Operation of a Ti:Sapphire Laser for the SLAC Polarized Electron Source*

Josef Frisch, Ray Alley, Mike Browne, Mike Woods
SLAC Stanford CA 94309

Abstract

A new laser system has been developed as the light source for the SLAC polarized electron source for the 1993 SLD physics run. A Q-switched and cavity-dumped Ti:Sapphire laser, pumped by a doubled YAG laser is used. This laser delivers typically 50μJ to the photocathode with the required 2 nanosecond, double pulse, 120Hz time structure. The laser operates at wavelengths between 760nm and 870nm. The laser was installed on the SLAC linac in January 1993, and is currently in use.

I. INTRODUCTION

The polarized electron source for the SLAC linac uses a semiconductor photocathode driven by a laser. For the 1992 physics run, a flashlamp pumped dye laser was used[1]. The new high polarization strained-lattice cathodes[2] intended for the 1993 run required higher optical pulse energies and longer wavelengths than the dye laser could deliver. The requirements for the new laser were:

Table 1. Laser Operating Parameters

Operating wavelength	760nm - 870nm
Pulse energy to cathode	>50μJ
Pulse length	2.0ns
Timing jitter	<50ps RMS
Pulse structure	2 pulses, 62ns apart
Repetition rate	120Hz
Energy stability	<3% RMS
Pointing stability	<5μR RMS
Reliability	>95% uptime
System Lifetime	>10,000 Hours

No commercial lasers were available which could meet these parameters, so a system was developed at SLAC.

II. LASER SYSTEM DESIGN

A. Optical layout

Titanium doped sapphire (Ti^{+3}:Al_2O_3)[3] is the only commercially available solid state laser material which can operate over the required wavelength range at the required powers and repetition rates. Frequency doubled YAG was chosen as the most practical pump source for Ti:Sapphire.

We decided to use 2 Ti:Sapphire cavities to produce the first and second pulses. This allowed independent control of pulse timing and intensity. Commercial YAG lasers with the required output energy (5mJ at 532nm) were not available with repetition rates greater than 60Hz. This necessitated the use of 2 YAG lasers operating interleaved to pump each of the Ti:Sapphire cavities. Figure 1 shows the overall system layout.

SLAC Ti:Sapphire Polarized Source Laser System Layout

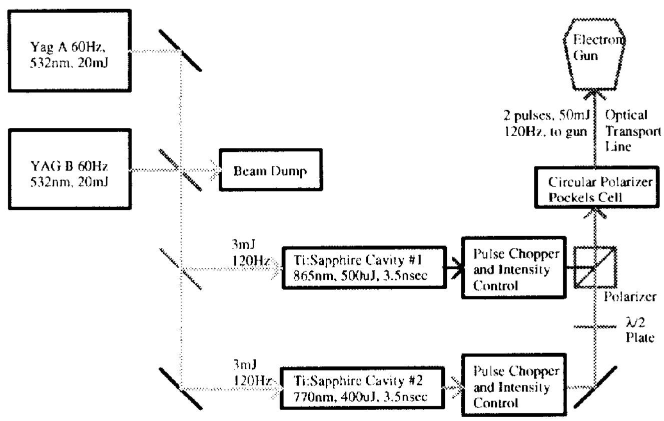

Figure 1. Laser System Layout

B. Optical Cavity Design

The Ti:Sapphire cavities are Q-switched[4] and cavity dumped[5] with an intra-cavity Pockels Cell and polarizer (Figure 2). When high voltage is applied to the Pockels cell, the polarization of the light in the cavity is rotated and lasing is inhibited. Removing the high voltage allows build-up of light in the cavity to begin. When the intra-cavity optical power reaches maximum, a fast high voltage edge is applied to the Pockels cell. This causes the circulating light to be extracted through one of the cavity polarizers. This produces a pulse whose length is the round trip length of the optical cavity.

SLAC Polarized Source Ti:Sapphire Cavity

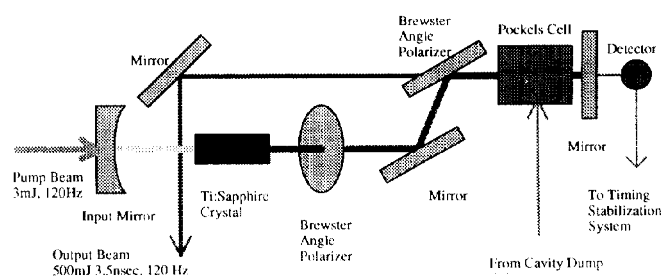

Figure 2. Laser Cavity Layout.

* Work Supported by U.S. Department of Energy Contract DE-AC03-76SF00515

0-7803-1203-1/93$03.00 © 1993 IEEE

A Pockels cell with a fast (150psec rise and fall time) avalanche transistor driver chops the output pulse to the required 2ns width. An additional Pockels cell after each cavity is used to control the output intensity.

B. Feedbacks

The Polarized source laser is required to run for long periods of time (weeks) without adjustment. A number of feedbacks have been incorporated into its design to allow long term stable operation (Figure 3.)

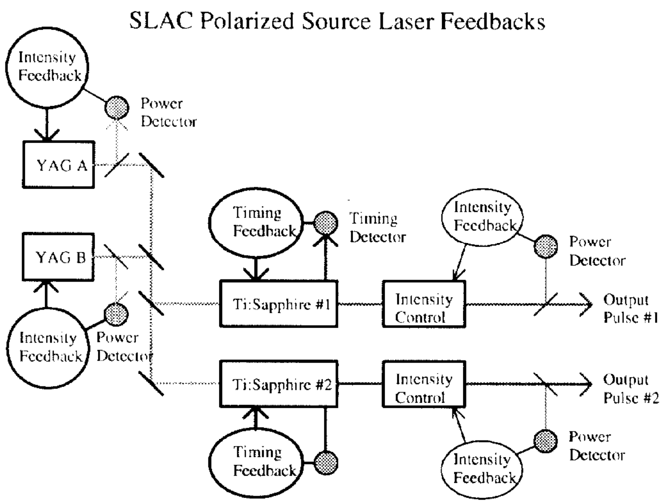

Figure 3. Laser feedbacks

A pair of feedback loops stabilize the output energy from each of the YAG lasers. A photodetector monitors the output energy and adjusts the flashlamp high voltage. Drifts in the YAG output beam steering are removed by optics which image the YAG rods onto the Ti:Sapphire crystals.

The primary source of intensity jitter in the Ti:Sapphire cavities is variations in the optical gain causing the timing of the Q-switched pulse to change. As the cavity dump time is fixed by the accelerator timing, these variations in build-up time cause variations in output intensity. Feedback loops which measure the build-up time of the light, and control the stop time of the Q-switch pulse are used to maintain the cavity-dump time at the peak of the optical pulse. The gain variations due to changes in each of the YAG lasers on each of the Ti:Sapphire cavities are independent so 4 separate timing feedback loops are used. Without the timing stabilization, the output intensity jitter from the Ti:Sapphire lasers is approximately 12%RMS. The feedbacks reduce this to approximately 5% RMS.

The output power from the Ti:Sapphire cavities is stabilized by intensity feedbacks which read the optical energy and control the high voltage to a Pockels cell. Separate feedbacks are used for pulses generated by each of the pump lasers.

C. Fast Feedforward

After the slow timing feedbacks have removed drifts in the build-up time of the optical power, the major remaining source of jitter is pulse to pulse fluctuations in gain due to intensity jitter in the pump YAG lasers. A "Fast Feedforward" system is used to eliminate this effect to first order. The fast feedforward measures the YAG output energy, and on the same pulse, adjusts the stop time for the Ti:Sapphire Q-switch to reduce the build-up time jitter. The fast feedforward reduces the output jitter from the Ti:Sapphire cavities to <3% RMS.

III. SYSTEM PERFORMANCE

A. Electron Beam Current

The laser system is currently installed on the SLAC polarized source driving a strained lattice GaAs photocathode. The maximum charge which can be extracted in nanosecond pulses from semiconductor photocathodes saturates as a function of incident laser energy[6]. A charge saturation curve for the source cathode at a wavelength of 863nm is given in figure 4.

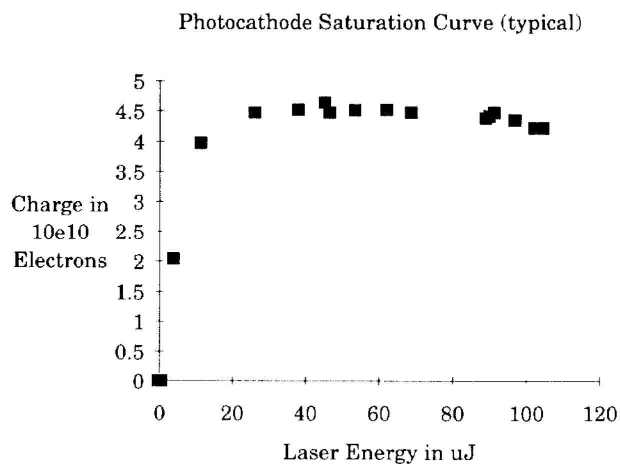

Figure 4. Photocathode charge saturation

This saturation in the charge extracted from the photocathode reduces the sensitivity of the electron beam current to fluctuations in the laser intensity. The laser is typically operated at the maximum of the saturation curve (approximately 50μJ) with a resulting output current stability of <1.6% RMS. The total current from the gun is adjusted by changing the spot size of the laser on the photocathode.

The charge limit for the first bunch reduces the available total charge for the second bunch. The charge limit is larger for shorter laser wavelengths. As the polarization of the second electron bunch is not important (it is used to generate positrons), we are able to operate the Ti:Sapphire cavity #2 at shorter wavelengths (770nm). This increases the charge limit for the second bunch to allow production of equal intensity bunches.

B. Position Stability

Position instabilities of the laser spot on the photocathode are the result of two primary sources. Motion of the YAG pump beams, and drift and vibration of the optical transport system. The Ti:Sapphire cavities themselves do not introduce significant beam motion.

Motion of the pump beams causes the position of maximum gain in the Ti:Sapphire cavity to move and the mode position to shift. This is particularly troublesome because the drifts of the two YAG lasers are independent, and the result is an output beam position which alternates at 60Hz. This motion is typically 40μm RMS (for a 8mm FWHM spot) at the photocathode. Vibration of the laser transport system produces similar amplitude motions. Under normal operating conditions, these motions do not significantly effect electron beam operation.

C. Wavelength and Polarization

At the present time there is no polarimeter to measure the electron beam polarization directly from the photocathode gun. A combination of measurements on the 50GeV beam and laboratory measurements on similar cathodes can be used to estimate the source polarization as a function of laser wavelength. Note: the laser polarization is >99%. For wavelengths longer than 860nm, the electron polarization at the gun is believed to be 80%±5%[7]. For shorter wavelengths, the polarization decreases at about 1% per nanometer.

The only wavelength tuning in the laser system is due to the limited bandwidth of the polarizers. The combination of polarizers in transmission and reflection produces a bandwidth of about 4nm FWHM. The center wavelength drifts (dependent on humidity) by ±3nm on a timescale of days.

The charge limit decreases and the optical energy required to saturate the cathode increases when the wavelength is increased. We operate the laser at wavelengths between 862nm and 868nm to maintain good polarization and charge limit.

D. System Reliability

The laser system was commissioned on the SLAC linac at the end of January 1993. Table 2 lists system downtime since that time. 1992 run uptime with the flashlamp pumped dye laser source are listed for comparison.

Table 2. Laser System Uptime

System Performance	**1992**	**1993**
Total hours	3980	2230
Uptime	97.0%	97.4%
Downtime - scheduled	2.0%	1.6%
Downtime - unscheduled	1.0%	1.0%

Scheduled maintenance of the laser has been dominated by wavelength and transport system changes to optimize polarization. In the future, scheduled downtime will probably be dominated by YAG laser flashlamp changes: 4 hours every 45 days or 0.4%. The laser system uses 4 planar triode tube pulsers. Maintenance on these units will probably increase scheduled down time to approximately 0.5%.

The largest unscheduled maintenance item has been avalanche transistor Pockels cell driver failures. These units produce the 150psec rise time, 2ns wide, 3KV pulses to chop the optical beam. The electrical performance of these units is excellent, and we are working to improve their reliability. Other unscheduled failures totaled 0.4%.

D. Overall Performance

This laser system has been used as the source for the SLAC linac for the production of >15,000 Z_0 bosons (as of 5/1/93) with approximately 60% electron polarization at the SLD detector.

IV. REFERENCES

[1] M. Woods et. al. "Polarized Light Sources for Photocathode electron guns at SLAC" *SLAC PUB 5965*. Submitted *10th intl. Symp. on H.E. Spin Physics - Nagoya 1992*

[2] T. Maruyama et. al. "Electron-spin polarization in photoemission from strained GaAs grown on $GaAs_{1-x}P_x$" *Physical Review B*, Vol. 24, No. 7, 15 Aug. 1992

[3] A. Sanchez et. al. "Crystal Growth, Spectroscopy, and Laser characteristics of Ti:Al_2O_3 ", *IEEE J. of Quantum Electron.*, Vol. 24, No. 6, (995-1002) 1998

[4] W. Koechner "Solid State Laser Engineering" *Springer-Verlag* 1976 (411-421)

[5] W.Koechner "Solid State Laser Engineering" *Springer-Verlag* 1976 (441-445)

[6]M. Woods et. al.,"Observation of a Charge Limit for Semiconductor Photocathodes" *SLAC PUB 5894* (Submitted to *J. Applied Physics*)

[7] J. Clendenin et al. "SLC Source Polarization" *SLAC SLCPOLSOURCE-TN-93-11* April 23, 1993 (unpublished)