Development of 91 cm size gratings and mirrors for LEFX laser system

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Abstract. We have developed large size diffraction gratings and flat mirrors for large size pulse compressor in LFEX laser system. The required size of grating is 1.8 m, and we use 2 segment system with 91 cm element gratings. The substrates of mirrors and gratings are made of newly developed fused synthetic silica glass for low thermal expansion. The coating on this fused silica substrates are made by the ion beam assisted deposition (IAD) process for low stress coating. The size of element grating is 91 x 42 x 9 cm, and the largest mirror is 86 x 43 x 9 cm. The grating was lured by a novel scanning beam interference lithography system (NanoRuler II) in Plymouth Grating Laboratory in USA. The diffraction efficiency of the grating is better than 95 %, and the wave-front error is better than $\lambda/3$ at 632 nm.

1. Introduction

For enhancing thermo-nuclear fusion reaction, a extremely high peak-power and high energy laser is required for Fast Ignition scheme to post heating the compressed fuel core generated by the implosion. This short-pulse high-energy laser is constructed using CPA (Chirped Pulse Amplification) scheme avoiding the nonlinear effect in the laser amplifier system. In such laser system, the pulse compression, beam transport and focusing, require large scale mirrors and gratings. Also this compressor should be constructed in a vacuum chamber for avoiding the dispersion and the nonlinear effect of the air. Therefore, mirrors and gratings should be compatible to the vacuum use for the stable operation. On the other hand, the grating substrate must have small thermal expansion coefficient because the diffraction angle of the laser light from the grating substrate, and only the fused silica or the low expansion glass can be used.

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The coating film stress on the silica material is a very critical problem due to the crazing generation especially in the vacuum condition. Therefore, the coating stress is a critical problem for manufacturing a large scale compressor. On the other hand, the coating should have a very high damage threshold (DT) for dealing strong laser light. These condition requires a very difficult selection of coating process and the substrate materials. Very fortunately, we found a very good coating chamber with IAD (Ion Assisted Deposition) for producing very high DT. So we can manufacture a very low thermal expansion diffraction gratings with high DT in the vacuum chamber.

The conventional fabrication method of diffraction grating was the laser beam interferometry using large size writing beams. However, in this method, the groove density written on the grating is strongly affected by the air temperature, pressure, humidity and the longitudinal mode of the writing laser. The best groove density error in the conventional method was about 0.5 ppm, but this groove density error is corresponding to the pointing difference of 2.2 micro-rad in the diffracted beam[1]. So we need a very precise groove density reproducibility for obtaining a small spot-size. We decided to use a quite new grating fabrication scheme using scanning beam interferometer (SBI) developed in MIT[2]. This method uses two small writing beams interfering on the substrate. The experimental results on the groove density reproducibility were better than 0.05 ppm. For designing a large scale pulse compressor, following issues should be considered.

2. Beam size

The final output of the LFEX laser system is 10 kJ at 1 to 10 ps with 4 beam-lines[2]. For this output, the output energy of each beam-line was estimated as 3 kJ. The most weakest component in the system is the diffraction grating, and the realistic DT of the grating at 1 ps was reported about 3 J/cm^2 in the beam cross section. So the required beam area is 1000 cm², and we selected 37 x37 cm beam size for some margin for the beam intensity modulation.

3. Size of compressor gratings

In LFEX laser, the required size of the first and the second gratings are 133 cm and 170 cm, respectively[3]. The detailed design of the compressor is given in the related paper by K. Kondo in this issue. These size of gratings are far from the realistic fabrication ability of the grating, and we planed to use grating segmentation instead of development of 2 m long grating.

4. Material of grating and mirror substrates

As described in previous part, the material for the grating should have a low expansion due to the temperature change for stable operation of the laser system. As shown in Table 1, BK-7 or Pyrex glass has a large thermal expansion coefficient, and the required thermal stability is less than 0.06 C, which requires a very critical thermal control. So we selected the silica glass material as the substrate of the grating and mirror. We selected a new silica material named "Synthetic Fused Silica" developed by TOSO Co. in Japan. This material is made from the reuse of the silica glass. The price of this new silica glass is 2 times higher than BK-7 material, and this is a reasonable price for our laser system.

Material	Thermal expansion coefficient	Temperature for 0.5 ppml
BK-7	7 x 10 ⁻⁶	0.06 ℃
Pyrex	2.8 x 10 ⁻⁶	0.14 ℃
Fused silica	0.4 x 10 ⁻⁶	1 ℃
Low expans Glass	ion 0.08 x 10 ⁻⁶	5 ℃

Table 1 Thermal expansion coefficients of different glass materials.

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This synthetic fused silica glass has several advantages against the conventional BK-7 glass, fused quartz, or synthetic silica glass.

- (1) Thermal expansion coefficient is 7 times lower than BK-7.
- (2) The bubble and homogeneity of the material are much better than the fused quartz.
- (3) The price is much cheaper than the synthetic silica glass (only 2 times of BK-7).

5. Coating process compatible to the vacuum

Normal coating on the silica glass shows a very high tensile stress due to the difference of thermal expansion coefficient between the coated film and substrate. This stress mainly come from the cooling process after coating. Normally this tensile stress generates crazings of the coating especially in the vacuum condition. This crazing is a critical problem of the coating in the vacuum when we use silica glass substrate.

For avoiding this crazing of the coating, the low temperature coating such as the ion assisted deposition (IAD) can be used. Very recently, a progressed IAD coating have been developed by D. Smith in Vacuum Process Technology Co. using plasma ion source[4]. This provides contamination free IAD with high DT for large scale optics (up to 1 m). We decided to introduce this IAD coating machine to Okamoto Optic Works in Yokohama, Japan, and started the manufacturing of the vacuum compatible mirrors and grating substrates.

6. Luring process with high groove density reproducibility

In LFEX laser system, the required size of one grating is about 1.8 m, and this size is far from the fabrication ability of the holographic grating. So we designed the segmented (tiled) grating system using smaller size element gratings. And we designed a very special diamond shape dual-side incidence pulse compressor for reducing the number of grating[3].

However, in the case of dual-side incidence compressor, we have a critical problem on the groove density error of element grating because the pointing error generated by the groove density difference generates a pointing error of the element beams diffracted by the element grating[1]. This phenomena is shown in Figure 1. We made a collaborative work with LLNL, and fortunately we found a very smart solution for this problem. If we use a half-size element grating to the beam size, the groove density error can be automatically cancelled due to the image rotation in the compressor[5]. This is a great advantage of our design because we do not need any position sensors to detect the grating adjustment.



Figure 1 Effect of groove density difference on the diffracted beam.

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For this reason, we decided to use a quite new luring method developed by Dr. M. Schattemburg in MIT, USA[2]. This luring method is using scanning beam interference (SBI) method and called Nanolurer. The groove density reproducibility of 0.05 ppm was already demonstrated. So we chose this scheme to scale up to 1 m size. This scale up was planed by D. Smith in VPT, as a new company ; Plymouth Grating Laboratory (PGL) in USA.

Very recently we have succeeded to manufacturing 2 full scale gratings with the diffraction efficiency of 94 %, and the wavefront error of better than $\lambda/3$. Figure 2 shows the photograph of the actual grating. We will receive 16 gratings in total within 3 months.



Figure 2 Photograph of newly developed 91 cm dielectric grating.

7. Summary

A large scale high-energy pulse compressor have been designed and constructed. The total number of about 1 m scale mirrors and gratings are 63 including the vacuum windows. A new fused silica material have been used as the substrates of large scale mirrors and gratings. A special top hat shape is chosen as the mirror and grating substrate to supporting the optics close to each other. The polishing and coating have been done successfully to provide better than $\lambda/4$ wavefront distortion. A new ion assisted deposition chamber have been introduced, and the adequate stress control of the coating have been observed. The damage threshold of these mirror exceed 30 J/cm² at 1 ns which is much higher than the average fluence. Precise gratings of 91 cm long are fabricated throughout a scanning beam interference lithography system.

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