

Laser Pumping of 5kV Silicon Thyristors for Fast High Current Rise-Times

Howard D. Sanders, Steven C. Glidden, Daniel M. Warnow

Applied Pulsed Power, Inc.
2025 Dryden Road
Freeville, NY 13068, USA
hds@appliedpulsedpower.com

Abstract—There are many applications currently using spark gap switches which would like to have the long lifetime of a solid state switch such as a silicon thyristor. This was not possible till now due to the relatively long turn-on times of silicon thyristors. The turn-on time of a silicon thyristor can be improved by providing the charge carriers using a laser source rather than an electrical source. Then the limit of the turn-on time is not the rate at which the charge carriers can be generated but on how fast the device can be seeded with photo-generated charge carriers.

Previous experiments have tried to create devices based on fast optical gating of high voltage silicon thyristors. However, these used thick expensive prototype devices. We examined the use of standard commercial silicon thyristors. The advantage of using commercial thyristors is their lower cost and smaller thickness. Thinner devices have a faster turn-on time with lower optical energy requirements.

We previously demonstrated 50ns turn-on times using 125W laser diode pumping of 5kV commercial devices that were designed for electrical triggering and had been modified for optical triggering. These devices were tested at up to 5kA peak current. This paper will describe how 500W laser pumping of silicon thyristors achieves turn-on times of less than 40ns using commercial devices designed for laser pumping and using a compact laser diode source.

Keywords-Thyristor, Laser Pumping

I. INTRODUCTION

Applied Pulsed Power, Inc. (APP) is working on developing laser pumped silicon switches with a goal of achieving <50ns risetimes to a peak current of >5kA. These Silicon switches use a standard thyristor design. Previously [1] reported results of <50ns risetimes to a peak current of >1kA used a 125W IR laser diode array and a device design now labeled as Phase I. The Phase I design involved allowing transmission of laser energy through the entire exposed anode.

With a few improvements, the laser pumped silicon switches now achieves 50ns risetimes to a peak current of 2500A. One improvement was the development of a 1kW IR laser source with the same size as the previous source. Another change was the addition of optical windows on the anode side of the device. This pattern, labeled as Phase II, in the anode metalization can be seen in Fig. 1.

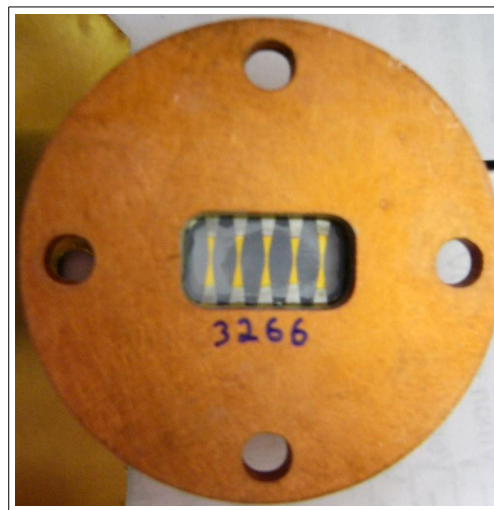


Figure 1. Optical window pattern in Anode Metalization.

In this paper laser pumping refers to seeding a thyristor with optically generated charge carriers to allow improved turn-on performance over electrical triggering. At the low power extreme of laser pumping the laser only serves to trigger the thyristor and does not improve the turn-on performance. This would be equivalent to light triggered devices. At the high power extreme of laser pumping the laser controls current conduction with the incident photon flux. This level requires much higher powers than examined in this paper.

II. LASER SOURCE

The laser source was a series array of IR laser diodes. Each diode in the array was designed to achieve 40W peak power and each one was tested to 27W peak power at 50A peak Current. Fig. 2 shows a picture of the laser diode array. The laser diode array was designed to achieve 1kW peak power at 50A peak current. The laser diode array was driven by a fast MOSFET based circuit. The circuit discharged 40nF through the diode array in series with 7.5Ω. The peak current was controlled by adjusting the circuit voltage. Fig. 3 shows the laser source operating at 650W peak power. Up to 650W, the peak power is linear with peak laser diode current at 32.5W/A.

Measurements of the reflectivity of the anode surface and transmission through the cathode surface indicated that only 20% of the incident power was deposited in the thyristor.

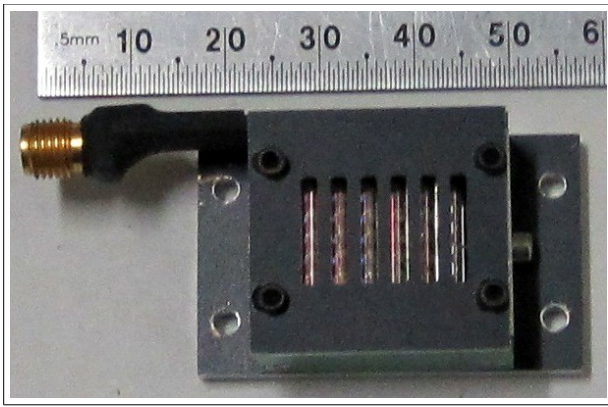


Figure 2. Picture of the laser diode array.

III. TEST DATA

It was determined with Phase I devices [1] that increased laser power resulted in improved turn-on time. However testing was previously limited by the 125W source. Testing with the 1kW source improved the turn-on time.

The current source was a series array of capacitors summing to 100nF or 170nF charged up to 3kV. The load was a series array of resistors summing to 0.5Ω or 1.5Ω. This circuit was tested with an ideal switch and achieved 15ns risetimes, much faster than any of the observed test results indicating that the test results were not circuit limited.

Fig. 4 shows the improvement in turn-on time with increased peak laser power from 30W to 650W. While there is initially a very marked improvement, the turn-on performance continues to incrementally improve with increased laser currents. At very low laser diode currents, the device basically acts like it has been electrically triggered. This can be seen in Fig. 5.

While electrical triggering resulted in long turn-on delays (~50ns) and achieved peak rate of current rise at half peak current, the laser gated results achieved short turn-on delays and a peak rate of current rise starting from turn-on. This performance of the laser gated devices is more like that of an ideal switch.

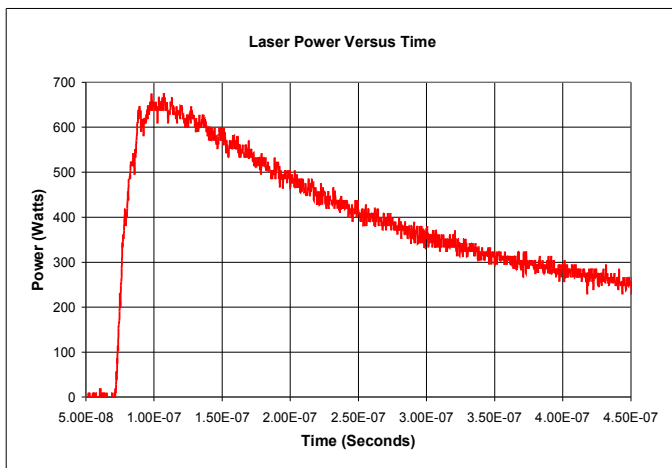


Figure 3. 650W peak power operation of the laser source.

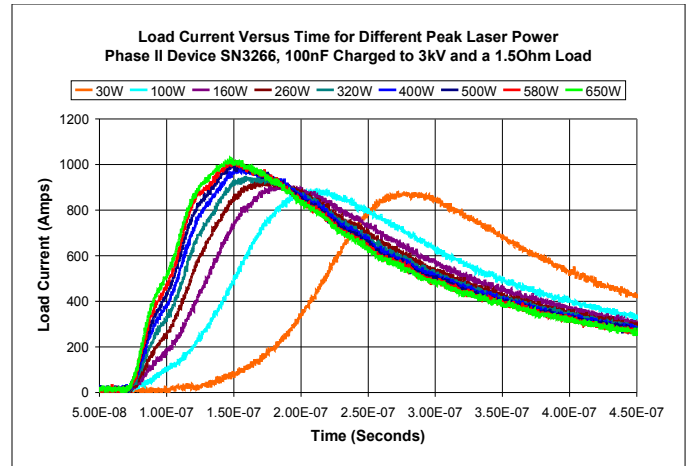


Figure 4. Improved turn-on with increased peak laser diode current.

Given the percent of the incident power deposited in the device, 650W would only generate $7e20$ charge carrier/second or enough to conduct at most 112A of anode current and given recombination rates this would be more likely around 3A of anode current. With the switch conducting >1kA the device uses thyristor action to generate the additional charge carriers required to conduct the current through the switch. The use of the thyristor design in conjunction with the laser pumping decreases the required optical power and thereby the cost of the switch package to commercially viable levels.

All of the devices could be both optically and electrically triggered. This allowed us not only to compare the improvement of optical triggering over electrical triggering, as in Fig. 5, but also examine the effects of the window on the resistance. Because the exposed Silicon is more resistive than the metal it is connected to, the Phase I devices would have a higher resistance than the Phase II devices which would have a higher resistance than devices with no optical window on the anode side. This result is shown in Fig. 6. The devices without optical windows, labeled as Electrical Only Triggerable, achieved higher current and efficiency than the Phase II or Phase I device. The effective increase was 12% resistance for the Phase II and 50% for the Phase I. This demonstrates the improvement of the window pattern used in Phase II.

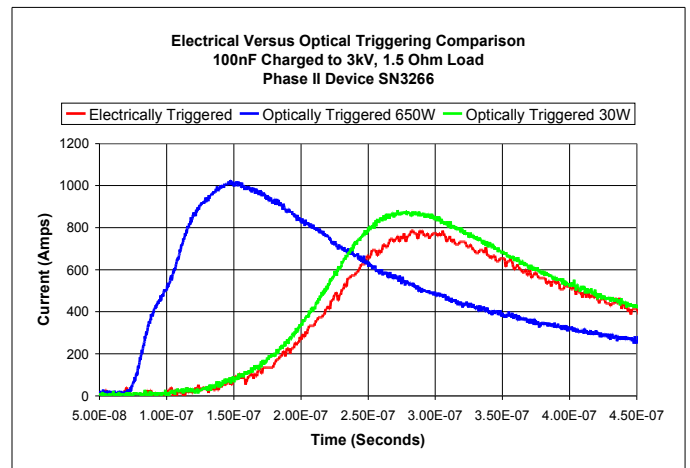


Figure 5. Comparison of Electrical and Optical Triggering.

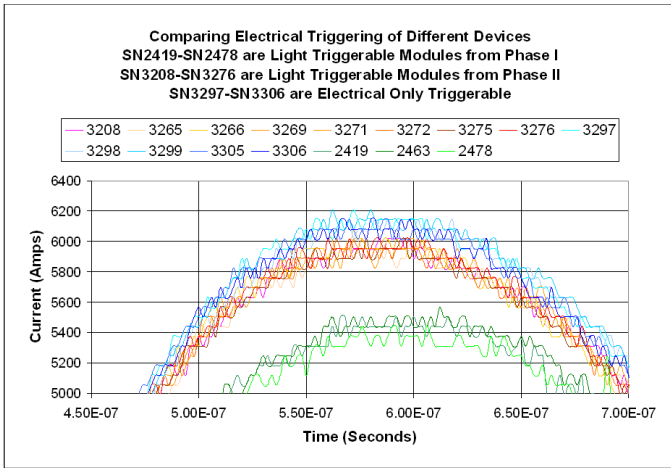


Figure 6. Comparison of Electrical and Optical Triggering.

As observed in Fig. 6, all results show only a small timing jitter, well within the accuracy of the test setup. Fig. 7 further shows 50ns risetime to 2500A peak current, short turn-on delay of 3ns and also the initial peak di/dt of 75kA/ns. These results are a significant improvement over the results from Phase I tests and over electrically triggered thyristors.

IV. PLANNED IMPROVEMENTS

Two paths are planned to further improve the laser pumped silicon switch performance. The first is to increase the laser source power deposited in the device by increasing the laser diode array power and by improving the coupling. We know that we can increase the laser source power by increasing the laser diode current and possibly achieve >1kW. Also we are working on improving the laser diodes to achieve higher power with smaller package and faster response. As mentioned in section III, the coupling is only at about 20% for the Phase II device. This is mainly due to the surface roughness of the anode which causes it to be highly reflective. We plan to improve this in the next generation of devices by further reducing the reflectivity of the anode surface. We expect to be able to increase the power deposited in the device by a factor of 4 through these changes.

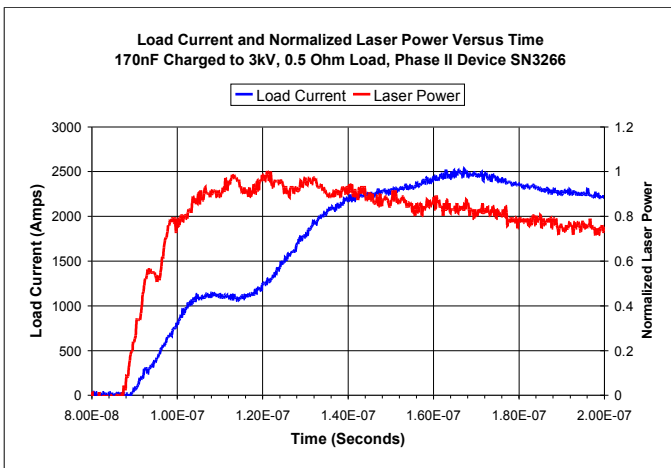


Figure 7. 50ns risetime, 75A/ns peak di/dt , 3ns turn-on delay.

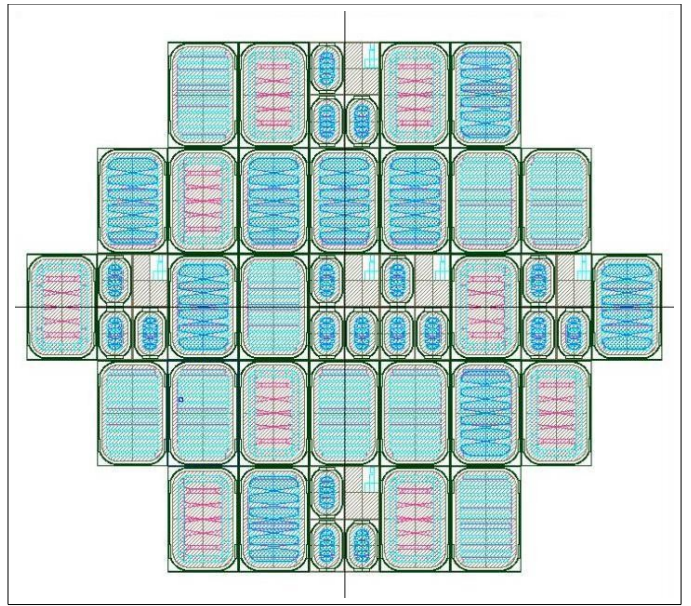


Figure 8. Next generation devices.

The other path being pursued is to design devices specifically for laser pumping. Fig. 8 shows a planned mask layout for a wafer including many different device designs. These different designs will let us determine which results in the best turn-on performance.

V. CONCLUSION

We have demonstrated that a thyristor based, laser pumped switch can achieve 50ns current risetimes to 2500A. This is a four-fold improvement over electrical triggering. We expect to achieve a further factor of two improvement with our planned upgrades.

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REFERENCES

- [1] S. C. Glidden and H. D. Sanders, "Fast optical gating of Silicon thyristors," Pulsed Power Conference, 2009. PPC '09. IEEE, pp. 1207-1209, January 2010.