FUTURE SEEDING EXPERIMENTS AT SPARC

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Abstract

This communication describes the research work plan that is under implementation at the SPARC FEL facility in the framework of the DS4 EUROFEL programme. The main goal of the collaboration is to study and test the amplification and the FEL harmonic generation process of an input seed signal obtained as higher order harmonics generated both in crystals (400 nm and 266 nm) and in gases (266 nm, 160 nm, 114 nm). The SPARC FEL can be configured to test several cascaded FEL layouts that will be briefly analysed.

INTRODUCTION

The SPARC FEL experiment is based on two main components, a high brightness photoinjector that is expected to provide a high quality beam at energies between 150 and 200 MeV (see Tab.I and ref.[1]) and a single pass FEL, whose undulator beam-line is composed by six undulator sections of 77 periods each, with a period length of 2.8 cm and a gap ranging from 6 to 25 mm[2].

The FEL will operate in self amplified spontaneous emission (SASE) mode at a wavelength of about 500 nm with an expected saturation length of about 10-12 m, according to the beam parameters listed in table 1. The flexibility offered by the variable gap configuration of the SPARC undulator and the natural synchronization of the electron beam with the laser driving the photoinjector, makes the SPARC layout particularly suited for a number of experiments where the FEL amplifier is seeded by an external laser source. The seed laser is driven by the same oscillator initiating the laser cascade which is used to run the photocathode and consists in a regenerative amplifier delivering 2.5mJ at 800 nm with a pulse duration shorter than 120 fs.

Table 1. List of the main SPARC beam parameters

Beam energy	155-200 MeV
Bunch Charge	1.1 nC
Rep. Rate	1 – 10 Hz
Peak current (>50% bunch)	100 A
Norm. emittances (integrated)	2 mm-mrad
Norm. emitt. (slice len. 300µm)	< 1 mm-mrad
Total correlated energy spread	0.2 %
Total uncorrelated energy spread	0.06 %
e-bunch duration (rms)	~ 4 ps

Different schemes of non-linear harmonic generation are then implemented to generate the shorter wavelength radiation for seeding the FEL. Second and third harmonic generation in LBO crystals will provide the powerful pulses required to reach saturation and study the non-linear pulse propagation in FELs and FEL cascades in superradiant regime, at 400nm and 266nm [3], [4]. The other method considered for the frequency up-conversion of the Ti:Sa fundamental wavelength, is based on the non-linear higher order harmonics generation of the Ti:Sa laser in a gas-jet or in a gas-cell [5]. While at SPARC we plan to seed the FEL with the harmonics up to the 9th of the Ti:Sa [6], the harmonic generation in gas allows to extend the seed source spectral range down to the EUV region of the spectrum and represents a promising technique to seed FEL amplifiers at shorter wavelengths.

In the following we will review some of the planned experiments with the two different seed sources.

SEEDING WITH HIGH HARMONICS GENERATED IN GAS

The experiment of seeding high harmonics generated in gas at SPARC is based on the installation of a gas jet interaction chamber and an in vacuum optical system which matches the transverse optical mode of the harmonic to that of the e-beam in the first undulator section [6]. The UV pulse is injected into the SPARC undulator by means of a periscope and a magnetic chicane deflecting the e-beam from the straight path. High-order odd harmonics of the Ti:Sa laser may be generated at the wavelengths 266nm, 160nm, and 114nm. The undulator resonance condition is tuned at these wavelengths by varying the beam energy and undulator strength K according to the plot shown in Fig. 1.

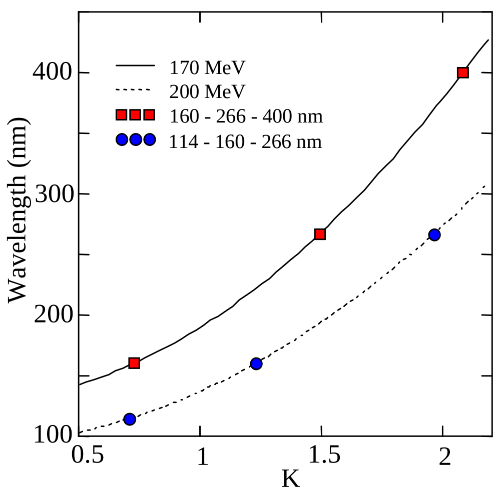

Figure 1: Seeded SPARC FEL operation wavelengths.

The high order harmonics result from the strong non-linear polarisation induced on the rare gases atoms, such as *Ar*, *Xe*, *Ne* and *He*, by the focused intense electromagnetic field of the "pump" laser. The emitted pulse is composed by a sequence of short bursts separated by one half of the fundamental laser period (400nm) and the spectrum contains the odd harmonics of the original laser. A simulation of the amplification of a pulse at 160nm with the typical time structure of harmonics generated in gas has been done with *Perseo*[7]. The laser pulse shape vs. the longitudinal coordinate is shown in Fig. 2 at different positions along the undulator. The radiation spectrum is also shown in Fig.2 and the effect of the spectral “cleaning” associated with the limited FEL bandwidth (FEL parameter $\rho \approx 4{\cdot}10^{-3}$) is evident. An analogous behaviour is observed at the third harmonic generated by the non-linear FEL dynamics. More detailed simulations based on an accurate model of the seed fields distribution and including transverse effects are under study.

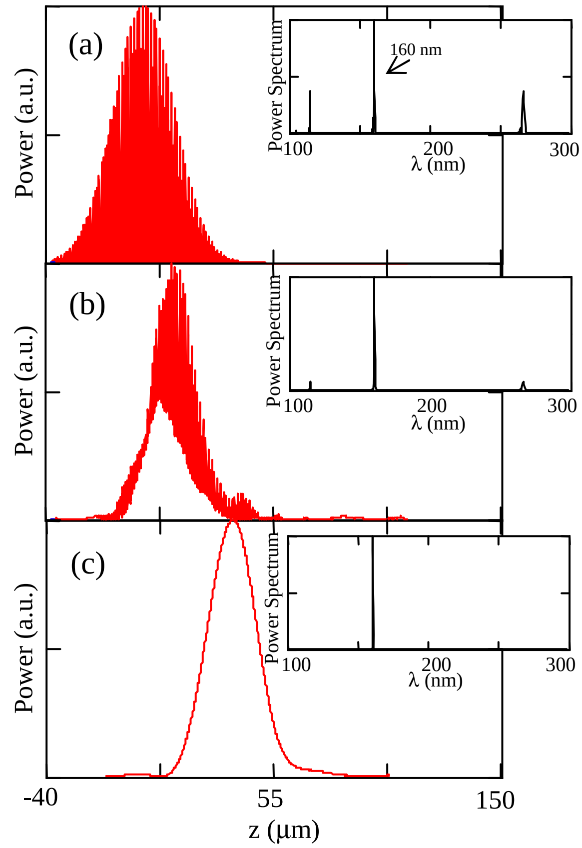

Figure 2 Power and spectrum of the radiation at different positions in the undulator for the SPARC FEL seeded at 160nm. Seed signal (a), after the first undulator section (b), at the end of the undulator (c). Beam energy 200 MeV, K=1.226, the other beam parameters as in Table 1.

SEEDING WITH 2ND AND 3RD HARMONICS OF TI:SA GENERATED IN CRYSTAL

The six SPARC undulators may be configured in order to set up a single stage cascaded FEL based on a modulator – radiator configuration, similar to the one tested at BNL [8]. The layout of this configuration is shown in Fig.3.

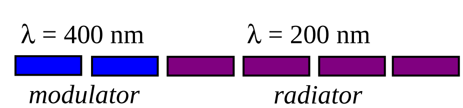

Figure 3 Single stage cascaded FEL layout.

The number of sections of the modulator and of the radiator may be tuned depending on the intensity of the laser seed. The availability of intense short pulses from the seed laser allows to test the superradiant cascade concept [4]. The seed laser power is indeed sufficient to bring at saturation a modulator made by a single undulator segment tuned at 400 nm. The pulse generated in these conditions propagates with the typical signature of superradiance in the following radiator composed by the remaining five sections. The feasibility of this experiment was studied in[9].

A second interesting configuration consists in the experimental test of the fresh-bunch injection technique [10]. The layout is shown in Fig.4. In this case the first two undulators (A and B) represent the modulator and radiator sections of single stage cascade, the following two undulators (C and D) are tuned off resonance with the seed wavelength and its higher order harmonics. These undulators play the role of the dispersive section where the radiation exiting the first radiator at 200 nm (B) is longitudinally separated from the electron beam part where the high quality beam has been heated in the previous sections, by the FEL interaction with the seed.

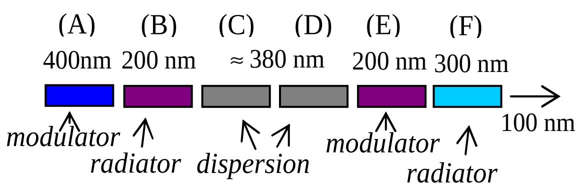

Figure 4 Fresh bunch injection technique layout.

Section (E) is the modulator of the second stage cascade and section (F) is the radiator that is tuned in order to match the resonance of its third harmonic with the second harmonic of the radiator (E). This is necessary since the K parameter excursion of the undulator is not sufficient to span the 1st to 3rd harmonic range and coupling on the higher order odd harmonics in a linear undulator based FEL has been considered [11].

The last configuration considered in this overview consists in the harmonic FEL cascade [12]. As in the last stage of the previous configuration, the two undulators are tuned at different, not-harmonic fundamental frequencies, but have instead one of their higher order harmonics in common. According to the SPARC FEL undulator properties, this scheme may be tested in configurations where the fourth of the sixth harmonic of the 266nm signal used as seed of the first section, are amplified as the third or fifth harmonics in the second section. This configuration has been analysed with numerical simulations in time dependent mode. Both the codes *Perseo* and a modified version of the code *Genesis 1.3* [13-14] which includes the self consistend dynamics of the higher order harmonics have been used. In the example considered in Fig. 5, we show the result obtained with *Perseo*. The cascade is driven by a seed of 2 MW peak power at a wavelength corresponding to the third harmonic of the Ti:Sa drive laser. The first undulator has the fundamental resonance at 266nm and the second section is tuned at 222nm. The two undulators have a common resonance at 44nm, corresponding to the 6th harmonic of the first section and the 5th of the second.

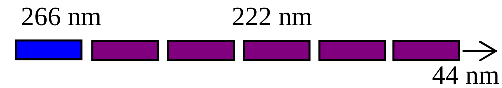

Figure 5 FEL Harmonic cascade FEL configuration.

The energy of the radiation pulse at the wavelength of 44nm vs the longitudinal coordinate in the radiator is shown in Fig. 6.

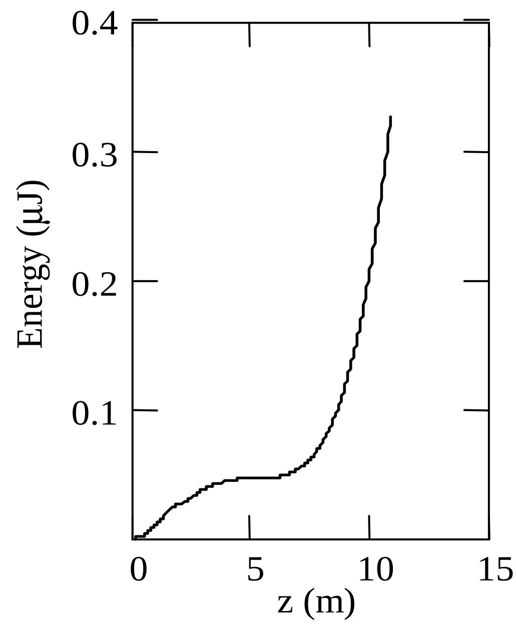

Fig. 6 Pulse energy vs. the longitudinal coordinate in the radiator.

A transition to superradiance where the pulse energy grows as $z^{3/2}$ occurs after about five meters of the radiator section.

The pulse shape is shown in Fig. 7 and the relevant spectrum is shown in Fig. 8.

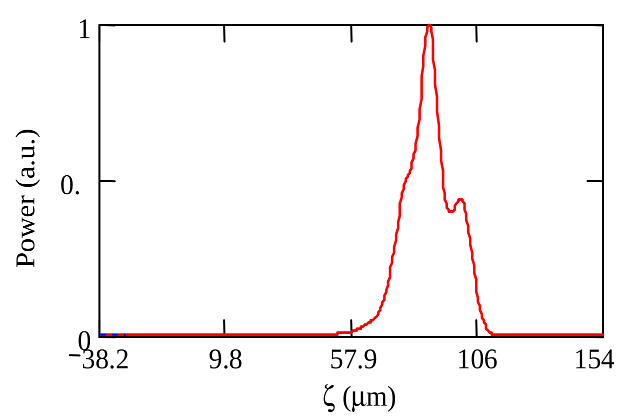

Fig. 7. Longitudinal profile of the radiation power at the end of the second undulator.

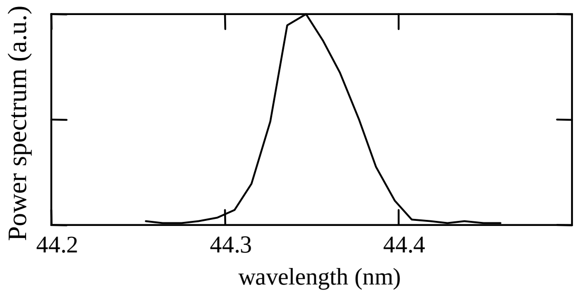

Fig. 8 Power spectrum of the radiation pulse as shown in Fig. 7.

CONCLUSIONS

We have given a brief overview of some of the experiments that will be implemented at SPARC thanks to the flexibility of the SPARC configuration and of the variable gap undulator. Seeding the FEL with harmonics generated in gas and testing schemes as the fresh bunch injection technique and the harmonic FEL cascade are among the capabilities of the SPARC hardware. The harmonic cascaded FEL scheme is in particular a promising scheme to extend to the short wavelength the operation range of a Free Electron Laser. A wavelength of 44nm was obtained in simulations with a beam energy of only 200 MeV.

The opportunities provided by the SPARC experiment of a deeper understanding of the amplification process and of experimentally testing and of the FEL dynamics through a whole cascade, may affect in the future the design of the foreseen FEL facilities aiming at the generation of radiation in the VUV-EUV region of the spectrum.

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