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Q-switching the Flash Ti:Sapphire Laser

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ABSTRACT

Q-switching the Flash Ti:Sapphire laser. KELLY CONE (California Polytechnic State University, San Luis Obispo, CA 93401) AXEL BRACHMANN (Stanford Linear Accelerator Center, Stanford, CA 94309).

The Stanford Linear Accelerator Center (SLAC) uses a flash lamp pumped Ti:Sapphire laser to generate the electron beam inside of the Linac. This laser system was installed at the SLAC Polarized Light Source in 1993. During the past, the system has been upgraded in several steps (eg. installation of Rhodium coated reflectors, cavity redesign, and remote controlled wavelength tunability)[1,2,3]. Q-switching the laser cavity to increase the peak pulse energy was successfully investigated and further improves the capabilities of the laser system for future polarized beam experiments. Two Pockels cells were used to perform the Q-switch and various diagnostics were used to characterize the modified laser pulse. The timing in relation to the laser trigger, pulse width, and pulse shape applied to the Q-switching Pockels cells (PC) were optimized. No damage to the laser cavity or optical elements occured. At optimal conditions of Q-switching, the pulse energy of the laser increased from 0.4 mJ to over 3 mJ in a 300 ns pulse. The Q-switched pulse energy can be further increased by extending the hold-off pulse applied to the PC. The laser pulse produced by the Q-switch was long enough {full width half maximum (FWHM) > 200 ns} for pulse shaping and demonstrated good intensity stability (< 0.5% jitter). The increase in output power suggests that Q-switching will be used for future accelerator projects.

I. Introduction

Particle accelerators are used in high energy physics to study the fundamentals of nature and advance our understanding of the interactions between subatomic particles. The SLAC Linac uses a polarized beam of electrons created by the photoelectric effect; a process through which circularly polarized photons from a flash lamp pumped Ti:Sapphire laser (120 Hz, tunable from 750-850 nm) are incident upon a GaAs photocathode. The emitted electrons are steered down the accelerator and their final velocity approaches the speed of light with energies up to 48 GeV. The current use of SLAC's polarized electron beam is the parity violation experiment, E-158. Physicists working on polarized beam experiments such as E-158 are interested in developing new ways to increase the output power of the Ti:Sapphire laser of the Polarized Light Source. Other areas of interest include the research and development of the polarized photocathodes at SLAC, and future accelerator projects such as the Next Linear Collider (NLC); which is a collaboration among national laboratories in America, Europe, and Japan.

One method for increasing the output power of a laser is known as Q-switching. For the experiment, two Pockels cells were used to perform a Q-switch on the Ti:Sapphire laser. Stimulated emission ("lasing") was prevented by supplying one Pockels cell with a square input pulse to generate a $\lambda/4$ phase shift of the light passing through the cell ($\lambda/2$ phase shift for round trip). In order to prevent damage to the laser cavity and optical elements, only a few hundred nanoseconds of the ~ 15μs long laser pulse was Q-switched. The energy stored during the Q-switch was slowly released by supplying a second Pockels cell with a ramped input pulse. The ramped input pulse allows the indices of refraction to “slowly” change (over a time period up to 300 ns) from the quarter-wave phase shift configuration implemented by the first Pockels cell to a zero phase shift. This approach gradually allows more photons to initiate stimulated emission from the excited Ti:Sapphire molecules again and also increases the width of the Q-switched pulse.

In this paper Q-switching was investigated starting at a short hold-off time to prevent damage to the laser cavity and other optical elements used in the experiment. The peak pulse power of the Q-switched laser was measured under different conditions (pulse width, pulse shape, and timing of the Pockels cells trigger in relation to the laser trigger) to determine optimal Q-switching of the laser.

II. Materials

The experiment was divided into three sections:

I. Use of Pockels cell with pulse shape control only (PC 1)
II. Use of Pockels cell with pulse shape control only and Pockels cell with square pulse (PC 2)
III. Use of Pockels cell with square pulse only

Q-switching was achieved by supplying a quarter wave voltage to the Pockels cell. The hold-off period took place during the applied high voltage (HV) and the release of stored energy occurred after the HV pulse or during the ramp down phase of the Pockels cell with pulse shape control. PC 1 uses a SLAC built high voltage controller, which generates a high voltage pulse according to a function generator[1] signal input. The function generator’s internal clock is synchronized with the SLAC 119 MHz RF signal to

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[1] Model DS345, Stanford Research Systems, Sunnyvale, CA

increase timing stability. Futhermore, the function generator is controlled by a Labview program to allow for arbitrary pulse shape modification. PC 2[2] uses a DEI pulser[3], which provides pulse level and pulse length control. The SLAC timing system is used to adjust timing signals for both Pockels cells.

The length of the laser pulse without Q-switching is determined by the length of the HV pulse provided by the laser power supply to the flash lamps, which is about 15 microseconds. The hold-off period of the Q-switch was not allowed to increase for more than 600 ns to prevent excessive levels of stored energy and resulting damage of the cavity elements during the energy release. Timing of the input pulses to the Pockels cells with respect to the laser trigger and to each other was modified to determine optimal Q-switching conditions. Also, the energy and shape of the Q-switched pulse were studied as a function of the HV pulse length and shape for PC 1. The reason for using two Pockels cells is the 300 ns pulse length limitation of the PC 1 driver electronics.

The pulse energy was measured using a joule meter[4]. To isolate the Q-switched pulse from the remaining laser pulse, a Pockels cell in between two crossed polarizers was used to allow only the transmission of a 300 ns long “slice” of the Q-switched laser pulse (Figure II). An oscilloscope[5] and Labview data acquisition program were used to record photodiode signals of the laser pulse. Images of the cross section of the laser beam under Q-switched and un-Q-switched conditions were taken by a triggered and gated CCD camera[6].

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[2] Model 1072 FV-750, Fastpulse Technology, Saddlebrook, NJ

[3] Model PVX-3110, Directed Energy, Inc., Fort Collins, CO

[4] Model J3-09, Molectron Detector, Inc., Portland, OR

[5] Model 2432A, Tektronix, Irvine, CA

[6] Model TM 250, Pulnix, Sunnyvale, CA

III. Methods

Theoretical Considerations

One concern regarding Q-switching is that the power of the laser can exceed the damage threshold of elements inside the laser cavity. In order to circumvent any damage, the peak power inside the laser cavity was calculated and compared with the damage thresholds of the optical elements inside the laser cavity. A typical un-Q-switched laser pulse of length 300 ns and energy of 500 μJ has an output power of 1.67 kW. The output power of the laser (with 85 % reflectivity output mirror) represents 15 % of the total power inside the laser cavity. Given that the radius of the laser beam is 0.5 mm at the waist, the power per unit area inside the laser cavity is 1.8 MW/cm^2. Since the damage thresholds of the Ti:Sapphire rod and Pockels cell (KD*P) are 3 GW/cm^2 and 0.87 GW/cm^2 respectively, no damage to the aforementioned optical elements is expected.

IV. Results

Pockels cell with shape control only

Pockels cell 1 (PC 1) was positioned inside of the laser cavity. The timing with respect to the laser trigger, high voltage and shape of the input pulses to PC 1 were varied and the resulting Q-switched laser pulse was analyzed using the photodiode detector (PD) and power meter. Figure III shows a comparison of the photodiode signals of the Q-switched laser pulse resulting from a square and ramped input pulse to PC 1. The FWHM of the Q-switched laser pulses resulting from square and ramped input pulses to PC 1 were 460 ns and 680 ns, respectively, each suitable for pulse shaping. Figure IV shows a plot of the energy of the Q-switched laser pulse vs. the function power of the ramped input pulse to PC 1. The data from Figures III and IV show that a square input pulse yields a Q-switched laser pulse of greater output power than a ramped input pulse. Figure V shows the relationship between the timing of the input pulse to PC 1 with respect to the long pulse of the laser; specifically, an earlier input pulse to PC 1 yields more intense Q-switched laser pulses.

Pockels cell with shape control only & Pockels cell with square pulse

The second Pockels cell (PC 2) was positioned inside the laser cavity (Figure I). The trigger to PC 1 was fixed and the timing to the trigger of the square input pulses to PC 2 was shifted. The resulting PD signals of the Q-switched laser pulse were analyzed to determine that 1 μs is the time difference between the input triggers sent to PC 1 and PC 2 that causes an overlapping of the two Q-switched laser pulses; which results in the highest peak power of the Q-switched laser pulse.

Pockels cell with square pulse only

To determine the correlation between the width of the square input pulse to PC 2 and the output intensity of the Q-switched laser pulse, PC 1 was removed from the laser cavity. The DEI pulser was connected to PC 2 and used to generate square input pulses of widths ranging from 150 ns to 450 ns. The PD and power meter were used to characterize the Q-switched laser pulse as the width of the square input pulse to PC 2 was increased in increments of 50 ns. Figure VI is a plot of the maximum photodiode signal of the Q-switched laser pulse vs. width of input pulse to PC 2.

This part of the experiment showed that wider input pulses to PC 2 increases the intensity of the Q-switched laser pulse. A 250 ns square input pulse to PC 2 resulted in peak laser pulse energy of 2.3 mJ, while a 600 ns square input pulse to PC 2 resulted in a peak laser pulse energy of 3.6 mJ. To determine the best time to apply the Q-switch, the SLAC control program (SCP) was used to vary the timing of the trigger for the input pulses to PC 2. The resulting Q-switched laser pulse was observed with the PD and power meter. Figure VII is a plot of the energy of the Q-switched laser pulse vs. the timing of the laser trigger. Figure VII shows that the energy of the Q-switched laser pulse increases when the square input pulse to PC 2 occurs earlier in the laser pulse.

Figure VIII is a plot of the PD signal of the laser pulse with and without a Q-switch performed using a 250 ns square input pulse to PC 2. At the optimal conditions of the Q-switch, the trigger for the square input pulses to PC 2 was set earlier in the laser pulse. The FWHM of the Q-switched laser pulse was ~ 200 ns, which allows for pulse shaping. Figure IX shows a comparison of laser beam profile images taken by a CCD camera with and without a Q-switch. The Q-switched laser beam shows a decrease of higher order TEM’s compared to the un-Q-switched laser. Figure X shows the intensity of the Q-switched laser with less than 0.5 % jitter.

V. Conclusion

A Q-switch was successfully performed on the flash lamp pumped Ti:Sapphire laser without inflicting damage upon the laser cavity or other optical elements. The Q-switched laser pulse was characterized for a 250 ns square input pulse of 2 kV to a single Pockels cell. The results suggest that the high voltage pulse to the Pockels cell should be triggered 7.6 μs after the laser is triggered.

This particular arrangement was able to increase the output power of the laser from 0.4 mJ to over 2.3 mJ. The laser pulse generated from the Q-switch demonstrated good stability (< 0.5% jitter) and pulse width of FWHM > 200 ns. This Q-switch technique will be used at SLAC for polarized photocathode R & D as well as future accelerator plans including the Next Linear Collider

VI. Acknowledgements

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VII. References

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APPENDIX

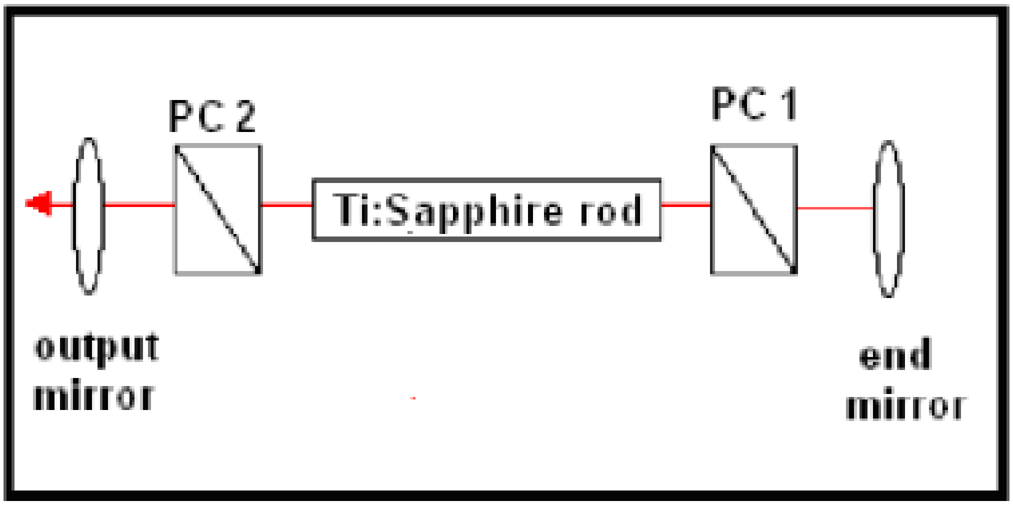

Figure I. Experimental Arrangement of Ti:Sapphire laser cavity
(PC: Pockels cell)

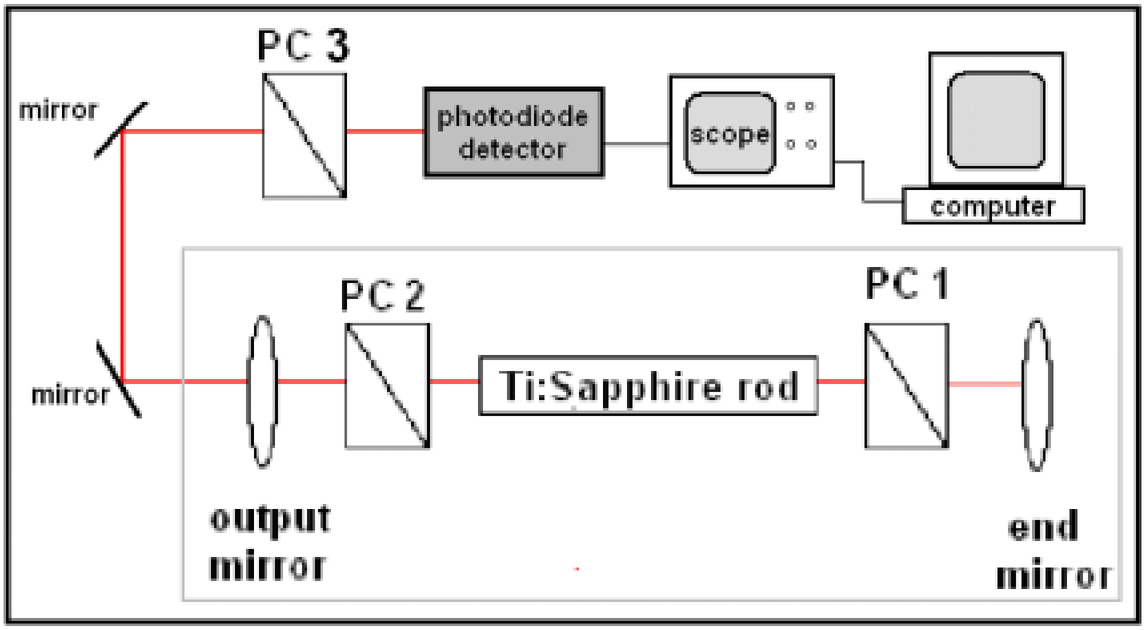

Figure II. Experimental Arrangement for Data Acquisition

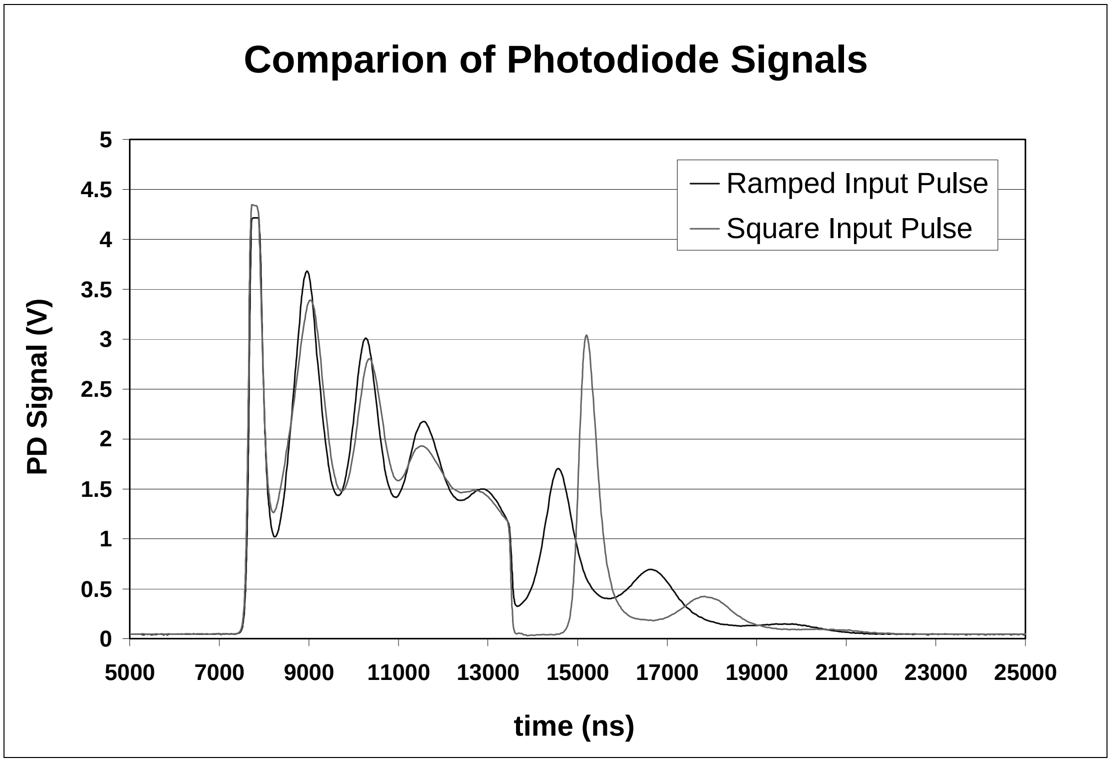

Figure III. Comparison of PD Signals of the Q-switched laser pulse generated by square and ramped input pulses to PC 1

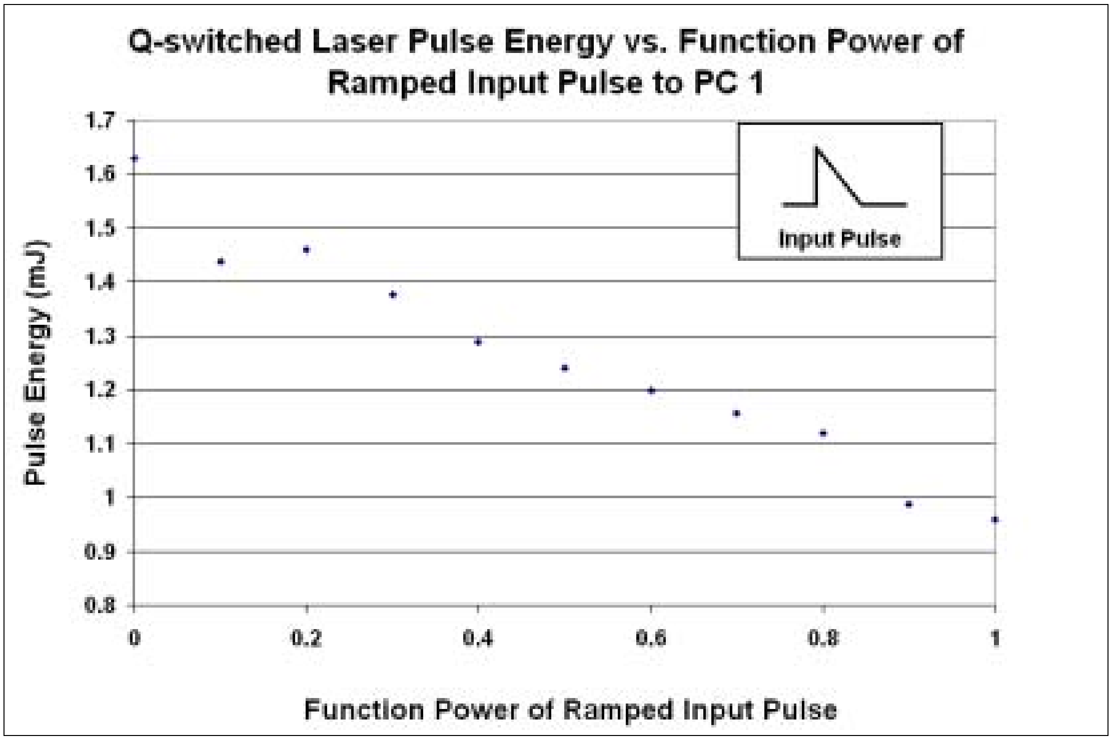

Figure IV. Plot of Q-switched Laser Pulse Energy vs. Function Power of Ramped Input Pulse to PC 1

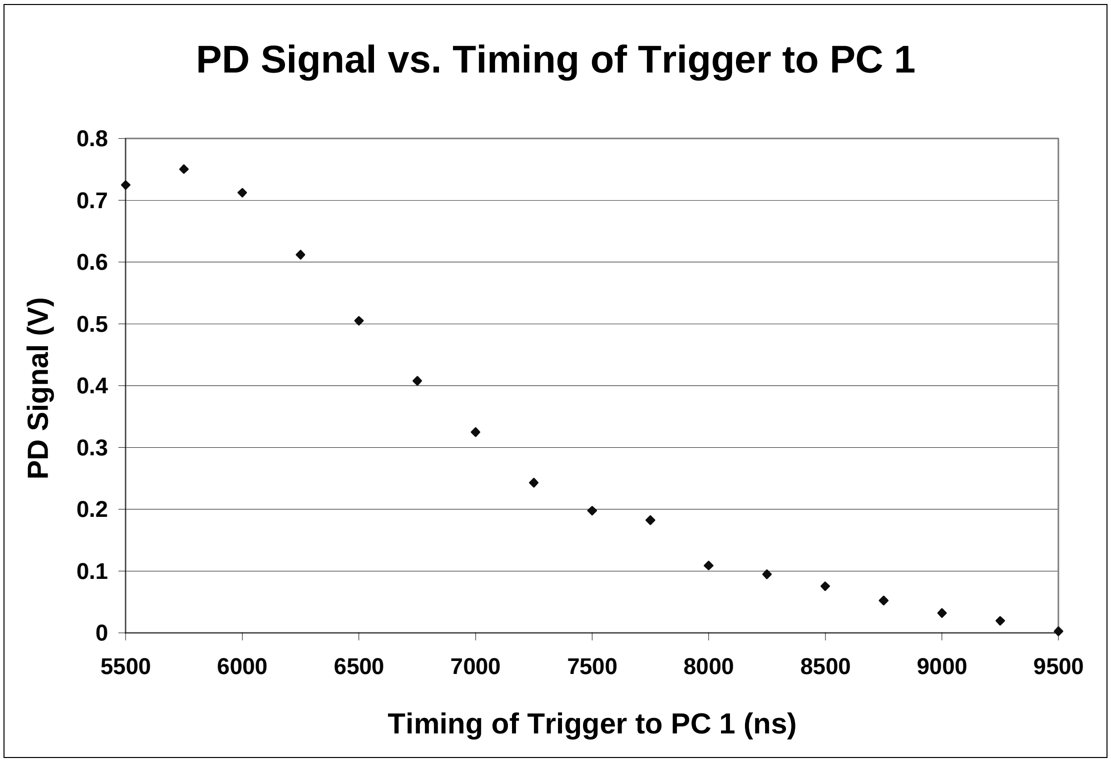

Figure V. Plot of PD Signal vs. Timing of Trigger to PC 1

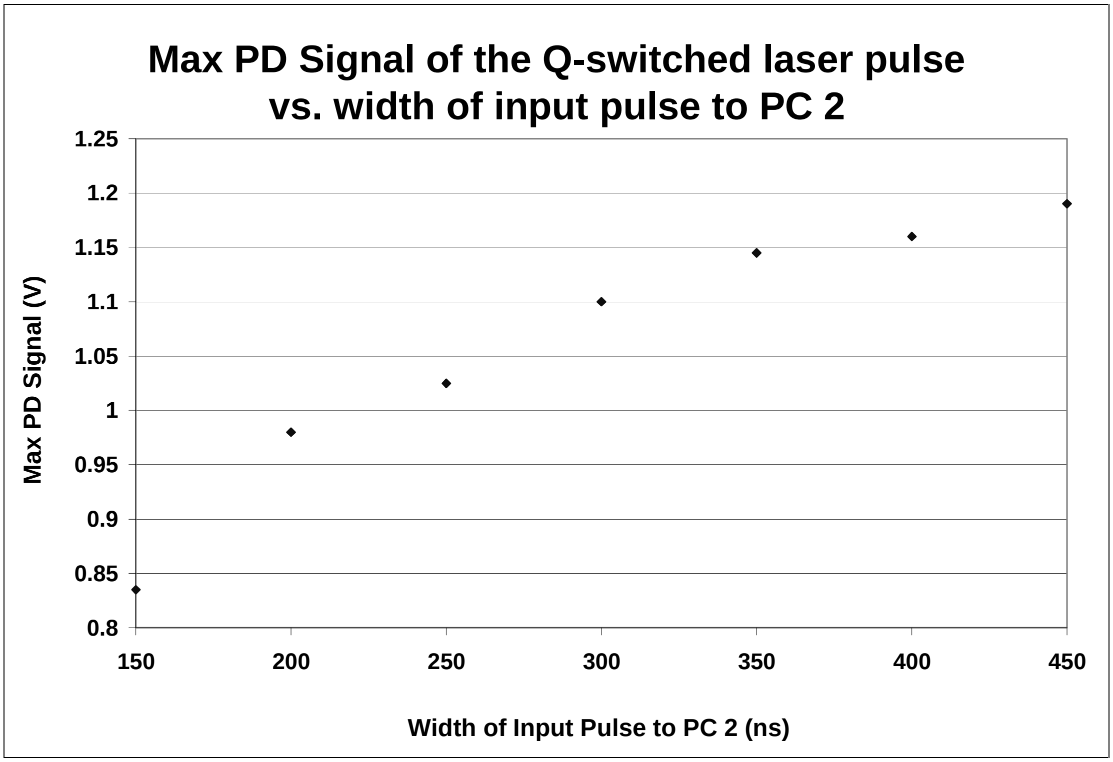

Figure VI. Plot of maximum PD signal of the Q-switched laser pulse vs. width of square input pulse to PC 2

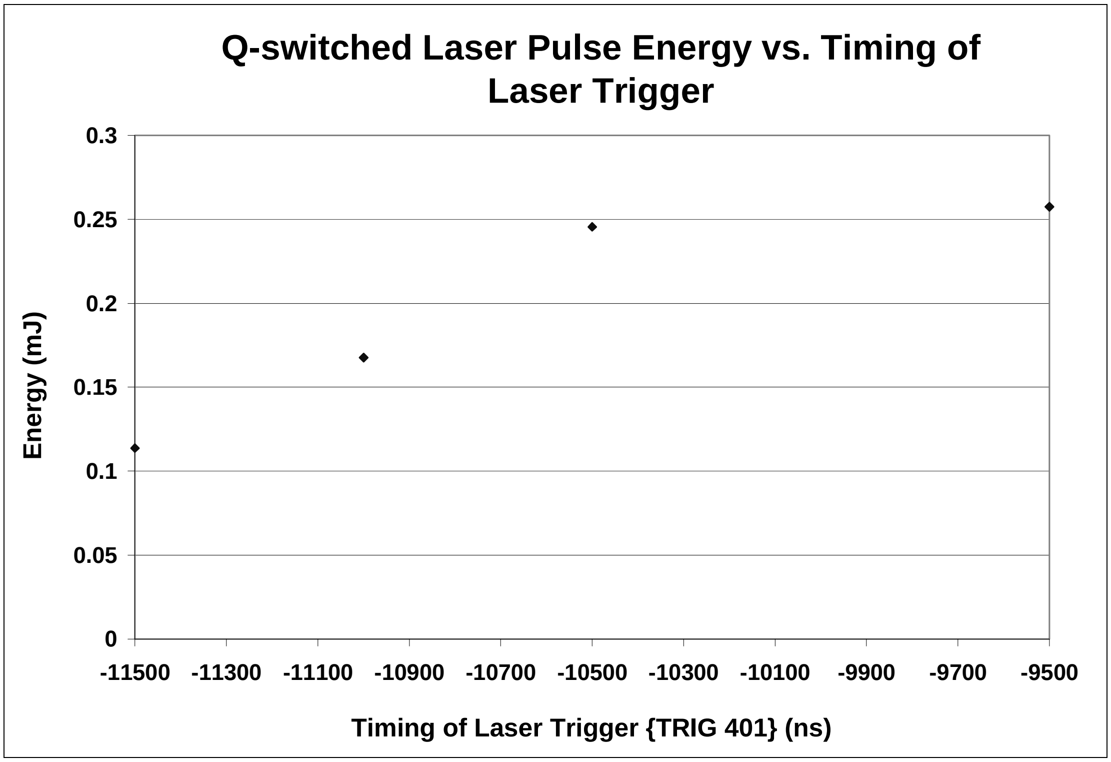

Figure VII. Plot of Q-switched laser pulse energy vs. timing of the laser trigger

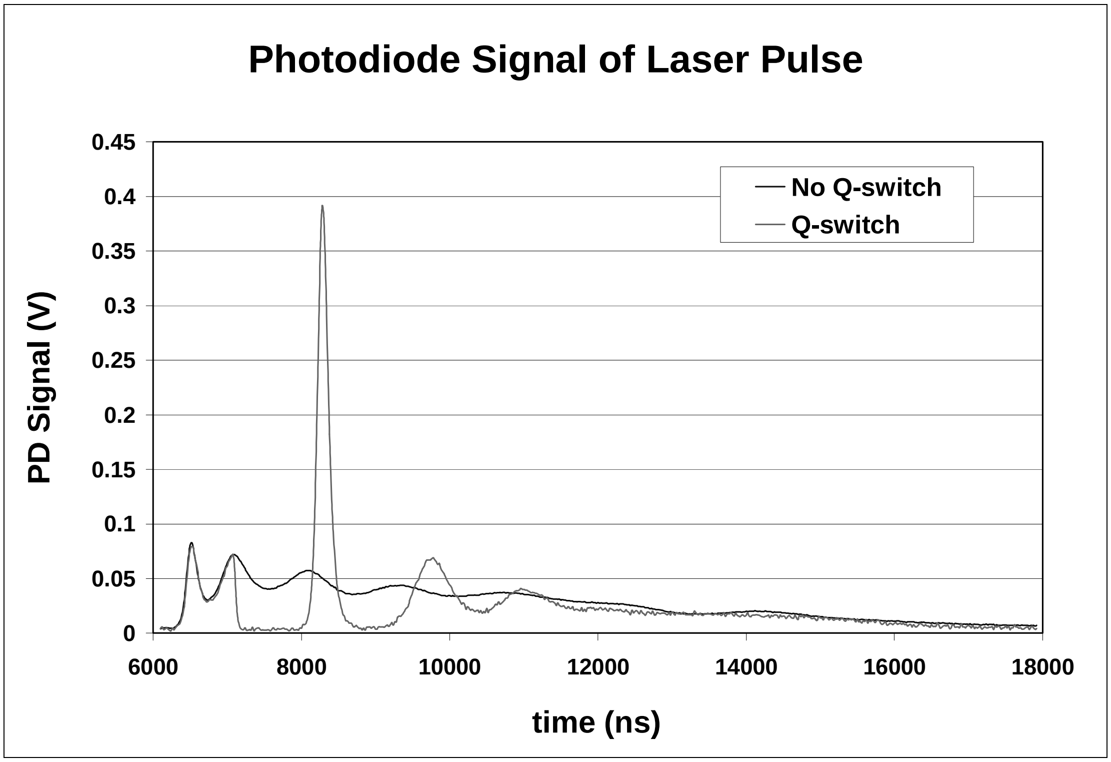

Figure VIII. Comparison of PD signals of laser pulse with and without a Q-switch

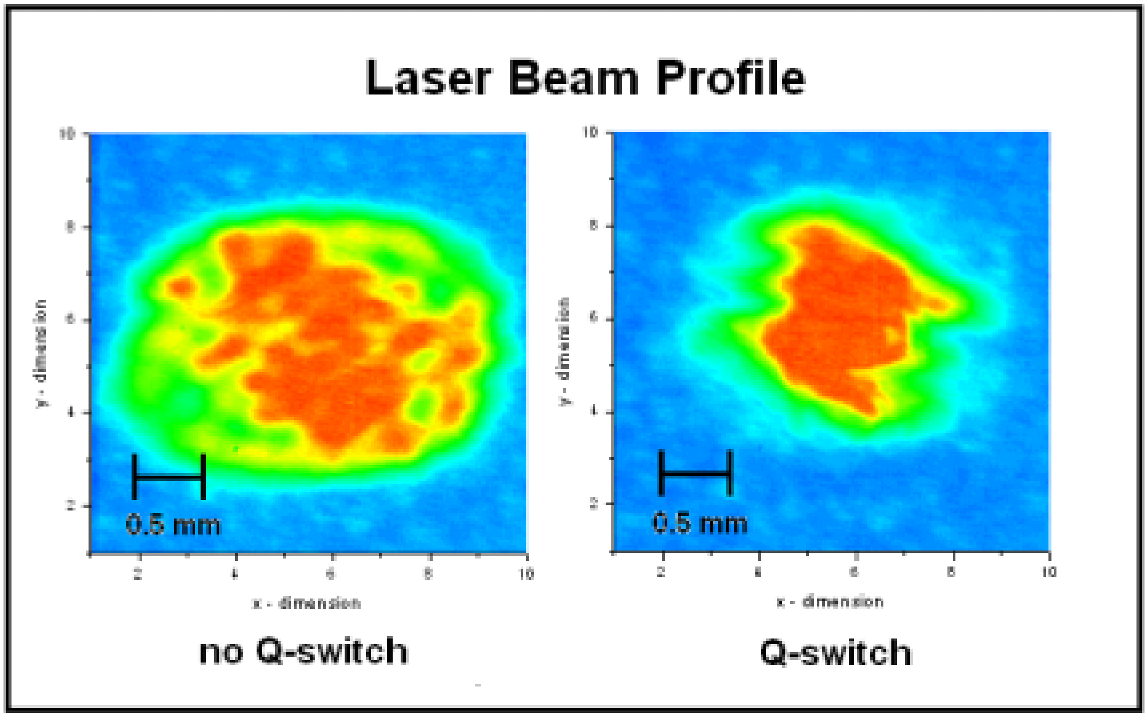

Figure IX. Comparison of Laser Beam Profile with and without Q-switch

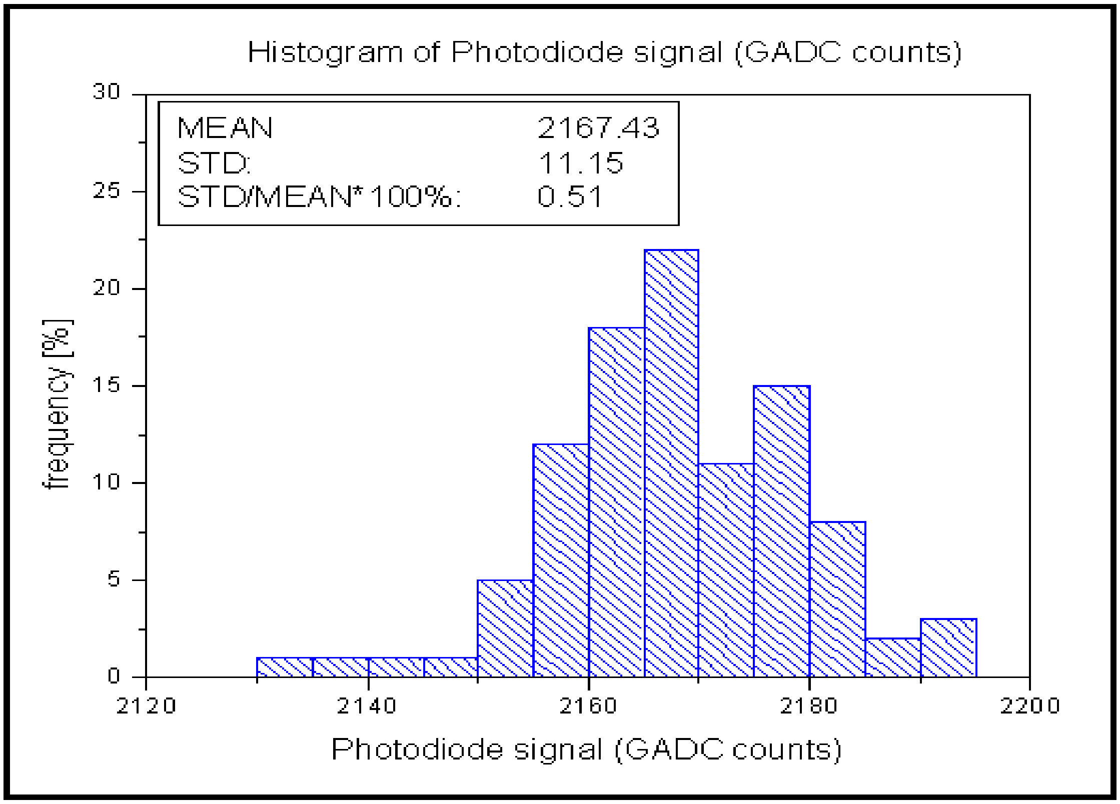

Figure X. Intensity Stability Histogram of Q-switched Laser
(GADC: Gated Analog-to-Digital Converter)