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A Compact, Short-pulse Laser for Near-field, Range-gated Imaging*

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ABSTRACT

This paper describes a compact laser, which produces high power, wide-angle emission for a near-field, range-gated, imaging system. The optical pulses are produced by a 100 element laser diode array (LDA) which is pulsed with a GaAs, photoconductive semiconductor switch (PCSS). The LDA generates 100 ps long, gain-switched, optical pulses at 904 nm when it is driven with 3 ns, 400 A, electrical pulses from a high gain PCSS. Gain switching is facilitated with this many lasers by using a low impedance circuit to drive an array of lasers, which are connected electrically in series. The total optical energy produced per pulse is 10 microjoules corresponding to a total peak power of 100 kW. The entire laser system, including prime power (a nine volt battery), pulse charging, PCSS, and LDA, is the size of a small, hand-held flashlight. System lifetime, which is presently limited by the high gain PCSS, is an active area of research and development. Present limitations and potential improvements will be discussed.

The complete range-gated imaging system is based on complementary technologies: high speed optical gating with intensified charge coupled devices (ICCD) developed at Los Alamos National Laboratory (LANL) and high gain, PCSS-driven LDAs developed at Sandia National Laboratories (SNL). The system is designed for use in highly scattering media such as turbid water or extremely dense fog or smoke. The short optical pulses from the laser and high speed gating of the ICCD are synchronized to eliminate the back-scattered light from outside the depth of the field of view (FOV) which may be as short as a few centimeters. A high speed photodiode can be used to trigger the intensifier gate and set the range-gated FOV precisely on the target. The ICCD and other aspects of the imaging system are discussed in a separate paper[1].

Keywords: short pulse laser diode, range gated imaging, high gain switching, intensified CCD, sub-nanosecond imaging, photoconductive switching, laser radar, LIDAR, LADAR.

2. INTRODUCTION

MASTER

A range-gated imaging system, which can be used to eliminate backscatter in strong scattering environments, is being developed for near-field target detection, by combining two high speed technologies. (1) A compact, high power, short pulse light source is produced by driving a 100 element laser diode array (LDA) of single heterojunction, wide-stripe, edge-emitting lasers with a low inductance, high voltage, GaAs photoconductive semiconductor switch (PCSS). (2) High-speed range-gated images are recorded with a microstrip gated micro-channel plate image intensifier (MCPII) followed by a charge coupled device (CCD) camera. The environments of interest include the turbid water found in a surf zone and dense smoke or

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other man-made aerosols which preclude the use of standard optical imaging technologies. The range of interest in these strong scattering media is approximately 25 feet. The field of view is wide angle (20-30°) with an adjustable depth of field that can be as small as a few centimeters.

Range-gated imaging has been discussed extensively in the literature[2] The work described in this paper is aimed at developing a practical system to push this technology into the sub-nanosecond regime. This is necessary in strongly scattering media to avoid saturation or reduce the background in the camera which is produced by scattered light from outside the range of interest in the field of view (FOV). The gated camera (MCPII-CCD) is described in another paper at this conference[1]. This paper describes the light source (PCSS-LDA), illustrates some of its properties, and discusses further research and development issues which are being explored.

3. GAIN SWITCHED LDAs

Gain switching in semiconductor lasers has been demonstrated previously using avalanche transistors to inject carriers into the lasers with short, 5-20 ns, current pulses[3]. The major difficulty with using this technique to produce high power, short pulse lasers, is the problem of delivering, high speed, high current pulses to large arrays of low impedance lasers. The current rise time in such circuits is generally limited by L/R, where L is the circuit inductance and R is the resistance of the load. The inductance of the circuit is usually dominated by the switch and component connections. Although the effective resistance of each laser diode is less than 1 Ω, the resistance of the array can be substantially larger if the lasers are wired in series. Unfortunately, fabrication and packaging techniques are best suited for producing arrays of lasers which are connected electrically in parallel.

To obtain sub-nanosecond rise times and high current pulses (100-700 A), high gain GaAs PCSS[4] and LDAs are being used. The inductance due to components and connections is minimized by using a transmission line and short connections as shown in figure 1. The strip transmission line is charged to a few kilovolts for a few microseconds with a pulse charging capacitive discharge unit (CDU). The energy stored in the transmission line is delivered to the LDA when the PCSS is optically triggered by a small laser which is driven by an avalanche transistor. The rise time of the current pulse is approximately 0.3 ns (determined by the PCSS) and the current pulse width is 2-4 ns determined by the length of the transmission line. The LDA is mounted as close to the switch as possible, and the individual lasers are connected in series with wire bonds.

Using a single bar of twenty lasers we have produced as high as 2 μJ by charging the transmission line to 5 kV and conducting 250 A through the lasers for 3 ns. With five bars in series (100 lasers), we have produced 12 μJ, charging to10-15 kV and conducting 300-400 A for 3 ns. Bandwidth-limited waveforms of a fast photodiode response to these pulses are

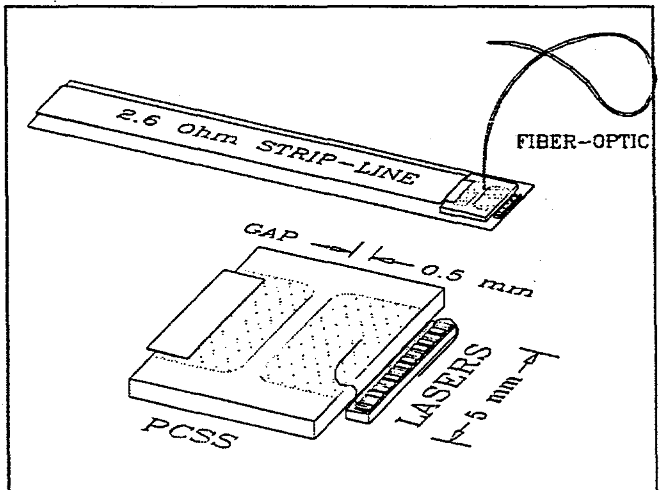


Figure 1. A strip transmission line, PCSS with fiber optic trigger, and LDA are shown at the top of this diagram. The bottom is a scaled enlargement of the PCSS and LDA. The PCSS is larger than the lasers.

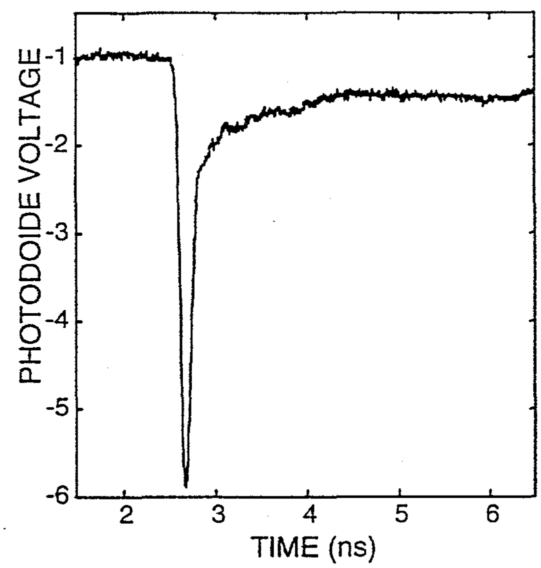
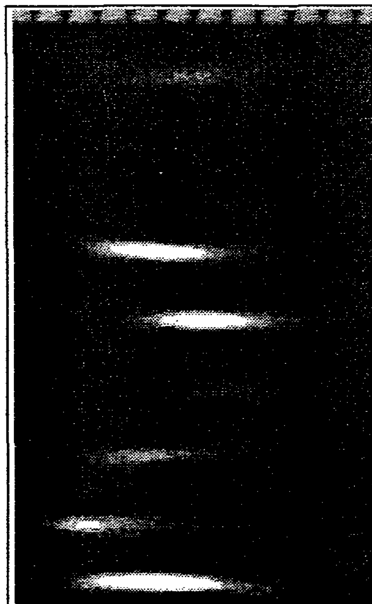


Figure 2. The optical signal (bandwidth-limited) from one laser in the LDA recorded with a fast photodiode shows has a width of 140 ps.. True optical pulse width is recorded with a streak camera (figure 3).



#	width	rise
1.	64	45
2.	<110	40
3.	<110	46
4.	?66	
5.	75	50
6.	74	39
7.	<150	33

Figure 3. Streaks from individual lasers were analyzed to determine widths and rise times in picoseconds. The brightest ones (2, 3, 7) saturated the film, so full widths at half maximum are unknown. Number 4 was too weak to measure accurately. The graticule at the top is in mm and the sweep rate is 16 mm/ns.

shown in figure 2. To get a true measurement of the pulse width, a streak camera was used to obtain the streaks and results shown in figure 3.

The potential of this technology for making simple, compact, high power, short pulse optical sources is illustrated in figure 4, where a CDU, PCSS, and LDA are shown. This "pen-light" size system runs off a 9V battery and requires only a 5V (TTL) trigger to initiate the optical pulse. The picture shows only one laser bar (20 lasers) which delivered 2 μJ per pulse, but a similar sized system can drive five laser bars (100 laser) and deliver 12 μJ per pulse. A still larger version is being developed and optimized for short pulse lasing. It should produce 50 μJ per pulse. Gain switching eliminates the need for Q-switching or mode-locking with precisely aligned electro-optics which would require additional high voltage drivers. Some of the advantages of this system over conventional miniature lasers are shorter optical pulses, a simpler optical design, optical triggering, reduced triggering jitter, and lower component count.

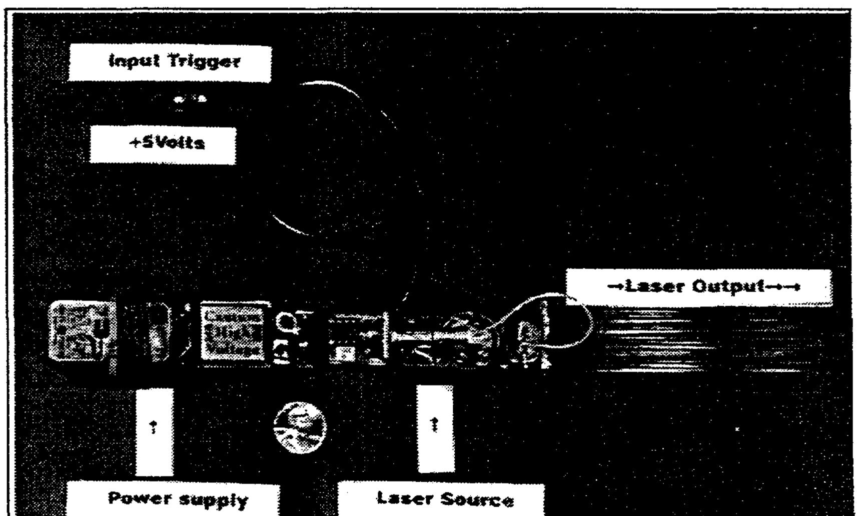


Figure 4. A battery powered short pulse source is shown in this photo. It produces 2 μJ with 20 lasers. A 100 laser version produces 12 μJ.

4. DELAY, JITTER, AND PEAK POWER

The time delay and jitter between the trigger signal and the output pulse from the lasers are determined by four components (and the propagation delay between them): (1) the avalanche transistor which drives the trigger laser, (2) the trigger laser, (3) the PCSS, and (4) the output lasers. The avalanche transistor and trigger laser are relatively small, low current devices with a 8-10 ns delay and 50-200 ps jitter. The delay to PCSS triggering is a function of the optical trigger energy, pulse shape, and location on the PCSS. Short fast rise time pulses are desired, but since the transistor limits the current to the trigger laser, higher energy pulses are wider and slower. PCSS triggering is also improved with higher optical energies. Hence, there is a system trade-off between pulse shape and energy which must be optimized.

By far the most sensitive parameter for delay and jitter in PCSS triggering is the location of the optical fiber over the active region of the PCSS. High gain GaAs PCSS always conduct current in filaments. The number and density of these filaments is a strong function of how they are optically initiated. Triggering is typically best when the fiber is close to one of the contacts and 500-1500 microns above the surface of the GaAs. The optimum position is a function of switch size, trigger laser energy, laser wavelength, and fiber optic diameter. Under optimized conditions, we have observed sub-nanosecond delays with jitter below 250 ps with 2.5 mm long PCSS. However, when the parameters are not optimized, we have observed delays of several nanoseconds and jitter of 1-5 ns. Switch lifetime is also a strong function of the fiber location above the PCSS. Damage produced near the contacts can cause the filament formation to vary dramatically from pulse to pulse, which affect switching initiation, and increase jitter. The areas of device longevity and switch jitter are presently being studied carefully. Research over the last few years has increased the lifetime of these switches from 10^4 to 10^7 at 10 A per filament and 6×10^5 at 80 A per filament. Jitter in the PCSS may also be improved, but at present our lower limit under optimum conditions is 250 ps.

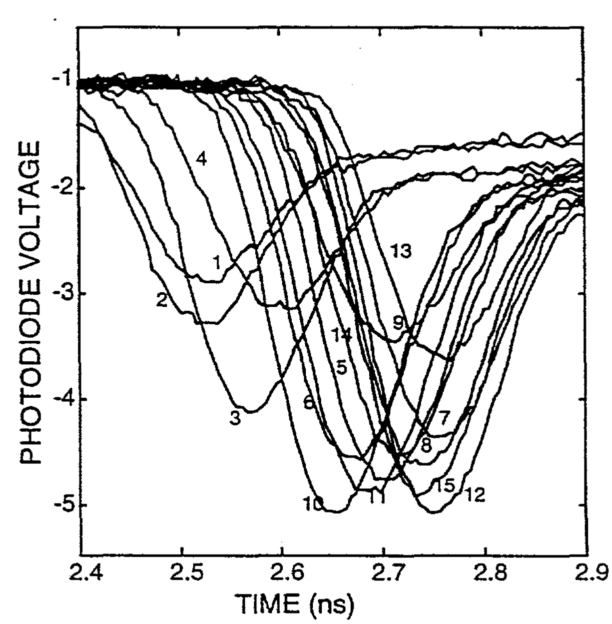


Figure 5. This plot shows variation in the amplitudes and delays of the optical pulses from each of the 15 lasers in the LDA. This variation is stable to less than 50 ps so improved synchronization can be achieved.

The delay and jitter in the output lasers is also an area of important research. Several interesting properties have been observed. There is a 2.5-2.8 ns delay between when the current pulse starts injecting carriers into the lasers and when they begin to lase. In some cases, increasing the injecting current, increases the delay. This anomalous behavior is contrary to the simple picture that carriers are simply injected until a lasing threshold is reached, because higher currents would imply shorter delays to the lasing threshold. Figures 3 and 5 show that the optical output from individual lasers is not simultaneous, even though they are being driven by one PCSS current pulse and are all wired in series. Jitter between the individual lasers impacts not only the system jitter, but also the peak optical power. Fortunately, the individual delays to lasing are very stable, and laser-laser jitter is less than 50 ps. However, systematic differences in these delay times are clearly shown in figure 5. There are two approaches to maximize the peak output power by synchronizing the laser pulses. One is to use fiber optics to deliver the output from the lasers. Since the variation in delay between lasers is stable, fiber lengths can be trimmed to align the pulses in time. This approach is feasible, but probably tedious and costly. The other approach is to determine what parameters control this delay and stabilize or adjust the fabrication of the lasers so that the systematic variation is reduced to below the jitter. Removing this systematic variation in the individual laser pulses would produce total peak powers of 10-20 kW , 50-100 kW, and 250-500 kW for the lasers described above which produce 2, 12, and 50 μJ, respectively. Presently, the total power is averaged over about 300 ps, producing about 1/3 of the potential peak power level.

5. SHORT PULSE LDA DEVELOPMENT

Results from some of the lasers, which we have pulsed with a PCSS driver, are shown in Table I. Of the lasers tested, single heterojunction, wide-stripe, edge-emitting lasers clearly produce the highest short pulse energies and peak powers. These are also the only ones which we have been able to gain switch. Although these lasers are relatively inexpensive, they are an older technology, which is not as promising for many other market-driven reasons, including their relatively poor beam quality. The limitations of the "off-the-shelf" quantum-well lasers are

Table I. Results from lasers tested with PCSS drivers.

		Rated		SNL tests			
LASER type	number of lasers	power (W)	width (ns)	power* (kW)	width (ns)	energy (μJ)	power ratio
single heterojunction broad edge emitting	100	-	-	50-75	0.100	12	-
single heterojunction broad edge emitting	100	-	-	12	1	12	-
single heterojunction broad edge emitting	40	240	200	2.5	5	12.5	10
single heterojunction broad edge emitting	20 & 15	240	200	12	0.075	1	50
multi-quantum well MOCVD, edge	637	1000	10	6.6	6	40	6.6
multi-quantum well edge	2	20	120	0.3	2	0.6	15
MOCVD, edge central narrow stripe	3	40	200	0.3	6	1.8	7.5
multi-heterojunction, large area, continuous	1	1	cont.	0.009	50	0.45	9

* These numbers assume that the optical pulses from the individual lasers in the arrays are synchronized as discussed in section 4.

being explored to see if they can be improved for short pulse operation without sacrificing their other desirable characteristics. At the same time, new lasers, which are optimized for short pulse operation and improved beam quality, are being designed for fabrication and testing.

In addition to using larger arrays of lasers, higher energies, powers, and power densities can be achieved by developing lasers which are designed for short pulse operation. Figure 6 shows a diagram of the approximate dimensions of the single heterojunction, wide-stripe, edge-emitting lasers which have produced the best short pulse results. Wider-stripe lasers are easier to assemble into large, high power arrays, but their beam quality is degraded by higher order lasing modes. Dead space between the lasers is often included to improve heat transport and dissipation. For our interests in the sub-nansecond regime, thermal transport is not an issue and much more closely spaced arrays can be manufactured, that would produce optical sources with higher power densities. The facet damage threshold, that may be reached by the high intensities of these very short pulses, can be increased by increasing the output surface area and with anti-reflection coatings. Since none of the lasers that we have tested to date were designed for short pulse operation, these and other improvements may increase the energy and power delivered in the sub-nanosecond regime by several orders of magnitude.

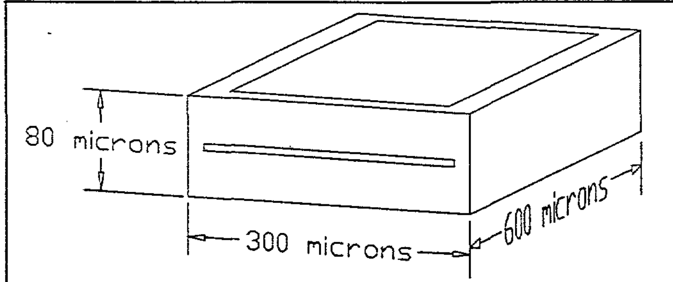


Figure 6. This diagram shows the approximate dimensions of some of the single heterojunction, wide-stripe, edge emitting lasers. To date this simple design has proven to be the most effective at gain switching when pulsed with a PCSS driver.

6. SHORT PULSE PUMPING WITH LDAs

For the range-gated imaging application described in our introduction, we have been developing the direct use of short pulse LDAs. However, improved beam quality, reduced jitter, and decreased component count may also be achieved in other systems by using LDAs for short pulse pumping. The total power achievable with PCSS driven LDAs is only limited by the number of LDAs. We have used single PCSS to switch 150 kV and 7 kA, and multiple switch systems are being tested to deliver 80 kA for other applications.

Assuming a single PCSS delivers 5 kA and 100 kV in pulses from 3-5 ns long. Scaling from the 100 laser result in Table I that used 350 A at 10 kV, we could drive 14 times as many lasers in parallel and at least 10 times as many in series or a total of 14,000 lasers. We would produce at least 140 times as much energy (1.7 mJ) and power (7 MW). This is a conservative estimate because going from 20 to 100 lasers produced more than five times the energy and power and it took only about 1.5 times the current and twice the voltage (3 times the power). (This improved operation was the result of improved coupling between the switched circuit and the lasers, i.e. a smaller fraction of the voltage was dropped across stray circuit inductance.) This estimate assumes the voltage and current required would increase linearly with series and parallel connections, so 1 PCSS can probably drive many more lasers than is estimated here.

A primary issue for many applications, however, is not total power but power density which can be delivered to a target. In this case, improved beam quality, smaller sources, and/or smaller beam divergences are the highest priority. Direct use of incoherent arrays of lasers will probably not meet these goals. However, a system where these LDAs pump a miniature crystal would have many of these desirable features. Gain switching the crystal would produce as short or shorter pulses than the LDAs and eliminate the need for electro-optical or passive Q-switching. The jitter would be comparable to the PCSS-LDA jitter described above. Most importantly the beam quality, source size, and beam divergence could be set by the design of the miniature crystal. Efficiency should be even better than long pulse pumping due to higher optical intensities and shorter times to accumulate losses. The optical efficiency will probably be limited by the efficiency of the configuration to couple the light from the LDAs to the miniature crystal.

7. RANGE-GATED SYSTEM TESTS AND ISSUES

Preliminary tests with the optical source described in this paper and a sub-nanosecond MCPII-CCD camera are described in an accompanying paper at this conterence[1]. The major issues for this application are total power, pulse width, wavelength, and jitter. The total power will limit the range or equivalently the scattering density for which this system is useful. The pulse width of the light source and the gate width of the camera limit the range resolution or the ability to reject scattered light from outside the range of interest. As described above, the PCSS-driven LDA have demonstrated the total power and pulse width required to meet these system requirements. However, these results have been achieved with 904 nm lasers. Since shorter wavelength lasers are detected more efficiently with state-of-the-art MCPIIs and more appropriate for some scattering media, our present goal is to obtain similar results with shorter wavelength or frequency doubled lasers.

Jitter in the optical source limits the options for triggering the camera. Jitter-free source and camera would allow immediate image collection at a specified range. However, as described in section 4, the PCSS-LDA is by no means jitter-free. Under the optimum conditions it may be as low as 250 ps, which will be acceptable for most applications (under water this would be an equivalent range jitter of 2.5 cm). If this jitter limits the imaging system or if optimal conditions for the PCSS can not be obtained, there are still ways to avoid the jitter problem. One way is to trigger the camera gate with the outgoing optical pulse. This requires short delay gate generator because the round trip time to the target may only be a few nanoseconds. A second way to obtain better resolution is to collect a set of images where the range of each image is recorded to the precision of the optical pulse width (100 ps) and the camera. In this mode, many images may have to be acquired to obtain the range of interest and this mode may only be useful for applications which search for targets by scanning over a relatively large range. Consistent and improved jitter is an area of high gain PCSS which is being pursued so that the more ideal situation of a jitter free optical source can be achieved.

8. CONCLUSION

This paper has described the development and testing of PCSS driven LDAs for short pulse applications such as a range-gated imaging system for near-field target identification in a highly scattering environment. Miniature systems have been discussed which produce 2 and12 μJ in 100 ps pulses at 904 nm, from 20 and 100 element LDAs, respectively. Since the optical power is not limited by the current injection capability of the PCSS, much higher total energies can be achieved from systems with more lasers and lasers which are optimized for short pulse operation. Two important areas of research and development for this application are the extension of these results to lasers with shorter wavelengths and the understanding and reduction in timing jitter caused by the PCSS.

9. REFERNCES

1. George J. Yates, Robert A. Gallegos, Thomas McDonald, Fred J Zutavern, and Wesley D. Helgeson, and Guillermo M. Loubriel, "Range-gated Imaging for Near-field Target Identification," to be published in *Proc. of SPIE 22nd International Congress on High-Speed Photography and Photonics*, Santa Fe, NM, 1996.

2. For references on range-gated imaging see:
   (a) I. P. Csorba, *Image Tubes* (Howard W. Sams & Co., Inc., 1985);
   (b) Matthew C. Thomas, George J. Yates, and Paul Zagarino, "Image Enhancement using a Range Gated MCPII Video System with a 180 ps FWHM Shutter," *Proc. SPIE 1995 Photoelectronic Detectors, Cameras, and Systems*, Vol. 2551, San Diego, CA, July, 1995, pp 174-180;
   (c) Greg Smolka and Barry Swartz, "Lasers Open Windows into the Briny Deep," *Photonics Spectra*, June, 1994, pp 93-100.
   (d) Larry R. Marshall, "Blue-green Lasers Plumb the Mysteries of the Deep,", *Laser Focus World*, April, 1993, pp 185-197.

3. J. Vanderwall, W. V. Hattery, and Z. G. Sztankay, "Subnanosecond Rise Time Pulses from Injection Lasers", *IEEE Journal of Quantum Electronics*, July, 1974, pp 570-572.

4. For references on high gain PCSS see:
   (a) A. Rosen and F. J. Zutavern, Eds., "High Voltage Lateral Switches from Silicon or Gallium Arsenide, in *High-Power Optically Activated Solid- State Switches*, Artech House, Boston, 1993;
   (b) G. M. Loubriel, F. J. Zutavern, H. P. Hjalmarson, R. R. Gallegos, W. D. Helgeson, and M. W. O'Malley, "Measurement of the Velocity of Current Filaments in Optically Triggered, High Gain GaAs Switches", *Applied Physics Letters, Vol. 64, No. 24, 13 June, 1994,* pp 3323-5;
   (c) Proceedings from: *IEEE Pulsed Power Conferences*, 1985-95 (odd years), *IEEE Power Modulator Symposia*, 1986-96 (even years), and SPIE *Optically Activated Switching Conferences I-IV*, 1990, 1992, 1993, 1994.