Output Characteristics of Side-Illuminated Photoconductive Semiconductor Switch Based on High Purity Semi-Insulating 4H-SiC

PYEUNG HWI CHOI1, YONG PYO KIM1, MIN-SEONG KIM2, JIHEON NYUT2, (Senior Member, IEEE), SUNG-HYUN BAEK2, SUNG-MIN HONG1, (Senior Member, IEEE), SUNGBAE LEE3, AND JAE-HYUNG JANG4, (Senior Member, IEEE)

1School of Electrical Engineering and Computer Science, Gwangju Institute of Science and Technology, Gwangju 61005, Republic of Korea
2First Research and Development Institute, Agency for Defense Development, Daejeon 34186, Republic of Korea
3Department of Physics and Photon Science, Gwangju Institute of Science and Technology, Gwangju 61005, Republic of Korea
4School of Energy Engineering, Korea Institute of Energy Technology, Naju 58330, Republic of Korea

Corresponding author: Jae-Hyung Jang (jjang@kentech.ac.kr)

This work was supported in part by the Agency for Defense Development, in part by the National Research Foundation of Korea (NRF) by the Korean Government (Ministry of Science and ICT) under Grant 2017R1A2B3004049 and Grant 2022R1H1A2092527, and in part by the Korea Institute of Energy Technology (KENTECH) Research under Grant KRG2021-01-011.

ABSTRACT Photoconductive semiconductor switch (PCSS) allowing side illumination was fabricated on high purity semi-insulating (HPSI) 4H-SiC. A 532-nm pulsed laser with variable optical energy was used to trigger the PCSS. The performance of the PCSS was characterized under the two different load conditions, 50-Ω load and 0.05-Ω, with a current viewing resistor (CVR). The PCSS exhibited significantly different output characteristics for the two different loads. The equivalent resistance of the PCSS with the 50-Ω load, which was calculated from the output voltage and current, was inversely proportional to the optical energy, but the one with a 0.05-Ω load exhibited saturation behavior with the optical energy. While the times at peak output with the 50-Ω load were similar at various optical energies, the times at peak output with the 0.05-Ω load were dependent on the optical energy. Output current oscillation was also observed after the PCSS was turned off in the case of 0.05-Ω load condition. The different output characteristics for the different load resistances were analyzed using the transient response of the equivalent circuits. The PCSS exhibited a minimum on-state resistance of 0.27 Ω with the optical energy of 8 mJ and a maximum output current of 657 A at the bias voltage of 4.8 kV. The operating voltage of the PCSS was limited by surface flashover, which caused an additional output pulse following the first output pulse.

INDEX TERMS High purity semi-insulating 4H-SiC, photoconductive semiconductor switches (PCSSs), side-illumination.

I. INTRODUCTION

Photoconductive semiconductor switches (PCSSs) have attracted interest for high pulsed power devices because of their advantages, including ultrafast response, electrically isolated triggering, and negligible jitter characteristics. Single PCSS or stacked PCSSs with time synchronization have been investigated for solid-state microwave generation, including ultra-wideband (UWB), high power microwave (HPM), and dielectric wall accelerator (DWA) [1], [2], [3], [4], [5]. The ability to simultaneously generate high voltage and high current has made them attractive for applications in firing sets, ground penetrating radar (GPR), and flash x-ray generators [6], [7], [8]. PCSSs have achieved high output currents up to the kA range in non-linear or lock-on mode, where an avalanche multiplication occurs [9], [10], and in linear mode operation, where the output current reaches hundreds of amperes [11], [12], [13].
The operational characteristics of PCSSs also have been investigated for high power switching with a load resistance ranging from 0.05 to 50-Ω. High power microwave pulse generators generally drive antenna so that the solid-state switches for microwave applications have been characterized with 50-Ω load impedance [2], [14], [15]. Linear transformer drivers (LTD) have driven load impedances lower than 1-Ω to maximize the circuit current output [16], [17]. To observe high current switching characteristics, a current viewing resistor (CVR) has been employed in series with the PCSS. Because the CVR has a resistance in the sub-Ω range, the on-state resistance of the PCSS is much higher than the resistance of the CVR and dominantly drives the output current. Most of the bias voltage is applied to the PCSS, and this allows the output characteristics of the PCSS under a high electric field to be investigated at a relatively lower bias voltage than one at a load resistance of 50-Ω. Conventional lateral-type GaAs-based PCSSs with gap sizes of 1.5 and 2 mm were characterized in series with a 0.1-Ω CVR [9]. When the PCSS was excited with an optical laser with a wavelength of 1064 nm and energy of 16 mJ, the PCSS switched the maximum output current of 1.5 kA at a bias voltage of 2 kV in lock-on mode, and the effect was investigated at various charging circuit capacitances. Another study on a GaAs based lateral-type PCSS operating in non-linear mode demonstrated the maximum switching current of 1.5 kA and investigated the failure mechanism of the PCSS with a 0.1-Ω CVR [10].

SiC-based PCSSs, in linear mode operation, have also been investigated for the higher hold-off voltage. A vanadium compensated semi-insulating (VCSI) 4H-SiC based PCSS employing a transparent window and silver mirror reflector was characterized with a 0.05-Ω CVR and exhibited the maximum switching current of 840 A at a bias voltage of 12 kV [18]. Another vertical PCSS based on VCSI 6H-SiC was tested with a load resistance of 20-Ω in series with a CVR and a current coil to monitor the current. To predict the operational characteristics of PCSS in linear mode operation, the PCSS resistance was modeled using the carrier density and a PSpice simulation. The simulation and experiment demonstrated high-power RF generation with a switching current of 590 A at a bias voltage of 18 kV [13].

To accurately measure the on-state resistance of a PCSS based on VCSI 4H-SiC, the impedance of the test circuit, including PCSS and a 0.0249-Ω CVR was analyzed and extracted photoconductivity of 4H-SiC substrate [19]. Another work conducted an equivalent circuit analysis for the test circuit including a load resistance of 100-Ω in series with a 0.1-Ω CVR [20]. By estimating the capacitance of the VCSI 6H-SiC based PCSS and the circuit inductance, PSpice model for PCSS was developed to accurately simulate the output waveform of the PCSS circuit triggered by double optical pulses with a time interval. To investigate the potential high frequency operation of the VCSI 4H-SiC based PCSS, both the physics modeling for the resistance and the impedance analysis of the test circuit were conducted with a 1030 nm laser at 1 MHz repetition rate [21]. While the above studies with circuit modeling confirmed the validity of the simulation results, the detailed output characteristics and current oscillation of the PCSS have not yet been investigated.

In this work, a side-illuminated vertical PCSS based on HPSI 4H-SiC was fabricated to investigate current switching capability. The side-illuminated vertical PCSS device exhibited high optical absorption efficiency so that a low on-state resistance can be achieved at low optical excitation energy [22]. A 532-nm laser was utilized for the optical coupling of the entire volume of the vertical PCSS. The PCSS with a 0.05-Ω CVR exhibited different output characteristics compared to one with a 50-Ω load. The transient response analysis of the equivalent circuit elucidated that the minimum on-state resistance, the time at peak output, and the current oscillation phenomena are closely related to the load resistance. In addition, the maximum switching current of the PCSS and the surface flashover, which limits the PCSS operating voltage, were investigated.

II. EXPERIMENTAL SETUP

A 500-µm-thick HPSI 4H-SiC substrate with a resistivity higher than 107 Ω·cm and a micro-pipe density lower than 0.1 cm–2 was used to fabricate the vertical-type PCSS devices. As shown in Fig. 1(a), 8-mm-diameter circular electrodes were formed on both sides of the 1.3 × 1.3 cm2 substrate by optical lithography, where the photoresist (AZ5214) was utilized for image reversal process and a mask aligner (M100, PRO Win) was used for optical exposure and flood exposure. Subsequently, the multilayer metallization consisting of Ni/Ti/Au (40/40/300 nm) was evaporated and lifted-off...
FIGURE 3. PCSS test circuit setup measured by (a) 50-Ω terminated oscilloscope (OSC) (b) 0.05-Ω current viewing resistor (CVR).

FIGURE 4. Optical pulse waveform measured with the 2-GHz Si photodetector (blue) and (a) output current waveforms of the PCSS measured by 50-Ω terminated oscilloscope with various optical energies and a bias voltage of 400 V (b) output current waveforms of the PCSS with a 0.05-Ω current viewing resistor at the bias voltage of 400 V.

FIGURE 5. (a) Minimum equivalent resistance ($R_{eq}$) and (b) time to reach the peak output current ($t_{peak}$) measured for variable optical excitation energy. The HPSI 4H-SiC PCSS was measured using the load resistances of 50-Ω and 0.05-Ω, respectively, as a function of the optical energy at a bias voltage of 400 V.

measured with a 50-Ω terminated DPO. The optical pulse was measured with a 2 GHz Si photodetector (DET025AL, Thorlabs), and then was utilized as a triggering signal for the output electrical pulse measurement.

III. RESULTS AND DISCUSSION

To investigate its output characteristics, the PCSS was tested at a bias voltage of 400 V and optical energies ranging from 20 µJ to 8 mJ. Fig. 4(a) shows the waveforms of the optical trigger pulse, where the time at the peak optical power was set to 0 to use it as the timing reference, and the electrical output current of the PCSS with a load resistance of 50-Ω. The typical output pulse exhibited a Gaussian shaped waveform. It was also found that the time to reach peak output current, $t_{peak}$, was similar for various optical energies. The peak output current of the PCSS illuminated by the optical energy 4 mJ was 7.84 A, and the FWHM of the output pulse was 7.9 ns. The output characteristics of the same PCSS measured with the 0.05-Ω CVR are shown in Fig. 4(b). When the same optical pulse was applied to the PCSS, the peak output current was 58 A, and the FWHM of the output pulse was 4.89 ns. It was observed that the $t_{peak}$ depended on the incident optical energy. The current pulse exhibited a steeper falling edge than the rising edge, and damping oscillation.

To qualitatively analyze the output characteristics, the equivalent resistance of the PCSS, $R_{eq}$, was calculated from the output voltage and current with the following equation:

$$R_{eq} = \frac{V_o - V_c}{I_c},$$  
(1)

where $V_o$ is the output voltage, $R_L$ is the load resistance. $V_c$ is capacitor voltage at time $t$, and can be calculated as:

$$V_c(t) = V_{bias} - \int_{-\infty}^{t} \frac{V_o(r')}{R_L C_c} dr',$$  
(2)

where $V_{bias}$ is the dc bias voltage applied by a high voltage supply and $C_c$ is the charging capacitance of 20 nF.

Fig. 5(a) shows the minimum $R_{eq}$ at various optical energies. When the PCSS was characterized with load resistances of 50-Ω and 0.05-Ω, the minimum $R_{eq}$ were the same at optical energies lower than 0.5 mJ, however, the minimum
where $\text{optical energy}$, $\text{PCSS}$. The $t_{\text{peak}}$ values measured with 50-Ω and 0.05-Ω loads were similar at optical energies lower than 0.5 mJ, but the $t_{\text{peak}}$ measured with the CVR increased at optical energies higher than 0.5 mJ, as shown in Fig. 5(b).

To analyze the different output characteristics of the two cases, equivalent circuit analyses were conducted. The equivalent circuits of the test circuit with the load resistances of 50-Ω and 0.05-Ω are shown in Figs. 6(a) and (b), respectively. The capacitance of the PCSS, $C_{\text{PCSS}}$, and inductance of the CVR, $L_{\text{CVR}}$, were measured to be 10 pF and 33.4 nH, respectively. In Fig. 6(a), the Internal on-state resistance of the PCSS, $R_{\text{PCSS}}(t)$, can be calculated as follows [23]:

$$R_{\text{PCSS}}(t) = \frac{V_c(t) - V_o(t)}{i(t) - I_{\text{C,PCSS}}(t)} = \frac{V_c(t) - V_o(t)}{i(t) - I_{\text{C,PCSS}} \left( \frac{dV_o(t)}{dt} + \frac{V_o(t)}{R_{\text{L}}C_c} \right)},$$

where $I_{\text{C,PCSS}}$ is the current along the capacitance of the PCSS.

Since the resistivity of the PCSS was determined by the optical energy, $R_{\text{PCSS}}(t)$ is identical regardless of the load resistance at the same optical energy. Then, $V_c(t)$ in Fig. 6(b) can be expressed as follows:

$$V_c(t) = V_{\text{PCSS}}(t) + V_{\text{L, CVR}}(t) + V_{\text{R, CVR}}(t) = R_{\text{PCSS}}(t) (I_{\text{CVR}}(t) - I_{\text{C,PCSS}}(t)) + L_{\text{CVR}} \frac{dI_{\text{CVR}}(t)}{dt} + I_{\text{CVR}}(t) R_{\text{CVR}},$$

where $V_{\text{L, CVR}}$ and $V_{\text{R, CVR}}$ are the voltages across the inductance and resistance of the CVR, respectively. $I_{\text{CVR}}$ is the current along the CVR. Then, $I_{\text{C,PCSS}}(t)$ can be expressed as follows:

$$I_{\text{C,PCSS}}(t) = C_{\text{PCSS}} \frac{dV_{\text{PCSS}}(t)}{dt} = \frac{C_{\text{PCSS}}}{C_c} \left( \frac{d(V_c(t) - V_{\text{L, CVR}}(t) - V_{\text{R, CVR}}(t))}{dt} - \frac{C_{\text{PCSS}}}{C_c} I_{\text{CVR}}(t) - L_{\text{CVR}} C_{\text{PCSS}} \frac{d^2I_{\text{CVR}}(t)}{dt^2} - R_{\text{CVR}} C_{\text{PCSS}} \frac{dI_{\text{CVR}}(t)}{dt} \right)$$

The $R_{\text{PCSS}}(t)$ acquired with a load resistance of 50-Ω is discretized with the time interval $\Delta t$ of 12.5 picoseconds, which is the sampling time during the measurement. To input the measured $R_{\text{PCSS}}(t)$ into the time domain equation, (4) was changed to the difference equation by discretizing the time with $\Delta t$ and can be expressed as the following equation:

$$V_N = R_N(I_N(1 + \frac{C_{\text{PCSS}}}{C_c}) + L_{\text{CVR}} C_{\text{PCSS}} \frac{I_{N+1} - 2I_N + I_{N-1}}{(\Delta t)^2} + R_{\text{CVR}} \frac{I_{N+1} - I_{N-1}}{2\Delta t} + L_{\text{CVR}} \frac{I_{N+1} - I_{N-1}}{2\Delta t} + I_N R_{\text{CVR}}.$$  

where $V_N$ is $V_c(t = N\Delta t)$, $I_N$ is $I_{\text{CVR}}(t = N\Delta t)$, $R_N$ is $R_{\text{PCSS}}(t = N\Delta t)$, and $I_{N-1}$ is $I_{N-1} + \Delta t$. The discrete sequence of $I_{N+1}$ can be obtained by (7), as shown at the bottom of the next page.

Considering that $V_N$ is capacitor voltage at $N\Delta t$, the current $I_N$ at $N\Delta t$ can be obtained by inserting the measured value of $R_N$ at the optical energy of 4 mJ into (7). The waveform of $I_N$ and transient output current waveforms, $I_{\text{CVR}}(t)$, are shown in Fig. 7, and the two waveforms are well-matched, which implies that the different output characteristics are due to the lumped components of test circuits and minimum $R_{\text{PCSS}}$ at both load conditions were same. The $dI_{\text{CVR}}(t)/dt$, which is the derivative of the output current with respect to time, was 11 A/ns at the time of 2.3 ns, which is the average $t_{\text{peak}}$ measured with a 50-Ω load at the optical energy of 4 mJ, so that an induced voltage of 367 V was applied to the inductance of the CVR. The induced voltage limits the output current increases with time. The $dI_{\text{CVR}}(t)/dt$ at the optical illumination energy higher than 0.5 mJ was so high that the time to reach the peak current, $t_{\text{peak}}$, was different with the time required for $R_{\text{PCSS}}$ to reach the minimum value, and $t_{\text{peak}}$ was delayed even further as the optical energy increased.

The current oscillation was observed, as shown in Fig. 4(b). Since the current along the shunt capacitance of the PCSS is far higher than the current along the high resistance of the PCSS, the current oscillation takes place due to the series RLC circuit composed with $R_{\text{CVR}}$, $L_{\text{CVR}}$, and $C_{\text{PCSS}}$. The oscillation period can be calculated as follows:

$$T_{\text{cir}} = \frac{1}{f} = 2\pi \sqrt{L_{\text{CVR}} C_{\text{PCSS}}}.$$
The calculated oscillation period was determined to be 3.63 ns. The average oscillation periods measured by the CVR at various optical energies are shown in Fig. 8. On the other hand, the test circuit with 50-Ω load has the higher load resistance and the much smaller parasitic inductance than the test circuit with CVR. With the higher damping and the lower reactance component, the current oscillation was suppressed.

To investigate the maximum switching current, the PCSS was characterized under bias voltages ranging from 100 V to 4.9 kV with a 0.05-Ω load at the optical energy of 8 mJ. The output waveforms under various bias voltages are shown in Fig. 9(a). The oscillation period at various voltages is essentially the same, but the ratio of the oscillation level at the first damping to the peak output current decreases as the bias voltage increases. As shown in Fig. 9(b), the peak output current increased linearly with bias voltage, and the maximum switching current was 657 A at a bias voltage of 4.8 kV. At a bias voltage of 4.9 kV, surface flashover, which limited the current switching capability of the PCSS, took place along the surface of the PCSS substrate, as shown in Fig. 10(a). Fig. 10(b) shows that both electrodes and the surface of the substrate were damaged due to the surface flashover. An appropriate surface passivation using a dielectric layer would be an effective way to improve the current switching performance of the side-illuminated vertical PCSS.

The performances of the PCSSs based on SiC substrates are compared in Table 1. Ma et al. [10] reported a lateral-type PCSS based on HPSI 4H-SiC with a load resistance of 50-Ω. It achieved a minimum on-state resistance of 1.5 Ω with the optical energy of 5.5 mJ. The device conducted the output current of 450 A at a bias voltage of 26 kV.

Collier et al. [17] reported that a vertical-type PCSS based on VCSI 6H-SiC based PCSS with a load resistance of 20-Ω demonstrated a minimum on-state resistance of 5.6 Ω with the optical energy of 31.9 mJ and an output current of 591 A.

\[
I_{N+1} = \frac{V_N - I_N}{R_N} \left( R_N \left( L_{CVR} C_{PCSS} \right) - L_{CVR} \left( \frac{L_{CVR} C_{PCSS}}{2\Delta t} \right) - I_{N-1} \left( R_N \frac{L_{CVR} C_{PCSS}}{2\Delta t} + R_{CVR} R_{CVR} R_{CVR} \frac{R_{CVR} C_{PCSS}}{2\Delta t} - \frac{L_{CVR}}{2\Delta t} \right) \right). \tag{7}
\]
at a bias voltage of 18 kV. Cao et al. [18] reported that a vertical-type PCSS based on VCSI 4H-SiC with a 0.05-Ω CVR exhibited a minimum on-state resistance of 7.5 Ω with the optical energy of 65 mJ and output current of 840 A at the bias voltage of 12 kV. Sullivan [24] reported that a vertical-type PCSS based on VCSI 6H-SiC with a load resistance of 10.2 Ω achieved a minimum on-state resistance of 0.66 Ω under the optical energy of 35.4 mJ and the output current of 1500 A at a bias voltage of 17 kV. Xiao et al. [25] reported that a lateral-type PCSS based on HPSI 4H-SiC with a load resistance of 50-Ω achieved a minimum on-state resistance less than 1 Ω with the output energy of 10.5 mJ. The output current was 84 A at a bias voltage of 6 kV. While the PCSSs with load resistances lower than 50-Ω achieved high current switching performances, the minimum on-state resistances, which were calculated using the output current at the CVR, were not clearly separated with the reactance. The transient analysis of the side-illuminated HPSI 4H-SiC based PCSS with load resistances of 50-Ω and 0.05-Ω exhibited the precise on-state resistance of 0.27 Ω. The maximum switching current capability of 657 A was demonstrated with a 0.05-Ω load under low optical illumination energy of 8 mJ.

### IV. CONCLUSION

The output characteristics of vertical-type PCSS based on HPSI 4H-SiC was investigated using side-illumination with load resistances of 50-Ω and 0.05-Ω. When the PCSS was characterized with 50-Ω load, \( R_{eq} \) was inversely proportional to the optical energy, and \( t_{peak} \) showed similar values at various optical energies. On the other hand, the \( R_{eq} \) measured with a 0.05-Ω CVR exhibited saturating behavior and \( t_{peak} \) was found to depend on the optical energy, which is affected by the induced current at the inductance of the CVR. The current oscillation was caused by the natural response of the series RLC circuit with \( R_{CVR} \), \( L_{CVR} \), and \( C_{PCSS} \). The PCSS in linear mode achieved a minimum \( R_{PCSS} \) of 0.27 Ω at the optical energy of 8 mJ and a maximum output current of 657 A at the bias voltage of 4.8 kV. Surface flashover was observed and was identified in the transient current pulse. The randomly occurring secondary pulses exhibited similar peak current and FWHM values.

### TABLE 1. Performances of SiC-based PCSSs with various load resistances.

| Ref. | Illumination type (structure) | Minimum on-state resistance (Ω) | Maximum switching current (A) | Optical energy (mJ) | Load res. (Ω) |
|------|-------------------------------|---------------------------------|-------------------------------|--------------------|---------------|
| [10] | Front (Lateral)               | 1.5                             | 450                           | 5.5                | 50            |
| [17] | Front (Vertical)              | 5.6                             | 591                           | 31.9               | 20            |
| [18] | Front (Vertical)              | 7.5                             | 840                           | 65                 | 0.05          |
| [24] | Side (Vertical)               | 0.66                            | 1500                          | 35.4               | 10.2          |
| [25] | Front (Lateral)               | <1                             | 84                            | 10.5               | 50            |

This work

| Side (Vertical) | 0.27 | 657 | 8 | 0.05 |

REFERENCES

[1] L. Pecastaing, A. S. De Ferron, V. Coudere, B. M. Shalaby, R. Negrier, M. Lalande, J. Andrieu, and V. Bertrand, “A pulsed modulator combined with very high PRF photoconductive switches to build a self-scanning UWB radiation source,” IEEE Trans. Plasma Sci., vol. 44, no. 10, pp. 1894–1901, Oct. 2016, doi: 10.1109/TPS.2016.2547279.

[2] L. Hu, J. Su, R. Qiu, and X. Fang, “Ultra-wideband microwave generation using a low-energy-triggered bulk gallium arsenide avalanche semiconductor switch with ultrafast switching,” IEEE Trans. Electron Devices, vol. 65, no. 4, pp. 1308–1313, Apr. 2018, doi: 10.1109/TED.2018.2802642.

[3] Q. Wu, Y. Zhao, T. Xun, Y. Zhang, and W. Huang, “Initial test of optoelectronic high power microwave generation from 6H-SiC photoconductive switch,” IEEE Electron Device Lett., vol. 40, no. 7, pp. 1167–1170, Jul. 2019, doi: 10.1109/LED.2019.2918954.

[4] C. Luan, J. Zhao, L. Xiao, Q. Yang, X. Ma, and H. Li, “All-solid-state electromagnetic pulse simulator based on the 4H-SiC photoconductive semiconductor switch,” Rev. Sci. Instrum., vol. 91, no. 1, Jan. 2020, Art. no. 014701, doi: 10.1063/5.0128450.

[5] Y. Shen, W. Wang, Y. Liu, L. Xia, H. Zhang, H. Pan, J. Zhu, J. Shi, L. Zhang, and J. Deng, “A compact 300 kV solid-state high-voltage nanosecond generator for dielectric wall accelerator,” Rev. Sci. Instrum., vol. 86, no. 5, pp. 5–9, May 2015, doi: 10.1063/4.921396.

[6] G. M. Loubriel, F. J. Zutavern, A. Mar, H. P. Hjalmarson, A. G. Baca, M. W. O’Malley, W. D. Helegeson, R. A. Falk, and D. J. Brown, “Longevity of optically activated, high gain GaAs photoconductive semiconductor switches,” IEEE Trans. Plasma Sci., vol. 26, no. 5, pp. 1393–1402, Oct. 1998, doi: 10.1109/7.736024.

[7] F. Davanloo, R. Dussart, K. J. Kivivaisari, C. B. Collins, and F. J. Agee, “Photoconductive switch enhancements and lifetime studies for use in stacked Blumlein pulsers,” IEEE Trans. Plasma Sci., vol. 28, no. 5, pp. 1500–1506, Oct. 2000, doi: 10.1109/27.901122.

[8] M. Wu, D. Jiannun, L. Hongwei, Z. Jinfeng, L. Jinfeng, W. Bing, Q. Yanling, H. Wenhou, W. Lingyan, J. Pin, and L. Hongtao, “Development of all-solid-state flash X-ray generator with photoconductive semiconductor switches,” Rev. Sci. Instrum., vol. 85, no. 9, Sep. 2014, Art. no. 093307, doi: 10.1063/1.4895829.

[9] W. Shi and Z. Fu, “2-kV and 1.5-kA semi-insulating GaAs photoconductive semiconductor switch,” IEEE Electron Device Lett., vol. 34, no. 4, pp. 93–95, Jan. 2013, doi: 10.1109/LED.2012.2226558.

[10] C. Ma, W. Shi, M. Li, H. Gui, N. Hao, and P. Xue, “Impact of current filamentation on the material and output characteristics of GaAs photoconductive semiconductor switches,” IEEE Trans. Electron Devices, vol. 61, no. 7, pp. 2432–2436, Jul. 2014, doi: 10.1109/TED.2014.2323052.

[11] D. Mauch, C. White, D. Thomas, A. Neuber, and J. Dickens, “Overview of high voltage 4H-SiC photoconductive semiconductor switch efforts at Texas tech university,” in Proc. IEEE Int. Power Modulator High Voltage Conf. (IPMHVC), Jun. 2014, pp. 23–26, doi: 10.1109/IPMHVC.2014.7287198.

[12] D. Mauch, W. Sullivan, A. Bullick, A. Neuber, and J. Dickens, “High power lateral silicon carbide photoconductive semiconductor switches and investigation of degradation mechanisms,” IEEE Trans. Plasma Sci., vol. 43, no. 6, pp. 2021–2031, Jun. 2015, doi: 10.1109/TPS.2015.2424154.

[13] Q. Wu, T. Xun, Y. Zhao, H. Yang, and W. Huang, “The test of a high-power, semi-insulating, linear-mode, vertical 6H-SiC PCSS,” IEEE Trans. Electron Devices, vol. 66, no. 4, pp. 1837–1842, Apr. 2019, doi: 10.1109/TED.2019.2901065.

[14] J.-W.-B. Bragg, W. W. Sullivan, D. Mauch, A. A. Neuber, and J. C. Dickens, “All-solid-state high power microwave source with high repetition frequency,” Rev. Sci. Instrum., vol. 84, no. 5, May 2013, Art. no. 054703, doi: 10.1063/1.4804196.
