Manufacturing Feasibility of Continuous Relief, Grayscale Diffractive Optical Elements

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Abstract

We are investigating the possibility of replacing binary diffractive optical elements and molded aspheric lenses with a continuous relief optical element known as a kinoform. With continuous relief optical elements, diffraction efficiencies of over 90% have been reported [1,2]. Using a grayscale master and altered properties of a normally analog resist, continuous relief optical elements can be produced with repeatable results. Typical binary structures require multiple masters to be generated. These masters approximate a continuous slope through a binary staircase profile. Alignment of these masters from layer to layer is critical and time consuming. With a gray scale master, multiple mask alignments are eliminated. As a first approximation to determine the manufacturing feasibility of such continuous relief optical elements a calibration master was procured from Canyon Materials. The following atomic force microscope (AFM) scan shows one set of blazed gratings produced from the master.

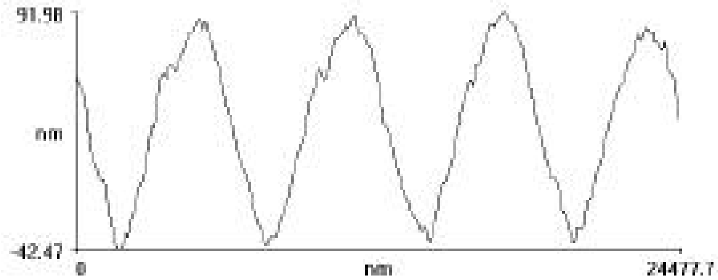

Figure 1. AFM scan of 8 µm blazed grating. Burleigh Instruments AFM was used.

These initial results led to an investigation into producing continuous relief optical elements from grayscale masters. This paper will present the fabrication issues associated with the kinoform elements and the resulting optical characteristics. Specific areas of interest include materials, diffraction efficiencies, wavefront quality, and manufacturing yields.

Introduction

We are investigating the manufacturing feasibility of using a gray-scale master in place of multiple binary masters to produce structures with a continuous profile. The grayscale masters for these experiments use a High Energy Beam Sensitive (HEBS) glass. HEBS glass turns dark when exposed to an e-beam with increasing optical density relative to the total electron exposure. The HEBS glass is a low expansion zinc-borosilicate glass that contains alkali to facilitate ion-exchange reactions that achieves the sensitivity of the glass toward high energy beams.[1] With the ability to control the darkening of the HEBS glass, Diffractive Optical Elements can be manufactured in a single photoprocessing procedure. Typical binary structures are manufactured using multiple masters and a mask aligner. The first layer is exposed and the substrate is processed to reproduce that level into the substrate. A second photoprocessing step is required where the next level mask is aligned to the first and the process repeats. The process of using binary masks results in a stepped approximation of a continuous profile. As the number of

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[1] Chuck Wu. Canyon Materials, Inc. Products Overview HEBS-Glass Calibration Plates.

binary levels increases, this stepped profile will more closely approximate a continuous slope. The efficiency of such devices is directly related to the number of phase levels and also to the inherent manufacturing inaccuracies. This limited efficiency can be improved by using the grayscale technology [3]. The following schematic (Figure 2) exaggerates the difference in this processing.

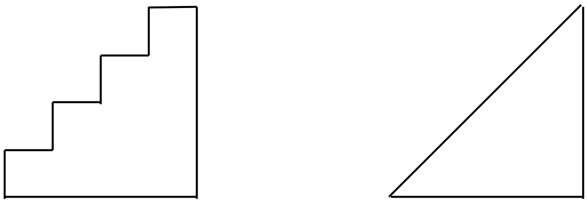

Figure 2. The staircase profile on the left is a binary approximation of the continuous profile on the right. The profile on the right is achievable using grayscale mastering. With binary masters, the steps on the staircase profile are reduced as the number of levels is increased; however the increased cost and the manufacturing inaccuracies can outweigh the efficiency improvements. For this reason, 4 to 8 level structures are typically used to approximate a blazed grating.

Experiment

Using the calibration mask from Canyon Materials, initial prints using a grayscale master were completed. This master contained grayscale images for producing blazed gratings with periods ranging from 8 to 400 μm. Figure 3 is a profilometer scan of the larger period structures (400 μm). These results showed significant potential with sharp edges and angled slopes.

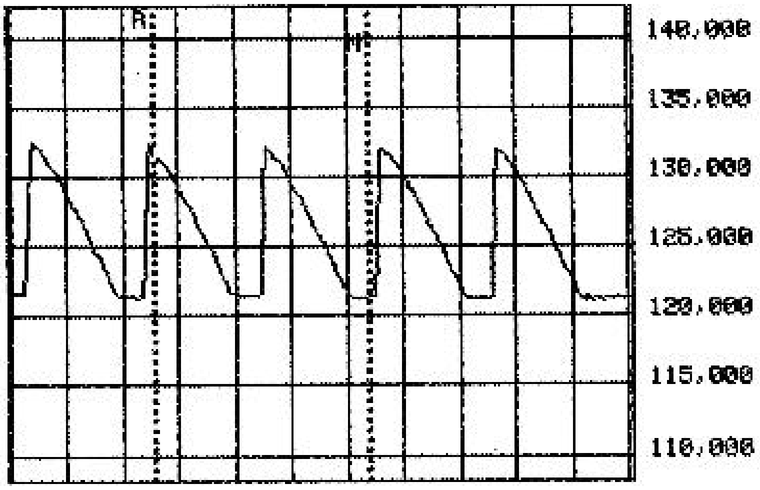

Figure 3. Dektak scan of a 400 μm blazed grating. The stylus used in this scan has a 12.5 μm radius and the vertical scale is in Angstroms.

Other areas on this sample with shorter periods were scanned using a Digital Instruments Atomic Force Microscope (AFM) to evaluate the surface morphology. Figure 4 shows the AFM scan of a 10 μm blazed grating.

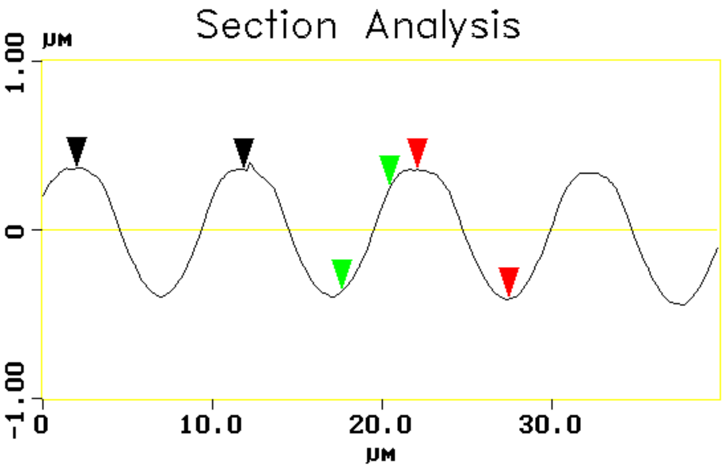

Figure 4. AFM scan of a 10 µm blazed grating.

These features appeared sinusoidal instead of the sharply angled blazed profile that was intended. This resulted from an inadequate match of the relative optical densities of the grating image in the master to our processing techniques. In this type of lithography, the modulation transfer function (MTF) of the contact printing process is a critical parameter. MTF is a measure of the reduction in contrast from the object to the image [4]. To correct for the MTF of our exposure tool, the peak optical density of the master image was reduced toward the bottom of the feature in order to obtain a sharp sidewall. The exposure dosage for the grayscale master was determined from the sharpest features in the larger blazed gratings, shown previously in Figure 3.

To continue with the experimental work, a new master was developed with 10 µm blazed gratings that are closer to the feature size of interest. Ten proximity corrections were included in this master to accurately determine the proper correction to obtain sharp, triangular features. The following AFM scans (Figure 5 and 6) display some early results from this master.

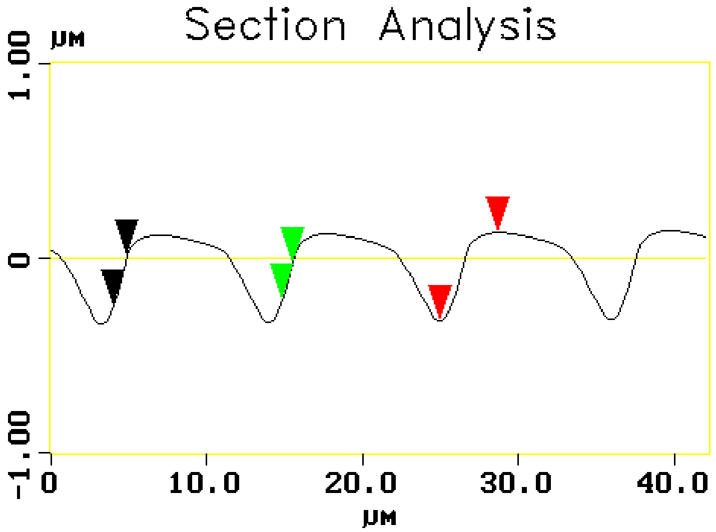

Figure 5. AFM scan of mask (10 µm blazed grating) printed from proximity correction master.

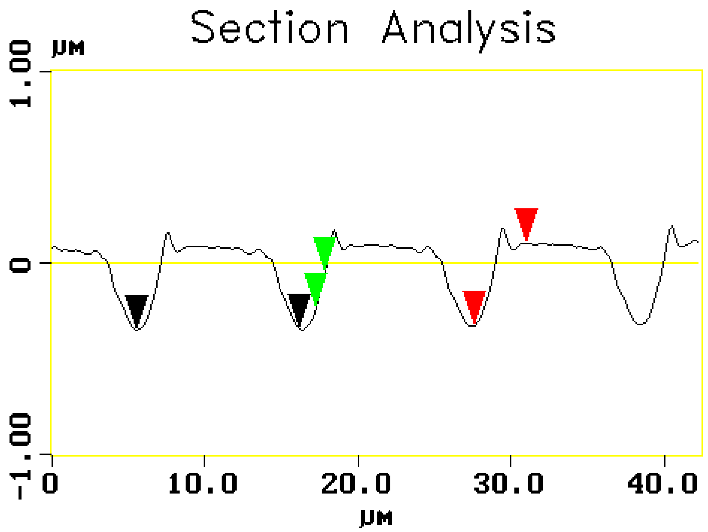

Figure 6. AFM scan of the resulting 10 μm blazed grating produced from mask.

These results show some promise toward achieving the desired triangular shape in the deeper areas of the grating. The degradation of the taller portions of the features resulted from photoprocessing issues not related to the master image. Adjusting these parameters should correct for the truncated shape of the blazed grating.

Further Work

Serious effort into correcting the blazed grating images in the master and projecting this corrected shape into different materials is required. Once the proper shape is achieved on the test structures, testing of the efficiency and wavefront quality will be performed. This information will allow the proper proximity correction for our exposure tool to be finalized and then optical devices can be created using the defined grayscale image levels. This investigation will continue through the process development and manufacturing issues for producing optical devices for solid state laser devices.

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References:

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[4] Eugene Hecht and Alfred Zajac, Optics, Addison-Wesley Publishing Company. Massachusetts, 1974.