Enhancing Chiral Optical Element Fabrication Through Polarization-Modified Bessel Beams

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The creation of chiral optical components plays a pivotal role in the fields of optics and photonics, broadening the array of tools available for manipulating and detecting atoms, molecules, and solids using light. Previous research has established that silica-based nanogratings produced through ultrafast laser writing can exhibit chiral characteristics [1]. However, the ability to customize these chiral properties is significantly limited when using conventional Gaussian beams due to their relatively small optical thickness. Recent advancements have introduced a multi-layer laser writing approach that unlocks new possibilities for achieving substantial chiroptic properties [2].

In this study, we introduce a novel approach centered on modifying the polarization of Bessel beams [3] to enable the one-step fabrication of nanogratings with varying orientations, thereby conferring them with chiral optical characteristics. To achieve this, we have devised a laser-written spatially variable half-waveplate capable of controlling polarization states within the injection plane of the Bessel beam. Leveraging the conical propagation of light within the Bessel beam, we can precisely program the evolution of polarization along the central core of the beam as it propagates. Figure 1 illustrates (a) the initial polarization state and (b) the polarization evolution of the Bessel beam, which rotates from 90 to 0 degrees during its propagation. Subsequently, we employ this beam with rotating polarization to fabricate nanogratings, resulting in a single-pass production of nanogratings with orientations that vary with depth, as shown in Figure 1(c).

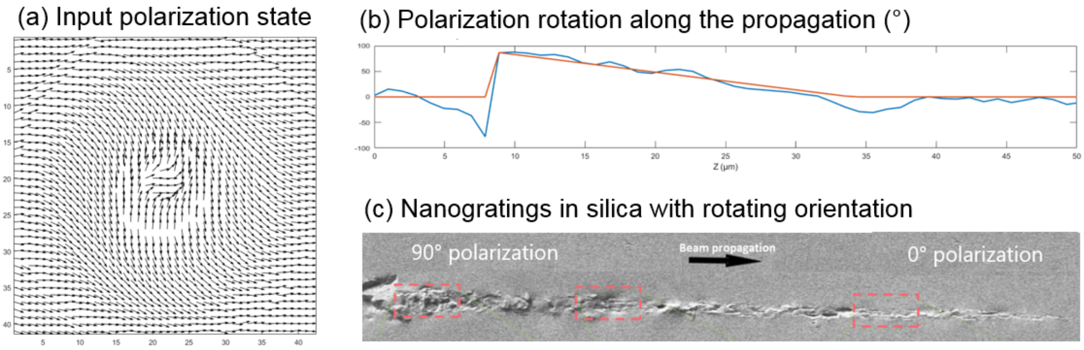

Fig. 1 (a) The experimental input polarization state generated by manipulating a variable half-waveplate through fs-laser-induced birefringence. (b) Experimental assessment of the polarization state at the focal point of the Bessel beam (shown in blue), compared to the anticipated behavior (indicated by the orange line). (c) Scanning Electron Microscope (SEM) image depicting the nanograting structures formed in fused silica (achieved in a single pass) utilizing the polarization-tailored writing beam. As anticipated, we observe a rotation in the orientation of the nanogratings with increasing depth, mirroring the polarization characteristics of the polarization-shaped writing beam.

We will present measurements of optical rotation and circular birefringence under various laser inscription parameters [4]. Our characterization reveals that the circular birefringence is twice as large when using the polarization-rotating Bessel beam compared to a 45-degree polarization Bessel beam, while simultaneously exhibiting four times smaller total linear birefringence.

Considering the ease with which the focal region length of Bessel beams can be scaled up [3], we anticipate that our approach will not only enhance the fabrication speed of nanogratings-based optical elements but also facilitate the development of intricate polarization-shaping optical components for novel applications in optics and photonics. These applications encompass optical rotators, isolators, optical tweezers, and beyond.

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References

[1] B. Poumellec, M. Lancry, R. Desmarchelier, E. Hervé, and B. Bourguignon, "Parity violation in chiral structure creation under femtosecond laser irradiation in silica glass?," Light Sci. Appl. **5**, e16178 (2016).

[2] J. Lu, E. Garcia-Caurel, R. Ossikovski, F. Courvoisier, X. Zeng, B. Poumellec and M. Lancry, "Femtosecond laser direct writing multilayer chiral waveplates with minimal linear birefringence," Opt. Lett. **48**, 271-274 (2023).

[3] R. Meyer, L. Froehly, R. Giust, J. Del Hoyo, L. Furfaro, C. Billet and F. Courvoisier, "Extremely high-aspect-ratio ultrafast Bessel beam generation and stealth dicing of multi-millimeter thick glass, " Appl. Phys. Lett. **114**, 201105 (2019).

[4] J. Lu, M. Hassan, F. Courvoisier, E. Garcia-Caurel, F. Brisset, R. Ossikovski, X. Zeng, B. Poumellec, and M. Lancry. "3D structured Bessel beam polarization and its application to imprint chiral optical properties in silica." *APL Photonics* **8**, no. 6 (2023).