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Optical design and studies of a tiled single grating pulse compressor for enhanced parametric space and compensation of tiling errors

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ABSTRACT

A new optical design of tiled single grating pulse compressor has been proposed, set-up and studied. The parametric space, i.e. the laser beam diameters that can be accommodated in the pulse compressor for the given range of compression lengths, has been calculated and shown to have up to two fold enhancement in comparison to our earlier proposed optical designs. The new optical design of the tiled single grating pulse compressor has an additional advantage of self compensation of various tiling errors like longitudinal and lateral piston, tip and groove density mismatch, compared to the earlier designs. Experiments have been carried out for temporal compression of 650 ps positively chirped laser pulses, at central wavelength 1054 nm, down to ~235 fs in the tiled grating pulse compressor set up with the proposed design. Further, far field studies have been performed to show the desired compensation of the tiling errors takes place in the new compressor.

1. Introduction

Petawatt class chirped pulse amplification (CPA) based high energy high power laser systems [1–5] have been developed world wide with the aim to study laser matter interaction at high intensities [6–9]. In order to achieve higher and higher laser peak power from such laser systems, one would require gratings having sizes larger than a meter in the pulse compressor stage to avoid laser induced damage of the gratings at large laser fluence [10–12]. Such large size gratings are difficult to manufacture and hence are very expensive. After the first experimental demonstration in year 2004, coherent tiling of smaller size gratings has been investigated as an alternative solution to these meter size monolithic gratings in the pulse compressors [13–16]. However, coherent tiling of the gratings against their relative translational and rotational movements, with required sub wavelength precision, is a challenging task [17–19]. In a tiled grating pulse compressor, various techniques based on near and far filed measurements have been used for coherent alignment of tiled gratings [20–23]. In general, easier alignment for coherent tiling and stable operation of a tiled grating pulse compressor can be achieved by adopting the pulse compressor designs that are insensitive to some of the tiling alignment errors [24–26] and/or the compressor designs having less number of tiling surfaces [27]. Earlier, we had proposed three configurations of a tiled single grating pulse compressor, namely GI, GII and GIII, which had certain advantages like: compactness, reduction in cost, ease of alignment and maintenance because the compressor configurations had just one tiled grating assembly [27]. However, the allowed parametric space, i.e. the range of compression lengths and beam sizes that can be accommodated in the pulse compressor with given grating sizes was limited, since these configurations had a folded design.

In this paper, we propose a new optical design of single tiled grating pulse compressor. We have carried out the parametric space calculations for the new pulse compressor design. The calculations show that, the proposed design of pulse compressor can accommodate laser beams having diameter up to two times larger than our earlier designs [27] for a given value of compression length. This in turn means that in the new optical design, one can compress laser pulses having energy up to four times larger than the old designs with the similar values of the grating size, compression length and laser energy fluence. Further, in the proposed optical design, the compression of the laser pulses is insensitive to the four grating tiling alignment errors, which are a) longitudinal piston error, b) lateral piston error, c) tip error and d) groove density mismatch error. The insensitivity of the new compressor design to these tiling errors is attributed to the image rotation [24,25] provided by the mirror reflections that causes spatially symmetric and horizontally inverted incidence of various laser beam hits on the tiled grating assembly. Based on this newly proposed optical design, a tiled single grating pulse compressor has been set-up and 650 ps positively chirped laser pulses with wavelength of 1054 nm were compressed to ~235 fs. The far field pattern studies using a He-Ne laser have also been carried out to show the compensation of the above stated tiling errors, which is further confirmed by the focal spot measurement of the compressed laser beam.

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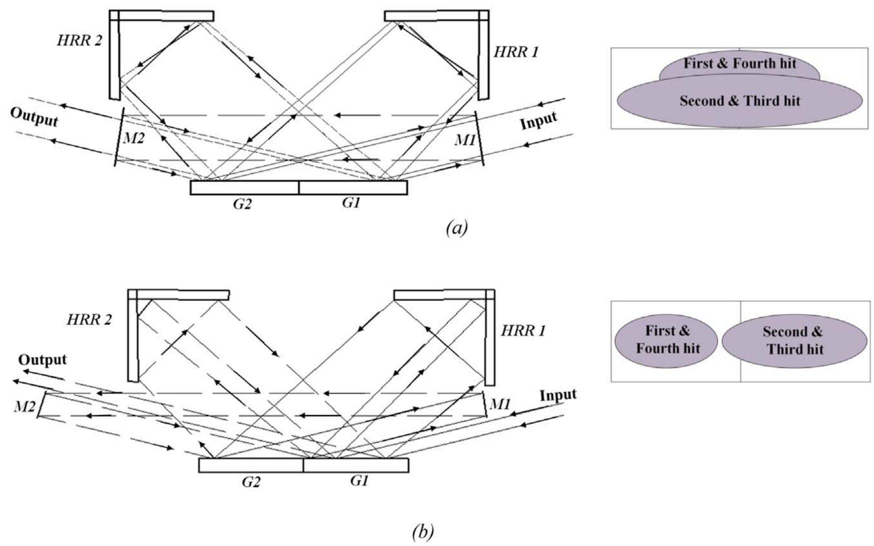

Fig. 1. Schematic designs of single grating pulse compressor along with the laser beam foot print on the grating assembly for (a) proposed optical design (b) older design GII.

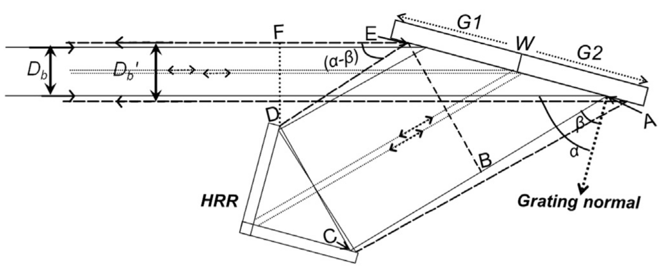

Fig. 2. Geometrical description of the new pulse compressor optical design for parametric space calculation.

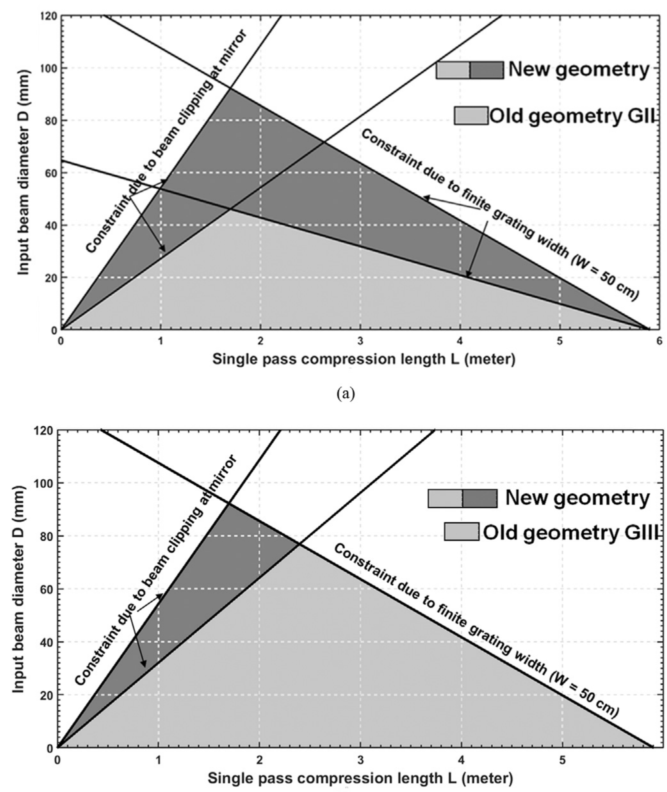

Fig. 3. Comparison of allowed parametric space for the present design of single grating pulse compressor with the previously proposed pulse compressor design (a) GII and (b) GIII.

2. Geometry description and parametric space formulation

The new optical design of single tiled grating pulse compressor is a modified version of the earlier pulse compressor design GII [27]. The schematics of the proposed design and the earlier design GII are shown in Fig. 1(a) and (b) respectively for the sake of comparison, along with the laser beam footprints on the tiled grating assembly (having coherently tiled gratings G1 and G2). In the pulse compressor design GII, the various laser beam hits on the tiled grating assembly are in a spatially asymmetric fashion (Fig. 1(b)). Whereas in the proposed new design, the laser beam hits are spatially symmetric with respect to the tiled grating junction (Fig. 1(a)). After the first hit on the grating assembly the laser beam is diffracted towards the first horizontal retro-reflector (HRR1). In the new design of pulse compressor, the HRR1 is kept in such a manner that the dark region created in the center of the beam at the tiled grating junction, coincides with junction of the mirrors of the retro reflector. With this arrangement, the diffracted laser beam from the left grating (or right grating) of the tiled grating assembly hits the left mirror (or right mirror) of the HRR1 first and then on the other mirror as can be seen in Fig. 1(a). In this way, the HRR1 reflects back the laser beam towards the grating assembly for the second hit, but with inversion in the horizontal plane (i.e. the grating's dispersion plane) about the grating junction line. To separate out the diffracted laser beam after the second grating hit from the input beam, the input beam is injected in to the pulse compressor with a small upward or downward angle from the horizontal plane, leading to a small separation between first and second laser beam hit on the gratings. After the second hit on the grating assembly, the beam is reflected using mirrors M1, M2 and the retro-reflector HRR2 for the next two hits. The image rotation provided by HRR2 and the mirror M1 and M2 in the present configuration, removes four tiling alignment errors mentioned in the introduction. Next, the off plane laser beam incidence on the grating leads to vertical spatial chirp in the beam after the second grating hit [28]. However, this vertical spatial chirp is also removed in the present pulse compressor configuration due to the image inversion provided by the mirror M1 and M2.

Various parameters used to calculate allowed parametric space for the present pulse compressor geometry are shown in Fig. 2. The parameters α, β, D_b, W and H are the incident angle, diffraction angle, input beam diameter, the total width and height of the tiled grating assembly respectively. The diameter of the spatially chirped beam D_b' (in dispersion plane of grating) after second grating hit can be