# Contrast enhancement by the transmission grating in the stretcher

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## Introduction

Ultra-high intensity lasers based on the chirped pulse amplification (CPA) have proven to be a very powerful drive source to accelerate electrons and protons, producing ultrafast coherent X-ray pulses and high quality bright proton beams [1-2]. The temporal contrast of such lasers plays a crucial role in these experiments. The contrast pedestal (CP) is a well-known common feature of such lasers. The CP appears in the temporal profile in a triangular shape, extending a few tens of picoseconds, typically at a level of $10^{-5}$ to $10^{-4}$ of the peak intensity close to the main peak. This feature has a very detrimental effect on laser-matter interactions with solid state targets due to the pre-plasma formation prior to the main peak that alters the subsequent interaction, or destroys the target. In this report, we demonstrate the contrast enhancement by using transmission gratings in the stretcher. We also report a novel method to accurately evaluate the CP induced by the stretcher and the impact of individual components in the stretcher on the CP by precisely quantitative characterisation of the surface roughness of large optics. This way, we are able to predict the CP of the high power laser pulses even before the actual laser system is constructed.

## Results and discussion

Our previous investigation of contrast of a Petawatt class Ti:Sapphire laser system, the Gemini laser at the CLF, showed that the second grating of the stretcher is mainly responsible for the CP in the compressed pulse temporal profile [3] . It was also demonstrated that the CP can be reduced by using better-quality gold gratings. However, the exact origin of the CP is still unclear. Theoretical work has suggested that a minute amount of spectral phase noise in the frequency domain can cause a temporally exponential profile similar to the CP [4]. This is probably the most plausible hypothesis among the other suggestions but difficult to prove.

In the laser stretcher, the spectral phase noise δφg(ω), experienced by the dispersed beam on the 2nd gold grating, may be expressed as:

$$\boldsymbol{\delta\varphi_g(\omega) = 4 \times \frac{2\pi}{\lambda}\frac{\delta Z(\omega)}{\cos(\gamma_0)}} \quad (1)$$

While the spectral phase noise δφg(ω), experienced by the dispersed beam on the 2nd transmission grating (TG), may be given by:

$$\boldsymbol{\delta\varphi_t(\omega) = 2\frac{2\pi}{\lambda}\left((n-1)\frac{\delta Z(\omega)}{\cos(\gamma_0)} + \delta n\frac{D}{\sqrt{1-\left(\frac{\sin((\gamma_0))}{n}\right)^2}}\right)} \quad (2)$$

where $\gamma_0$ is the Littrow angle of the grating placed in the stretcher, δZ(ω) the grating surface roughness converted in the frequency domain, n the refractive index of TG substrate, δn is the refractive index variation due to the inhomogeneity of substrate and D the thickness of TG. As seen from the equation (1) and (2), $\delta\varphi_g \approx 4\delta\varphi_t$ if the δn or D of the TG substrate is small enough to be neglected. Therefore, in principle, deploying high quality TG to replace the gold gratings in the stretcher could possibly result in a significant enhancement in the CP. Towards this goal, we have replaced the gold gratings in the Gemini laser stretcher with a pair of TGs. The G1 transmission grating of the stretcher is obtained from the Ibsen, and G2 transmission grating (1#TG) from the PGL. Initially, the 1#TG is made from a standard grade substrate. Unfortunately, we didn't observe any improvement in the contrast pedestal with 1#TG, compared with the gold grating stretcher. However, we noticed that the phase noise induced by the substrate material inhomogeneity of 1#TG is roughly equivalent to that induced by the surface roughness of the grating. To minimise the impact of the TG substrate material, we have then replaced the 1#TG with a new PGL transmission grating (2#TG) in the stretcher, which was made from the highest grade substrate, reducing the influence of substrate material inhomogeneity by a factor of ~5. As shown in Fig. 1, the measured contrast of the Gemini laser pulse demonstrates that the contrast pedestal was improved by nearly one order of magnitude within the ~7 ps regime close to the main peak by using 2#TG.

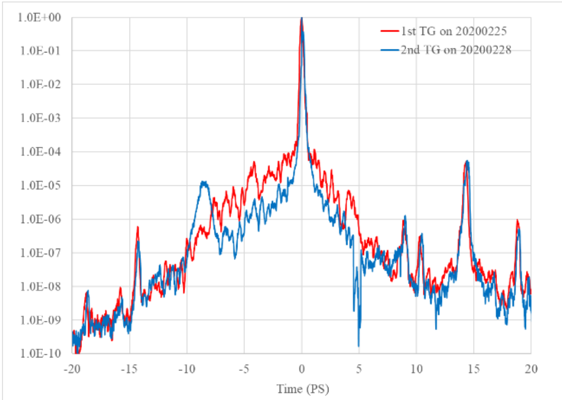



Fig. 1 Measured contrast of Gemini laser for the stretcher with 1# TG and 2#TG

In order to understand the effect of spectral phase noise induced by the surface roughness of individual optical components in the stretcher on the CP, we quantitatively characterised the surface quality of various large optics used in the Gemini laser stretcher, including two gold gratings, two PGL transmission gratings and dielectric back mirror. The surface quality were measured by a commercial interferometer, ZYGO XP/D at the CLF and ZYGO Dynafiz at AWE. With a stitching technique, the surface quality could be measured over ~300 mm in length with a required spatial resolution of ~50 µm/pixel. Since we cannot reliably measure the large curved mirror to the required special resolution, we assume that the curved mirror in the stretcher has a similar surface quality to that measured profile of the dielectric back mirror. This assumption has been proved reasonably true by the experimental measurement. Fig. 2 shows a typical stitched surface height profile of a 320 mm long gold grating.

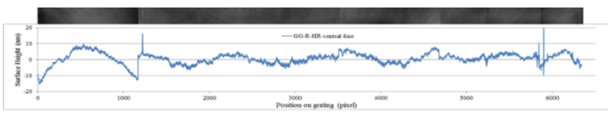
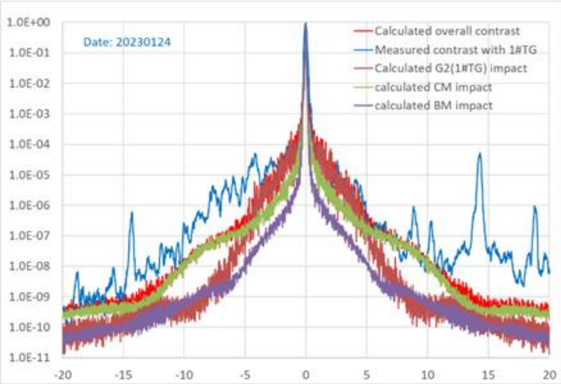
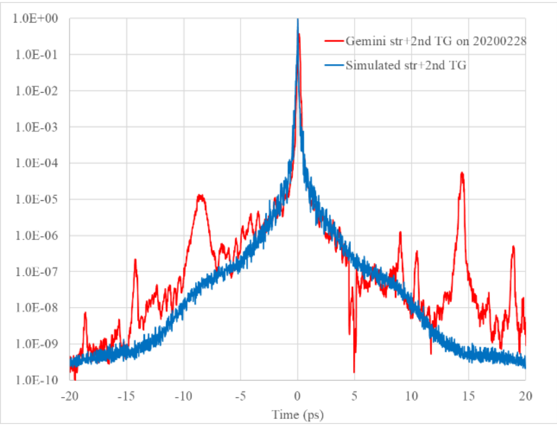


Fig. 2 Typical stitched measured grating surface height profile

Based on the measured surface profile of large optics in the stretcher, we have calculated the overall contrast associated with the Gemini laser stretcher, taking account of effect of beam size on the optics for a Gaussian beam propagating through the stretcher. We have also evaluated the contribution of each individual components in the stretcher to the contrast pedestal. Fig. 3 shows the calculated overall contrast induced by the stretcher with 1#TG and 2#TG, and the impact of each individual large optics in the stretcher on the contrast pedestal, compared with the measured contrast of the Gemini laser pulses. As seen, the simulated results are in a good agreement with the measured contrast. It is observed that in the regime beyond the ~5 ps, the impact of curved mirror makes a dominant contribution to the contrast pedestal while within ~5 ps regime the 1#TG seems a major limiting factor. For the stretcher with a higher quality 2#TG, the impact of curved mirror seems becoming the major limiting factor for further improvement of the contrast pedestal. In addition we could use the measured surface profile of large optics to evaluate the contrast pedestal induced by other stretcher configuration, e.g. a single grating Offner stretcher, with a similar stretching factor to that of Gemini laser stretcher. This work is currently on-going. The contrast study and simulation results presented in this report should provide a guideline for our future design of ultra-high power short pulse laser systems.




(a)




(b)

Fig. 3 (a) Measured and calculated contrast with 1#TG and contribution of individual optics; (b) measured and calculated contrast with 2#TG.

## Conclusions

We have demonstrated that the contrast pedestal is enhanced by deploying high quality transmissions grating in the Gemini laser stretcher. We have shown that it is possible to accurately evaluate the impact of stretcher and individual components in the stretcher on the contrast pedestal of high power laser pulses by precise quantitative characterisation of the surface quality of large optics. This underpinned the principal source of contrast pedestal of high power CPA laser pulses. This method may open a way to predict the temporal quality of the high power laser pulses even prior to the actual laser system is constructed.

## References

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