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Manufacturing of functional surfaces by replicating glass moulds structured by multiphoton polymerization.

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Abstract

The present work deals with the fabrication of very low aspect ratio microstructures generated by Multi-Photon Polymerization (MPP) on glass substrates for their further use as good quality and high resolution replication moulds for optoelectronic devices. A commercial UV-curable resin from the ORMOCER® family was employed for the fabrication of the polymeric microstructures on two different substrates: glass and sapphire. These microstructures were replicated by injection (IM) moulding on polymeric components with an area of several cm2. The results of this work indicate that high resolution moulds can be fabricated through MPP, favouring the fabrication of high-quality replications. Additionally, the microstructures are proven to be resistant to their use through multiple replications. In fact, the topographical characterizations of the first and last replicas show similar characteristics, proving the reliability MPP for the fabrication of high quality moulds.
Keywords: Multiphoton polymerization, femtosecond laser, replication, injection moulding, optical surfaces.

1. Introduction

During the last decades, the fabrication of 3D microstructures in photosensitive resins by the MPP technique has been already presented as a reliable method for obtaining high resolution sub-micron details [Sun HB et al, 2004; Gontad et al, 2019]. Nowadays, the tendency towards the miniaturization of the electronic devices makes the MPP process a suitable methodology for the manufacturing of most of the optical components, such as LED lighting modules and camera optics, or any ultrathin plastic display. Nevertheless, the processing times related to this technique, and so the costs associated, are not adequate for the industry

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requirements. The proposed alternative technology, developed in the frame of the European project FLOIM, consists in an automated in-mould process for the industrial manufacturing of optoelectronic components based on optical quality thermo-plastic injection overmoulding [Linfa Peng et al, 2014].

The work presented here is focused on the fabrication of a diffraction grating by MPP over glass substrates and its latter replication by IM. Both master and replicas have been analysed in terms of their topographical characteristics, comparing height and width throughout several injections.

2. Experimental setup

Masters were fabricated with a laser micromachining workstation from OPTEC, in combination with an Amplitude Satsuma HP2 laser (280 fs, 515 nm) and micrometric precision XYZ linear stages (Aerotech). The power of the laser system was firstly reduced with the combination of a L/2 waveplate and a linear polarizer, and then set by software control. The photosensitive resin used for the MPP process, ORMOSTAMP© (Microresist GmbH), contains a specific photoinitiator for this particular wavelength, being the laser radiation focused inside the resin through an Olympus microscope objective (60×, NA 1.42). The topographical characterization of the 3D microfabricated structures and the replicated samples are performed with an optical profilometer (SensoFar S-Neox).

The diffractive structures were created using 50 mW, 500 kHz, and 3mm/s, and then rinsed with a 50:50 mixture of Methyl Isobutyl Ketone and Isopropanol until all the non-polymerized resin was eliminated. The injection moulding process was performed with an ENGEL injection moulding machine, model VICTORY 40. The material chosen for the replication of the microstructures is Zylar® 960, which is a high flow transparent styrene acrylic copolymer for low temperature (200°C) replications to enlarge the lifetime of the masters.

3. Results and analysis

Previous results on the fabrication of diffractive gratings by MPP over Stainless Steel covered with a thin layer of resin [Otero et al, 2020] showed the good quality of the replicas obtained by injection moulding with Zylar. In the case presented in this manuscript diffractive structures were directly fabricated over glass slides with no specific surface pre-treatment but a surface cleaning with Ketone and Isopropanol. In a first stage, moulds were fabricated on common microscopic glass slides with very good results regarding the dimensions of the structures and the adhesion of all the lines to the surface. However, even though the moulding process was done at low temperatures, the glass slides could not withstand the temperature and pressure conditions of the injection moulding and all of them break during the replications. For this reason, another material with better resistance to thermal and physical shocks was selected. Round Sapphire glasses were cleaned with Ketone and Isopropanol and treated with Ormoprime© to enhance the adhesion of the structures to the glass surface. Most of the replicas were successfully injected but some of them presented several defects, even though the immediate previous and later injections generated perfect replicas. These defects are apparently related to some random thermal mismatch during the injection that did not melt the polymer properly to its optimum fluid state. In the figure below it is showed the main structural differences between the master, a well injected replica, and another replica with injection defects where the direction of the not-totally-melted flux can be appreciated perpendicular to the direction of the fabricated lines. In the case where the injection failed, the shape and the dimension of the replicated lines are far away from the expected values. Master and well replicated lines are around 0.8 µm height and 2.5 µm width, while in the faulty replica the dimensions are between 0.1 and 0.3 µm in height, and between 3 and 4 µm in width due to the poor melting of the Zylar during the injection.

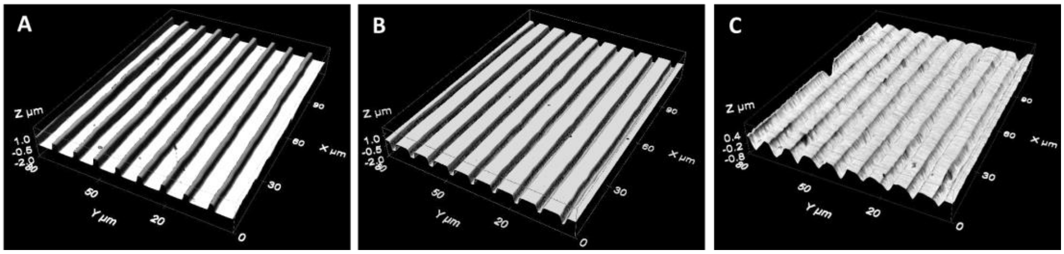

Fig. 1. 3D topographies of (A) the lines fabricated by MPP; (B) lines well replicated in Zylar polymer; (C) lines replicated with defects.

4. Conclusions

The results obtained validate multi photon polymerization as a viable technique for the microstructuring of injection moulding diffraction gratings by using Ormostamp® resin. Micro and nano-structures were successfully replicated on Zylar® 960 samples, demonstrating that optical functional surfaces can be fabricated by the described procedures. The microstructured moulds have shown good behaviour during the IM, surviving several IM cycles at industrial conditions.

Nevertheless, due to the flowing grade of Zylar® 960, some samples were not properly replicated during the IM process and some defects can appear from time to time masking the real topography of the fabricated structures. Further effort should focus on selecting alternative polymers with better flowing properties and/or different injection moulding process parameters, and even alternative moulding methods which guarantee better and more repeatable replication results.

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