Evaluation of new gratings for the Vulcan 10 PW OPCPA upgrade project

Contact **andrey.lyachev@stfc.ac.uk**

A. Lyachev, T. Winstone, I. Musgrave, C. Hernandez-Gomez, I. N. Ross, Y. Tang and J. L. Collier
Central Laser Facility, STFC, Rutherford Appleton Laboratory, HSIC, Didcot, Oxfordshire OX11 0QX, UK

M. Divoky
Institute of Physics, v.v.i., Na Slovance 2, 18221 Praha, Czech Republic

Introduction

A key part of the Vulcan 10 PW OPCPA upgrade project [1] is the grating specification for the final stretcher and compressor design. These gratings will need to satisfy a number of criteria. They should have large aperture > 0.6 m and be efficient across the 150 nm spectral bandwidth centred around 910 nm [2-5].

Gratings with the required line density at the large aperture required are not readily available from any manufacturer. We have approached several large grating manufacturers and we are currently working with Plymouth Grating Laboratory (PGL) on the production and testing of small aperture grating samples with line density from 900 l/mm up to 1100 l/mm. Here we present resent results of the grating samples tests we have conducted.

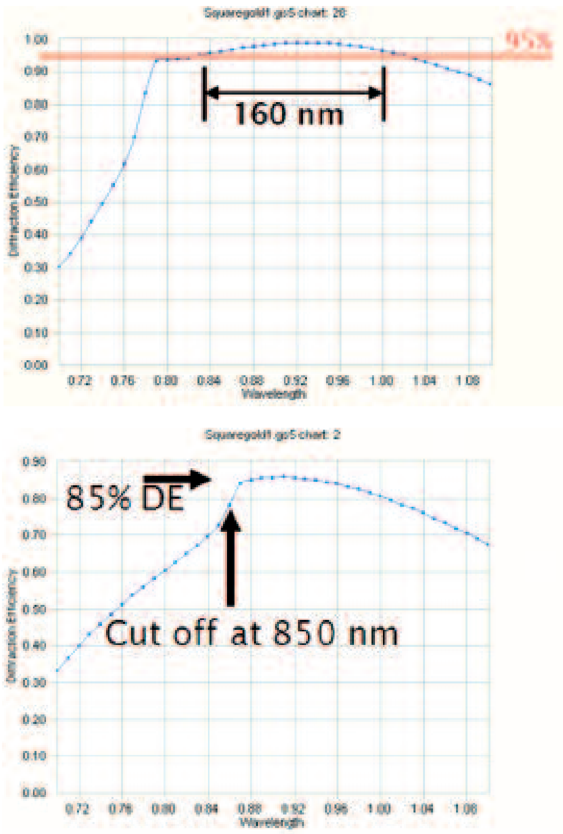

Figure 1. Calculated diffraction efficiency for a) out of plane Littrow and b) in plane non Littrow configurations.

Expected diffraction efficiency

Two types of future compressor geometry may be realised using either out of plane Littrow or in plane non Littrow configurations. We modeled the performance of the gratings under these two different configurations. Calculations of expected diffraction efficiency from 900 l/mm gold gratings at S-polarisation for the required spectral region are presented in Fig.1 for the a) out of plane Littrow and b) in plane non Littrow configurations respectively.

As can be seen from the graphs the out of plane Littrow configuration demonstrates very good efficiency of over 95 % within our pulse spectrum, compared to the in plane non Littrow configuration.

Experimental setup

The main test parameters we were concerned with are the diffraction efficiency and the spatially homogeneity of the diffracted beam. The diffraction efficiency of the grating samples was measured for different incident angles using a small diameter laser beam tuneable to different wavelengths within the required spectral region. Additionally a scan was made across each sample at 900 nm. The near field snap shots were recorded at a central wavelength of 900 nm as well.

The experimental layout for the diffraction efficiency test is presented in Fig.2. A non-modelocked Coherent MIRA laser was used as a narrow bandwidth tuneable source, the wavelength was measured by a spectrometer, and it provided about a 2 mm diameter beam. A half wave-plate was used to rotate the output polarization from the MIRA to obtain S-polarization (polarization parallel to the grooves of the grating). To

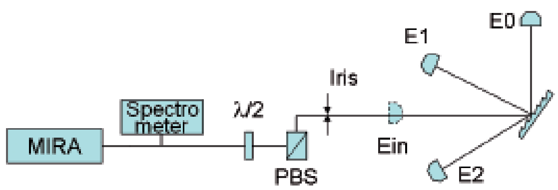

Figure 2. Grating sample diffraction efficiency test layout.

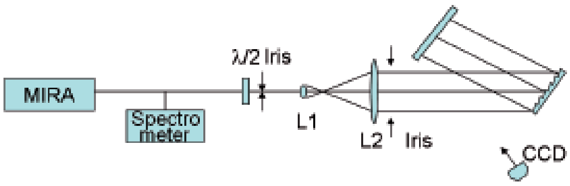

Figure 3. Grating sample reflected beam near field test layout.

improve the contrast ratio between S and P polarizations a polarization beam splitter was used.

The laser power E_{in} incident on the grating was measured along with the power E_0 in the zero order reflected beam and the powers E_1, E_2 in the visible diffraction orders. The diffraction was estimated as $E_{ff} = E_1/E_{in}$ and the absorption as $Abs = E_{in}\text{-}E_0\text{-}E_1\text{-}E_2/E_{in}$.

For the near-field measurements a beam expanding telescope was set up before the grating to fill the whole grating area and images of the diffracted beam were captured using a CCD. The layout is shown in Fig.3. Two lenses were used in a telescope configuration to enlarge the beam (L1 focal 7.5 mm, L2 focal 500 mm). The edge of the beam was masked to give a better profile. The profile was checked on diffusive screen both before the grating and after it. The grating was in the in plane configuration with the diffracted beam about 15 degrees away from Littrow. The wavelength used was 900 nm. The CCD used to image the beam was a uEye 640*480 USB camera.

Results

We have received two sets of sample gratings from the PGL over last year. First, gold gratings with a binary profile and different line densities have been tested. There were a few grating samples on 2” glass substrate with groove densities 900 l/mm, 1000 l/mm and 1100 l/mm; and several grating samples written onto 4” silicon wafers with the same groove densities. Second, a set of 900 l/mm line density gold and silver gratings with a different manufacturing technique were investigated afterwards as will be detailed below.

Results of grating samples test with different line densities are presented in Fig.4. The diffraction efficiency scan for different wavelengths is shown for 900, 1000 and 1100 l/mm gold binary type gratings, for Littrow (24 dgr) out of plane (6.5 dgr) configuration.

These tests are in qualitative agreement with our calculations for 900 l/mm shown above. For the Littrow configuration for 900 l/mm the grating efficiency is good with a slight decrease in efficiency towards the longer wavelengths. The 1000 l/mm grating exhibits flat diffraction efficiency as well but the 1100 l/mm grating shows an unexpected and quite linear decrease in efficiency over the spectral range.

The spatial variation of diffraction efficiency demonstrates the best performance for 900 l/mm and is worse for other samples, it is even visible on a CCD.

Absorption of gold for all samples was varying between 2 % and 3 % within the scanning wavelength range.

Non Littrow in plane configuration was tested as well for 900 l/mm samples at 12.7 and 32 dgr. The diffraction efficiency was quite flat in the region where only the first diffraction order existed. There was then an expected sudden drop in efficiency around 850 nm where the second diffraction order appeared as agreed with our previously shown calculations.

After the above results were obtained the gratings laid down on silicon wafers were also tested. Spatial diffraction efficiency was measured at Littrow off plane (~7 dgr) configuration at 900 nm wavelength for several points on the wafer. The silicon substrate gratings showed much better uniformity of diffraction efficiency than the glass substrate samples.

These results were discussed wtith PGL who then developed the second set of grating samples for us to test. There were several gold and silver grating samples written onto 4” silicon wafers with 900 l/mm groove densities of Sinusoidal and Binary types. All gratings have been tested on the same way as the first set of samples.

The silver gratings demonstrated improved near-field uniformity and over 90 % diffraction efficiency for longer wavelengths, but it reduced to 80 % for shorter wavelengths. Absorption of silver was higher ranging between 3 and 8 %.

Results of gold grating samples test in the second series is shown in Fig.5. For the Binary type grating at Littrow out of plane configuration the diffraction efficiency is quite uniform and over 93 % for most of wavelengths. The Sinusoidal type grating shows decrease in efficiency over the longer wavelengths but

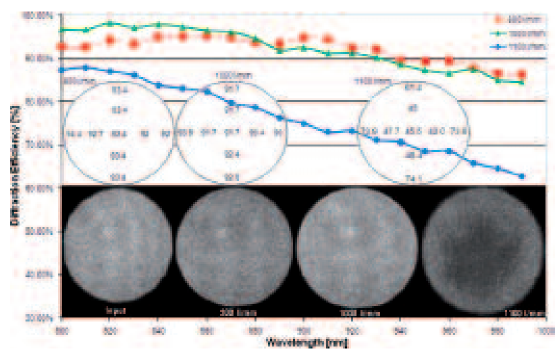

Figure 4. First test results of gold grating samples with different line densities.

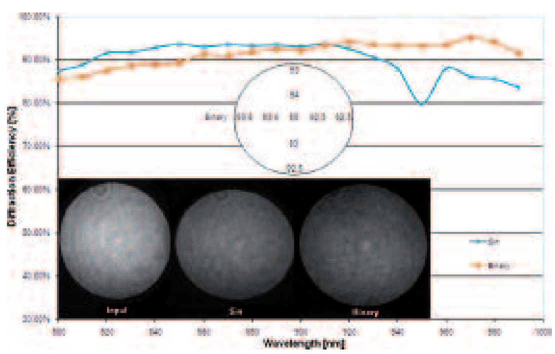

Figure 5. Second test results of 900 l/mm gold grating samples for Sinusoidal and Binary types.

slightly improved efficiency for the shorter wavelengths.

Spatial diffraction efficiency is uniform for the Binary type of grating as shown in the picture.

Absorption of gold was rather high at around 6 % for the Sinusoidal and varying within 4 and 10 % for the Binary type grating samples.

Conclusions

In conclusion, we have demonstrated in collaboration with Plymouth Grating Laboratory that it is possible to develop highly efficient broadband reflective gratings for the Vulcan 10 PW OPCPA upgrade project. We have tested a number of grating samples and it is promised to obtain one uniformly efficient of over 93 % with maximum absorption around 3 %. Further work of gratings design is ongoing at the PGL and we are expecting to test more grating samples soon.

References

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