New Multilayer Dielectric Gratings will Double the Output Power of High Energy Laser

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Abstract

New ion etched Multi Layer Dielectric diffraction gratings (MLD gratings) have been designed with the goal of improving the efficiency and damage threshold when used in chirped pulse amplification (CPA) laser compression scheme. A pair of dielectric gratings has been installed inside a complete CPA configuration to measure efficiency and damage threshold. 96 % efficiency per pass and a damage threshold twice the one observed on gold coated gratings have been observed.

1 Introduction

The use of the chirped pulse amplification (CPA) technique is now widely developed to obtain powerful laser pulses of high energy in the femtosecond or picosecond regime [1] - [4]. We can indicate some important laser centers using this technique: Osaka University and JAERI in Japan, Lawrence Livermore and Rochester in US, Rutherford and AWE in UK, GSI and Iena in Germany, CEA and LULI in France and many others all over the world. The compression stage is based on diffraction gratings, usually two gratings working by reflection. Fig. 1 shows the principle of a CPA technique using two diffraction gratings pairs. Associated with the need to have large size gratings with high efficiency, laser induced damage remains the main limiting factor to go towards higher energy.

Up to now, usual gratings working at 1.053 µm or around 800 nm, are coated with a gold layer to present the best reflectivity. The damage threshold is then reached when the gold is damaged due to the very high power laser beam when compressed.

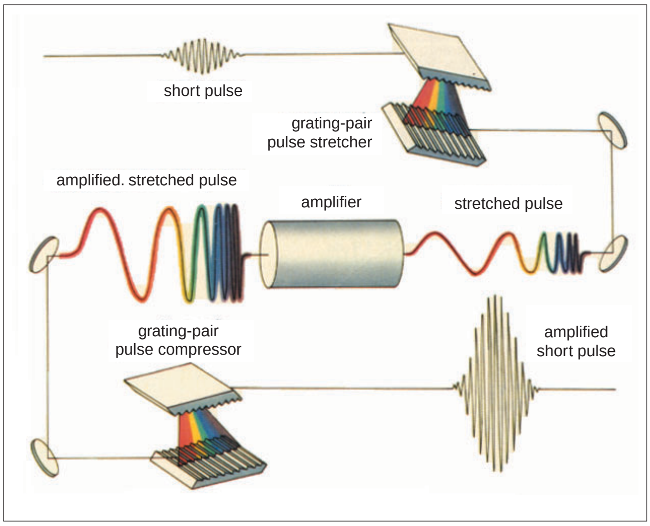

Fig. 1 Principle of a Chirped Pulse Amplification Technique Using Two Diffraction Gratings Pairs

Considering the gold gratings limitation we have studied and developed a new technique [5] to engrave the grating grooves inside the upper layer of a high damage threshold multilayer dielectric coating in order to avoid the use of the gold layer.

We will give hereafter the performances of gratings for pulse compression either classical with gold coating either ion etched inside a multilayer dielectric coating and present the experimental performances obtained in a 100 TW class laser CPA set-up.

2 Classical Gold Coated Holographic Gratings

From the beginning of the CPA technique (in the years 1986), it has been demonstrated that it was possible to obtain quite high efficiency on TM polarization with sinusoidal profile holographic grating coated with gold.

In this respect, efficiency calculations (performed in a collaboration between Jobin Yvon (JY) and Prof. Nevière at the "Laboratoire d'Optique Electromagnétique" in Marseille, France) did reach the conclusion that a number of grooves 1740 per mm is a good choice for optimizing efficiency at 1.053 µm. Absolute efficiency on TM polarization is reaching 95 %. Later on, CPA gratings with 1480 per mm and 1200 per mm are produced with similar efficiencies.

An example of performances measured on a 1740 grooves per mm grating, 400 mm diameter size, optimized for 1.053 µm, is shown in Fig. 2.

Measured efficiencies are near the theoretical efficiencies and homogeneous over the surface of the gratings. λ/6 quality diffracted wavefront has been measured. Typical damage threshold in right section of the beam of holographic gold coating grating is 2 J/cm^2 in nanosecond regime and 1 J/cm^2 in picosecond regime, as measured on the CEA and LULI facilities.

Fig. 3, Fig. 4 and Fig. 5 show the performances of this gold coated holographic gratings.

Fig. 2 Gold Coated Grating; 1740 grooves per mm, Blaze 1.053 µm, Blank Diameter 420 mm

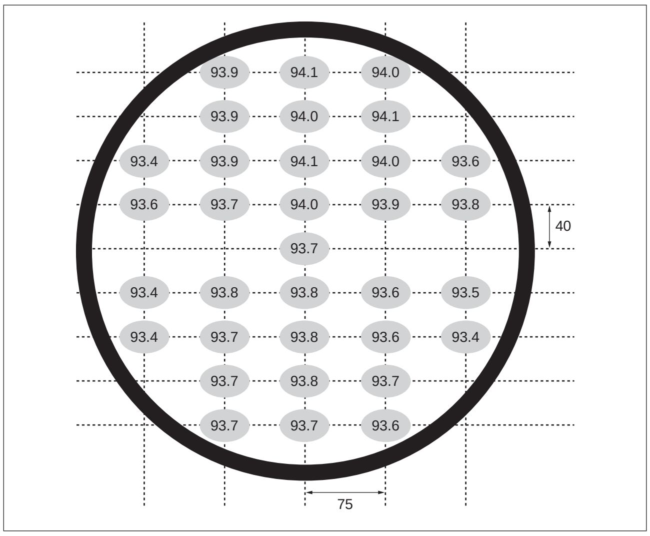

Fig. 3 Measured Efficiency Map

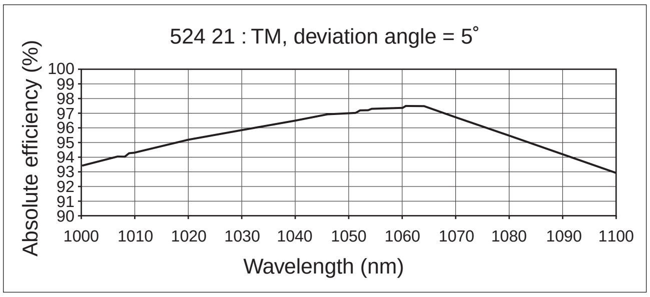

Fig. 4 Calculated Theoretical Efficiency of a Sinusoidal Groove Profile Holographic Grating Coated with Gold

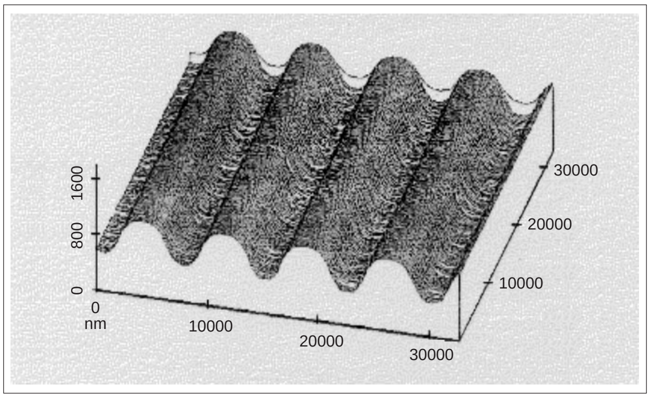

Fig. 5 Sinusoidal Groove Profile of Holographic Grating

3 New Multilayer Dielectric Coated Gratings

We have first performed a theoretical study of new structure of diffraction gratings engraved by ion etching in the upper layer of a high laser damage threshold dielectric multilayer coating. A trapezoidal shape engraved in the multilayer have been chosen and toleranced.

Fig. 6 shows the basic construction of a MLD grating and Fig. 7 shows its production method.

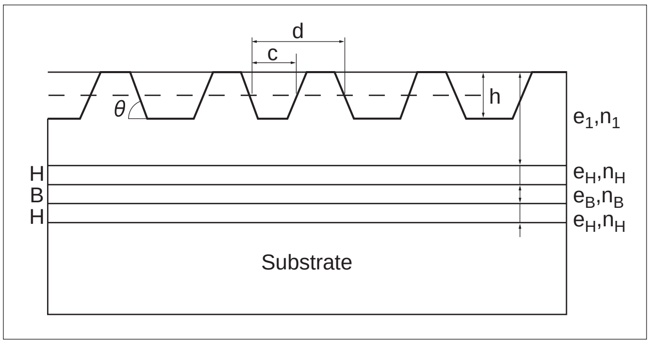

Fig. 6 Construction of Ion-etched Multilayer Dielectric Grating
A multilayer dielectric mirror is deposited on to the substrate. The top layer may be thicker than the others and is ion-etched.

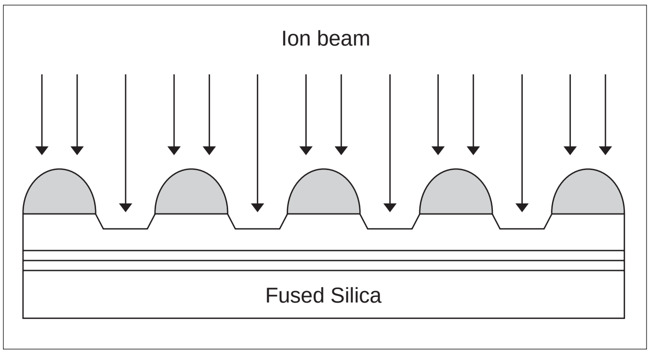

Fig. 7 Production of MLD Gratings
An holographic grating is first recorded on top of the dielectric coating. Then the profile is transferred using ion etching process.

For a configuration defined by groove density, wavelength, high and low refraction indexes, the solution for the structure is finely determined by the thickness e1 of the upper layer, the groove depth h (or h/d where d is the period) and the groove width c at half depth (or c/d). High efficiency is obtained for TE polarization.

After manufacturing and test some sample gratings, we select the low index upper layer for production of usable gratings inside a real laser compressor. Extensive damage threshold tests of sample gratings have been performed at LULI [6] : measurements with small laser spots (100 microns focused beams), one shot measurements and statistical measurements.

One shot measurements gave 2.5 J/cm^2 in femtosecond regime (in right section of the beam)

4 Parameters of Manufactured Dielectric Gratings

4.1 First Pair of Manufactured Gratings MLD

First pairs of manufactured gratings MLD were listed below:

- Groove density : 1740 per mm
- Efficiency at 1056 nm : up to 100 %
- Incidence angle : 72.25°
- Multilayer dielectric coating, 20 layers
- SiO_2 upper layer
- Dimension: 120 × 140 mm^2

A pair of such gratings has been produced, efficiencies has been measured: 98 % (peak), and 96 % (average), near the 100 % theoretical value. Wavefront quality has been measured at λ/6 as expected.

Fig. 8 shows the theoretical efficiency of the MLD grating according incidence angle.

Fig. 9 shows the theoretical and measured efficiency of a MLD grating.

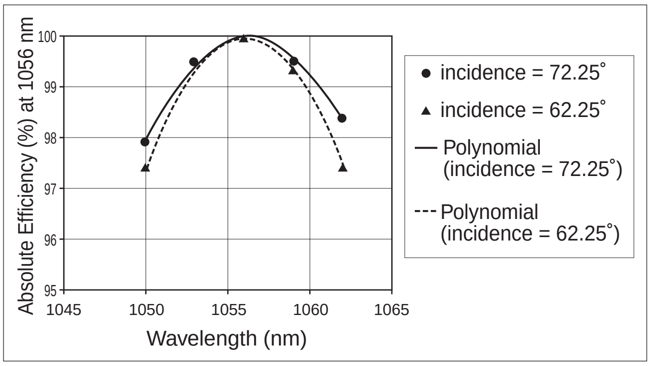

Fig. 8 Theoretical Efficiency of Dielectric Grating According Incidence Angle
(High index 1740 grooves per mm)

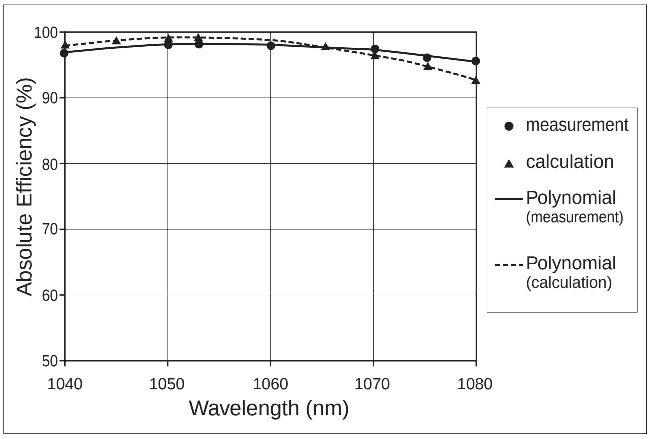

Fig. 9 Theoretical and Measured Efficiency of Manufactured 120 × 140 mm^2 Dielectric Grating (dev = 10°)

Then the pair of gratings has been installed inside the laser compressor at LULI [6], the size of the beam was reduced from 90 mm to 18 mm.

Fig. 10 shows an experimental set-up for large diameter tests.

The input energy is measured at the input of the compression chamber. The surface of the second grating (where the intensity is the highest) is imaged onto a ccd camera. The ratio between the maximum fluence and the average fluence is 1.21 (beam profile).

A 2nd order autocorrelator is measuring the pulse duration at the output. The output energy is measured, allowing to determine the diffraction efficiency over the whole aperture of the laser beam.

The damage inspection is visual using a numeric camera. It permits to know when the gratings had microscopic (over 1 mm) damages.

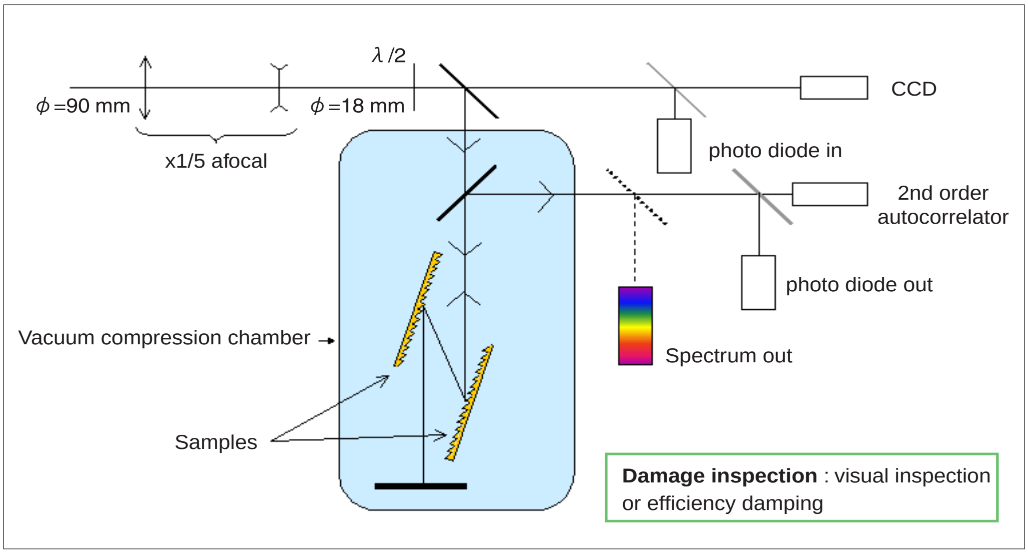

Fig. 10 Experimental Set-up for Large Diameter Tests

The stretched pulses were compressed by the sample gratings which created the sub-picosecond pulses and tested their damage threshold.

4.2 Second Pair of Manufactured MLD Gratings

We have then manufactured a pair of large MLD gratings in dimension 210 × 420 mm^2 (Fig. 11). We reach a good efficiency uniformity (Fig. 12). This pair of gratings is delivered to LULI laboratory to be used in their terawatt compressor in order to double the output power of the laser.

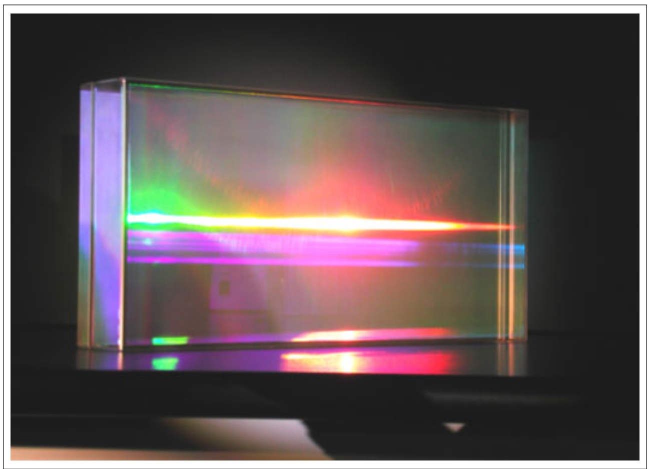

Fig. 11 Multilayer Dielectric (MLD) Grating
1740 grooves per mm – blaze 1.053 μm – blank size : 210 × 420 mm^2

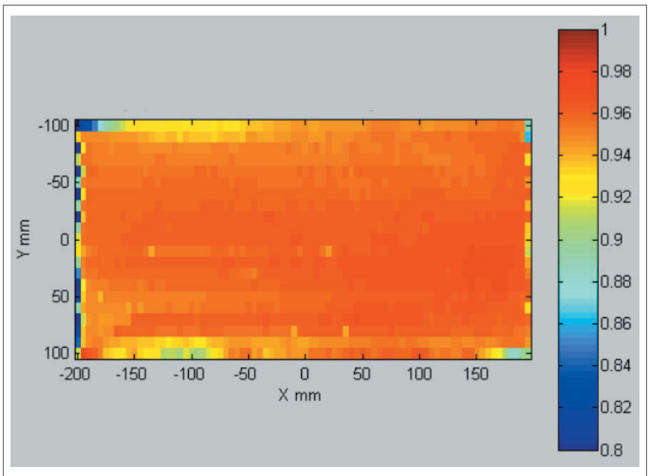

Fig. 12 Measured Efficiency Map of 210 × 420 mm^2 MLD Grating
Average efficiency: 96 %

5 Measured Performances of the Dielectric Gratings in CPA Configuration

Following performances have been measured : The angle of incidence was i = 72.5°. The compressed pulse was measured at 275 fs pulse duration. The overall diffraction efficiency was 85 %. This means that for each pass the efficiency was as high as 96 %. The damage threshold was above 1.7 J/cm^2 at i = 72.5° (or 0.51 J/cm^2 on the surface of the gratings). 5 shots at this fluence did not create any visible damage. The first one occurred at 2.0 J/cm^2.

Then we can estimate the total benefit in output energy for a laser equipped with a dielectric gratings compressor in comparison with a laser equipped with a classical gold coated gratings compressor :

The gain in damage threshold is 1.7 to 1 (J/cm^2), which allows to increase the input energy by a factor, 1.7.

The gain in efficiency (4 pass) which is 0.85 to 0.60 will also increase the output energy. Further damage test on newly produced MLD gratings have demonstrated a factor 2.5 increase in laser damage threshold in comparison with gold coated gratings.

6 Future Developments

The manufacturing of gold coated holographic gratings for laser pulse compression is well established. High performance in efficiency homogeneity and diffracted wavefront quality is obtained for large size gratings.

New dielectric gratings present very encouraging results in term of efficiency and damage threshold. A factor 2 improvement in energy output has been obtained in a compressor with this new technique for gratings in dimensions 120 × 140 mm^2. Large size (210 × 420 mm^2) dielectric ion etched gratings have been successfully manufactured with beautiful efficiency.

Today we have in production at JY several pieces MLD gratings in even larger size: 335 × 485 mm^2.

7 Conclusion

New "Petawatt" class laser centers in Japan, US or France request even larger gratings areas. A new concept is to adjust 2 (or more) gratings in phase to constitute a mosaic of gratings. A first 2 gratings mosaic prototype has been produced in US at Rochester University [7]. This new kind of mosaic gratings equipped with multilayer dielectric coated gratings will constitute the basis of the future large gratings pulse compressors.

References

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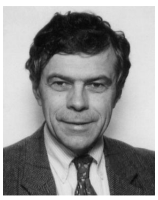

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