Free-electron Lasers at DESY: Status, Challenges and Opportunities

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An overview of the current status and future plans of Free-electron Lasers at DESY is presented. Information on the worldwide first FEL operating in the soft X-ray spectral range, called FLASH, is given in a nutshell. Advanced technologies that will be incorporated in the near future in order to further develop the machine are highlighted, such as seeding the FEL using high-harmonic generation (HHG). The valuable experience gained in the past with FLASH paves the way towards the future European XFEL on the DESY site.

The Free-electron LASer in Hamburg (FLASH) has started regular user operation in summer 2005 [1, 2]. This is a unique facility built for the vacuum-ultraviolet and soft X-ray region. The lasing wavelength can presently be tuned from 47 nm to 6.9 nm. Peak and average brilliance of the machine exceeds both that of the brightest synchrotron and laser plasma sources by orders of magnitude. Up to 10^{13} photons per pulse with durations of 10-50 fs result in intensities of more than 10^{16} W/cm^2 by using appropriate focusing optics [3]. Due to its unprecedented characteristics FLASH opens up exciting research opportunities allowing fundamental studies on atoms, ions, molecules and clusters, plasma formation, diffraction imaging of nanoparticles, spectroscopy of bulk solids and surfaces, photochemical reactions, spin dynamics, and the development of advanced photon diagnostics and experimental techniques [4-26]

This laser works on the principle of Self-Amplified Spontaneous Emission (SASE). Here, the lasing medium is a high-density bunch of electrons accelerated to relativistic velocity passing the periodic magnetic field of an undulator. The interaction between the generated undulator radiation and the electrons induce a periodic charge density modulation across the bunch that cause many electrons ($\sim 10^6$) to radiate in phase and thereby greatly enhancing the intensity of the radiation. Its routine operation paves the way to similar sources capable of working in the limit of hard X-rays that are currently proposed or under construction worldwide [1]. The European XFEL at the DESY site is expected to deliver first photons in 2013 [2]. The technical challenge is the preparation and accurate steering of a high quality electron beam over very long distances. Some of the most fascinating proposals for applications that have been made are the investigation of femtosecond structural changes during chemical reactions, or the structure determination of large single macromolecular assemblies.

In a SASE-FEL the intensity strongly fluctuates from pulse to pulse. The fluctuations are inherent to the SASE process and result from start of the amplification process from shot noise. One possibility to reduce these fluctuations is to produce much longer radiation pulses. In 2009,

[1]see e.g. http://hasylab.desy.de/facilities/sr_and_fel_labs/index_eng.html
[2]see e.g. http://www.xfel.eu

DESY plans to install a new acceleration section for the production of electron bunches with 10 times larger pulse durations while retaining the present peak current. An alternative approach is to operate the FEL as an amplifier of injected seed pulses from a high-harmonic generation (HHG) source by overlapping the seed and the electron bunch in the undulator section with μm and fs precision. This way, not only a higher shot-to-shot stability at GW power but a pulse duration of the order of 20 fs can be obtained. An experiment recently performed at the SPring-8 Compact SASE Source (SCSS) has successfully demonstrated HHG seeding at ~ 160 nm [27]. At FLASH, an experiment ("sFLASH") to study the feasibility of seeding at shorter wavelength (30 nm and below) is in preparation at a dedicated commissioning beamline, while SASE pulse trains are simultaneously delivered to the present FEL user beamlines [28].

Currently there are five beamlines for XUV radiation in operation. The layout of the experimental area is schematically depicted in Fig. 1.

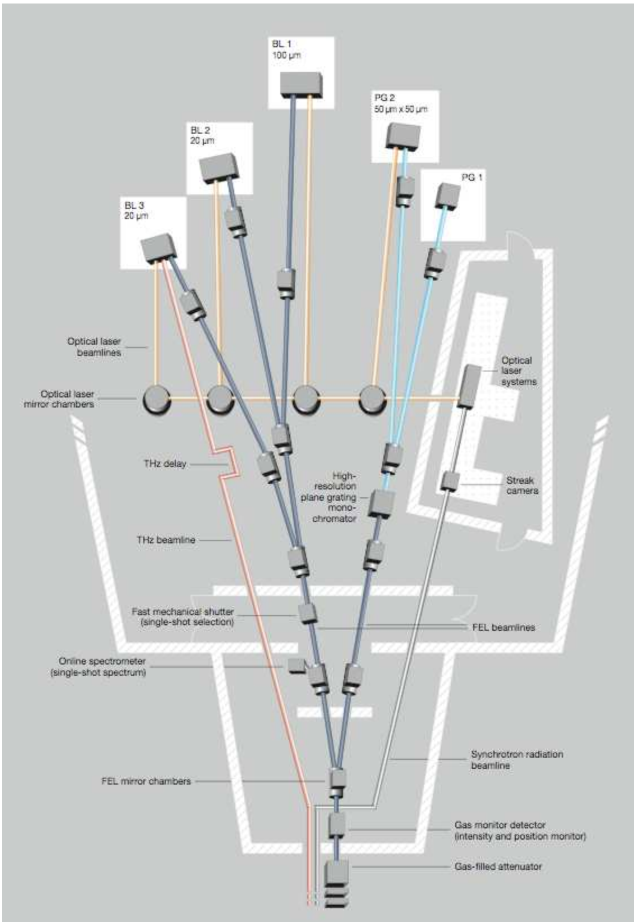

Figure 1: Overview of the FLASH facility including direct (BL1, BL2 and BL3), monochromatised (PG1 and PG2), optical and Teraherz (THz) FEL beamlines. Approximated focal sizes are given next to the station name. Various photon diagnostic tools are installed at different places in the experimental hall

The direct "non-monochromatized" beam is delivered to the beamlines BL1, BL2 and BL3. The high-resolution plane grating monochromator beamlines PG1 and PG2 are selecting a narrow bandwidth of the FEL pulse [29, 30]. For inelastic scattering experiments PG1 is equipped with a high resolution, two-stage spectrometer which is permanently installed in this station. Femtosecond time-resolved pump-probe studies using an optical laser synchronized to the FEL can be performed at BL1-BL3 and PG2 [31-34]. In addition THz radiation can be generated on demand in an electromagnetic undulator located behind the SASE undulator and transported to the endstation of BL3 [35]. Since both, the XUV and the THz pulses are generated by the same electron bunch they are naturally synchronized which opens another window of opportunities for time-resolved studies in the far-infrared spectral range in particular since the generated THz pulses are carrier envelope phase stable.

In summary, the operation of the FLASH facility has made very good progress during the past years pointing towards a bright future with the European XFEL. The author thanks the FLASH team at DESY and all collaboration partners for their contributions.

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