BEAM HANDLING DEVICES

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LUXOR is active in the development of spectroscopic instrumentation for photon diagnostics and photon handling in the EUV and soft X-ray region.
It is here presented the R&D activity that can be performed by LUXOR in the field of beam handling devices for FEL radiation in the EUV down to few nanometers, using optics in reflections (i.e. mirrors and gratings).
In particular, the main items here presented are:
1) design and realization of spectrometers for the online single-shot analysis of EUV FEL radiation
2) design and realization of time-compensated broad-band monochromators for the spectral filtering of the FEL emission
3) design and realization of beam-splitter for EUV ultrashort pulses
4) design and realization of optical systems for focusing of the FEL beam

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NATIONAL AND INTERNATIONAL COLLABORATIONS ON RELATED ARGUMENTS

- ULTRAS, Politecnico Milano (Sandro De Silvestri): generation, analysis and utilization of high-order harmonic radiation produced by the interaction between an ultrashort laser pulse and a gas jet
- ENEA, Frascati (Luca Giannessi): SPARC project for the seeding and spectral analysis of the FEL radiation
- HASYLAB-DESY, Hamburg (Joseph Feldhaus): online single-shot spectral analysis of the FEL TTF-2
- INFN, Laboratori Nazionali Legnaro (Valentino Rigato): development of multilayer coated optics
- beamline BEAR, Elettra (Trieste): characterization of optical components and optical materials

OBJECTIVES

The objective of the R&D activity is the acquisition of expertise in the field of beam handling devices for EUV and soft X-ray FEL pulses.

1. **Spectral analysis of EUV FEL radiation**

   The acquisition of the single-shot FEL spectrum is essential both during the development and characterization of the source, and for the experiments.
   A single-shot online EUV and soft X-ray spectrometer is an essential instrument for the FEL facility.

2. **Design and realization of time-compensated broad-band monochromators**

   A filter tunable in the spectral interval of operation of a FEL facility can be useful to suppress the background radiation and the high-order harmonics. The filter can be realized by a broad-band grating monochromator. The design has to preserve the time duration of the FEL pulse and to give an output beam with zero dispersion.
   A tunable EUV and soft X-ray filter is of general interest for many users, then it is part of the FEL facility.

3. **Development of optical systems for focusing of the FEL beam**

   The focusing of the FEL beam on the sample to be tested is required by almost any experiment.
   The study and development of focusing systems for the FEL pulses is an essential competence to be acquired.

4. **Design and realization of beam-splitter for EUV ultrashort pulses**

   The realization of beam splitters for the FEL beam is required both for the temporal characterization of the FEL pulse (measurement of the pulse time duration) *and for a large class of experiments* (e.g. pump and probe).

DESCRIPTION OF THE BEAM HANDLING DEVICES

Here and in the following, only grazing-incidence reflective optical elements will be adopted with a suitable coating for the EUV. In such a way, the risk of damaging the optical surfaces is minimized, because the cross section on the optical surface is higher with respect to normal incidence, thus presents a smaller photon density. Grazing-incidence optics can be used down to short wavelengths (2 nm). Obviously, the choice of the best coating and of the cooling method of the optics has to be studied in details.

1. SPECTRAL ANALYSIS OF EUV FEL RADIATION

LUXOR has a long experience in design and realization of spectrometers and monochromators for the UV, EUV and soft X-Ray spectral region:

- design and characterization of the monochromator for the beamline ALOISA at ELETTRA [1]
- design and characterization of the monochromator for the beamline BEAR at ELETTRA [2]
- design and realization of spectroscopic instrumentation for analysis of high-order harmonic EUV radiation generated by the interaction between an ultrashort laser pulse and a gas jet [3, 4]
- design and realization of spectroscopic instrumentation for lab applications [5]
- design of innovative configurations for spectroscopy in the EUV [6, 7]

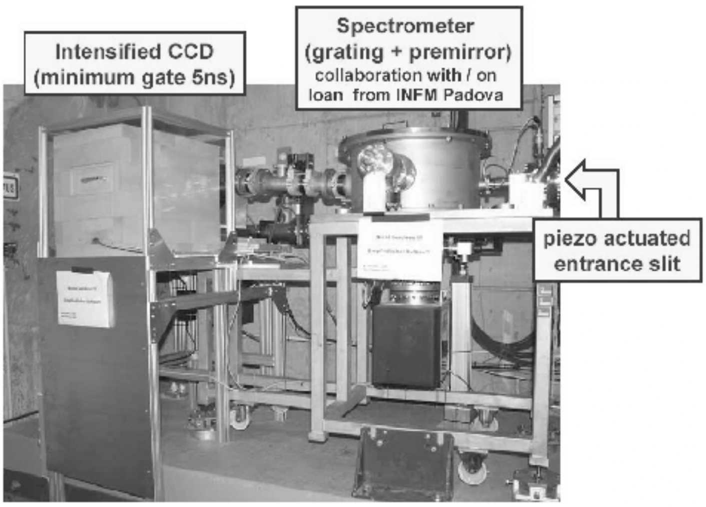

Fig. 1. The LUXOR spectrometer installed at DESY

In particular, LUXOR has an active collaboration with the HASYLAB team at DESY in the framework of the TESLA project. A spectrometer designed and realized at LUXOR is at present installed at the end of the FEL LINAC tunnel at DESY for the monitoring of the spectrum of the FEL emission in the 25-45 nm region (see Fig. 1). The instrument will be used during the whole commissioning phase of TTF2 [8, 9].

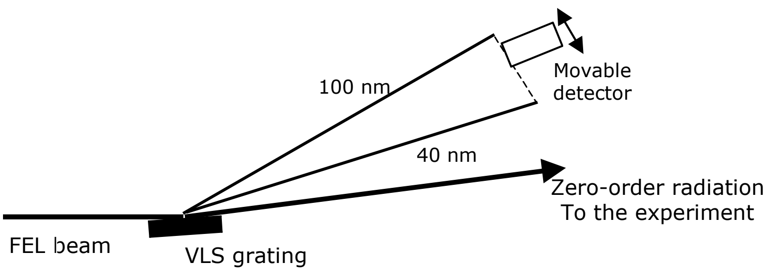

Fig. 2. Schematic of the online spectrometer. Different gratings can be selected to cover different spectral regions.

The spectrum from an EUV source can be measured online by a grazing-incidence flat-field spectrometer equipped with a variable-line-spaced (VLS) plane grating. The polynomial law of variation of the groove density along the grating surface is selected in order to give the focusing of the spectrally dispersed radiation on an almost flat surface, where a plane detector can acquire the spectrum. The radiation reflected at zero-order is propagating unperturbed to the following sections (Fig. 2).

The acquisition of the FEL spectrum is essential both during the development and characterization of the source, and for the definition of the experimental conditions for the users. The users has to know the FEL spectrum for each shot. Since the FEL is operated at low repetition rate (10-50 Hz), the spectrum has to be obtained in single-shot operation. ***A single-shot online spectrometer is then an essential diagnostic instrument for the FEL facility.***

With regard to the spectral diagnostic of the SPARC FEL, an active collaboration between LUXOR and ENEA (Luca Giannessi and Andrea Doria) is proceeding on the design of a vacuum normal incidence spectrometer for the 40-550 nm spectral region (EUV, VUV and visible) to be used with the SPARC FEL experiment. LUXOR has the complete capability to design, realize and calibrate such an instrument.

2. TIME-COMPENSATED INSTRUMENTS FOR BEAM HANDLING DEVICES

The use of grazing-incidence gratings as beam handling devices for EUV ultrashort pulses gives the advantages of working at grazing incidence, with high reflectivity and low power density on the optical surface, but also problems related to the preservation of the pulse time duration. Only the zero-order beam maintains the extremely short pulse duration, because the grating acts like a mirror. Instead the time duration of the diffracted orders is altered: the total difference in the optical paths of the rays diffracted by N grooves illuminated by incident radiation at wavelength λ is $\Delta_{OP} = Nm\lambda$, where m is the diffracted order. This effect is dramatic in the fs time scale. For example, a 1200 gr/mm grating illuminated on 30 mm gives a maximum delay in the first diffracted order of 1.2 ps at 10 nm. In case of an ultra-short pulse, this reduces both the time resolution capability and the peak intensity. In addition to this, the grating introduces also a spectral broadening, since the different spectral components of the pulse are diffracted in different directions.
Nevertheless, it is possible to design time-compensated configurations with gratings, by using two gratings in subtractive and compensated dispersion. In such a configuration, the second grating compensates both the time and spectral broadening of the first one [10]. LUXOR has the capability of designing time-compensated instruments using gratings. Two examples are here briefly discussed.

1. Time-compensated broad-band monochromators

A tunable filter in the EUV can be useful to suppress the background radiation and the high-order harmonics. The selection of the portion of the spectrum to be transmitted can be done by a broad-band time-compensated monochromator ($\lambda/\Delta\lambda \leq 1000$). The configuration is schematically shown in Fig. 3. It consists of two cylindrical grazing-incidence gratings and an intermediate slit. The first grating provides a spectrally dispersed image of the source at the slit plane. The slit carries out the spectral selection, transmitting only a portion of the spectrum. The second grating is used in order to compensate both for the time-delay introduced by the first grating and for the spectral dispersion. The output pulse preserves the duration of the input FEL pulse (provided that the whole FEL pulse is spectrally transmitted) with zero dispersion. The optical design can be modified by adding two plane mirrors in order to give an output beam parallel and in the same direction of the input beam.

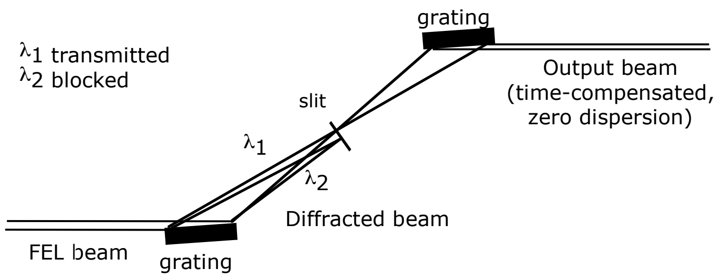

Fig. 3. Broad-band monochromator.

A tunable EUV and soft X-ray filter could be interesting for many users and experiments, then it is part of the FEL facility.

2. Time-compensated beam-splitters

A simple beam-splitter consists in a diffraction grating: the incident beam is diffracted in several output beams, corresponding to the zero order and the diffracted orders. As previously said, the zero

order beam maintains the extremely short pulse duration, while the time duration of the diffracted orders is altered. In addition to this, the grating introduces also a spectral broadening, since the different spectral components of the pulse are diffracted in different directions.
A time-compensated beam splitter uses two grating in compensated configuration: both the time and spectral broadening introduced by the first grating are compensate by the second one (Fig. 4). The gratings are mounted in the so-called Z-configuration, with the incidence angle on the second grating equal to the diffraction angle from the first one, so the output beam is parallel to the input. In such a way, the rays with a longer optical path from the first grating have a shorter optical path from the second grating, and viceversa. Furthermore, also the spectral dispersion of the non-monochromatic radiation is almost compensated by the Z-configuration, since the second grating has a subtractive spectral dispersion with respect to the first one.
The groove profile of each of the two gratings can be realized in order to have a similar intensity on the two output beams.

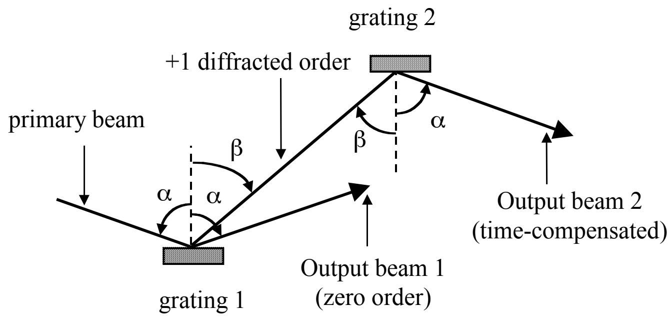

Fig. 4. Layout of a time-compensated beamsplitter

A schematic of a beam splitter for variable wavelengths and with a variable delay between the two beams is shown in Fig. 5. All the optics are operated at grazing incidence, with incidence angle in the range 80°-86°. The two gratings are rotated with the input wavelength in order to work at constant subtended angle and maintain the output beam 2 in a fixed direction, parallel to the input beam. The mirror M1 has to reflect the zero order in a fixed direction: it is rotated and translated with the wavelength. Mirrors M2 and M3 are rotated and translated to select the delay between beams 1 and 2.

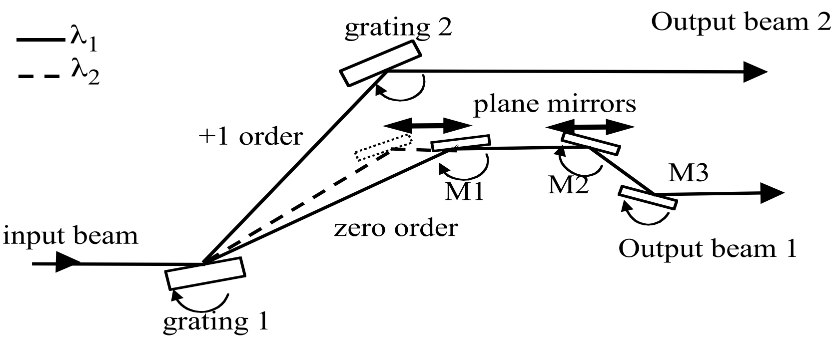

Fig. 4. Schematic of the beam-splitter to be realized.

The realization of beam splitters for the FEL beam could be required both for the temporal characterization of the FEL pulse (measurement of the pulse time duration) and for a large class of experiments (e.g. pump and probe).

FOCUSING OF THE FEL BEAM

The FEL beam has to be focused on the sample in the experimental chamber. Since different power densities and/or different illuminated areas are required, the obvious choice is to select among different spot sizes. The focusing in the 2-100 nm region is efficiently done by grazing-incidence mirrors, with the advantages previously listed. Several solutions can be proposed. We can cite for example the use of a couple of deformable cylindrical mirrors in the Kirkpatrick-Baez configuration, whose radius of curvature can be varied between infinite (plane mirrors, no focusing) and a given value. A different choice is to have 2-3 ellipsoidal mirrors with different radius of curvature that can be inserted in the optical path.

The proposed solutions have to take into account that the minimum focal spot size is limited by diffraction to ≈2.44·λ·*f*/#, where λ is the wavelength and *f*/# the numerical aperture of the beam. For example, a 20 μm spot at 10 nm requires a divergence of 1.2 mrad. Taking into account the very low intrinsic divergence of the FEL beam and the actual distance between the FEL source and the mirror (tat could be of the order of tens of meters), the miror has to be operated with high demagnification, then its exit arm results short. The mechanical mounting of the optics has then to be carefully studied to avoid interference between the focusing optics and the diagnostic instruments around the sample.

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AVAILABLE RESOURCES AT LUXOR RELATED TO THE ITEMS HERE DESCRIBED

- Ray-tracing program specially developed for simulation of optical systems for ultrashort pulses both in visible and UV
- Lab facilities for characterization of optical components in the EUV and soft X-ray
  - normal-incidence monochromator for the 30-500 nm region
  - grazing-incidence monochromator for the 5-30 nm region
  - absolute calibrated detectors in the 5-500 nm region for the absolute calibration of optical components (e.g. detection efficiency of detectors, absolute efficiency of gratings and mirrors)
  - vacuum chambers for accommodation of optics and detectors to be tested