Evaluation of eplication performance in the nanometer range by hot molding of Diffractive Optical Elements

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Abstract

Two experiments were carried out. Firstly, copper samples were diamond turned under different cutting conditions and replicated by means of hot pressing in PMMA. The replication fidelity of the machining works (surface roughness) was assessed. Secondly, a Fresnel lens was replicated (by means of hot pressing) using a diamond turned electroless copper mould. The fidelity of transfer of the fresenel zones was evaluated.

1. Introduction

The application of single point diamond turning to produce microstructures in non-ferrous metals has gained popularity in different industry sectors such as digital camera lens, light guided plate in back light modulus for flat displays, etc. A large number of works address the improvement of moulding in particular, injection mouling to replicated diffractive optical elements [1]. Since injection moulding is a rapid process of pattern transfer, the replication fidelity may sometimes be compromised [2-3]. The objective of this paper is to investigate the replication fidelity of nanostructures and microfeatures generated by diamond turning of electroless copper samples using hot pressing process.

2. Experiments

Two types of replication tests were carried out. First, a flat surface was face turned with a round nose diamond tool (0.5 mm nose radius, 0^o rake angle and 12^o clearance angle, Contour Fine Tooling®) in electroless copper using different cutting conditions as follows: depth of cut varying from 1 to 20 micrometers with constant feedrate of 5 μm/rev; and the feedrate varying from 5 to 20 micometres with constant depth of cut of 5 μm. The spindle speed was kept constant at 1000 rpm. These cutting conditions generated several surface finishes which were assessed. Subsequently, the machined surface was replicated by hot pressing onto poly methyl methacrylate pellets commonly used for plastic injection. The apparatus used for hot pressing was a press used to mould bakelite samples for metallographic characterization. The second type of the test, consisted of molding a concave cavity containing a Fresnel lens. The mould was generated by diamond turning with a special geometry diamond tool with half radius (50 µm, 0^o rake angle and 12^o clearance angle) and replicated by the same process. The topography and surface finish were evaluated by means of an Optical Profiler (WYKO NT1100 made by VEECO™) and scanning electron microscope LEO model 440. Four measurements were taken at the same neighbor in both samples at every 90^o quadrant.

3. Results

Tables 1 shows the transfer ratio as function of the feedrate and Table 2 shows the transfer ratio as function of depth of cut. Transfer Ratio (TR) may be defined as: $[(Rrms_{mach}-Rrms_{repl})*100\%]/Rrms_{mach}$. Absolute values of roughness RMS of both the machined mould and replicated sample are also shown. The difference in surface roughness Rrms between the machined sample and the replicated sample is smaller than 1 nm. The measurements were made at matching points in the machined mould and replicated part (Fig.1a and 1b). The results showed that even nanostructures generated by the material removal process, for example, crystal grain elastic recovery are well replicated with differences in the ranges of tenths of a nanometer which is within the vertical resolution of the profiler (as shown in Fig. 1c and 1 d).

Figures 2(a) and 2(b) show the e-Cu insert with a concave Fresnel profile machined with a half radius tool and the replica obtained by hot pressing process. Figs. 2(c) and 2(d) show the 3D image both sample. Table 3 shows the transfer ratio of the Fresnel zones (7 zones). In this case the transfer ratio of the Fresnel structure is defined as the ratio between mold zone height and the replica zone height. For all zones, the transfer ratio was between 99-100%.

Table 1. Transfer ratio as a function of feedrate (µm/rev) variation.

f	Rrms ± σ Mach.(nm)	Rrms± σ Repl.(nm)	TR %
5	13,99±2,01	13,96±1,21	0,21
10	16,82±2,6	16,74±1,25	0,48
15	19,17±0,71	18,79±0,39	0,80
20	22,29±1,87	22,46±2,14	-0,76

Table 2. Transfer ratio as a function of depth of cut (µm) variation.

ap	Rrms ± σ Mach.(nm)	Rrms± σ Repl. (nm)	TR %
1	11,26 ±0,47	11,06 ±1,85	1,81
3	13,71 ±2,93	13,6 ±0,62	0,81
5	14,77 ±2,26	14,39 ±1,21	0,21
10	14,39 ±1,15	14,53 ±1,05	-0,96
15	15,38 ±2,22	15,46 ±3,36	-0,52
20	14,33 ±2,6	14,51 ±1,43	-1,24

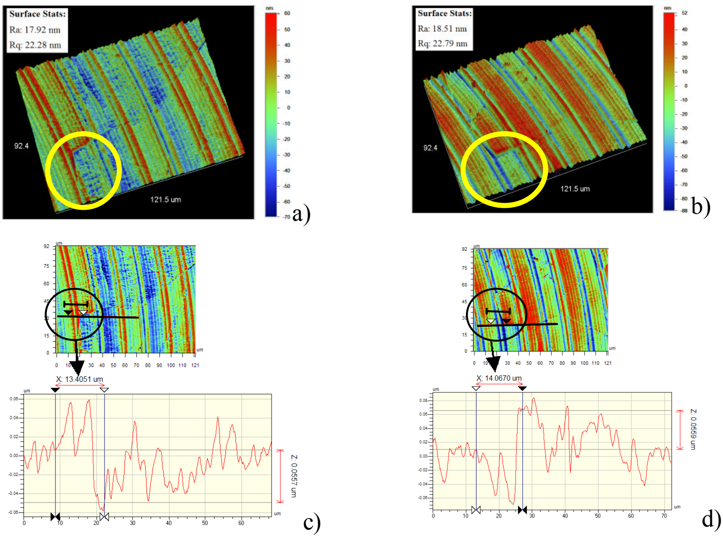

Figure 1. 3D image of the probed samples a) machined and; b) replicated. The cross section profile measure at a specific line on the surface show a good agreement between c) the machined and; d) the replicated sample.

4. Conclusions

Results showed that even nanostructures generated, for example, by random grain elastic recovery of crystal is well replicated with differences in the ranges of tenths of a nanometer which is within the vertical resolution of the profiler. The difference in surface roughness between the machined and the replicated sample was smaller than

1 % in average. The Transfer ratio of the Fresnel structures in the micrometer range was between 99-100%.

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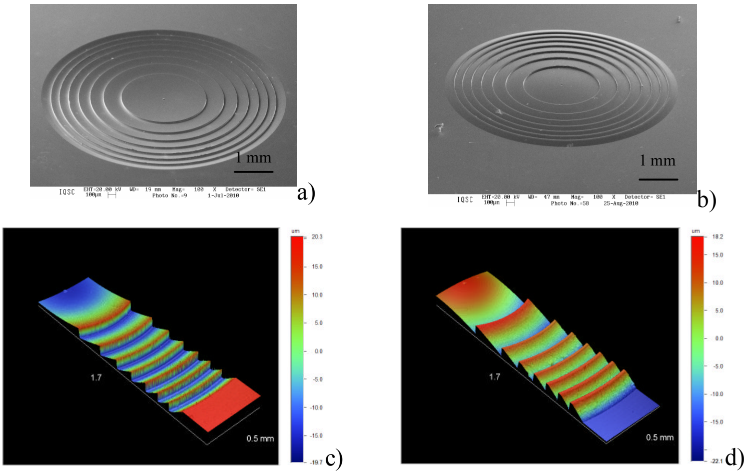

Figure 2. (a) e-Cu insert with a concave Fresnel profile machined with a half radius tool; (b) convex replica obtained by hot pressing process;(c) 3D image of the e-Cu insert with a concave Fresnel profile machined and d) 3D image of convex replica obtained by hot pressing process.

Table 3. Transfer ratio of the mold and replica for the Fresnel Lens

Fresnel Zone	1	2	3	4	5	6	7
Mold Height (μm)	29,53	28,58	28,61	27,64	26,35	25,48	24,78
Replica Height (μm)	29,08	28,4	28,42	27,41	26,45	25,65	24,68
TR (%)	**99,59**	**99,38**	**99,34**	**99,17**	**100**	**100**	**99,59**

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