STREAK CAMERA MEASUREMENTS OF THE APS PC GUN DRIVE LASER*

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Abstract

We report recent pulse-duration measurements of the APS PC Gun drive laser at both second harmonic and fourth harmonic wavelengths. The drive laser is a Nd:Glass-based chirped pulsed amplifier (CPA) operating at an IR wavelength of 1053 nm, twice frequency-doubled to obtain UV output for the gun. A Hamamatsu C5680 streak camera and an M5675 synchroscan unit are used for these measurements; the synchroscan unit is tuned to 119 MHz, the 24th subharmonic of the linac s-band operating frequency. Calibration is accomplished both electronically and optically. Electronic calibration utilizes a programmable delay line in the 119 MHz rf path. The optical delay uses an etalon with known spacing between reflecting surfaces and is coated for the visible, SH wavelength. IR pulse duration is monitored with an autocorrelator. Fitting the streak camera image projected profiles with Gaussians, UV rms pulse durations are found to vary from 2.1 ps to 3.5 ps as the IR varies from 2.2 ps to 5.2 ps.

INTRODUCTION

To optimize beam quality, minimize emittance, and compare with simulations, we measured the pulse duration of the APS photocathode (PC) gun drive laser. Drive laser pulse duration measurements have shown conflicting results. At SLAC, the UV harmonic component was found to be greater than that of the fundamental or visible harmonics [1]; whereas, at the FNAL Laser Lab, recent data have shown the pulse duration of the UV to be comparable than that of the green [2] with a multi-pass amplifier. The nonlinear dependence on fundamental wavelength power density should cause the pulse duration of the second harmonic beam to decrease [3]; however, this effect may be offset by group velocity mismatch. The last streak camera measurement of the APS drive laser was made approximately 15 years ago [4]. Before the streak camera could provide pulse duration measurements, calibration of the unit was required. Calibration data was obtained employing two methods: 1) a high-precision Colby delay generator and 2) at the visible wavelength, using an etalon cavity.

EXPERIMENTAL ARRANGEMENT

The streak camera with attenuation and focusing optics was installed in the APS Injector Test Stand (ITS); a plan view schematic is presented in Figure 1. The dichroic filter is 99.5% reflecting at 263 nm. Roughly 5.5 orders of attenuation were required to safely and accurately measure the UV component at nominal full energy, E_{uv} =100 µJ; this energy is achieved at an IR amplifier pump current setting, I_{set} = 170 A. The dichroic filter provided an optical density (OD) of 2.5 and protected the downstream optics for fourth harmonic wavelength measurements. For second harmonic measurements, the mirrors in the transport line between the Laser Room and the ITS provided an equivalent level of attenuation. In addition, the input slit to the streak camera

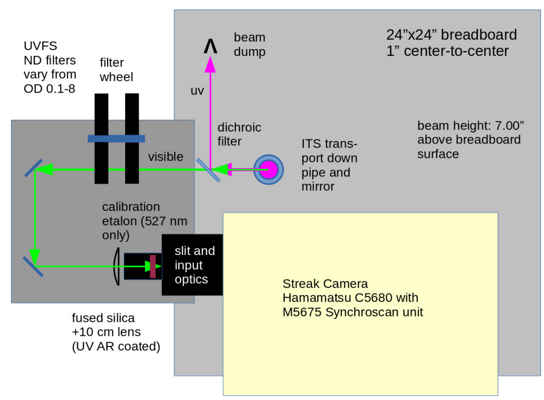

Figure 1: Streak Camera schematic.

was set at 5 µm to further limit the power density on the photocathode.

Laser

The APS PC Gun drive laser has been upgraded since first being described in Ref. [5]. The most significant modification to the CPA system was the replacement of the two flashlamp-driven amplifiers with a pair of laser diode-driven heads. The laser diodes operating at 808 nm pump electrons directly to the closely placed $^2H_{9/2}$ and $^4F_{5/2}$ excited states from which they rapidly decay to the nearby $^4F_{3/2}$ upper level of the Nd^{3+} atoms [6]. Efficient pumping results in substantially less energy deposition and reduced thermal effects in the laser rods; however, thermal lensing effects are still noticeable as rep rates or pump levels are varied. Harmonic light is generated in a pair of 1-mm-thick β-barium borate (BBO) crystals. Second harmonic (SH), visible (527 nm) green light is measured after the second doubling crystal; therefore, its temporal profile is likely to be slightly broadened.

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Streak Camera

The streak camera is a Hamamatsu C5680 mainframe unit with an M5675 Synchroscan plug-in. The M5675 unit is tuned for 119 MHz, the 24th subharmonic of the linac 2856 MHz s-band frequency. The input optics barrel includes a quartz window for efficient UV transmission to the S-20 photocathode.

EXPERIMENTAL RESULTS

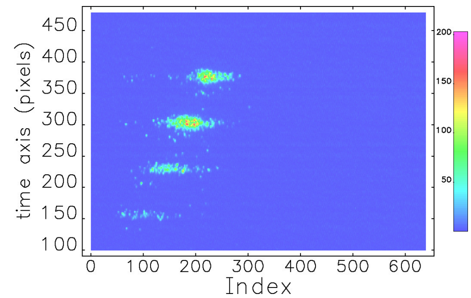
Images from the read-out camera were captured with a MAC-based LFG frame grabber system. The system generated 640x480 pixel^2 images; with 480 pixels along the vertical, time axis of the images. We found that our frame grabber was unable to reliably produce interlaced images. Either the odd field would be bright and the even field dim or vice versa. By reconstructing the missing line (even or odd) with the average of the two adjacent lines (odd or even), we were able to recover the images with little loss of resolution.

Temporal Calibration Techniques

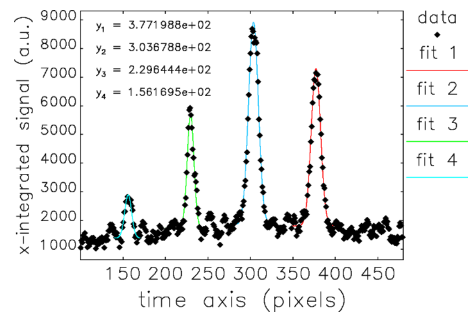
In the absence of available factory data sheets for this 119-MHz synchroscan unit and since it was a new run, we elected to calibrate the system using both an rf delay method and an optical method. Streak camera calibrations with this synchroscan unit installed in the mainframe were performed with a Colby delay unit (PN109122; SN#8081195, borrowed from the FNAL laser lab) to provide discrete and known ps-regime delay changes for different images. Image jitter appeared low, but since the system did not have a phase-locked-loop delay box option, there was some drift between shots at the ps level. We used 20- and 30-ps steps on the fastest ranges, increased the steps for the slower ranges, and averaged the mean positions of the images. The resulting calibration factors with 1x1 pixel binning in the CCD were: R4: 2.66 ±0.05 ps/pixel, R3: 1.92 ±0.08 ps/pixel, R2: 1.12 ±0.07 ps /pixel, R1: 0.52 ±0.03 ps/pixel. These tests were done with the UV component of the laser at reduced-power.

To avoid the possible phase drift shot-to-shot of the laser and/or streak system, a custom etalon procured from Hamamatsu in the past was also used that could be mounted to the streak camera input barrel. We chose the 2 spacers (measured by a caliper) for a 36.4-ps roundtrip time between the coated (for green) pair of reflecting mirror surfaces. Thus a single laser 527-nm micropulse entering the etalon resulted in 3-4 peaks in the streak images due to the multiple reflections/passes in the etalon. The spacing was sufficient to use with all four streak ranges. An example image for Range 1 is shown in Figure 2.

Although there is a noticeable transverse walking of the image at the 1/2-mm level in the horizontal axis, the observed peak-position spacings on the time axis are quite uniform at 73.2 pixels. This gives a calibration factor of 0.50 ps/pix. The multiple peaks were each fit to single Gaussians by a MATLAB-based processing program, ImageTool [7],



(a) **Etalon streak.**



(b) **Fits to projected distribution peaks.**

Figure 2: (a) An example of a streak image with multiple peaks from the etalon test and (b) Gaussian fits on Range 1 using a 36.4-ps spacing between peaks (527 nm).

and the amplitude, position means, and sigmas were calculated as well as their statistical errors. The results for the etalon tests are summarized in Table 1 for all four streak ranges, including the corresponding Colby calibration data in the last column.

These calibration factors can then be multiplied by the static spread function results (focus mode) for the Green and UV input to give 1-ps and 1.2-ps sigma resolutions on Range 1, respectively. The ratio is very close to the data sheet values in focus mode, and this illustrates the fundamental effect of photoelectron energy spread increasing in the tube for the UV photons. The result is consistent with our having minimized potential space charge effects in the tube by attenuating the input signals by factors of 10^5. We were not successful in tuning Range 1 to 0.30 ps/pix which is the factory number for the 117-MHz unit used with this camera and tube. We attribute this to a lower-gain rf amplifier in the 119-MHz unit for Range 1.

Table 1: Summary of 119-MHz Synchroscan Unit Calibrations: Streak Ranges 1-4. Etalon spacers were measured by a caliper at 36.4 ps equivalent, and we used the Green component of the laser.

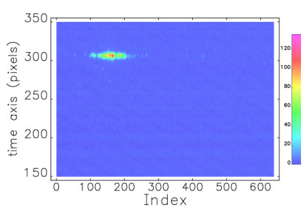
Range	Peak separation (pixels)	Etalon calibration (ps/pixel)	Colby calibration (ps/pixel)
1	73.2	0.50 (2)	0.52±0.03
2	32.2	1.13 (2)	1.12±0.07
3	19.2	1.90 (3)	1.92±0.08
4	14.1	2.58 (3)	2.66±0.05

Pulse Duration

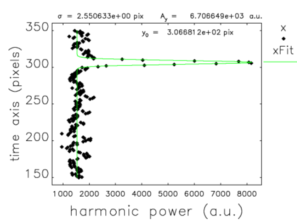
The pulse duration of both second and fourth harmonic laser components were measured as a function of the pulse compression. Compression of the IR pulse is varied by changing the beam path length through the compressor optics using a horizontal retro-reflector (HRR) on a sliding translation stage. Pulse duration, σ_t is determined from the observed profile width, σ_p by subtracting in quadrature independent contributions,

$$\sigma_t = \sqrt{\sigma_p^2 - \sigma_{in}^2 - \sigma_{disp}^2 - \sigma_j^2}, \quad (1)$$

where σ_{in} is the instrument resolution, σ_{disp} is due to chromatic temporal dispersion, and σ_j represents jitter. Here we assume $\sigma_{disp} = \sigma_j = 0$ because of the monochromatic source and single pulse observation. An example of a UV focus mode image (non-streaking) and profile are presented in Figure 3. The size of the profile in Fig. 3 is 2.55 pixels;



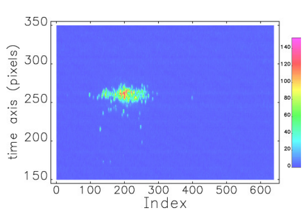
(a) **UV focus mode.**



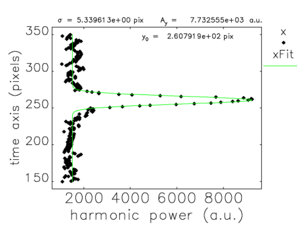
(b) **Gaussian fit.**

Figure 3: UV focus mode image and Gaussian profile fit.

the average value of this and other focus mode data are used to determine σ_{in}. Streaking in Range 1 near maximum compression (HRR=115 mm), the profile size shown in Figure 4 is 5.34 pixels. Employing Eq. (1), these two sizes yield a duration of 4.69 pixels or 2.35 ps.



(a) **UV streak mode.**



(b) **Gaussian fit.**

Figure 4: UV streak image and Gaussian profile fit for HRR=115 mm.

The variation of pulse duration with compressor setting (HRR) was investigated at both second and fourth harmonic wavelengths. An initial measurement was done with low-power UV at I_{set} =149 A; the results are plotted in Figure 5. Neutral density filters were not necessary at this power level, implying a 3-order reduction in UV light levels or $E_{uv} \approx 100$ nJ. The data in Fig. 5 are fit [8] to the hyperbolic function,

$$\sigma_t^2(z) = \sigma_0^2 + A\left(z^2 - z_0^2\right), \quad (2)$$

where $\sqrt{A}$ represents the far-field longitudinal divergence of the beam and σ_0 and z_0 represent the size and location

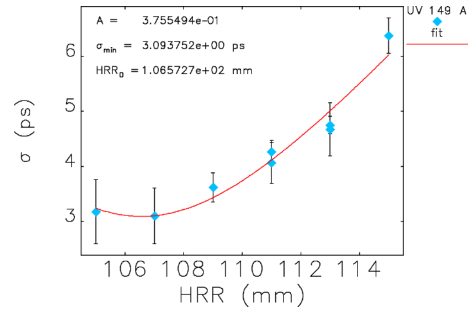


Figure 5: Variation of low-power UV pulse duration with compressor length.

of the pulse length minimum; finally, z=HRR. With the insertion of 3.0-OD neutral filters, full-power measurements of green and UV pulse length were conducted as the compressor setting was varied. In addition, an autocorrelation measurement of the IR drive beam was also conducted. The IR, green, and UV data are presented in Figure 6 along with a fit of Eq. (2) to the UV results.

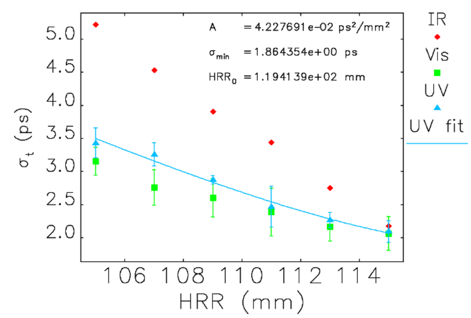


Figure 6: Variation of full-power IR, green, and UV pulse duration with compressor length.

We note that the focusing of the UV at 170 A has changed from that at 149 A, possibly due to thermal lensing effects in the Nd:glass laser rods. For the full power case, the pulse duration of the green is less than the IR ; however, the green pulse length is also slightly shorter than the UV. We believe this is not due to broadening in the streak camera but probably due to group velocity mismatch (GVM) in the second BBO doubling crystal [9, 10]. GVM increases from 100 fs/mm at 1000 nm to approximately 600 fs/mm at 527 nm [11]. Also, the minimum pulse duration is larger for the reduced pump current case; this may be caused by a smaller number of longitudinal cavity modes that can lase within the linewidth of the medium at low power. Narrowing of the bandwidth will lead to temporal broadening of the pulse.

SUMMARY

Both UV and green beam pulse durations were measured over a range of compressor settings. Full energy UV pulse lengths varied from 3.5 to 2.1 ps as green varied from 3.0 to 2.0 ps. Over the same compressor scan, autocorrelation indicated IR pulses varying from 5.3 to 2.2 ps. We obtained good agreement between the optically- and electrically-derived calibration factors for the four ranges of the streak camera synchroscan unit. Reduced data indicates the Range 1 calibration to be 0.5 ps/pixel. The pulse duration data provides a benchmark for future on-line cross- and auto-correlation measurements, as well as input for simulations.

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