YTTERBIUM FIBER LASER FOR ELECTRO-OPTICAL PULSE LENGTH MEASUREMENTS AT THE SWISSFEL

F. Müller*, S. Hunziker, V. Schlott, B. Steffen, D. Treyer, Paul Scherrer Institute (PSI), Switzerland
T. Feurer, University of Bern, Switzerland

Abstract

Pulsed Yb fiber lasers emit at 1030 nm which provides a better phase matching in standard EO crystals (GaP, ZnTe) than the wavelength of Ti:Sa lasers (800 nm). We present a mode locked ytterbium fiber laser which is phase locked to the RF. A subsequent fiber amplifier is used to boost the power and to broaden the spectrum due to nonlinear effects. The produced pulses have a spectral width of up to 100 nm and are therefore suitable for EO bunch length measurements, especially for spectral decoding.

INTRODUCTION

In accelerator diagnostics the knowledge of the electron bunch length and the temporal structure plays an important role. Electro optical (EO) techniques offer the possibility for non destructive single shot pulse length measurements [1]. This laser based method requires an environmentally stable and robust laser system with a small jitter and a broad spectrum. Ytterbium (Yb) fiber lasers fulfill these criteria. Yb has a number of interesting properties as a small quantum defect which leads to high pump efficiencies, a long upper state lifetime, a broad gain spectrum and a good phase matching to the THz field in GaP and ZnTe crystals [2, 3]. Combined with the advantages of fiber based systems, as compactness, freedom from misalignment and robustness, Yb fiber laser systems offer an attractive alternative to Ti:Sa lasers for EO measurements. Besides, the price of an Yb laser system is only a fraction of the costs of a Ti:Sa laser system. The EO setup contains the fiber laser and a compact bunch length monitor [4].

LASERSYSTEM

Setup

The laser consists of an oscillator and a single pass amplifier. A schematic of the oscillator is depicted in Fig. 1. The ring resonator has a fiber and a free space part. The latter is basically necessary for dispersion compensation and for the mode locking mechanism, which is based on nonlinear polarization evolution (NPE) [5]. The polarization state is controlled by the three wave plates, which allow to rotate the polarization in a way, that the short and intense part of the pulse remains in the oscillator where the rest, which underwent less polarization rotation is coupled out

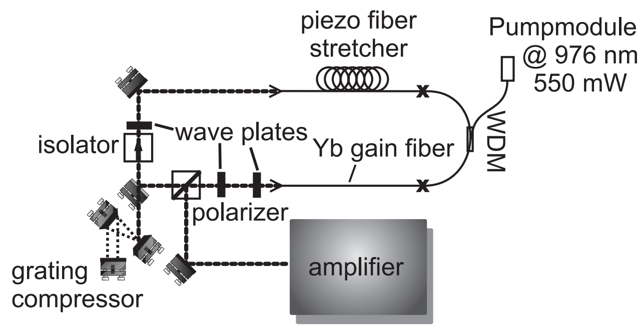

Figure 1: Scheme of the oscillator; WDM, wavelength division multiplexer

by the polarizer. This fast and passive effect is responsible for mode locking. The unidirectional way of propagation is defined by the isolator. The amplification and the pumping is done in fiber. The piezo stretcher modulates the resonator length and therefore the repetition rate, which is used to synchronize the laser to a reference signal.

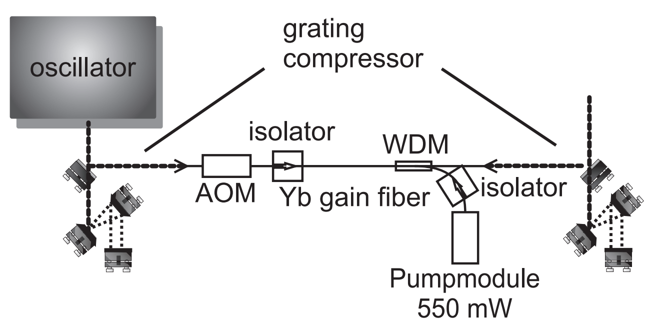

Figure 2: Scheme of the amplifier; AOM, acousto optic modulator; WDM, wavelength division multiplexer

The amplifier is shown in Fig. 2. After the oscillator a first grating compressor modulates the pulse width in order to compensate the dispersion of the following fiber section. The AOM reduces the repetition rate which allows to boost the pulse energy without increasing the average power. Near the end of the fiber, the amplified pulses become short, the intensity increases and strong nonlinear effects occur which broaden the spectrum.

The according spectra are shown in Fig. 3. In the inset plot the spectrum of the oscillator is depicted, which has a spectral width of about 40 nm. It has the typical parabolic shape of self similar pulses [6]. After amplifi-

* felix.mueller@psi.ch

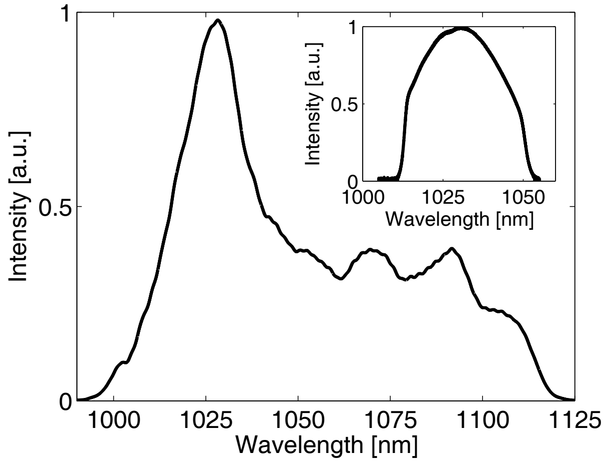

Figure 3: Broad spectrum of the amplifier as used for the EO monitor. Inset: Spectrum of the oscillator

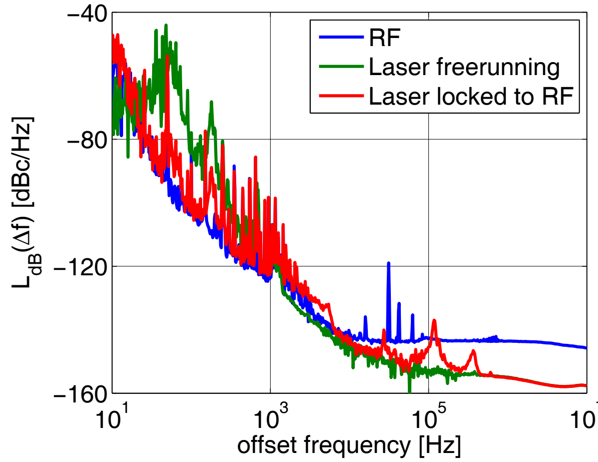

Figure 4: Phase noise measurement of the reference signal, the free running and the locked laser

cation, the broadened spectrum goes from 1 μm to 1.1 μm, providing more than 100 nm of useful bandwidth. For spectral decoding [7, 8] the spectral width directly determines the resolution respectively the temporal range of measurement. Due to the large product of intensity and interaction length in fibers, the oscillator as well as the amplifier produce chirped pulses of up to 10 ps FWHM. The spectral phase of the oscillator is mainly linear, which means that the pulse length can be easily compressed with standard grating compressors down to 60 fs FWHM. After the amplifier the phase has also higher order terms which complicates the pulse compression. The pulses can still be compressed to less than 50 fs FWHM but with some remaining pedestals.

Table 1: Specifications of the Laser System

	Oscillator	**Amplifier**
Average power	50 mW	20 - 100 mW
Repetition rate	50 MHz	0.1 - 1 MHz
Pulse length	60 fs	50 fs
Pulse energy	2 nJ	20 - 200 nJ
Spectral bandwidth	40 nm	100 nm
Central wavelength	1030 nm	1050 nm

Some of the specifications of the laser are summarized in Table 1.

Synchronization

EO Measurements are based on a spatial and temporal overlap between a chirped laser pulse and the electric field of an electron bunch in a nonlinear crystal. This requires a good synchronization to a reference signal (RF) and a low jitter of the laser above the loop bandwidth. The phase locked loop (PLL) modulates the resonator length with a piezo fiber stretcher and locks the 10th harmonic of the repetition rate to the reference clock (500 MHz).

In Fig. 4 the phase noise measurement of the reference signal and of the fiber laser is illustrated. The phase noise of the free running laser for low offset frequencies is typically quite high, where it decreases rapidly for higher frequencies and becomes even smaller than the phase noise of the reference signal. Hence, the laser has to be locked only up to about 1 kHz offset frequency. This loop bandwidth can be seen in the measurement of the locked laser. It follows the reference signal as long as it is more stable and stays freeruning above. The remaining integrated jitter between 1 kHz and 10 MHz is 41 fs.

PREPARATIONS FOR EO MEASUREMENTS AT THE SLS

First EO measurements will take place at the Swiss Light Source (SLS) at PSI where the bunch length of the electron bunches is between 2 ps (LINAC) and 70 ps (storage ring) FWHM. Additionally, there is an ongoing experiment (FEMTO slicing) which generates much shorter pulses by cutting a temporally short part (100 fs) out of the main bunch [9, 10]. An amplified femtosecond Ti:Sa laser pulse interacts with the electrons and modulates their energy. After a dispersive element the energy modulation transforms into a longitudinal one.

The simulated charge distribution is depicted in Fig. 5 for several turns at the THz beamline [11]. Directly after the interaction the modulation has more or less the same temporal length as the laser pulse. Due to the damping of the machine, this modulation becomes longer from turn to turn and finally vanishes. This behavior is shown for turn 0 up to turn 3, which shows the temporal shape after three round trips. The coherent synchrotron radiation can be used to test the EO setup with a whole set of pulse lengths from several ps down to 100 fs, which is the lower limit of the EO techniques due to the limited bandwidth of the EO crystals [2]. Since this modulation of the electron

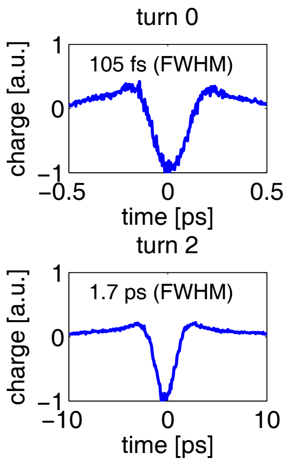

Figure 5: Charge distribution of the sliced bunches from turn 0 to turn 3

bunch is done with a second synchronized laser, the laser to laser stability and the relative jitter plays a decisive role for pulse length measurements. The jitter determines how long the chirped laser pulse has to be in order to get a temporal overlap. It can be deduced from a cross correlation between these two pulses. This measurement delivers a first characterization of the whole laser setup. It has been done in a collinear cross correlation setup in a BBO crystal of 50 μm thickness. The initial pulse length of the lasers were 60 fs (Yb) and 100 fs FWHM (Ti:Sa). In case of an ideal synchronization with no jitter, one would get the cross correlation as depicted in Fig. 6 (blue curve), any jitter results in further broadening this curve.

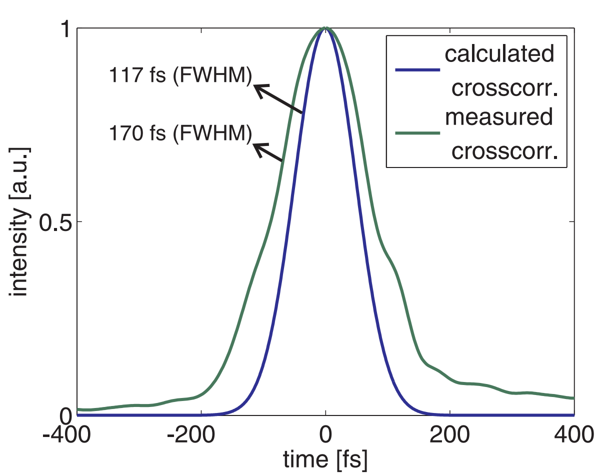

Figure 6: Calculated jitter-free (blue curve) and measured (red curve) cross correlation of the Yb and the Ti:Sa Laser.

The relative jitter between the two lasers is about 120 fs, which is suitable for the planned experiments.

CONCLUSION AND OUTLOOK

A mode locked Yb fiber laser has been built, which suffices the requirements for EO pulse length measurements. The synchronization has been characterized and successfully tested with a cross correlation experiment. First measurements with the EO setup, consisting of the laser and the EO monitor, are planned at the SLS linac during summer 2009. Further optimizations can be done by measuring shorter pulses during FEMTO slicing. In parallel we are planning a packaging of the laser for operation at the 250 MeV Injector which is currently under construction.

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