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Report

Harmonic Generation of Sub ps and Fourier Limited Pulses

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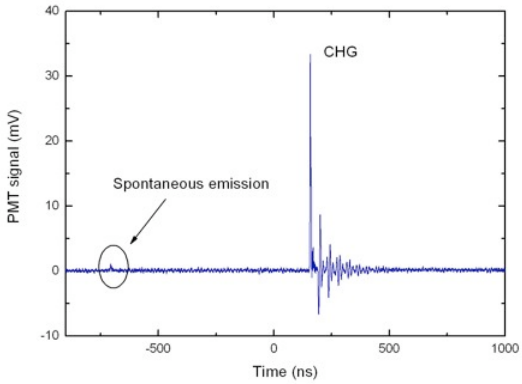
Abstract

We have successfully generated sub-ps harmonic pulses seeding of the Elettra electron bunch with an external laser. We have optimized the source and produced 2[nd] (390 and 260 nm) and 3[rd] (195 and 130 nm) harmonic radiation with respect to the fundamental (780 nm) and duplicated (390 nm) of the seed laser. We have improved the shot to shot stability that is now of few percent in amplitude. We made a spectral characterization of the harmonics that show to be very close to the Fourier limit (<1.4). We made some polarization studies since the Elettra optical klystron is built with variable polarization undulators. Finally we have developed two *proof of principle* experiments to demonstrate the usability of this sub-ps light source for user experiments.

First Lasing

We succeeded in generating sub-ps harmonic pulses seeding the Elettra electron bunch with an external laser. This achievement has been accomplished for the first time on April 29, this year, after commissioning and installation of the seed laser (see milestone M4.6). The 2.5mJ, 100 fs, infrared (780nm) seed pulses has been focused on the single bunch stored in the ring while crossing the modulator area of the Elettra optical klystron. The modulator was tuned at the seed wavelength and polarization (i.e. linear horizontal). The radiator was tuned at the third harmonic at 260nm for linear polarization. After transversal alignment and synchronization we observed an increase of a factor 30 on the emission of the seeded bunch certainly due to coherent emission consequent to the microbunching induced by the seed field. The effect is shown in figure 1 where the harmonic signal can be compared directly to the spontaneous emission. Due to the minimum limit on the modulator gap it was necessary to operate the storage ring at 0.9 GeV that is a quite low value for the proper operation of beam stabilization feedbacks.



In figure 1: first evidence for CHG obtained seeding the Elettra electron bunch with an external laser. It is a single shot acquisition of the emission from the optical klystron (OK) as a function of time. At about -700 ns it is visible the signal associated to the spontaneous emission (unseeded) while at + 150ns we have the coherent emission obtained via seeding.

Starting from this milestone we worked until the Elettra shut-down at the end of the first week of October, to improve the performance of the source. We summarize in the following the main progress obtained during this period and we underline some issue that we consider relevant for the seeding mechanism.

Seeding with the second harmonic at 390 nm:
A non-linear crystal for duplication has been installed in order to produce second harmonic from the seed pulses. The pulse duration hasn't been measured but it should be very close to the one of the fundamental. The energy per pulse is about 0.5 mJ. Seeding at this wavelength permits to shift the CHG emission at higher energies. We observed the harmonic emission at 130 nm (3^{rd} harmonic – see figure 2) that corresponds to photon energy of 9.5 eV that can already be used for photoelectron spectroscopy intentions. Moreover, reducing the seed wavelength permitted to open the gap of the modulator and to increase the electron beam energy up to 1.5 GeV. As a result we obtained a longer lifetime and a more stable beam.

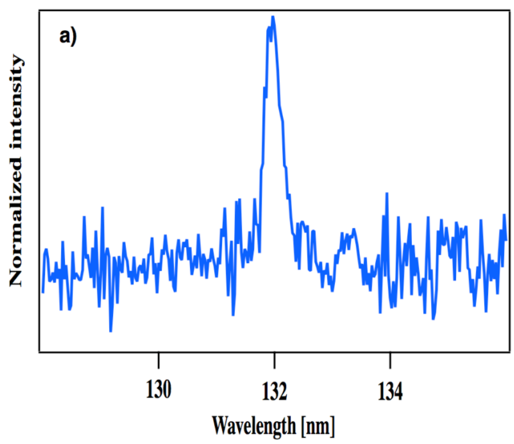


Fig 2: spectrum of the 3^{rd} harmonic obtained seeding at 390 nm.

Stability:
We observed a considerable improvement on the CHG emission stability (shot to shot amplitude jitter) after increasing the beam energy and after improving the synchronization setup. The first results were obtained with the Elettra User Timing System that presents an overall jitter of about 20ps, i.e. a little shorter with respect to the bunch length (~30 ps). The amplitude jitter was about 100 %. The new setup is based on low noise digital dividers and IQ vector modulator. With those equipments the final jitter is about 2.5 ps and is limited by the radio frequency noise and laser oscillator instability. The shot to shot stability is now of few percent (see figure 3).

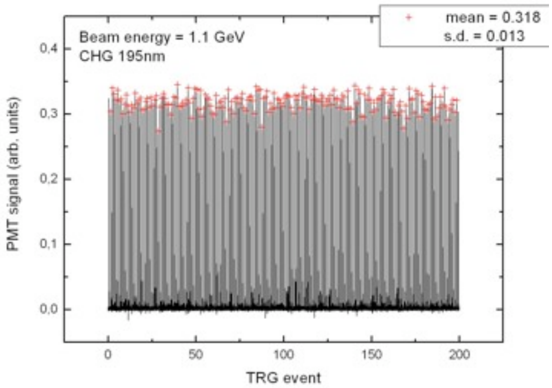


Fig. 3: sequence of 200 consecutive acquisitions of the CHG amplitude (seed 390 nm and generation of the 2nd harmonic)

Spectral characterization:
We have measured the spectral profile of the harmonic emission. The natural width results to be very close to the Fourier limit. In particular we could measure with good statistics the spectra at 195 nm (2nd of the seed at 390 nm) to be equal to 1.4 the Fourier limit.

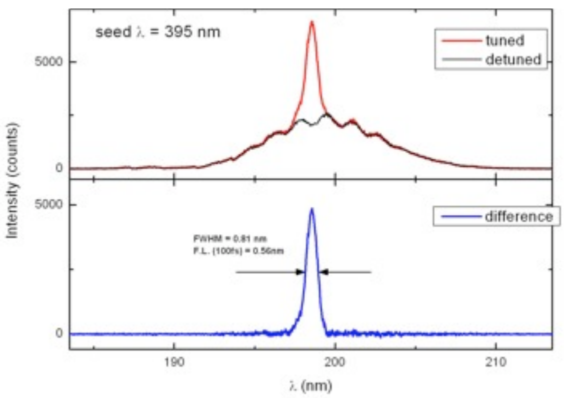


Fig. 4: spectral characterization of CHG emission at the 2nd harmonic of 390nm seed. The harmonic emission spectrum (blue line) is obtained subtracting the unseeded contribution (black) from the global acquisition (in red). Note that only one bunch of 1160 is seeded due to the limited repetition rate of the laser system. The natural with of the coherent emission results to be 1,45 times the Fourier limit.

Polarization study:
Since the optical klystron of Elettra is built up with variable polarization undulators we have measured the polarization dependency of the harmonic emission and its angular distribution (i.e. off-axis emission). Regarding the on-axis emission only, we observe a gain of a factor ≅ (see figure 5).

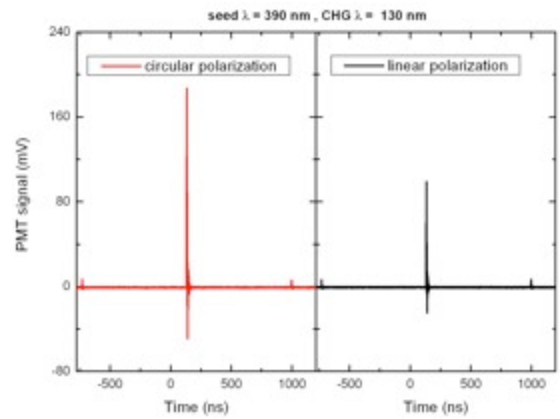


Fig. 5: single shot acquisitions of the CHG amplitude at the 3rd harmonic of 390nm for circular (red) and linear (black) polarization.

Proof of principle experiments:
In collaboration with a group of the University of Milano (CIMAINA - P.Piseri) and with the Elettra Nanospectroscopy beamline (A.Locatelli) we have developed two proof of principle experiments to demonstrate the usability of the source for users experiments. In the first case we have measured via ion spectrometry the mass spectra of the Pyrimidine molecule in a gas phase setup. In the second case, the harmonic emission has been focused into the PEEM microscope of the adjacent beamline that shares with us the optical klystron. We could record the image from a patterned sample and measure its valence band photoemission spectra. The results have been compared with those obtained with synchrotron radiation of the same wavelength and have been submitted for publication.

Acknowledgement

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