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High-Bandwidth Measurement of Laser-Induced Transient Responses in SiC Devices for Understanding Single Event Burnout Phenomena

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Abstract. A laser-based experimental system was developed to investigate Single Event Burnout (SEB) in high-voltage silicon carbide (SiC) devices. By enabling transient measurements under high reverse-bias conditions, the setup emulates ion-induced charge generation with femtosecond laser pulses. Time-resolved waveforms and charge collection trends were obtained, showing consistency with previous heavy ion experiments. This confirms the system's capability to reproduce SEB-relevant dynamics. Further improvements in spatial resolution and impedance matching are required for detailed analysis of internal charge transport mechanisms.

Introduction

Silicon carbide (SiC) is widely recognized as a promising material for radiation-hardened (rad-hard) electronic devices due to its wide bandgap, high breakdown field, and excellent thermal conductivity. These properties give SiC devices strong resistance to Total Ionizing Dose (TID) effects [1–3], making them suitable for harsh radiation environments such as space and nuclear applications. However, energetic ions can generate dense electron-hole pairs in the device, causing Single Event Effects (SEEs) that may result in functional degradation or catastrophic failure. Among these, Single Event Burnout (SEB) is a particularly serious failure mode in power devices and has been widely observed in SiC Schottky Barrier Diodes (SBDs) and MOSFETs [4, 5].

While SEB has been studied in various SiC devices, most previous work has focused on macroscopic failure modes such as breakdown or permanent degradation from localized damage. Fewer studies have examined the internal physical processes—particularly transient charge transport in the prompt phase following ion strikes—that trigger SEB. Better understanding of these processes is crucial for accurate modeling and robust design.

Heavy ion testing with particle accelerators is commonly used to study SEB, but such methods are limited by high cost, restricted beam access, and narrow energy options. As a more accessible and flexible alternative, tabletop pulsed-laser systems have been used to emulate ion-induced charge generation. While this method allows controlled and repeatable testing, most laser-based studies have only evaluated SEB indirectly—typically by measuring total collected charge—without resolving the time evolution of carrier transport that leads to failure [6-8]. This is mainly because transient measurements under high-voltage bias conditions, as required for SiC power devices, are technically demanding due to the need for high-speed, high-voltage-capable measurement systems.

In this study, we developed a laser-based measurement system that enables both high time resolution and operation under high reverse bias. This allows direct observation of transient voltage waveforms resulting from laser-induced charge transport, providing new insight into SEB mechanisms in SiC power devices.

Sample Description

The test sample used in this study was a silicon carbide (SiC) Schottky Barrier Diode (SBD), model S6307 (1200 V, 30 A) from ROHM. To allow laser irradiation of the epitaxial layer (sensitive region) without damaging the front-side electrode structure, a 50 µm × 50 µm window was fabricated on the backside ohmic electrode using focused ion beam (FIB) processing.

The chip carrier was designed with a laser-through hole, as illustrated in Fig. 1(a), to allow optical access to the backside of the mounted device. The SBD was mounted such that its backside window aligned precisely with this through hole, enabling focused laser light to reach the sensitive region from the bottom side. Electrical connections were made using short bonding wires to two 50 Ω strip-lines (10 GHz analog bandwidth), as shown in Fig. 1(b).

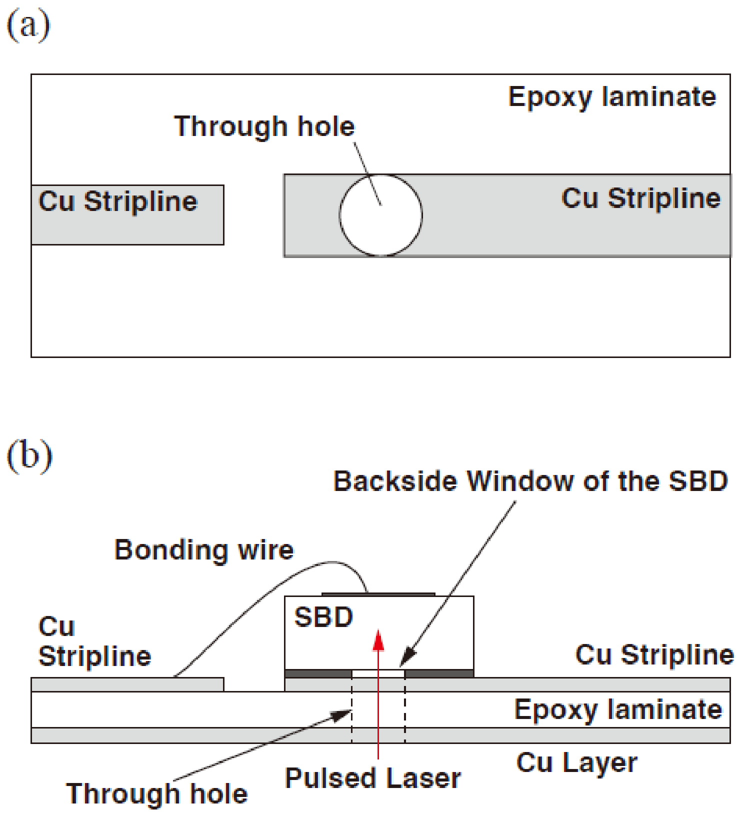

Fig. 1. (a): Top view of the chip carrier with a laser-through hole. (b): Side view of the chip carrier with the SBD mounted and wire-bonded.

Laser and Measurement Setup

A Single Event is triggered by the flow of electron-hole pairs generated within a device by the incidence of a single energetic ion. In this study, we emulate the generation of such electron-hole pairs using a pulsed laser. An overview of the developed measurement system is shown in Fig. 2. A 400 nm laser was used to induce two-photon absorption in the SiC epitaxial layer, thereby generating electron-hole pairs. This wavelength was obtained by frequency-doubling an 800 nm Ti:sapphire laser using a lithium triborate (LBO) nonlinear optical crystal. After exiting the LBO crystal, the laser beam passed through a neutral density (ND) filter to control the irradiation power, then through a half mirror and an objective lens, which enabled precise adjustment of the focal depth within the device. The irradiation position was monitored using a CCD camera to ensure accurate alignment. The laser had a pulse width of 130 fs, a repetition rate of 1 kHz, and an incident power of 280 μW.

To capture the transient response of the device, a reverse bias voltage (ranging from 100 V to 900 V) was applied through a Bias Tee with a 10 GHz analog bandwidth. The resulting transient signals were recorded using a single-shot oscilloscope with a 15 GHz analog bandwidth. However, the overall analog bandwidth of the measurement system was limited to 10 GHz due to the combined bandwidth constraints of the Bias Tee and strip-line configuration.

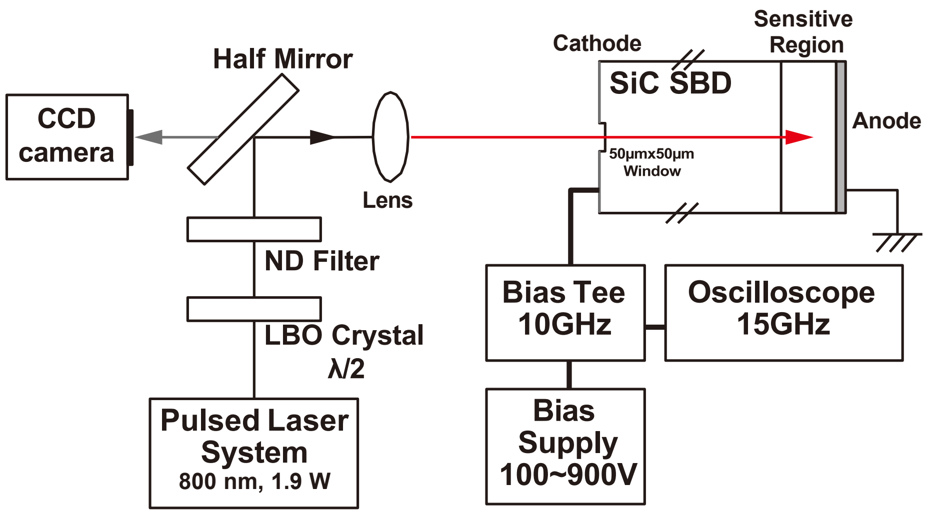

Fig. 2. Laser-based measurement setup for transient response detection. A 400 nm pulsed laser is focused onto the SiC SBD through optical components. Transient signals are measured via a high-bandwidth circuit and captured by a 15 GHz oscilloscope.

Experimental Results and Discussion

Figure 3 shows transient voltage waveforms measured at reverse bias voltages of 300 V, 500 V, and 900 V. To reduce high-frequency noise, each waveform was smoothed using a Savitzky–Golay filter. In all cases, the waveforms exhibit a sharp rising edge followed by an exponential decay—typical of ion-induced transient behavior in semiconductor devices. The rise time was approximately 10 ns across all bias conditions, whereas the temporal resolution of the measurement system was 35 ps, confirming that the system could capture the full transient behavior, which lasted about 50 ns. Furthermore, the peak amplitude increased with higher reverse bias, indicating more efficient charge collection under stronger electric fields. A small pre-peak was also observed before the main transient, possibly due to overshoot or reflection caused by the measurement system.

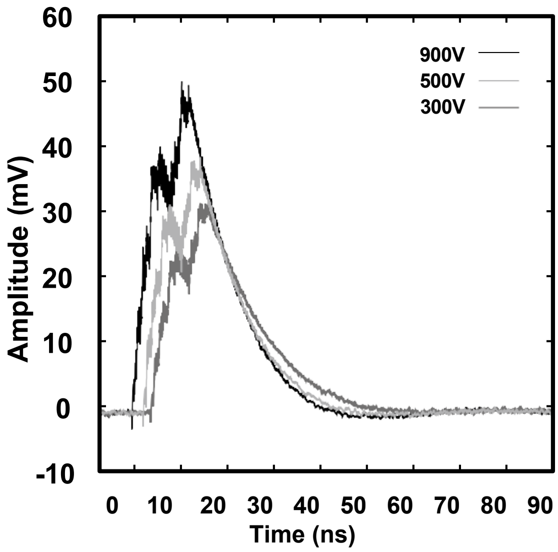

Fig. 3. Transient voltage waveforms smoothed by a Savitzky–Golay filter.

Figure 4 illustrates the dependence of total collected charge on reverse bias voltage. The charge was calculated by integrating the transient voltage waveform over time, which represents the total amount of charge observed during the transient event. As reverse bias increased, total collected charge also increased. This is typically explained by the expansion of the depletion region under higher electric fields, which enhances charge collection efficiency.

Therefore, it can be inferred that the laser reached the vicinity of the depletion region and generated electron-hole pairs. This interpretation is consistent with the observation that larger current responses were recorded under higher bias, indicating efficient carrier collection.

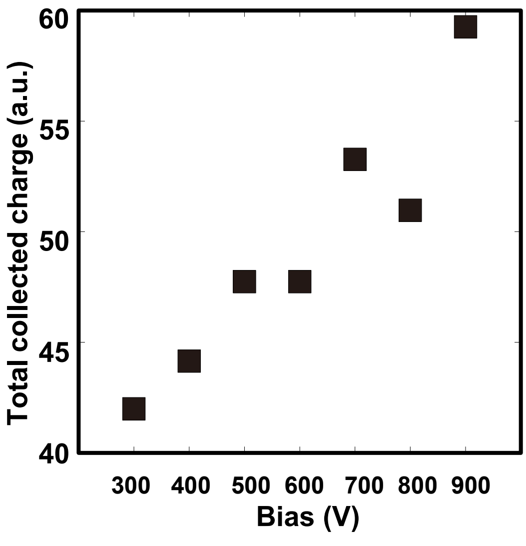

Fig. 4. The dependence of total collected charge on the reverse bias voltage.

Although the total collected charge increases with higher reverse bias, this trend cannot be fully explained by the expansion of the depletion region. As shown in Fig. 5, C–V measurements indicate that the depletion width saturates at approximately 400 V. Therefore, additional mechanisms must be responsible for the continued increase in collected charge at higher voltages.

A likely mechanism is impact ionization in the high-field region, which can generate secondary carriers and thereby increase the total collected charge. This effect becomes more pronounced as the electric field approaches the threshold for initiating carrier multiplication. This interpretation is consistent with previous heavy-ion-induced charge-collection studies on SiC Schottky Barrier Diodes [4].

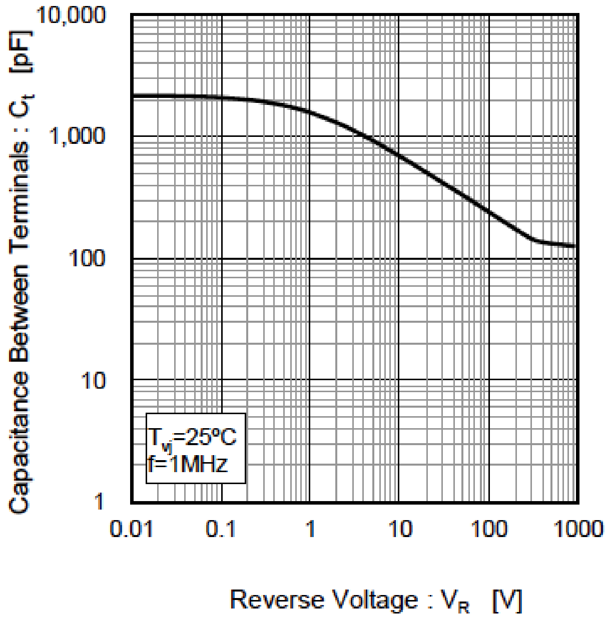

Fig. 5. C-V characteristic of the ROHM S6307 [9].

Summary

In this study, we successfully developed a laser-based experimental system capable of operating under high-voltage bias conditions for silicon carbide (SiC) devices. While improvements in spatial resolution and impedance matching are still required, the system enabled time-resolved measurements of transient responses induced by laser-generated charge carriers within the sensitive region of the device.

The observed transient characteristics, including the dependence of the collected charge on reverse bias voltage, exhibited trends similar to those reported in ion-beam irradiation experiments. This consistency supports the utility of the proposed laser-based approach as a practical and flexible alternative for investigating Single Event Effects (SEEs), particularly Single Event Burnout (SEB), in SiC power devices.

Acknowledgement

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