A design of IGBT with the hole current bypass structure

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Abstract: IGBTs modules have the characteristics widely used in industry, electric power, smart grid and other fields. But the IGBTs modules in the current working state, the device performance and reliability are facing severe challenges. This paper provides a new design of forming hole current bypass and integrated emitter ballast resistance structure by adjusting N+ region of the IGBT's MOSFET component structure , To improve the IGBT chip Latch-up problem and N Plus chip, the emitter current is more uniform.

Introduction

The insulated gate bipolar transistor (IGBT) represents the most commercially advanced device of high-imput impedance MOSFET control with low forward-voltage drop bipolar current .IGBT concept was discovered and developed to provide an improved alternate power device to bipolar power transistors. One of the major shortcomings of the bipolar power transistor is its low-current gain when designed to operate at high voltages. This increases the size, weight, and cost of its discrete gate drive circuit. In addition, the bipolar power transistor needs snubber circuits to compensate for its poor safe operating area (SOA). The resulting system solution obtained with bipolar power transistors is cumbersome in design, difficult to manufacture, and expensive for implementation in consumer and industrial applications.

The MOSFET And Bipolar Component Of IGBT Structure

The basic structure for an n-channel symmetric blocking IGBT structure is illustrated in Fig.1 The current-carrying terminals for the IGBT structure have been labeled the emitter and collector terminals because this made the device structure pin compatible with existing bipolar transistor circuits when the IGBT was initially developed. Unfortunately, this is contradictory to the physics of operation of the internal bipolar transistor within the IGBT structure. The control terminal for the IGBT is labeled as a gate terminal because it has an MOSFET structure similar to that in a power MOSFET device. [1] The IGBT structure is formed by using four (N plus–P well–N substrate–P back P doping) alternating semiconductor layers. This creates a basic Bipolar structure. However, the Bipolar component structure is made inoperative by including a deep P+ diffusion and short circuiting the P-base region to the N+ emitter region using the emitter electrode as shown in the figure. When thyristor operation is suppressed, the IGBT structure operates as a transistor as discussed in more detail below. The symmetric blocking IGBT structure is often referred to as the nonpunch-through (NPT) IGBT structure because the electric field does not extend through the entire width of the lightly doped portion of the N-drift region. [2]

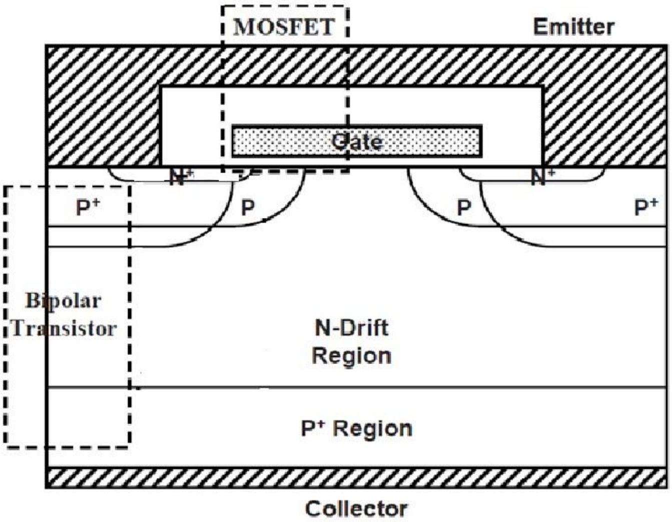


Fig.1 The MOSFET and bipolar component of IGBT structure

During IGBT work, the rapidly disappearing internal MOSFET action causes a heavy hole flux across the base Rb in the reverse direction , creating a voltage drop. When this voltage drop exceeds 0.7 V, a high injection of electrons occurs from the N+ emitter into the P base. Thus, latching takes place with lower collector current values due to the hole overcurrent as shown in Fig.2. Common usage of IGBTs in circuits demanding forced-gate turn-off calls for ensuring that the dynamic latching current be kept far above the maximum operating current . Because static latching current is less than the dynamic latching current, imposition of this design constraint will serve to avoid static latching .It may therefore be viewed as a worst-case design criterion , which , if fulfilled , will guarantee nonlatching operation , under all operating onditions of the device. [3]

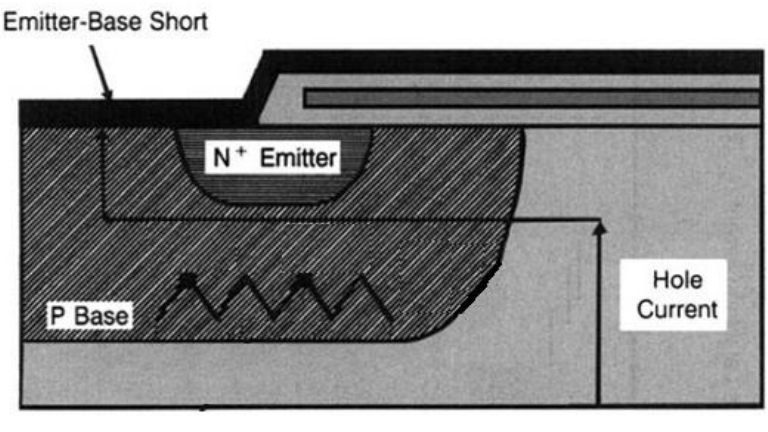
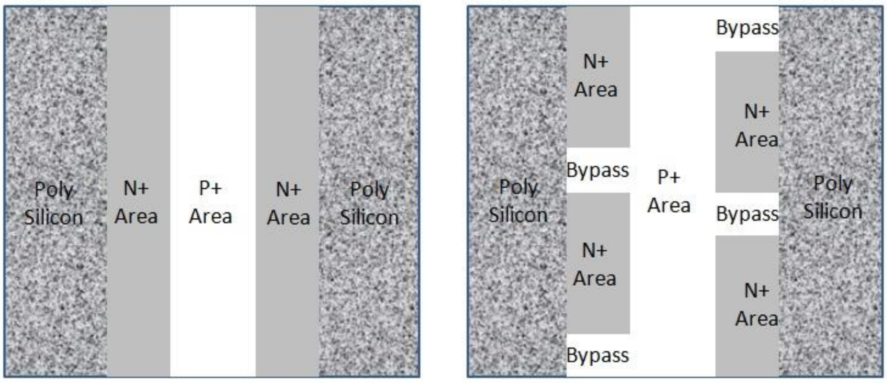


Fig.2 The hole current path in the IGBT under high current

Under the latching, the upper NPN transistor in the IGBT is no longer inactive . the hole current Ip ,flowing laterally into the P base , traverses a path under the N+ emitter and is collected by the emitter metal at the emitter/P-base short . This laterally flowing hole current forward biases the N+ -emitter/P-base junction .Although this hole collection takes place along the full lengh of the P base, to calculate the forward drop across the N+ -P junction, an effective hole current moving under the entire emitter length may be used . IGBT could perform latch-up like a thyristor . The solutions to the latching problem . Latching current can be raised by decreasing the current gain of the PNP transistor ; decreasing the sheet resistance of the P base ; using a shorter total emitter length ; and a combination of the above three methods.

Forming hole current bypass and emitter ballast resistance structure by adjusting N+ region

In this paper, a liner cell as an example, the typical surface MOSFET structure as Fig.3 (a) shown, Through adjusting of N+ doping region shape and area, from the original linear continuous shape, modified for intermittent shape as Fig.3(b) shown, N+ disconnected regions were filled by P+ doping region.



(a) typical surface MOSFET structure (b) adjusting of N+ doping region

Fig.3 Forming hole current bypass and emitter ballast resistance structure by adjusting N+ region

The latch-up of the IGBT structure is produced by the forward biasing of the N+ emitter/P-base junction by the flow of the bipolar current in the P-base region under the N+ emitter region. The forward biasing of the junction can be mitigated by providing an alternate path (called the bypass) for the bipolar current(hole current). A cross section of the structure with the bipolar current bypass is shown in Fig.4. This structure is created by eliminating the N+ emitter region on one side of the device cell structure. The latch-up current density for the IGBT structure with the bipolar bypass path can be derived by using the approach used in the previous sections. A simple view of the structure is that half of the bipolar current (Ip2) flows via the bypass path while the rest of the bipolar current (Ip1) flows under the N+ emitter region. [4]

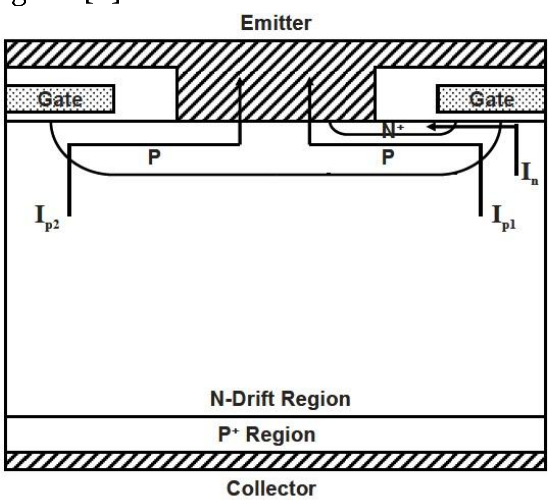


Fig.4 IGBT structure with the bipolar current bypass path

Because the N+ linear region of the disconnect, increased the resistance per unit area of N+ emitter region, forming a integrated N+ emitter ballasting resistance. A commonly used approach to increasing the uniformity of the emitter current distribution within a IGBT is by the addition of an emitter ballasting resistance. The emitter ballasting resistance must be distributed within the all portions of the emitter fingers to provide the stabilizing influence. In addition, since the entire emitter current flows through the emitter ballasting resistance, its magnitude must be small to avoid increasing the on-state voltage drop and power dissipation. [5]

Conclusions

This paper provides a new design of forming hole current bypass and emitter ballast resistance structure by adjusting N+ region. It Can effectively alleviate the problem of IGBT latch-up, make the N+ emitter current more uniform, to chip in parallel, also can reduce the short circuit current.

The IGBT structure with the bipolar current bypass path has a larger onstate voltage drop because of the reduction in the channel density. The reduced channel density also produces a reduction in the saturated current level. This can be taken advantage of to produce current saturation prior to the on-set of latch-up.

Acknowledgements

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References

[1] Josef Lutz ,Heinrich Schlangenotto, Uwe Scheuermann ·Rik De Doncker: *Semiconductor Power Devices*. Published by Springer Science + Business Media (2011), p.316.

[2] S.M.Sze, KwokK.Ng : *Physics of Semiconductor Devices*. Published by John Wiley & Sons, Inc., Hoboken, New Jersey(2007), p.300.

[3] Stamations V ,Kartalopoulos : *The Insulated Gate Bipolar Transistor IGBT Theory AND DESIGN*. Published by John Wiley & Sons, Inc. (2003), p.306.

[4] B. Jayant Baliga: *Fundamentals of Power Semiconductor Devices*. Published by Springer Science + Business Media. (2008), p.937.

[5] Dieter K. Schroder: *SEMICONDUCTOR MATERIAL AND DEVIC CHARACTERIZATION*. Published by John Wiley & Sons, Inc. (2006), p.16.