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# 1200V SC(Schottky Controlled Injection)-Diode – An Advanced Anode Concept for Low Injection Efficiency

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## 1. Introduction

Many high voltage PiN-diode concepts, such as SSD (Static Shielding Diode) [1], have been reported to improve trade-off relation between forward voltage drop (VF) and reverse recovery loss[2]. Most of these conventional diodes adopt the technologies of low hole injection efficiency with Schottky contact and the carrier lifetime control techniques to realize small reverse recovery loss. However, these technologies have the problems of large leakage current under reverse bias condition, voltage ringing during reverse recovery and poor dynamic ruggedness.

In this paper, we propose a 1200V novel PiN-diode concept without carrier lifetime control, realizing low VF and low recovery loss. A concept of this new diode, called SC (Schottky Controlled Injection)-diode, is a combination of flat and linear distribution of carrier concentration from anode side to cathode side and reducing injection efficiency at both sides. Furthermore, we have successfully obtained low leakage current at high temperature over 175°C with high carrier lifetime and high reverse recovery ruggedness combining a deep P anode layer design.

## 2. Device concept

Figure 1 shows the schematic cross sectional view of the conventional PiN diode and the proposed SC-diode. It is necessary to adopt heavy lifetime control for PiN diode, because of the very high injection P+anode and N+cathode region. On the other hands, the anode region of SC-diode consists of deep P anode layer and P-Schottky region with Schottky contact and middle doping concentration. The electrons injected into the N- drift region flow into the anode electrode throughout P- Schottky contact and compose a main electron current flow. Thus, only few electrons flow into the P anode layer and very low hole injection is realized.

A comparison of the simulated on-state carrier concentration is shown in Fig.2. The curved line is the conventional carries profile which has high injection efficiency at both sides. In order to reduce carrier injection efficiency, it is necessary to control the lifetime by electron irradiation or other methods. This lifetime control causes the shape of this curved profile and poor electrical characteristics, for example, large leakage current, high forward voltage drops and large voltage ringing. The slight gradient carrier profile of SC-diode is effective in removing the stored charge uniformly and slightly. As a result, SC-diode can prevent voltage ringing effectively.

In contrast to SSD, the SC-diode controls hole-injection from only P anode layer by adjusting the width of P-anode in Fig. 3. The injected electrons from cathode side flow to anode electrode throughout P-Schottky region. This P-Schottky region does not inject holes, because of Schottky contact. Furthermore, the middle doping concentration of P-Schottky region realizes high breakdown voltage without punch-through breakdown.

At the cathode side, we apply the similar concept of transparent collector of IGBT to this SC-diode. As a result, we have obtained the very low injection efficiency at both side and the carrier concentration with monotonically increasing from anode to cathode side obtained with high carrier lifetime in drift region.

## 3. Experimental results

Figure 4 shows measured reverse recovery waveforms for the SC-diode having low hole-injection efficiency. Experimental results for trade-off characteristics between VF and recovery loss are also shown in Fig. 5. There were obtained by only varying the width of P anode layer. These clearly verify that the SC-diode realizes drastic reduction of reverse recovery loss without lifetime control.

A comparison of measured reverse leakage current is shown in Fig. 6. The conventional diode with heavy lifetime control and the SC-diode without lifetime control have almost the same VF and recovery loss. The leakage current of the SC-diode is less than one-tenth of that of the conventional diode at 150°C.

Therefore, this SC-diode realizes high reverse recovery ruggedness of more than $1x10^4$ A/μsec•$cm^2$ at the condition of high recovery current of 1060 A/$cm^2$ as is shown in Fig. 7. Figure 8 shows impact ionization which has occurred only at deep P anode layer. This avalanche current comes to this P anode electrode throughout Ohmic contact certainly and then we have obtained the high dynamic ruggedness.

## References

[1] Y. Shimizu, M. Naito, S. Murakami and Y. Terasawa, IEEE Transactions on ED, vol.31, pp.1314-1319, 1984
[2] H. Schlangenotto, J. Serafin, F. Sawitzki and H. Maeder, IEEE Electron Devise Letters, vol.10, pp.322-324, 1989

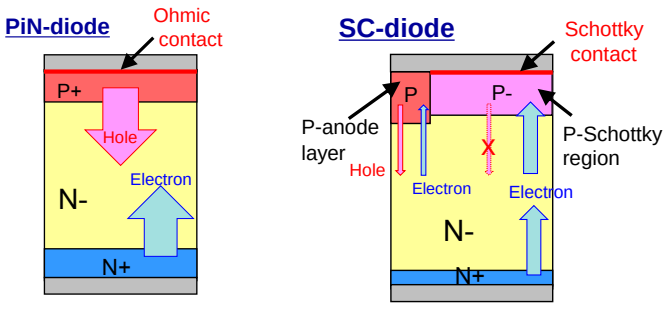
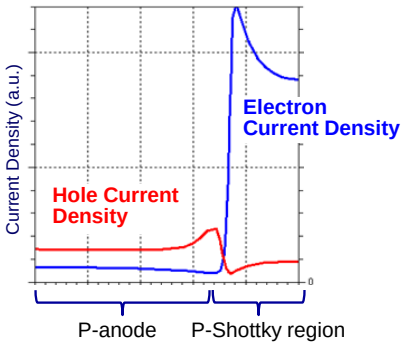



Fig.1 Schematic cross sectional views of conventional diode and SC-diode.



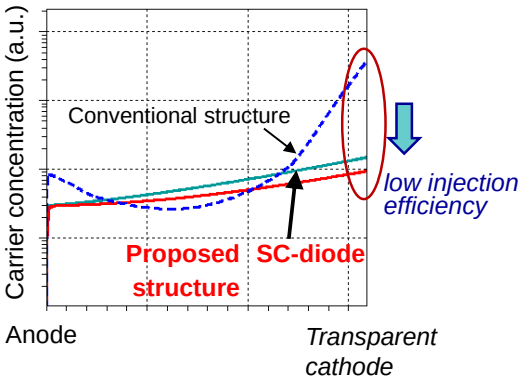




Fig.2 Comparison of carrier concentrations between SC-diode and conventional diode in forward bias condition.

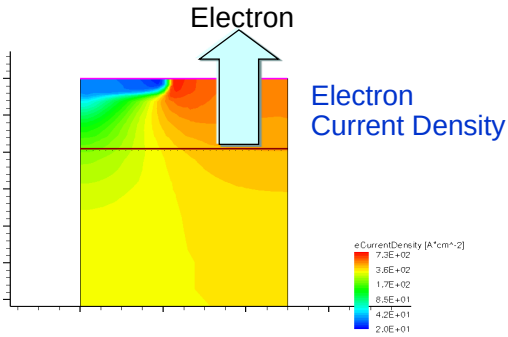



Fig.3 Calculated electrons come to anode electrode throughout P-Schottky region.

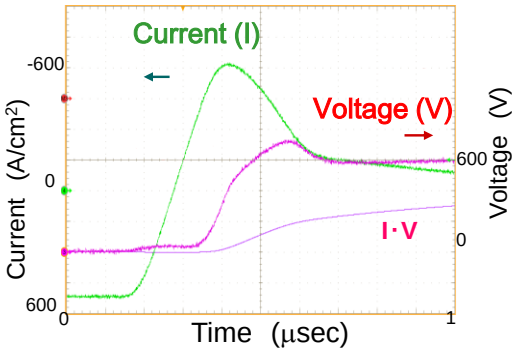



Fig.4 Measured reverse recovery waveforms (di/dt=6060A/μsec･cm$^2$ ) with low hole injection efficiency.

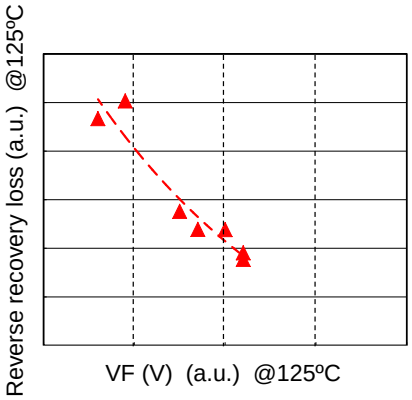



Fig.5 Experimental results for trade-off characteristics between VF (V) and reverse recovery loss (mJ/cm$^2$) without lifetime control.

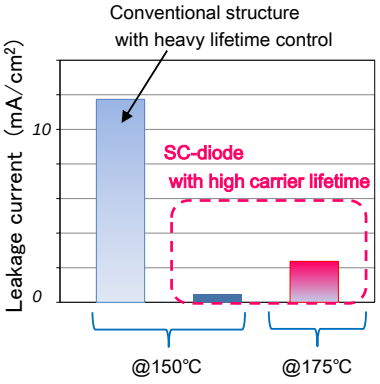



Fig.6 Comparison of measured reverse leakage current between SC-diode and conventional diode with heavy local lifetime control.

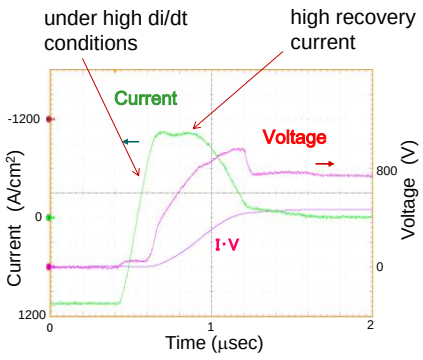



Fig.7 Measured reverse recovery waveforms under high di/dt conditions and high recovery current.

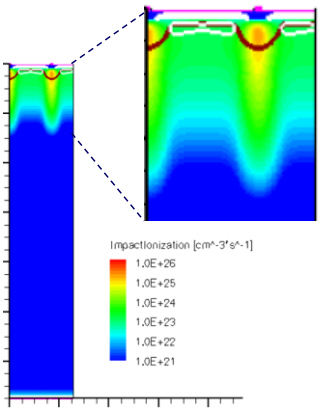



Fig.8 Calculated impact ionization occurs only at bottom of P anode layer.