FIRST LASING IN THE WATER WINDOW WITH 4.1 NM AT FLASH

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Abstract

The free-electron laser facility FLASH at DESY, Germany has been upgraded in 2009/10. The electron beam energy has been increased from 1 to 1.25 GeV by adding a 7th superconducting accelerating module. In September 2010, for the first time, lasing in the water window at a fundamental wavelength of 4.1 nm has been achieved. The water window is a wavelength region between 2.3 and 4.4 nm in which water is transparent for light. This remarkable achievement opens the possibility for new class of experiments, especially for biological samples in aqueous solution.

INTRODUCTION

The free-electron laser FLASH [1–3] is a single-pass high-gain SASE-FEL at DESY (Hamburg, Germany). The facility has been initially designed for a beam energy of 1 GeV and – with the given fixed gap undulators – for a smallest wavelength of 6.4 nm. [4]

The water window is the wavelength region between the K(1s) absorption edges of Oxygen (λ = 2.3 nm or 543 eV) and Carbon (λ = 4.37 nm or 284 eV). Carbon absorbs the FEL radiation, water becomes more and more transparent. In the water window, new classes of experiments like in-vivo experiments with biological probes in water solution, study of carbon containing molecules and many more are possible.

Fig. 1 shows the achievable wavelength of FLASH for a given beam energy. The lasing wavelength λ is given by

$$\lambda = \frac{\lambda_\mathrm{u}}{2\gamma^2}\left(1 + \frac{K^2}{2}\right) \qquad (1)$$

with the undulator period $\lambda_\mathrm{u} = 2.73$ cm and a K parameter of $K = 1.23$. In order to reach the water window, the beam energy needs to be increased to more than 1.2 GeV.

ENERGY UPGRADE

With the upgrade in 2009/10 a 7th superconducting accelerating module has been installed. The last four modules form now a string powered by two klystrons, one 5 MW klystron for modules 4 and 5, and one 10 MW klystron for modules 6 and 7. The new module is a prototype for the European XFEL. [5, 6] It has an excellent energy reach of 240 GeV. With eight nine-cell superconducting niobium cavities, the average gradient per cavity reaches an impressive 30 MV/m.

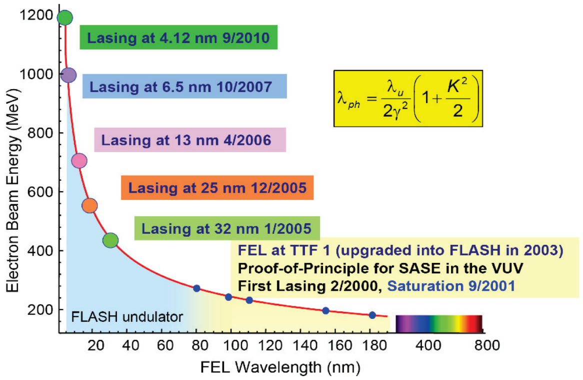

Figure 1: SASE wavelength as a function of energy for the FLASH undulator. Some first lasing events are indicated.

In addition, a new accelerator module 1 has been installed together with one module containing four 3rd harmonic superconducting cavities [7, 8]. The 3.9 GHz cavities allow linearizing the longitudinal phase space to optimize the bunch compression process.

The new module 1 has a higher energy reach to compensate the deceleration of about 15 MeV of the 3rd harmonic cavities when optimized for best bunch compression. The energy at the first bunch compressor is now 150 MeV compared to the previous 127 MeV.

Together with an improved distribution of RF power, the total energy of the electron beam could be pushed to 1250 MeV in September 2010. This energy is with off-crest acceleration in modules 1, 2, and 3 required for bunch compression.

Only little conditioning of the waveguides and couplers have been necessary to reach the maximum beam energy. Most conditioning has been done already just after the shutdown in spring 2010.

A schematic layout of FLASH is shown in Fig. 2, and main parameters[1] are listed in Table 1. [3]

LASING IN THE WATER WINDOW

First lasing in the water window has been achieved Sept. 25, 2010 with a wavelength of 4.1 nm. Figure 3 shows the first measured wavelength spectrum centering at 4.12 nm.

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[1] The performance is different for each photon wavelength, and it differs also depending on the electron bunch charge and the bunch compression scheme used. Therefore, the FEL parameters shown Table 1 should be taken as an indication of the overall span of the performance.

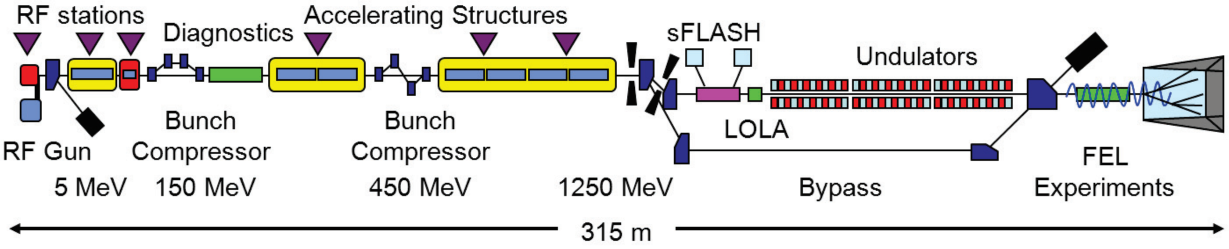

Figure 2: Layout of the FLASH facility (not to scale).

Table 1: FLASH Parameters 2011 [3]

Electron beam		
Energy (max.)	MeV	1250
Bunches / train		1 - 500
Bunch spacing	μs	1 - 25
Repetition rate	Hz	10
FEL radiation		
Wavelength (fundamental)	nm	4.1 - 45
Average single pulse energy	μJ	10 - 400
Pulse duration (FWHM)	fs	50 - 200
Spectral width (FWHM)	%	0.7 - 2
Peak power	GW	1 - 3
Peak brilliance	*	10^{29} - 10^{31}
Average brilliance	*	10^{17} - 10^{21}

* photons / (s mrad^2 mm^2 0.1 % bw)

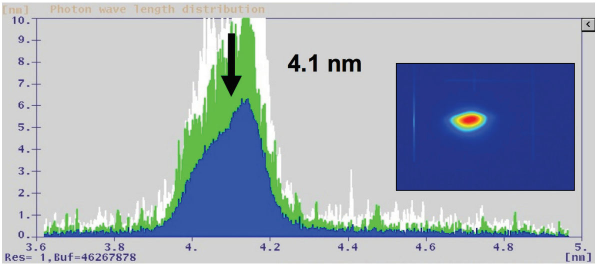

Figure 3: SASE FEL radiation at 4.12 nm measured with a spectrometer. The transverse photon beam profile on a Ce:YAG screen is shown as well.

FLASH uses carbon coated silicon mirrors to transport the FEL radiation to the five experimental stations. These mirrors absorb the radiation which is inside the water window and therefore cannot be used for these wavelengths. Fortunately, some of them have a partial Nickel coating. The reflectivity of Ni is not as good as carbon coated silicon, but has a negligible absorption for wavelengths within the water window. An in-house experiment using a wavelength of 4.3 nm has been performed in spring 2011. It could be shown, that the reflectivity of the mirrors are as expected and that the radiation of the water window can be efficiently transported to one FLASH beamline. About 45 % transmission has been achieved with two plane mirrors and a spherical multilayer mirror to focus the beam to 1 μm scale spot sizes in the experiment. Ion- and fluorescence spectra at different targets, like 1s-oxygen in the gas phase and solid Al-oxide have been observed. The experimental results will be published elsewhere. [9]

ACKNOWLEDGMENT

I am grateful to the organizers of the FEL 2011 conference to have invited me to present these exciting news of FLASH. Reaching the water window is the result of an enormous and continuous effort of the DESY staff to improve the FLASH facility. I would like to thank all colleagues from DESY and the collaborating institutes for their participation in the upgrade, commissioning, and operation of FLASH.

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[5] The outer vessel and the cold mass of the European XFEL prototype module PXFEL1 has been manufactured in China by order of the IHEP institute, Beijing. The module has been assembled in cooperation of IHEP/Beijing, CEA-IRFU/Saclay, IN2P3-LAL/Orsay, INFN/Milano, CIEMAT/Madrid and DESY.

[6] D. Kostin, W.-D. Möller, A. Gössel, K. Jensch, "Superconducting accelerating module tests at DESY", Proc. SRF2009, 20-25 Sep. 2009, Berlin, Germany, pp. 180 (TUPPO005)

[7] The 3rd harmonic cavities and the cold mass have been built at FNAL, Batavia in collaboration with DESY and the advice and help of members of the TESLA Technology Collaboration.

[8] E. Vogel et al., "Test and commissioning of the third harmonic RF system for FLASH", Proc. IPAC 2010, Kyoto, Japan, pp. 4281 (THPD003)

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