X-ray spectrometers and monochromators with femtosecond resolution based on two-dimensional VLS gratings and reflection zone plates

The Institute for Applied Photonics e.V. develops novel optics and instruments for the utilization of soft X-rays. The two-dimensional (2D) variable line space (VLS) gratings and reflection zone plates, fabricated by the company Nano Optics Berlin (NOB) GmbH, form the basis for a new generation of ultrafast spectrometers and monochromators. These developments rely on 10 years of research at the BESSY GmbH and afterwards at the Institute for Nanometer Optics and Technology of the Helmholtz-Zentrum Berlin GmbH.

For the first time ever, the practical implementation of a total reflection zone plate (TRZP) as a monochromator-spectrometer was successfully realized 2008 at the femtoslicing beamline.

The 20-fold higher transmission and a pulse elongation in the order of 30 fs, with an energy resolution which is comparable to that of a conventional plane grating monochromator, enabled numerous internal and external users to perform their highly ranked experiments at BESSY II.

The “FemtoSpeX“ beamline can currently cover an energy range from 300 eV to 1200 eV with parallel recording of the XANES spectra of elements, at a time resolution down to ~ 100 fs.

The principle to combine tree functions (reflection, energy dispersion and focusing) in one optical element was extended for the development of a new generation of spectrometers for the spectroscopy at highly diluted materials, fs monochromators for the generation of high harmonics (HHG) and laser plasma X-ray sources.

A new approach for the monochromatization and focusing of HHG sources in the vacuum ultraviolet and soft X-ray range – as generated by femtosecond lasers, which operate in the near infrared spectrum – was developed and realized with a single optical element, i.e. an RZP, for the first time ever.

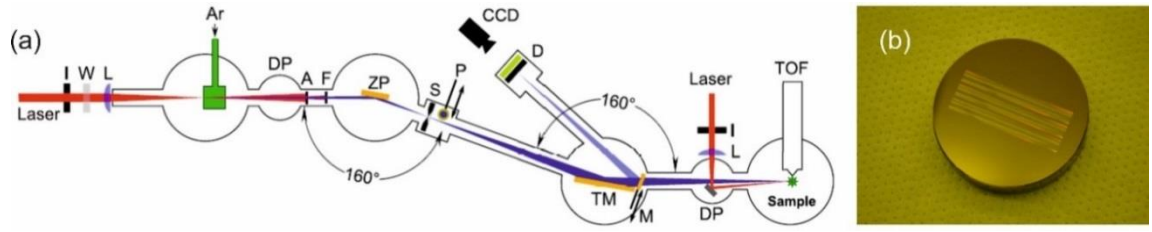

Figure 1: Schematic representation of the experimental setup (a). Notations: I – iris diaphragm, W – wave plate, L – lens, DP – differential pumping station, A – aperture, F – aluminum foil, ZP – zone plate, S – slit, P – movable photo diode, TM – toroidal mirror, M – movable plane mirror, D – position sensitive detector, TOF – time-of-flight electron spectrometer/ photo of a reflection zone plate array for 17^{th} , 19^{th} and 21^{th} harmonic of 800 nm (b).

The off-axis RZPs, used as focusing monochromators, enable to optimize the trade-off between energy resolution and temporal dispersion of the fs pulses efficiently.

In the design from Fig. 1(a), a single harmonic with an effective pulse length of 45 fs is selected. A high transmission efficiency (approximately 28% at 32.55 eV) results from the mentioned properties, with a simplified handling of the extreme ultraviolet beam.

The balance between energy and time resolution can be obtained within a single RZP by making use of sections of different line density. This feature ensures the flexible application of an RZP-based monochromator.

In cooperation with the NOB GmbH, the IAP e.V. now works on the extension of the monochromator energy range up to 1200 eV for the new generation of high energy HHG sources. The new spectrometers and monochromators are already in stock.

A further improvement of the time resolution is possible with the use of monochromators which compensate the time delay ("time delay compensating monochromator", TDCM).

Currently, the IAP e.V. develops a new type of TDCM with a pulse elongation below 5 fs, with continuous tuning in the energy range from 100 eV to 1000 eV. The TDCM consists of two identical 2D VLS gratings, which are arranged in opposed diffraction orders, as shown in Fig. 2.

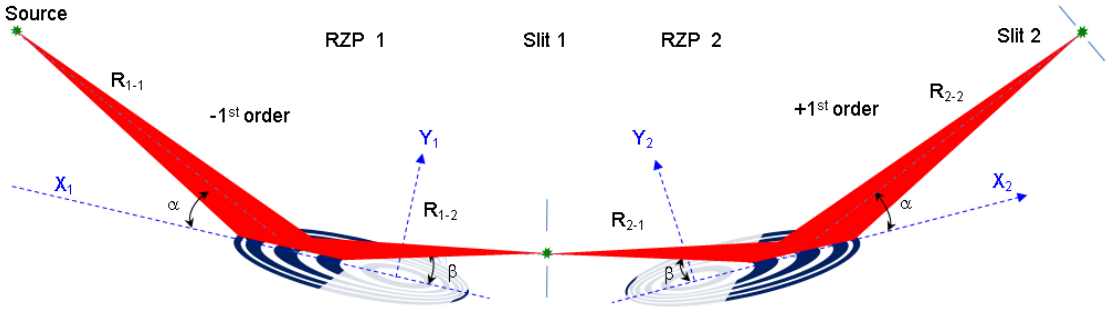

Figure 2: Principle of a time delay compensating monochromator, based on two RZPs.

Compared to existing TDC monochromators with six components, the proposed design yields an efficiency which is enhanced by one order of magnitude in the energy range from above.

In the class of laboratory instruments, the multi-channel RZP fluorescence spectrometer offers a unique performance for scanning electron microscopes in the energy range from 40 eV to 1000 eV.

Besides, the IAP e.V. offers support with the design and construction of highly efficient X-ray optical spectrometers including the two-element "Hettrick-Underwood" spectrometers for the parallel recording of spectra, but also custom-developed spectrometers and monochromators which are based on two-dimensional VLS gratings and RZPs.