Laser Sources for MIT-Bates and IASA

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Abstract: We report the development of a high power mode-locked external cavity diode laser/Ti:sapphire laser system to be used as a source for cw and pulsed electron accelerators. It provides up to 3.4 W average power with a corresponding pulse energy of 1.1 nJ at 2856 MHz repetition rate and tunable between 815-835nm.

Spin polarized electrons beams have offered a new tool for the detailed study of structures in diverse research fields such as atomic, particle and semiconductor physics. A reliable, stably running source of polarized electrons is of paramount importance for the success of such investigations. Of particular relevance to this letter are electron sources of either pulsed type such as MIT-Bates Linear Accelerator Center, Boston, USA or continuous wave type (CW) such as Jefferson Lab, Newport News, Virginia, USA, MAMI, Mainz, Germany and IASA, Athens, Greece.

The polarized electrons are produced by laser illumination of GaAs type semiconductor photocathodes [1]. This method requires the development of good quality photocathodes and the existence of high power CW or pulse laser systems in the wavelength range between 760 nm – 860 nm. Nowadays, it was demonstrated that electrons with high polarization greater than 75 %, can be extracted from GaAs photacathodes with quantum efficiency more than 0.4 % for optimum illumination at 830 nm [2]. Also, commercially available lasers in this wavelength range (760 nm – 860 nm) are either continuous wave (CW) or mode-locked systems with 76 MHz pulse repetition rates. Considering that the existing accelerator technology requires different time structures, the commercially available lasers give a poor match to the electron accelerator requirements.

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Specifically using a CW laser to produce the electrons, suffers from some main disadvantages. Since the above accelerator systems are RF driven, the beam has to be chopped. The result is the small capture efficiency for the produced electrons due to the chopper losses (typically 0.15 to 0.40). So there is an inefficient utilization of the beam current produced by the photocathodes. Also the beam current into the accelerator is significantly limited. Moreover due to the need for a chopped beam, there is an inefficient use of the photocathodes lifetime which contributes to an important reduction of its usable lifetime.

The commercially available mode-locked laser systems produce picosecond pulses with 76 MHz repetition rates. Considering the requirements of the accelerators frequency (2856 MHz for MIT-Bates, 1500 MHz for Jefferson Lab, 2450 MHz for MAMI and 2380 MHz for IASA-Athens), the conclusion is that the mode-locked laser systems operate at a low subharmonic of the accelerating RF field. The result is that the average beam current becomes very low [3]. Correspondingly the value for the pulsewidth required from the laser source is set by the chopper/buncher employed in each accelerator and typically varies between 50 and 120 ps.

To address the issue of pulse repetition rate from the laser source, a number of research groups have recently developed custom, pulsed laser systems to be used in cw accelerators. These systems have been based on (a) semiconductor diodes that follow the gain switched, master oscillator, power amplifier design (4) and the actively mode-locked, compound external cavity diode design (5) and (b) passively mode-locked Ti:sapphire design (6). These systems have been successfully tested and used in cw accelerators, but as a result of their relatively low average power (up to 500 mW) and pulse energy (less than 150 pJ) they cannot be used in pulsed accelerators.

In this paper we report on a laser system capable of delivering a 60 to 110 ps pulse train at 2856 MHz repetition rate, tunable between 815-835 nm, with up to 3.4 W average power which corresponds to a pulse energy of 1.1 nJ. This system has been designed for use in the MIT-Bates Linear Accelerator Center which presently uses a cw Ti:sapphire oscillator.

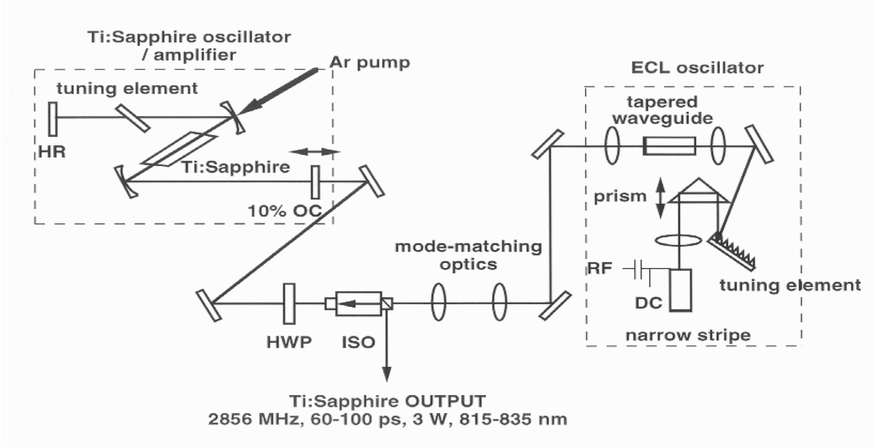

FIGURE 1. Schematic of ECL/Ti:sapphire laser system

A schematic of the laser system is shown in Fig. 1. It comprises of a harmonically mode-locked, tunable, external cavity semiconductor diode laser (ECL) which provides the seed signal and an Ar-ion pumped Ti:sapphire oscillator which amplifies it. As the beam profiles from the two oscillators differ, the mode-locked pulse train from the ECL is down collimated with a 5:1 beam expander into the Ti:sapphire oscillator through its output coupler. To avoid mode-locking loss and instabilities arising due to feedback from the Ti:sapphire oscillator, the ECL cavity is isolated using a broad band (40 dB) Faraday isolator which also acts as the output tap of the system on the return beam from the Ti:sapphire oscillator.

The ECL oscillator has been discussed in detail elsewhere (5) and here only a brief description will be given. The compound cavity contains two GaAlAs laser diodes and is formed between the back facet of the narrow stripe diode and the front facet of the tapered amplifier diode. The narrow stripe diode is modulated with a high power rf signal (up to 500 mW) and the tapered amplifier is driven with a dc current of 2 A to provide the mode-locked output pulse train. In the present implementation the diodes used have been coated to allow maximum gain at about 825 nm for use with GaAsP photocathodes and the ECL can routinely provide 60-70 ps long pulses with up to 250 mW of average power with a tuning range between 815 to 830 nm. The repetition rate of a mode-locked laser is set by its cavity length and the ECL oscillator has been configured for use with the 2856 MHz rf master oscillator of the MIT-Bates accelerator. As this frequency corresponds to an impractically short laser cavity of 5.25 cm, the ECL was built with a 31.5 cm long cavity (corresponding to 476 MHz fundamental frequency) and was therefore mode-locked on its 6th harmonic. The choice of this fundamental cavity frequency is fortuitous as its 5th harmonic corresponds to the IASA-Athens master oscillator frequency at 2380 MHz making very easy the testing of the system.

The Ti:sapphire oscillator is a commercial unit with the standard astigmatically compensated cavity which includes a Lyot filter tuning element and which has been modified to allow cavity length adjustment. It employs a 10% output coupler to allow adequate seeding without substantial loss of output power. In the absence of any seeding the Ti:sapphire oscillator provides up to 3.5 W of output at 830 nm for 18 W of pump power. To ensure synchronization with the ECL pulse train, the Ti:sapphire cavity length was set at 63 cm, corresponding to a fundamental frequency of 238 MHz or the 12th subharmonic of the rf frequency.

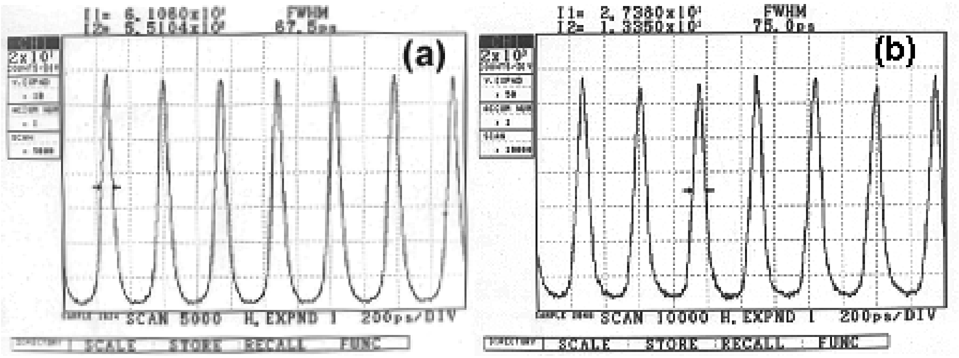

FIGURE 2. Pulse train at 2856MHz from (a) ECL and (b) amplified.

Fig. 2a shows the temporal profiles of the pulse trains obtained directly from the ECL operating at 2856 MHz repetition rate with 250 mW average power. The pulses are clean with full width at half maximum (FWHM) is 65 ps and the peak to background ratio is 30:1. Fig. 2b shows the corresponding amplified train from the Ti:sapphire. The pulses are still clean but they are slightly broadened to 75 ps and the peak to background level is now 25:1.

With the present configuration the maximum average power was obtained from the system after optimization of the cavity parameters and was 3.4 W at 2856 MHz, corresponding to 1.1 nJ pulse energy in the 110 ps capture window for the MIT-Bates accelerator. This figure, which can be improved further, must be compared with the obtainable pulse energy of 770 pJ from the present system (cw Ti:sapphire) (7). Apart from the pulse energy increase, the ECL/Ti:sapphire system is expected to lead to a significant improvement in the lifetime of the photocathode because of the threefold reduction in illumination of the photocathode from the mode-locked pulses.

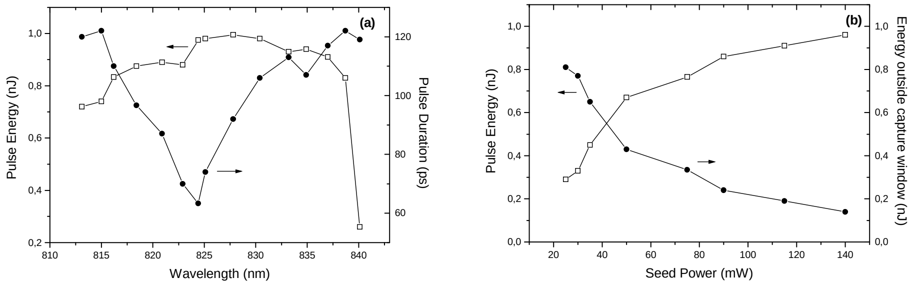

FIGURE 3. (a) Pulse energy and duration against wavelength, (b) pulse energy in and out of capture window (110ps).

Fig 3a shows the tuning curves of the laser system output when operated at 2856 MHz. These curves have been obtained only by adjusting the tuning elements in the ECL and Ti:sapphire oscillators. The average optical power from the system is determined by the Ti:sapphire oscillator and was approximately constant to 3 W throughout the measured tuning range. The measurements for the pulse energy have been made assuming that there is a 110 ps long, useable capture window. The tuning curve for pulse energy is flat within 20% of the maximum value of about 1 nJ, over a 20 nm range centered at 825 nm and is larger that the tuning range of the ECL oscillator. As the system is tuned further away from the peak wavelength of the ECL, the pulse energy in the output pulse train decreases and a cw background develops. The reason for this tuning range extension is due to a small feedback through the isolator into the ECL. Fig 3a also shows the pulsewidth change against wavelength which varies between 60 and 110 ps. It should be noted however that no optimization of the cavities parameters has been made during these measurements. The key to obtaining high pulse energies from the system is to ensure a high level of seed power from the ECL to the Ti:sapphire. In order to assess this, a variable attenuator was installed after the ECL oscillator and before the beam down collimation optics. Fig 3b shows the pulse energy against the seeding power as measured before the Ti:sapphire output coupler for 2856 MHz operation. For seeding powers lower than 50 mW, more than 50 % of the energy is lost outside the capture window.

We have measured the amplitude stability of the seed pulse train directly from the ECL oscillator and from the Ti:sapphire using a fast photodiode and a 1 GHz analogue oscilloscope. The output stability is better than 1% from the ECL oscillator and about 5% from the Ti:sapphire. The reduction in stability in the amplified signal was traced to the Ti:sapphire oscillator and was not due to the seeding process and we are currently in the process of investigating this.

In summary we have demonstrated a laser system that generates mode-locked pulses with up to 3.4 W average power and pulse energy of 1.1 nJ at 2856 MHz. The system can generate pulse trains with 60-110 ps long pulses and repetition rates at multiples of 476 MHz over a 20 nm tuning range. It is therefore suitable for generating electron bunches for use in continuous wave accelerators but more importantly it can be used in pulsed accelerators where high energy pulses are a prerequisite and no pulsed laser sources are currently available. Scaling to even higher pulse energies should be possible by optimization of the output coupling of the Ti:sapphire oscillator.

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