Replacement of the transmission grating in the Gemini pulse stretcher

Contact *chris.hooker@stfc.ac.uk*

C J Hooker, Y Tang

Central Laser Facility, STFC Rutherford Appleton Laboratory,

Harwell Oxford Campus, Chilton, OX11 0QX, U.K

Introduction

The pulse stretcher used in the Gemini facility was originally made using two gold-coated reflection gratings. Contrast studies [1, 2] on both Gemini and other CPA laser systems showed a feature called the pedestal, shown in the example in Figure 1 below, that began about 25 ps ahead of the compressed pulse, and extended for a longer time after it. Investigation of this feature showed that it was due to the large grating of the pulse stretcher, where the spectrum of the pulse is dispersed. Studies on a smaller-scale pulse stretcher demonstrated that using transmission gratings in the stretcher reduced the amplitude of the pedestal by a factor close to 10. A large transmission grating was obtained, and in 2014 the pulse stretcher was rebuilt using a pair of transmission gratings in a modified optical configuration [3]. This change reduced the amplitude of the pedestal slightly, but only by a factor of three rather than the expected factor of 10.

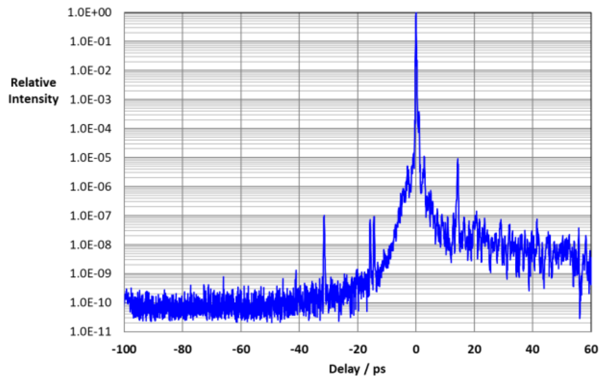

Figure 1. A typical contrast scan made with a Sequoia instrument, showing the contrast pedestal within 20 ps of the main pulse.

Interferometric roughness measurements of gratings

Detailed modelling of the behaviour of gratings used in pulse stretching and compression strongly suggested that the pedestal was a consequence of residual surface roughness of the grating introducing spectral phase noise in the dispersed beam. The surface quality of both gold grating and transmission grating was measured using a ZYGO DynaFiz interferometer with a height resolution of a fraction of a nanometer. This yielded the surface profile of the gratings with a spatial resolution of ~51 µm, which is 5 times smaller than the minimum spatial scale required to reveal features contributing to the pedestal in the time domain of ~20 ps around the main pulse. The limitations of the interferometer made it necessary to record the profile in a number of 60mm by 10mm segments, and then stitch them together to create a complete picture of the profile along a 330 mm strip of the grating. Figure 2 shows the composite image of the gold grating that was obtained in this way, together with the typical surface profile of the central line.

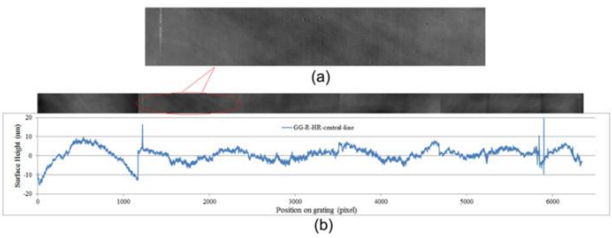

Fig.2 Measured gold grating surface profile: (a) a typical 60mm x 10.2mm slice; (b) stitched surface profile of the whole grating.

In the case of the transmission rating, the measurement includes both the effects of surface roughness and the inhomogeneity of the substrate. The spectral phase noise induced by a transmission grating is given by

$$\Delta\varphi = \frac{2\pi}{\lambda}\{(n-1)\Delta z + Z\Delta n\} \quad ,$$

where n is the refractive index, Δz the surface roughness, Z the thickness of the grating and Δn the substrate inhomogeneity. It was realized that the substrate inhomogeneity of a large transmission grating could play an important role in generating a pedestal similar to a reflection grating if the substrate of the transmission grating was relatively thick. The substrates of our gratings have a thickness of 25 mm, and this implies the substrate inhomogeneity has an effect four times greater than the surface roughness.

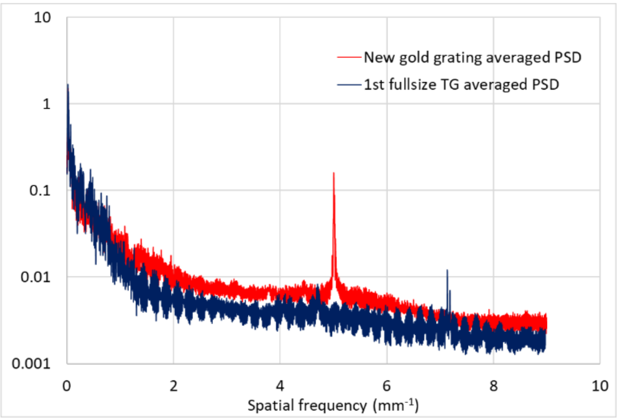

Figure 3. Averaged 1D PSD of measured gold grating and transmission grating along the dispersion direction

Figure 3 shows the averaged 1D power spectral density of the measured grating surface profiles along the dispersion direction. This indicates that both gratings should have a similar pedestal within ~5ps of the main peak while the transmission grating results in a better contrast in the pedestal tail. The effect of the measured irregularities on the contrast of the compressed pulse was modelled, and the calculated results based on the measured surface profile showed that the scale and size of non-uniformities present on the surface of the gold grating were sufficient to cause the observed pedestal.

The fused silica used for the first transmission grating was a standard grade (Corning 5F), which has a refractive index inhomogeneity specified as $\leq 5 \times 10^{-6}$. In Gemini the pulse makes two passes through the stretcher, which involves four passes through the transmission grating substrate. It appeared that the inhomogeneity of the substrate could be the reason for the smaller than expected reduction in the pedestal. The fused silica used for the substrate needs to have a very low level of inhomogeneity to avoid the small-scale perturbations leading to the formation of the pedestal. We therefore ordered a new transmission grating to be fabricated on a substrate of Corning fused silica with quality grade 1A. This grade has an inhomogeneity specification of $\leq 1 \times 10^{-6}$, which is five times better than the original. The new grating was delivered in January 2020.

Installation and testing of the new grating

On installation of the new grating, the change in alignment of the stretcher was barely detectable. All the beam spots were still visible on the cameras of the automatic alignment system with their positions almost unchanged, and the automated control corrected the errors in a few seconds.
The new substrate is a slightly different thickness, so the stretch of the pulse was not exactly the same as before due to the change in overall dispersion. However, the compressed pulse was detectable at the original compressor length setting using the Grenouille, which allowed the length to be optimized very easily: the required change was less than a millimetre.
Sequoia scans taken before and after the grating change show that the pedestal near the main pulse has been reduced by approximately a factor of 10, as can be seen in Figure 4, below. The main pulse itself appears cleaner and slightly shorter than before when measured in the usual way with a Grenouille, and this is attributed to an improvement in the uniformity of the groove structure, resulting from better fabrication techniques developed by the manufacturer. However, in the second scan there is a pre-pulse at 8.8 ps before the main pulse. Other pre-pulses and post-pulses were present in the trace made with the original grating, and these are unchanged. The conclusion appears to be that the 8.8ps pre-pulse is being generated by the new grating in some way.

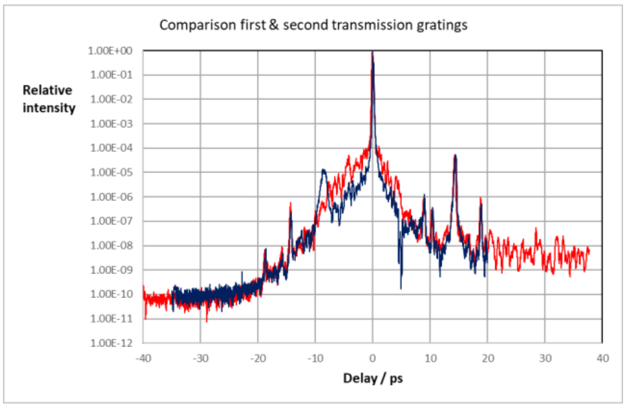

Figure 4. Comparison of Sequoia scans taken with the original transmission grating (red) and the new grating (blue). The level of the pedestal just before the main pulse is almost a factor of 10 lower with the new grating. The main pre- and post-pulses are the same, but the broad pre-pulse at -8.8 ps is new, and its origin has not yet been identified.

Experiments to investigate the source of the pre-pulse were planned for access time in March 2020, but were curtailed by the start of the Covid-19 lockdown period, and there has been no opportunity to resume the testing. However, since operations resumed following the end of the lockdown, one experiment has been completed with the new grating in the stretcher, and the pre-pulse did not cause any noticeable effects. The experiment in question was an electron acceleration experiment using gas targets, which are inherently far less susceptible to pre-pulses. It remains to be seen whether a solid-target experiment can be performed successfully with the new grating in place.

Conclusions

Replacing the transmission grating in the Gemini pulse stretcher with a new grating on a substrate with higher optical homogeneity has resulted in an improved quality of pulse compression and a reduction in the intensity of the close-in contrast pedestal by a factor of ten. The new grating also appears to introduce a pre-pulse 8.8ps before the main pulse, although the origin of this is not yet clear, and it did not prevent the first experiment since the change from being successful. The pre-pulse will be investigated further during the next available system access period.

Acknowledgements

The interferometric measurements were made using the ZYGO DynaFiz instrument at AWE Aldermaston. The authors are grateful for permission to use this instrument, and to Dr David Egan for his assistance in obtaining the measurements.

References

1. C. Hooker, Y. Tang, O. Chekhlov, J. Collier, E. Divall, K. Ertel, S. Hawkes, B. Parry and P. P. Rajeev, “Improving coherent contrast of petawatt laser pulses,” Opt. Express 19, 2193-2203 (2011).

2. D. Kaganovich, J. R. Peñano, M. H. Helle, D. F. Gordon, B. Hafizi, and A. Ting, “Origin and control of the subpicosecond pedestal in femtosecond laser systems,” Opt. Lett. 38, 3635-3638 (2013).

3. Y Tang et al, CLF Annual Report 2014-2015, article 57