Development of BlueFRD1 for Low-noise FRD

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Abstract In today's power device market, where efficient power utilization is required, energy loss reduction by fast recovery diodes (FRDs), which are used in a wide range of applications, is essential. Low noise is also important for general-purpose applications. We have developed BlueFRD1, a new platform FRD with low noise and excellent V_F switching-off characteristics due to its new structure.

1. Introduction

The world's electricity consumption will continue to increase in the future due to industrial development. Toward the realization of a sustainable world, power semiconductor devices used in various applications, such as white goods, electric vehicles, and industrial equipment, are required to be smaller and more efficient. Among them, fast recovery diodes (FRDs) are widely used in high-frequency rectifiers, PFC, DC/DC converters, inverters, and switching power supplies, etc., and play an important role in the effective utilization of power.

FRDs are characterized by fast reverse recovery time during switching operation and low energy loss during switching-off. However, short switching operation times are prone to noise due to ringing. This noise may also cause electromagnetic interference in surrounding circuits and equipment. Therefore, if ringing is pronounced, the FRD is rendered less practical for general-purpose applications.

In this paper, we report on the development of an FRD that combines low V_F and low energy loss during switching operation with low noise during recovery operation.

2. Features of BlueFRD1

2.1. What is BlueFRD1?

BlueFRD1 is a new-generation FRD we have developed as a new process platform with improved trade-off characteristics between V_F *and* switching-off loss (=Q_{rr}) and improved ringing generation during switching-off compared to our conventional FRDs.

2.2. Features of BlueFRD1

Figure 1 shows a schematic diagram of the structure of our conventional FRD and BlueFRD1 in this development.

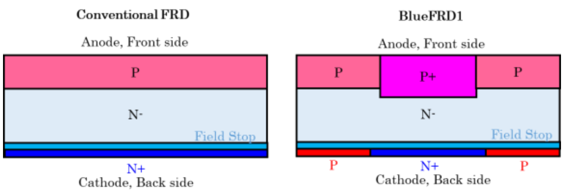

Figure 1: FRD Structure of Our Conventional and Newly-developed Products

The conventional structure is a basic vertical structure diode, consisting of a front anode, back cathode, and field stop layer on an N-layer substrate. In general, thinner N-layers are effective in improving energy loss during switching-off of FRDs. However, simply making the N-layer thinner means that there will be fewer undepleted regions during switching-off operation. Therefore, there is a concern that sudden carrier depletion may easily occur, and noise may be generated by hard recovery. A solution to this problem is to form a P-layer on the cathode. The presence of a P-layer in the cathode provides holes during switching-off operation, reducing carrier depletion and preventing hard recovery. In other words, the thinning of the N-layer and the formation of the cathode P-layer enable both low loss and soft recovery.

However, if a P-layer is formed on the cathode, voltage tolerance degradation due to secondary breakdown is likely to occur. This is because the injection of holes from the cathode P-layer during breakdown causes conductivity modulation, which locally lowers resistance and leads to breakdown due

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to current concentration. BlueFRD1 in this development aims to form a deep anode P-layer (Deep P) in the surface active region and to use the deepest Deep P-layer in the anode diffusion layer as a breakpoint. By installing multiple such Deep P-layers in the active area, the breakdown points are distributed and the occurrence of breakdowns due to localized concentration of current is suppressed. Figure 2 shows a schematic of the current density at breakdown voltage for the basic diode structure and BlueFRD1 structure. In BlueFRD1, the breakdown point changes from the corner section to the Deep P-layer. Another feature of this development is that the positioning of the deep P-layer, the back cathode P-layer, and the N layer is aligned to prevent the secondary breakdown phenomenon from occurring. Align the planar positions of the P-layers on the front and back surfaces so that there is no cathode P-layer directly below the Deep P-layer. This prevents the supply of holes from the cathode P-layer during breakdown at the Deep P-layer.

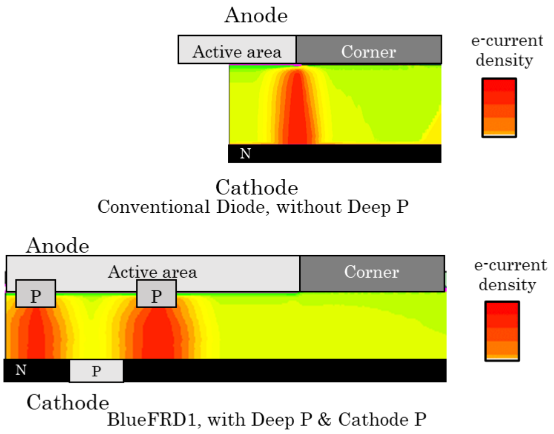

Figure 2: Breakdown Point Schematic, Conventional (top) and BlueFRD1 (bottom)

3. Development Study Details of the BlueFRD1

3.1. Thin Wafer Process Technology

The thinner wafers required for low Q_{rr} entail the risk of mechanical strength degradation and wafer breakage, so it was necessary to review the entire chip manufacturing equipment and manufacturing process, starting from the conventional FRD manufacturing line. A process step to form a P-layer on the backside cathode was also required. We applied our proven thin wafer process technology as a process to stably realize the above [(1), (2), (3)].

3.2. Examination of the BlueFRD1 Structure

In the BlueFRD1 product developed this time, 650V, 50A, the rating for air conditioner PFC applications, was set as the target index. One of the features of the BlueFRD1 structure mentioned earlier is that a Deep P-layer is formed so that it overlaps the cathode N_+ layer. The depth of this Deep P-layer was verified by simulation and the results are shown in Figure 3.

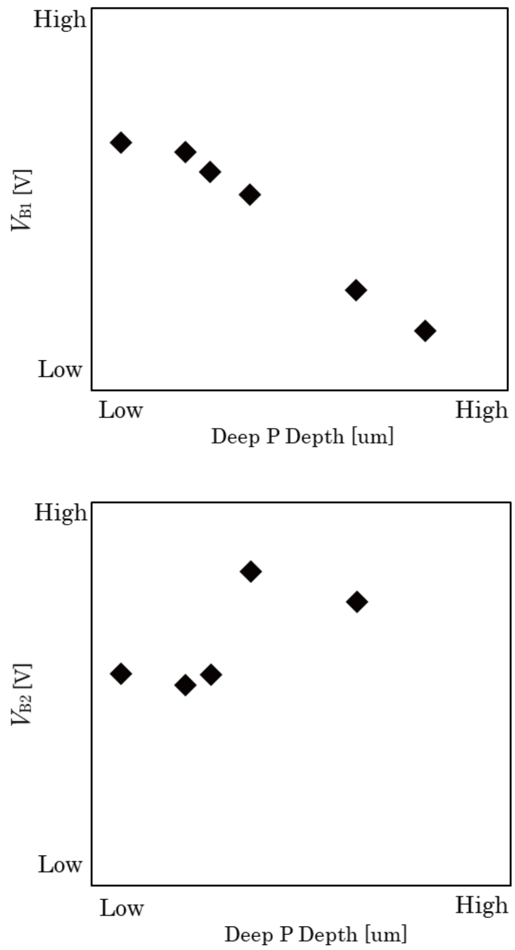

Figure 3: Simulation of Deep P Depth and Voltage Tolerance, Primary Breakdown (top), and Secondary Breakdown (bottom)

The normal static voltage tolerance is V_{B1} for the primary breakdown and V_{B2} for the voltage at which the secondary breakdown occurs. The deeper the Deep P-layer, the closer the distance between the anode and the cathode, and the thinner the drift N-layer, and so the smaller the primary breakdown voltage V_{B1}. However, if Deep P is deep, it is possible to increase the secondary breakdown voltage in line with the design aims. The reason for this is explained by the results from the simulation of hole current density at the depth of Deep P in Figure 4. In conventional diode structures with only anode surfaces, the Hall current density at breakdown is equal everywhere in the transverse direction at a given depth. During breakdown, electrons move to the cathode side. In the upper part of the cathode P-layer area, electrons move laterally toward the cathode N layer, which has a low barrier. When the voltage drop due to this lateral shift exceeds the barrier, the PN junction is turned on and holes are injected, facilitating secondary breakdown. On the other hand, the deeper the Deep P-layer is, the more electrons flow into the cathode N immediately below it, because the current is concentrated in the Deep P. Therefore, hole injection from the cathode P-layer can be suppressed. As a result, the secondary breakdown voltage can be increased.

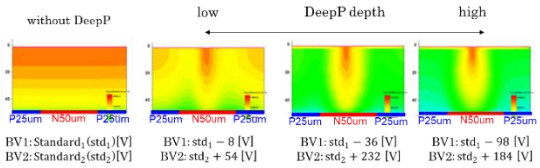

Figure 4: Current Density Simulation at Breakdown

4. Evaluation of the Development of BlueFRD1

4.1. Breakdown Evaluation of BlueFRD1

In Chapter 2, BlueFRD1 was described as being characterized by making secondary breakdown less likely to occur. However, it is difficult to accurately monitor the secondary breakdown voltage as the breakdown current is increased. Therefore, we checked whether avalanche tolerance could be improved in the Unclamped Inductive Switching (UIS) test (Figure 5). The test evaluation samples were the BlueFRD1 development product and a sample with the same chip size and thickness as BlueFRD1, but with only an N-layer for the cathode and with or without a deep P-layer. When the tolerance of the evaluation sample (2), which has a basic diode structure with no Deep P-layer and only an N layer for the cathode, is set to 1, the tolerance of the evaluation sample (1) with the BlueFRD1 structure was increased by approximately 2.8 times. On the other hand, sample (3) with a deep P-layer and only a cathode N increased by only about 1.5 times. Aligning the Deep P-layer with the P-layer of the cathode in addition to forming it is effective in improving avalanche tolerance.

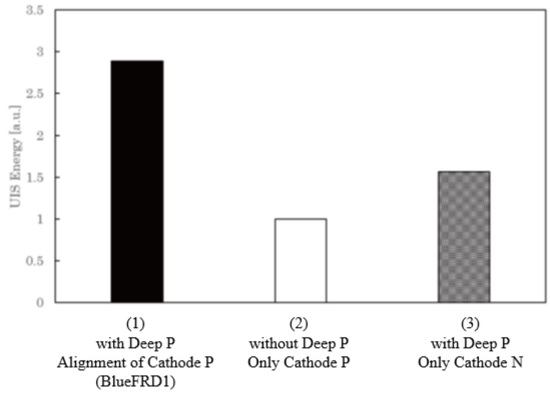

Figure 5: UIS Test Results

4.2. BlueFRD1 Switching-off Characteristics

The V_F-Q_{rr} trade-off characteristics of the developed BlueFRD1 and the conventional product are shown in Figure 6, and the switching-off waveforms are shown in Figure 7.

The conditions under which the switching-off characteristics were obtained in the RRSOA (Reverse Recovery Safe Operating Area) test were: 650V-rated IGBTs on the high side, collector-emitter voltage V_{CE} = 400V, collector current I_C = 50A, gate voltage V_{GE} = +15V/0V, and temperature Ta = 25°C.

Figure 6 shows that BlueFRD1 has improved the V_F-Q_{rr} trade-off curve toward smaller values than the conventional product. In other words, energy loss during switching-off was reduced. Figure 7 also shows that ringing, which had appeared in the conventional product during recovery operations, was reduced in BlueFRD1.

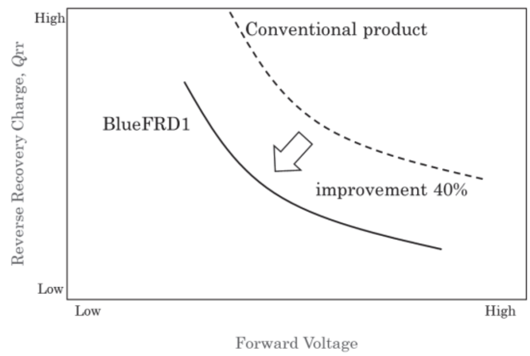

Figure 6: V_F-Q_{rr} Trade Characteristics

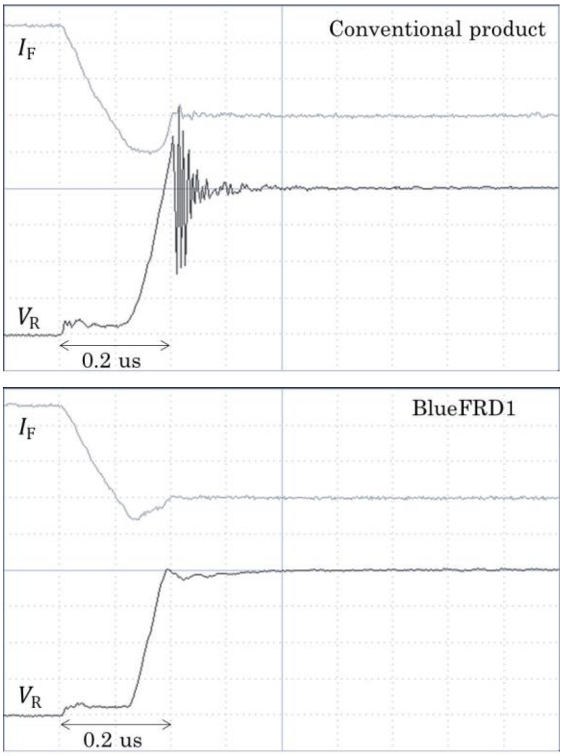

Figure 7: Switching-off Waveforms, Conventional (top) and BlueFRD1 (bottom)

5. Conclusion

By reducing the wafer thickness and optimizing the structure of the diffusion layers on the front and back surfaces, we have developed the BlueFRD1 to have lower energy loss during switching operation and lower noise than conventional products.

BlueFRD1 product development is currently underway. We will promote the technological development of a new generation of FRDs to meet applications that require even lower V_F, higher tolerance, and other properties. And, through responding to the demands of the market, we contribute to the realization of a sustainable world.

References

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