OPERATION OF THE EUROPEAN FEL AT ELETTRA BELOW 190 nm: A TUNABLE LASER SOURCE FOR VUV SPECTROSCOPY*

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Abstract

Thanks to an intensive technological effort in the framework of the EUFELE collaboration, the European FEL at ELETTRA was able to break the previous record for the shortest wavelength of an FEL oscillator. Novel solutions were adopted for multilayer mirrors to allow FEL operation in the wavelength region between 160 and 190 nm, which is one of the main targets of the project. The characteristics of the FEL pulses measured at 176 nm (spectral profiles, high intensity, meV bandpass, MHz repetition rate) make it a competitive light source for spectroscopy, in particular for fluorescence and Raman studies in the VUV spectral range. Proof of principle experiments have been performed on different types of silica glasses, yielding information on the mechanisms of light absorption in this material

INTRODUCTION

FEL oscillators present features that make them extremely useful as light sources for scientific research. The main goal of the EUFELE collaboration is to extend the operating range of the European Storage Ring FEL at ELETTRA to the VUV, in particular covering with tunability the wavelength region between 157 and 193 nm - where no intense conventional laser sources are available - and to demonstrate its potential as a research facility.

Thanks to a coordinated effort performed within the EEC project, recent advances in multilayer mirror research and development made it possible to break the 190 nm technological barrier for the FEL operation.

At the end of the EUFELE project, the European FEL at ELETTRA can be operated in this previously inaccessible wavelength region. We present here experimental results concerning the performance of the FEL in the VUV, and the first fluorescence measurements performed on silica specimens to explore the important issue of light absorption in this material.

FEL OPERATION BELOW 190 nm

The lasing of the European Storage Ring FEL in the VUV is the result of a concerted effort concerning on one side the optimization of the ELETTRA operation in 4 bunch mode at various energies between 0.75 and 1.5 GeV, and on the other side the design and growth of robust multilayer mirrors in this wavelength region. We have already reported on the developments concerning the storage ring operation in previous reports [1,2], which were preliminary to lasing attempts in the VUV: of particular importance has been the possibility of operating the machine at low energy, which made it possible to maintain a high gain while reducing the radiation damage on the optics [3] (which is mainly due to hard X-rays from the insertion device itself but also from the bending magnet, both of which present a strong dependence on electron beam energy). The spectra shown in Fig. 1 were taken at 0.75 GeV, but successful lasing was obtained also at 0.9 GeV.

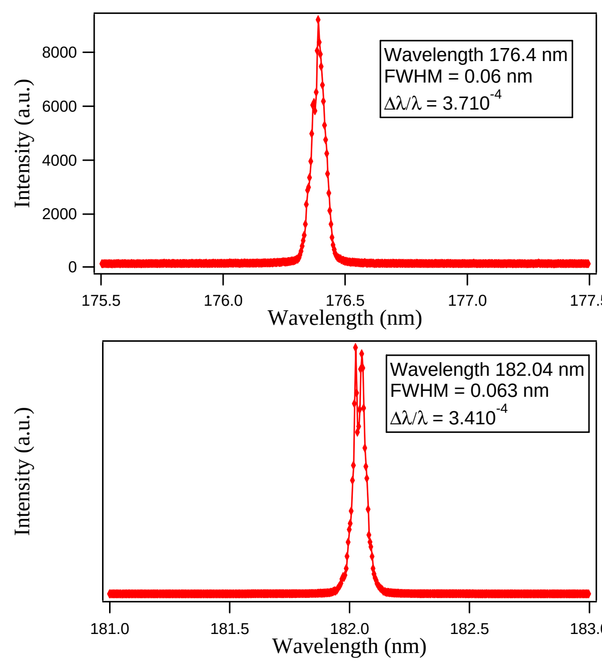

Figure 1. FEL spectra at 176 and 182 nm.

The R&D work on multilayer mirrors was performed in parallel during the last years [4], based on extensive studies of material improvement, growth condition optimization and novel multilayer formulae. Model single layers and multilayers were the object of various irradiation tests performed at ELETTRA, exposing the test specimens to synchrotron radiation emitted by the FEL port with the storage ring in multibunch mode.

As a result of this irradiation campaign a prototype pair of mirrors was produced using a fluoride multilayer with

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increased robustness. With this pair of mirrors, lasing was obtained in the 176 – 183 nm range delivering few mW of power. Figure 2 shows the reflectivity of these mirrors measured before and after FEL operation. No significant degradation of the optical properties has been observed after several hours of continuous operation.

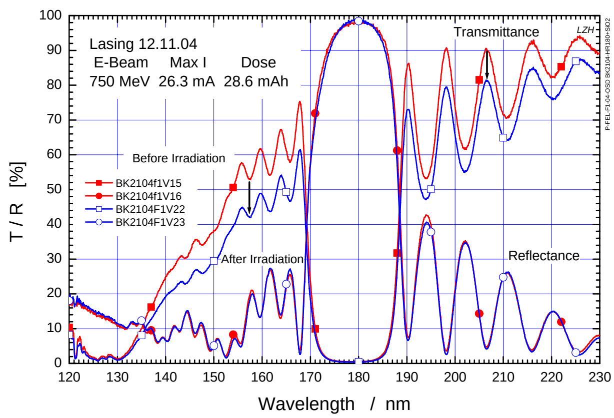

Figure 2. Spectral behaviour (reflectivity and transmittance) of the front optical cavity mirror before and after the first lasing experiment (received dose corresponding to an integrated current of 29 mAh).

The same recipe used for this pair of prototype mirrors can be used to lase in the wavelength region between 160 and 190 nm, that cannot be accessed with tunability and high intensity by means of conventional lasers. At the time of writing, a prototype mirror centered at 165 nm is being manufactured and will be tested soon.

A SOURCE FOR VUV SPECTROSCOPY

Thanks to this progress, the European storage ring FEL at ELETTRA becomes a very interesting source for VUV resonant spectroscopies, in particular for flux-hungry techniques like fluorescence and especially Raman scattering. We summarize its main features:

- high repetition rate (4.63 MHz)
- high average power (it may exceed 100 mW)
- almost Fourier transformed pulses
- pulse duration < 10 ps
- spectral width $\delta\lambda/\lambda < 4\text{x}10^{-4}$
- easy tunability.

This last feature is of course critical to be able to perform resonant spectroscopy in the VUV, which is of great interest because it makes it possible to excite in a selective and resonant fashion many of the outer orbitals in matter.

A spectral width of ~ $4\text{x}10^{-4}$ corresponds to 2 - 3 meV FWHM bandpass for photons of 6 - 8 eV: it is worth noticing that such bandpass is very well suited to study the electronic properties of condensed matter systems, even without further monochromatization. It should be also emphasized that a cw macrotemporal structure of the FEL, although preferable, is not essential for photon in – photon out spectroscopies such as fluorescence and Raman scattering; consequently, the FEL can be used for such experiments even if a perfect macrotemporal stability cannot be achieved.

As a test experiment, we studied the fluorescence yield of different silica specimens using the FEL as excitation source: in particular we studied the response to FEL excitation at 180 nm of suprasil 2, for which the absorption at this wavelength is a very important issue in materials and optical sciences, also in view of the technological use of silica as a transparent material in the UV/VUV. In Fig. 3 we present the fluorescence signal from suprasil 2, that shows clearly how the main decay channels for the absorption at 180 nm are the bands at 650 and 300 nm. While the former is very well known and is associated to nonbridging oxygen hole centers [5], the nature of the latter is still unclear and it requires further studies to associate it to one ore more point defects [6].

We emphasize the necessity of an intense light source for this study: since at 180 nm the absorption of suprasil 2 is still weak (even though the technological interest is to make it even weaker for optimal transmittance in the VUV), the fluorescence signal is difficult to be detected. For comparison, we studied the response to the same excitation of infrared grade quartz, which is not transparent in the VUV: the fluorescence bands are at completely different wavelengths (280 and 400 nm), which are barely detectable for suprasil 2, and the overall signal is indeed several orders of magnitude more intense. These results show that the European storage ring FEL at ELETTRA can be used for photon in – photon out spectroscopy in the VUV, exciting with tunability specific absorption bands of matter.

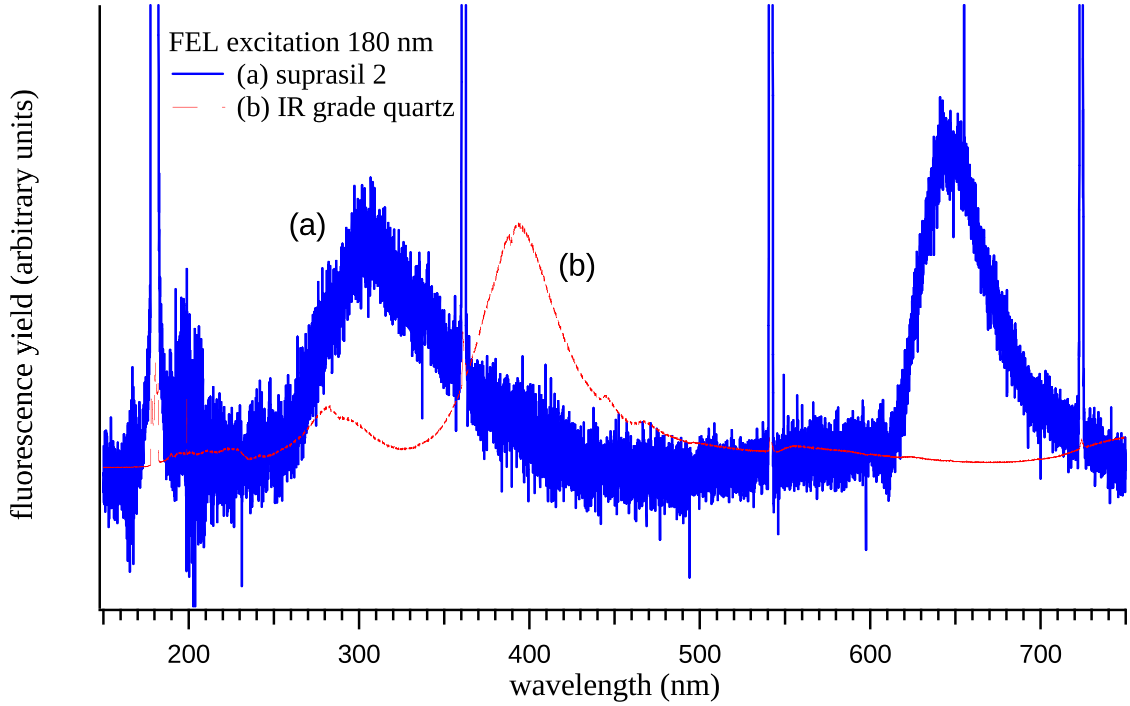

Figure 3. Fluorescence signal from suprasil 2 (a) and infrared grade quartz (b) specimens using the FEL at 180 nm as excitation source.

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