Advancing manufacturing route for multi-level diffractive optical elements by combining nanoimprint lithography and LiGa process

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The need for diffractive optical elements (DOE) is strongly growing for applications such as decorative or security features enabling counterfeit authentication with covert laser readable (CLR) nanostructures [1]. In order to reach optically advanced holograms, the use of multi-level pattern is necessary [2]. The pattern origination of these quasi 3D DOE is possible at wafer level, e.g. by electron-beam lithography and anisotropic dry etching of a silicon (Si) master. In most cases, the final DOE need to be transferred into another material such as metal, e.g. when used as an insert for injection molding or for metallic (micro-) parts. Especially in the latter example, the transfer of the DOE by electroplating involves a photolithography step with a negative resist, for example SU-8, defining their final geometry and size. This approach is referred as the CLR-LiGA [3]. Nevertheless, up to date and from the best of our knowledge, the removal of the costly Si-master by etching cannot be avoided. This paper proposes an alternative and sustainable fabrication scheme that enables the multiple use of the costly original pattern and saves the valuable Si-master.

The developed manufacturing route is based on the combination of nanoimprint lithography (NIL) and LiGa process as sketched in Fig. 1. The process compatibility is achieved by using a diligent selection of commercially available materials. Firstly, the Si-master prepared with the DOE (design by Mimotec SA) is replicated into a UV cross-linkable PDMS (Shin-Etsu Chemical Co., Ltd.), Fig. 1a. Subsequently, the UV-PDMS copy is replicated into a hard stamp made of OrmoStamp® (UV-cross-linkable hybrid polymer from micro resist technology GmbH), Fig. 1b. Then, the hard stamp is employed for combined thermal- and UV-NIL into a NIL resist (mr-NIL 6000E, micro resist technology GmbH) coated on a Si wafer, Fig 1c. This concludes the NIL process. Hereafter, the replicated wafer involving the nanostructures in mr-NIL 6000E is covered with a seeding layer, followed by photolithography with an SU-8 based resist defining the electroplating template, Fig 1d. Then, the electroplating of Nickel is performed, Fig 1e. Finally, the metallic parts with the DOE are released by wet etching the Si substrate and by removing the resists by plasma ashing, Fig. 1f.

The results confirm that the pattern original is replicated with high fidelity into UV-PDMS and OrmoStamp®, Fig. 2a-c, as the replicated holograms show a similar quality as the initial ones. The DOE is successfully replicated into mr-NIL 6000E, indicated by the well-defined hologram image (Fig. 3a-b). The SU-8 lithography is performed without affecting the previously replicated NIL pattern. After the electroplating and release of the final components, the functionality of the final DOE is successfully verified Fig. 4a-c).

In conclusion, the proposed combination of NIL and LiGa advances not only state-of-the-art fabrication for metallic DOE, as demonstrated in this work. The innovative manufacturing route also foster a wide range of additional applications, as the process can be easily adapted for the mass manufacture of other metallic components, e.g. with anti-reflection or bio-mimetic surface pattern.

References
Figure 1. Proposed manufacturing route: a) Si-master (dark grey) with DOE replication into UV-PDMS (light grey). b) Replication of the UV-PDMS flexible stamp into OrmoStamp® (orange). c) NIL into mr-NIL 6000E (green) on Si-wafer. d) Seeding layer (light yellow) and SU-8 (dark yellow) UV-lithography. e) Electroplating of Nickel (light blue). f) Release of final component by etching Si wafer and resists.

Figure 2. Fabrication of the working stamp: a) Si-master wafer which is replicated into b) the UV-PDMS material forming an intermediate copy which is replicated into the c) OrmoStamp® material providing the final working stamp. Pattern fidelity of the hologram formed by the CRL-structures is verified for the Si-master as well as for the OrmoStamp® working stamp.

Figure 3. Replication of NIL resist: a) optical microscope image of mr-NIL 6000E replicated nanostructures showing a good fidelity. b) Verification of wll-defined readable hologram.

Figure 4. Applying LiGA process for metallic DOE: a) Substrate after the SU-8 photolithography and development. b) Schematic and optical top-view image of the electroplated final Nickel components with DOE. c) The functionality of the DOE is successfully verified.