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High Power Insulated Gate Bipolar Transistors (IGBTs)

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New approaches for high power IGBTs such as (1)Self-aligned deep p^+ diffusion,(2)Stripe gate-source pattern, (3)Hole bypass structure and (4)Impurity controlled n^+-buffer layer by Silicon Direct Bonding (SDB) technique,are reviewed. All of these novel approaches make possible high power handling capability with high speed and ruggedness against SOA.These excellent IGBT features satisfy increasing demands for high frequency power conversion applications.

1.Introduction

Requirements for high speed, high power devices have been increasing with increasing demands for high frequency power conversion applications. Power bi-MOS configurations have been investigated as new devices to satisfy the demands for high speed, high power applications. Through the investigations, it has become widely recognized that IGBTs are superior to both bipolar transistor and power MOS FET,in respect to high power handling capability,high switching speed and even SOA (Safe Operating Area).This paper presents an overviews of high power IGBT technologies.

2.Design Considerations

The basic IGBT concept was invented 8 yeas ago by Becke and Wheatly.1) As shown in Fig.1, IGBT is rather similar to vertical DMOS structure, except for the p^+-drain region for hole current injecton to realize low on-resistance with conduction modulation in n^--drift region. The pnp-tansistor operation is initiated by electron flows into the drift region through the n-channel,stimulating hole injection from the p^+-drift layer. The hole and electron current flows take differnt paths: electron current flows through the channel while hole current flows into the p-base to reach the source electrode. Because of this structue,at early developement stage, it was reported that the parastic thyristor was easily subject to latch-up,preventing a high current turnoff ability of more than a few 100 amps.per cm^2. Another drawback thought to be difficult was rapid stored carrier removal during turn-off interval.To overcome the problems, keeping suerior IGBT features, various breakthrogh methods have been developed to satisfy the demands for a high power IGBT.

3.New Approachs for High Power IGBT

As shown in Fig.1, Various novel technolgies have been developed and implmented for high power IGBTs.

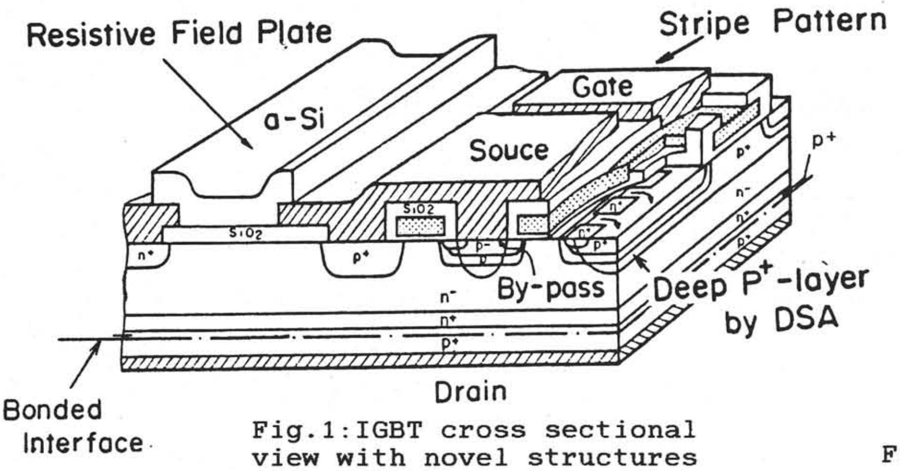


Fig.1:IGBT cross sectional view with novel structures for high power realization

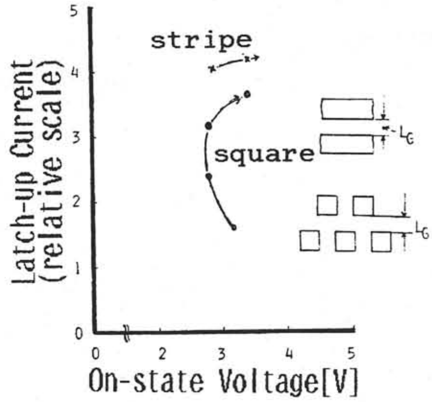


Fig.2:Dynamic latch-up current vs.on-state voltage

3.1 <u>Approaches for High current IGBT</u>

<u>Self-aligned deep p^+diffusion</u>.2)

In order to prevent parasitic thyristor latch-up phenomenon, it is important to suppress direct electron injection from n^+-source to p-base layer while maintaining p-base lateral resistance as low as possible.

A deep p^+-base diffusion, as near the channel as possible, is one of the effective method to reduce p-base resistance and thus to increase latch -up current level. A new self alignment process was developed to satisfy this requirement. The final device structure is shown in Fig.1. These additional p-base siginficantly improves latch- up current level.

<u>Stripe gate-source pattern</u> 3)

Hexagonal or squere source pattern conventionally used for power MOSFETs, are not the best one for IGBTs. The stripe pattern realizes better overall characteristics,as shown in Fig.2. Arrow indicates LG decrease direction.

<u>Hole bypass structure</u> 4)

Figure 3 shows typical relations between on-state current and voltage for MOSFET and IGBT. A non-latch up condition is realized by satisfying JS>JL conditions where JS and JL are saturation and latch-up current respectively.This concept was realized by hole bypass structure.The cross sectional structure and topview are shown in Fig.1 and Fig.4. The shallow p-diffsion layer partly extends into the channel region,effectively reducing the p-base sheet-resistance and increasing latch-up current level, without sacrificing on-state voltage as shown in Fig.3. All of the new approaches are used to realize a high power IGBT with large SOA..

3.2 <u>Approaches for High voltage,high speed IGBT</u>

<u>SDB technique</u>

For high blocking voltage realizations without switching speed degaradation, it is important to optimize n-drift layer design.The SDB

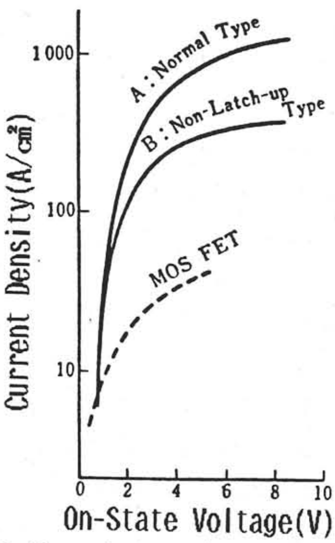


Fig.3:On-state characteristics comparison between MOSFET and IGBTs

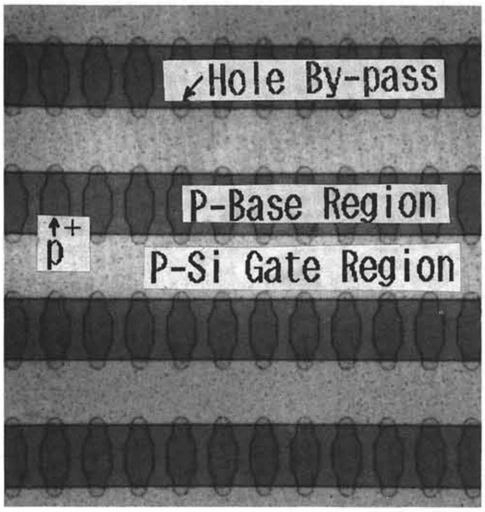


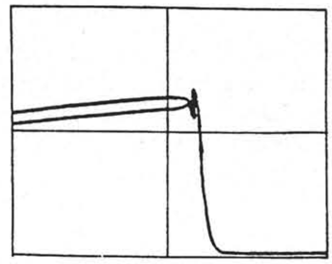
Fig.4 Topview of hole bypass sturcture

technique was developed and utilized to realize an optimum n^{+}buffer/p^{+}-drain structure,adjusting the hole injection effciency and realizing a high resitivity n^{-}layer of more than 100 cm for an 1800V breakdown voltage. The SDB technique easily attains a high resistivity layer,because auto diffusion problem is not involved. Advantages in n^{-}-buffer structure are twofold.First is it's optimized thick n^{-}-drift layer,resulting in an excellent trade-off relationship between on-state voltage and turn-off time. The other is the hole injection effciency adjustment. An impurity controlled n^{-}buffer shows high turn-off time with the same electron irradiation dosage for carrier life-time control. A novel resistive field plate, shown in Fig.1, is another key technology for high voltage IGBT with out chip aera reduction. A 1800V IGBT fabricated with these new methods showed 0.4 s fall time with 3V on-state voltage at $25A/cm^{2}$.

4.Possibility as a High Power device

Large Chip Desin 6)

As IGBT conductivity temperature coefficient in the large current area,



Turn-off current: 50A for each device

Fig.5 Typical turn-off waveforms for two IGBTs, operated in parallel

is negative,it is easy to keep excellent current balance in IGBT parallel running.Figure 5 shows turn-off current wave-forms for two IGBTs, operated in parallel with excellent current balance. This IGBT feature promise large chip design and IGBT multi-chip usage. A 1kV-300A IGBT mod ule with four 75A IGBTchips (13.6 X 13.6mm) are commercially availble.

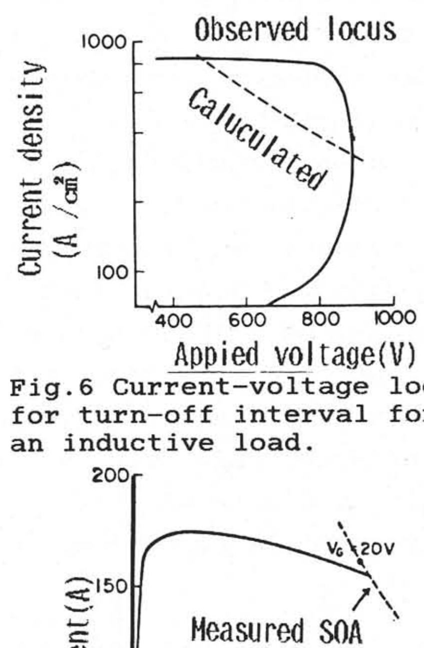


Fig.6 Current-voltage locus for turn-off interval for an inductive load.

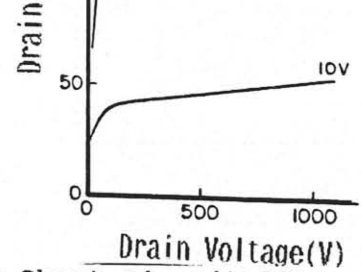


Fig.7 Short circuit SOA and high current saturation characteristics.

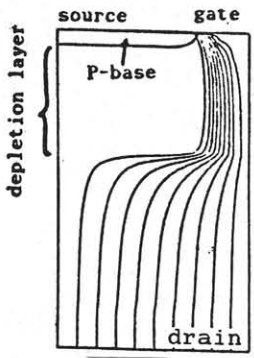


Fig.8 channel electron flow line during turn-off interval.

Safe Operating Area (SOA) 4),5)

The SOA is determined by maximum allowable voltage current products of turn-off interval and short-circuit failure.Fig.6 shows current voltage locus of turn-off interval for an inductive load.Current density and voltage product reached $7X10^5 W/cm^2$ in the turn-off transient. High voltage/ saturation current characteristics and short circut SOA are shown in Fig.7. Allowable power dissipation also reached $8X10^5 W/cm^2$. This is several times stronger than that of bipolar transitors.

In oder to understand ruggedness numerical simulation was carried out. Fig.8 shows channel electron current flow line during voltage recovery, showing that channel electron current flows only under the gate electrode and,in turn, current in the depletion layer is carried by only hole. After electron current completely ceases, all of the current is carried out by

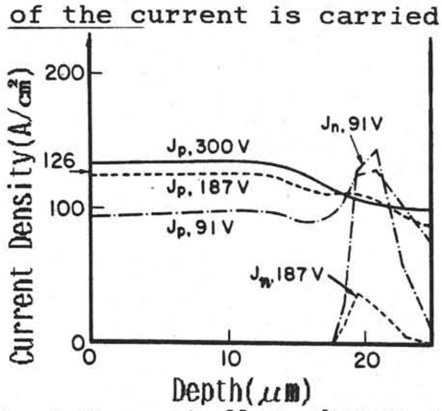


Fig.9 Current flow change with voltage with voltage recovery beneath the P-base(Jn:electron current,Jp:hole current)

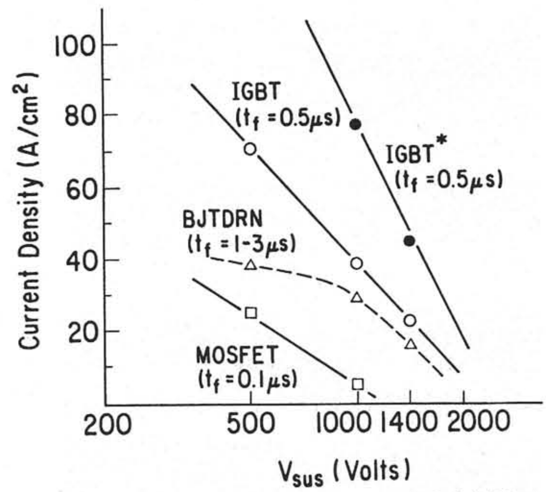


Fig.10 Power handling capability comarison(IGBT:IGBT with large SOA, IGBT*:IGBT with low on reistance)

holes as shown in Fig.9, hole current density becoming greater than average current density.Thus, it is predicted that the SOA will become greater as the total p-base area becomes larger for a unit device area.

As compared in Fig.10, IGBT handling power coverage area is very wide, showing the possibility to replace not only bipolar transitor,but even power MOSFET for cost sensitive applications and even high power GTOs for high speed applications.

5.Summary

New approaches to realize high power non latch-up IGBTs are reviewed. Excellent high power IGBT characteristics,such as large current handling capability with easy gating, high blocking voltage with high switching speed and ruggednesss in the SOA are confirmed.All of the IGBT's features satisfy demands for high frequency power convedrsion applications.

References

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