ICSO 2016

International Conference on Space Optics

Biarritz, France

18–21 October 2016

Edited by Bruno Cugny, Nikos Karafolas and Zoran Sodnik

Low aberration monolithic diffraction gratings for high performance optical spectrometers

Peter Triebel

Tobias Moeller

Torsten Diehl

Alexandre Gatto

et al.

esa icso proceedings cnes

International Conference on Space Optics — ICSO 2016, edited by Bruno Cugny, Nikos Karafolas,
Zoran Sodnik, Proc. of SPIE Vol. 10562, 1056207 · © 2016 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2296116

Low aberration monolithic diffraction gratings for high performance optical spectrometers

Peter Triebel, Tobias Moeller, Torsten Diehl; Carl Zeiss Spectroscopy GmbH (Germany)
Alexandre Gatto, Alexander Pesch, Lars H. Erdmann, Matthias Burkhardt; Alexander Kalies; Carl Zeiss Jena GmbH (Germany)

ABSTRACT

Gratings are the core element of the spectrometer. For imaging spectrometers beside the polarization sensitivity and efficiency the imaging quality of the diffraction grating is essential. Lenses and mirrors can be produced with lowest wavefront aberrations. Low aberration imaging quality of the grating is required not to limit the overall imaging quality of the instrument. Different types of spectrometers will lead to different requirements on the wavefront aberrations for their specific diffraction gratings. The wavefront aberration of an optical grating is a combination of the substrate wavefront and the grating wavefront. During the manufacturing process of the grating substrate different processes can be applied in order to minimize the wavefront aberrations. The imaging performance of the grating is also optimized due to the recording setup of the holography.
This technology of holographically manufactured gratings is used for transmission and reflection gratings on different types of substrates like prisms, convex and concave spherical and aspherical surface shapes, free-form elements. All the manufactured gratings are monolithic and can be coated with high reflection and anti-reflection coatings. Prism substrates were used to manufacture monolithic GRISM elements for the UV to IR spectral range preferably working in transmission. Besides of transmission gratings, numerous spectrometer setups (e.g. Offner, Rowland circle, Czerny-Turner system layout) working on the optical design principles of reflection gratings. The present approach can be applied to manufacture high quality reflection gratings for the EUV to the IR.
In this paper we report our latest results on manufacturing lowest wavefront aberration gratings based on holographic processes in order to enable at least diffraction limited complex spectrometric setups over certain wavelength ranges. Beside the results of low aberration gratings the latest achievements on improving efficiency together with less polarization sensitivity of diffractive gratings will be shown for different grating profiles.

Keywords: passive optical components, diffractive optics, grating, custom design grating, aberration-corrected grating, free-form or toroidal grating, monolithic grism, holography, gray-scale lithography, ion etching, remote sensing application

1. GRATING MANUFACTURING PROCESS

The process applied for the manufacturing of the grating structure is a standard process which is used for many years. ZEISS has been manufacturing monolithic diffraction gratings for applications in the EUV, UV, VIS and NIR. This paper discusses monolithic gratings that are directly etched into a transparent material, in this case fused silica, and contain no organic residues or resists. In general holographic gratings can be produced into plane, curved (convex, concave or free-form shape) substrates [1-7] and prism substrates.

Concerning the final element is a spherical or aspherical grating, the manufacturing process starts with the prism substrate manufacturing. The surface which is supposed for the grating structure will be coated with a photoresist layer. ZEISS has established a homogeneous and reliable process for curved substrates, which enables the lithography on such substrates. The next process step is the holography. The holography will be done either by using a bi-directional opposing wave-approach [6] or using the symmetric approach (see. Fig. 1 left side) depending on the final grating structure. The bi-directional opposing wave-approach [65] results into an already blazed resist-grating structure and is highly adapted to the substrate curvature and grating parameters. The final process of etching the grating into the substrate is done by a proportional transfer ion beam etching process.

The complete process of manufacturing a monolithic grating is shown in Fig. 1.

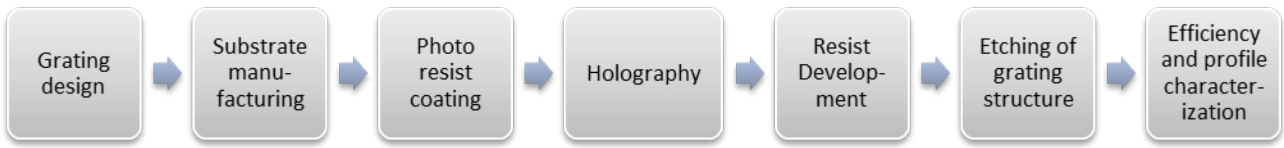

Fig. 1: Complete in-house manufacturing process of master gratings

The method used Rigorous Coupled Wave Analysis (RCWA) [8] that is known as well suited technique to simulate spectra or diffraction responses. The approximation of simulated efficiencies and polarization properties will be aligned with already manufactured grating profiles to achieve high conformity between theoretical simulation and manufactured profiles while analyzing their efficiency and polarization sensitivity.

Ray Tracing based simulations are used to simulate and optimize the holographic recording setup with its individual optical elements at their positions together with tolerancing calculations. The design of the exposure optics is adapted to achieve highest imaging quality with respect to blaze profile, line straightness and groove density variation.

In Fig. 2 left side the symmetric holographic exposure setup is shown for generating symmetric grating profiles, like sinusoidal, lamellar or binary. The Fig. 2 right side shows the opposing wave approach for generating blazed gratings already in the photoresist.

The exposed photoresist will be developed and in the second step etched with ion beam etching processes.

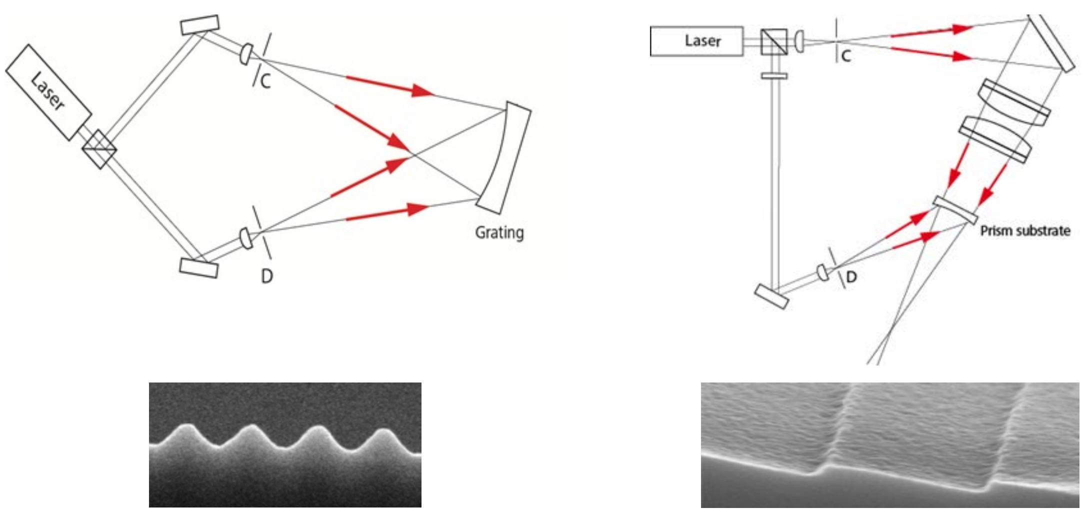

Fig. 2: left side - the symmetric holographic exposure setup, right side - the opposing wave approach using a converging and diverging wave transmitting the grating substrate

The results for low aberration monolithic gratings were achieved using this process and manufacturing of the grating substrates with ZEISS-inhouse manufacuturing euqipment. The grating structure is directly etched into the grating substrate, in this case fused silica.

2. EXPERIMENTAL RESULTS

The description of the manufacturing process characterizes the capabilities for designing and manufacturing of monolithic gratings with different surface profiles. In this chapter the experimental results will be discussed of an already manufactured modified grating profile with a period of 1000 l/mm and depth of 1.6µm on a plane substrate.

2.1 EXPERIMENTAL RESULTS - EFFICIENCY ENHANCEMENT

The efficiency of the -1st diffraction order (application order) was measured using a monochromator setup. The efficiency measurements were done in the wavelength range between 700nm and 1000nm. In Fig. 3 the results of the measurement of incident TE- and TM-polarized light are shown.

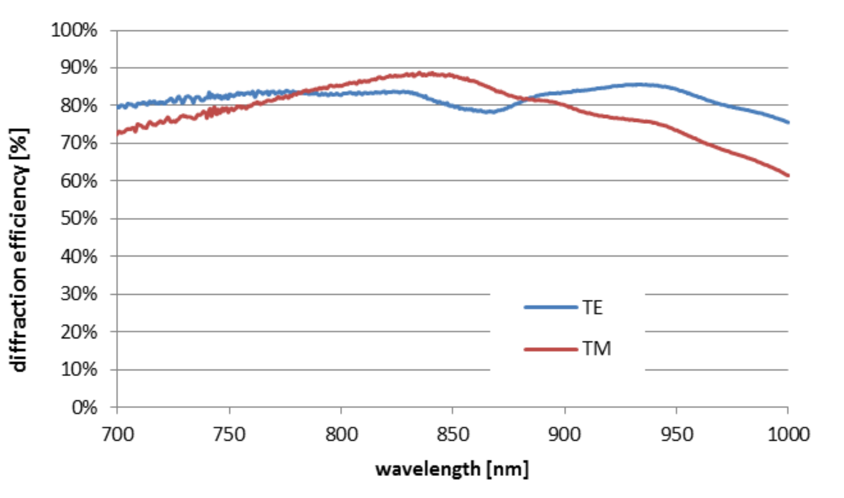

Fig. 3: Efficiency measurement of the -1st diffracted order in transmission for TE- and TM-polarized incident light was using a monochromator setup AOI 20°.

The comparison of simulations with the experimental results shows that the simulated values are in a good accordance to the experimental results. A transmission of around 80% to 90% without Fresnel-reflection on the back surface was measured.

2.2 EXPERIMENTAL RESULTS – POLARIZATION SENSITIVITY ENHANCEMENT

Beside the simulations of the polarization sensitivity, the efficiency measurement of the -1st diffraction order (application order) for TE- and TM-polarized incident light was used to calculate the measured polarization sensitivity. The polarization sensitivity is defined as the equation (T(s)-T(p))/ (T(s)+T(p))

In Fig. 4 the measured polarization sensitivity is shown.

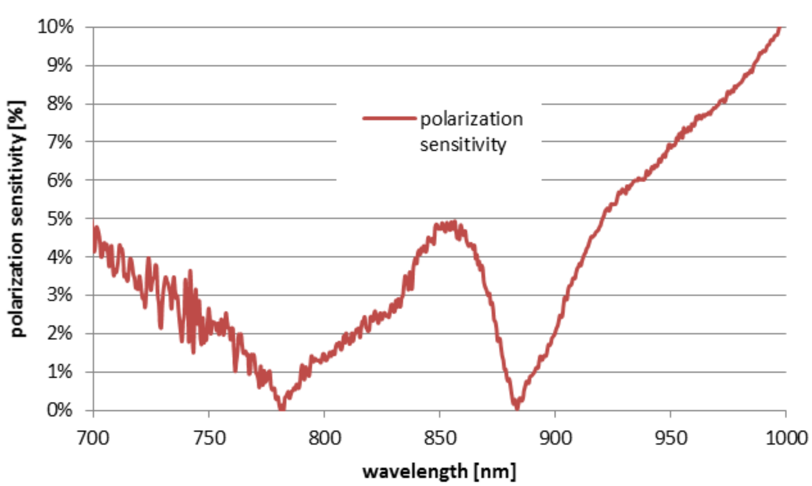

Fig. 4: Polarization sensitivity of the -1st diffracted order in transmission using TE- and TM-polarized incident light. The angle of incidence was 20°.

The experimental results are demonstrating that the modified lamellar grating structure lowers the polarization sensitivity below 5% for wavelengths smaller than 900nm and 10% for wavelengths between 900nm and 1000nm without any efficiency decrease. The comparison with the simulations shows equivalent values.

The principle of lowering the polarization sensitivity adapting the grating was shown and leads to a significant effect up to 10% lowering result.

2.3 EXPERIMENTAL RESULTS – LOW ABBERATION GRATING

Besides the grating performance parameters like efficiency and polarization sensitivity the imaging performance of a grating is essential to provided high-sophisticated spectrometers.

During the complete manufacturing process of a grating the wavefront aberrations were measured. Processes are established to provide grating substrates with lowest wavefront aberrations. The holographic process is also optimized in order to minimize the wavefront aberration.

Recent results show that holographic gratings can be produced with aberrations below 10nm rms. Such wavefront aberrations can be achieved also on plane and on curved substrates as well.

In this paper we report on the wavefront measurement of a grating monolithically structured on a plane substrate. The wavefront was measured in an auto-collimation setup of an interferometer using the illumination wavelength of 633nm. The measurement was done in transmission at the application order.

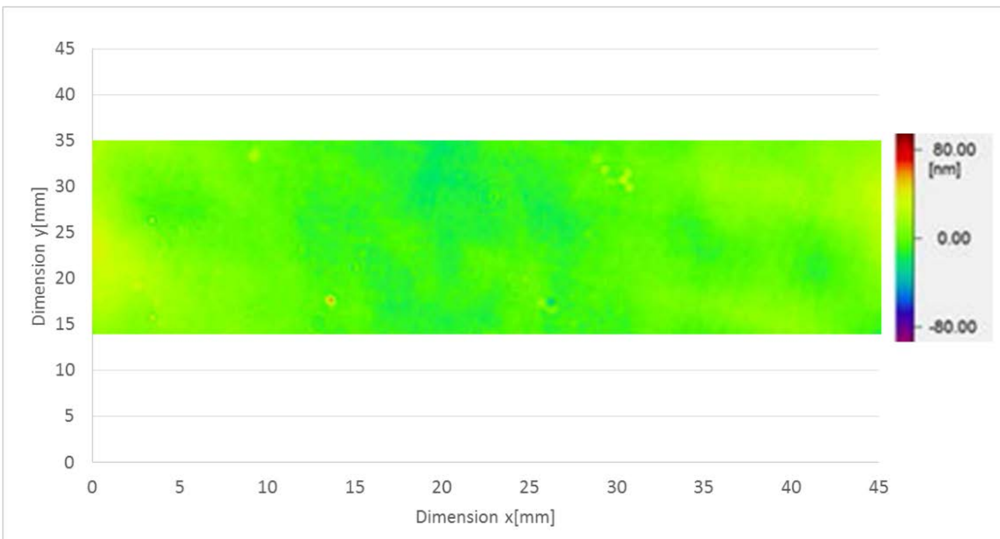

Fig. 5: Wavefront measurement of a plane grating in transmission. An rms value of 7nm was measured

3. CONCLUSION

The paper presents an advanced manufacturing approach starting with the substrate manufacturing and the holographically recording in combination with ion beam plasma etching. This approach leads into an enhancement of the efficiency of a spectrometric grating in combination with lowering the polarization sensitivity.

Besides the parameters of the grating performance of the microstructure like efficiency and polarization sensitivity the imagining properties of those gratings are essential to provide lowest aberration images in the detector plane.

It was shown the actual approach of manufacturing gratings yields low aberrations with wavefront distortions below 7nm rms measured at 633nm at the application order. The values were measured in transmission which includes also the properties if the substrates together with the grating.

The efficiency with values between 70% and 80% show a high transmission in the investigated wavelength range between 700nm and 1000nm together with polarization sensitivities below 5% between 700nm and 900nm.

In conclusion the present results enable an improvement of instrumental performance towards throughput and the radiometric response.

REFERENCES

[1] S. T. Gulde, M. G. Kolm, D. J. Smith et. al "SENTINEL 4: A GEOSTATIONARY IMAGING UVN SPECTROMETER FOR AIR QUALITY MONITORING – STATUS OF DESIGN, PERFORMANCE AND DEVELOPMENT, ICSO 2014, No. 66253
[2] P. Triebel, T. Diehl et al." Optical gratings and grisms: Developments on straylight and polarization sensitivity improved microstructures", Proceedings of SPIE Vol. 9611, 9611-44, 2015
[3] http://www.zeiss.de/gratings
[4] http://www.zeiss.de/spectral
Downloaded From: http://spiedigitallibrary.org/ on 11/14/2013 Terms of Use: http://spiedl.org/terms
[5] Alexandre Gatto, "Microstructured optics for high performance optical systems", Proceedings of SPIE Vol. 8613, 86130U (2013)
[6] Oliver Sandfuchs, Matthias Burkhardt, Reinhard Steiner, Alexandre Gatto, Robert Brunner, "Holographically microstructured gratings for high-performance spectrometers", DGaO Proceedings 2011, http://www.dgaoproceedings. de, ISSN: 1614-8436, 0287-2011-B027-2
[7] Jacqueline Maass, Oliver Sandfuchs, Alexandre Gatto, et al., "Talbot-carpets of periodic and quasi-periodic close-packed 2D mask structures calculated by a modified chirp-z-algorithm", Proceedings of SPIE Vol. 8428,
[8] M. G. Moharam and T. K. Gaylord, "Rigorous coupled-wave analysis of planar-grating diffraction," J. Opt. Soc. Am. 71, 811-818 (1981)