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Stéphane Sebban
Julien Gautier
David Ros
Philippe Zeitoun *Editors*

X-Ray Lasers 2012

Proceedings of the 13th International Conference on X-Ray Lasers, 11–15 June 2012, Paris, France

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Preface

These proceedings comprise invited and contributed papers presented at the 13th International Conference on X-Ray Lasers (ICXRL 2012) which was held 11–15 June 2012 in Paris, in the famous Quartier Latin, inside the historical Center of Cordeliers. This conference is part of a continuing series dedicated to recent developments and applications of x-ray lasers and other coherent x-ray sources with attention to supporting technologies and instrumentation.

New results in the generation of intense, coherent x-rays and progress towards practical devices and their applications are reported in these proceedings, including areas of research in plasma-based x-ray lasers, 4th generation accelerator-based sources and higher harmonic generation.

Recent achievements related to the increase of the repetition rate up to 100 Hz and shorter wavelength collisional plasma-based soft x-ray lasers down to about 7 nm are presented. Seeding the amplifying plasma with a femtosecond high-order harmonic of infrared laser was foreseen as the required breakthrough to break the picosecond frontier. Numerical simulations based on the Maxwell-Bloch model are presented in these proceedings, transposing the chirped pulse amplification technique to the x-ray domain in order to increase the time over which the femtosecond seed can be amplified.

These proceedings also include innovative applications of soft x-ray lasers based on techniques and diagnostics relevant to topical domains such as EUV lithography, inertial confinement fusion, or warm dense matter physics.

We would like to thank the International Advisory Board for helping to organize the scientific program and the Local Organizing Committee for operation of the meeting. Also we would like to thank the Conference Secretary and the supporting staff for running the conference smoothly and editing these conference proceedings.

Paris, France

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Chapter 1
Coherent Pulses from a Seeded Free-Electron Laser in the Extreme Ultraviolet

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Abstract We report results of a free-electron laser operating with the high gain harmonic generation configuration in the wavelength rage from 60 to 20 nm. With the recent experiments done at the FERMI free-electron laser facility in Trieste we demonstrated the capability of the used method to produce highly coherent pulses allowing to improve the performances of FELs in the EUV spectral range overcoming some of the limitations that are typical of systems based on the self amplified spontaneous emission (SASE). Taking advantage of the seeding scheme adopted for FERMI high photon energy stability and a very high longitudinal and transverse coherence have been measured. The operation of the FERMI FEL facility will allow improving the use of the FEL light for those experiments that require a small spectral bandwidth or a precise control of the photon energy.

1 Introduction

FERMI@Elettra is a fourth generation light source under commissioning that has been built at the Elettra laboratory in Trieste. When in operation FERMI@Elettra will allow the Elettra user community to perform new kinds of experiments that could exploit the characteristic of such a new light source like short pulses and high peak intensity.

Free electron lasers have been recognized since the first proposal [1] and demonstration [2, 3] as possible sources that could be efficiently used for the generation of laser like pulses in the x-ray spectral range. Although it has been necessary to

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wait for the technology to be mature in order to support the requirements for x-rays FELs, the theory of high gain single pass FELs was developed [4, 5] showing how the self amplified spontaneous emission (SASE) FELs could be designed to operate in the x-ray spectral range. Since the first theoretical works, several projects have been done for demonstrating and use such a capability.

After first experiments in the infrared [6] and in the visible [7] the wavelength range has been rapidly extended from the VUV [8] up to the soft x-ray [9]. More recently the final goal to reach the hard x-ray spectral range has been achieved showing FEL operations at 1.5 and 1.2 Ångstrom [10, 11].

The recent progress on short wavelength FELs has been accompanied by the progress of other sources of laser-like pulses in the VUV and soft x-ray spectral range. Several methods have been proposed and studied for the generation of x-ray laser-like pulses that use the nonlinear response of materials to very high power laser pulses in the visible and near infrared [12–16].

In this work we will report about the recent results achieved at FERMI@Elettra with the first seeded FEL operated in the range between 65 and 20 nm.

2 The FERMI@Elettra Free Electron Laser

The FERMI FELs will produce photons in the ultraviolet and soft x-ray range, between 80 and 4 nm (Fig. 1).

Three experimental programs define the scientific case and have driven the design of the facility. The three FERMI experimental beamlines, Diffraction and Projection Imaging (DiProI), Elastic and Inelastic Scattering (EIS), Low Density Matter (LDM), require for their experiments high peak brightness, fully coherent, narrow and stable bandwidth photon pulses. Wavelength tunability and variable polarization, circular and linear, are also required [17, 18].

In order to cover the large spectral range FERMI has been designed with two FEL lines. FEL-1, based on a High Gain Harmonic Generation (HGHG) [19] single stage, is seeded by an external UV laser at about 260 nm [20]. FEL-1 produces photons in the wavelength range between 80 and 20 nm (15 eV to 62 eV). To reach 4 nm wavelength (310 eV), starting from an external seed laser in the UV range, a double stage HGHG cascade has been adopted for FEL-2.

Both FELs use the high energy and brightness electron bunches produced by a linear accelerator (Fig. 2). The accelerator is based on a normal conducting LINAC working at 3 GHz RF frequency and 50 Hz repetition rate. The high brightness electron beam is generated by a photocathode RF gun. Two stages of magnetic compression are used to get extremely short electron bunches (less than 1 ps) with high peak current.

A fourth harmonic RF structure (12 GHz, X-band) provides the longitudinal phase space linearization needed to optimize the compression process. At high compression factors, i.e. high peak bunch currents, micro-bunching instabilities are predicted; to cure them, a laser heater [21] is installed at 100 MeV to increase in a controlled way the incoherent energy spread of the electron beam.

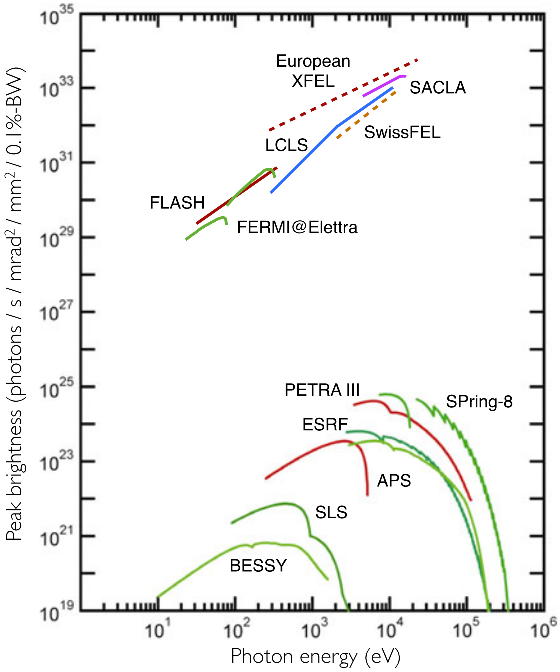

Fig. 1 Diagram showing the expected performance of FERMI in terms of peak brilliance as compared to other FEL and synchrotron radiation facilities (Image from: P. Schmüser, M. Dohlus, J. Rossbach, and C. Behrens, Free-Electron Lasers in the Ultraviolet and X-Ray Regime: Physical Principles, Experimental Results, Technological Realization, 2nd edition to be printed in Springer-Verlag, Berlin (2013))

Each stage of the two FEL lines is made up by the modulator, where the electron beam is seeded by the external laser, a dispersive bunching section, and the radiator, where the interaction between the electron beam and the produced coherent radiation produces the exponential growth of the FEL radiation. In Fig. 3 we show the schematic layout of the first FEL, FEL-1, that is based on a single stage harmonic generation.

For both FEL-1 and FEL-2 the final radiator is made up by six APPLE-II undulators, with magnetic periods of 55 and 35 mm respectively. APPLE-II undulators provide full control of the polarization of the FEL radiation and the variable gap allows changing the wavelength of the emitted radiation.

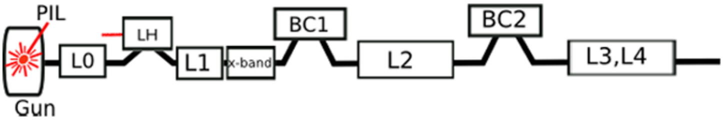

Fig. 2 Schematic layout of the FERMI linear accelerator. Electron bunches are produced in the *Gun* by 5 ps pulses from a Photo-Injector Laser (*PIL*). A first acceleration structure (*L0*) is used to accelerate the beam up to 100 MeV, where there is the laser heater (*LH*). Further acceleration is produced by *L1*, and an *x-band* cavity is used to linearize the phase space before the first bunch compressor (*BC1*). Further acceleration is produced by *L2* and *L3*, *L4* and if needed additional compression can be achieved using the second bunch compressor chicane (*BC2*)