PHOTOCATHODE LASER FOR THE SUPERCONDUCTING PHOTO INJECTOR AT THE FORSCHUNGSZENTRUM ROSSENDORF

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Abstract

We report on the design of the photocathode laser for a superconducting RF gun, which is presently under development at the Forschungszentrum (FZ) Rossendorf. This laser is foreseen to drive the RF gun in CW mode with up to 1 nC bunch charge. It generates pulses of 12...14 ps duration with 500 kHz repetition rate and 0.8 µJ pulse energy at 263 nm wavelength. This should provide sufficient pulse energy for generation of bunches with 1 nC charge using caesium telluride photocathodes. Due to two active modelockers in the laser oscillator, the latter operates in tight synchronism to the RF master oscillator of the linac.

The laser consists of a short-pulse oscillator, a pulse picking Pockels cell, a regenerative amplifier and a wavelength conversion unit. The latter converts the infrared laser radiation to the ultra-violet (UV). This unit turns out to be a particularly critical element of such a photocathode laser driving a RF gun in CW mode.

INTRODUCTION

Photo injectors within RF guns are important for FELs, since they provide an efficient means for generating high-density electron bunches with low emittance. Most of the existing photo injectors are operated in pulsed or in burst mode.

At the FZ Rossendorf a superconducting RF gun is being developed [1], which needs an appropriate laser for illumination of the caesium telluride photocathode. This laser should deliver pulses of 500 kHz repetition rate at a wavelength within the range of 260 to 270 nm. The desired bunch charge of 1 nC demands a UV pulse energy in the order of 0.5 to 1 µJ. The present paper describes a first setup for a suitable laser system.

LAYOUT OF THE LASER

Fig. 1 shows the general scheme of the laser system, which consists of the following main building blocks:

- the laser oscillator,
- a pulse picker,
- a regenerative amplifier,
- a wavelength conversion stage.

The laser oscillator generates the initial picosecond seed pulses. Its Nd:YLF laser rod is pumped by two fiber-coupled laser diodes of 805 nm wavelength. Modelocking for generation of short picosecond pulses is accomplished by two active modelockers. One of them is a standard acousto-optic modelocker driven with a 27.08 MHz RF signal, while the second one is an electro-optical phase modulator for 1300 MHz. A detailed description how to operate several modelockers in a single cavity can be found in [2] and the references therein.

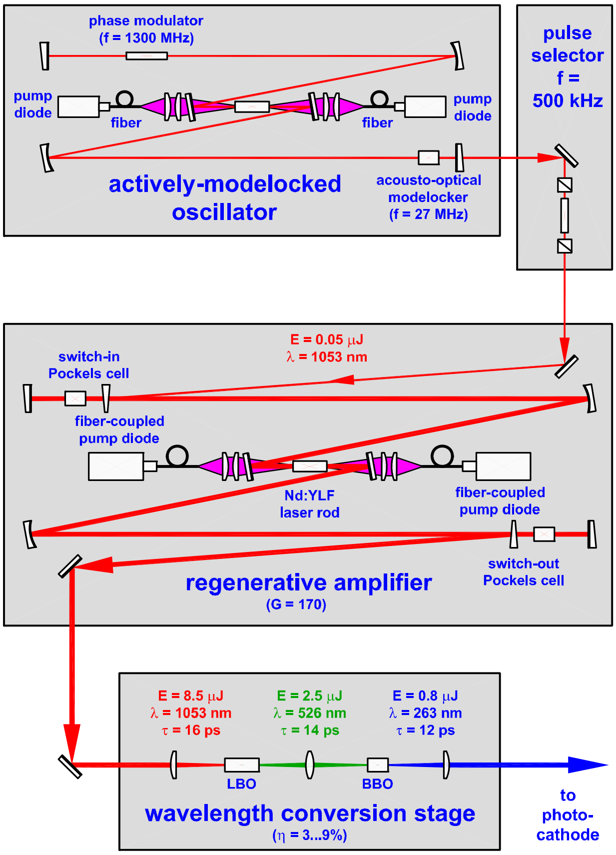

Figure 1: Optical scheme of the present photocathode laser.

The oscillator generates a CW pulse train of 54.16 MHz repetition rate and provides a single-pulse energy of 0.05 µJ. Since the signals for the active modelockers are derived from the electronic RF master oscillator of the gun, the laser pulses are synchronized with an accuracy of about 1 ps.

A subsequent electro-optic pulse selector reduces the high repetition rate of the pulses from the oscillator to the desired value of 500 kHz. This pulse train is further amplified by a regenerative amplifier (regen). The regen is based on a folded resonator with 25 ns round-trip time.

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In addition to the diode-pumped Nd:YLF laser rod, it contains two BBO Pockels cells. The first one switches the laser pulse from the oscillator into the cavity of the regen. Subsequently, this pulse performs 14 round trips in the resonator and is thereby amplified to an energy of 8.5 µJ.

THE WAVELENGTH CONVERTER

After switching the amplified pulses out of the resonator with the second Pockels cell, they are directed towards the wavelength conversion stage. This stage contains two consecutive nonlinear frequency doubling crystals that convert the infrared laser pulses of 1053 nm wavelength to the ultra-violet (263 nm wavelength).

The general scheme of this conversion unit is similar to the one used in the photocathode lasers of FLASH and PITZ. At first, a 12 mm long LBO crystal converts the pulses to green light. A further 8 mm long BBO crystal generates from this the UV output pulses

It turns out that both, the energy of the generated UV pulses as well as the profile of the UV beam depend in a highly sensitive way on the size of the beam waist in the BBO crystal. Tab. 1 as well as Fig. 1 show the results of appropriate measurements done for four different diameters of the beam in this crystal. Although the highest output energy of 0.83 µJ is achieved for the strongest focusing down to a diameter of 260 µm, this leads to a non-circular beam profile.

On the other hand, the most homogeneous output beam that largely maintains the original circular cross section is obtained when the beam diameter in the BBO crystal is larger. The optimum in this respect amounts to 703 µm. Unfortunately, this is accompanied by a drop of the laser intensity in that crystals by a factor of two, and only a smaller portion of the green light is converted to the UV. Since the conversion process is now operated far from saturation, the energy stability becomes much worse and we typically obtain a pulse energy between 2 and 4 µJ.

Table 1: Dependence of the resulting UV pulse energy on the focussing condition at the BBO crystal

Diameter of the beam waist [µm] in the BBO crystal	Measured output energy [µJ] of the UV pulses
260	0.83
352	0.71
527	0.49
703	0.45

Although the average power of the CW laser in comparison to the pulsed lasers at FLASH and SHARP (table 2) is significantly larger, its peak power is at least one order of magnitude less. This is reflected by the measured peak intensity in the UV. So, the above measurements show, that the present design of the wavelength converter cannot be used together with the photocathode laser for a CW gun without substantial modification.

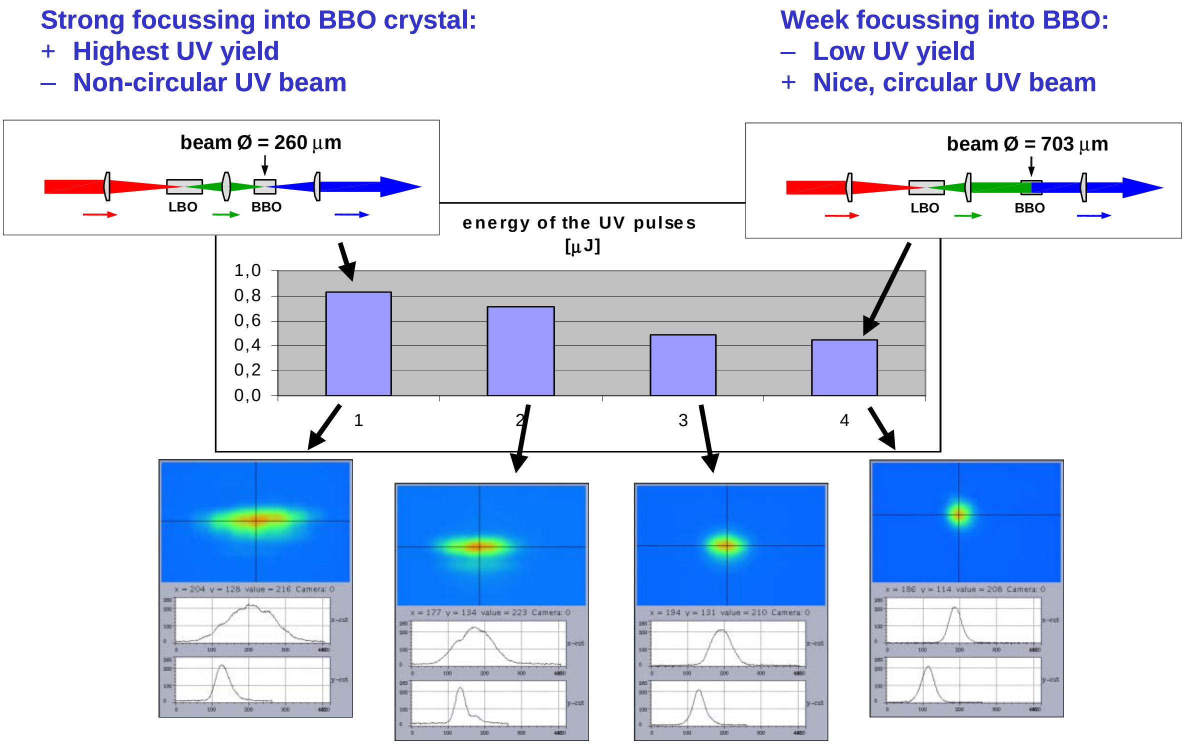

Figure 2: Intensity profile of the UV output at four different sizes of the focussed beam diameter in the BBO crystal (from left to right: 260, 352, 527 and 703 µm).

In order to still reach a reasonable conversion efficiency, the laser radiation must be stronger focused into the conversion crystals. This, in turn leads to a significant perturbation of the beam profile due to the limited acceptance angle as well as due to the walk-off between green and UV light in the BBO crystal.

Table 2: Comparison of the pulse parameters of the photocathode lasers at FLASH/PITZ and at the FZ Rossendorf

	FLASH, PITZ	**ELBE (f = 0.5 MHz)**	**ELBE (f = 13 MHz)**
pulses per s	$0.008\cdot10^6$	$0.5\cdot10^6$	$13\cdot10^6$
pulse energy (UV)	20 μJ	1 μJ	0.08 μJ
pulse duration	20 ps	20 ps	4 ps
average UV power	0.16 W	0.5 W	1 W
peak intensity (UV)	1	0.05	0.02

CONCLUSION AND OUTLOOK

From the above described measurements follows, that the photocathode lasers for RF guns in CW mode should be set up for the shortest pulse duration possible. This would yield better conversion efficiency to the UV at the same laser pulse energy. Since even sub-picosecond lasers with an average power larger than 10 W exist, the lower limit for the pulse duration is determined by space charge effects in the RF gun. Too short pulses however, will lead to an increased longitudinal emittance of the electron beam.

Further work is mainly required to develop an improved wavelength conversion unit to end up with reasonable conversion efficiency and simultaneously a nearly circular profile of the UV laser beam. A possible solution that is presently investigated at the MBI might be based on cylindrical lenses for focusing the beam differently in horizontal and vertical direction. Compensation of the walk-off between fundamental and harmonic wave that occurs in the crystals is another option.

ACKNOWLEDGEMENT

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