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Ultra-stable flashlamp-pumped laser*

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Abstract. We present the design and experimental results for the flashlamp-pumped Ti:Sapphire laser system used at the Stanford Linear Accelerator Center (SLAC). This laser system is used in conjunction with the Polarized Electron Source to generate polarized electron beams for fixed target experiments (e.g. the E-158 experiment). The unique capabilities such as high pulse-to-pulse stability, long pulse length and high repetition rate is discussed. Emphasis is placed on recent modifications of the laser system, which allow ultra-stable operation with 0.5% rms intensity jitter.

1 INTRODUCTION

The flashlamp-pumped Ti:sapphire laser system initially was installed at the Stanford Linear Accelerator Center's Polarized Electron Source in 1993 and has been described previously [1, 2]. Since then, the laser system has had significant upgrades [3, 4]. This paper documents recent modifications and the performance of the laser system mainly during the past year.

2 LASER SYSTEM

The scheme of the laser system is depicted in figure 1. The Ti:sapphire laser cavity consists of a 2 meter concave high reflector and a flat output coupler with a reflectivity of 85 % and a spacing of 1m. Both mirrors are coated for a ~ 50 nm bandwidth. A Ti:sapphire laser rod (0.1 % Ti doping) of 6 inch length and 4 mm diameter is pumped by 2 flashlamps. Rhodium coated, double elliptical reflector surfaces focus the pump light into the center of the laser rod. Within the cavity, a birefringent tuner (BRT) oriented at Brewster's angle allows for wavelength tuning with a typical bandwidth of ~ 0.7 nm FWHM.

The extra-ordinary optical axis of the Ti:sapphire crystal is oriented parallel to the plane of the rod's optical surfaces. If no precautions are taken to align the

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crystallographic axis of the Ti:sapphire rod with respect to the Brewster angle of the BRT, a rotatable half wave plate in between laser rod and BRT is necessary to maximize the amount of p-polarized light transmitted.

Cooling of the laser head is provided by a closed loop of ultra-pure water flow (conductivity 18 MΩ) at ~ 2.5 GPM. The closed loop water temperature is maintained by a 3 or 5 ton chiller.

The flashlamps are pulsed by a SLAC built modulator / power supply. The modulator provides the high voltage pulse needed to fire the flashlamps. A 1.2 μF capacitor is charged by a 10 kV, 8 kJ/s power supply. Upon ignition of a thyratron, the capacitor is discharged through the flashlamps in series. The pulse has a peak current of 1 kA and a duration of 22 μs. Between pulses, a current through the flashlamps is maintained by a simmer power supply in parallel. The simmer current reduces the high voltage needed for conduction in the lamps and thereby extends their lifetime. The modulator and the laser cavity were designed to operate at a maximum repetition rate of 120 Hz.

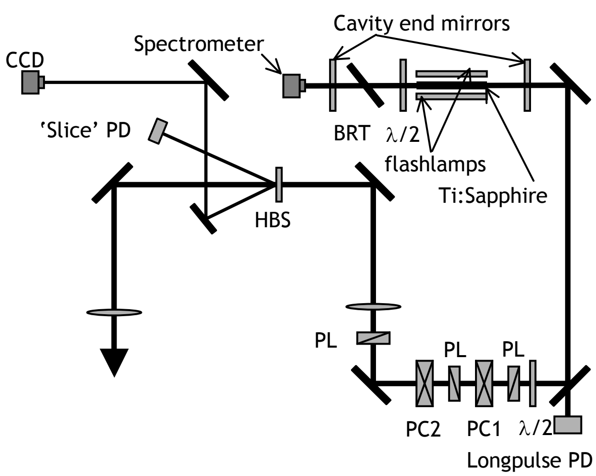


FIGURE 1: Scheme of laser system setup including pulse shaping components and diagnostics.

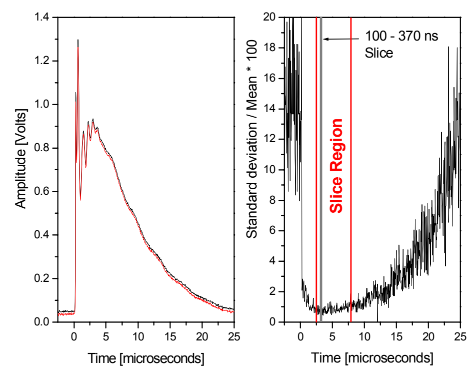


FIGURE 2: 100 shot envelope of cavity pulse (left); shot to shot intensity stability across pulse, region of lowest jitter and 'Slice' timing (right).

Downstream of the cavity, polarizer / Pockels cell combinations allow duration and intensity modifications of the laser pulse. The 'Slice' pockels cell is used to separate a 50 to 370 ns 'slice' out of the ~ 20 μs long pulse delivered by the cavity. Slicing is applied within the region of lowest intensity jitter of the total pulse length. Figure 2 gives an example of the pulse shape generated by the cavity. Also, the stability of the laser pulse as a function of time and the corresponding region of slicing is depicted. A fast pockels cell allows temporal modification of the sliced laser pulse (Top Hat

Pulse Shaper – TOPS). A trapezoidal pulse shape is needed to achieve a flat energy profile in the electron beam due to beam loading effects. The high voltage pulse shape of the pockels cell driver is set by a function generator. A 25 ns time resolution of the applied function was found to be sufficient.

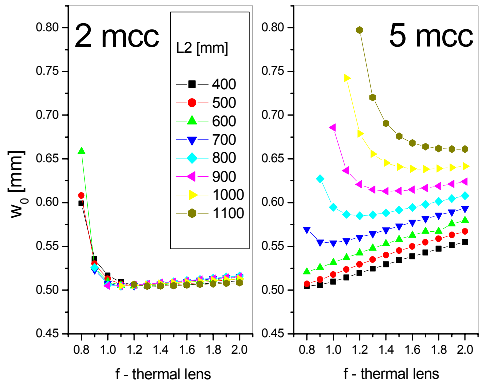
Further downstream, a pair of Pockels cells are used to generate circularly polarized light of either helicity at the photocathode. An optical transport system (OTS), ~ 20 meter in length, delivers the laser beam to the photocathode. The OTS preserves the laser helicity and images the polarization Pockels cell onto the photocathode. A detailed description of helicity control and methods to minimize helicity correlated beam assymetries has been published by Humensky et al. [4].

3 DIAGNOSTICS

The laser performance is monitored by photodiodes, a CCD camera and a spectrometer (see figure 1). Leakage light through 45^o folding mirrors or sampled beams provide signals for routine intensity, beam profile, intensity jitter and wavelength measurements. A photodiode installed upstream of the pulse-shaping optics monitors the cavity output (Longpulse PD). Downstream of the pulse-shaping optics, two one-percent samples of the laser beam are separated by a holographic beam sampler. One sample is used to monitor the intensity of the sliced pulse (Slice PD). The second sample is focused onto a CCD camera and provides an image of the beam cross section. The laser wavelength is measured by a fiberoptic spectrometer, using the leakage light of the cavity end mirror.

4 CAVITY MODELING

A significant improvement compared to previous laser performance has been achieved by measurement of the thermal lensing of the cavity and inclusion of the results into the cavity design. The focal length of the thermal lens under typical operating conditions has been derived by measurement of the laser spot size as a function of distance from the cavity center until a minimum of the beam waist was observed. With a 1.1 to 1.2 m focal length, the thermal lens dominates the cavity optics. As a result of high voltage pulse instabilities, fluctuations of the thermal lens may occur. One goal of cavity design was to minimize thermal lens induced spot size changes within the active medium. Modeling of the beam waist within the laser rod was conducted for a 5 meter concave end mirror (used historically) and a 2 meter concave end mirror. Also, the separation of the end mirrors was included in our calculations. We have found a minimum sensitivity to thermal lensing using a 2 meter concave end mirror and a separation of ~ 60 cm from the cavity center. A



second set of calculations was performed to study matching and stability of wave front curvature at the end mirror curvature as a function of thermal lensing and mirror separation. The calculations also suggest improved performance for a 2 meter concave mirror. The results are plotted in figure 3.

FIGURE 3: Results of cavity modeling: Spotsize at the cavity center as function of thermal lens focal length and end mirror location (L2) for a 2 and 5 meter concave mirror curvature; spot size resulting from a 2 mcc mirror shows less sensitivity to thermal lensing.

5 CAVITY HALF WAVE PLATE AND LASER ROD CRYSTALLOGRAPHY

As described above, the half wave plate installed in the cavity insures the proper orientation of the plane of p-polarized light incident on the BRT (installed at Brewster's angle). High fluences within the cavity and multimodal operation leads to 'hotspots' within the beam profile resulting in a high probability for optical damage of cavity components. Indications of optical damage typically increase laser jitter and decrease cavity output power. During extended periods of operation, the cavity half wave plate frequently needed replacement due to damage of coatings and bulk material.

To alleviate this problem, the laser rod was installed with controlled crystallographic orientation. With the Ti:sapphire rod mounted in the laser head assembled to a degree where rod manipulation is still possible, the assembly was placed between a polarizer and analyzer. A collimated diode laser beam (830 nm) was aligned through polarizer, laser rod and analyzer. The polarizer ensures linearly polarized light incident to the laser rod (with the plane of p-polarization parallel to the plane required by the Brewster angle of the BRT). The laser rod acts as a thick, multiple order quarter wave plate and transforms linearly polarized light into an elliptical state. The degree of ellipticity is a function of the angle between the polarization plane of incident light and orientation of the Ti:sapphire's extraordinary optical axis. The amount of ellipticity caused by laser rod's optical orientation is detected by the measurement of the light transmitted through laser rod and analyzer. A high degree of ellipticity maximizes the light transmitted through the crossed polarizers. By rotation of the laser rod around its geometrical axis, generation of elliptically polarized light can be minimized, which is the case if one of its optical axis is parallel to the plane of incident linearly polarized light. Under this condition, the light passing through polarizer, laser rod and analyzer shows maximum extinction. Using this procedure, the laser rod can be mounted in an oriented fashion and the need for the cavity half wave plate is eliminated. As a result, the peak to peak intensity stability as well as the total laser power increases.

6 LASER PERFORMANCE

The performance of the laser system is summarized in Table 1. The E-158 2002 spring and fall experimental runs have shown ultra-stable operation for several months without interruption except scheduled flashlamp changes. Flashlamps were changed after ~ 1.45×10^8 pulses (2 weeks at 120 Hz). The maximum laser power of the cavity is ~ 7 W at 120 Hz (or 58mJ). In our development laboratory we achieved a 0.3% rms laser intensity jitter, while at the injector 0.5% was typical. After slicing and pulse shaping we obtained up to 500 μJ in a 370 ns long (sliced) pulse. All downstream optics account for an additional attenuation of 10 – 15%.

TABLE 1. Laser operating parameters

Mode structure	Multimodal
Wavelength	Tunable (805nm,850 nm)
Bandwidth	0.7nm
Repetition rate	120 Hz
Peak power	58 mJ
'Sliced power' (370 ns)	500 μJ
Stability	0.5 % rms

7 CONCLUSIONS

Our results show that the careful setup of a flashlamp pump laser system can achieve a level of performance required for generation of highly stable polarized e^-beams. Despite advances in diode laser technology, flashlamp pumping remains a viable option if tunable and high power lasers are required for the generation of polarized e^- beams for high energy physics experiments.

8 REFERENCES

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