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THE USE OF OPTICALLY TRIGGERED, HIGH GAIN GaAs SWITCHES FOR UWB PULSE GENERATION

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ABSTRACT

A high peak power impulse pulser that is controlled with high gain, optically triggered GaAs Photoconductive Semiconductor Switches (PCSS) has been constructed and tested. The system has a short 50 Ω line that is charged to 100 kV and discharged through the switch when the switch is triggered with as little as 90 nJ of laser energy. The laser that is used is a small laser diode array whose output is delivered through a fiber to the switch. The current in the system ranges from 1 kA (with one laser) to 1.3 kA (with two) and the pulse widths are 1.9 and 1.4 ns, respectively. The peak power and the energy delivered to the load are 50 MW to 84 MW and 95 mJ to 120 mJ for one or two lasers. The small trigger energy and switch jitter are due to a high gain switching mechanism in GaAs. This experiment also shows a relationship between the rise time of the voltage across the switch and the required trigger energy and switch jitter.

INTRODUCTION

This research has focused on optically triggered, high gain GaAs switches for high speed, high power electronics and optoelectronics. The practical significance of this high gain switching mode is that the switches can be activated with very low energy optical triggers.¹ For example, this work will show that a 90 nJ optical pulse has triggered switches that have delivered 50 MW for ~1 ns in a 50 Ω system, and previously we have switched 6 MW for ~100 ns in a 0.25 Ω system.² The GaAs switches used in this experiment are lateral switches: they have two contacts on one side of a wafer separated

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by an insulating region of intrinsic material (see Figure 1). At electric fields below 4 kV/cm, the GaAs switches are activated by the creation of, at most, one electron hole pair per photon absorbed. This linear mode demands high laser power, and after the light is extinguished, the carrier density decays in 1- 10 ns. At higher electric fields these switches behave very differently. The high field induces carrier multiplication so that the amount of light required is reduced by as much as five orders of magnitude^{1,2}. This high gain mode is characterized by fast current rise times (~400 ps) and filamentary currents with densities of several MA/cm² and diameters of 50- 300 μ m (from the photographs of recombination radiation). In the "on" state there is a characteristic, constant field across the switch called the lock-on field. The switch current is circuit-limited provided the circuit maintains the lock-on field.² Table 1 shows the results from this experiment and the best results that we have achieved (in other work) with the high gain GaAs switches when triggered with compact laser diode arrays. The works of many others has been presented at various conferences.³

Figure 1. Schematic of the lateral switches that are used in this study. Light illumination is either uniform (as shown) or through a small fiber optic line that ends near one of the contacts.

Table 1. Summary of results from tests where high gain GaAs switches are triggered with laser diode arrays (LDA).

	This Exp.	Other*
Switch Voltage (kV)	100	155
Switch Current (kA)	1.0	5.2
Peak Power (MW)	50	50
Rise time (ps)	430	430
R-M-S jitter (ps)	150	150
Optical Trigger Energy (nJ)	90	90
Repetition Rate (Hz)	1,000	1,000
Electric Field (kV/cm)	67	100
Device Lifetime (No. pulses)	NA	500,000

* Not all the results are simultaneous.

EXPERIMENTAL SETUP

The circuit that was used in these tests is shown in Figure 2. It operated in bursts of up to 5 pulses at a repetition rate of 1 kHz. We charged a nominally 1.0 ns long, 47 Ω , parallel plate transmission line. This line is discharged with either one or two switches into a 50 Ω load. We measured the voltage on the transmission line and the current through the load. A typical transmission line voltage waveform is shown in Figure 3. The voltage on the line, shown at 100 ns/div., rose to a peak value with a charge time of 210 ns. At this point the laser activated the switch and the line voltage dropped. If only one switch was triggered, the resulting load voltage was a monopulse. If both switches were triggered simultaneously the load current was a monocycle (bipolar pulse). Previous studies show that, as the switched field increases, the switch rise time decreases and the trigger energy is reduced.² We used switches with an insulating region of 1.5 cm at a voltage of 100 kV. At this voltage, the energy on the charge line was 54 mJ. Because the fields across the switch were above air breakdown the switches were immersed in a dielectric liquid (Fluorinert®). To avoid corona and breakdown, the transmission line was in SF₆ gas.

Figure 2. Schematic of the circuit that was used in these experiments. A short (1 ns), 47 Ω transmission line (the charge line) was charged to high voltage at a burst repetition rate of 1 kHz. Two switches were used on either side of the line to discharge the line into a 50 Ω load.

Figure 3. The voltage on the charge line. The waveform is displayed at 20 kV/div. (0 is one division from the top) and at 100 ns/div. The charge time is 210 ns and the peak voltage is 100 kV. When the voltage reaches its peak value of 100 kV the laser diode arrays triggers the switch (at the center of the waveform) discharging the line.

RESULTS

In the first set of tests both laser diode arrays were used to activate one switch and obtain a monopulse. The highest current measured with this system is shown in Figure 6. The width of the current pulse and its peak value depend on the time delay between when the two laser diodes are triggered. When both diodes are triggered to produce simultaneous current pulses, the current is largest and the current pulse width is smallest. The highest current (figure 6) was 1.3 kA with a rise time of 430 ps and a pulse width of 1.4 ns. This corresponds to 84.5 MW (peak) with 180 nJ of trigger energy. With one laser diode activating one switch the current is about 1.1 kA with a rise time of about 770 ps and a pulse width of 1.8 -1.9 ns.

Figure 6. The current through the $50\ \Omega$ load when both laser diodes are used to trigger one switch. This is the highest peak current (1.3 kA), the highest peak power (84.5 MW), and the smallest width (1.43 ns) that we measured.

The difference in current waveforms when we use one laser versus two may be due to two different reasons: a difference in the switch inductance and a the dynamics of the high gain process. Our circuit simulations show that the current risetime for a total inductance of 18 nH would be about 430 ps with a width of 1.3 ns. An inductance of 40 nH results in a rise time of 740 ps with a width of 1.6 ns. Thus it may be possible that one filament with an inductance of 40 nH results in one current waveform and two filaments with about half the inductance create a faster current pulse with a faster rise and smaller width. The problem with this scenario is that the inductance we expect, based on the pictures of the filaments that gave rise to these current waveforms, is much smaller. In this setup the inductance of a filament is estimated to range from 15 nH to 21 nH for filament radii of 300 μm to 50 μm , respectively, assuming that the filament keeps that radius for 1.5 cm. The pictures show a filament that starts small but ends with a width of about 1 cm. The inductance would be much smaller (4 nH). Thus, there are other factors contributing to the different waveforms. One possibility is that the gain in one filament may be affected by the presence of the other filament resulting in a faster process: the lower current density in each filament may allow it to create more carriers, especially if there is an upper bound in the carrier density. Another possibility is that both filaments are generating carriers and thus the time required for their combined resistance to drop from $2Z$ to $Z/2$ (where Z is the impedance of the system) is reduced by a factor of two

Two laser diode arrays were used to trigger the switches. Each consisted of three laser diodes coupled to a 300 μm fiber optic. Each array delivered 90 nJ in 4.2 ns at 876 and 857 nm to a spot near the positive high voltage (100 kV) side of the switch. For other tests, these same laser diode arrays were configured to produce a longer pulse (20 ns) with larger energy (1.8 μJ) and power (90 W). The waveforms for the laser output are shown in Figures 4 and 5 for the 90 nJ and 1.8 μJ configurations, respectively.

All the monitors were calibrated. The calibration of the low bandwidth voltage monitor was straightforward. We assume the calculated values of the impedance of the system. The calibrations of the load resistor and current viewing resistor in parallel with it were carried out at low voltages and at low bandwidth. For this system, charged to 100 kV with a line impedance of 47 Ω and a load resistor of 50 Ω , the maximum current that we expect is 1.0 kA. We measured up to 1.3 kA. Because the electrical skin depth at the high frequencies is smaller than at the frequencies where the current viewing resistor is calibrated, its resistance may be higher than measured. This affects the calibration and may be the reason why the currents are too high.

Figure 4. The output (arbitrary units) from the laser diode arrays configured in such a way that the total energy in the pulse is 90 nJ. The pulse duration is 4.2 ns. The peak power is 21 W.

Figure 5. The output (arbitrary units) from the laser diode arrays configured in such a way that the total energy in the pulse is 1.8 μJ . The pulse duration is about 20 ns. The peak power is 90 W.

The second set of tests utilized both laser diodes, each triggering one switch, to produce a monocycle. Figure 7 shows the current waveform. In theory, with ideal switching, the monocycle should be composed of two monopulses of opposite polarity each with half the pulse width. Thus, we expect a monocycle composed of a negative and positive pulses with a width (each) of 0.9 ns. What we observe is a width of 1.0 ns for the negative pulse and 1.3 ns for the positive pulse. The reason for this is a timing error of about 200 ps. The minimum width should occur when both switches are triggered simultaneously. It is very important to trigger both switches at the same time to obtain full voltage and to obtain the proper waveform. In our tests, the switch jitter did not allow us to always reproduce the waveform of Figure 7 even with identical starting conditions.

Figure 7. The current through the 50 Ω load when each of the two laser diodes is used to trigger one switch.

Low jitter triggering at 90 to 180 nJ of optical energy depends on the rise time of the pulse charging (voltage) waveform. We tested this effect in an experiment where the first to last timing spread was recorded for different voltage rise times (210, 590, and 865 ns) and different laser energies (90 nJ and 1.8 μ J). Neither laser energy triggered the switch with the 865 ns rise time. The 90 nJ did not trigger the switch when the voltage rise time was 590 ns. The 1.8 μ J did trigger the switch when the rise time was 590 ns but only about half the time. The first to last timing spread was 6 ns for one ten pulse sequence and up to 100 ns in others. For the 213 ns rise time both laser energies resulted in timing spreads of < 1 ns. The experiment shows a relationship between the rise time of the voltage across the switch, the required trigger energy, and switch jitter. This is in marked contrast to the switch rise time for linear photoconductivity where the drop in switch resistance is dependent only on the laser pulse and the carrier lifetime. Note that the dielectric relaxation time, $\rho\epsilon$, is 11.6 μ s. Thus, these effects are occurring at times that are much shorter than the relaxation time. It may be possible that the effect that we observe is related to trap filling in the GaAs because trap filling affects the electric field distribution.

CONCLUSION

This study has shown that it is possible to obtain high peak power (>50 MW) impulses in a system with an impedance of 50 Ω using laser diode triggered PCSS operated in the high gain mode. The system was operated at a burst repetition rate of 1 kHz. The system is very small because laser diode arrays of very small energy output (90 nJ) were utilized to trigger the switches. The ability of the laser diodes to trigger the switches was enhanced

by fast (210 ns) charging of the transmission line which the switch discharges. An added benefit of the faster charging was a small switch jitter (150 ps). The small jitter may allow the use of these pulsers in transmitter arrays.

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