said control device diffusions.

36. The device of claim 32 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

37. The device of claim 33 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

38. The device of claim 34 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

39. The device of claim 35 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

THIS SHEET HAS BEEN
REPLACED

IGBT WITH INTEGRATED CONTROLABSTRACT OF THE DISCLOSURE

A monolithic IGBT and control circuit therefore are integrated into a common chip. The IGBT is formed in a first area of the chip and the control circuit is formed in a second laterally spaced area and in a P well. Means are provided to prevent hole injection from the P⁺ substrate into the P well during IGBT operation. The means includes a sufficient spacing between the areas; a P⁺ collection region between the areas or an N⁺ diffusion between the areas which is connected to the P⁺ substrate. The areas are surrounded by a common field termination structure which, however, leaves a small surface bridge between the two areas. Control conductors from the control area to the IGBT area cross over the narrow area, and not over the field terminations. A lateral PNP transistor which is integrated in the chip and is external of the IGBT area is connected to the central N⁺ diffusion between IGBT and control areas and permits its connection to the P type substrate only when the IGBT area conducts.

This Sheet Has Been Replaced

THIS SHEET HAS BEEN
REPLACED

IR-1127
(2-171)

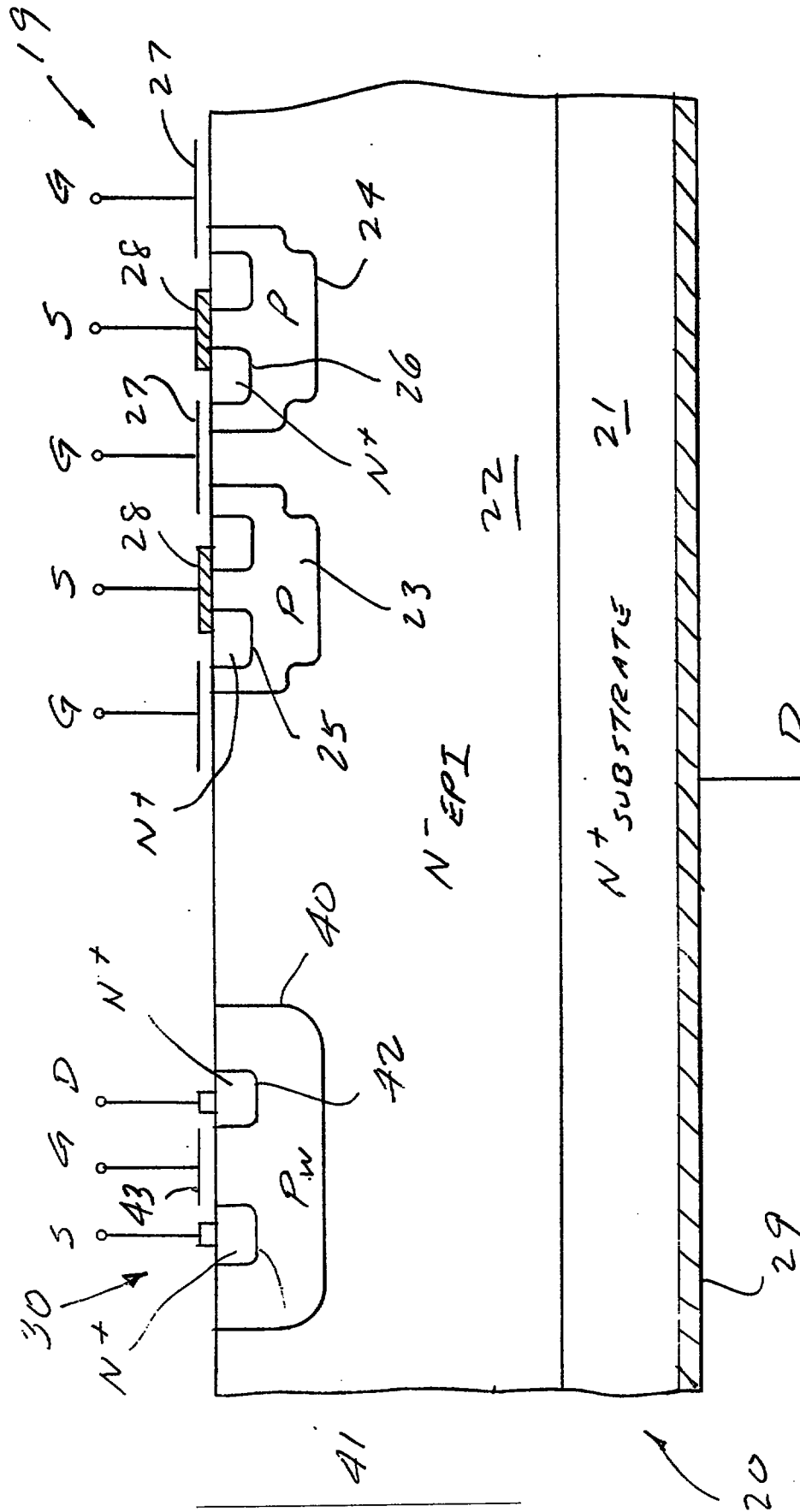


FIG. 1
(PRIOR ART)

This Sheet Has Been Replaced



THIS SHEET HAS BEEN
REPLACED

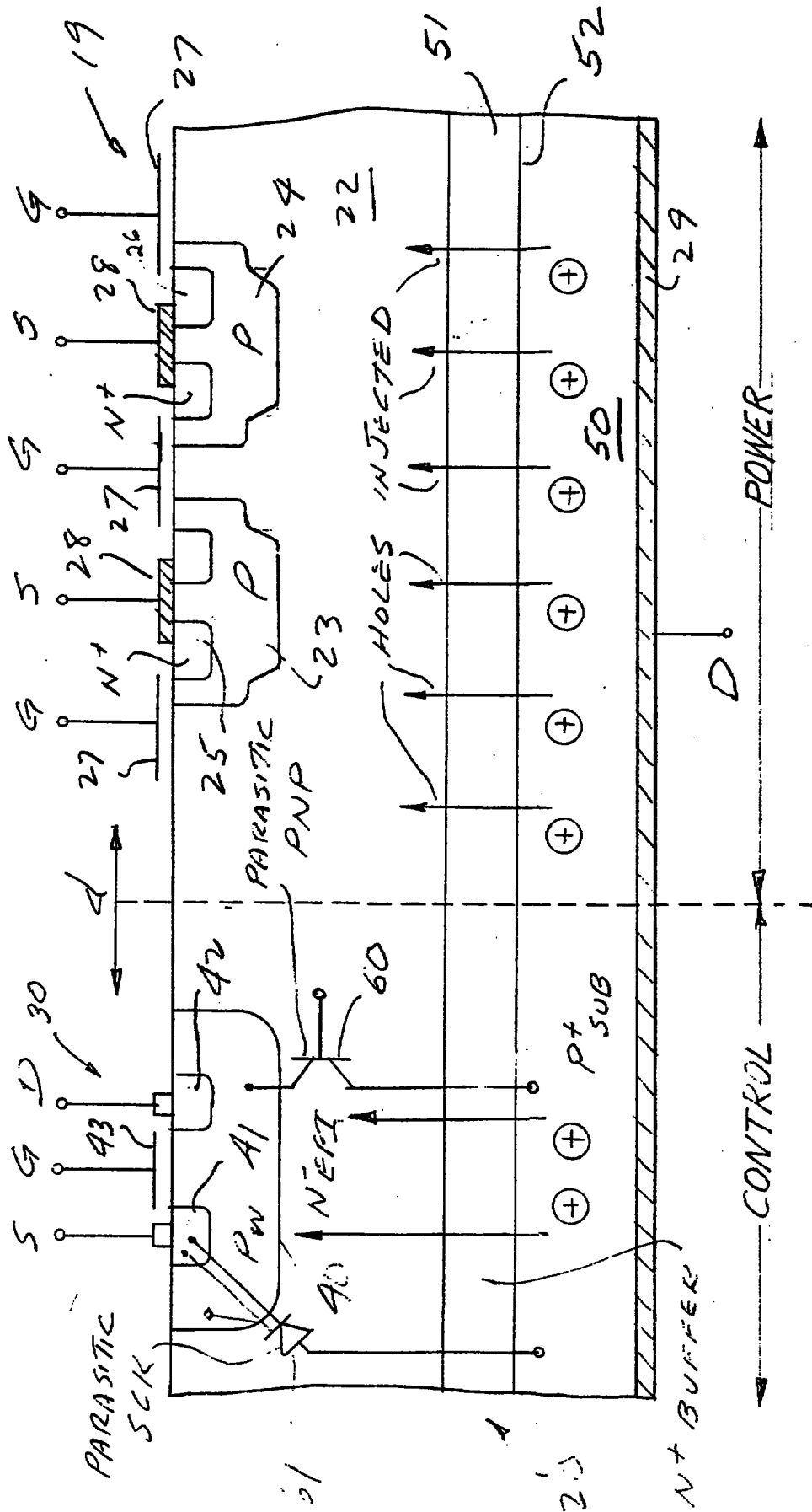


FIG. 2

Hand-drawn schematic diagram of a power MOSFET and IGBT structure. The diagram is divided into two sections by a vertical dashed line.

Left Section (MOSFET):

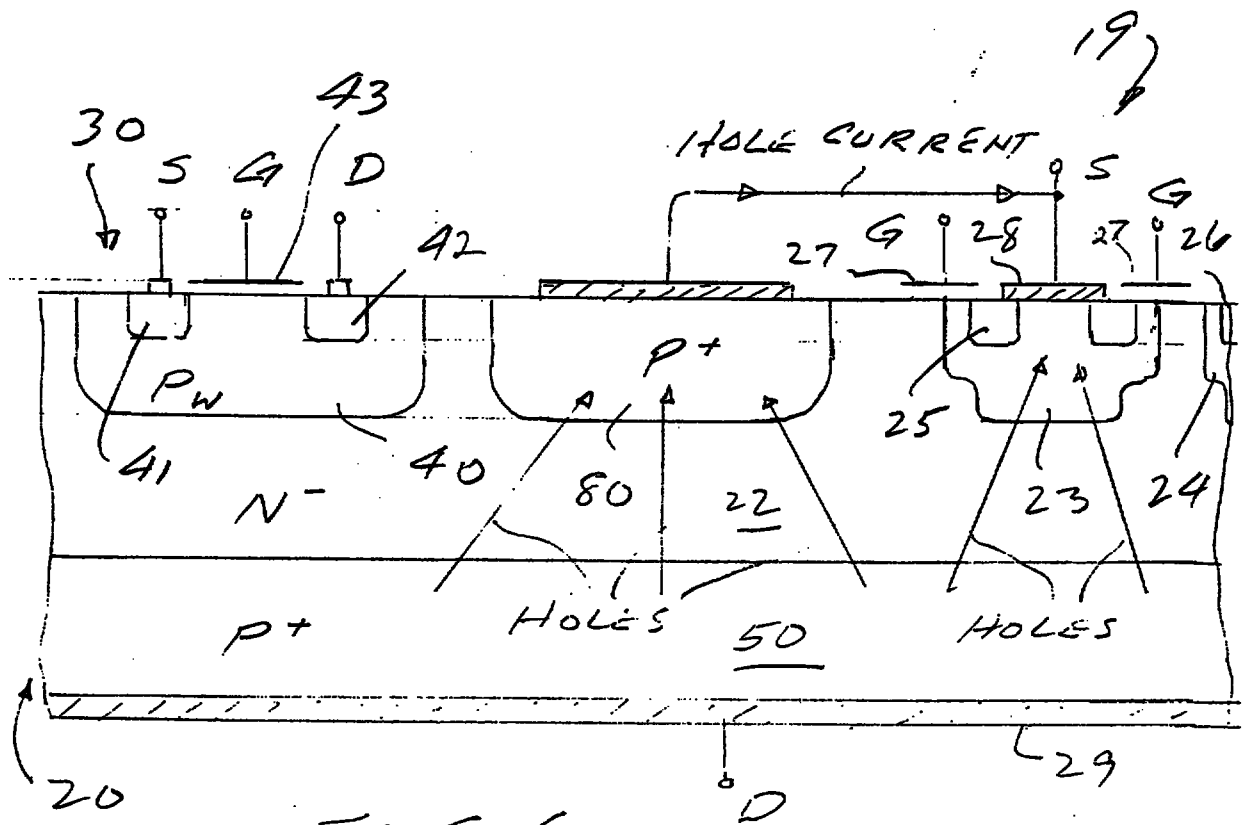
- Layers:** SiO_2 (top), PW (poly), $N^+ EPI$ (epitaxial), and $P^+ SUB$ (substrate).
- Contacts:** Gate (G) with contacts 41 and 43; Drain (D) with contact 42; Source (S) with contact 40.
- Regions:** 70 (gate oxide), 71 (drift region), 42 (drain), 40 (source).

Right Section (IGBT):

- Contacts:** Gate (G) with contacts 27 and 28; Source (S) with contact 27; Drain (D) with contact 27.
- Regions:** 22 (drift region), 23 (collector), 24 (emitter).

Labels:

- CONTROL:** Indicated by an arrow pointing to the left section.
- IGBT:** Indicated by an arrow pointing to the right section.
- 20:** A label at the bottom left corner.
- 29:** A label at the bottom right corner.



15156



FIG. 4

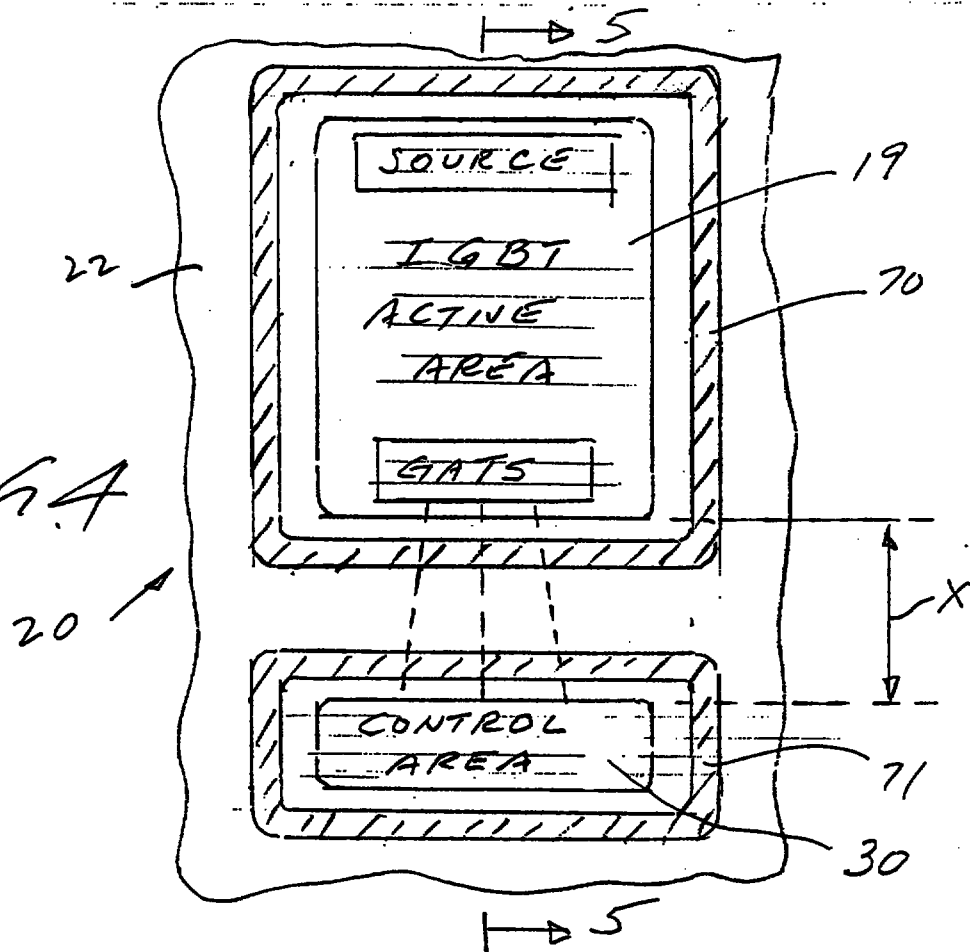
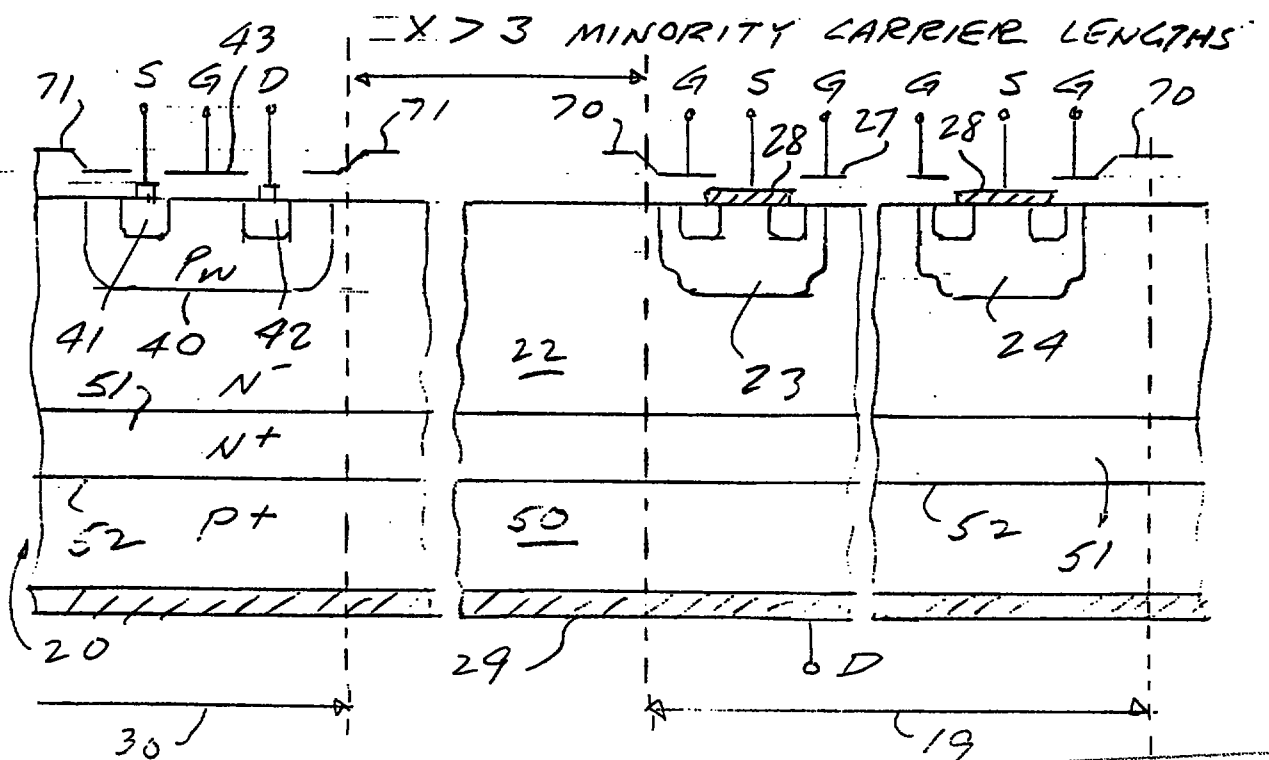


FIG. 5





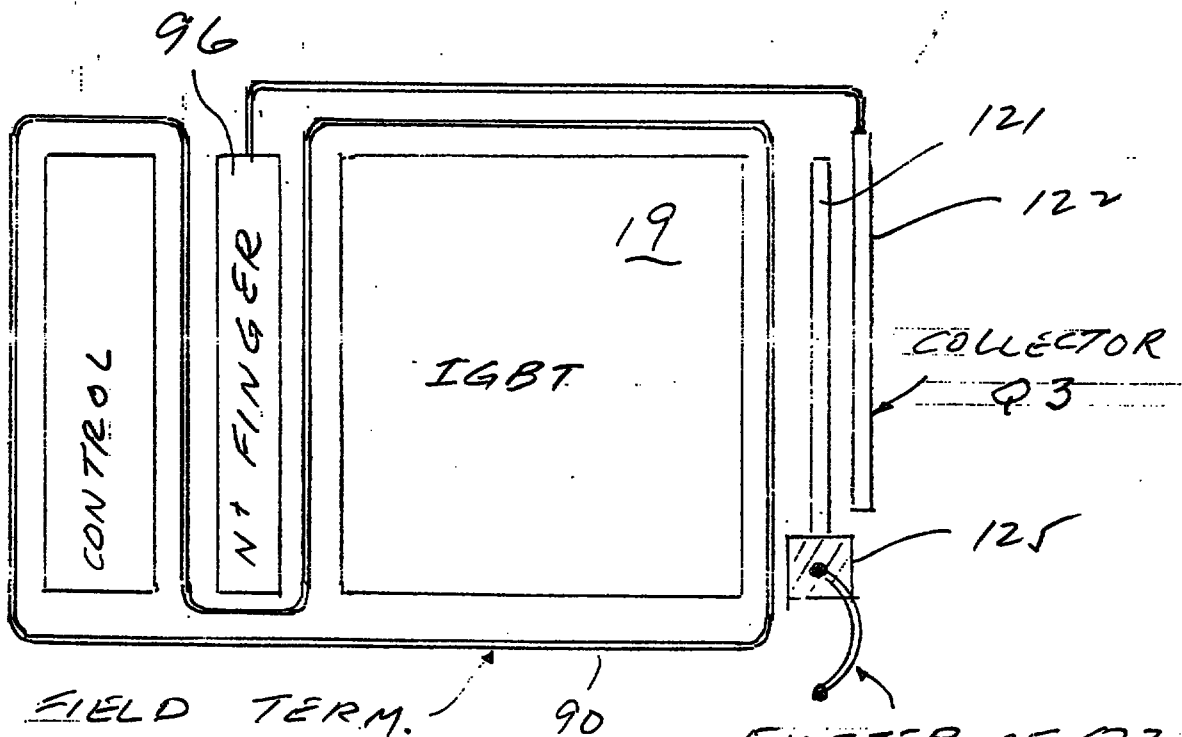
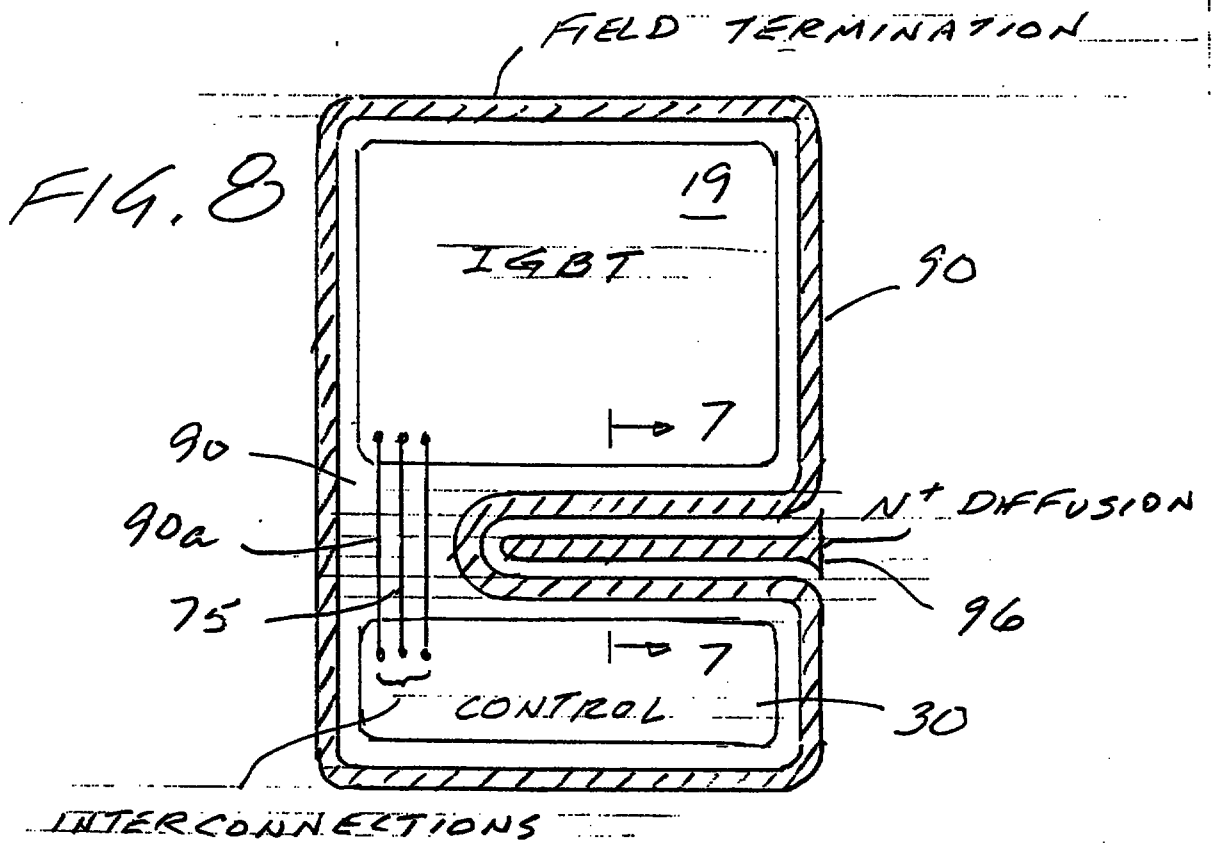
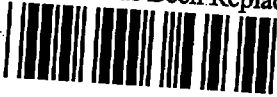


FIG 13

EMITTER OF Q3
CONNECTED TO
TAB VIA A WIRE



FIG 10

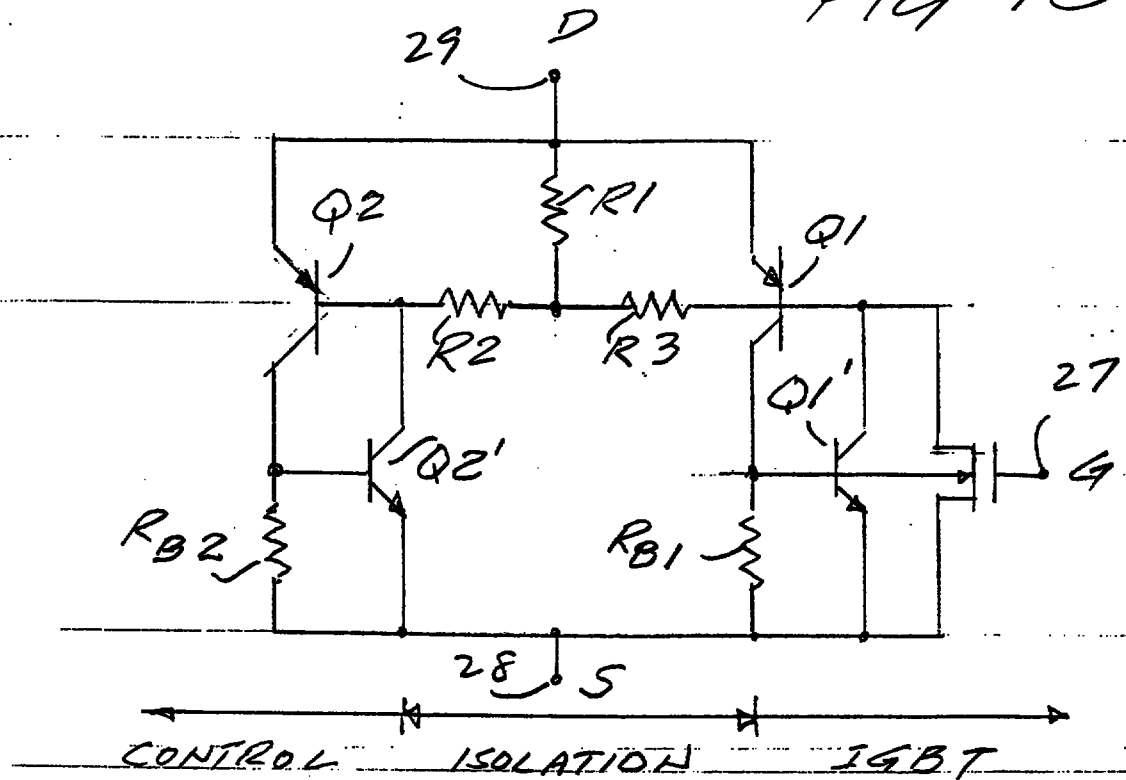
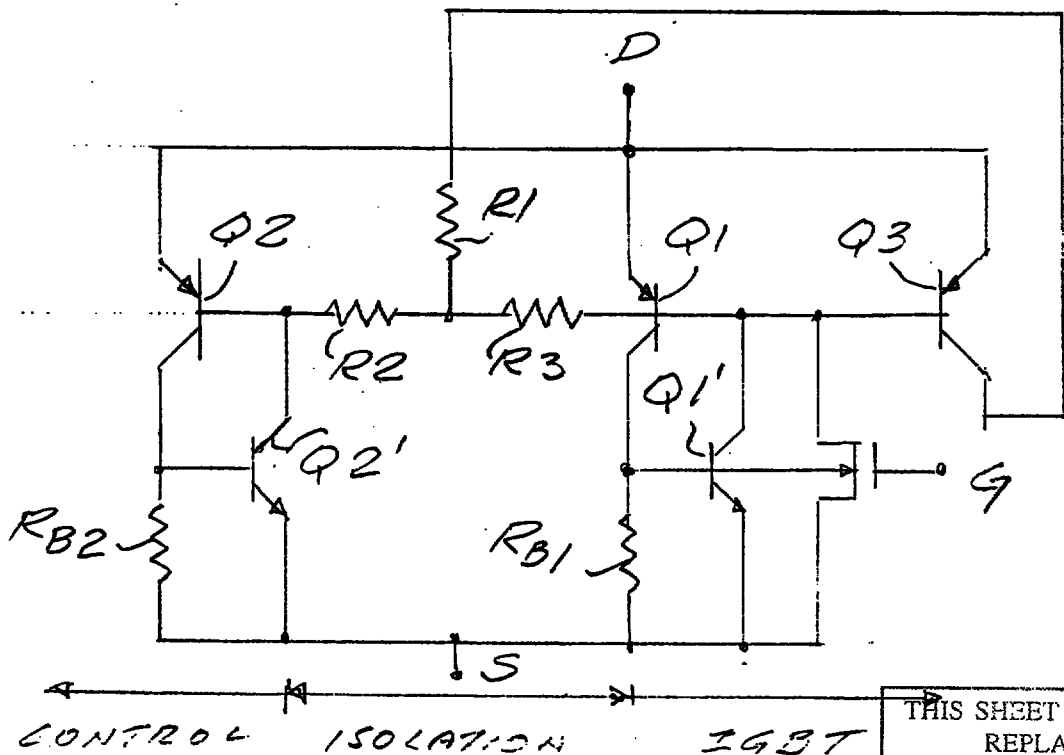


FIG 11



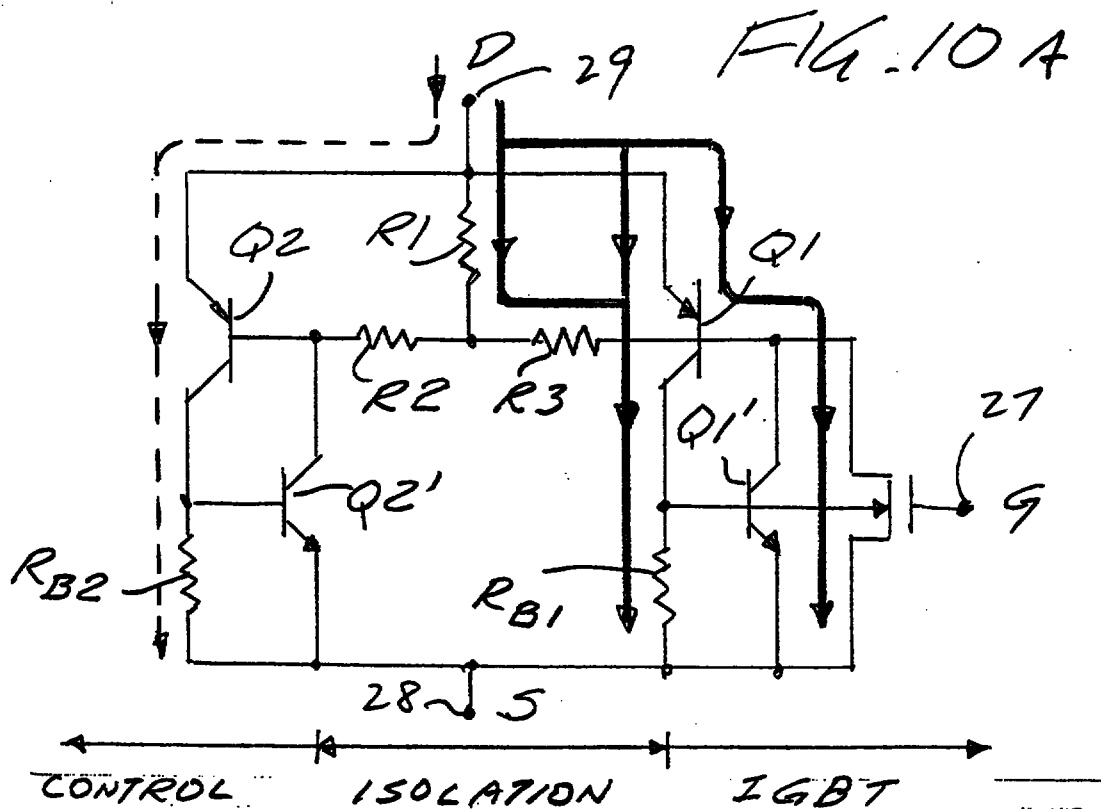
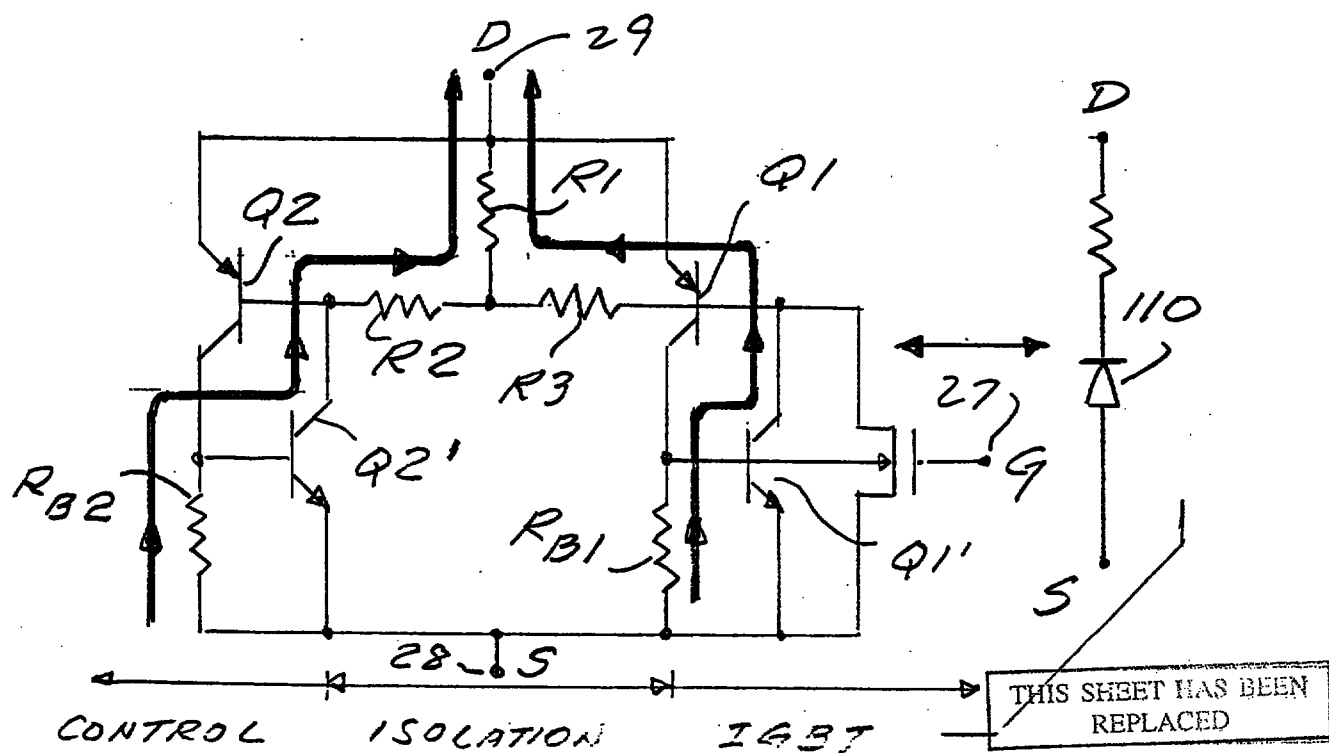
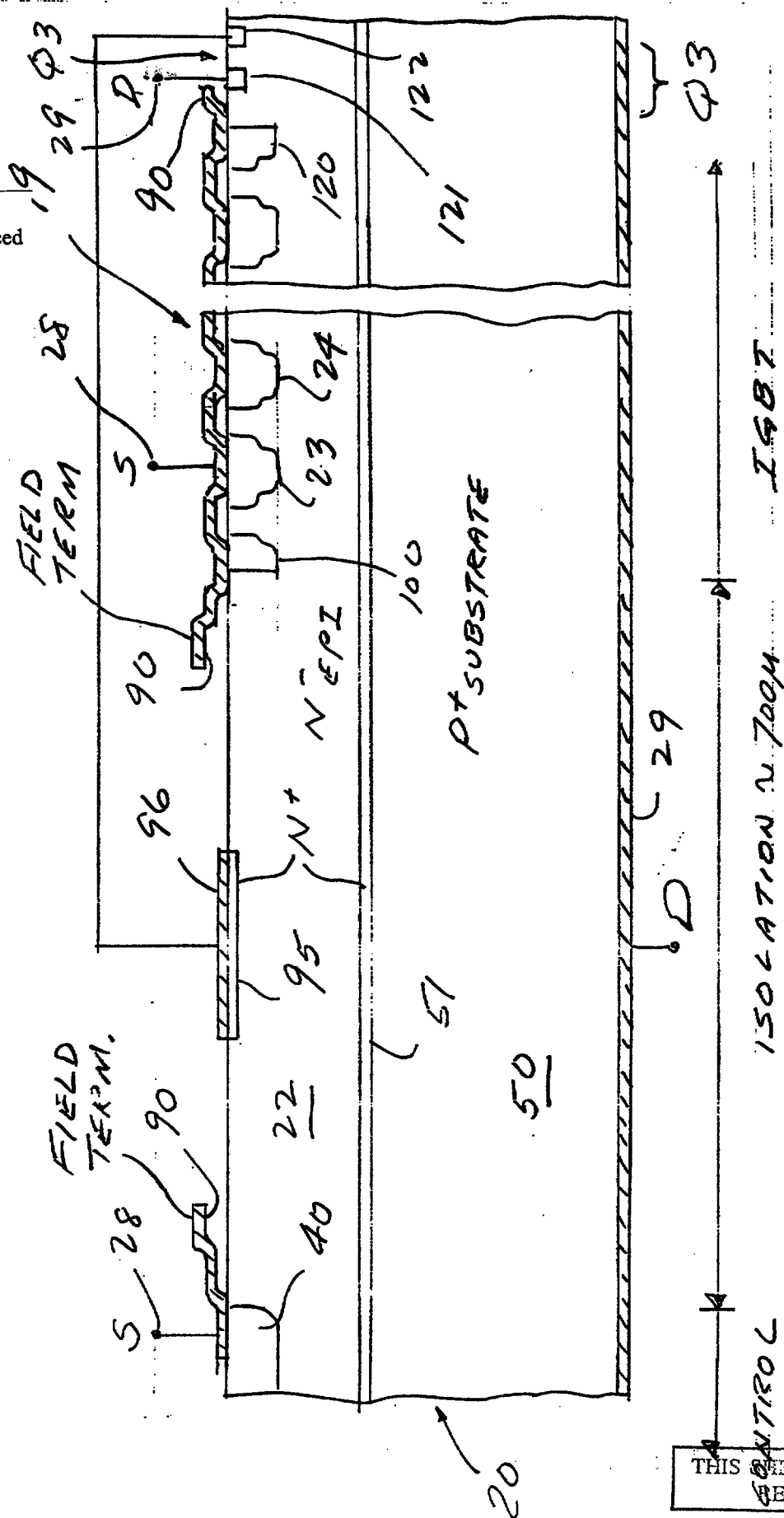


FIG. 10B



[illegible]

2/4/11



THIS SHEET HAS BEEN
REPLACED

REPLACEMENT SHEET

30 DEC 1996

- 1 -

IGBT WITH INTEGRATED CONTROLRELATED APPLICATIONS

This application is related to copending application Serial No. 08/121,288, filed September 14, 1993 in the name of Bruno C. Nadd (IR-1016) and to copending application Serial No. 08/298,383, filed August 30, 1994 in the names of Bruno C. Nadd and Talbott M. Houk (IR-1070), both of which are assigned to the assignee of the present invention.

BACKGROUND OF THE INVENTION

This invention relates to insulated gate bipolar transistors (IGBTs), and more specifically relates to a novel monolithic semiconductor chip structure having an IGBT and control circuits therefor which are integrated into a common monolithic chip (or die).

It is well known that control circuits can be integrated into the same chip as contains a discrete power MOSFET section. Such devices are sold by the International Rectifier Corporation, the assignee of the present invention, under its trademark SMARTFET. The structure of such devices is also shown in copending application Serial Nos. 08/121,288 (IR-1016) and 08/298,383 (IR-1070), referred to above.

Attempts to extend the above concept of a monolithically formed control circuit with a power IGBT (one which handles 1 watt or more of power) have not been successful. This is because the control circuits are contained in a "P well" or P-type diffusion in the same

REPLACEMENT SHEET

30 DEC 1996

- 2 -

N epitaxially formed layer (epi) as receives the junctions forming the IGBT. Thus, when the IGBT conducts in the forward direction, the P⁺ substrate is forward biased relative to the N epi so that a copious number of minority carriers (holes in the case of the N channel device being described) are injected into the N epi. Because the P well containing the control junctions is close to the IGBT power junctions, holes are also injected under the P well. This has several consequences:

1. The P well acts as the collector of a vertical PNP transistor (with the N epi and P⁺ substrate). As a result, high parasitic current is injected into the P well and to ground (since the P well is usually grounded).
2. The N⁺ source and drain diffusions in the P well act as the cathodes of vertical parasitic thyristors. The triggering of these parasitic thyristors can destroy the chip.
3. The injection of minority carriers into the P well can disturb the operation of sensitive, low power level analog circuits.

Therefore, a smart IGBT with junction-isolation has not been practical.

One attempt to overcome the problem produced by minority carrier injection has been to employ dielectric isolation of the control circuit from the main body of the chip. This structure, however, requires very expensive and very complex processing.

BRIEF DESCRIPTION OF THE INVENTION

In accordance with the present invention, a novel monolithically integrated power IGBT and control

REPLACEMENT SHEET

30 DEC 1996

- 3 -

section therefore are junction-isolated, but the effect of minority carrier injection from the IGBT section to under the control section is substantially reduced.

In the following description of the invention, an N channel IGBT having an N⁺ lateral buffer layer is described. Thus reference will be made, for convenience, to the forward bias of the P⁺ substrate, N⁺ epi junction. This language is intended to cover the junction to the N⁺ buffer if such a buffer is used. Moreover, the invention applies equally to P channel devices and, in general, to any MOS gated bipolar device.

In a first embodiment of the invention, the control section or P well is laterally spaced from the periphery of the active IGBT region by greater than about three diffusion lengths of the minority carrier. As a result, the P⁺ substrate to N⁺ epi junction will be effectively de-biased under the P well so that the concentration of minority carriers under the P well is very substantially reduced. Note, however, that the implementation of the above concept requires added silicon chip area. Further, the low sheet resistivity N⁺ buffer layer commonly used to reduce the β of the PNP portion of the IGBT interferes with the de-bias of the P⁺ substrate, N⁺ buffer junction.

In accordance with a second embodiment of the invention, a further P⁺ diffusion is placed between the control P well and the IGBT active area. The further P⁺ diffusion is connected to the source (or cathode) electrode of the IGBT section. Consequently, most hole current outside of the active IGBT area will be diverted to the further P⁺ diffusion and to the IGBT source

REPLACEMENT SHEET

30 DEC 1996

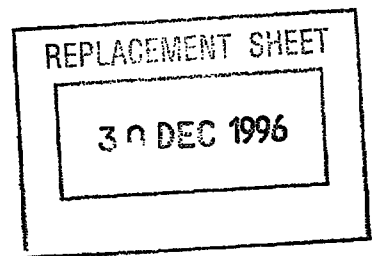
- 4 -

electrode. Note that with this approach some hole current can still flow to under the P well.

In a third embodiment of the invention, the region between the P⁺ substrate and N⁻ epi and surrounding the active area is, in effect, short-circuited so that the P⁺ substrate, N⁻ epi junction under the control P well is fully de-biased. A preferred way to carry out this embodiment employs an N⁺ diffusion on the upper surface of the chip and surrounding one or both the control P well or active IGBT area and the connection of the N⁺ diffusion to the back or bottom of the chip and to the P⁺ substrate.

Consequently, the P⁺ substrate under the IGBT area is forward-biased relative to the N⁻ epi (or N⁺ buffer layer if one is used) during forward conduction. Electrons will flow laterally through the N⁻ epi or the N⁺ buffer layer and outwardly of the active IGBT area and up to the novel N⁺ diffusion at the upper surface of the chip. This causes a lateral voltage drop in the N⁺ buffer layer (or N⁻ epi) so that the P⁺ substrate to N⁻ epi junction is progressively de-biased, moving laterally away from under the active area. By appropriately choosing the resistance R_s between the buffer layer and the new N⁺ diffusion and the lateral resistance of the buffer layer R_b such that R_s is much less than R_b, the voltage across the N⁺/P⁺ junction under the control P well is almost zero and only negligible hole injection can occur.

In the preferred embodiment of the invention, a proper field termination is required on both sides of the N⁺ diffusion. However, interconnections must be made from the control circuit to the IGBT, for example, source



- 5 -

contacts, gates, Kelvin sources, current sense leads, and the like. In order to make these connections without crossing over the high voltage field termination, a novel topology is provided wherein the control section and IGBT section are enclosed by a common continuous field termination which is reentrantly bent around both sides of the N^+ diffusion, but leaves a narrow conductor-routing-channel spaced from the end of the N^+ diffusion. Control conductors of metal, polysilicon or the like can be disposed over and atop this narrow routing-channel.

In the preferred embodiment of the invention, a parasitic diode is created between the main drain and source electrodes as a consequence of the use of the novel N^+ diffusion between control and IGBT sections. This diode prevents the use of the chip in applications requiring reverse voltage blocking, and cannot be used in applications requiring an external fast recovery diode. In accordance with another feature of the invention and to overcome the effect of this parasitic diode, a novel lateral PNP transistor is integrated into the IGBT section and is connected to and enables the operation of the N^+ diffusion only when the IGBT is forward biased. Thus, the parasitic diode is open-circuited during those times when it could interfere with the chip operation.

Other features and advantages of the present invention will become apparent from the following description of the invention which refers to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a cross-section of a portion of a SMARTFET structure of the prior art.

30 DEC 1996

- 6 -

Figure 2 shows a cross-section of a portion of an IGBT in which a P well is formed in the same chip and illustrates the problems created.

Figure 3 shows a cross-section of a portion of an IGBT in which a control circuit is formed in a well which is dielectrically insulated from the chip.

Figure 4 shows the topology of a chip employing a first embodiment of the invention.

Figure 5 shows a cross-section of Figure 4 taken across the section lines 5-5 in Figure 4.

Figure 6 shows a cross-sectional view of a portion of a SMART-IGBT chip having a P⁺ region positioned between the active region and control region in accordance with the invention.

Figure 7 shows another embodiment of the invention, employing an N⁺ diffusion between the active IGBT area and the control area and is a cross section of Figure 6 taken across the section lines 5-5 in Figure 6.

Figure 8 shows a preferred embodiment of the topology of the active and control areas of Figure 7.

Figure 9 shows a cross-section similar to that of Figure 7 to more realistic scale and shows certain circuit components defined by the junctions.

Figure 10 is an equivalent circuit diagram of Figure 9.

Figure 10A shows the current in the circuit of Figure 10 when the IGBT is forward biased.

Figure 10B shows the current paths in the circuit of Figure 10 under reverse voltage and illustrates a parasitic diode.

Figure 11 shows the addition of a PNP diode to the circuit of Figure 10 to eliminate the effect of the parasitic diode of Figure 10B under reverse voltage.

30 DEC 1996

- 7 -

Figure 12 shows the structure of Figure 9 with the added PNP diode of Figure 11 implemented therein.

Figure 13 shows a preferred topology for the structure of Figure 12.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring first to Figure 1, there is schematically shown a small portion of a MOSFET chip of silicon 20 in cross-section. Silicon chip 20 has an N^+ substrate 21 and a layer 22 of epitaxial silicon which receives junctions which define the active MOSFET section 19 and its control circuit 30. Thus, the active power MOSFET section includes a plurality of P type MOSFET bases, such as bases 23 and 24, which are distributed over the active MOSFET area of chip 20 as shown in U.S. Patent 5,008,725. Each of bases 23 and 24 receive respective N^+ annular sources 25 and 26, respectively. A conventional polysilicon gate structure 27 overlies a conventional gate diode which covers the channel regions formed in bases 23 and 24. A main power source electrode 28 and drain electrode 29 are provided as usual.

The control section 30 is monolithically integrated into the same chip 20 with the active power MOSFET 19. Thus, a P well 40 is diffused into layer 22 and is laterally spaced from active MOSFET area 19. P well 40 contains any desired control circuitry for turning on and off the active area 19, such as, for example, thermal sensors, current sensors, undervoltage sensors and the like, such as those described in co-pending application Serial No. 08/298,383 (IR-1070), described above. A lateral control transistor is schematically shown in Figure 1, comprised of N^+ source diffusion 41, N^+ drain diffusion 42, and gate 43, all

30 DEC 1996

- 8 -

contained in P well 40 and junction isolated from active MOSFET area 19. The control transistor in P well 40 may then be suitably coupled to the gate 27 to effect a control of the active MOSFET in response to any desired sensed parameter. Thus, intelligence is monolithically integrated into the chip containing a power MOSFET device.

The concept of simply integrating a junction-isolated control section in an IGBT chip has created seemingly insurmountable problems. These problems are best understood from a consideration of Figure 2 which shows the simple addition of a P⁺ substrate 50 to the chip 20 of Figure 1 (in place of N⁺ substrate 21 of Figure 1), causing it to operate as an IGBT. Note that a conventional N⁺ buffer layer 51 may also be added in Figure 2 in order to reduce the β of the PNP portion of the IGBT. All other components having the same numerals as Figure 1 have the same function. Note that power section 19 will now operate in an IGBT mode due to the presence of P⁺ region 50.

The device of Figure 2 cannot operate satisfactorily because, during forward conduction in the IGBT mode, the junction 52 between the P⁺ substrate 50 and N⁺ buffer 51 (or the junction to N⁺ epi 22 if no buffer is used) is forward biased along its length. Therefore, a copious number of minority carriers (holes in the embodiment of Figure 2) are injected in the epi layer 22 and under P well 40. This hole injection is shown by the arrows in Figure 2, and causes several problems:

1. The P well 40, taken with N⁺ epi 22 and P⁺ substrate 50 forms a parasitic PNP transistor 60. Since the P well is commonly grounded (not shown), the minority

REPLACEMENT SHEET

30 DEC 1996

- 9 -

carriers in epi 22 turn the PNP transistor 60 on, causing a high parasitic current in the P well 40 to ground.

2. The N^+ diffusions 41 and 42 in well 40 act as the cathodes of parasitic four-layer thyristor 61. The triggering of this parasitic thyristor 61 can cause the destruction of the device.

3. The injection of minority carriers under P well 40 also will disturb the operation of the sensitive low level analog circuits which are integrated into well 40.

As a consequence of the injection of minority carriers under a junction-isolated control well, this technology has not been used to create a "SMART IGBT" analog to the "SMARTFET" device.

One known structure which has avoided the minority carrier injection problem employs a dielectrically isolated P well 70, as shown in Figure 3, which is isolated from the N^+ epi by a silicon dioxide liner 71. In Figure 3, parts similar to those of Figure 2 have similar identifying numerals. This solution, however, requires very expensive and complex fabrication procedures.

The present invention achieves results similar to those of Figure 3, but employs junction-isolation techniques which can be carried out with cost-effective fabrication.

In a first embodiment of the invention, the boundary of the active IGBT area in Figure 2 is spaced by three diffusion lengths or more from the boundary of the P well 40. Thus, Figures 4 and 5 show one possible arrangement for this embodiment, wherein components similar to those of Figure 2 are given similar identifying numerals. Figures 4 and 5 also show field

REPLACEMENT SHEET

30 DEC 1996

- 10 -

terminations 70 and 71 which surround the active IGBT area 19 and the control area 30, respectively. The dotted lines 75 indicate the connection of the control circuit 30 to the gate 27 and source (and other related terminals) of the active IGBT area 19. Note that other control areas and other IGBTs or other power devices can be integrated into epi layer 22 of Figures 4 and 5 at areas laterally removed from area 19.

In accordance with the invention, the distance between the periphery of the P well 40 and the periphery of the active IGBT junctions is greater than about three minority carrier lengths. As a result of this spacing, junction 52 is de-biased under control section 41 and the level of minority carrier injection under the control section 40 will be much lower. Note that the sheet resistivity of the N^+ buffer layer can also be increased to assist in de-biasing the junction 52 or 51 under the control region 30.

Figure 6 shows a second embodiment of the invention where components similar to those of Figure 2 have similar identifying numerals. Note that the buffer layer 21 is not shown in Figure 6, but can be used if desired. In Figure 6, a P^+ diffusion 80 is added as shown and is disposed between the control section 30 and the IGBT section 19. The P^+ region 80 is further connected to IGBT source electrode 28.

In operation, holes schematically shown in Figure 6 by arrows are injected into region 22. However, the holes outside of area 19 are preferably collected by diffusion 80, so that fewer holes can be collected by P well 40.

Figures 7 and 8 show a still further embodiment of the invention, wherein components similar to those of

REPLACEMENT SHEET

30 DEC 1996

- 11 -

prior figures have the same identifying numerals. Figure 8 also shows a novel continuous field termination 90 which almost fully encloses each of IGBT area 19 and control area 30, leaving a narrow neck 90 over which control lead 75 can travel without crossing the high voltage field termination 90. The area between laterally spaced IGBT region 19 and control region 30 then receives an N^+ diffusion 95 (Figures 7 and 8) which is between and co-extensive with adjacent lengths of reentrantly folded termination 90. Diffusion 95 has a contact 96 which is connected to P^+ region 50 as shown by dotted line 97. In practice, connection 97 can be a wire-bond connection or the like. It is possible that the connection is automatically made simply by the action of a saw during wafer cutting.

The operation of the device of Figures 7 and 8 is as follows:

When the IGBT section 19 is conducting, junction 52 is forward biased. A lateral electron current, shown by the arrows, flows in the buffer layer 51 (or in the epi 22 if no buffer is used) and to the N^+ diffusion 95. This causes a lateral voltage drop along resistance R_B in the buffer layer. Therefore, the junction 52 is progressively de-biased from the edge of IGBT area 19, toward control area 30. By making the resistance R_S to diffusion 95 much lower than R_B , the voltage across junction 52 under P well 40 can be reduced to almost zero so that the level of minority carrier injection in that region is negligible. Making $R_S \ll R_B$ can be accomplished by appropriately fixing the width W_S of diffusion 95, relative to the epi layer 22 resistivity and the buffer layer 51 resistivity.

REPLACEMENT SHEET

30 DEC 1996

- 12 -

Since the control logic in control area 30 is normally referenced to the source 28 of the IGBT, a proper field termination is required on both sides of the N^+ diffusion 95, previously described as terminations 70 and 71 in Figures 4 and 5, and 90 in Figures 7 and 8. The interconnections of these areas by conductors 75 must pass over and be insulated from terminations 70 and 71. In the embodiment of Figure 8, however, the IGBT 19 and control section 30 are both substantially fully enclosed by termination 90 except for the narrow surface channel or neck region 90a over which the connections 75 can be routed without crossing over termination 90. The neck region 90a is sufficiently narrow to prevent meaningful P^+ carrier injection from under the IGBT section 19 to under the control section 30. As previously stated, interconnections 75 can be made of metal or conductive polysilicon traces or the like over the grounded P well 40.

The connection 97 of the N^+ diffusion 95 to the backside of the wafer can be made with a wire bond to the lead frame (not shown) which may support the chip 20, or, if the chip is in a TO-220 type package, it can be made to the center pin, for example, of the package. In many cases, the connection will be made through the saw-damaged chip edge of the chip 20, created during wafer cutting.

Figure 9 shows the chip 20 of Figure 7 to a more realistic, but still schematic, scale. Parts of Figure 9, similar to those of Figure 7, have the same identifying numerals. Because of limitations of scale, the source and gate structures in well 40 and in bases 23 and 24 are not shown in Figure 9. Shown, however, is an active area termination cell 100 for IGBT 19 and an

REPLACEMENT SHEET

30 DEC 1996

- 13 -

intentional isolation spacing of about 700 microns between active IGBT area 19 and P well 40.

Figure 9 next shows vertical PNP transistors Q1 and Q2 which are formed by the junctions of IGBT 19 and control area 30. It further shows the access resistance R1 between buffer layer 51 and N⁺ diffusion 95 and resistances R2 and R3 of the buffer layer between the bottom of resistance R1 to the approximate location of the bases of PNP transistors Q2 and Q1, respectively.

The equivalent circuit of Figure 9 is shown in Figure 10. Figure 10 also shows NPN parasitic transistors Q1' and Q2' which are the parasitic NPN transistors of the N source, P base and N⁺ epi 22 for the IGBT section 19 and the corresponding transistor of section 40, respectively. Also shown in Figure 10 are resistors RB1 and RB2 which are the effective resistances between the base and emitter of the NPN transistors Q1' and Q2', respectively.

Under normal circumstances, transistors Q1' and Q2' should not conduct to avoid latch up of its corresponding parasitic thyristor. This is avoided in transistor Q1' by designing a very low value for resistor RB1.

However, the implementation of lateral NMOS transistors in the control section results in a much higher value for RB2 and for the gain of transistor Q2. Consequently, the control section is much more latch-up sensitive than the IGBT section and hole injection by transistor Q2 should be avoided. This is the purpose of the N⁺ finger 95.

Figure 10A shows the currents in heavy line when the IGBT is forward biased. During forward bias, the base-emitter junction of transistor Q1 is forward

REPLACEMENT SHEET

30 DEC 1996

- 14 -

biased. The base-emitter junction of transistor Q2 sees only $V_{be} (Q1) \cdot R1 / (R3 + R1)$. By properly choosing the geometry (and thus the ratio $R1/R3$) it is possible to almost eliminate the current in transistor Q2 (see dotted line in Figure 10A) and the risk of latch-up in the control section.

This approach prevents the latch-up of the control section in the forward-biased mode. However, as shown in Figure 10B, there is a parasitic diode 110 between the drain 29 and source 28 under reverse bias. Diode 110 consists of the base collector junctions of transistors Q1' and Q2', in series with RB1 and RB2; and R2 and R3, respectively, and R1.

This parasitic diode 110 has two damaging consequences:

1. It prohibits applications where a reverse voltage capability is necessary (such as in electronic ignition).

2. It cannot be used in applications where there is an external fast recovery diode, since the internal parasitic diode 110 will carry a part of the current diode. Diode 110 is outwardly extremely slow and its recovery current induces latch-up in the control section 30. In other words, if one re-applies a positive voltage on the drain 29 while the base/collector junction of transistor Q2' is full of minority carriers, the Q2/Q2' thyristor will latch.

As a further feature of the invention, the effect of the parasitic diode 110 is eliminated by connecting R1 of Figures 9, 10, 10A and 10B to the drain 29 only when the IGBT is forward biased. Thus, as shown in Figures 11 and 12, a lateral PNP transistor Q3 is added outside of the field termination 90 of IGBT section

REPLACEMENT SHEET

30 DEC 1996

- 15 -

19, shown from edge cell 100 to edge cell 120 in Figure 12. The P diffusion which defines emitter 121 in Figure 12 is connected to drain 29 as by a wire bond, and the P diffusion which defines collector 122 is connected to contact 96 of N⁺ diffusion 95.

In operation, when the IGBT 19 is forward biased, Q1 conducts and so does Q3. This dynamically connects R1 to the drain 29. When the IGBT 19 is reverse biased, Q1 and Q3 are not conducting and R1 is floating. Therefore, no reverse current flows in the structure.

Q3 can be a low voltage transistor (the same as the reverse blocking rating as the IGBT 19 itself, usually 10 to 50V). Thus, it can be made with a narrow base (for example 10 microns) and have a high gain so that it is fully saturated when the IGBT 19 is forward biased.

Figure 13 schematically shows the implementation of transistor Q3 in the chip surface. Components similar to those of Figure 8 have the same reference numerals in Figure 13. Note that emitter and collector regions 121 and 122, respectively, are connected to a tap 125 of drain 29 and N⁺ finger 96, respectively.

Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein, but only by the appended claims.



REPLACEMENT SHEET

30 DEC 1996

- 16 -

WHAT IS CLAIMED IS:

1. An insulated gate bipolar transistor and a control circuit therefore integrated into a common semiconductor chip; said semiconductor chip having a P type silicon substrate and having a low concentration N type region formed on the top surface thereof and a P⁺ region formed on the bottom surface thereof; a first area of said low concentration region receiving diffusions defining the base, source and channel regions of an insulated gate bipolar transistor; a second area of said low concentration region being laterally spaced from said first area; said second area including a P well diffusion and control circuit diffusions in said P well; and coupling means coupling said insulated gate bipolar transistor in said first area to said control circuit diffusions; and means disposed between said first and second areas for limiting the injection of holes from said P⁺ region into said P well diffusion during the injection of holes to produce the operation of said insulated gate bipolar transistor in said first area.

2. The device of claim 1 wherein said means disposed between said first and second areas includes a relatively large lateral spacing between said areas, which is at least about three diffusion lengths of holes in said low concentration N type region.

3. The device of claim 1 wherein said means disposed between said first and second areas includes a second P⁺ diffusion into the top surface of said low concentration N type region, and means connecting said second P⁺ diffusion to said source of said insulated gate



REPLACEMENT SHEET

30 DEC 1996

- 17 -

bipolar transistor, whereby said second P⁺ diffusion will collect holes which would otherwise be collected by said P well in said second area.

4. The device of claim 1, wherein said means disposed between said first and second areas includes an N⁺ diffusion into the top surface of said low concentration N type region; and means electrically connecting said N⁺ diffusion to said P type substrate.

5. The device of claim 1 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

6. The device of claim 1 which further includes field termination means disposed on the upper surface of said device, and which at least partially surrounds said first and second areas.

7. The device of claim 6 wherein said field termination means encloses the opposite sides of said narrow neck region, and the full remaining peripheries of each of said first and second areas.

8. The device of claim 1 wherein said low concentration N type region is an epitaxially grown region.

9. The device of claim 1 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a gate electrode disposed above said channel regions; and a



REPLACEMENT SHEET

30 DEC 1996

- 18 -

drain electrode connected to the bottom of said P⁺ region at said bottom surface.

10. The device of claim 2 wherein said low concentration N type region is an epitaxially grown region.

11. The device of claim 3 wherein said low concentration N type region is an epitaxially grown region.

12. The device of claim 4 wherein said low concentration N type region is an epitaxially grown region.

13. The device of claim 5 wherein said low concentration N type region is an epitaxially grown region.

14. The device of claim 6 wherein said low concentration N type region is an epitaxially grown region.

15. The device of claim 10 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a gate electrode disposed above said channel regions; and a drain electrode connected to the bottom of said P⁺ region at said bottom surface.

16. The device of claim 11 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a



REPLACEMENT SHEET

30 DEC 1996

- 19 -

gate electrode disposed above said channel regions; and a drain electrode connected to the bottom of said P⁺ region at said bottom surface.

17. The device of claim 12 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a gate electrode disposed above said channel regions; and a drain electrode connected to the bottom of said P⁺ region at said bottom surface.

18. The device of claim 13 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a gate electrode disposed above said channel regions; and a drain electrode connected to the bottom of said P⁺ region at said bottom surface.

19. The device of claim 14 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a gate electrode disposed above said channel regions; and a drain electrode connected to the bottom of said P⁺ region at said bottom surface.

20. The device of claim 6, wherein said means disposed between said first and second areas includes an N⁺ diffusion into the top surface of said low concentration N type region; and means electrically connecting said N⁺ diffusion to said P⁺ region; said N⁺ region being disposed between and spaced from said field termination means at locations where said field



REPLACEMENT SHEET

30 DEC 1996

- 20 -

termination extends along coextensive portions of said first and second areas.

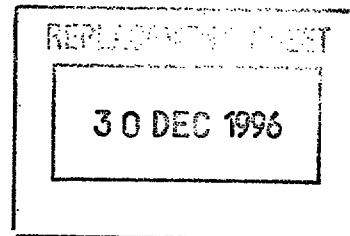
21. The device of claim 20 wherein the upper surfaces of said first and second areas are joined at a narrow neck regions; said coupling means comprising conductors disposed atop and across said neck region.

22. The device of claim 21 wherein said field termination encloses the opposite sides of said narrow neck region, and the full remaining peripheries of each of said first and second areas.

23. The device of claim 22 wherein said low concentration N type region is an epitaxially grown region.

24. The device of claim 23 which further includes a source electrode connected to said source and base regions of said insulated gate bipolar transistor, a gate electrode disposed above said channel regions; and a drain electrode connected to the bottom of said P⁺ region at said bottom surface.

25. The device of claim 4 which further includes a lateral PNP transistor integrated into said first area and having its collector connected to said N⁺ region, its base region being the said N type region and its emitter region being connected to said P⁺ region such that it conducts only when said insulated gate bipolar transistor is forward biased whereby said N⁺ region is connected to said P⁺ type substrate only when said IGBT is forward biased.



- 21 -

26. The device of claim 20 which further includes a lateral PNP transistor integrated into said first area and having a source region connected to said N⁺ region, and being biased to conduct only when said insulated gate bipolar transistor is forward biased whereby said N⁺ region is connected to said N type substrate only when said IGBT is forward biased.

27. The device of claim 24 which further includes a lateral PNP transistor integrated into said first area and having a source region connected to said N⁺ region, and being biased to conduct only when said insulated gate bipolar transistor is forward biased whereby said N⁺ region is connected to said N type substrate only when said IGBT is forward biased.

28. An IGBT and a control circuit therefore monolithically integrated into a common semiconductor chip; said semiconductor chip having a bottom P type layer and a substantially coextensive N type layer atop said P type layer; a first area of the surface of said N type layer receiving diffusions which define an IGBT; a second area of the surface of said N type layer receiving a P well which contains control device diffusions therein which are junction isolated from said first area; the junction between said N type layer and said P type layer extending continuously from under said first area to under said second area; and means for at least partly de-biasing said junction in the area under said control area when said IGBT area is in conduction and minority carriers are being injected from said P type layer and into said N type layer.



REPLACEMENT SHEET

30 DEC 1996

- 22 -

29. The device of claim 28 wherein said means for de-biasing comprises the lateral spacing of said first and second areas by more than about three diffusion lengths of minority carriers injected from said P layer into said N layer during the forward conduction of said IGBT area.

30. The device of claim 28 wherein said first area has an IGBT source, and wherein said means comprises a P⁺ diffusion disposed into the surface of said N layer and between said first and second areas and connected to said IGBT source.

31. The device of claim 28 which further includes an N⁺ diffusion into the surface of said N layer and disposed between said first and second areas, and being connected to said P layer.

32. The device of claim 28 which further includes coupling means for coupling said control device diffusions to said diffusions which define an IGBT whereby said IGBT is operated in response to control signals from said control device diffusions.

33. The device of claim 29 which further includes coupling means for coupling said control device diffusions to said diffusions which define an IGBT whereby said IGBT is operated in response to control signals from said control device diffusions.

34. The device of claim 30 which further includes coupling means for coupling said control device diffusions to said diffusions which define an IGBT



REPLACEMENT SHEET

30 DEC 1996

- 23 -

whereby said IGBT is operated in response to control signals from said control device diffusions.

35. The device of claim 31 which further includes coupling means for coupling said control device diffusions to said diffusions which define an IGBT whereby said IGBT is operated in response to control signals from said control device diffusions.

36. The device of claim 32 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

37. The device of claim 33 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

38. The device of claim 34 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

39. The device of claim 35 wherein the upper surfaces of said first and second areas are joined at a narrow neck region; said coupling means comprising conductors disposed atop and across said neck region.

REPLACEMENT SHEET

30 DEC 1996

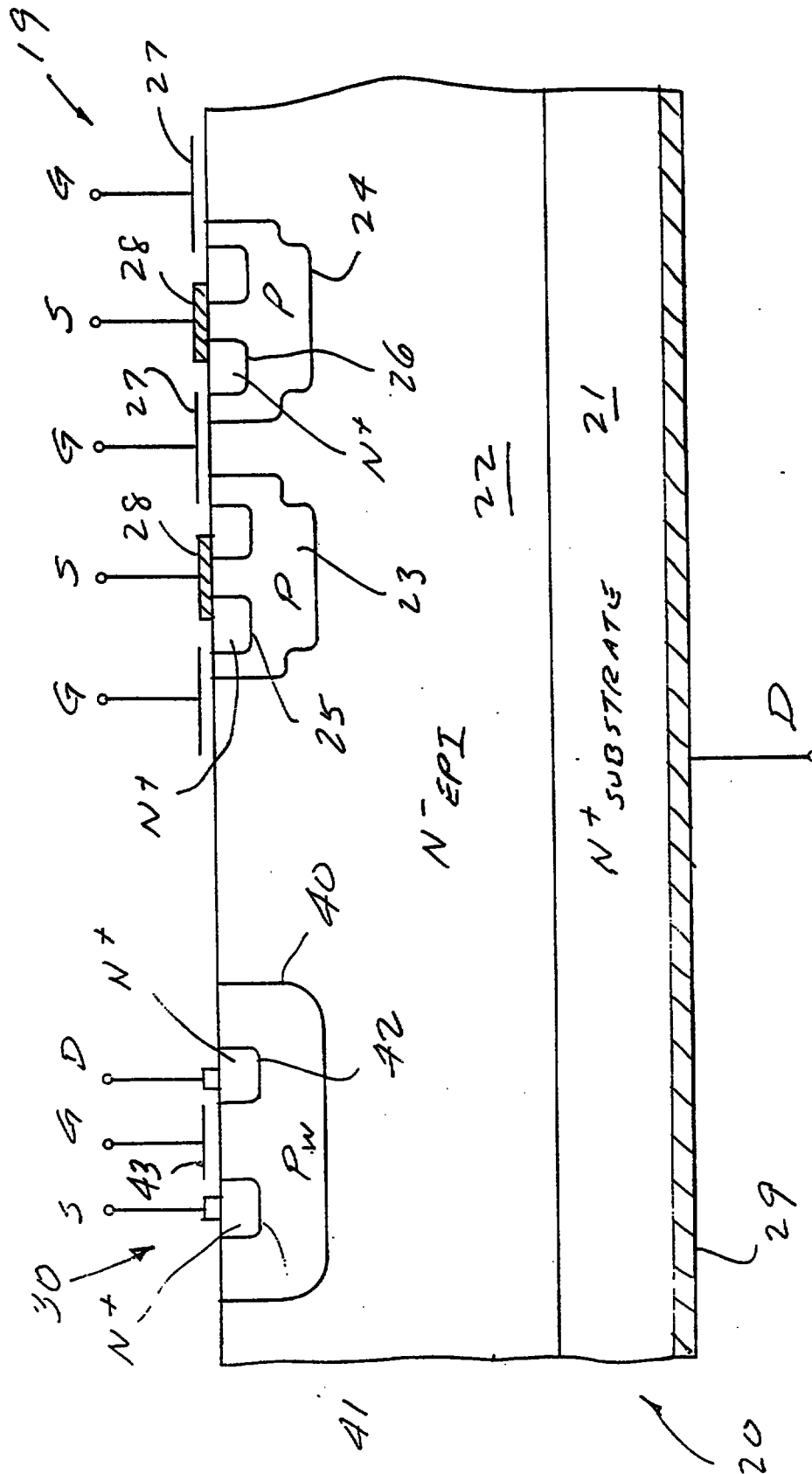
- 24 -

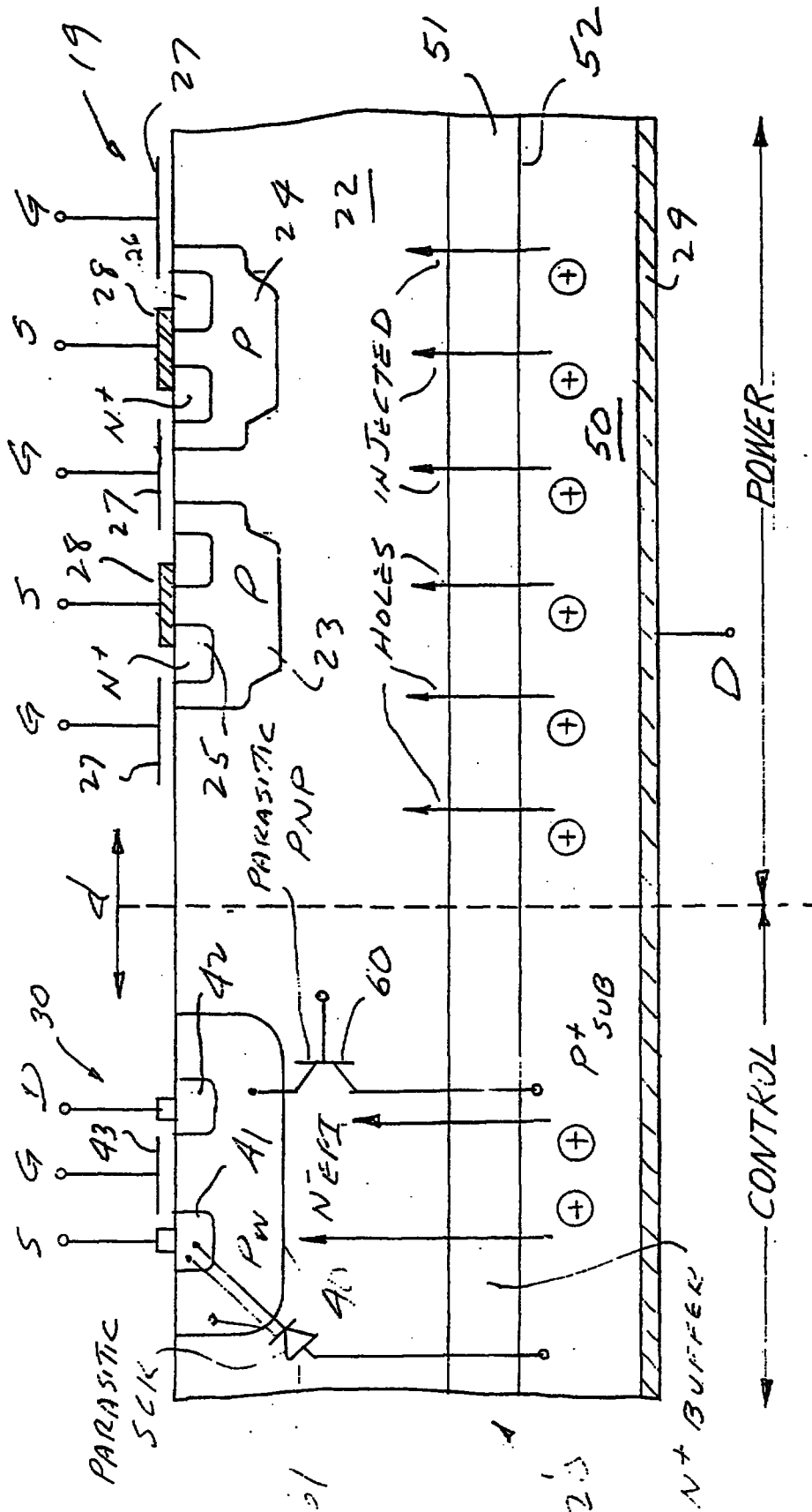
IGBT WITH INTEGRATED CONTROLABSTRACT OF THE DISCLOSURE

A monolithic IGBT and control circuit therefore are integrated into a common chip. The IGBT is formed in a first area of the chip and the control circuit is formed in a second laterally spaced area and in a P well. Means are provided to prevent hole injection from the P⁺ substrate into the P well during IGBT operation. The means includes a sufficient spacing between the areas; a P⁺ collection region between the areas or an N⁺ diffusion between the areas which is connected to the P⁺ substrate. The areas are surrounded by a common field termination structure which, however, leaves a small surface bridge between the two areas. Control conductors from the control area to the IGBT area cross over the narrow area, and not over the field terminations. A lateral PNP transistor which is integrated in the chip and is external of the IGBT area is connected to the central N⁺ diffusion between IGBT and control areas and permits its connection to the P type substrate only when the IGBT area conducts.

(No figure suggested)

30 DEC 1996



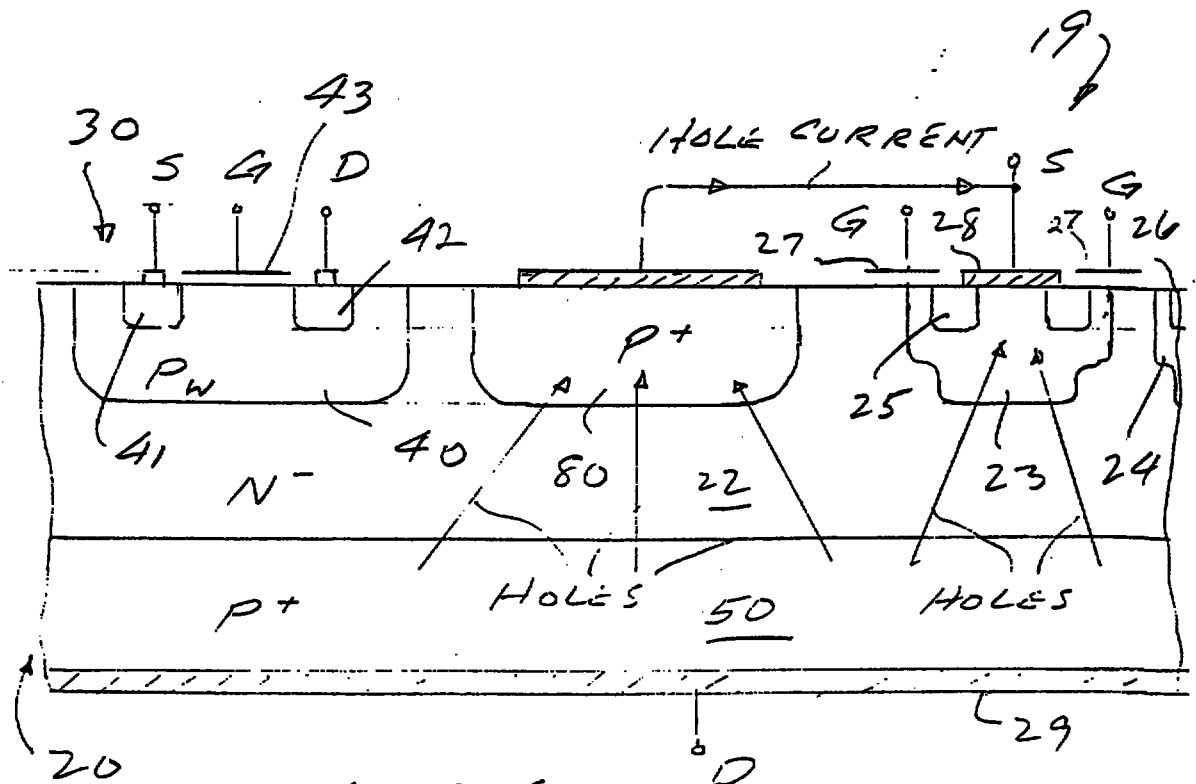
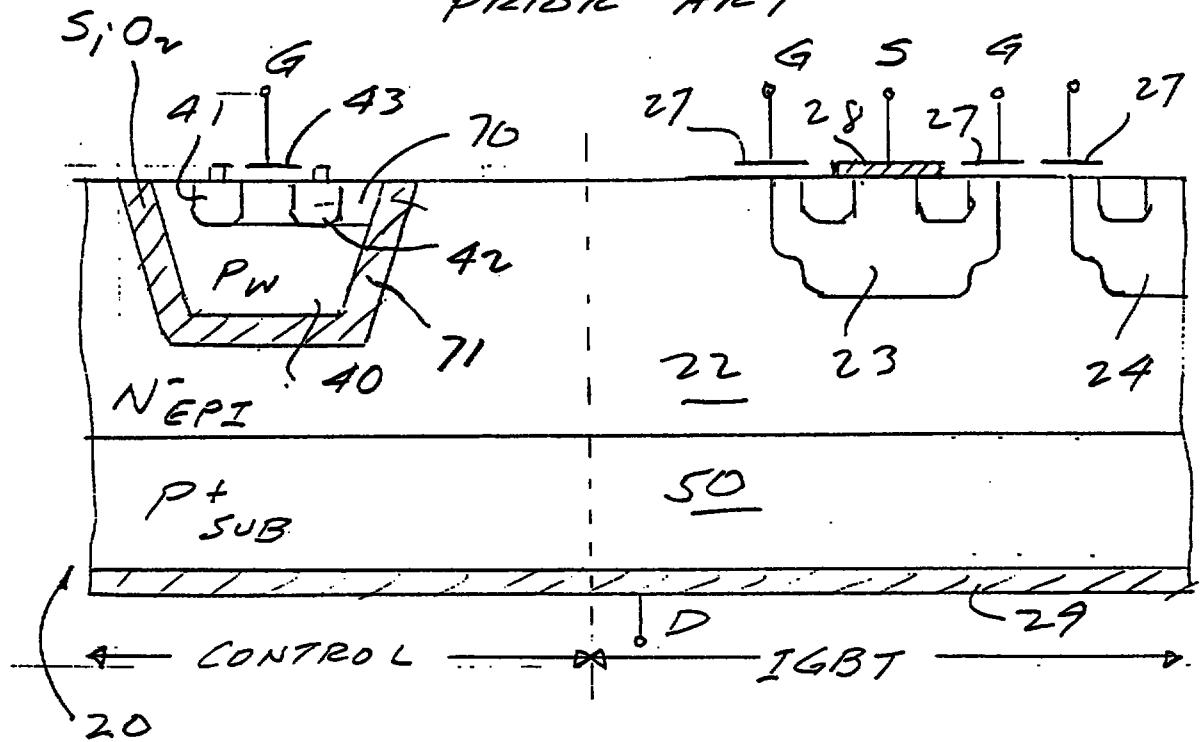


30 DEC 1996

- 3 -

FIG 3

PRIOR ART



30 DEC 1996

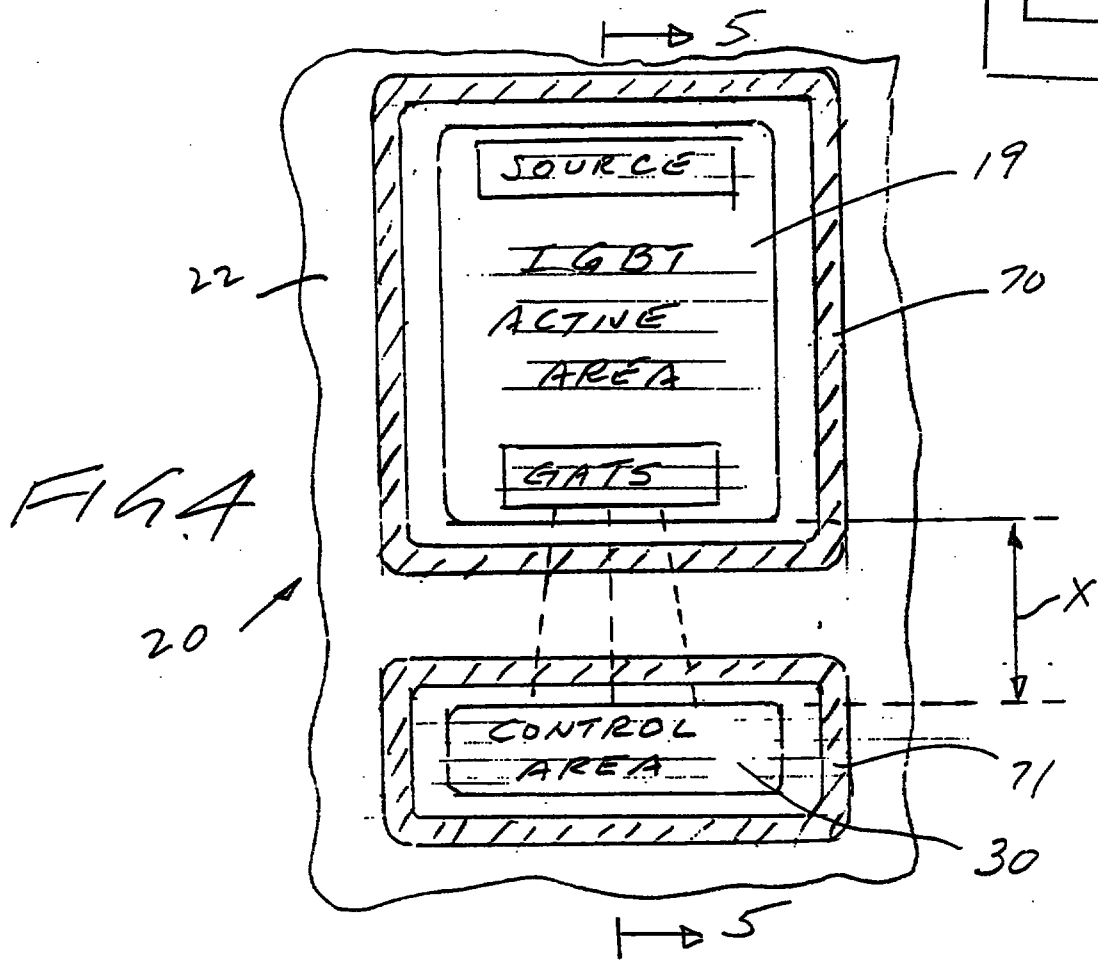
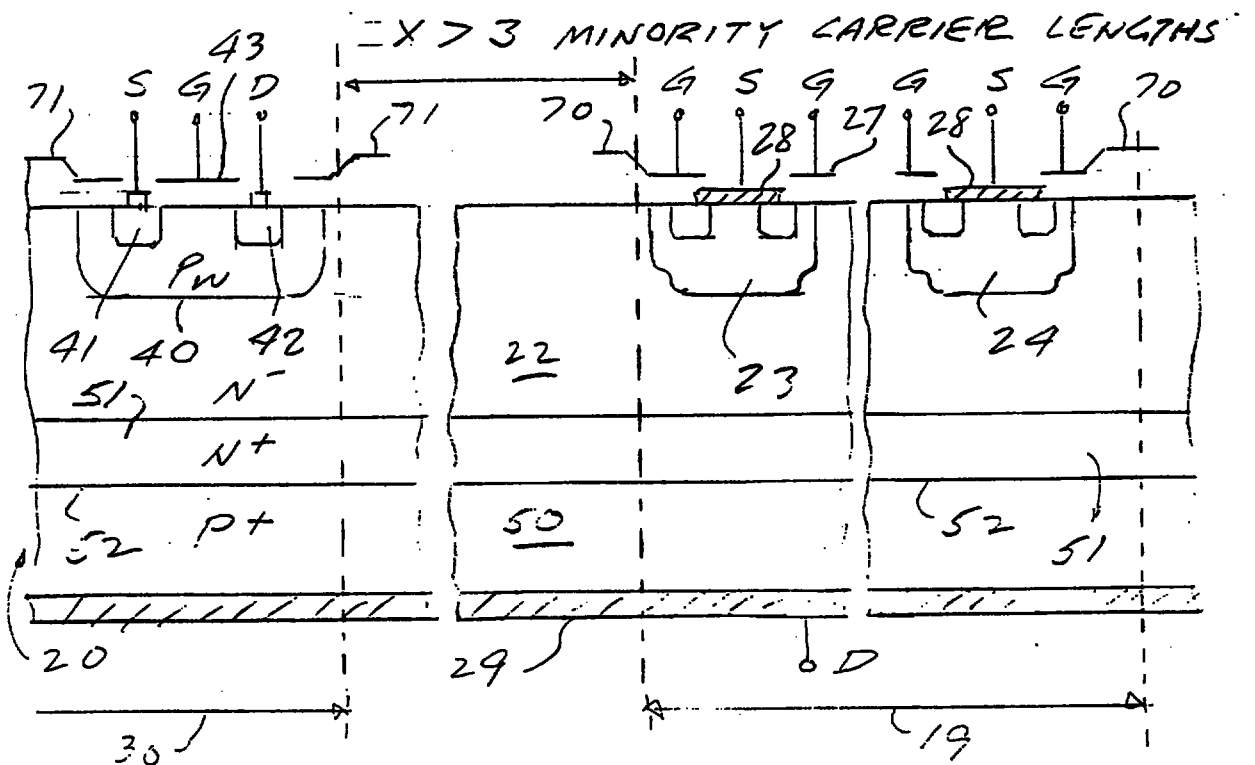
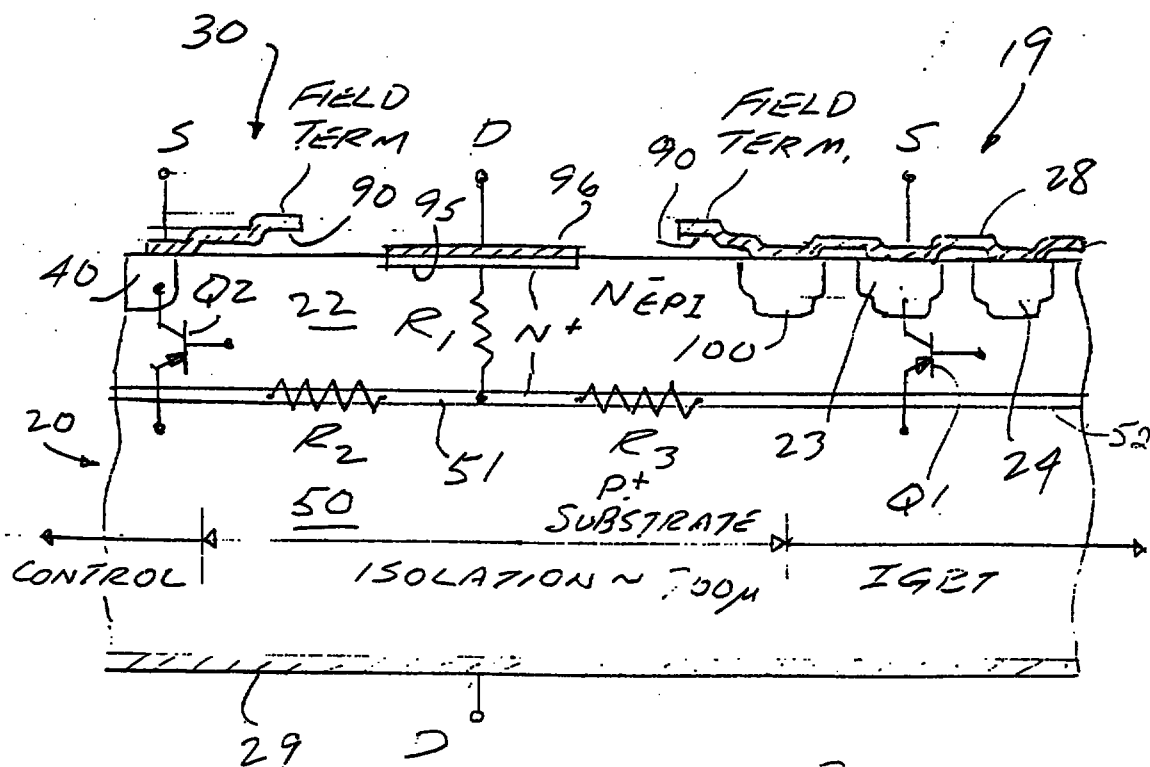
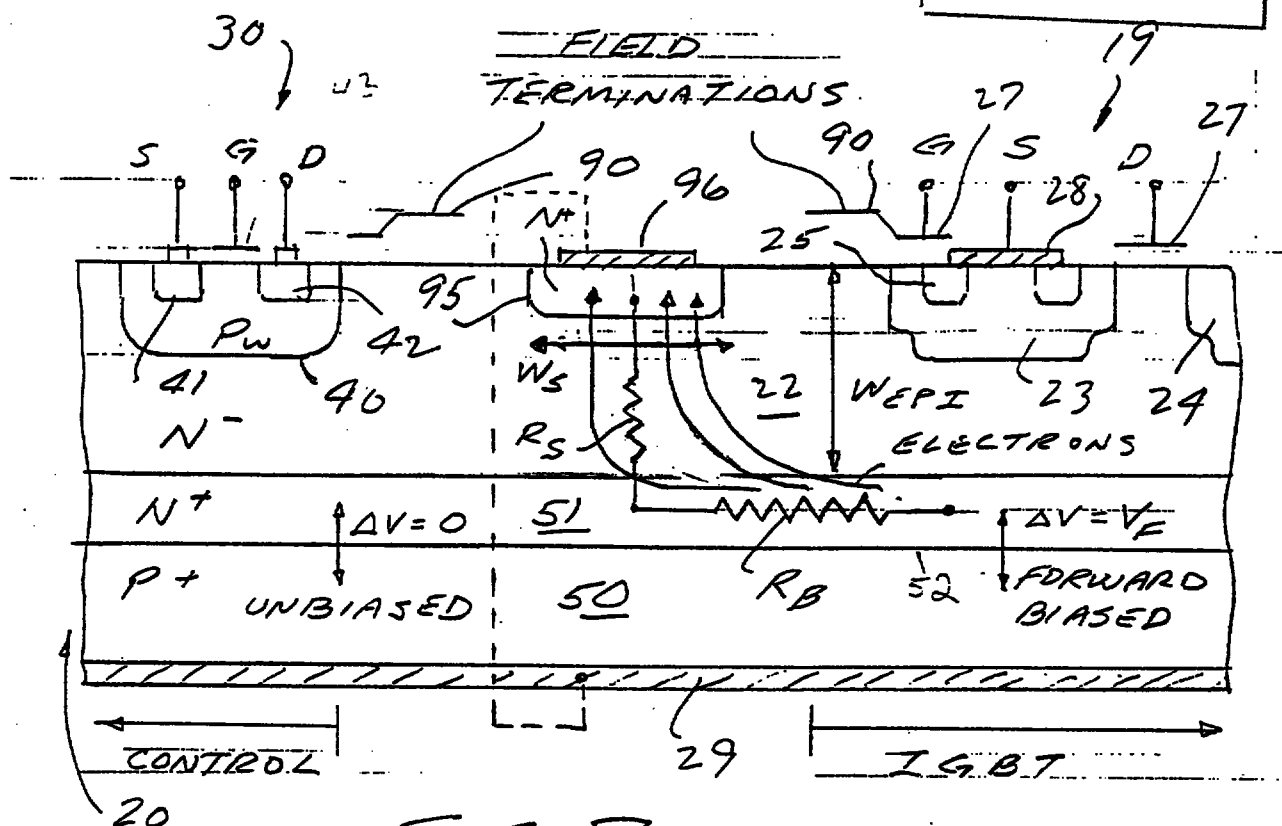
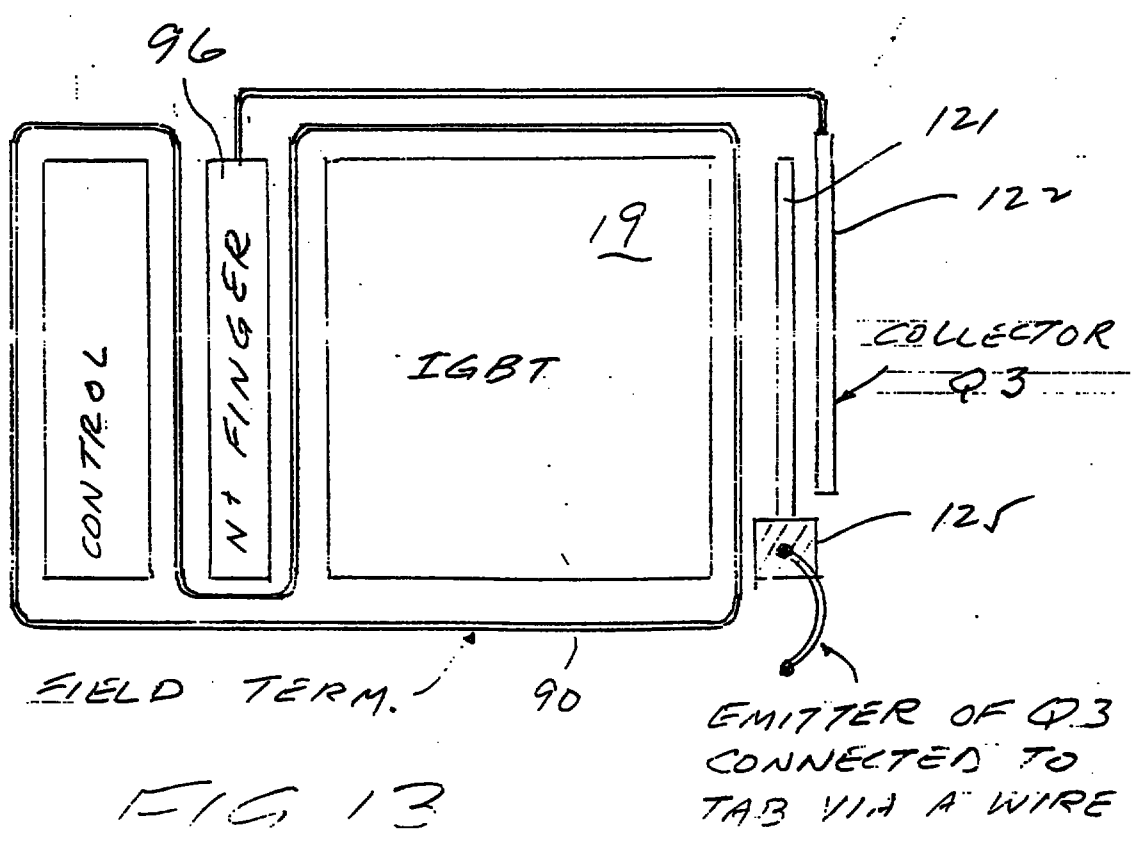
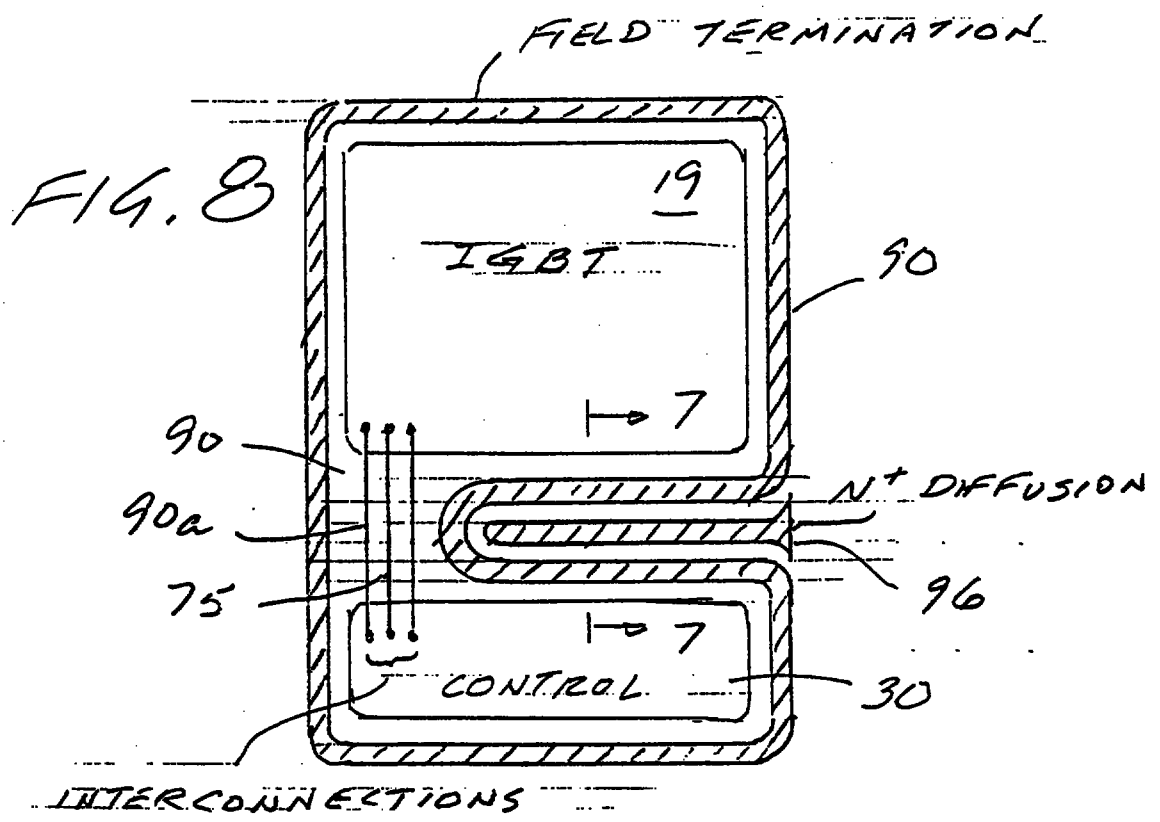


FIG. 5



30 DEC 1996





70 DEC 1996

- 7 -

FIG 10

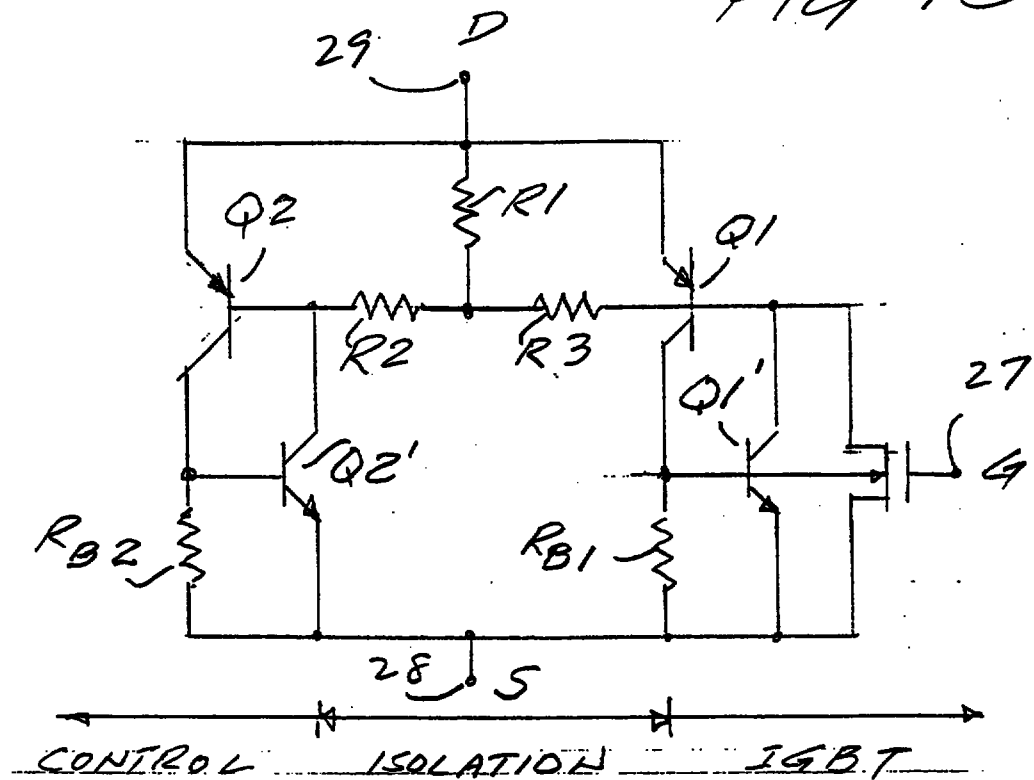
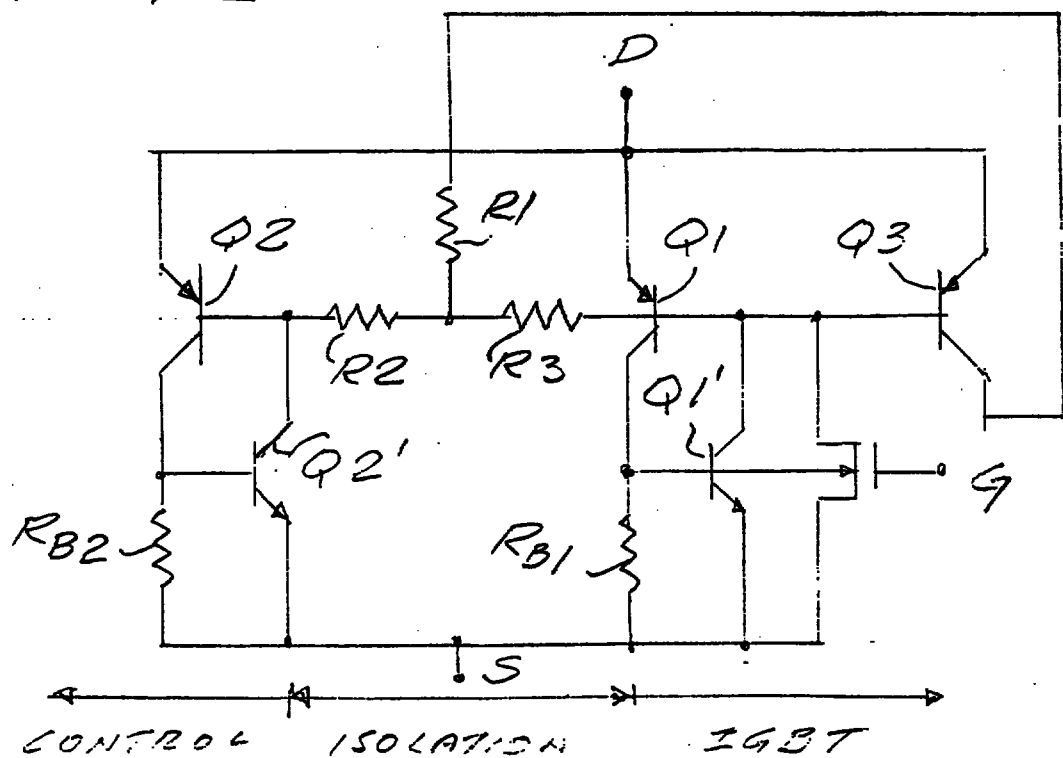


FIG 11



30 DEC 1996

- 8 -

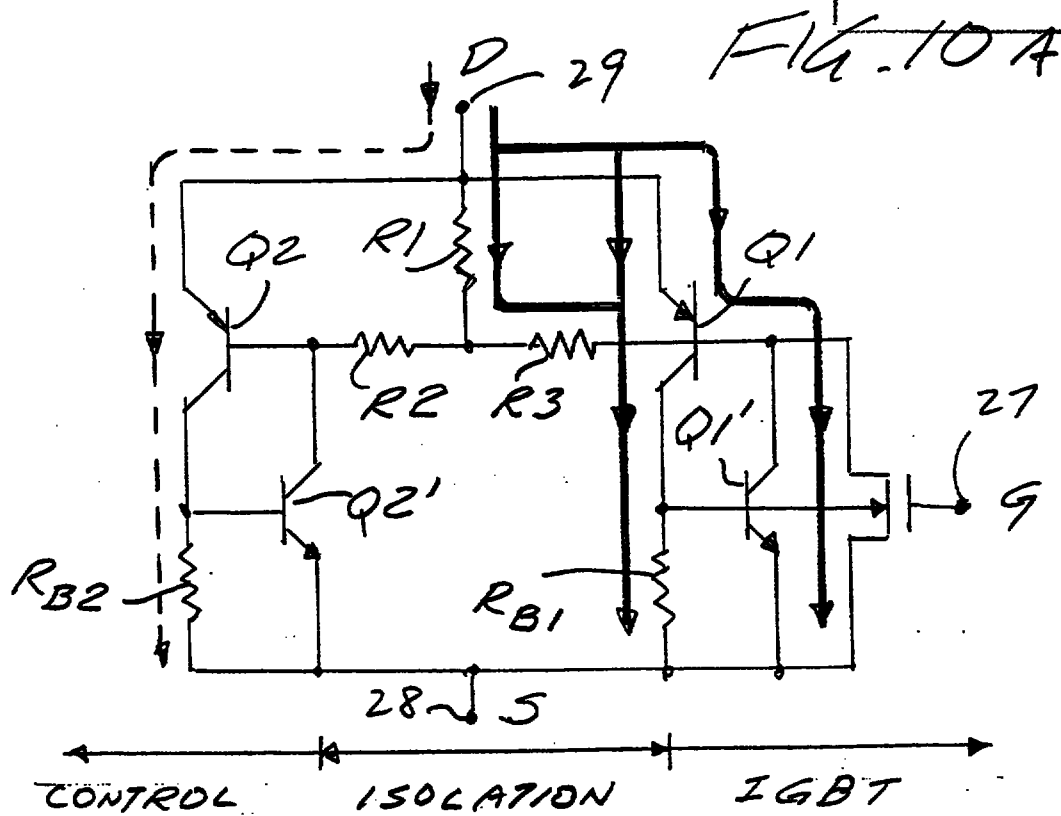
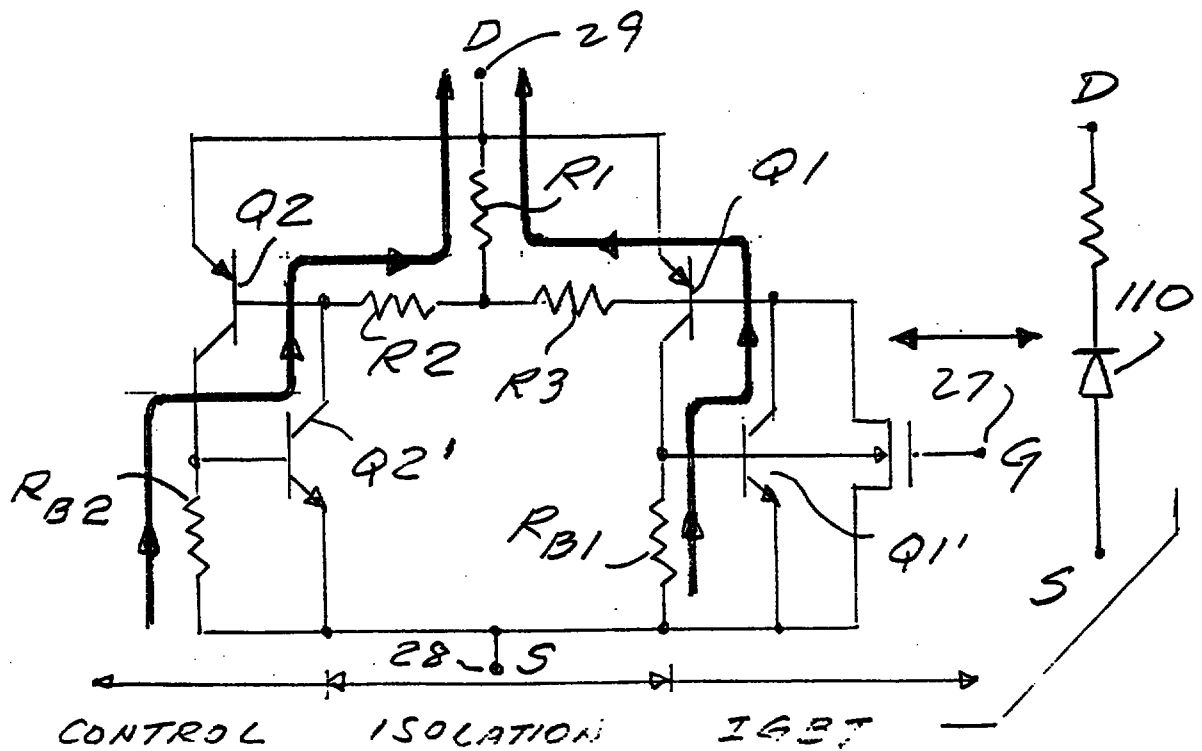


FIG. 10B



2/6/17

