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## **AN9007**

### **High Performance 1200V PT IGBT with Improved Short-Circuit Immunity**

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### **Abstract**

High performance 1200V punch-through type IGBTs, designed with improved short-circuit immunity are now fabricated on silicon direct bonded wafers. The emitter ballast resistance (EBR) structure is used to improve short-circuit immunity. These IGBTs exhibit short-circuit times which are longer than 50 microseconds. They exhibit remarkable DC and AC characteristics such as 2.0V of  $V_{ce(sat)}$  and 90 nanoseconds of turn-off time at 125°C. The temperature dependence of the IGBT has a positive coefficient like that of an NPT type IGBT.

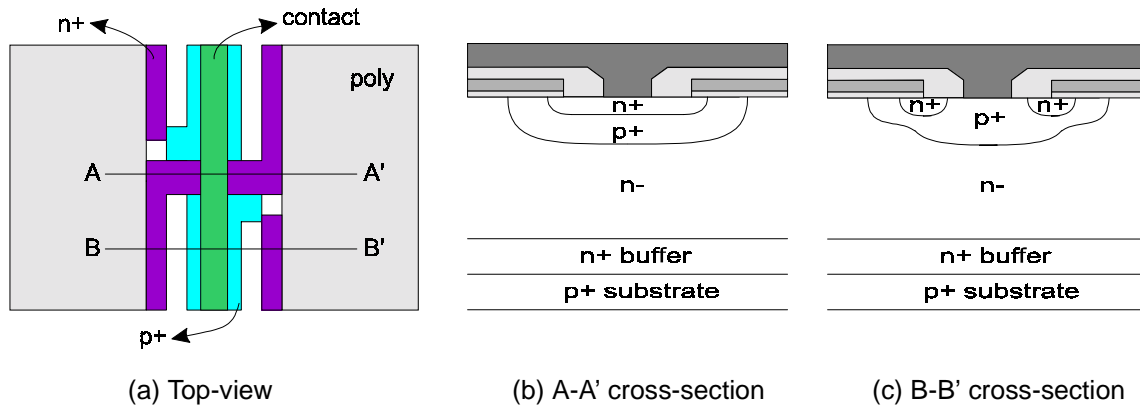
### **Introduction**

IGBTs are widely used in high voltage, high current applications thanks to their excellent input and output characteristics over other devices[1].

IGBT development has been mainly focused on the reduction of conduction and switching loss by optimizing the cell structure and lifetime control. Recently, improved ruggedness and short circuit immunity are the main focus of IGBT development, as its application on inductive loads is expanded. The NPT-IGBTs[2] provide improved ruggedness, switching loss and paralleling than the PT-IGBTs even though their  $V_{ce(sat)}$  is rather high. However, the real switching loss of the NPT-IGBT is much higher than the calculated switching loss considering the loss generated by the tail current which is below 10% of the rated collector current[3].

The turn-off time and tail current of the IGBT is reduced without high dose electron irradiation thanks to the thin and heavily doped buffer layer. This is not possible in conventional PT-IGBTs.

## Device Structure



**Figure 1: Structure of the proposed IGBT**

The short-circuit immunity of the fabricated IGBT is improved by employing the EBR pattern. The EBR pattern is generated by extending the n+ emitter stripe. Hence, no additional masking or processing step is required. The top-view and the cross-section of the IGBT are illustrated in Figure 1. The n+ emitter is connected to the cathode electrode only in the center of the narrow n+ emitter stripe. The electron current which flows through the channel located far from the contact generates a substantial voltage drop. The emitter stripe is bent and separated by a heavily doped p+ region in order to increase the emitter ballast resistance, and to reduce the voltage difference across the n+ emitter and p-well.

Therefore, the parasitic npn bipolar transistor is prevented from turning on when a huge amount of hole current flows through the p-well underneath the n+ emitter and the IGBT is in a short-circuit state.

## Experiment

Silicon direct bonding (SDB) wafers[4,5], which are directly bonded with n- float zone wafer and p+ CZ wafer, are used as the starting material. The SDB wafer is a good candidate for the high voltage IGBT because of the accurate controllability of the base thickness, base concentration, the n+ buffer thickness and the n+ buffer concentration[4]. A heavy dose of phosphorus is implanted on the n- wafer before bonding. Annealing, grinding, CMP etching and polishing follow bonding and a 100  $\mu\text{m}$ -thick drift layer is achieved. Formation of the n+ buffer with a doping concentration of higher than  $3 \times 10^{17} \text{ cm}^{-3}$  and a thickness of less than 10  $\mu\text{m}$  is achieved with the SDB process, as opposed to the thin and heavily doped n+ buffer layer obtained, due to the inevitable thermal cycle during epitaxial growing, with conventional PT-IGBTs. The drift layer thickness is 105  $\mu\text{m}$  to obtain a BV of 1200V. The chip size of the fabricated IGBT which has 10A rated current is  $5300 \times 4010 \mu\text{m}^2$  including the junction termination.

## Results

### Short Circuit Characteristics

The short-circuit capability of the fabricated IGBT has been tested at room temperature with the test circuit shown in Figure 2. The supplied collector voltage is 600V and the gate voltage is 15V. The switching waveforms of the IGBT with the EBR pattern are shown in Figure 3(b) and the conventional stripe patterns are shown in Fig 3(a).

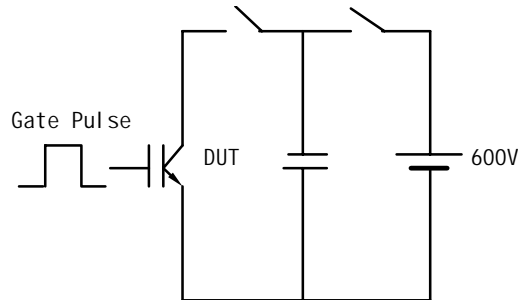
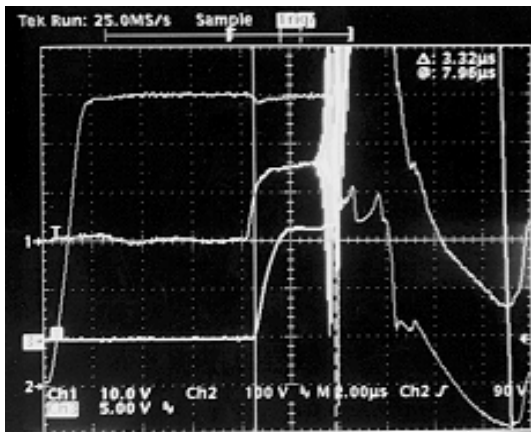
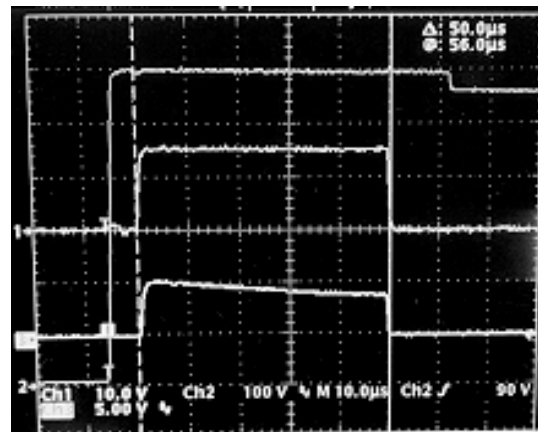


Figure 2: Schematic Diagram of the Short Circuit Test Circuit



(a) conventional - without EBR pattern



(b) New IGBT with EBR pattern

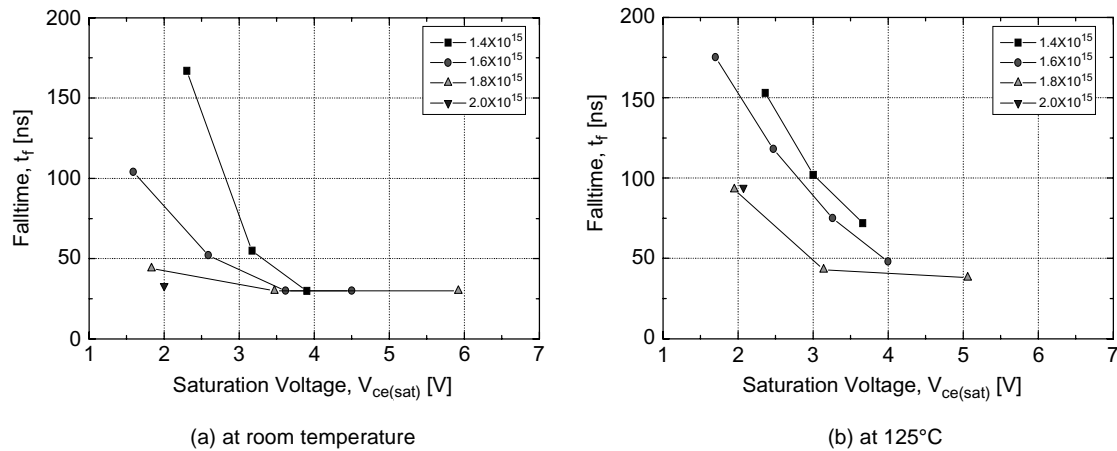
Figure 3: Short Circuit Capability at Room Temperature.

The figures show that the short-circuit rated IGBT is immune to short circuits for longer than 50  $\mu$ s, while the conventional IGBT does not exhibit short-circuit immunity.

### On-state characteristics

The fabricated IGBT has a thin and heavily doped n+ buffer layer as stated above. It is known that the switching speed is determined by the injection rate and the recombination rate of the hole injection from the p+ substrate into the drift region. The thin and heavily doped n+ buffer substantially suppresses the hole injection [6]. In addition, the tail current of the IGBT is reduced because the

recombination of the hole carrier during turn-off occurs at the collector side in the drift layer, where the high dose buffer provides sufficient recombination centers. Hence, the IGBT does not require high dose electron irradiation to achieve fast switching characteristics. The electron irradiation ranges from 0 to 10 Mrad. The effects of the buffer implant dose on device characteristics were investigated. The  $V_{ce(sat)}$ -fall time trade-off curves with various buffer implant doses are shown in Figure 4.



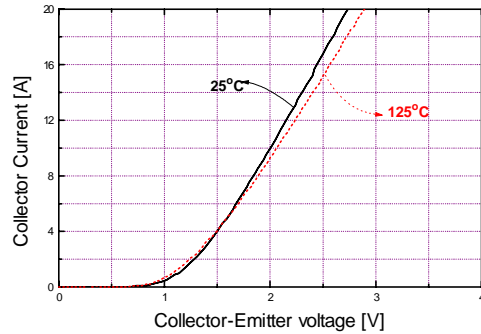
**Figure 4:  $V_{ce(sat)}$ -Fall Time Trade-off Curves of the Fabricated IGBT at  $T_j = 25^\circ C$  and  $T_j = 125^\circ C$**

The  $V_{ce(sat)}$  has been measured at the collector current of 10A with a gate bias of 15V. The threshold voltage is maintained around 5.5V. The fall time was measured from 90% to 10% of the collector current.

The curves show that the IGBT exhibits better performance as the buffer concentration increases from  $1.4 \times 10^{15}$  to  $2.0 \times 10^{15} cm^{-2}$ . The IGBT with a buffer dose of  $2.0 \times 10^{15} cm^{-2}$  exhibits 2.0 volt of  $V_{ce(sat)}$  and 90 nanoseconds of fall time without electron irradiation. The leakage currents of the fabricated IGBT have been measured at 1200V. The leakage current decreases as the electron irradiation dose decreases. The IGBT without additional lifetime control shows leakage current of less than 10 nA.

### Temperature Coefficients

Figure 5 shows the I-V curves of the IGBT without electron irradiation at room temperature and with  $T_j = 125^\circ C$ . The temperature dependence of the IGBT has a positive coefficient like that of an NPT type IGBT. The cross point at which (JZTC)[7], the  $V_{ce(sat)}$  curves at  $T_j = 25^\circ C$  and  $T_j = 125^\circ C$ , cross one another rises as the electron irradiation dose increases. As a result, the temperature dependence of the IGBT becomes negative at the rated current when the electron irradiation dose is higher than 8 Mrad.



**Figure 5: I-V Curves of the Fabricated IGBT without Electron Irradiation at  $T_j = 25^\circ\text{C}$  and  $T_j = 125^\circ\text{C}$**

### Discussion

The short circuit current of the fabricated IGBT is designed to be 350% to 400% higher than the rated current, while the conventional IGBT is designed to be 500% to 600% higher than the rated current. The short-circuit rated IGBT with the EBR pattern sacrifices on state voltage drop by around 0.2V due to the reduction in channel current.

The turn-off loss of the fabricated IGBT without electron irradiation is higher in comparison to an IGBT with electron irradiation, even though the IGBT has a positive temperature coefficient and shows excellent reliability. Hence, the IGBT characteristics are optimized with electron irradiation and a heavily doped buffer layer. This results in an IGBT with  $V_{ce(sat)} \sim 2.4\text{V}$ ,  $E_{off} \sim 60\mu\text{J/A}$ ,  $t_f \sim 150\text{ ns}$  and a positive temperature coefficient.

A fabricated SDB IGBT is compared with a PT-IGBT and an NPT-IGBT below:

**Table 1. Properties of the PT-IGBT, the NPT-IGBT and the SDB PT-IGBT**

|                         | PT type  | NPT type | SDB type     |
|-------------------------|----------|----------|--------------|
| Vce,sat                 | Low      | High     | Low          |
| Switching Speed         | Slow     | Fast     | Fast         |
| Leakage Current         | High     | Low      | Low          |
| SCSOA                   | Medium   | Large    | Large        |
| Lifetime Control        | Yes      | No       | Yes/No       |
| Buffer                  | Heavy    | No       | Ultra Heavy  |
| Temperature Coefficient | Negative | Positive | Nega/Posi    |
| Parallel Operation      | Hard     | Easy     | Easy         |
| Reliability             | Medium   | High     | High         |
| Turn-off loss           |          |          |              |
| at low temp.            | Low      | Low      | Very Low     |
| at high temp            | High     | Low      | Low          |
| Voltage rating          | Medium   | High     | High         |
| Starting Material       | Epitaxy  | FZ wafer | N+ FZ + P+CZ |

This table shows that the SDB IGBT is a good solution in high voltage, high power applications because of the high conduction and switching characteristics. It may be concluded that the SDB IGBTs have the advantages of both NPT-IGBTs as well as PT-IGBTs.

### Conclusion

High performance 1200V IGBTs, fabricated on SDB wafers, were characterized. The EBR pattern, which is generated by increasing the distance between the channel and collector without an additional mask, is used to enhance the short-circuit immunity of the IGBT.

The fabricated IGBTs are immune to short-circuits for longer than 50 microseconds. They exhibit 2.0V of Vce(sat) and 90 nanoseconds of falling time at 125°C. In addition, the temperature dependence of the IGBT has a positive coefficient like that of an NPT-IGBT. Hence, they are a promising solution for high voltage, high current applications.

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