A Simple Method to Improve Etching Uniformity when Making Phase Type CGHs on a Thick Glass Substrate

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Abstract: A simple method to optimize the etching uniformity when making a CGH on a thick optical glass substrate is described, which uses a Teflon ring to enclose the substrate during reactive-ion etching (RIE).
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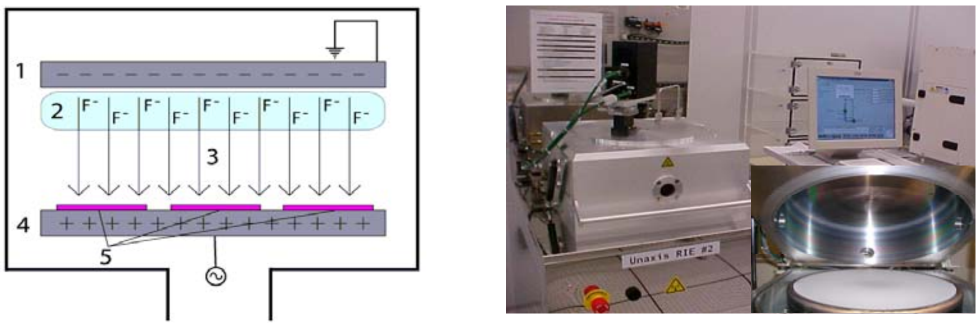
1. Introduction

Increasing use of aspherical elements in optical systems ranging from commercial products to EVU lithography objectives often make computer generated holograms (CGHs) a necessary component in testing optical aspherics with low uncertainty. In a general testing configuration with CGHs, the CGH generates the reference wavefront with the desired shape to match the tested asphere. However, CGHs have several disadvantages. They introduce errors into the test system, have relatively low diffraction efficiency, generate multiple diffraction orders involved in the optical path concurrently, and CGHs fabrication is time consuming and costly. These are the key issues which limit this technique. The measurement results for testing an asphere depend on the accuracy of the CGHs, because CGHs fabrication errors produce errors in the reference wavefront which affect the test results. The CGH fabrication errors consist of substrate errors and pattern errors. The pattern errors can further be categorized as pattern distortion errors, etching depth errors, duty-cycle errors, and surface roughness errors. Generally, the pattern distortion errors are related to the pattern generation process, and depend on the accuracy of the optical or e-beam writing machine. The other pattern errors are mainly affected by the post fabrication process, especially the etching process. Usually, CGHs employed in optical asphere testing are binary diffractive optical elements, of either amplitude or phase type. Amplitude CGHs, also called chrome-on-glass type, have been widely applied in most systems of asphere testing with CGHs, because the pattern formed by a thin chrome coating makes the CGHs insensitive to CGH fabrication errors when used in transmission [1]. The disadvantage of chrome-on-glass CGHs is the lower diffractive efficiency and undistinguishable zero order of diffraction. 10% diffractive efficiency is the maximum for the first diffraction order. In some cases, when the light intensity is too low to have good interferogram contrast when using an amplitude type CGH, phase type CGHs are used because the diffraction efficiency can be up to 40% for the first order of diffraction, and the light intensity from the zero order is controllable or can even be eliminated. Phase type CGHs have a surface relief profile created by etching the pattern into the glass substrate. Some authors [1, 2] have discussed the mechanism whereby the CGH fabrication errors generate wavefront errors. The variation in etching depth is one of the error sources that result in errors in test wavefront. The major etching method employed in pattern transfer on glass substrates to make phase type CGHs is called reactive-ion etching (RIE). RIE was originally developed for making semiconductor devices; the process is sensitive to the feature size and substrate materials. CGH normally has a large range of line widths, and is made on a thick glass substrate. These make it hard to etch CGH uniformly. We developed a new process to optimize plasma chamber condition, which can minimize the features size effect. We also investigated a simple method in which a Teflon annular disk is used to enclose the substrate in a conventional RIE process. By employing these improvements, a CGH on 50 mm diameter substrate, with 5 mm thickness, was made with only 2% etching depth uniformity variation.

2. CGH Reactive-ion Etching

RIE uses chemically reactive plasma to selectively remove material from the exposed area. The plasma is generated under low pressure (vacuum) by applying a strong radio-frequency (RF) electromagnetic field between electrodes, as depicted in Figure 1. High-energy ions from the plasma attack the substrate surface and react with it. In RIE, the energy of charged particles colliding with the surface in a glow discharge is determined by three different potentials established in the reaction chamber: the plasma potential; that is, the potential of the glow region, the self-bias and the bias on the capacitively coupled electrode[3]. Commercially available RIE equipment is typically designed for Si wafer micofabrication. Wafers are normally less than 1 millimeter thick. When much thicker substrates are introduced into the RIE chamber, especially dielectric materials with large areas, e.g., glass substrates, the field potentials and potentials uniformity between two electrodes are changed with respect to the situation with a normal wafer. The fact of non-uniform potentials in RIE chamber above the substrates will lead to non-uniform etching depths. The etching rate close to the substrate edge is larger than at the center. This effect is called edge effect. In CGHs fabrication, thicker substrates are typically required. Based on the CGH fabrication error analysis [1, 2], the CGH substrate errors, e.g., surface flatness error, parallelism error, etc., can reproduce errors in reference wavefront and need to be minimized. Therefore, high surface quality substrates are usually required, a typical surface flatness error is better than $\lambda/10$ peak to valley (λ = 632.8 nm). High precision optics can always be fabricated from a relative thicker substrate because of the mechanism of optical fabrication (lapping, polishing process, etc.). Additionally, to minimize the mechanical deformation induced by CGH mounts and gravity, thicker substrates are necessary in making CGHs. The thickness of substrates varies from few millimeters to tens of millimeters depending on the diameter of CGHs to be made.



A B

Fig.1Reactive-ion Etching facility. A) Diagram of a common RIE setup. An RIE consists of two electrodes (1 and 4) that create an electric field (3) meant to accelerate ions (2) toward the surface of the samples (5). B) Picture of commercial RIE

The edge effect could be demonstrated by observing the glass substrate etching in the following experiments. In our experiment, a RIE tool (shown in Fig.1 b) was used for dry etching a 50 mm diameter fused silica substrate, with 5 mm thickness. The pattern is a nested dual-zone Fresnel zone plate, shown in Fig. 2. Pattern feature sizes vary from half mm down to 12 micrometers. In a general plasma etching, the ions and other species in plasma can reach the local pattern with a bigger feature size much easier than that with a smaller feature size. These result in a varied etching rate on different locations with respect to a different pattern density on a single substrate. This phenomena is called loading effect [4, 5]. By means of optimizing the plasma chamber pressure, gas flow rate and gas combination to increase the plasma mean free path and the chemical reactivity, an effective etching recipe was successfully developed to minimize the loading effect, as shown in table 1.

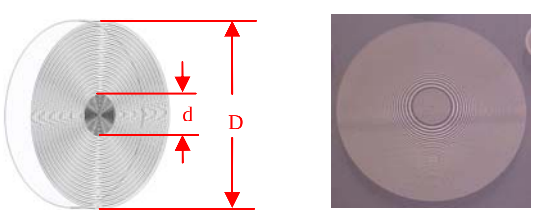


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Fig.2 Nested dual-zone pattern; A) pattern Diagram d=12.7 mm, D=50 mm; B) Photo mask of dual-zone zone plate

Table 1 RIE recipe for nested dual-zone

RF Power	O_2 Flow	CHF_3 Flow	Pressure
300 W	5 cm^3/min	45 cm^3/min	0.033Pa

For the edge effect study, the etching time was 17 minutes, using the recipe in Table 1. Part was then measured under a profilometer after stripping off the residual photo resist. Two orthogonal lines through the substrate center were scanned with the corresponding profiles shown in figure 3. More than 40 points were sampled with non-uniform intervals along each individual test line, higher density sample points were scanned at edge area of substrate. A strong edge effect was observed with nearly 20% etching depth variation in each test line. We also observed that the slopes of etching rate are varied along profile shown in figure 3. The curve slope is much smaller in the center than at the edge, where the corresponding uniform area is about 20 mm in diameter, which is 40% of whole diameter. To better understand the sensitive distance from edge to central on substrate with a strong edge effect, a 100 mm diameter glass wafer was used and patterned at the center using the same mask, and then etched with same recipe for same etching time. The etching depth data cross the pattern area are plotted in figure 4. The etching depth uniformity was improved from 20% down to 5%. The 50 mm pattern diameter located in the center of the 100 mm wafer, corresponds to 50% of the wafer diameter, which is comparable to the 40% of uniform area observed on thick substrate. Based on these two experiments, we can assume that the uniform etching area for a dielectrical substrate is the central 50% of the substrate diameter.

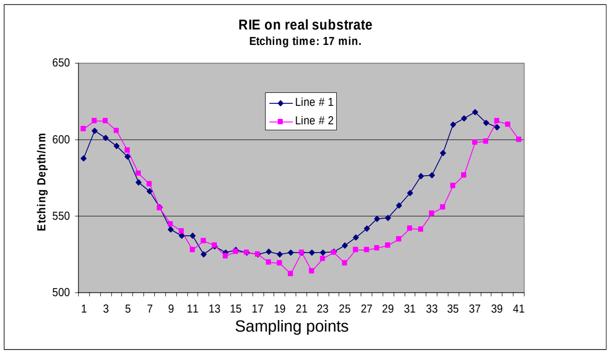

Fig.3 Etching Depth with Sample substrate

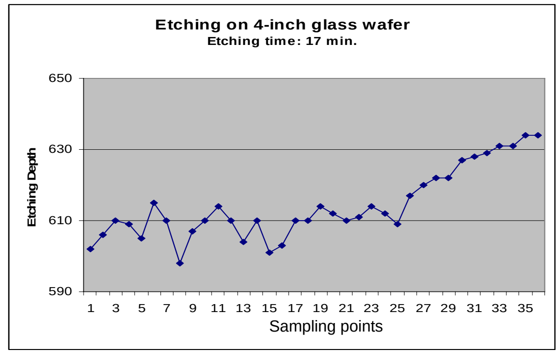

Fig.4 Etching Depth on 4-inch glass wafer

Following this observation, we propose a simple method to use a dielectrical material as dummy part to enclose the substrate. The dummy part has about two times the radius of the glass substrate. To verify this approach, a Teflon annular disk was made as shown in figure 5. The diameter is 100 mm, and the central hole diameter is 50 mm, the same as the substrate diameter.

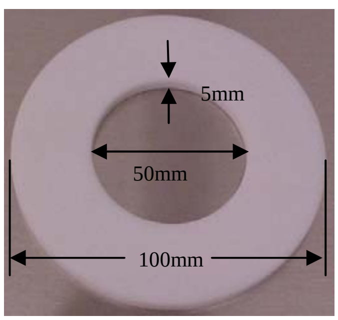

Fig.5 Teflon adapter for 50mm substrate etching

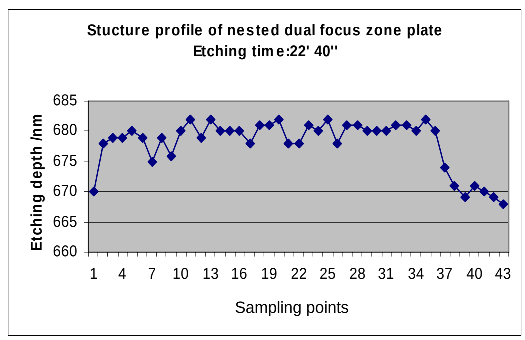

Fig.6 Final part profile by RIE with implementing of Teflon adapter

Under the same etching recipe shown in table 1, the real substrate was then successfully etched with 2% uniformity variation in the etching depth. The result is plotted in figure 6. Compared to the initial etching process on the same substrate, the etching uniformity was improved almost by one order of magnitude. The 2% pattern depth uniformity is acceptable for our error budget of CGHs fabrication.

3. Conclusion

In this paper, we have studied the plasma etching non-uniformity of CGH patterns on a thick glass substrate. An optimized plasma etching process was investigated, and a simple method using a Teflon ring to enclose the glass substrate during the dry etching process was developed. With this new process and approach, a phase type CGH was made with 2% etching depth uniformity. In future work, this method needs to be extended to more general applications, e.g. to substrates with larger diameters.

4. References

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