Micro-Optical Components Manufactured in Glass by Femtosecond Laser Irradiation Followed by Chemical Etching

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Abstract

Femtosecond laser 3D processing technologies of transparent dielectrics have known an important development in recent years. One of them, known as "Femtosecond Laser Irradiation Followed by Chemical Etching" (FLICE), can achieve volumetric (3D), high-precision and low-cost processing of common glasses such as fused silica. Using a laser system (f100 aHead Enhanced from FEMTOprint) dedicated to the FLICE technique and applied to glass samples subsequently laser-polished, we manufacture custom-made micro-optical components that can be used for integration in imaging micro-systems.

1. Introduction

Due to the increasing demand of free-form micro-optical components to be used in optical systems, new manufacturing processes are required. Many of them provide components made of polymers, characterized by a relatively low-damage threshold, which limits their usage in high-power or high-temperature applications. Hence, more and more attention is paid on glass processing technologies [1] in order to manufacture robust micro-optical components. Among them, the FLICE technique [2], gathering laser irradiation and chemical wet etching, allows generating custom 3D surfaces, which can be used, once polished, to shape light.

2. Micro-Fabrication Strategy

The FLICE technique is first based on a local in-volume structural modification of the glass induced by a femtosecond laser irradiation. The focused laser beam generates a non-linear multi-photon absorption effect, locally modifying the etching selectivity of the material. Thus, all processed areas are then preferentially etched in a hot aqueous Potassium Hydroxide (KOH) solution under sporadic ultrasonic agitation. Thanks to the profound change of the chemical etch-rate, up to two orders of magnitude compared to that of pristine material, glass can be freely micromachined, and chosen volumes of material can be subtracted so that a shaped-surface can be released. The 3D geometry is generated here from a 500 µm-thick fused-silica (FS) wafer. Unlike laser ablation or wet-etching techniques, only the surface of the component, embedded within the wafer, is eventually etched. Hence, the contours of the superfluous volume, along with access trenches to the embedded surface, are also exposed in order to subtract the unwanted material during etching. Therefore, the process starts by drawing the 3D surface of the refractive component located a few tens of microns below the wafer surface, followed by drawing of the closed contours, giving a direct access to the wafer surface which delimits the cover, *i.e.* the superfluous volume to be removed. In order to avoid shape defects resulting from spatially non-uniform etching, this cover is cut with additional access chimneys to provide evenly distributed access of KOH to the 3D laser-exposed surface. These slices also help to fragment the cover, making it easier to separate.

Although lower than for direct femtosecond laser ablation, surface roughness remains significant and avoids the FLICE technique to generate FS micro-optical components without an additional surface treatment. The latter is achieved by CO_2 laser polishing. Indeed, FS absorption at $\lambda = 10.6$ µm is so strong that only its surface temperature first rapidly increases. The quick temperature elevation leads to a viscosity drop followed by a surface relaxation. This fast non-mechanical polishing has the advantage of removing only the high spatial frequencies without generating unwanted additional waviness or bowing. Thus, the initial shape is preserved for high-quality micro-optical component generation.

3. Example: The conical microlens

As an example, we manufacture conical microlenses, also known as axicons, which are particularly interesting components for Bessel-like beam generation. Their shape characterized by a sharp tip makes them difficult to fabricate, particularly in glass [3][4]. The reported components have a diameter of 500 µm and are specified at 5°

angle. After the wet-etching step, the embedded components are released at 67 µm under the surface (Fig. 1 (a) & (b)). The resulting component's surfaces are characterized by a remaining roughness measured, after applying a filter with a 20 µm cut-off, at the level of R_q = 120 nm, *i.e.* still too high for optical applications (Fig. 1(b) inset). Hence, they are processed by CO_2 laser leading to a decrease of its surface roughness towards R_q = 2 nm (Fig. 1(c) & (e)). The measured profile of the polished component is close to the ideal conical shape (Fig. 1(e)), with an averaged angle of 5.15° depending on the radial profile considered and a waviness lower than 60 nm (RMS) (Fig. 1(d)). Due to polishing, the tip gets slightly rounded with a radius of curvature measured at 261 µm (Fig. 1(c)). When the quasi-Bessel beam generated by the axicon is imaged along its propagation [5], the rounded-tip is responsible for a slight modulation of its on-axis light intensity along with a delay in the Bessel beam formation from the tip (Fig. 1(f)). Nevertheless, the generated beam displays a nearly constant FWHM of 6 µm (Fig. 1(f) inset) along more than 4 mm propagation, proving its non-diffracting character.

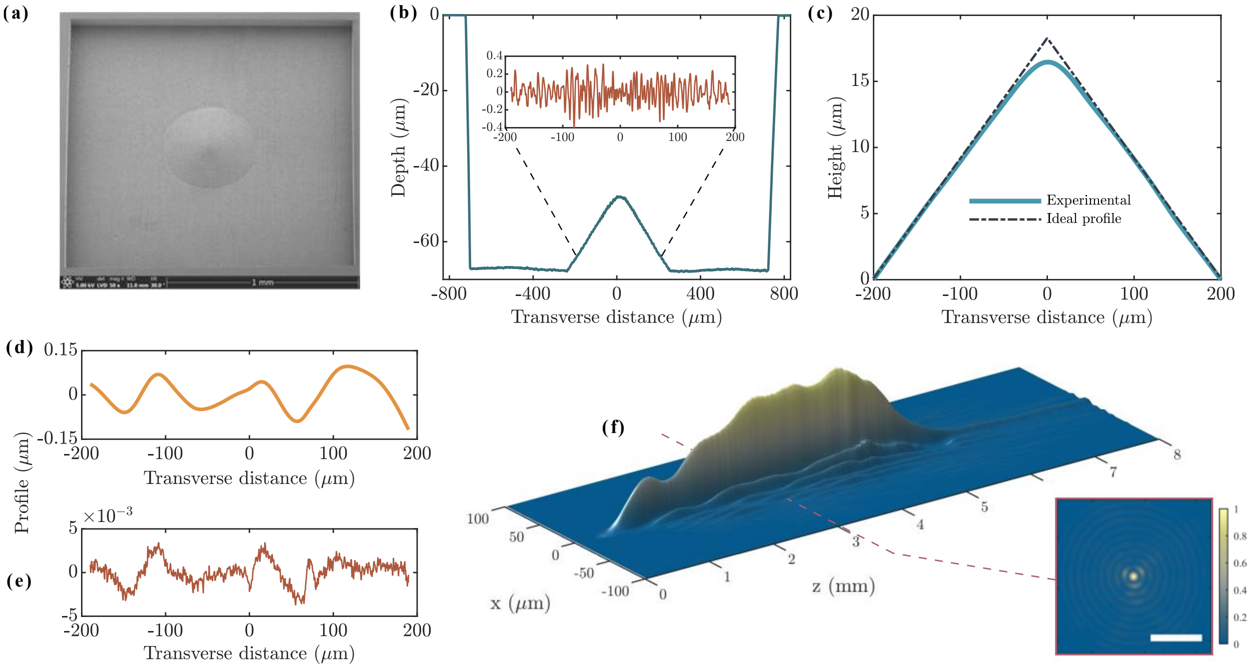

Figure 1 : (a) SEM image of wet-etched axicon of 500 µm diameter before polishing, (b) embedded axicon profile; inset: typical roughness profile before polishing, (c) experimental cross-sectional profile of the laser-polished axicon, (d) resulting waviness profile and (e) resulting roughness profile after applying a filter with 20 µm cut-off, (f) evolution along the propagation direction of the transverse intensity distribution of a collimated beam shaped by the axicon into a Bessel beam (inset: transverse intensity at z = 3 mm. The scale bar is 50 µm).

4. Conclusion

We report the use of FLICE technique combining femtosecond laser irradiation and chemical wet-etching in order to manufacture micro-optical components made of glass. We show that high-quality surface profiles can be obtained leading, e.g. to the fabrication of axicons able to shape quasi-Bessel beams. Such miniature components are intended to be integrated into optical micro-systems used for biomedical imaging.

References

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