SAND2023-05467C

ELECTRICAL & COMPUTER ENGINEERING

Investigating Operation Modes in Gallium Nitride Photoconductive Switches:

Nicolas Gonzalez and Jane M. Lehr
University of New Mexico

H. Hjalmarson, R. J. Kaplar, A. Mar, S. Miller, E. Schrock, G. Pickrell
Sandia National Laboratories

Abstract ID #

TWENTY-THIRD IEEE INTERNATIONAL PULSED POWER CONFERENCE

ABSTRACT

One of the most promising devices studied since the late 80s is the photoconductive semiconductor switch (PCSS) which has shown outstanding switching characteristics in gallium arsenide (GaAs) but suffers from poor power handling and lifetime limitations under pulsed power conditions. Advances in the fabrication processes of wide bandgap (WBG) semiconductors along with their outstanding properties, including electrical strength and thermal conductivity, allow their consideration as an important candidate for high-power switching devices.

Gallium nitride (GaN) has been considered a prime candidate for the high-gain mode of operation of the PCSS. While multiple researchers have reported linear operation of WBG-based PCSS, the non-linear, high-gain mode of operation has been quite elusive over the last years. Recent experiments show clear evidence of high gain operation in lateral GaN PCSS devices with average electric fields < 30 kV/cm and pulsed laser energies of a few tens of microJoules.

MOTIVATION

- WBG semiconductors such as GaN have the theoretical potential of surpassing GaAs in PCSS applications, its higher critical electric field strength (3.0-3.5 MV/cm) along with its high electron saturation velocity (~2x10^7 cm/s) make it suitable for pulsed power applications.
- When compared to linear mode, high-gain mode takes substantially less laser energy to be excited. It might be feasible to employ commercially available small laser sources coupled with a GaN-based PCSS as a novel solid-state switch if these energy levels are sufficiently low (~µJ).

arpa·e EPSCoR Sandia National Laboratories

This material is based upon work supported in part by the Advanced Research Projects Agency-Energy (ARPA-E), U.S. Department of Energy, and in part by the National Science Foundation EPSCoR Cooperative Agreement OIA-1757207. Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

EXPERIMENTAL SETUP

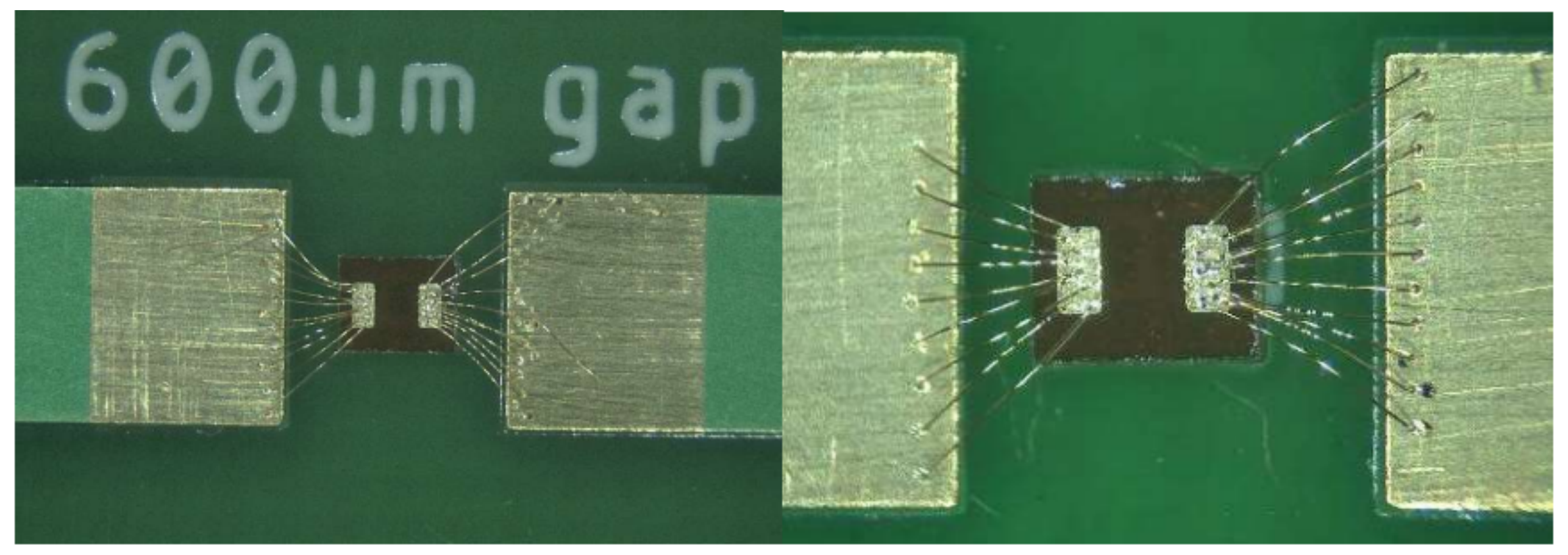

Figure 1. 600µm gap lateral GaN PCSS ball-bonded to PCB

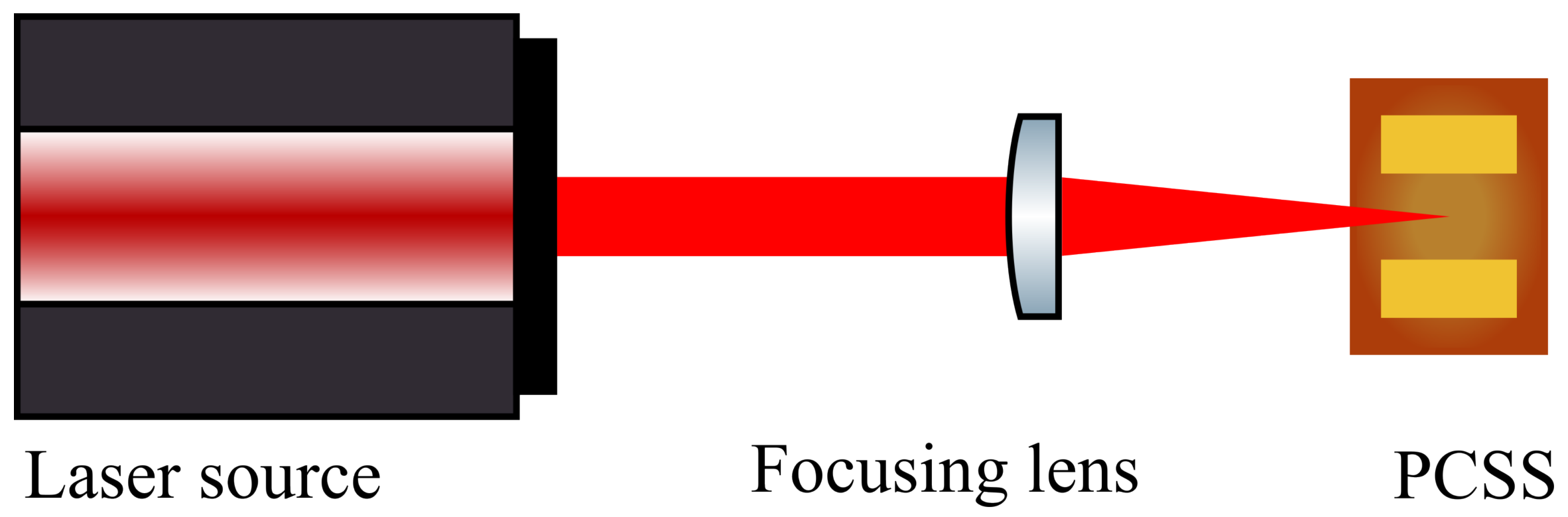

Figure 2. Optical array used in PCSS Experiments

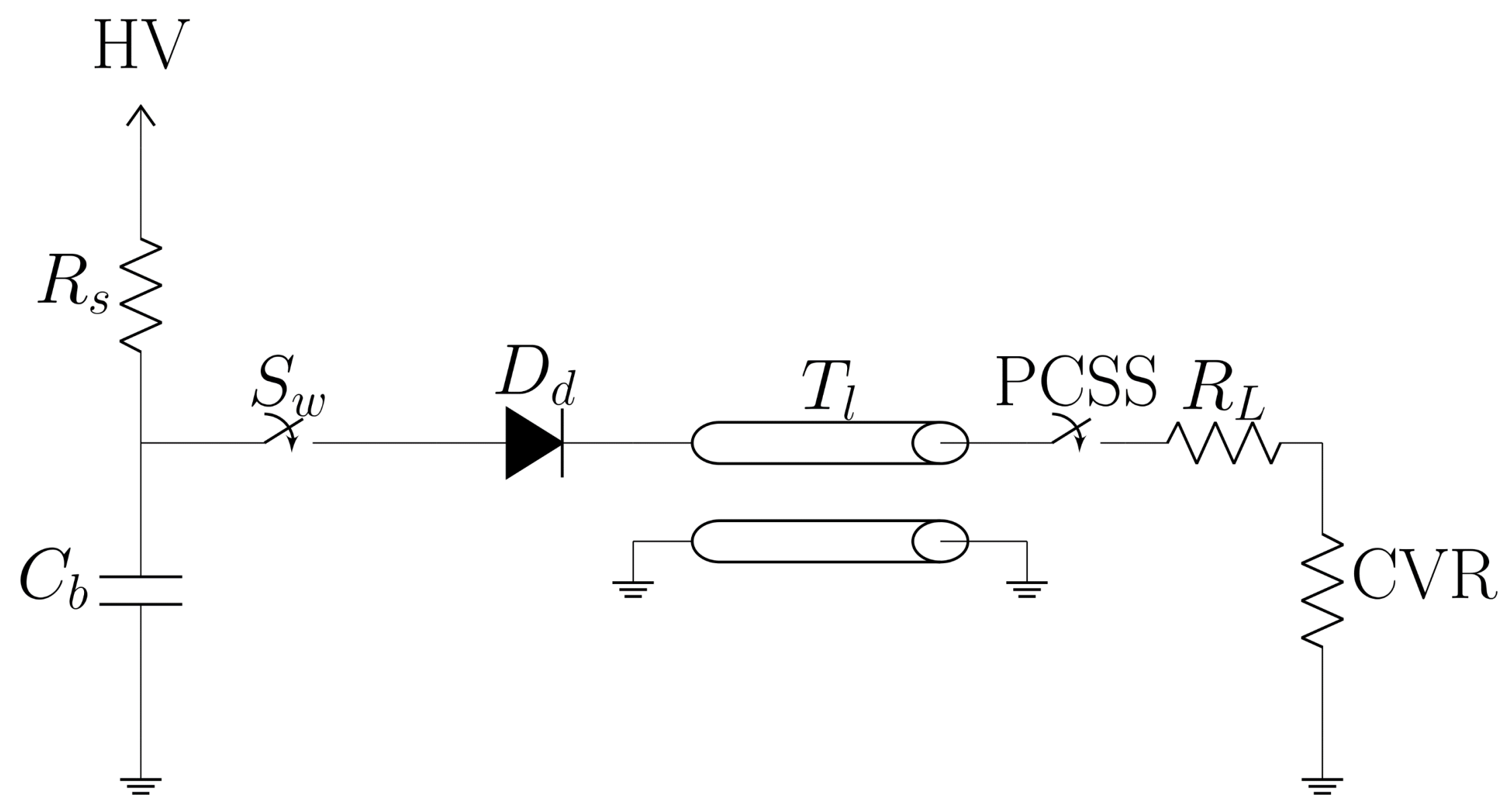

Figure 3. Circuit Schematic for GaN PCSS test bed.

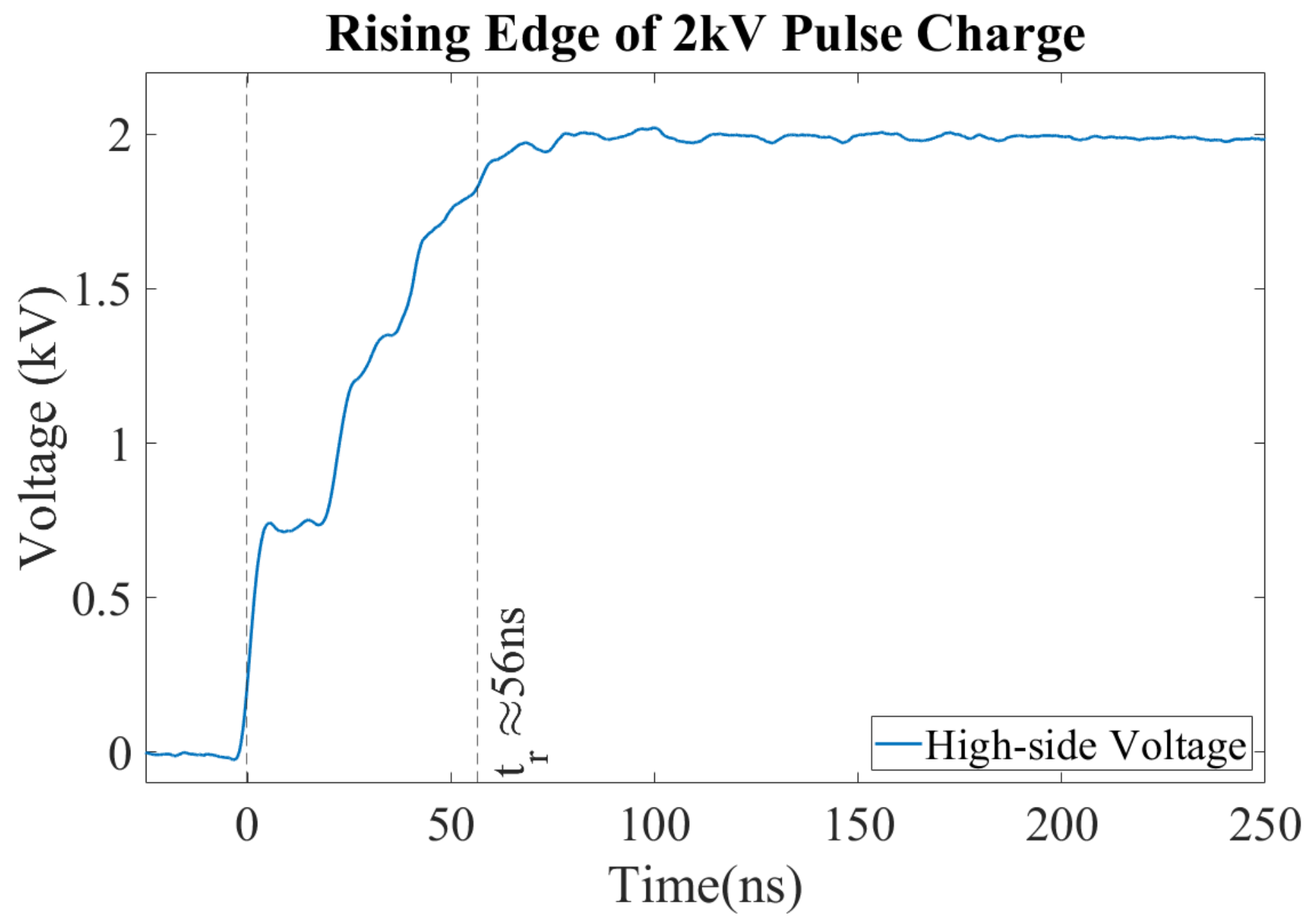

Figure 4. Pulse Charge Waveform measured at PCSS anode with single ended probe

RESULTS

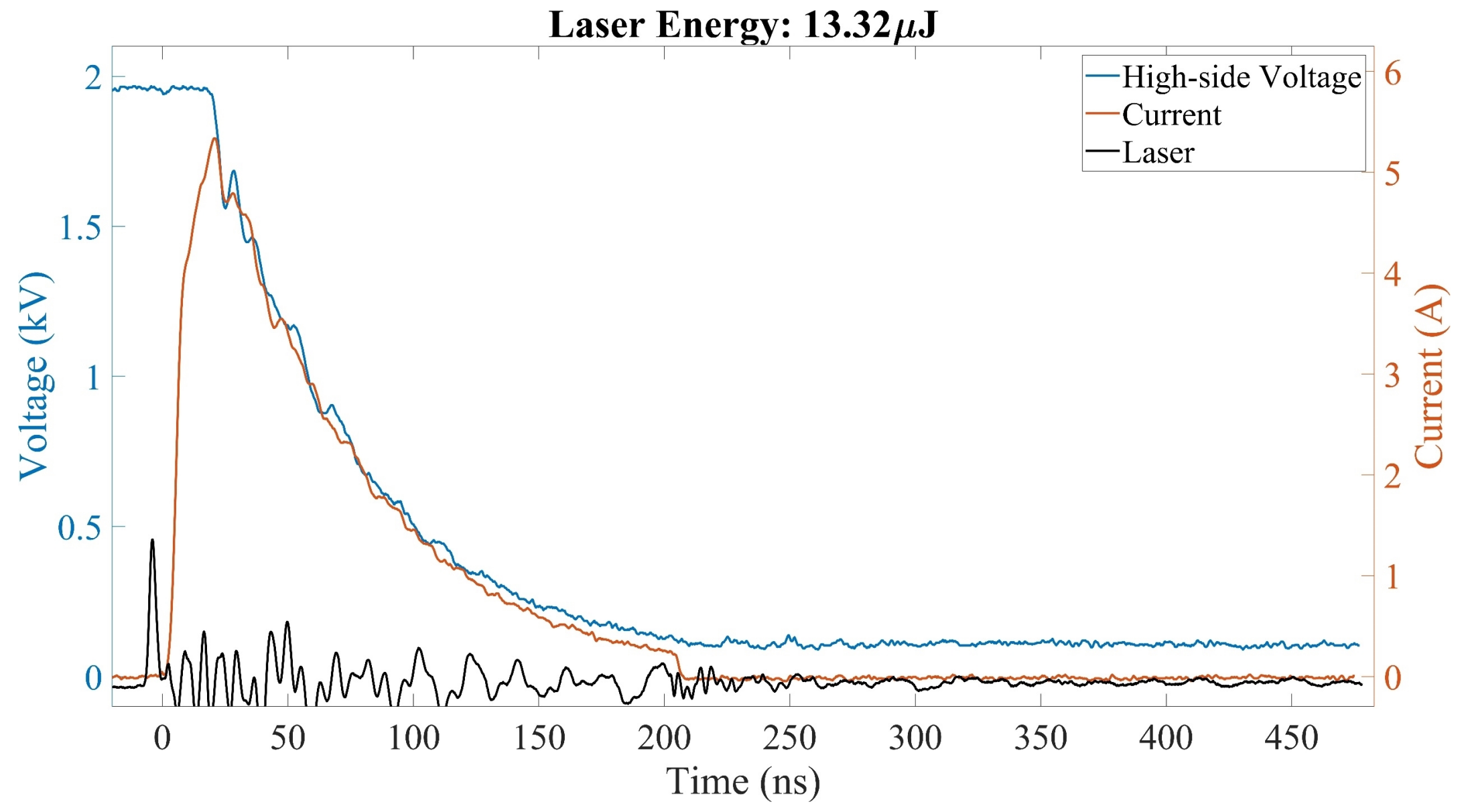

Figure 5. Wave forms during closing event of GaN–based PCSS for incident laser wavelength = 650nm.

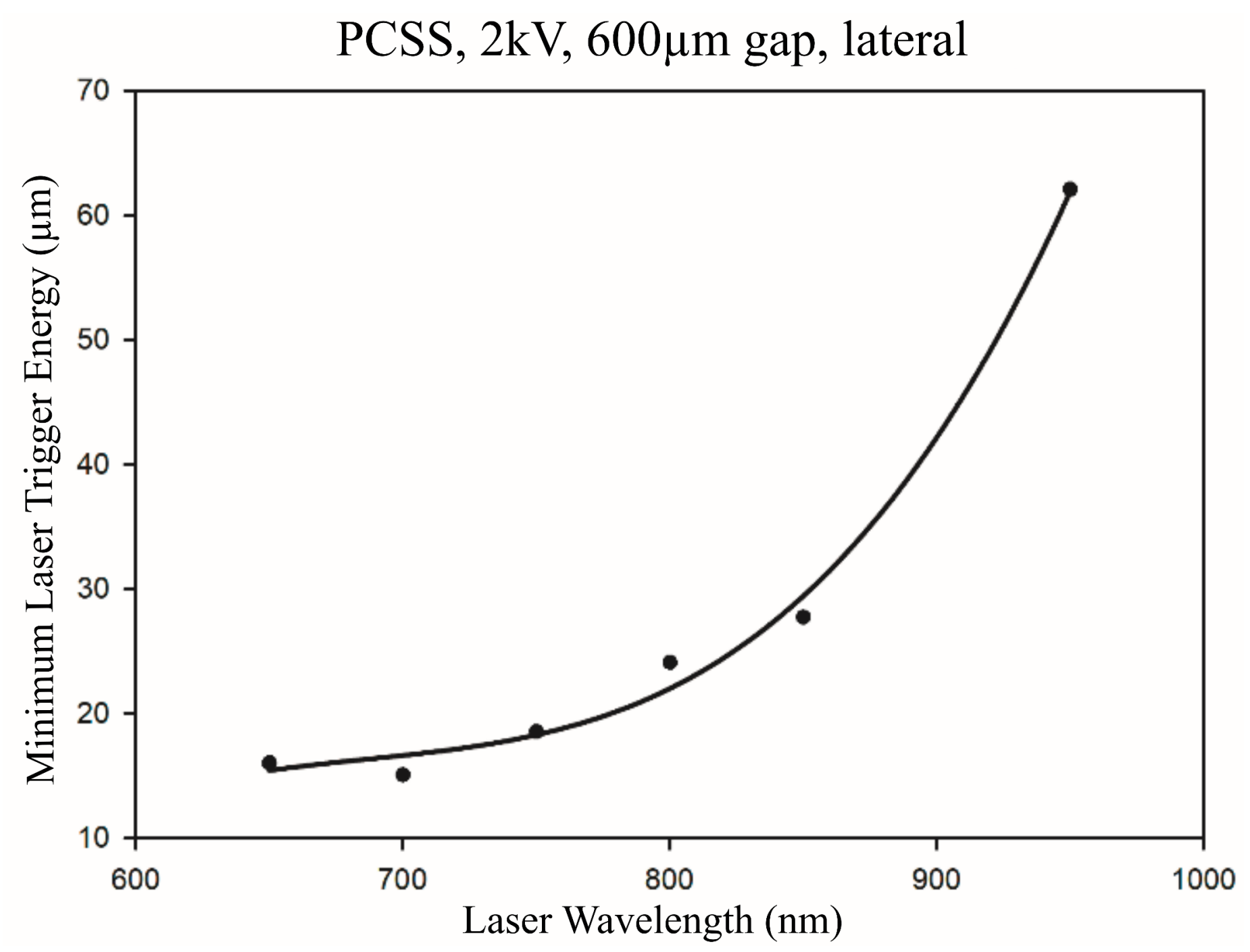

Figure 6. Minimum Laser energy to trigger high gain mode

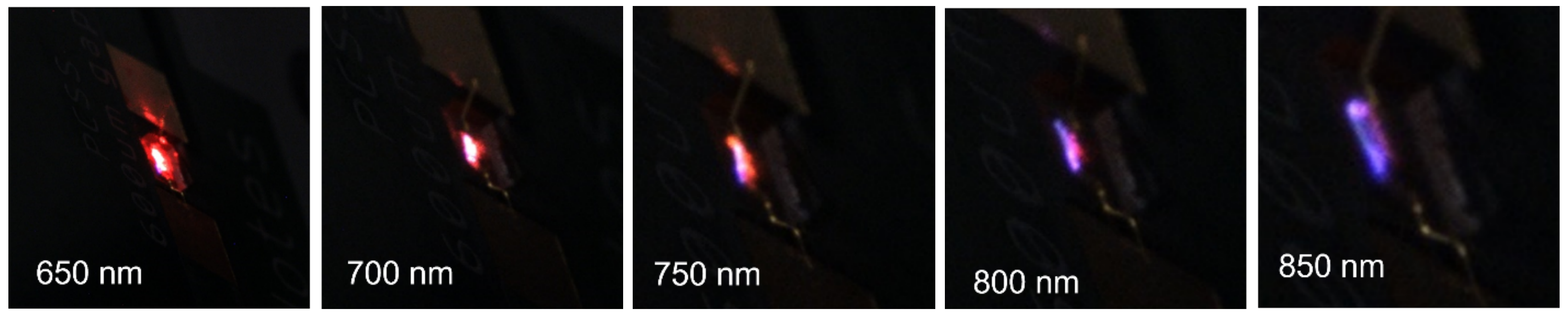

Figure 7. Light emission from GaN-based lateral PCSS during closing event

CONCLUSIONS AND FUTURE WORK

- The initial results show that low-energy lasers can experimentally drive the high-gain mode, and that the amount of laser energy needed to do so varies on the wavelength. Since the majority of high-energy laser diodes operate in the IR-NIR, we utilized wavelengths between 650 and 950 nm for our tests; however, we intend to broaden the laser source's spectral range in order to study the high gain mode activation conditions over a wider range of wavelengths.
- Although lateral geometries are frequently employed, we anticipate that the vertical arrangement of the electrodes will enhance the switch's performance. Spectrometry methods will be employed to ascertain the involvement of deep donors during carrier avalanche formation present during high-gain mode switching once we have vertical switching devices.
- In addition to these preliminary findings, it is crucial to determine how the quality of the laser beam affects the switching process. Optimizing the use of laser energy is critical in the design process of an integrated PCSS and laser source system.
- There is no consensus on how the high-gain mode develops in III-V semiconductors, despite concepts like avalanche injection via transferred-electron effect having previously been proposed to describe the mechanism that makes the high-gain mode possible. The goal of these and subsequent tests is to develop such a model.

REFERENCES

1. E. A. Hirsch et al., "High-Gain Persistent Nonlinear Conductivity in High-Voltage Gallium Nitride Photoconductive Switches," 2018 IEEE International Power Modulator and High Voltage Conference (IPMHVC), Jackson, WY, USA, 2018, pp. 45-50, doi: 10.1109/IPMHVC.2018.8936660.
2. G. Pickrell, A. Armstrong, A. A. Allerman, M. H. Crawford, D. Feezell, M. Monavarian, A. Aragon, F. J. Zutavern, A. Mar, E. A. Schrock, J. D. Flicker, J. J. Delhotal, J. D. Teague, J. M. Lehr, K. C. CROSS, C. E. Glaser, M. Van Heukelom, R. J. Gallegos, V. H. Bigman, and R. Kaplar, "Advanced gan device technologies for power electronics." [Online]. Available: https://www.osti.gov/biblio/1806873