Preprint
UCRL-JC-148007

Large Aperture, High-Efficiency Multilayer Dielectric Reflection Gratings

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This article was submitted to
Conference on Lasers and Electro-Optics/Quantum Electronics & Laser Science Conference, Long Beach, California, May 19-24, 2002

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

April 12, 2002

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Abstract: We have designed and fabricated a 355 x 150 mm multilayer dielectric diffraction grating, 1800 l/mm for 1030 nm light, that exhibits >99% diffraction efficiency and a diffracted wavefront flatness of <0.15 λ. This grating is an enabling component of a 1 ps, high rep-rate machining laser currently in operation at LLNL.

OCIS codes: (050.0050) Diffraction gratings, (220.0220) Optical fabrication, (140.0140) Laser optics

1. Introduction

The successful design and fabrication at the Lawrence Livermore National Laboratory (LLNL) of meter-sized high-efficiency reflection gratings was an important enabling technology for the pulse compressor of the LLNL Petawatt Laser [1,2]. These gratings, now becoming available for pulse compressors in other institutions, rely on the reflecting properties of a gold coating to achieve their needed high efficiency. As interest grows in increasing the intensity of laser pulses, the absorption of light by a metal surface becomes a limiting factor in the power obtainable from a pulse compressor. We have been working for some time to devleop high-efficiency gratings from all-dielectric materials [3-7] .

2. Grating Design

The grating used for this particular high average-power laser system serves as the stretcher and compressor. The pitch (1800 l/mm), central wavelength (1030 nm) and incidence angle (63°) were specified as part of the overall system design. Design of the grating involves consideration of the reflective properties of the stack coupled with the diffractive properties of a surface relief grating etched into the uppermost layer of this stack. The overall design is optimized such that: 1) the MDG gives maximum diffraction efficiency into the −1 reflected order at use wavelength and angle, and 2) the multilayer stack exhibit AR or at least neutral reflective properties at the exposure wavelength and angle. This second criteria is to prevent back reflections from creating standing waves and resultant pattern degradation in the photoresist film during the laser interference lithography process.

Tantala/Silica were chosen as the high/low refractive index layers for the multilayer stack. The grating is etched into a top SiO2 layer of a specified thickness. The layer immediately underlying this grating layer is of Al2O3, a material which is resistant to the etch process, thus providing more process latitude for the transfer etch. The thickness of the Al2O3 layer is determined by the optimized optical design.

Figure 1 shows a map of the −1 order diffraction efficiency as a function of angle and duty cycle(ratio of grating width to grating period)., for a fixed wavelength and groove height. The most sensitive parameter in terms of manufacturability is seen to be the duty cycle; a value of less than 0.35 is required to obtain the highest efficiency.

3. Grating Fabrication

Witness and production substrates were coated with a multilayer stack according to the optimized design using ion-assisted e-beam evaporation. These substrates were then vapor-primed with HMDS to promote resist adhesion, then coated with ~500 nm of a high-contrast photoresist, and softbaked at 100C for 90 min. in a convection oven. Witness parts were spin coated, and the large production parts were coated using a meniscus coater [8] . The parts were exposed to interfering collimated beams from a fringe-stabilized single-frequency 413nm Kr-ion laser, using LLNL's meter-scale laser interference lithography station. Exposures and development with a liquid base solution development, resulted in surface relief gratings in the resist layer, cleared to the top SiO_2 layer and of the proper duty cycle. Grating profiles were measured nondestructively using atomic force microscopy (AFM) at the

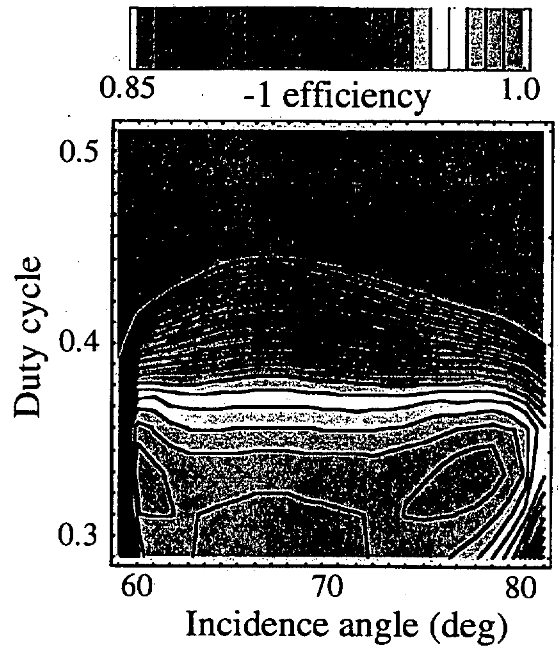


Figure 1. Theoretical efficiency of dielectric grating design as function of incidence angle and duty cycle, dor fixed grating height of 700 nm.

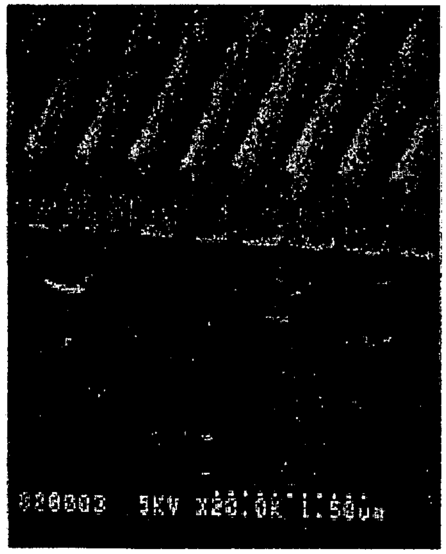


Figure 2. SEM of witness MDG.

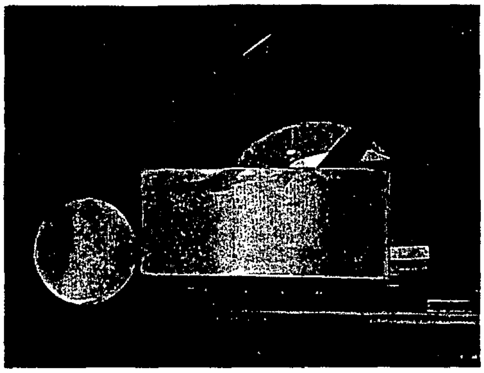
end of the develop, etch and resist-strip steps to assure clearance to the substrate and the correct duty cycle. T. Re-patterning could be done if grating profiles were not acceptable after the exposure/development step. Q/A'd parts were then hardbaked to cure the resist mask for subsequent transfer etching.

The grating profiles were transfer-etched into the topmost SiO_2 layer in an Oxford Instruments ion-beam etcher with a 40 cm ion gun. The procedure was optimized using planetary motion of the target platen and masking between the source and the platen to achieve ion-current uniformity over >30 cm radial aperture. The system was configured to run as a reactive ion beam etcher, by introducing the active chemical etching species along with Ar in the ion source. Prior to etching into the SiO_2 layer a 'descumming' process to ensure that the photoresist was completely removed in the grating grooves. This resist strip step was also performed subsequent to the etching to remove the remaining photoresist mask. The SiO_2 etching was performed using CHF_3 as the fluorine source. SiO_2 etch rates of ~2 nm/.min were typically achieved in this system.

Ride-along witness parts coated with identical multilayer coatings were destructively examined using scanning electron microscopy (SEM). An example of the microstructure one ride-along part is shown in Figure 2

4. Grating Performance

A photograph of the finished grating is shown in Figure 3. Figure 4shows the –1 order diffraction efficiency as a function of angle for 1030 nm, TE polarized light, taken as a series of spot measurements using a 2-channel ratioing power meter. Eficiencies > 99% are measured near the use angle of 63°. The Littrow angle for this grating is 68° at this wavelength. The spatial uniformity of the grating efficiency could not be measured at 1030, but a scanning photometric efficiency map was done using a portable 1064 laser at 71° incidence angle. This is shown in Figure 5. The average efficiency of 89.5 agrees well with model predictions for this wavelength and angle. The efficiency is extremely uniform spatially, exhibiting a standard deviation of 0.55%. This is attributable to the etch-stop layer and tight control of our areal exposure uniformity.



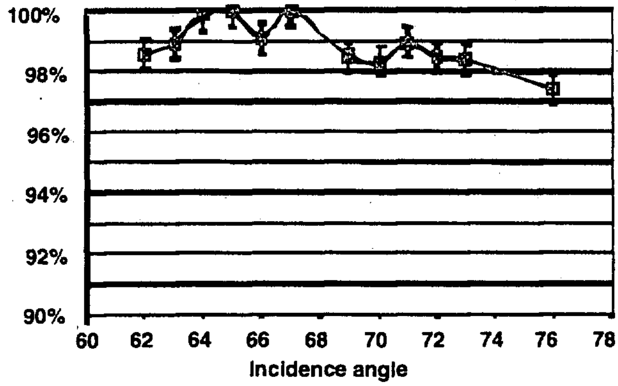


Figure 3. Photograph of 355x150 mm MDG also Shown with 150 mm round grating of same design

Figure 4. –1 order diffraction efficiency as function of angle for 130 nm, TE polarization.

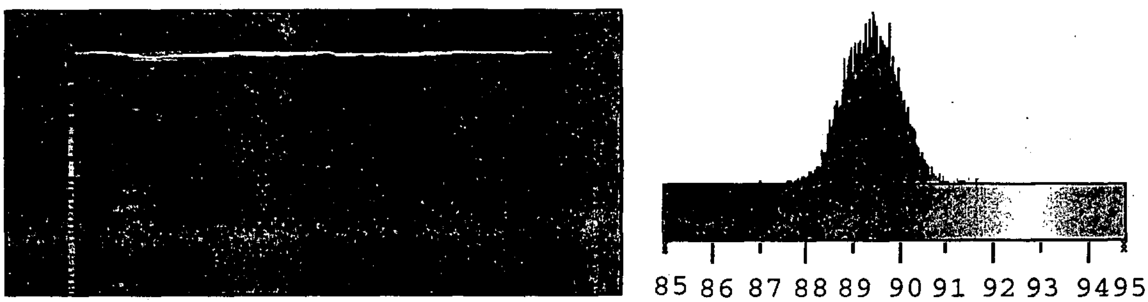


Figure 5. Diffraction efficiency map at 1064, 71 deg, TE polarization. Average = 89.%, σ = 0.55%, 9900 data points.

The –1 order diffracted surface figure of this part, measured at 632 nm, is shown in Figure 6. This data, converted to use wavelength, results in a diffracted wavefront of ~0.15λ based on an average of lineouts across the long axis of the grating.

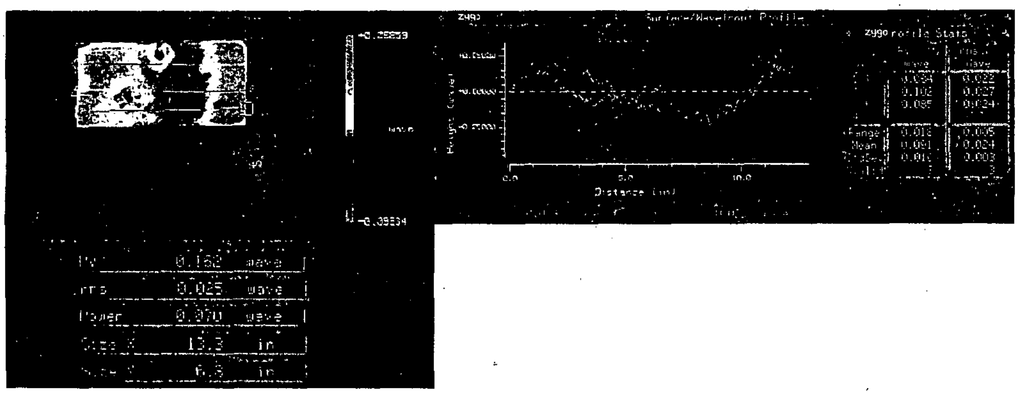


Figure 6. Full-aperture diffracted surface figure of grating at 633 nm.

4. Summary

This grating met or exceeded all specifications for its use in a short-pulse machining laser. The compressor throughput achieved by its high efficiency has allowed the realization of specified power to target without risk of thermal lensing in the upstream amplifiers.

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6. Acknowledgements

This work was performed under the auspices of the United States Department of Energy by the Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48.