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Triggering Mechanism for Neutron Induced Single Event Burnout in Power Diode

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1. Introduction

Cosmic ray neutrons can trigger catastrophic failures in power semiconductor devices. It has been reported that parasitic transistor action causes single-event burnout (SEB) in power MOSFETs and IGBTs [1-4]. However, power diodes do not have an inherent parasitic transistor. This paper describes the triggering mechanism of SEB in power diode for the first time using transient device simulation. Initially generated electron-hole pairs created by incident recoil ions result in transient current, which increases the electron density in the vicinity of the n^-/n^+ boundary. The space charge effect of the carriers leads to an increase in the strength of the electric field at the n-/n^+ boundary. Finally, the onset of impact ionization at the n^-/n^+ boundary can trigger SEB. It was clarified that the impact ionization at the n^-/n^+ boundary is a key point of the SEB triggering mechanism in power diode.

2. White neutron-irradiation experiments

The white neutron-irradiation experiment showed that the failure rate of the power devices increases sharply with an increase in the applied voltage when the voltage exceeds a certain threshold value. The SEB threshold voltage is a crucial design criterion against chance failure. Previous research found that the SEB threshold voltage of IGBTs depends on the drift region thickness [1]. In the case of diodes, the SEB threshold voltage has a different tendency to IGBTs (Fig. 1). This result shows evidence that the SEB mechanism in diodes is different from that in IGBTs.

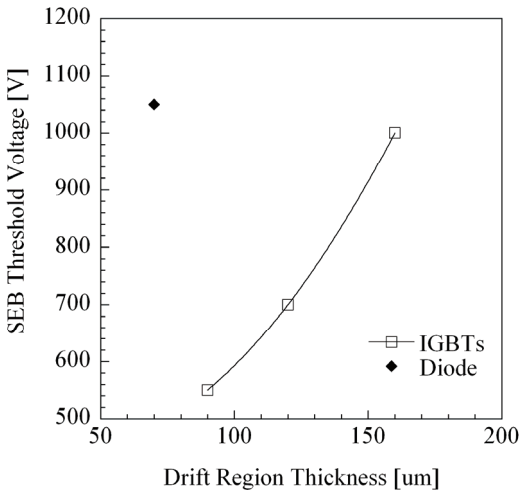

Fig. 1 Drift region thickness dependency of SEB threshold voltage

2. Transient device simulation of SEB in power diode

A transient device simulation was performed to clarify the triggering mechanism of SEB in power diodes. The simulation described the initially generated electron-hole pairs caused by incident recoil ions during reverse bias. The self heating effect was modeled by incorporating a thermal diffusion equation. Figure 2 compares the simulated SEB current with and without the impact ionization model. The first current peak indicates that the initially generated electron-hole pairs along the ion track are accelerated by the electric field in the depletion region. Without the impact ionization model, the SEB current of the diode returns to a stable condition and does not fail. Therefore, the simulation result shows the importance of dynamic avalanche due to highly localized current density for triggering SEB in power diode. Figure 3 shows the electric field distribution along the ion track at the points shown in Fig. 2. The electric field expressed by point 1 peaks at the p/n- junction. However, the electric fields expressed by points 2 and 3 have double-sided peak values at the p/n^- junction and n^-/n^+ boundary. The generated holes traveling to the anode side increase the effective doping density at the n^- region along the ion track. The increase in the effective doping density at the n^- region leads to a decrease in the depletion width and consequently to a decrease in the electric field of the middle n^- region.

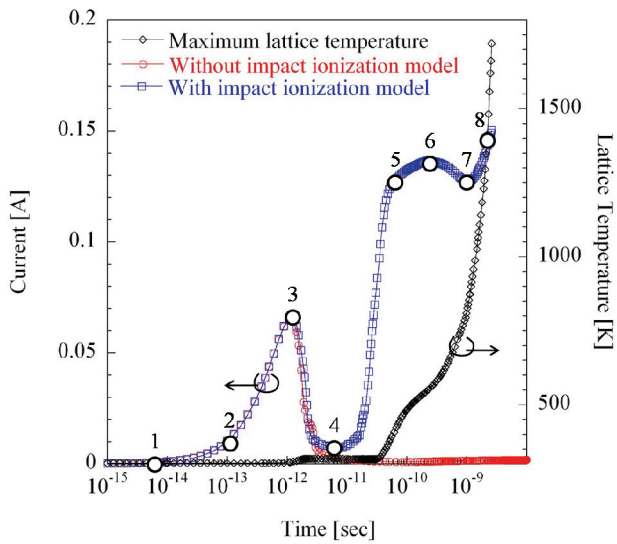

Fig. 2 Comparison of simulated SEB current with and without impact ionization model

In contrast, the electrons traveling to the cathode side increase in density in the vicinity of the n^-/n^+ boundary. Consequently, the second electric field peaks at the n^-/n^+ boundary. Punch-through of the electric field at the anode contact of the device surface occurs at the first current peak expressed by point 3, as shown in Fig.3. The double-sided peak electric fields indicate that a current induced dynamic avalanche (CIDA) has occurred. In addition, the change in the electric field distribution corresponds to the negative differential resistance (NDR) regions in the secondary breakdown [5]. Point 4 shows that the peak electric field shifts to the n^-/n^+ boundary due to highly localized current. Moreover the electric potential distribution adopts a funnel-like shape, and the potential at the n-/n+ boundary falls, as shown in Fig. 4.

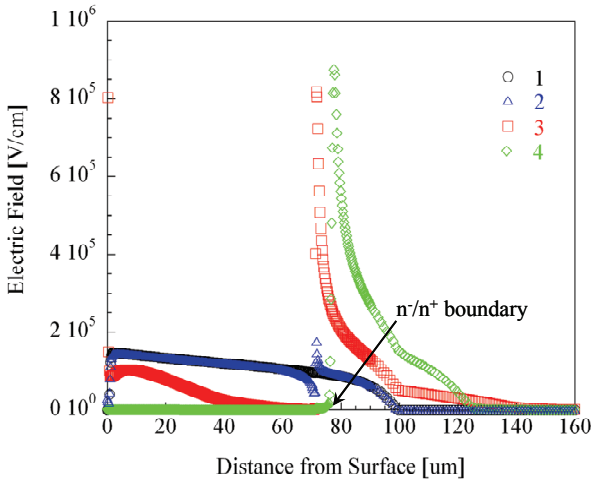

Fig. 3 Electric field distribution along ion track at the times shown in Fig. 2.

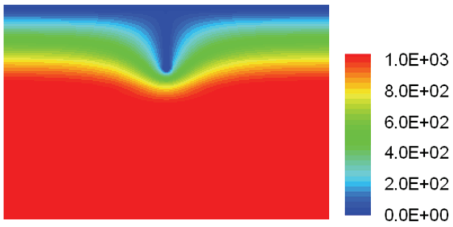

Fig. 4 Electrostatic potential [V] at point 4 shown in Fig. 2

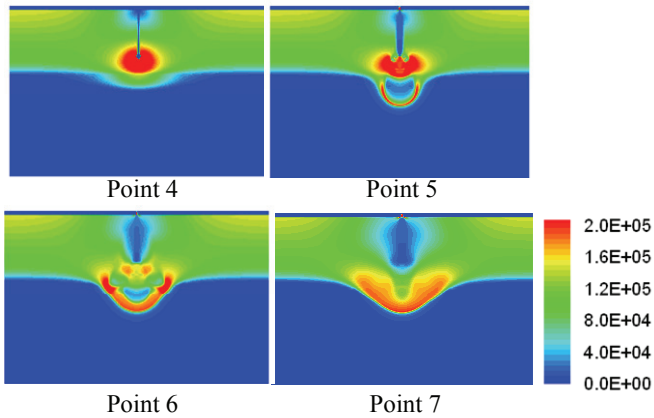

Fig. 5 Electric field [V/cm] at the times shown in Fig. 2.

Points 5 and 6 indicate the double-sided peak electric field at the n^-/n^+ boundary and deep within the n^+ diffusion, as shown in Fig. 5. Point 7 shows that a decrease in the impact ionization rate at the n^-/n^+ boundary results in a temporary decrease in the SEB current as shown in Fig. 2. Subsequently, the peak electric field shifts to only deep within the n^+ diffusion. In addition, the electrostatic potential along the ion track decreases linearly. This result indicates that a power diode behaves locally like a resistor. This eventually leads to failure of the power diode. The temperature distribution adopts a shape perpendicular to the device surface, reflecting the current flow. The device eventually reaches a maximum lattice temperature at the surface.

4. Conclusions

This paper clarified that CIDA at the n^-/n^+ boundary is the key point of the SEB triggering mechanism in power diodes. The SEB threshold voltage of IGBTs is lower than that of diodes because of their inherent parasitic transistor action. However, the SEB threshold voltage can be controlled by the device design, such as by increasing the n^- drift thickness. Therefore, highly reliable design against chance failure can be established by optimizing the design of the current gain of the parasitic transistors. In contrast, power diodes do not have an inherent parasitic transistor. Device simulation showed that the SEB failure mechanism is closely related to diode secondary breakdown. Double-sided impact ionization corresponds with the NDR region when static breakdown occurs under high current conditions. An efficient way to suppress double-sided impact ionization is to design a diode with a wider n^- region thickness. Design of the SEB threshold voltage is crucial for establishing highly reliable power devices. Moreover, it was demonstrated that the SEB threshold voltage can be designed by optimizing the device parameters.

References

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