AN INJECTION MODELOCKED TI-SAPPHIRE LASER FOR SYNCHRONOUS PHOTOINJECTION

Curt Hovater and Matt Poelker
Thomas Jefferson National Accelerator Facility
12000 Jefferson Ave., Newport News, VA 23606

Abstract

The CEBAF 4 GeV accelerator has recently begun delivering spin-polarized electrons for nuclear physics experiments. Spin-polarized electrons are emitted from a GaAs photocathode that is illuminated with pulsed laser light from a diode laser system synchronized to the injector chopping frequency (499 MHz) [1]. The present diode laser system is compact, reliable and relatively maintenance-free; however, output power is limited to less than 500 mW. In an effort to obtain higher average power and thereby prolong the effective operating lifetime of the source, we have constructed an injection modelocked Ti-sapphire laser with picosecond pulsewidths and gigahertz repetition rates. Modelocked operation is obtained through gain modulation within the Ti-sapphire crystal as a result of injection seeding with a gain-switched diode laser. Unlike conventional modelocked lasers, the pulse repetition rate of this laser can be discretely varied by setting the seed laser repetition rate equal to multiples of the Ti-sapphire laser cavity fundamental frequency. We observe pulse repetition rates from 223 MHz (fundamental) to 1560 MHz (seventh harmonic) with average output power of 700 mW for all repetition rates. Pulsewidths ranged from 21 to 39 ps (FWHM) under various pump laser conditions.

1 INTRODUCTION

Historically, successful operation of spin-polarized electron sources has been subject to maintaining a long photocathode lifetime. Photoelectron yield (i.e., quantum efficiency) diminishes with time for a number of reasons [2]; eventually the photocathode must be reactivated or replaced. Such procedures are labor and time intensive and reduce polarized-electron beam availability. For this reason, there is great interest within the accelerator community to develop methods for enhancing the effective operating lifetime of the source. Although laser issues do nothing to address the causes for quantum efficiency degradation, a high power laser source allows gun operation for a longer period of time before the photocathode must be reactivated or replaced.

A new approach to synchronous photoinjection is to use a modelocked Ti-sapphire laser [3]. Modelocked Ti-sapphire lasers are high power, tunable light sources with pulse repetition rates typically less than 100 MHz. Basu et al., used a gain switched diode laser to injection seed a Ti-sapphire laser pumped with a Q-switched doubled Nd:YAG laser [4]. They obtained 19.4 ps (FWHM) pulses at a rate of 200 MHz within the Q-switched macropulse. In a similar manner, we report using a gain-switched diode laser to modelock a slightly modified, commercial standing-wave Ti-sapphire laser. In contrast to work reported in Ref. 4, the pulse repetition rate of the modelocked Ti-sapphire laser was varied by setting the diode seed laser repetition rate equal to different multiples of the Ti-sapphire laser cavity fundamental frequency. Pulse repetition rates from 223 MHz to 1.56 GHz were observed with 700 mW average output power for all repetition rates. In this manner, GHz repetition rates are obtained with manageable cavity length (70 to 30 cm) and no intracavity modelocking elements are necessary. The gain switched diode laser serves as a simple, stable master oscillator; it is a trivial matter to obtain gain-switched pulse repetition rates to 4 GHz [5] suggesting that operation at even higher repetition rates may be achieved with this method.

2 EXPERIMENT

2.1 Injection Modelocked Ti-Sapphire Laser

Experiments were performed with a modified Spectra Physics Ti-sapphire laser Model 3900 (Fig. 1). The flat high-reflector (HR) mirror supplied with the laser was replaced with a 2% transmissive "input" coupler. The input coupler serves as an input port for the seed laser beam. Both the output and input coupler mirrors were wedged at 2 degrees to avoid etalon effects that might cause undesirable optical feedback. The Ti-sapphire crystal (20 mm x 5 mm dia.) was mounted on a water-cooled copper heat sink. The pump laser was focused into the crystal with a 15 cm radius of curvature mirror and approximately 80% of the pump laser light was absorbed. The free running Ti-sapphire laser operated at ~ 852 nm. When pumped with 6 W of green light from a multiline argon laser, the Ti-sapphire laser emitted 700 mW through output coupler mirror (5% transmissive) and 300 mW through the input coupler. The cavity length was 67 cm as determined by observing the beat signal between different longitudinal modes of the laser using a fast photodiode (Optoelectronic Model PD-15) and an RF spectrum analyzer.

The seed laser (SDL 5410-G1) was gain switched the usual way [5]. The laser was biased near threshold and an RF signal (~ 1 W) of the appropriate frequency was added using a bias-tee network. It was important to

0-7803-4376-X/98/$10.00

operate the diode laser within a narrow range of DC bias current. Beyond this range, pulsewidths broadened and/or secondary pulses were observed with the fast photodiode and sampling oscilloscope (Tektronix Model 11801B with SD-32 sampling head). The average output power from the gain-switched diode laser was approximately 5 mW although there was some variation associated with pulse repetition rate. The wavelength of the diode laser output was ~ 859 nm, roughly 7 nm different from the free-running Ti-sapphire laser wavelength. The gain-switched diode laser output was passed through an optical isolator (approx. 40 dB isolation) and then directed into the Ti-sapphire laser cavity through the 2% transmissive input coupler.

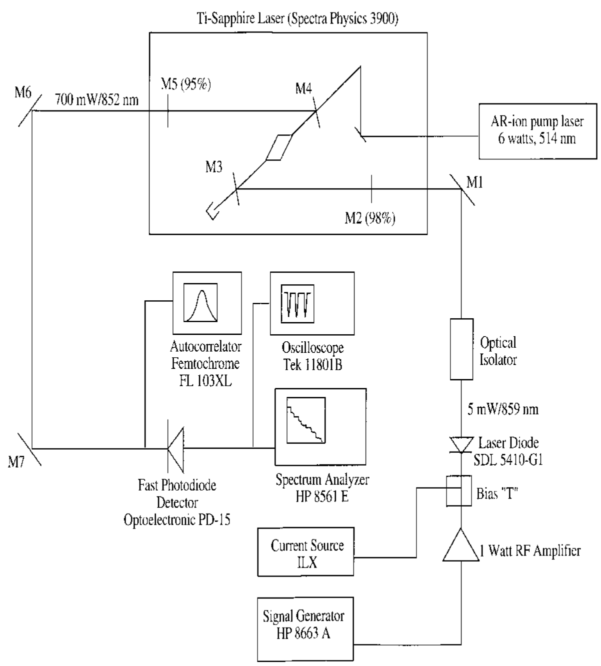

Figure 1. Schematic of the injection modelocked Ti-sapphire laser.

The Ti-sapphire laser output went from DC to pulsed modelocked when the seed laser was aligned to ensure proper spatial modematching between the two lasers and the pulse repetition rate of the seed laser was set to within 10 kHz of the Ti-sapphire laser cavity fundamental frequency (or harmonic). We believe that modelocking occurs as a result of gain modulation caused by the presence of the seed laser beam within the Ti-sapphire laser crystal. The pulsed seed laser extracts gain from the Ti-sapphire laser crystal, which effectively serves to provide period loss in a manner similar to an acoustooptic modulator within a conventional modelocked laser. It was a relatively simple matter to obtain pulse repetition rates equal to harmonics of the Ti-sapphire laser cavity fundamental frequency; only the frequency of the RF signal applied to the diode laser was changed (Fig. 2). We observed pulse repetition rates up to 1.56 GHz, the seventh harmonic of the Ti-sapphire laser cavity fundamental frequency. The modelocked average output power remained nearly the same compared with DC operation; maximum average power through the output coupler was 700 mW with 6 W pump power. The wavelength of the modelocked Ti-sapphire laser output was ~ 854 nm, which was 2 nm different from the free-running operation and 5 nm different from the seed laser wavelength. Unfortunately, the laser in its present state suffers from severe pulse-to-pulse amplitude noise. There were brief periods of amplitude-stable pulsed operation. Typically, however, slight adjustments to the seed laser alignment were necessary and/or the seed laser pulse repetition rate needed to be adjusted by several kHz to reestablish amplitude-stable pulsed output.

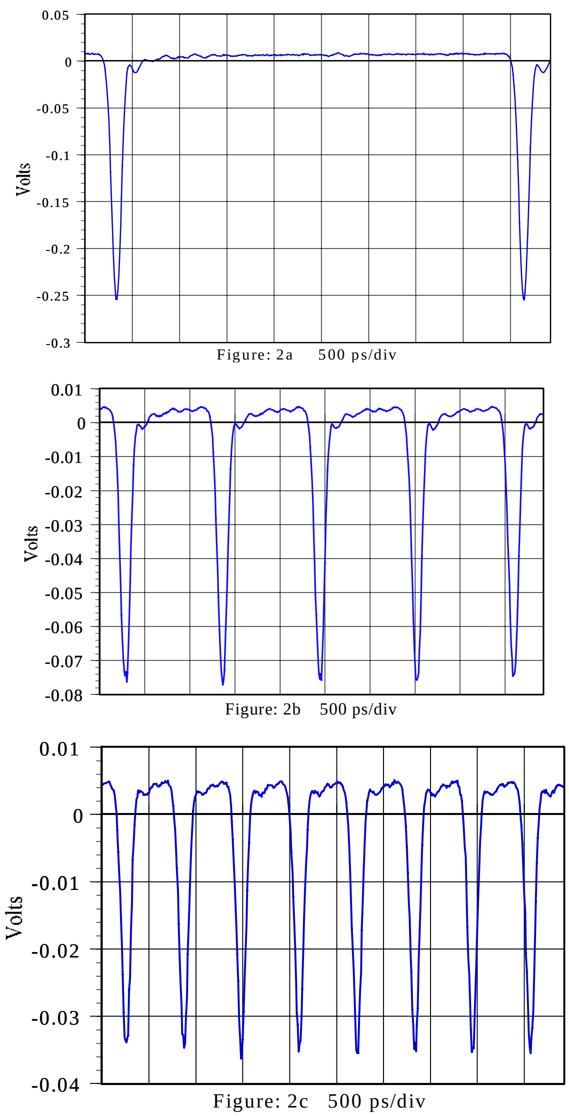

Figure 2. Oscilloscope traces showing the fast photodiode signals for three different pulse repetition rates: a. 223 MHz, b. 892 MHz, and c. 1.56 GHz.

2.1. Pulsewidth Measurement

Autocorrelator measurements were performed to ascertain gain-switched diode seed laser and modelocked

Ti-sapphire laser pulsewidths. The autocorrelator (Femtochrome Model FR-103XL) relies on non-colinear, background-free second harmonic generation within an $LiIO_3$ crystal. The seed laser pulsewidth was ~ 47 ps (FWHM), a value consistent with gain-switched operation of common diode lasers. Modelocked Ti-sapphire laser pulsewidths ranged from 21 to 39 ps (FWHM); pulsewidth increased with higher pump laser power.

2.2. Phase Noise Measurement

Phase noise measurements were performed to quantify pulse timing jitter of the gain-switched diode laser master oscillator and modelocked Ti-sapphire slave laser. These measurements were performed with an HP 8563B spectrum analyzer and vendor-supplied software. Integrated RMS phase noise (10 Hz to 1 MHz) was measured at the fifteenth harmonic of the fundamental frequency. Measurements indicate that phase noise on the seed laser pulsed output is slightly less than 0.1 degree, a value comparable to the phase noise of the synthesized source used to excite gain-switched operation. A phase noise plot of the modelocked Ti-sapphire laser output is shown in figure 3.

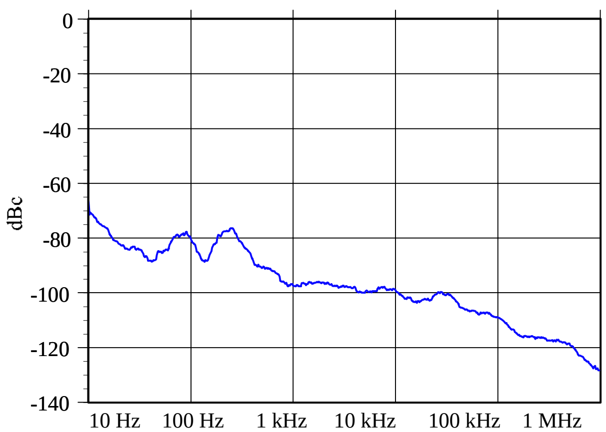

Figure 3. Phase noise measurement of the Ti-sapphire laser at 223 MHz measured at the 15th harmonic.

The integrated RMS phase noise is 0.2 degrees, a value two times that of the gain switched diode laser output. Phase noise of 0.2 degrees corresponds to timing jitter of 2.5 ps. This value compares favorably with the Jefferson Lab IRFEL modelocked Nd:YLF drive laser and is adequate for most photoinjector applications [6].

3 SUMMARY

Although pulse-to-pulse amplitude fluctuations prevent the laser in its present state from being used for photoinjection, it has a number of appealing features that warrant further research. The laser emits GHz pulse repetition rates that meet Jefferson Lab requirements and average output power is higher than can be obtained from the diode laser system presently used. Modelocked Ti-sapphire laser pulsewidths range from 21 to 39 ps (FWHM) and will provide manageable electron beam at Jefferson Lab that is not dominated by severe space charge effects. The modelocked Ti-sapphire laser has low timing jitter as a result of injection seeding using a simple, stable gain switched diode laser. We are presently designing a Ti-sapphire laser that incorporates active cavity length control in an effort to minimize amplitude noise on the Ti-sapphire laser output. The new laser will also use an intracavity Faraday rotator to force unidirectional, traveling wave oscillation in an effort to reduce amplitude noise associated with spatial hole burning within the Ti-sapphire crystal. In addition, unidirectional traveling wave oscillation will provide for more efficient output coupling. The present laser design has an output coupler and an input coupler. Although it was not discussed in detail, there is significant pulsed output that is wasted through the input coupler (~ 40%). The new ring cavity, design has one mirror that serves as both the output and input coupler. All of the pulsed output is usable because the seed and Ti-sapphire laser beams are not colinear when oscillation within the Ti-sapphire laser is forced to be unidirectional. In conclusion, the results presented here provide "proof of principle" that injection modelocking using a gain switched diode laser is a promising method to obtain high power, pulsed laser light with GHz pulse repetition rates.

4 ACKNOWLEDGEMENTS

Authors would like to thank Chris Cuevas who assisted in the data acquisition. This work was supported by the U.S. Department of Energy under contract number DE-AC05-84ER40150.

REFERENCES

[1] M. Poelker, Appl. Phys. Lett ., **67**, 2762 (1995).
[2] K. Aulenbacher, Proc. of the Workshop on Photocathodes for Polarized Electron Sources for Accelerators, edited by M. Chatwell et al., SLAC Report 432 rev. p. 1, 1993.
[3] J. Hoffmann, P. Hartmann and C. Zimmermann, accepted for publication Nucl. Instrum. Meth. A.
[4] S. Basu, P. May, and J. M. Halbout, Opt. Lett., **14**, 1272 (1989).
[5] P.T. Ho, in *Picosecond Optoelectronic Devices*, edited by C. H. Lee (Academic, New York, 1984).
[6] M. Shinn and S. Benson, Proc. IEEE PAC, 1052 (1995).