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REALIZATION OF A COST-EFFECTIVE DEFORMABLE GRATING FOR THE EXTREME-ULTRAVIOLET

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Abstract. The application of a deformable grating to the realization of a time delay compensated monochromator is presented. The grating is realized as a replica on a thin glass substrate and the deformation is realized with a mechanical bender. The monochromator is conceived for the spectral selection of a single harmonic in the spectral range 20-80 nm in beamlines exploiting the high harmonic generation process. A possible optical design requiring only two deformable gratings, a mirror and an intermediate slit is presented.

1. Introduction

High-order Harmonic Generation (HHG) in gases is a well consolidated process that permits to realize beamlines in a scale range varying from table-top apparatus [1, 2] up to big scale facilities [3, 4].
Among the great variety of size and complexity, laboratories based on small table-top size beamlines are attractive for their flexibility, allowing to realize a large class of experiments that do not necessitate, or even are not compatible with, the use of large-scale facilities (FELs and synchrotrons).
Many experiments require, or benefit of, the monochromatization of the XUV radiation produced in the HHG process, intending with this the selection of one single harmonic. This task can be realized using either multilayer mirrors or grating monochromators. When high spectral purity and tuning flexibility is required, grating monochromators are preferred. After the spectral selection performed with a single grating, the temporal duration of the XUV pulses is increased because of the pulse-front tilt given by diffraction. For applications requiring very high temporal resolution, this effect cannot be tolerated and time-delay compensated monochromators have to be used. Those devices exploit the use of two gratings in which the second one compensates for the temporal broadening produced by the first one: in this way the optical path lengths of the different diffracted rays are equalized at the image plane. Monochromators, compensated or not, can work in classical [5] or conical [6] diffraction. Both the configurations present pros and cons [7] and the choice of the diffraction geometry depends on the specific experimental case.
In the depicted scenario there are two, among others, driving interests:

- the one of the scientific community on cost-effective laboratories;
- the one for a time-delay compensated spectral monochromatization of the XUV radiation.

The combination of these two requests lead us to the investigation here presented: a cost-effective time-delay compensated monochromator working in the extreme ultraviolet.

2. The proposed instrument

The way we have explored in order to contain the instrumental cost foresees the reduction of required optical elements, in this case only the two gratings arranged in the compensated configuration and a mirror. Always with the aim of containing costs, the gratings are planar (at rest position) and realized as replicas on a thin glass substrate. Excluding the possibility of working with a movable intermediate slit and target area, the gratings have to work at a constant deviation angle. The resulting diffraction geometry is then the classical diffraction mount where the optical power necessary to maintain at focus the XUV radiation at the intermediate plane and at the target area is realized bending the gratings into a cylindrical shape. The radius of curvature of the two gratings depends on the selected harmonic. Employing only the two cylindrical gratings, the radiation is energetically selected and temporally compensated but the focal spot at the target area is not stigmatic; to obtain this, a third optical element, that is, a cylindrical mirror, is added. The resulting optical layout is presented in figure 1. Compensated monochromators using classical diffraction mounts, realized with planar gratings and working in parallel light, use two gratings and four mirrors; the design here proposed two gratings and a mirror. The reduction in the number of optical elements simplify the alignment and has a direct effect on the size of the vacuum chambers and consequently on the requirements for the vacuum system.

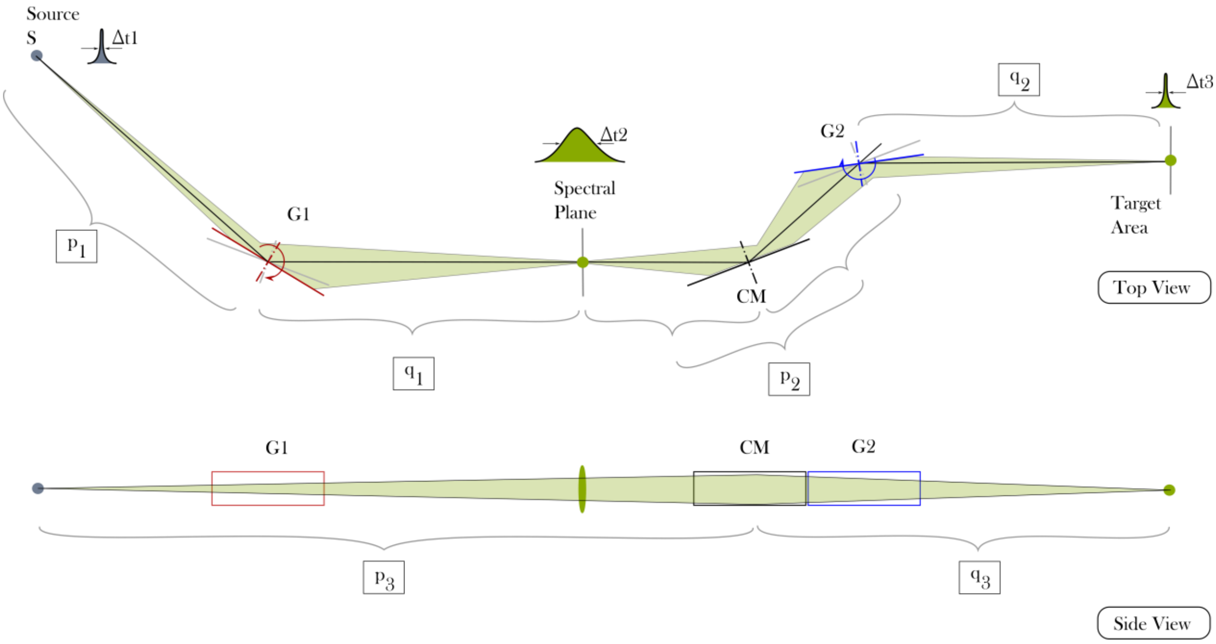

Figure 1. Optical layout of the proposed monochromator utilizing two deformable (cylindrical) gratings and a cylindrical mirror.

The focalization of the radiation, emerging from the generation point *S*, is separated between the two (orthogonal) planes: the dispersion plane (*Top View* in figure 1) and the vertical plane (*Side View* in figure 1). In the dispersion plane the spectral content of the impulse generated in *S* is dispersed and focalized at the *Spectral Plane* by *G1*, then the radiation is refocused at the *Target Area* by *G2* that recompress the impulse to the original time duration. In this plane, the dispersion plane, the effect of the cylindrical mirror *CM* is null. The effect of *CM* is in the vertical plane, where to be negligible is the effect of G1 and G2. *CM* is located before *G2*, in this way the difference between the two arms *p3* and *q3* is reduced and the so are the aberrations introduced by it. Each one of the two gratings, G1 and

G2, is equipped with a rotator stage, used to select the wavelength of the propagated radiation, and a pusher, used to bend the grating.

3. The deformable grating: actuator mechanism and surface characterization

Different bending mechanisms have been proposed [8, 9], each of them try to cope with the different problems that the bending action produces: the parasitic forces and the gravity sag to cite the more evident ones. To maintain the design approach economic, we decide to use a s-spring design based on a single stepper actuator. In figure 2 a) the mechanical assembly is shown. The equations for the radius of curvature and the grating rotations are reported in [10]. A possible geometry for the beamline schematized in figure 1 is summarized in table 1.

Table 1. Parameters of the beamline presented in figure 1.

Beamline and gratings parameters			Cylindrical mirror parameters		
Spectral region	nm	20 - 80	Entrance/exit arms p3 ; q3	mm	1600 ; 1000
Acceptance angle (full)	mrad	4	Sagittal radius	mm	64.4
Grating arms p1 = q1 = p2 ; q2	mm	p1 = 600 q2 = 800	Incidence angle	deg	87
Grating subtended angle	deg	165	Mirror size	mm	130 x 12
Grating groove density	1/mm	246			
Grating size	mm	50 x 10			

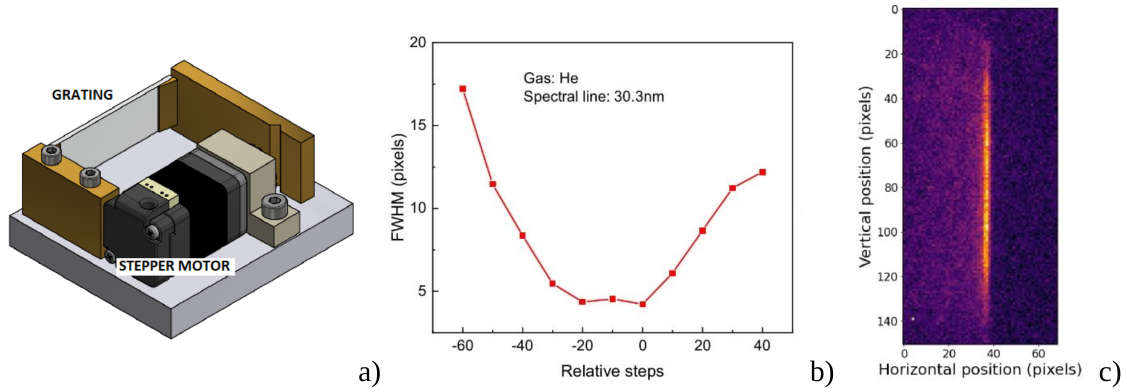

Figure 2. a) Mechanical realization of the bendable actuator. b) focusing curve acquired at 30.3 nm. c) focal spot (in the horizontal direction only) at 58.4 nm.

3.1. Grating characterization with AFM

To characterize the grating surface an Atomic Force Microscope has been used. Maps the surface on areas of 50 µm × 50 µm have been acquired and the Roughness Average (Ra) and the RMS Roughness (Rq) have been estimated obtaining: Ra = 3.71 nm and Rq = 4.76 nm.

3.2. Grating characterization with wave-front sensor

The deviation of the grating shape from the ideal one has been monitored as a function of the curvature radius using a Shack-Hartmann wave-front sensor. Only the central part of the grating, approximately 22 × 15 mm, has been observed due to the diameter of the probing beam. The grating has been deformed from the planar condition to R=8 m. The dominant terms to monitor are: Astigmatism-0, Defocus and Astigmatism-45. The combination of the first two produce the desired cylindrical shape, the last one, unwanted, is responsible for torsional stress induced by the bending process. We observe that the ratio of the Astigmatism-0 and the Defocus remains almost constant for the different tested curvatures, confirming that the surface bends into a cylindrical shape. The

Astigmatism-45 has a (small) value of approximately −0.25 μm. This value remains almost constant up to R ≈ 20 m. Further bending leads to a decreasing of this aberration that reaches zero at R = 8.7 m.

3.3. Laboratory tests

Laboratory tests have been carried out to validate the focalization power of the grating. The measurements have been taken using as a source a hollow-cathode lamp filled with He and Ne. The width of the entrance slit (that is, the size of the source) is 100 μm. The grating working parameters are different from the ones considered in Table 1, in particular in the experimental apparatus the entrance and exit arms where 700 mm long and the deviation angle was 163 deg. The image on the output slit plane has been acquired by a 2D CCD detector (Princeton Instrument, 1240 x 400 format, 20 um pixel size). Figure 2b) presents an example of focusing curve, i.e. the full width at half maximum of the focused radiation as a function of the motor steps (and so, as a function of the grating curvature). The curve is obtained with a radiation of 30.3 nm and the minimum value is 5 pixels corresponding to 100 μm. This value confirms the goodness of the focalization process. In figure 2c) is showed the focal spot at the output slit plane.

4. Conclusions

We have presented a low-cost deformable diffraction grating that can be used to realize a compensated monochromator in the XUV spectral region. The conceived beamline uses two bendable plane gratings and a cylindrical mirror. This solution allows also to simplify the mechanical design of the vacuum chambers. The focalization power has been tested with XUV radiation in the range 20 nm – 80 nm and confirms the utility of this device for the spectral selection of ultrafast pulses in HH beamlines. Despite the use of a cost-effective commercially-available replica gratings, good focalization properties have been obtained in laboratory tests.

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