Replication of diffractive optical elements by injection molding

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ABSTRACT

In this paper we describe the replication processes of DOE carried out at the Diffractive Optics Laboratory / UNICAMP for replicating DOE. In particular we present the results obtained in the replication by injection molding of microlens array, diffraction gratings and polarizing elements. The measurements of the geometric dimensions of the DOE masters, the nickel shims and the replicated structures were accomplished by perfilometry, AFM and SEM microscopy. The optical properties of both the DOE masters and their replicas were evaluated by measuring of the diffraction efficiency as a function of the incident wavelength, for orthogonal polarizations.

1. INTRODUCTION

Diffractive optical elements (DOE) can be design to realize many optical functions as diffraction gratings, computer holograms, polarizing beam-splitters, etc.[1, 2] DOE are interesting for industrial application,[3] due to their small size and low weight allowing the packaging of optical systems. In particular, surface relief DOE present the additional property that can be replicated for mass production reducing hugely the costs of the elements.

The replication process consists basically of three steps:[4, 5] the photoresist master fabrication, the nickel shim (electroformed) and the replica's generation. In this paper, we described the replication of relief DOE and microlens arrays by injection molding.

2. THE REPLICATION PROCESS

The three steps of replication: the recording of the master, the nickel electroforming and the replica generation are squematically shown in Figure 1. The replication step can be performed by injection molding, hot embossing or casting.[4, 5] The suitability of each replication process depends on the costs and on the resolution requirements of each element. As it is described in the literature[4, 5] the casting presents the better resolution, for high aspect ratio structures, however, the associted costs and the production time are relatively high. On the other hand, the injection molding[5] is distinguished for mass-production and resolution capable to copy pits of about 500nm of width and 125 of depth in the large scale production of CDs and DVDs.

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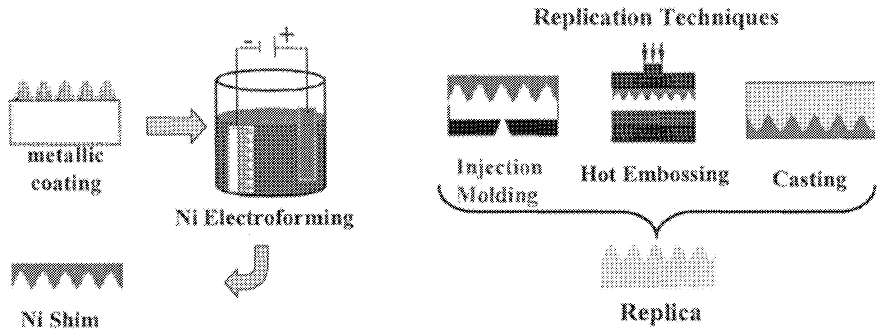

Figure 1: Steps of the replication process. The relief of the master structure is transfered to shim by nickel electroforming. The shim can be used wth differents techniques for the replica generation.

The master structures are recorded on a glass substrate coated with a photorresist film. For the microlens generation we use two steps:[6-8] the lithography and the melting of the resist. In the litography, the photoresist film is exposed to master an array of circular spots. After the developement an array of cylinders were obtained on the glass subtrate. The cylinder diameter is the diameter of the circle spot in the mask and the cylinder height is the thickness of the photorresist film. In the next step, the array is backed up to the melting resist temperature and later cooled to the room temperature. Due to the surface tension of the liquid photorresist the cylinders are deformed in spherical surfaces forming the lens profile, as shown in Figure 2a.

To study the replication of DOE we choose as basic master a surface releif diffraction grating recorded by the projection of fringe pattern of light on the photorresist film.[4, 8] The light modulation is transferred to photorresist by the development process: during the developement the illuminated regions of the photorresist film are removed generating the relief. The Figure 2b shows SEM microscopy of these strctures. The conditions of exposure and developer can be controlled for the generation of different profiles, consequently having different diffraction properties.

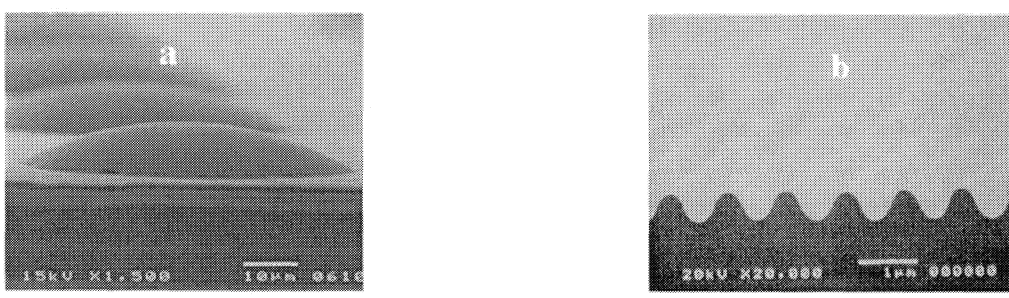

Figure 2: Sem microscopy showing a) the typical profile of a microlens master and b) the periodic relief structure of a DOE.

To check the accuracy and resolutions of the replication process by injection molding, these two types of structures have beem analize. First we record a set of microlenses master arrays with differents diameters D (between 80μm and 250μm) and heights H. These microlenses arrays have beem used in the development of the nickel electroforming step and later, inserted in a injection molding machine. Figure 3 shows the images of SEM microscopy of microlenses replicas made with three different dimensions a) D=80μm and H=8.8μm, b)D=130μm and H=12.8μm, c)D=250μm and H=11μm. The microlens replica showed in the Figure 3a corresponds to the master shownin Figure2a. The replicas are obtained in polystyrene and present good uniformity and repeatability in areas of 3cm^2.

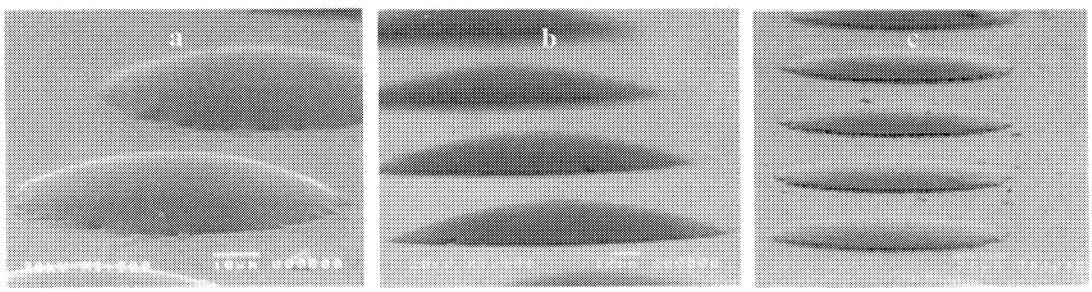

Figure 3: SEM microscopy of different microlenses replicas.

For the analysis of the replication of DOE by injection molding, several surface relief gratings with different periods Λ (0,5μm, 0,8μm, 1μm and 1,6μm) and depths are recorded in a same glass substrate (Figure 3a). The variation of the grating depth was defined by changing the dose of incident energy, during the exposure.

After the development of the glass master, the shim was obtained by nickel electroforming and the structures were replicated by injection, in a CD industry [5][8]. Figure 4 shows the photographs a) of the glass master, b) of the nickel shim c) and of the aluminized polycarbonate replica.

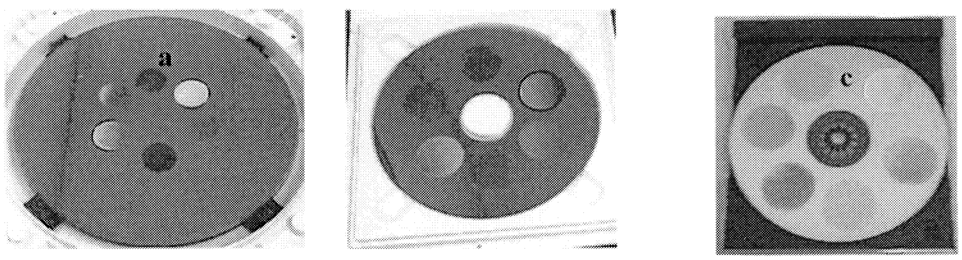

Figure 4: DOE in the different steps of the replication process: A) The glass master, B) The nickel shim, C) The polycarbonate replica.

3. THE CHARACTERIZATION

The geometric characteristics of microlens (diameter, curvature, sphericity) were analyzed by different techniques :[8] electronic microscopy, perfilometer, interferométric microscopy, etc. Among them, the perfilometer furnished the better quantitative and precise evaluation of the diameter D and height H of the structures in the different stages of the replication process. Figure 5 shows examples of the profiles measurements of the structures: a) photorresist master, b) nickel shim and c) replica in polystyrene. The results of these measures, for three different microlenses are listed in Table 1 for comparison.

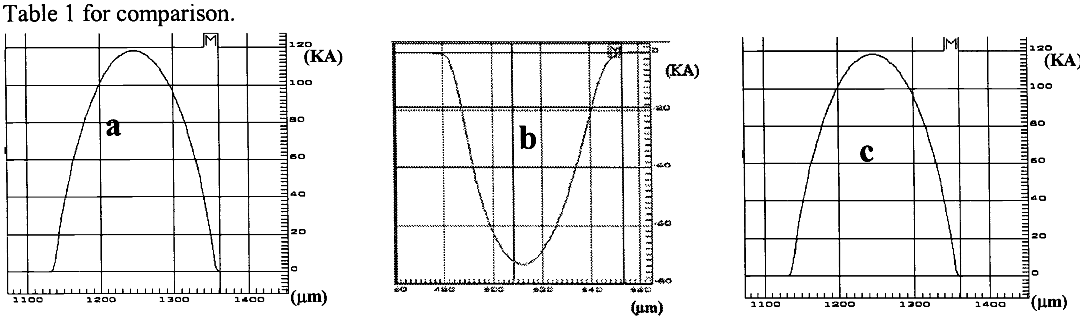

Figure 5: Profiles of the microlens measures by perfilometry, a) the photorresist master, b) the nickel shim and c) the polystyrene replica.

Matriz		Molde		Réplica	
D (µm)	H (µm)	D (µm)	H (µm)	D (µm)	H (µm)
254±2	11,0±0,2	252±2	11,5±0,2	246±3	11,3±0,2
133±2	12,6±0,2	132±2	12,2±0,2	133±1	12,2±0,2
80±2	8,8±0,2	*	*	80±1	8,3±0,4

Table 1: Comparative measurement of the microlenses at the differentes steps of the replication process. The points marked with * correspond to shim dimensions that can't measured with the perfilometer tip.

As can be observed in Table 1 the changes in the lens diameter (D) as well in their heights (H) are smaller than the experimental errors. From these results we can conclude that the injection molding used condition are quite apropriate for the replication of microlens array for the used dimensions.

On the case of DOE, to analyze the accuracy of the whole replication process, the relief profile of the master, the shim and replica were characterized by AFM and SEM and their diffraction optical properties were measured.

The Figure 6 shows an example of the AFM microscopy of a) nickel shim and b) its replica in polycarbonate. Table 2 contains the results of the measurement of the shim and their replica.

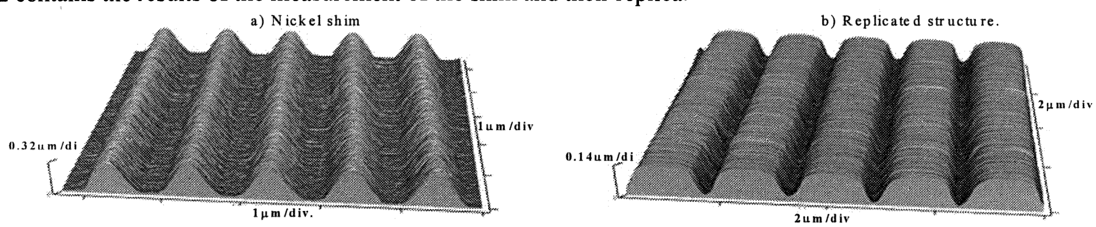

Figure 6: The AFM microscopy of the profiles, a) nickel shim and b) replicated structure.

Shim		Replica	
Λ [µm]	h [nm]	Λ [µm]	h [nm]
1,020±0,004	152±3	0,962±0,003	99±4
1,014±0,003	452±6	0,964±0,002	140±5
1,010±0,006	415±6	0,965±0,003	117±3
0,510±0,001	142±4	0,484±0,003	63±2
0,510±0,003	228±7	0,480±0,001	70±3
0,515±0,006	225±5	0,483±0,004	68±3
0,510±0,002	240±7	0,483±0,003	68±4
0,817±0,002	300±4	0,770±0,002	105±3
1,020±0,004	293±4	0,969±0,003	115±3
1,634±0,007	312±5	1,548±0,005	145±4

Tabela 2: Comparative AFM measurement of the shims and their replicas of DOE.

Previous performed AFM measurements show a good accuracy between the masters and their electroformed nickel shims.[8] In table 2 large variations were observed between the shim and the replicas. A larger reduction of the grating depth (h) occurs, in the replicas, when the grating period decreases. For gratings with period (Λ) =0.5 µm we measured a reduction of about 70% in the depth of the replicas. From these measurements, we conclude that the maximum achieved aspect ratio for the used injection conditions was h/Λ=0.15.

The optical properties of the replicated surface relief grating were analyzed by the measurement of the first order diffraction spectrum, at the of Littrow condition of incidence, for the two orthogonal polarization states. Figure 7 shows an example of measured diffraction spectrum of the master and of its replica. For this couple the period of the master (measured by AFM) is Λ=1μm and the depth (h) h≈0.45μm while for the replica the period is Λ=1μm and the depth h≈0,14μm. This change in the depth can justifies the large variation observed in diffraction spectrum between the master and its replica.

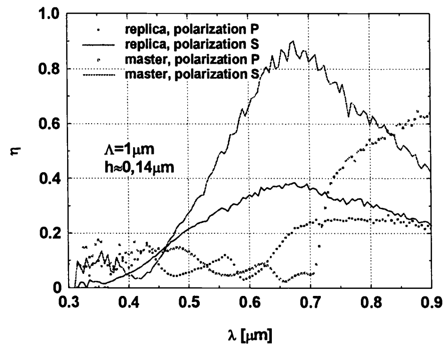

Figure 7: Diffraction spectrum of the master and its replica.

In spite off the depth variations, the replicated gratings can exhibit a significant polarization effect. This can be observed in the first order diffraction spectrum shown in Figure 8. For a replica with period Λ=0,5μm and depth h=70nm, for the large wavelength range between 0,6μm<λ<0,9μm., the replica presents an extinction rate between 6 and 8.

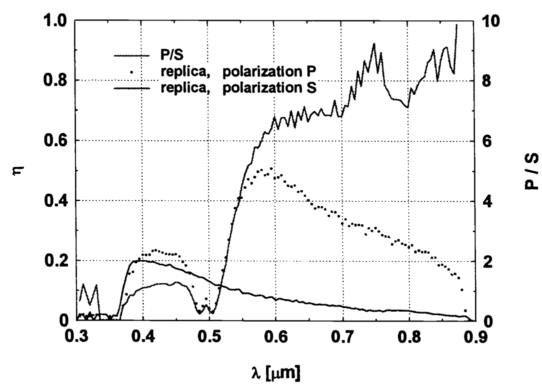

Figure 8: Diffraction spectrum for a replicated polarizing DOE, that reaches an extinction rate (p/S) higher than 6.

4. CONCLUSIONS

In this work we described the replication of arrays of microlenses and of holographics surface relief gratings by injection molding. The replication of microlenses arrays is quite satisfactory achieved by injection molding. For the case of DOE replication, we verified a considerable reduction in the depth of the replicated grating that limits the process employeed to aspect ratios (h/Λ) up to 0.15, for the used injection conditions. Although the change in the depth of the replica alters significantly the diffraction spectrum of the grating (Figure 7), the diffraction efficiency of the replica achieves about 40%, for unpolarized light. A polarizing effect can be observed also (Figure 7). An extinction ratio of about 7, between the orthogonal polarizations, can be observed in the first diffracted order in a wavelength band of about 300 nm.

In order to achieve higher aspect ratios, new sets of tests are now in course. In these tests we are changing the injection conditions such as temperature, pressure and time of injection. On this new series of tests, the parameters of the structures are designed in order to obtain the maximum diffraction efficiency for differents regions of the spectrum (UV, VIS or IV).

5. ACKNOWLEDGMENTS

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