Large Area Pulse Compression Gratings Fabricated Onto Fused Silica Substrates Using Scanning Beam Interference Lithography

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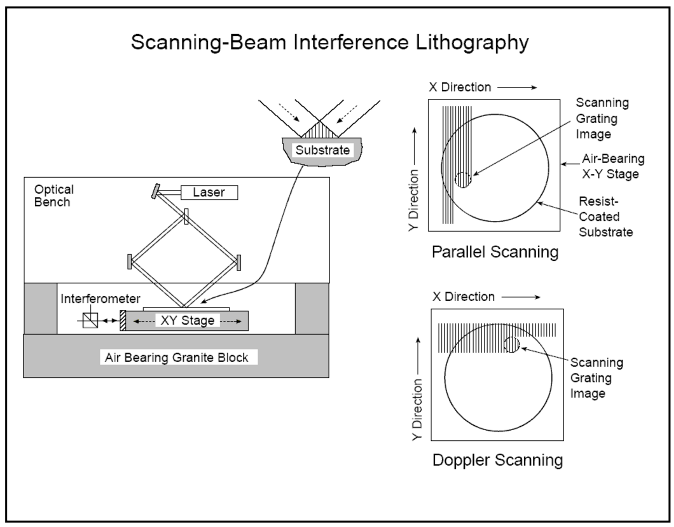
Abstract
Large area multilayer-dielectric (MLD) gratings for high energy pulse compression have been manufactured using a new exposure method called scanning beam interference lithography (SBIL). This technique uses two small beams to form a small area of low distortion, high contrast fringes. The fringes in this small area are phase-locked to a substrate on an x-y stage. As the stage and substrate are scanned underneath the illuminating fringe-spot a resist layer is exposed. The diagram at right shows the fundamental operation of the system. Light from a laser is split into two beams which recombine to form fringes at the substrate (the details of the fringe-locking system are omitted from this diagram). A position-sensing interferometer monitors movement of the substrate stage. The fringe phase is controlled to be stationary with respect to the substrate. Any number of scanning methods may be used but most common (shown) are parallel scanning in the fringe direction and Doppler scanning perpendicular to the fringe direction. The device used to form the fringes, perform the fringe-locking, and scan the substrate is called a Nanoruler.



There are a number of advantages to large area grating fabrication using SBIL. These include:

- The small optics allow the use of motorized stages to control the fringe period and the fringe angle. These may be changed quickly for different grating requirements.
- Deformations in the fringes from defects in the optical system are averaged out first by scanning, and secondly, by overlapping sequential scans. Ultimately, the only effect deformations have is to slightly decrease the integrated fringe contrast. Gratings formed by this method have no “ghost” defects.
- The air path length for fringe formation is very short. Contrast-reducing air turbulence effects are virtually non-existent.
- Exposure control and grating line-width control are exceptional. This translates to good control of diffraction efficiency across the part (See below).
- Exceptional control of the fringe period to less than 1 ppm.
- Ability to place fiducials with a different period for alignment or as depth measurement pads for metrology of subsequent etching operations.

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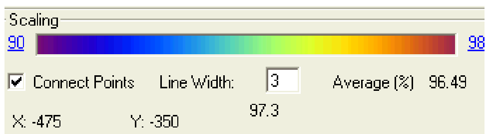
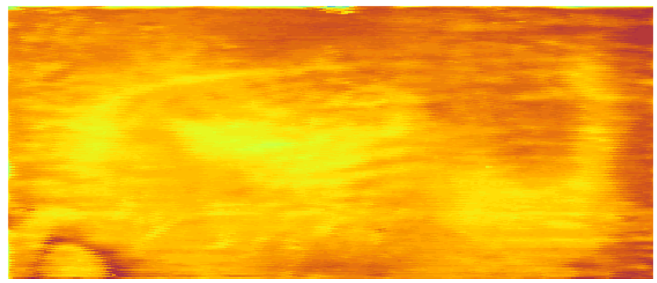
- Limited control of the fringe-locking allows correction of systematic errors in the substrate stage optics.
- In the case of a grating used in a single-pass compressor , the surface errors of the substrate may be corrected by slightly shifting the grating lines while writing. The grating will no longer be symmetrical must then be used in only one of the two 1st orders.
- Larger gratings (for instance, up to 2 meters) may be fabricated by building a larger x-y air-bearing stage.

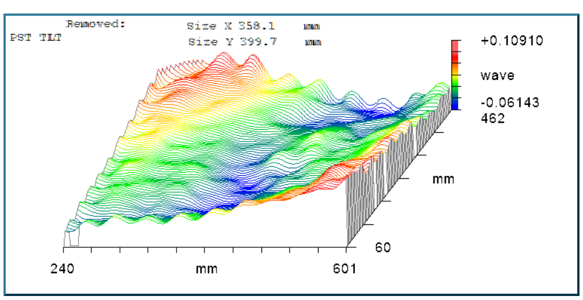
Measured diffraction efficiency of an Osaka University 91cm x 42cm grating at 1740 lines/mm – Average diffraction efficiency for this part is 96.5%. The pattern is due to non-uniformity of the MLD coating



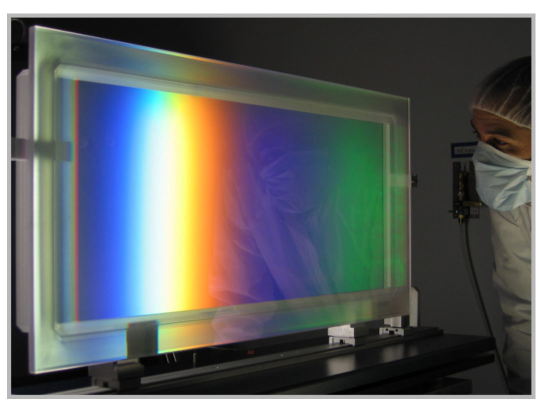


All high-energy compressors gratings must operate in a vacuum environment. Conventional coatings made onto fused silica substrates become highly tensile in a vacuum and often fail by crazing. However, fused silica is a highly suitable substrate for use in tiling situations where small changes in a BK7 type substrate temperatures could cause period errors and phase mismatch. An MLD coating was developed jointly with Osaka University and Okamoto Optics in Japan. This coating uses ion-assist methods to induce compressive stress into the films during coating. This step is necessary for fused silica substrates which form the tensile films due to a thermal mismatch with the coating materials. The coatings were optimized further to have high-damage thresholds at 1054 nm.

The gratings are etched into the top layer of the multilayer and are cleaned of all processing residue. The wavefront of the gratings is measured in a 700 mm clear aperture interferometer operating at 1054 nm. The final gratings are measured in an atmosphere of dry Nitrogen, the closest approximation to a dry vacuum environment. Below is shown a result of a grating measured at the Littrow angle. The results given are for a SINGLE-pass wavefront since these are the units of the known reference flat files that are subtracted from the measurement. A 91cm x 42 cm Osaka grating is shown during inspection on the interferometer stage at right. This grating operates in a double-pass compressor and therefore could not be wavefront corrected as described above.



Single-pass wavefront measurements at 1054 nm: P-V 0.171 Wave, rms 0.031 wave



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