JINR POWERFUL LASER DRIVER APPLIED FOR FEL PHOTOINJECTOR

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Abstract

The JINR develops a project of superconducting linear accelerator complex, based on a superconducting linear accelerator, for applications in nanoindustry, mainly for extreme ultraviolet lithography at a wavelength of 13.5 nm using kW-scale Free Electron Laser (FEL) light source. The application of kW-scale FEL source permits realizing EUV lithography with 22 nm, 16 nm resolutions and beyond.

JINR-IAP collaboration constructed powerful laser driver applied for photoinjector of FEL linear accelerator which can be used for EUV lithography. To provide FEL kW-scale EUV radiation the photoinjector laser driver should provide a high macropulse repetition rate of 10 Hz, a long macropulse time duration of 0.8 ms and 8000 pulses per macropulse. The laser driver operates at wavelength of 260-266 nm on forth harmonic in the mode locking on base of Nd ions or Yb ions The laser driver micropulse energy of 1.6 μJ should provide formation of electron beam in FEL photoinjector with the bunch charge about 1 nC.

EUV LITHOGRAPHY BASED ON FEL

The project is aimed at construction of accelerator complex, based on a 0.7 GeV superconducting linear accelerator, for applications in nanoindustry, mainly for extreme ultraviolet lithography (EUVL) using kW-scale Free Electron Laser (FEL) light source. The superconducting linear accelerator at electron energy 0.7 GeV will produce coherent FEL radiation for extreme ultraviolet nanolithography at a wavelength of 13.5 nm and an average radiation power of 0.7 kW. Accelerator complex involves a dedicated channel for extreme ultraviolet lithography with a few nanoscanners operating simultaneously in a processing line with 22 nm, 16 nm and beyond using FEL radiation at a wavelength 13.5 nm. The project is based on the technology realized on FEL FLASH (Free Electron Laser in Hamburg) facility at DESY (Hamburg) [1]. FLASH has produced several GW powers for EUV radiation with a wavelength of 13.5 nm, a target goal for the next generation lithography. The driving engine of FLASH facility is an L-band superconducting accelerator [1]. It is designed to operate in a pulsed mode with a pulse duration of 800 microsecond and repetition rate of 10 Hz [1]. The maximum accelerated macropulse current is 10 mA.

The present analysis [2-4] shows that this technology holds great potential for increasing the average power of a linear accelerator and the efficiency of conversion of electron kinetic energy into light (Table 1).

Table 1: Parameters of EUVL Accelerator Complex and Laser Driver

Acceleration complex	
Electron energy, GeV	0.68
FEL length, m	110
Macropulse frequency, Hz	10
Macropulse time duration, μs	800
Number of pulses per macropulse	8000
Micropulse frequency, MHz	10
Micropulse radiation energy, mJ	8.5
Macropulse radiation energy, J	68
Peak radiation power, GW	34
Average radiation power, kW	0.68
Number of scanners	8
Laser driver	
Wave length, nm	260-266
Microimpulse time duration, ps	8-12
Laser radiation energy per micropulse, μJ	1.6
R.m.s relative variation of radiation energy per micropulse	10%
R.m.s. relative variation of micropulse time duration	1%
Variation of repetition frequency, kHz	±1.3
Fluctuation of repetition frequency, Hz	50-100

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JINR POWERFUL LASER DRIVER

The basic parameters of the JINR powerful laser driver applied for the FEL photoinjector of EUV lithography accelerator complex are given in the Table 1. The laser source operates at wavelength of 260-266 nm. The micropulse repetition frequency should be stabilized with a high accuracy of 50-100 Hz and should be varied in a range of ±1.3 kHz. The laser operates on forth harmonic in the mode locking (ML) on base of Nd ions or Yb ions.

The principal scheme of the JINR powerful laser driver applied for photoinjector is presented in Fig.1. The powerful laser driver consists of separate modules: the master oscillator (MO), the preliminary amplifier (PA1), the acoustic-optical modulator (AOM) and the preliminary amplifier (PA2), the system of the macropulse turning repetition rate used in the master oscillator, the system of the beam driver formation (SBDF) applied for co-ordination of the beam sizes in the fiber and the rod laser parts, the system of the macropulse temporary bending shape and the optical table on which are mounted the output laser driver elements - the rod amplifiers, the generator of second harmonic (SHG) and the generator of fourth harmonic (FHG) and other optical elements. The generators of second and fourth harmonics (SHG and FHG) transform the wave length from 1.047 μm to 0.262 μm.

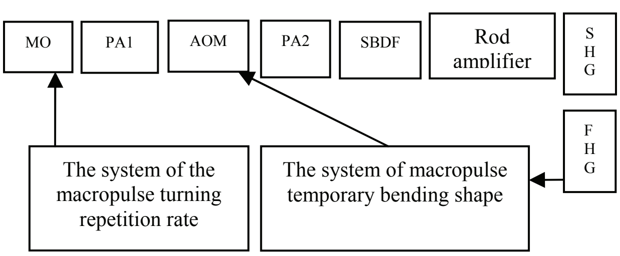

Figure 1: Scheme of powerful JINR laser driver for FEL photoinjector.

The master oscillator (MO) and the preliminary amplifiers (PA1 and PA2) are constructed on the base of the active fibers on the Yb^{3+} ions. The rod amplifiers on the YLF crystals activated by the Nd^{3+} ions are required to reach a high output radiation power. The micropulse time duration in the main harmonic corresponds to 10 ps, the average radiation power is equal to 2 mW. The acoustic-optical modulator (AOM) reduces the initial MO radiation frequency of 40 MHz to 10 MHz, forms the macropulses with time duration of 800 μs from CW radiation and provides the macropulse temporary bending shape at which the rectangular macropulse shape is formed at a driver output on fourth harmonic. The system of the turning of the frequency regulates the micropulse repetition frequency in accordance with the base klystron signal of the acceleration section. The system of the formation of macropulse temporary bending shape forms with AOM help the macropulses of rectangular shape on the laser system output. The system of the beam driver formation (SBDF) is used for co-ordination of the beam sizes in the fiber and the rod laser parts. The adjustment of PA1 and PA2 is performed by the specially developed computer code PULSER of the driver adjustment. The code provides diode pumping adjustment of the currents and varies the output power of the fiber laser. It permits to vary the micropulse repetition frequency in a range of (1-10)Hz, the macropulse time duration and number of micropulses per one macropulse. Main goal of the PULSER code is adjustment of the AOM driver temporary structure. The macropulse shape depends on the PA2 current and number of micropulses, however in all cases it is close to rectangular shape. The average power corresponds to P_{av}=0.94mW at macropulse repetition frequency ν=10Hz, macropulse time duration of τ=800μs, number of micropulses of N = 8000 and PA1 current of $I=69\%I_{max}$. The peak power of micropulse at PA1 current of $I=69\%I_{max}$ corresponds to P_{peak}=1-1.2 kW. The power oscillations do not exceed ±0.75% P_{av}.

Further amplification of the radiation and its frequency transformation in second and fourth harmonics is produced in the laser set up placed on the optical table (Fig.2).

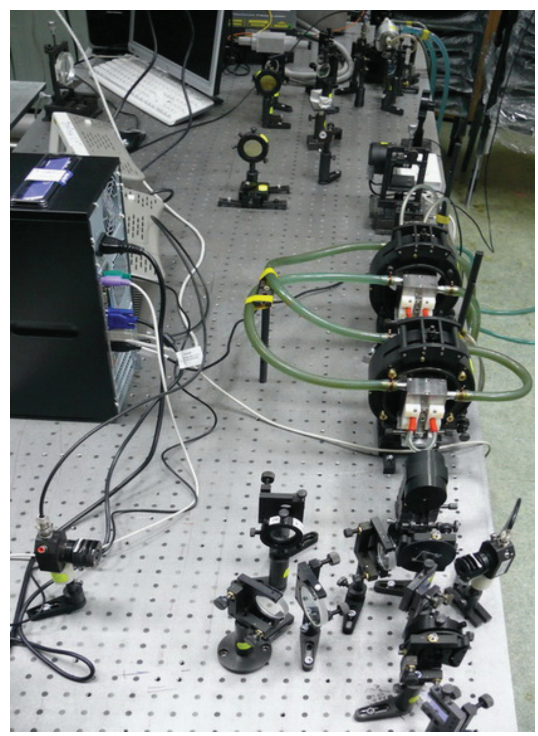

Figure 2: Common view of powerful JINR laser driver on an optical table.

The optical schema of laser set up is given in Fig.3. The PA1 radiation gets on the pivotal amplifiers A1 and A2 after the output collimator combined with the Faraday

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insulator with help of the telescope *tel* and the beam apodisation module *cos*^{2}. After double passage on him, escalated radiation moves on the generator of the second harmonica (SHG) made from KPT crystal, then on generator of the fourth harmonica (FHG) made from BBO crystal. The generators of second and fourth harmonics (SHG and FHG) transform the wave length from 1.047 μm to 0.262 μm. Hereinafter several in detail stop on separate components of the laser set.

The amplifiers A1 and A2 with active elements (AE) constructed from the YLF crystals activated by Nd ions. They have size Ø5×75 mm^2 and are pumped by two pulse xenon lamps IHP5/72. To obtain the signal of rectangular shape at the amplifier output each lamp pair is powered from individual energy storage on basis of the LC contour. The pulses can be switching on as simultaneously so with a time delay. It is possible to reduce essentially the energy of storages and heat loads on AE amplifiers when the time delay is produced between contours of the lamp storages.

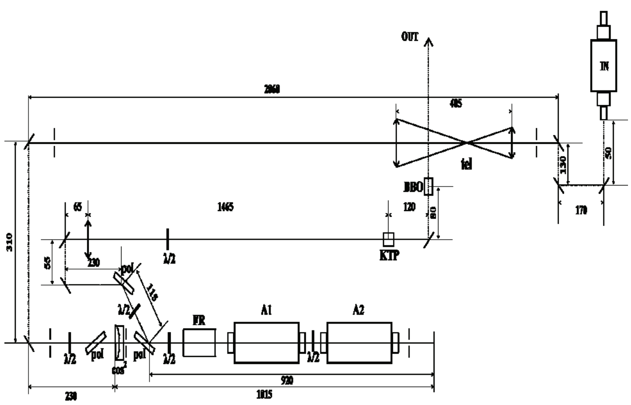

Figure 3: Optical scheme of the laser set up.

As it follows from experiments with pivotal Nd:YLF amplifiers to reach required parameters the electric power in each amplifier should be correspond to P_{el} = 1000 W. The optical power of thermal lens is equal to $D=1.125\cdot10^{-4}$ m^{-1} per each W loaded to the amplifier of the electric power. Two located consecutively active elements A1 and A2 introduce in the phase of the laser radiation the additional lens with F=440-404 cm. The average power of the radiation is equal to P=1.5 W without correction and it decreases on 18% after correction and corresponds to 1.26 W at macropulse repetition frequency of 10 Hz, number of micropulses of 8000 in each macropulse.

It corresponds to micropulse energy of W_{micro}=16 μJ and macropulse energy of W_{macro}=126 μJ at wave length 1.047μm. Therefore the micropulse energy at the output of laser driver is about 1.6 μJ at 10% radiation conversion efficiency into fourth harmonic.

The observable dependence of the gain (G) on temperature is other important peculiarity of the pivotal amplifiers from Nd:YLF. The maximal amplification and minimal slope of G is achieved at AE temperature of T=13-15˚C. The standard scheme of water cooling on the basis of water pump with external water sidebar for our scheme is not desirable. The application of a chiller which provides the temperature lower then pluming water is preferable for AE cooling.

The correction of the macropulse temporary bending shape at the amplifier input brings the additional losses in the laser radiation. However these losses are not so large. The macropulse energy with correction is 20% less comparing with the micropulse energy without correction. The beam energy distribution in the nearest and far fields influents essentially on the laser driver work. The application of a high quality AE from Nd:YLF permits to conserve the beam quality after two passage through it.

We provide the beam focus in the crystals of the generators of second and fourth harmonics to reach a high transmission in these harmonics. It is important to have a high beam quality in the far field for this goal. The fourth harmonic we obtain at the reduplication of the radiation of the second harmonic in the BBO crystal. Not transformed part of the main harmonic radiation is separated by the 45^0 mirror, installed directly after the KPT crystal. The BBO crystal with 1 cm length is referred to sliced toward synchronism of I - type under angle of 48.8^0. The entrance crystal verge is brightened on wavelength 523.5 nm, the output - on wavelength of the fourth harmonic 262 nm. Not transformed part to energy of the second harmonica is cut by the dichroic mirror. The maximum micropulse energy corresponds to W_{micro} =1.62 μJ.

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REFERENCES

[1] T.Aberg et al, Conceptual design report, DESY, TESLA-FEL 95-03, (Hamburg, 1995).

[2] E.Saldin et al., FEL’09, MOPC54 (2009).

[3] E.Syresin et al., RUPAC10, 178 (2010).

[4] E.Syresin et al, J.of Surface Investigations, X-ray, Synchrotron and Neutron Technique, 5, 520 (2011).