FEL ACTIVITY DEVELOPED AT JINR

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Abstract

Different methods for diagnostic of ultrashort electron bunches are developed at JINR-DESY collaboration within the framework of the FLASH and XFEL projects. Photon diagnostics developed at JINR-DESY collaboration for ultrashort bunches are based on calorimetric measurements and detection of undulator radiation. The MCP based radiation detectors are effectively used at FLASH for pulse energy measurements. The infrared undulator constructed at JINR and installed at FLASH is used for longitudinal bunch shape measurements and for two-color lasing provided by the FIR and VUV undulators. The JINR also participates in development of the Hybrid Pixel Array Detector on the basis of GaAs (Cr) sensors.

The JINR develops a project which is aimed at preparation of conceptual project and simulations of accelerator complex, based on a 0.7 GeV superconducting linear accelerator, for applications in nanoindustry, mainly for extreme ultraviolet lithography using kW-scale FEL light source.

FLASH MCP-BASED PHOTON DETECTOR

The free electron laser FLASH has been in operation at DESY since the year 2000 [1,2]. The electron energy now reaches 1 GeV, rms bunch length is 50 μm, the FWHM radiation pulse duration is about 30 fs, the normalized emittance is 2 π·mm·mrad, the bunch charge is 1 nC, the peak power is up to 1 GW, the peak brilliance is of 10^{28} ph/s/mrad2/mm2/(0.1%bw).

Successful operation of FLASH strongly depends on the quality of the radiation detectors. The key issues are: the wide wavelength range 6-100 nm, the wide dynamic range (from the spontaneous emission level to the saturation level), and the high relative accuracy of measurements which is crucial for detection of radiation amplification and characterization of statistical properties of the radiation.

The key FLASH photon detector developed by the JINR-DESY collaboration is a micro-channel plate (MCP) detector intended for pulse energy measurements [3-5]. The MCP detector is used for measurement of statistical properties of the radiation allowing determination of the pulse length. Key element of the detector is a wide dynamic MCP which detects scattered radiation from a target. With four different targets and MCPs in combination with optical attenuators, the present FLASH detector covers an operating wavelength range 6 -100 nm, and a dynamic range of the radiation intensities, from the level of spontaneous emission up to the saturation level of SASE FEL.

The gold target is perfect for the wavelength range above 10 nm, however its reflectivity falls dramatically for shorter wavelengths, and different targets and geometries of the detector are used. We added three more targets to gold mesh: two iron meshes, and one copper mesh (Fig.1). This helps us to operate the detector in a range below 10 nm.

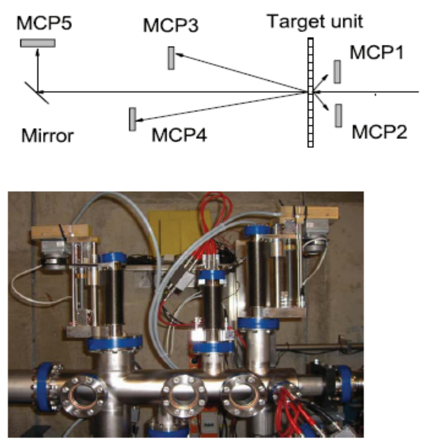

Figure 1: Layout of the MCP detector.

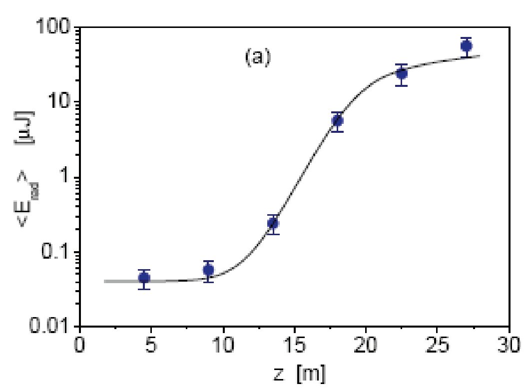

Figure 2: Measured average energy in the radiation pulse versus the undulator length.

For tuning SASE at very short wavelengths we use movable MCPs directly facing photon beam. Light intensity variation by a factor of 50 is controlled by a mechanical attenuator of light located in the target unit. To have full control of light intensity in a wide range we installed a side MCP which detects radiation reflected by the iron mirror. The mirror serves for two purposes. One is to deflect the photon beam off- the axis, which allows placing the MCP in better background conditions.

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The dependence of the measured average energy in the FLASH radiation pulse on the undulator length is shown in Fig. 2. In the saturation regime the average pulse energy is 40 μJ and the wavelength is 13.7 nm.

FLASH FAR INFRARED UNDULATOR

In the FLASH was equipped with an infrared electromagnetic undulator (Fig.3), tunable over a K–parameter range from 11 to 44, and producing radiation up to 200 μm at 500 MeV and up to 50 μm at 1 GeV [5-8]. The purpose of the device is two-fold: firstly, it is used for longitudinal electron bunch measurements, secondly, it is a powerful source of intense infrared radiation naturally synchronized to the VUV FEL pulses, as both are generated by the same electron bunches and being therefore well suited for precision pump-probe experiments.

Figure 3: FLASH far infrared undulator constructed by JINR.

The undulator was designed and constructed by JINR to the FLASH requirements [5-8]. The undulator period corresponds to 40 cm, the number of periods is 9, the magnetic field is varied in range of 0.1-1.1 T. Output undulator radiation has the following parameters: wavelength 5-200 μm, peak power 4 MW, micropulse energy 1 mJ, micropulse duration 0.5-6 ps. The spectrums of FLASH infrared undulator at different K-parameters are given in Fig.4.

The energy radiated by the undulator is defined by the number of electrons per bunch N and a form-factor F(λ) characterized by a ratio of the bunch length to the wavelength:

$$\varepsilon_{coh} = \varepsilon_e \times \left[N + N(N-1)\left|\bar{F}(\lambda)\right|^2 \right],$$

where ε_e is energy radiated by single electron. The form-factor is equal to $|F(\lambda)|^2 = \exp(-2\pi\sigma/\lambda)^2$ for Gaussian bunch with r.m.s. length σ. When the wavelength is comparable with or longer than the bunch length, the coherent radiation dominates. Measuring the spectrum (Fig.5) that regime one can extract the form-factor and thus the charge distribution and the bunch leading spike length. The Gaussian fit (Fig.5) corresponds to the r.m.s. leading spike length of σ_{ls}= 12 μm.

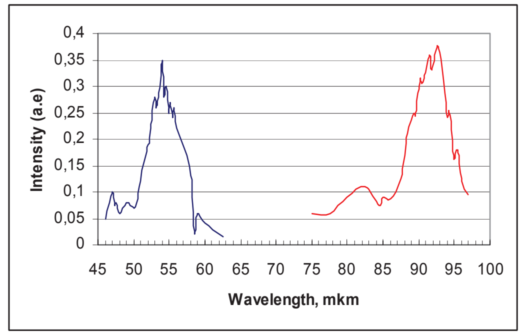

Figure 4: Spectrums of FLASH infrared undulator radiation.

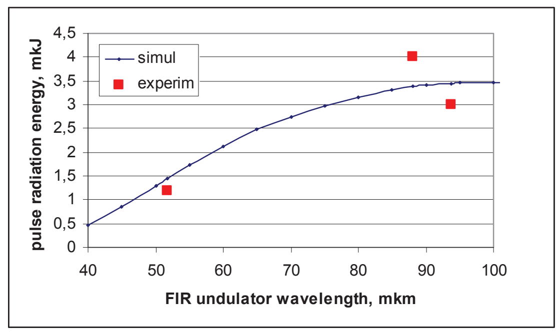

Figure 5: Dependence of the pulse radiation energy emitted into central cone of the FIR undulator on the wavelength.

XFEL DYAGNOSTICS

A bunched electron beam of extremely high quality is needed in the XFEL to get coherent radiation in subnanometer wavelength [9]. JINR proposes to design Hybrid Pixel Array Detector on basis of GaAs (Cr) detectors (Fig. 6) [10]. The technology of the pixel detector with resolution of 50 μm was developed on basis of the JINR-Toms State University GaAs (Cr) sensors and the Medipix chips.

Figure 6: Spectrometric detector on basis of GaAs (Cr) pixel censor with 256×256 channels of 50 μm resolution and Medpix chip.

The sensitivity of GaAs detector is essentially improved in comparison with Si detector at photon energy larger 15 keV (Fig.7).

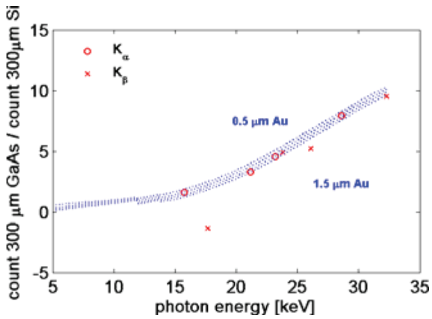

Figure 7: Dependence of ratio of counts in GaAs and Si detectors on photon energy.

ACCELERATOR COMPLEX FOR EXTREME ULTRAVIOLET LITHOGRAPHY

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 using kW-scale Free Electron Laser light source (Table 1) [11-12].

Table 1: FEL Parameters for EUVL

Electron energy, MeV	680
FEL length, m	110
Bunch charge, nC	1
Peak current, A	2500
Macropulse duration, ms	0.16
Micropulse rep. rate, MHz	10
Number of pulses in macropulse	1400
Macropulse rep. rate, Hz	40
Undulator period, cm	2.73
Undulator length, m	30
Radiation wavelength, nm	13.5
FWHM spectrum bandwidth, %	2
Radiation pulse energy, mJ	8.5
Peak power, GW	34
FWHM pulse duration, fs	250
FWHM spot size, mm	0.3
FWHM angular divergence, μrad	48
Average radiation power, W	480
Number of scanners	8

The project involves the construction of a 0.7 GeV superconducting linear accelerator to produce coherent FEL radiation for extreme ultraviolet nanolithography at a wavelength of 13.5 nm and an average radiation power of 0.5 kW.

The application of kW-scale FEL source permits realizing EUV lithography with 22 nm, 16 nm resolutions and beyond. The project for construction of an accelerator complex for EUV lithography is based on the technology realized on FEL FLASH. Present analysis [11] 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. Thus, it will be possible to construct a free electron laser facility operating at a wavelength of 13.5 nm, an average power of up to 0.5 kW, and an electron energy of 0,7 GeV (Table 1). Using a powerful FEL source allows this approach to be redefined as single source for multiple tools. The powerful kW-scale FEL radiation can be distributed between EUV lithography 'multiple tools' operated at an average power of 60 W due to multilayer mirrors installed at the entrance of each lithography scanner and FEL time structure.

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