SEEDING THE FEL OF THE SCSS PROTOTYPE ACCELERATOR WITH HARMONICS OF A TI: SA LASER PRODUCED IN GAS.

G. Lambert, M. Bougeard, W. Boutu, B. Carre, D. Garzella, M. Labat, CEA, Saclay, France
M.E. Couprie, O. Chubar, Synchrotron Soleil, Saint-Aubin, France
G. Lambert, T. Hara, H. Kitamura, T. Shintake SPring-8/RIKEN Harima Institute, Hyogo, Japan.

Abstract

A particular seeded configuration will be tested in 2006 on the SCSS prototype accelerator (SPring-8 Compact Sase Source, Japan). This facility is based on a thermionic cathode electron gun (1 nC), a C-band LINAC (5712 MHz, 35 MV/m) and an in-vacuum undulator (15 mm of period. 2 sections of 4.5 m length). The maximum electron beam energy is 250 MeV and the SASE emission from visible to 60 nm can be obtained. The external source, coming from the High order Harmonic Generation (HHG) process, can be tuned from the 3rd (266 nm) to the 13th harmonic (60 nm) of a Ti: Sa laser generated in a gas cell. The experiment contains a first chamber, dedicated to harmonic generation and a second one for harmonic beam diagnostics and adaptation of the harmonic waist in the first undulator section. The tests have been performed in Saclay (15 mJ, 10 Hz, 50 fs). An energy of 2 μJ with a high stability for the 3rd harmonic and a good transversal shape with an optimized energy level and a high stability for the 13th harmonic have been obtained at the first undulator center place. The performances using analytical formulas, GENESIS and SRW have been updated. The chambers will be installed on the SCSS prototype accelerator in the beginning of October for the seeding tests.

INTRODUCTION

These last years, most of the new FEL sources were dedicated to the so-called Self Amplified Spontaneous Emission (SASE) [1], which provides with a very high brightness photon beam at short wavelength but with limited temporal coherence. Consequently, a few FEL facilities, like ARC-EN-CIEL (Accelerator Radiation Complex for Enhanced Coherent Intense Extended Light) a French proposal for a 4th generation light source [2], have adopted a new configuration: a seeding configuration, in which High order Harmonics of a laser Generated in gas (HHG) are injected into a FEL, giving its full coherence property to the emitted radiation. It also reduces the saturation lengths allowing a more compact source [3]. In addition, other SASE projects have decided to implement it on their facility: SCSS prototype accelerator (SPring-8 Compact Sase Source) [4] and SPARC (Sorgente Pulsata e Amplificata di Radiazione Coerente) [5]. Recently such a seeding experiment with high harmonics produced in gases was performed in an X-ray laser [6]. It is proposed here to seed the FEL of the SCSS prototype accelerator at a 60 nm radiation, corresponding to the 13th harmonic of a Ti: Sa laser (H13) generated in a gas cell. June, the first lasing of the SCSS prototype accelerator FEL [7] has been observed at 49 nm. The characteristics of the electron beam, undulators, laser and harmonics come from ref. [8] and the basic layout is given in Figure 1.

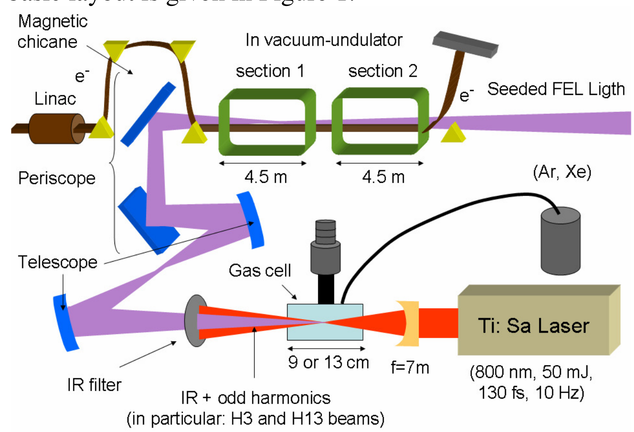


Figure 1: General layout of the seeding experiment with harmonics generated in a gas cell.

HHG SYSTEM

The harmonic generation in gas results from the strong non linear polarization induced on the rare gases atoms, such as Ar, Xe, Ne and He, by the focused intense electromagnetic field E_{Laser} of a "pump" laser [9]. In our case, a 7 m focal length lens focuses a Ti: Sa laser in a cell (Figure 2) filled with Xe or Ar gases, which are well-adapted for the generation of 60 nm radiation. The laser passes through the cell and is aligned by means of two pinholes of 1 mm of diameter, made on Tantalus plates, which create a constant leak of gas.

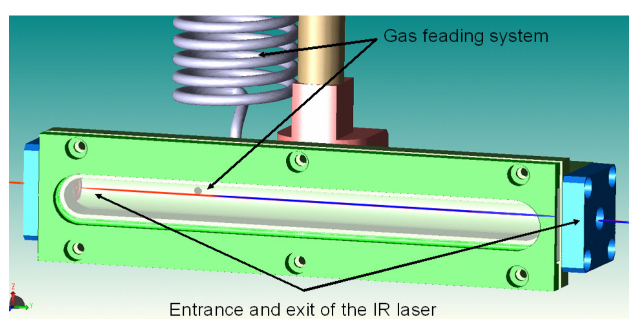


Figure 2: Gas cell system producing HHG light.

The general experiment is based on a system of two chambers (Figure 3).

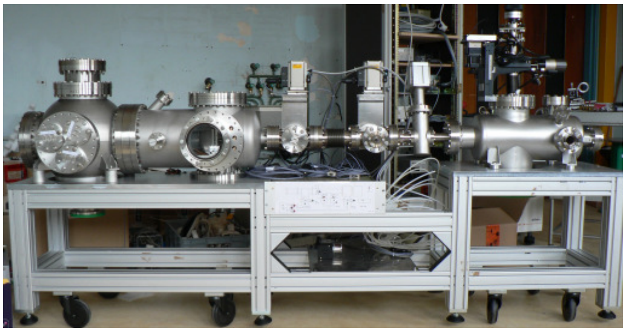


Figure 3: General layout of the HHG system.

The first one is dedicated to the HHG production (Figure 4). The cell position is motorized for accurate alignment of the IR laser and optimization of the harmonic production rate.

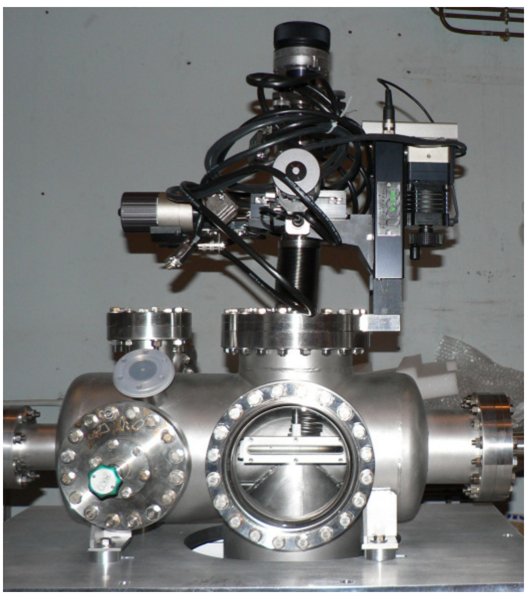


Figure 4: HHG chamber with gas cell and motorization system.

The second one (Figure 5) has been designed for adjusting the harmonic beam at the focusing point in the first undulator section by means of two SiC spherical mirrors. A periscope system is used to align the harmonic beam with the e-beam.

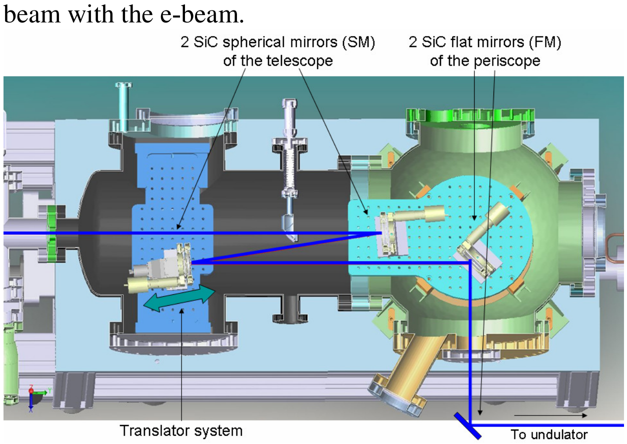


Figure 5: Refocusing system and periscope.

FIRST HHG TESTS IN SACLAY

The first tests have been performed in Saclay with the LUCA laser beam (1 to 15 mJ, 20 Hz, 50 fs, 5 m long of focal lens). In the starting phase of tests, the seeding wavelength was the 3rd harmonic (H_3, 266 nm), which is a more intense and easily useable source (can be propagated outside vacuum, and detected with a VUV photomultiplier). The behavior of the harmonics (Figure 6 for the 3rd harmonic) in operation is mainly optimized with the IR beam diameter (a), power, focusing position in the cell and the gas pressure (b). The respective optimal values, in the test configuration, are 20.8 mm, 115 mW, 4 cm before the cell center and 5 10^{-3} mbar in the first chamber.

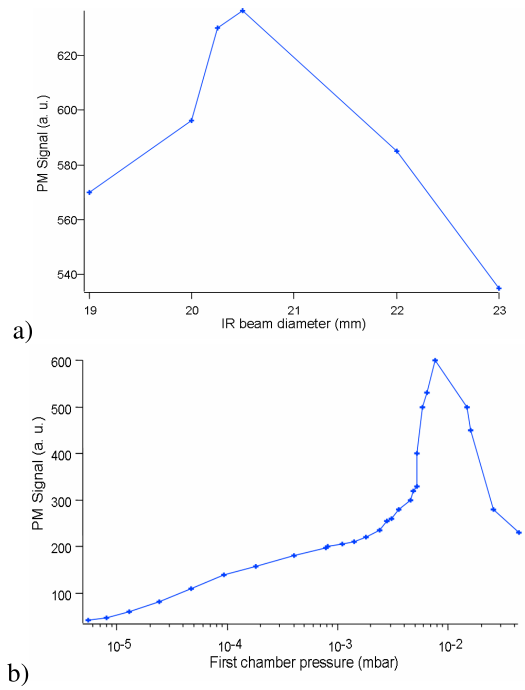


Figure 6: Optimization of the 3rd harmonic flux, generated in a 9 cm cell filled with Ar gas, with the Hamamatsu PM R759, as function of the IR beam diameter (a) and of the gas pressure in the first chamber (b).

The transverse profiles (Figure 7) of the 3rd harmonic, observed with a VUV CCD camera (COHU solid state camera) are quit similar to a Gaussian fit.

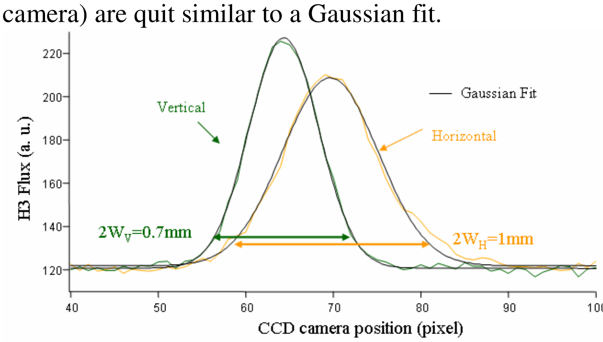


Figure 7: Horizontal and vertical profiles of the 3rd harmonic, at the theoretical focusing point in the first undulator section.

Figure 8 shows the influence of the gas pressure on the optimum of the flux on the two different harmonics.

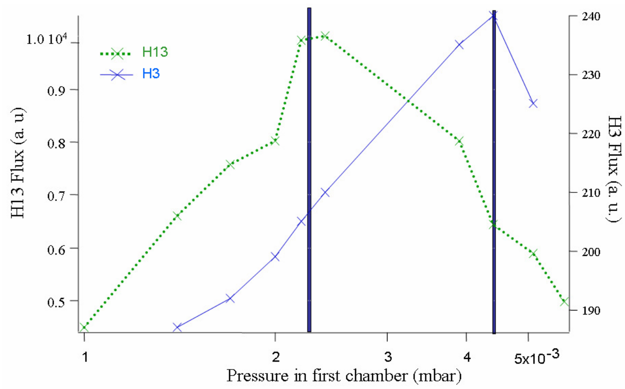
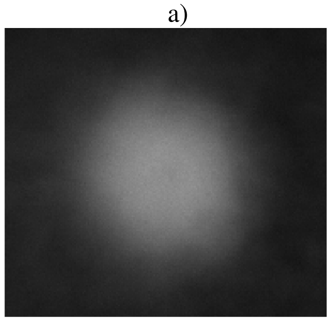


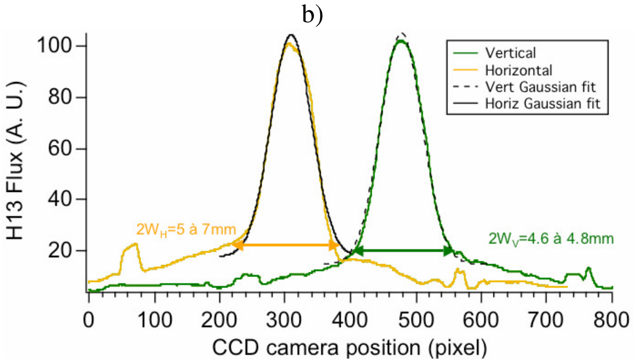
Figure 8: Comparison between optimization of 3rd and 13th harmonics (resp. H3 and H13) as function of the pressure inside the gas cell (proportional to the first chamber pressure)

The shape of the 13th harmonic can be observed (Figures 9 a and b), 3 m after the cell corresponding to 8 m before the theoretical focusing point in the first undulator section. A Micro-Channel Plate (MCP, Hamamatsu F2221) was used with a phosphor screen (P43) associated to a CCD camera and placed after a Sn filter (eliminating the IR laser and selecting especially the 13th harmonic). The beam section presents some light aberrations particularly visible in the horizontal profile. These latter must be really more important in the first undulator section, where the interaction occurs with the e-beam (the overlapping can be decreased of 15%), but can be compensated using a toroidal mirror.

a)



b)



Figures 9 a and b: Transverse section (a) and profiles (b) of the 13th harmonic, 3 m after the cell but 8 m before the theoretical focusing point in the first undulator.

IMPLANTATION ON THE SCSS PROTOTYPE ACCELERATOR

The harmonic generation experiment will be located in the SCSS prototype accelerator tunnel, together with the accelerator and the undulator sections, between the chicane and the shielding wall (Figure 10). The focusing of an intense IR laser comes from the laser hutch, on the opposite side of the shielding wall. The Ti: Sa laser is based on a Tsunami mode-locked oscillator, a Spitfire regenerative chirped-pulse amplifier and a Coherent multipass amplifier and delivers more than 50 mJ at 100 fs. On an optical table, the IR beam is adapted for harmonic generation optimization and synchronized with the e-beam.

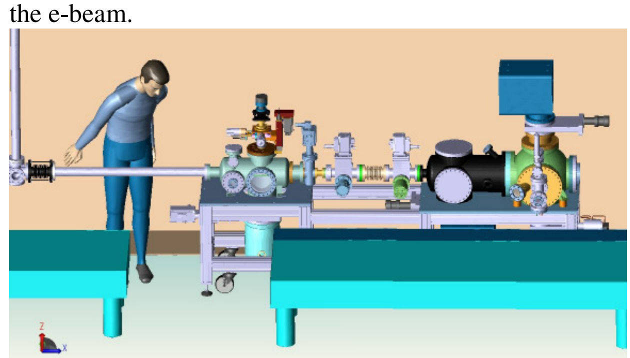
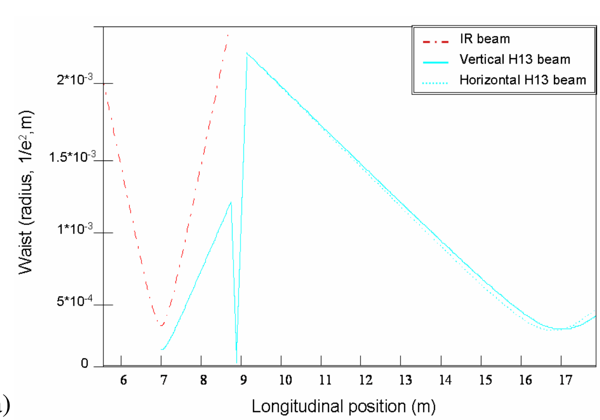
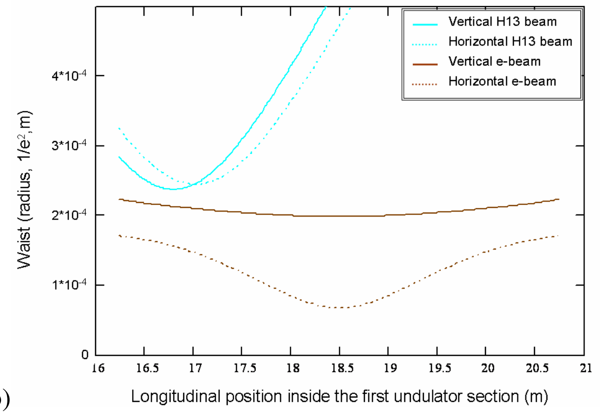


Figure 10: Location for the HHG experiment on the SCSS prototype accelerator.

The laser waist propagation in horizontal (x) and vertical (y) (W_{ox} and W_{oy}) has been calculated [10] to evaluate the geometrical aberrations caused by the two spherical mirrors at the theoretical focusing point in the first part of the first undulator section. Correlated to the e-beam transverse sections, the filling factor (measuring the overlapping of the two beams) can be calculated and is then implemented in our simulation codes (see next section). Figures 11 a and b present the focusing of the IR beam and the 13th harmonic vertical and horizontal propagations, which are quite similar until the focusing part, where the geometrical aberrations lead to a difference of 35 cm in the focusing position between the vertical and horizontal propagations. (b) is a zoom of (a) with the implementation of the e-beam dimensions [8].



a)

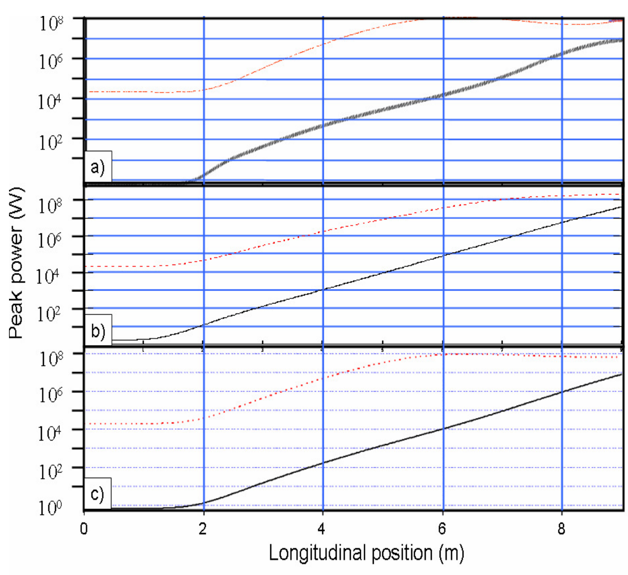


b)

Figure 11: a) propagation of focused IR laser and the 13th harmonic, b) focusing inside the first undulator section and overlapping with the e-beam.

SIMULATIONS

New calculations (with ref. [8] characteristics) with SRW [11], analytical expressions from G. Dattoli [12] and Genesis [13] (respectively Figures 12 a, b and c), have been performed for comparing the SASE and the seeding configuration, with 20 kW of seed (corresponding to a slightly pessimistic value of what can be expected). The different simulations converge very well to a similar evolution. First, the saturation peak power levels are very similar (10^8 W). Second, the saturation length for the SASE case is about 10.5 m (10^7 W at 9 m) for all the simulations but varies from 6m to 7.5 m in the seeding case.



Figures 12 a, b and c: Comparison between SASE (black plain line) and seeding configuration (red dash line) with a) SRW b) analytical expressions and c) Genesis.

CONCLUSIONS

Using state-of-the-art High Order Harmonics in gas for seeding a FEL appears very interesting, because the seed radiation is fully coherent and tunable in the VUV-XUV range. Moreover, it reduces the saturation lengths in a more compact source. From the HHG part, the experiment has been perfectly designed and optimized for producing harmonics and especially the 13th. New tests will be performed in situ (near SCSS area in September) with a more performing vacuum system, a more powerful laser system and with different optical characteristics, allowing to still increase the harmonic production and to completely test remote control system before installing it inside the accelerator tunnel for the seeding experiment (October).

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