Recent Trends in IGBT Technology

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The power semiconductor devices although appeared in 1950s, did not cease to evolve. Indeed, in the beginning of the 1980s, a new concept of device appeared. In this concept, MOS and bipolar technologies were integrated to obtain hybrid devices such as the IGBT with higher characteristics combining the advantages of these two last technologies [1].

1. Introduction

MOS devices have very fast switching speed and require very low gate current drive. However, MOSFET are majority carrier devices and so their on-resistance drastically increases with Drain-Source voltage rating, restricting their exploitation to voltages less than a few hundred volts.

On the other hand, bipolar transistors have good on-state characteristics but long switching times, especially at turn off. They are current controlled devices with small current gains, which require complex base-drive circuits to provide the base current during on-state, which increases power losses in the control electrode.

The IGBT is a hybrid device obtained by the integration of a BJT and a MOSFET in a Darlington configuration. The IGBT allows a great reduction of conduction losses even for high voltage rating (low on-state resistance), low power gate drive losses (insulated grid) and it can switch today in of less than 100 ns, whereas only 3 µs about 20 years ago. In addition, the current density of IGBT is 20 times larger as compared to MOSFET and 5 times as compared to BJT. The IGBT is, basically, a horizontal channel and vertical current MOSFET cell (VDMOS), except for the N^+ Drain layer, which is substituted by a P^+ layer at the collector.

2. PT and NPT technologies

To block a high valued voltage, it is necessary to have a thick and slightly doped layer. Whereas, a good on-state characteristics requires a thin and high doped layer. This dilemma gave birth to new two concepts, PT and NPT (Fig.1).

Historically, there are two types of IGBT structures, PT and NPT. The NPT structure has been introduced in the market in 1982 and PT in 1985.

3. Light punch through LPT and IGBT

The basic idea of the LPT - IGBT (Fig. 1 and Fig. 2) is to combine the advantages of PT and NPT concepts. The "LPT" structure improves the collector side of NPT - IGBT design through a lightly doped thin N^+ buffer that is added to stop the field (LPT or FS). This structure makes it possible to realize a thinner N^- drift layer as compared to the conventional NPT device. This permits the reduction of V_{cesat} and so results in reduction of the overall loss.

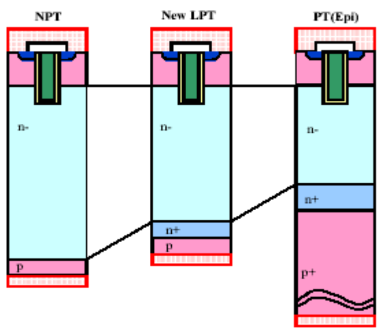

Fig.1: Structures: NPT, PT and LPT.

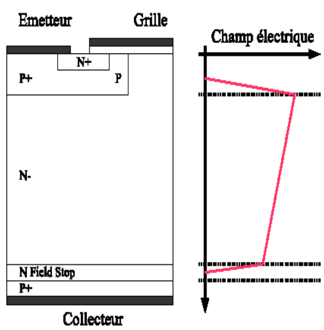

Fig.2: Planar LPT IGBT structure.

4. Trench gate technology

The planer gate structure has been conventionally adopted for general-purpose high voltage IGBTs. To improve the basic characteristics of the planar gate type IGBT, such advanced semiconductor technologies as miniaturisation of a cell and shallower junction have been introduced and implemented, but those technologies are not effective for breaking through the high-performance limitation of planar gate structure IGBTs. To reduce the saturation voltage, the trench gate structure, implemented in 1987 (Fig.3), is both effective and acceptable for high performance improvements of high voltage IGBT [2]. The developed trench gate IGBT has the following advantages:

i. Channel resistance that strongly influences saturation voltage of IGBT can be considerably reduced, since the channel width per chip area increases in accordance with more enhancement of the cell density
ii. Saturation voltage is sufficiently lowered because the trench gate structure has neither JFET region nor its related JFET resistance. Those are formed between adjacent cells for planar gate structure.

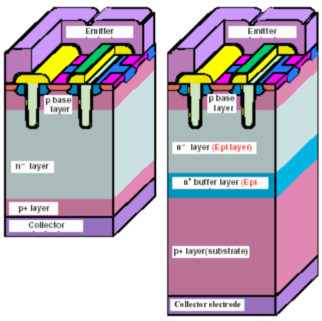

Fig.3: Trench: NPT IGBT, PT IGBT.

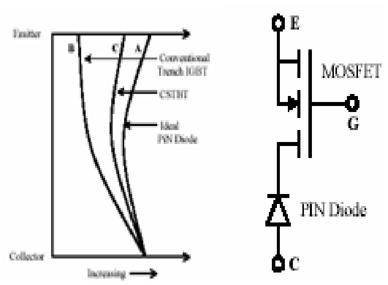

Fig.4: Charges distribution.

5. CSTBT technology

By comparing the distribution of the carriers in a diode and a trench IGBT Fig. 4, one can remark that in the trench gate IGBT, the distribution deviates from the ideal case corresponding to the symmetrical distribution in a diode. Indeed, the excess carrier distribution steadily decreases as it approaches the emitter side of the device. This non-ideal behaviour becomes even more pronounced in devices with high blocking voltage ratings. The decreased carrier concentration near the emitter side effectively increases the resistance of the PIN diode, which results in an increase in on-state voltage (VCESAT).

To improve the carrier concentration at the emitter side, a new chip design called Carrier Stored Trench Bipolar Transistor (CSTBT) has been developed (Fig.5). The CSTBT is manufactured with an additional n type buried layer. The buried layer provides “stored” carriers to produce the modified carrier distribution shown in curve C of Fig. 4. The resulting carrier distribution is closer to the ideal case and produces increased conductivity in the n-layer. The result is a substantial reduction in the on-state voltage of the device [3].

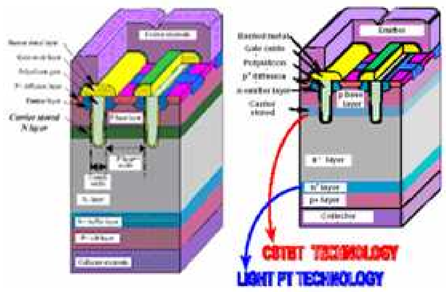

Fig.5: CSTBT, LPT CSTBT.

6. Conclusion

Various technologies of the IGBT were examined in this article with the state-of-the-art technology, the Trench LPT CSTBT. The marketed components reach 3.5 KV 1.2 KA, whereas components of 6.5 KV to 10 KV are under test. The IGBT technology is promoted for more significant developments in the future.

References

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[2] H. Iwamoto and A. Kawakami, IEE Proc.-Electr. Power Appl. **147**, No. 3, May (2000).
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