SEEDING SPARC FACILITY WITH HARMONIC GENERATION IN GASES : PRELIMINARY TESTS OF THE HARMONIC GENERATION IN GAS CHAMBER

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Abstract

A coherent short wavelength source can be realized with a Free Electron Laser using High Gain Harmonic Generation configuration. The injection of an external light source in the first part of an undulator results in a coherent light emission in its second part. The SPARC FEL (Frascati, Italy) can be configured to test such schemes. We propose to use the High Order Harmonic Generation (HOHG) in gases process as the seed. HOHG produces a coherent XUV source by focusing an intense laser pulse into a gas medium. This beam, composed of odd harmonics of the fundamental laser, is then shaped using a telescope of two spherical mirrors, allowing the focusing at a given position, in the SPARC undulator. Appropriate tuning of the undulator gaps will amplify either 3rd or 5th harmonic seeded or non-linear harmonics of those wavelengths, allowing the perspective of producing VUV coherent radiation. The vacuum chambers for harmonic generation and shaping have been realized and tested at the CEA (Saclay, France). We present these tests.

INTRODUCTION

Free Electron laser (FEL) can be used in single pass mode to generate intense and short pulse duration in XUV domain. The common scheme is called self-amplified spontaneous emission (SASE) where the radiation starting from shot noise of the electron beam, grows up along the undulator [1]. This process produces short wavelengths with high peak power and a good spatial mode. However, the temporal coherence of the generated pulses are only partial and the intensity fluctuations are important. One new scheme for single pass FEL is High Gain Harmonic Generation (HGHG) which is more compact and can produce a XUV radiation with the same properties of SASE radiation but with fully temporally coherent pulses and small energy fluctuations [2, 3]. In this configuration, an external laser source is seeded into a first undulator where an energy modulation is imposed on the electron beam by its interaction with the laser. This energy modulation is converted into a spatial density modulation as the electron beam crosses a dispersive section. The microbunched electron beam coherently emits at the nth harmonic of the laser fundamental frequency. The tuning of the undulator selects the amplified harmonic. The properties of the output radiation are determined by the seed laser which can have a high degree of temporal coherence. Seeded FEL amplifier operation in combination with harmonic generation has been demonstred experimentally in midinfrared and VUV domain [4, 5]. A way to reach shorter wavelengths is to use a seed laser in VUV domain. Development in femtosecond laser technology have made possible to imagine new coherent short wavelength sources. One of these sources, called High Order Harmonics Generation (HOHG), is based on the interaction between the laser beam and a gas target [6, 7]. Microjoule energies can be obtained at wavelengths down to 50 nm [8, 9]. It has been proposed to use HOHG as seed to inject an undulator, either in the amplifier or in the HGHG configuration [10]. HOHG seem to be a very good candidate to seed FEL cascade, to extend the operating wavelength of FELs down to sub nm. The SPARC configuration will allow the study of the problems related to the injection of an external radiation seed in a single pass FEL and the analysis of the coupling efficiency of the electron-photon beams in terms of the input parameters [11].

EXPERIMENTAL LAYOUT

SPARC undulator is composed of 6 sections of 75 periods each. The e-beam energy may be varied up to 150-200 MeV. A Coherent femtosecond laser which delivers 120 fs, 2.5 mJ pulse with a central wavelength at 800 nm and a modified repetition rate of 10 Hz, generates HOHG in a gas jet. The VUV radiation is then injected into the undulator by means of a magnetic chicane. Electron and photon beams are then superposed at the entrance of the undulator (figure 1). SPARC undulator parameters allow to test different configurations [12, 11, 13].

HIGH-ORDER HARMONIC GENERATION

HOHG is obtained by focusing an intense laser pulse into a rare gas medium. The non-linear interaction between gas medium and the laser field leads to the creation of new frequencies and, after the gas medium, one can observe odd high order harmonics of the fundamental frequency co-propagating with the fundamental laser beam. This VUV radiation also exhibits an excellent spatial and temporal coherence [14, 15, 16]. The coherence properties of the har-

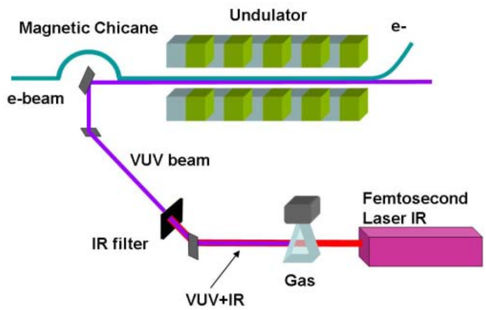

Figure 1: Experimental layout to seed harmonics generated in gas into FEL.

monics are similar to those of the fundamental laser beam which make them suitable for seeding experiment.

The setup for the production of the harmonics in gas is mainly composed of two chambers (figure 2). The laser is sent in the first chamber where HOHG occurs. Then, 1.5 meters downwards, the second chamber is used to adapt the harmonic beam mode for a correct overlap with the e-beam in the undulator.

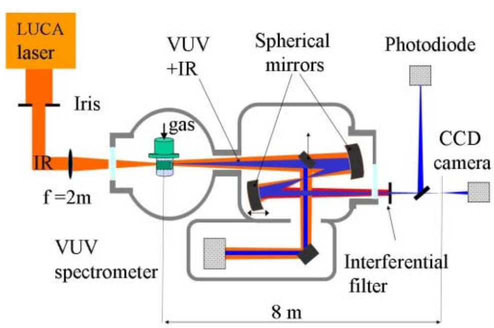

Figure 2: Experimental setup

To test the harmonic chambers, we used as fundamental source the femtosecond laser system (LUCA) of the Saclay Laser-matter Interaction Center (SLIC). LUCA is a multi beam femtosecond laser based on 2 TW, 20 Hz CPA Titanium:Sapphire System [17]. The duration of the recompressed pulse is about 60 fs and the energy can be varied up to 17 mJ at 800 nm. To obtain a well-defined spatial mode and to optimize the efficiency conversion we apertured the 30 mm beam up to 12 mm, the beam is then focused by a plano-convex lens (f=2m) and delivered into the target chamber through an antireflecting coated 790 nm window. As interaction medium, we use a 1 cm long-windowless cell, where gas is injected by bursts of 1.3 μs through an electromagnetic valve synchronized with the incoming laser pulses. In the second chamber, two concave mirrors, reflecting at 266 nm nearly normal incidence, adapt the waist in the middle of the first undulator. The distance between the gas jet and the middle of the first undulator is about 8 m. Both spherical mirrors have motorized mounts, one translation stage is added on the second optic, for the adaptation of the focusing point in the undulator.

High harmonics generated in the chambers pass through an interferential filter centered at 266 nm (H3) eliminating IR beam as well as other harmonics. The 266 nm radiation is then detected with a calibrated VUV photodiode blinded for diffused IR light. The first step to optimize the harmonic yield was to control the laser aperture and the cell focus position [18, 19]. Closing an iris placed before the lens means decreasing the energy laser and increasing the focal spot size, therefore decreasing the focal intensity. Figure 3 shows, in argon, an optimum harmonic signal for an aperture size of 14 mm corresponding to 2.5 mJ laser energy, an intensity of $2 \times 10^{14}\ W/cm^2$ and a focal spot diameter of 340 μm.

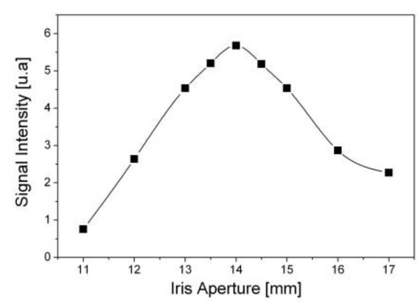

Figure 3: Harmonic signal as a function of aperture size.

The optimal laser cell position is then obtained for a focal plane 1.5 cm after medium. At this position the spot diameter is about 370 μm corresponding to an intensity $1.8 \times 10^{14}\ W/cm^2$.

The influence of the pressure at optimal laser aperture has also been studied: 3rd harmonic signal increases slowly with the backing pressure (figure 4). With higher backing pressure, electromagnetic valve limits the pressure in cell. The number of 3rd harmonic photons generated in the optimized conditions are 1.3×10^{13} and the corresponding conversion efficiency reaches 4×10^{-3}. In the same conditions, when 3rd harmonic is generated by a chirped 120 fs pulse, the number of photons decreases by factor 4.

We used a VUV spectrometer composed of a LiF prism and a photomultiplier to measure H3 and H5 with an entrance pinhole of 5 mm. Scanning on the prism angle being manual, we only measured maximum signal at one position of the prism angle for H3 and H5 allowing the coarse comparison of the relative contribution of each harmonic (figure 5).

The harmonic beam propagation is crucial for evaluating the overlap between the light wave and the electron bunch in the undulator. The harmonic beam is shaped using two concave mirrors optimized for 266 nm wavelength with re-

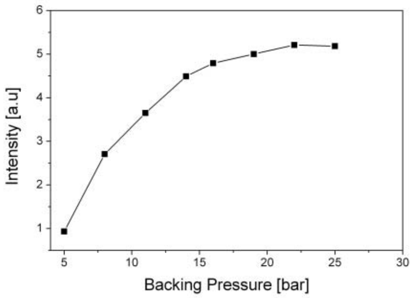

Figure 4: Pressure dependence of H3 in Argon.

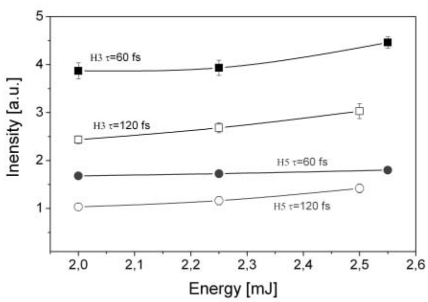

Figure 5: 3rd and 5th harmonics in argon as function of energy laser for two pulses width.

spectively a focal length of 200 mm and 150 mm. The distance between the two mirrors is about 38 cm. The incidence angle of 2° induces small geometric aberrations. The total transmission for 3rd harmonic is 90 %. The spatial profile of the 3rd harmonics has been measured using a CDD camera. Figure 6 shows the evolution of H3 from the exit of the chambers through out the undulator. The focal spot size is about 940 μm. The theoretical fit with a quasi-gaussian beam [20] gives a M^2 value of 1.6 and a 3rd harmonic size of 220 μm at generation point . With these measurements, we will able to determine the filling factor which takes into account the interaction between electrons and photons.

Conclusion

These preliminary tests allowed us to find the good geometric configuration for the generating medium for HOHG. The telescope system focuses the 3rd harmonic beam, which is slightly astigmatic, at the estimated entrance of the first undulator with a focus waist size of 300 μm. In Argon, we obtain 10 μJ on the 3rd harmonic. The peak power of this coherent VUV light was estimated to be 0.15 GW at 266 nm assuming a pulse width of 60 fs (same as the pump laser) and 19 MW when 3rd harmonic is generated by a chirped 120 fs laser pulse. Calculations with PERSEO

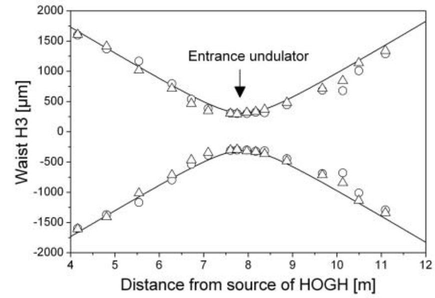

Figure 6: Longitudinal evolution of the beam waist of the 3rd harmonic in vertical (△) and horizontal (○) direction. In solid line indicate the quasi-gaussian beam fit.

and with GENESIS 1.3 code have shown that saturation can be reached with SPARC undulator, using a 266 and 160nm wavelength seed with only a few kW power [11].

Next step will consist in testing the seeding of SPARC FEL with this scheme.

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