OPTICAL LASER SYNCHRONIZED TO THE DESY VUV-FEL FOR TWO-COLOR PUMP-PROBE EXPERIMENTS

Ingo Will (MBI, Berlin)

Harald Redlin, Stefan Düsterer, Josef Feldhaus, Elke Plönjes (DESY, Hamburg)

Abstract

The VUV-FEL at DESY provides ultra-short pulses with pulse durations below 50 fs. In order to utilize the short pulse duration for time resolved experiments, an OPCPA laser system has been installed delivering 150 fs pulses at a wavelength of 800 nm with 50 µJ pulse energy at 1 MHz repetition rate during the FEL burst. The laser is synchronized to the FEL with an accuracy better than 0.5 ps. In addition, the delay between optical laser and FEL pulses can be precisely adjusted, enabling high-resolution two-color pump-probe experiments.

The paper describes the laser system and the synchronization concept. First results of measurements of the synchronization accuracy by using a streak camera are presented.

INTRODUCTION

The VUV-FEL at DESY [1] presently provides ultra-short pulses with pulse durations below 50 fs in the VUV wavelength range. To explore a wide field of time resolved applications using two-color pump-probe experiments, a supplementary laser providing ultrashort pulses in the visible and near-infrared spectral range is required. Such a laser should generate femtosecond pulses with the same temporal structure as the pulses from the VUV-FEL. A particularly important feature of this FEL is that it generates trains (bursts) of femtosecond pulses instead of single pulses in its standard operation mode. The typical spacing of the individual pulses ("micropulses") in the train presently amounts to 1 µs, i.e. the repetition rate in the train is 1 MHz. Consequently, the solid-state laser should be able to generate similar pulse trains which may be up to 800 µs long in future operation of the FEL. Naturally, the individual femtosecond pulses of the train should be precisely synchronized to the output pulses of the FEL.

It turned out that particularly the requirement to generate trains (bursts) of synchronized femtosecond pulses severely influenced the decision on the type of the laser and on its general layout.

LAYOUT OF THE OPCPA LASER

Fig. 1 shows the general scheme of the laser system that generates the desired trains of femtosecond pulses. It is based on Optical-Parametric Chirped-Pulse Amplification (OPCPA) [3, 4]. The initial seed pulses generated by a Titanium Sapphire (Ti:Sa) oscillator are amplified in two stages by Optical-Parametric Amplification (OPA). Both OPA stages consist of nonlinear LBO crystals which are pumped by a special burst-mode Nd:YLF laser. The pump laser is an appropriately adapted version of the photocathode laser [5, 6] that drives the photo injector of the linear accelerator of the VUV-FEL.

In order to pump the OPA an additional flashlamp-pumped amplifier is required to boost the available output energy to 1.1 mJ per micropulse. The number of micropulses per burst is adjustable by appropriately programming the window of the second pulse-picking Pockels cell of the amplifier chain. A whole pulse train (fig. 2) can contain up to 800 micropulses, the total energy amounts to 0.88 J in this case. The pump laser can operate at a 5...10 Hz repetition rate. Conversion to the second harmonic is accomplished using a 10 mm long LBO crystal with a typical efficiency of 60%. The duration of the individual micropulses in the train is 15 ps at 1047 nm wavelength and 12 ps after conversion to green light (λ = 524 nm).

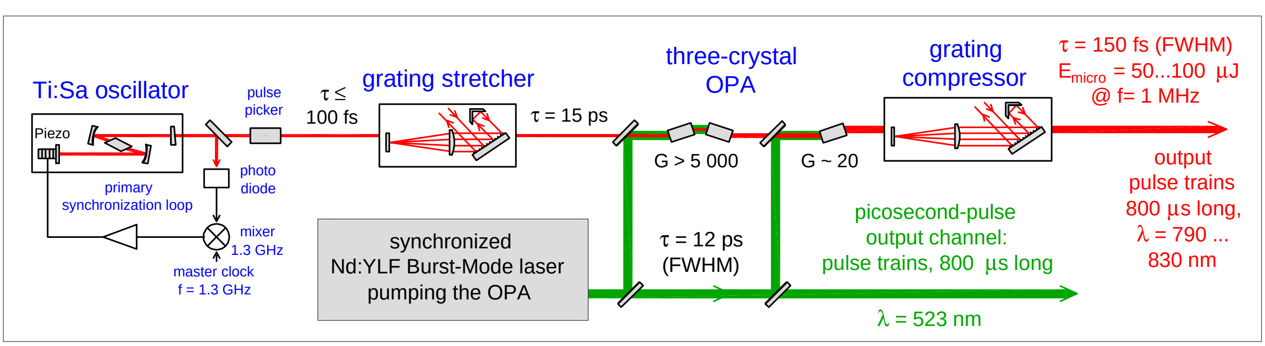

Figure 1: Basic scheme of the OPCPA laser system

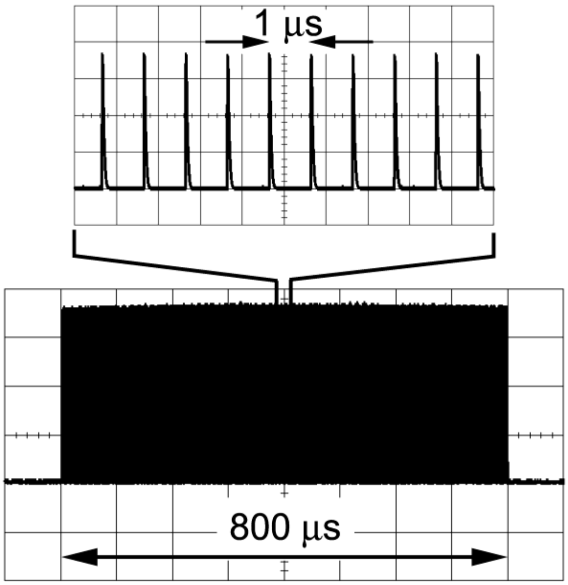

Figure 2: Pulse trains from a Nd:YLF burst-mode laser which is used as the pump laser of the optical-parametric amplifier

In order to utilize the energy of the pump laser efficiently, the seed pulses from the Ti:Sa oscillator are stretched to $\tau \geq 15$ ps (FWHM) by means of a stretcher that contains a grating of 1200 lines/mm. These pulses are fed into the preamplifier, which consists of two LBO crystals of 12 mm length and reaches an amplification of 5000. Subsequently, the pulses pass the final amplifier stage containing a single 8 mm long LBO crystal. This amplifier is operated near saturation. It reaches a typical gain of twenty and increases the energy of the micropulses up to ~100 µJ.

Naturally, the parametric amplification process selects only those pulses from the uninterrupted 108 MHz train of the Ti:Sa oscillator which coincide with the micropulses of the bursts from the Nd:YLF laser. An additional Pockels cell between the Ti:Sa oscillator and the stretcher reduces the load of the target due to the un-amplified Ti:Sa pulses by nearly three orders of magnitudes.

At the output of the laser system, the pulses are recompressed by a grating compressor. We typically reach an output pulse duration of 150 fs. This is a significant increase of the pulse width in comparison with the pulses of the Ti:Sa oscillator. It is mainly caused by spectral narrowing during the amplification process as well as by accumulation of a nonlinear chirp in the pulse stretcher, the compressor, the LBO crystals and in the other optical components within the optical beam path.

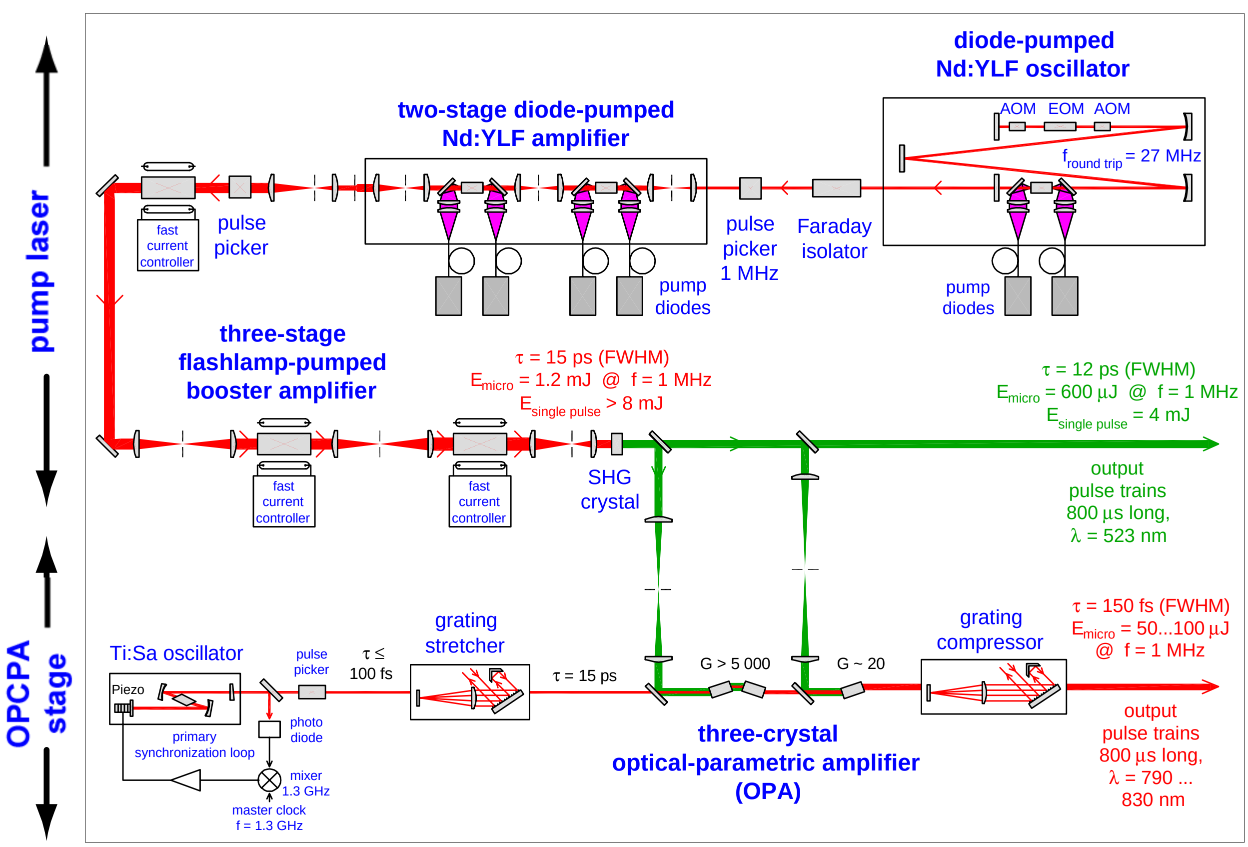

Figure 3: Optical layout of the OPCPA laser system

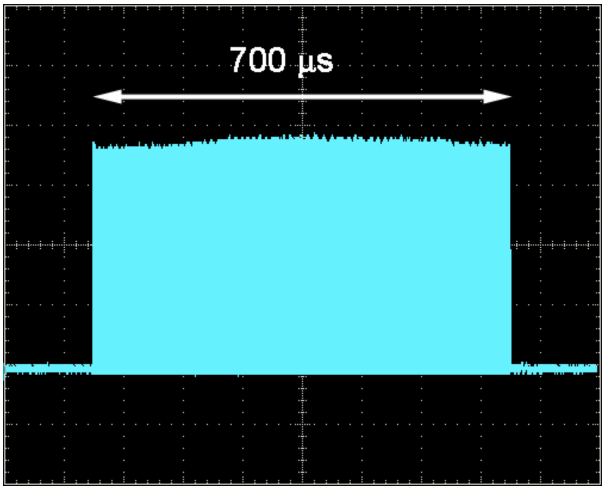

Figure 4: Output pulse trains of the OPCPA system containing 700 micropulses

SYNCHRONIZATION

Synchronization between the FEL and the OPCPA laser system is accomplished using the signals from a common RF master oscillator of the linear accelerator (LINAC) as the reference. Consequently, the quality of the master oscillator and the distribution network strongly determines the synchronization accuracy actually reached.

Synchronization of the OPCPA system means that both the pump laser and the Ti:Sa master oscillator have to be synchronized to the external RF clock. The pump laser uses an actively modelocked oscillator which allows for a straightforward synchronization with sub-picosecond accuracy [5]. The synchronization system for the passively modelocked Ti:Sa oscillator is based on electronic synchronization loops which contain appropriate phase detectors. In these phase detectors, a fast photodiode is used to electronically detect the optical pulses from the laser. After passing through a band-pass filter, the signal is amplified and the phase is compared to the phase of the reference signal by means of a standard double balanced mixer. The output signal from this phase detector is further amplified in an appropriate feedback amplifier. It is then transferred to a fast piezo-electric translator, which carries the high-reflecting end mirror of the resonator of the Ti:Sa oscillator. This allows to control the mechanical length of the laser resonator. When the loop is closed, the system adjusts the resonator length in such a way that the output of the mixer becomes zero, i.e. the mutual phase between the laser and the RF reference signal is constant. Adjustment of the absolute phase is accomplished by manually adjustable phase shifters.

In order to efficiently reduce the unfavourable influence of electrical noise and imperfections of the mixer, the feedback loop actually contains two different phase detectors that compare the phase of the laser signal to the 108 MHz and to the 1300 MHz signals from the electronic master oscillator of the LINAC that drives the FEL. Initially, a pre-synchronization is performed using the low-resolution phase detector that operates with the 108 MHz reference signal, which is equal to the round-trip time of the oscillator. In a second step, a more precise synchronization is achieved by selecting the high-resolution phase detector, which uses the 1300 MHz reference signal. We use this 12-th harmonics instead of the round-trip frequency itself as the reference, since this improves the obtainable accuracy of the synchronization loop significantly. Automatic switching between both phase detectors is accomplished by means of an appropriate electronic TTL circuitry.

We determine the actually reached synchronization accuracy by imaging both the pulses from the OPCPA laser and the radiation from a bending magnet that is located at the output of the LINAC simultaneously on to the photocathode of a synchroscan streak camera (type Hamamatsu C5680). The distance of the centre of mass between both pulses determines their mutual timing (Δt in Fig. 5). A jitter between both pulses should translate linearly into a variation of their vertical distance on the screen of the streak camera. Fig. 6 shows the jitter measured with this method over a period of 10 minutes. The jitter obtained by this methode is $\sigma = 0.5$ ps. This includes both the jitter of the synchronization of the OPCPA system as well as the timing stability of the whole LINAC with respect to the RF master oscillator. That is why we regard this value of the jitter as an upper limit for the accuracy of the synchronization loop of the laser.

In the future, we plan to use the described measurement technique to automatically correct the phase of the reference RF signal delivered to the primary synchronization of the laser. Alternatively, one can shift the OPCPA output pulse using an adjustable optical delay. This should enable us to compensate for effects of slow thermally induced drifts in the cables and the synchronization electronics of the OPCPA laser system.

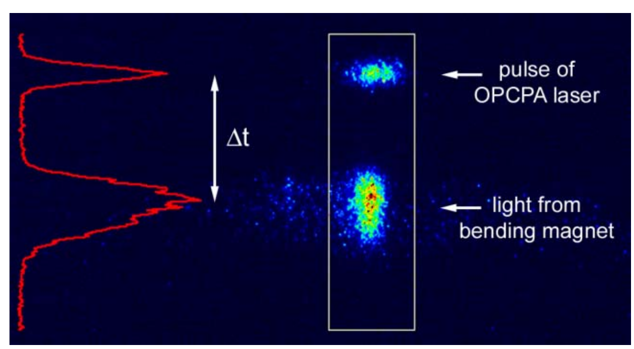

Figure 5: Streak camera image obtained by simultaneously imaging the pulses from the OPCPA system and the light from a bending magnet onto the photocathode of the synchroscan streak camera. (The time axis goes in vertical direction)

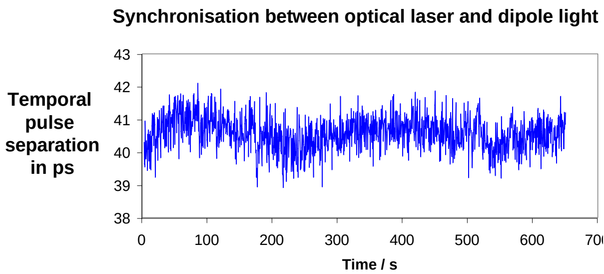

Figure 6: Synchronization jitter between OPCPA and light from a bending magnet measured with a streak camera

SUMMARY

We have developed a special laser system, which provides the ultrashort pulses needed for two-color pump-probe experiments with the VUV-FEL at DESY Hamburg. This laser system uses the Optical-Parametric Chirped-Pulse Amplification (OPCPA) technique for generating trains of intense femtosecond pulses with the same time structure as the FEL radiation. Their centre wavelength is presently tuneable between 790 and 830 nm.

We have measured that the pulses are synchronized to the electron bunches of the LINAC with an accuracy better than 0.5 ps.

The laser system was installed in an air-conditioned hutch near the experimental area of the FEL in 2004. Appropriate software controls, beam transport to the experimental stations and suitable delay lines have been implemented. First pump-probe experiments are under-way.

ACKNOWLEDGEMENT

This work was funded by the European Commission under Contract no. HPRI-CT-1999-50009.

REFERENCES

[1] J. Rossbach at al., "A VUV free electron laser at the TESLA test facility at DESY", Nuclear Instruments and Methods in Physics research A 375, pp. 269-273 (1996).

[2] S. Schreiber at al., "First lasing at 32 nm of the VUV-FEL at DESY", Proc. FEL 2005

[3] I.N. Ross, P. Matousek, M. Towrie, A.J. Langley, J.L. Collier, "The prospects for ultrashort pulse duration and ultrahigh intensity using optical parametric chirped pulse amplification", Opt. Comm. 144 (1997), pp. 125-133

[4] X. Yang at al., Multiterawatt laser system based on optical parametric chirped pulse amplification, Opt. Lett. 27 (2002), pp. 1135-1137

[5] I. Will, G. Koss, I. Templin, "The upgraded photocathode laser of the TESLA Test Facility", Nuclear Instruments and Methods in Physics research A 541 (2005), pp. 467-477

[6] I. Will, A. Liero, D. Mertins, and W. Sandner, "Feedback-Stabilized Nd:YLF Amplifier System for Generation of Picosecond Pulse Trains of an Exactly Rectangular Envelope", IEEE J. of Quant. Electron. QE 34, pp. 2020-2028 (1998).