Compressor Design for a 30fs-300J 10PW Ti:sapphire Laser
Divided-compressor with an Object-Image-Grating Self-tiling Tiled Grating

Zhaoyang Li[1], Tao Wang[1], Guang Xu[2] and Yaping Dai[1]
[1]*Shanghai institute of laser plasma, No. 1129 chenjiashan Road, Jiading, Shanghai, China*
[2]*Shanghai institute of optics and fine mechanics, No. 390 qinghe Road, Jiading, Shanghai, China*

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Abstract: A 30fs-300J Ti:sapphire laser need an optimized compressor to compress the 8ns/90nm deep chirped long pulse to 30fs. We proposed a compressor design, which reduces the grating number, grating size, vacuum compression chamber cubage, and system complexity by using a divided-compressor structure and an object-image-grating self-tiling method.

1 INTRODUCTION

Femtosecond 10 petawatt (PW) lasers are being planned and constructed recently in the worldwide. A 30fs-300J 10PW laser based on Ti:sapphire is right now under plan in China. This system will use the well-known chirped-pulse amplification (CPA) technique to support its output capability (Mourou, 1988).

The primary design of the system linear chirped ratio is around 8ns/90nm. Therefore, the pulse compression process will be challenged by several problems, including large-size gratings, long compression distance, and huge vacuum compression chamber (Kramer, 2013). In this paper, we attempt to give a basic compressor design to solve the above problems.

2 COMPRESSOR STRUCTURE

The primary parameter of the positive chirped pulse after the amplification chain is given by Tab.1. And the compressor should compress the 400J, 8ns chirped pulse to less than 30fs.

In order to reduce the vacuum chamber, as shown in Fig.1, the treacy compressor (Treacy, 1969) will be divided into two compressors: a double-pass and a single-pass grating pairs are used as the 1st stage and the 2nd stage compressors, which are located in air and a vacuum chamber, respectively.

Table 1: Beam parameter after the amplification chain.

Centre wavelength	800nm
FWHM	90nm
Single pulse energy	400J
Duration	8ns
Beam diameter	Φ150mm

The compression pulse from the 1st stage compressor is delivered via a fused silica window into the vacuum chamber and is further compressed by the 2nd stage compressor.

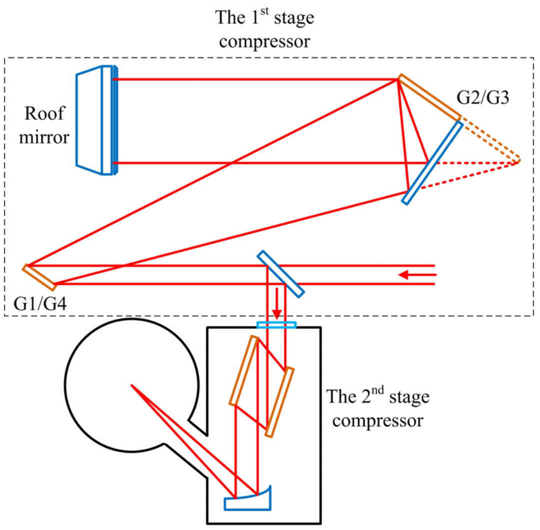

Figure 1: Divided-compressor design.

The thickness of the fused silica window is

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designed as 20mm to balance the air pressure and the nonlinear effect. The compressed duration of the 1st stage compressor is a key paramter, which need to be shorter enough to reduce the 2nd stage compressor, as well as the vacumm chamber, but longer enough to avoid the pulse distortion, fused silica damage, air ionization, and so on. Generally, the requirement of the pulse temporal and spatial distortion by self-phase modulation (B integral) and self-focusing is higher than that of the others. Therefore, the B integral should be as small as possible, and the beam breakup distance must be much longer than the window thickness. The beam breakup distance can be given by

$$z = \frac{G}{n_2 k I} \tag{1}$$

where G is a coefficient from 3 to 10 depended on different cnditions. Here we choose 3 to leave the largest margin.

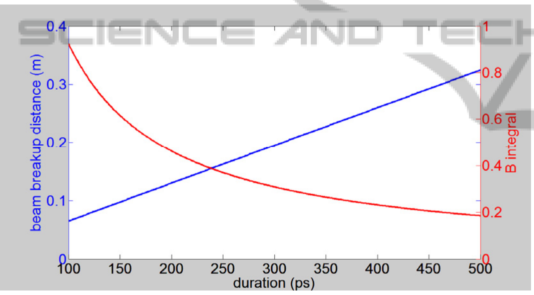

Figure 2: B integral and beam breakup distance versus duration.

The evolution of B integral and beam breakup distance for pulse duration is given by Fig. 2, and the 300ps is chosen. Accordingly, the B integral is 0.3, and the beam breakup distance is 0.2m. The intensity is 6GW/cm^2 which is below the 10GW/cm^2 threshold of air ionization, and the fluence is 1.84J/cm^2 that is below the 20J/cm^2 threshod of fused silica damage for a 300ps pulse (Stuart, 1995).

3 PARAMETER OPTIMIZATION

3.1 The 1St Stage Compressor

Beside of the output parameters of a laser beam from the amplification chain, there are many other parameters determine the geometry of a treacy compressor, such as unclipping spectrum range, part-clipping spectrum range, grating groove density, grating size, slant distance of grating pair, beam incident angle, and so on. The grating groove density and the incident angle are two basic parameters which influence the other ones, and in this section we will calculate parameters of the 1st stage compressor by choosing a suitable grating groove density and an optimized incident angle.

The unclipping spectrum range of our design is set as 90nm around the centre wavelength to allow the FWHM passing without clipping. The design of a treacy compressor must satisfy some limitation conditions:

- Grating equation;
- Grating-beam overlap;
- Sufficient wide spectrum window.

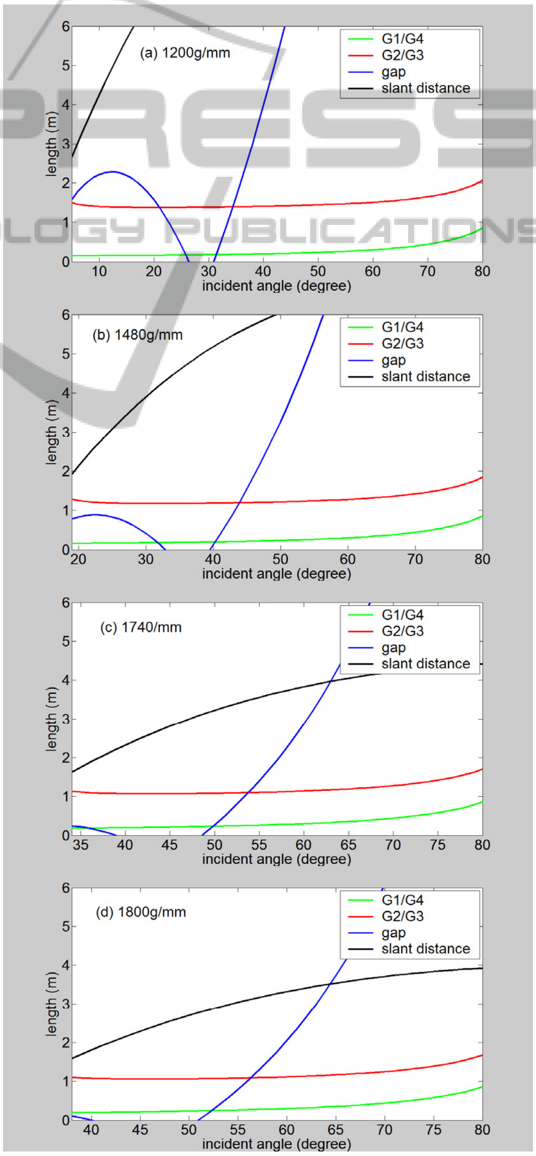

Figure 3: Grating size, gap and slant distance for 1200, 1480, 1740 and 1800 g/mm versus incident angle.

This design is based on the broad bandwidth 800nm dielectric grating due to high damage threshold and wide spectral range (Martz, 2009) and (Wang, 2010), therefore types of available groove density include 1200g/mm, 1480g/mm, 1740g/mm and 1800g/mm. Fig.3 shows the evolution of beam-grating gap, grating size (a tradition single-pass 4-grating compressor with the 1st, 2nd, 3rd, and 4th grating G1, G2, G3, and G4. G1&G4 and G2&G3 have some sizes, respectively.), and grating pair slant distance for various amounts of incident angle with different grating groove densities. And Fig.4 gives the evolution of cut off wavelength of the part-clipping spectrum range for various values of incident angle with four types of grating groove density.

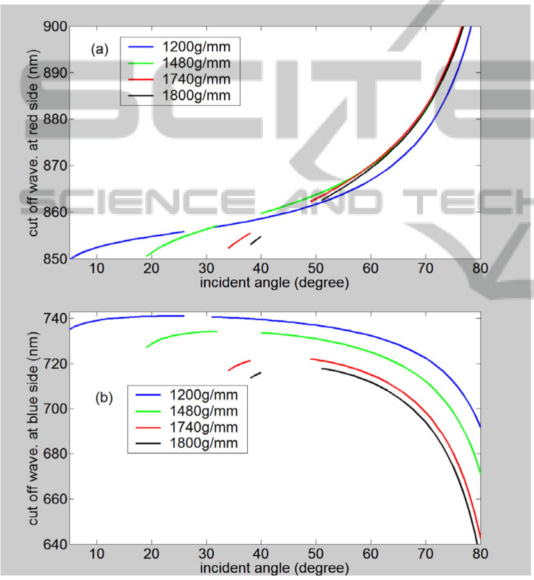

Figure 4: Cut off wavelength of the part-clipping spectrum range for 1200, 1480, 1740 and 1800 g/mm versus incident angle.

Our chosen principles of grating groove density and incident angle include: relatively large beam-grating gap, short length of grating and slant distance, and wide range of part-clipping spectrum range. And the optimized parameters are given by Tab.2.

Table 2: Optimized 1st stage compressor parameter.

Grating density (g/mm)	1740
Incident angle (degree)	52
Grating size (m)	1.10
Slant distance (m)	3.37
Wavelength range (nm)	721-864

According to Martz's work, the high diffraction efficiency spectrum window of the broad bandwidth dielectric grating is relative to the incident angle, and the 52 degree incident angle could meet the requirement of 721-864nm spectrum window.

To avoid the first grating damage where a short pulse is achieved, a large incident angle is preferred. The fluence with the optimized 52 degree incident angle is 1.13J/cm^2 (below the 1.76J/cm^2 damage threshold for a 120ps pulse reported by Martz).

3.2 The 2nd Stage Compressor

The 2nd stage compressor needs to dechirp the rest chirp, and a 30fs short pulse will be obtained after it. Hence, it is very easy to cause a grating damage. In femtosecond regime, the damage threshold of the broad bandwidth dielectric grating (0.18J/cm^2 for a 120fs pulse reported by Martz) is lower than that of the gold coated grating (0.6J/cm^2). Thus, Horiba Jobin Yvon's gold coated gratings are used in the design of the 2nd stage compressor. The 0.6J/cm^2 damage threshold determines the smallest incident angle is 71 degree. A 74 degree incident angle is chosen to make the fluence 0.5J/cm^2. Because of the small spatial chirp, a single-pass parallel grating pair is designed as the 2nd stage compressor. And the other parameters are 1740g/mm grating groove density, 0.336m slant distance, 0.544m grating size, 0.37m grating-beam gap, and 95-1078nm spectrum range.

3.3 Dispersion and B Integral

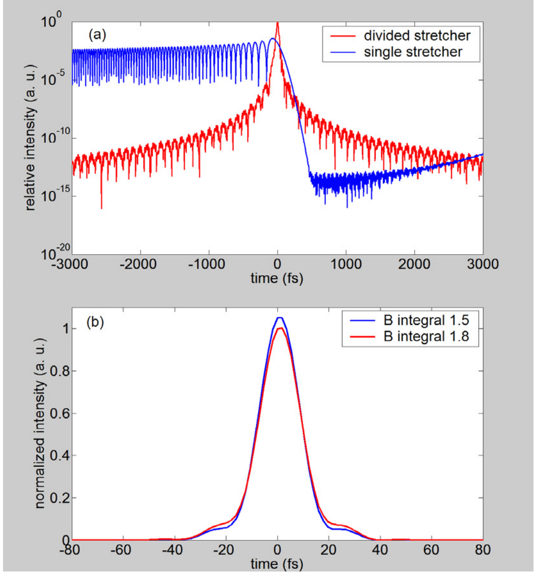

Figure 5: (a) Compression pulse with and without 3rd dispersion compensation. (b) Compression pulse with and without extra 0.3 B integral.

The non-equivalent incident angles of the 1st and 2nd stage compressors will lead to a big amount of uncompensated 3rd dispersion, and the nonlinearity effect within the fused silica window would introduce self-phase modulation (B integral), hence these two factors will distort the compression pulse temporal profile.

Fig. 5 (a) shows the compression pulses with a single-stretcher and with a divided-stretcher, respectively. The incident angle and the grating groove density of the single-stretcher are equivalent to those of the 1st stage compressor. The 2nd dispersion of the single-stretcher-divided-compressor system could be compensated, but the 3rd dispersion cannot be eliminated completely. In this way, a divided-stretcher is designed to match the divided-compressor to compensate both the 2nd, 3rd, and 4th order dispersion. The incident angle, the grating groove density, and the chirped ratio of the divided-stretcher and those of the divided-compressor are matched exactly. Moreover, the divided-stretcher has another advantage: the smaller-stretcher can be precisely adjusted to match the 2nd order dispersion of the whole system without changing the larger-stretcher and the divided-compressor.

Besides, we could also adjust the incident angle of the single-stretcher to compensate both the 2nd and the 3rd but the 4th order dispersion within the single-stretcher-divided-compressor system.

The control purpose of the B integral within the amplification chain is 1.5. Fig. 5(b) shows the compression pulse with a 1.8 B integral added the influence of the fused silica window, and this distortion is acceptable.

4 TILED GRATING

The requirement size of the second grating in the 1st stage compressor is 1.1m. However, the largest size of the available grating is 0.56m. Therefore, the object-image-grating self-tiling method is used to double the effective grating size to 1.1m, and the size of the corresponding mirror is 0.8m (Li, 2010).

The object-image-grating self-tiling method is a very easy way to enlarge the effective grating size, as shown in Fig.6, which reduce the number of tiling errors within a tiled grating from 6 to only 3. Besides, the tiling condition monitoring of the proposed compressor design, as shown in Fig.1, is very convenient, which can be achieved only by observing the distribution of the main beam focal spot. Unlike the traditional grating tiling, no additional monitoring lasers are needed in a compressor with only one tiled grating. And a similar demonstration experiment is shown in Fig.7, we just need 3 steps to achieve an ideal object-image-grating self-tiling tiled grating by adjusting θy, θz, and Δx (illustrated by Fig.6) one by one.

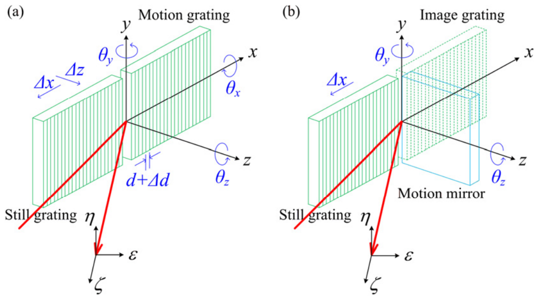

Figure 6: Degrees of freedom within (a) a tradition grating tiling and (b) an object-image-grating self-tiling.

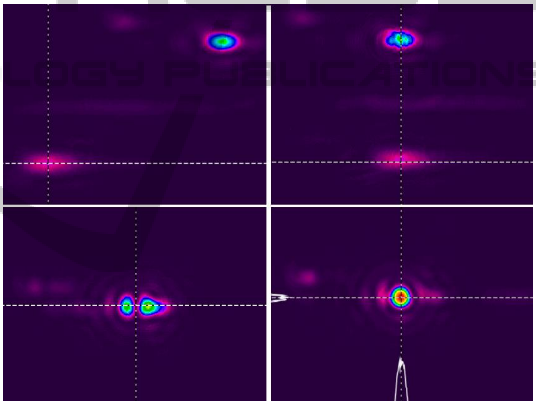

Figure 7: Steps to achieve the ideal tiling condition.

5 CONCLUSIONS

A divided-compressor is designed for a 30fs-300J 10PW Ti:sapphire laser to compress the 8ns/90nm deep chirped laser pulse. This design could satisfy the 30fs-300J compression requirement. The number and the size of gratings, the cubage of the vacuum compression chamber, and the complexity of the system are reduced.

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