Micron-precision in cleaving glass using ultrafast Bessel beams with engineered transverse beam shapes

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Ultrafast lasers in association to beam shaping have shown to be excellent candidates for transparent material processing [1]. Non-diffractive solutions such as Bessel beams allows for precise energy deposition since they are robust to undesired non-linear effects and as they do not distort along the propagation [2]. This offers important opportunities in laser-assisted cleaving, i.e. mechanical medium separation after single-pass laser illumination. Here we break the Bessel beam cylindrical symmetry using a novel anisotropic and non-diffractive solutions to investigate both lateral intensity contributions on material response and induced processing effect for non-cylindrical defects. Using such beam shape, we report a strong cleavability enhancement as well as an improvement of the final robustness of the separated glass in comparison with Bessel beams. We demonstrate cleaving for laser-writing speed as high as 25mm/s with ~1µm accuracy over the whole 20mm sample length.

We engineer an Asymmetrical Bessel beam (ABB) shape that exhibits a 3-hot spots transverse intensity profile (Fig 1.a) and preserves non-diffractive properties of symmetrical Bessel beams (SBB) (Fig 1.b and c). We process 150µm thick glass samples by a succession of laser shaped pulses along a line, using different beams shapes and beam orientations (Fig 1.d). The samples are fractured under a 3-points bending test (Fig 1.e) which presses samples along the laser processed line (Fig 1.e). We measure sample fracture toughness by measuring the sample deflection from the first contact to failure position. Our results exhibit unintuitive features: ABB-parallel case (3-hot spots along the laser writing direction, see Fig 1.d) leads mostly to sample breaking while ABB-orthogonal provides systematically a nice cleaving for pulse energies up to 12µJ. Scanning Electron Microscopy (SEM) pictures reveal that cleaving happens exactly at the center of the central channel all over the sample thickness and on the whole sample length, as shown in Fig 1.g therefore with 1 µm precision. This case even provides a better cleavability than with usual Bessel beams and better preserves the toughness of cleaved edges. Finite Elements Methods (FEM) simulations allow us to attribute the high cleaving efficiency to the elliptical shape of the main laser-induced channel (Fig 1.h), due to the elongated main lobe of the ABB profile, in agreement with [3].

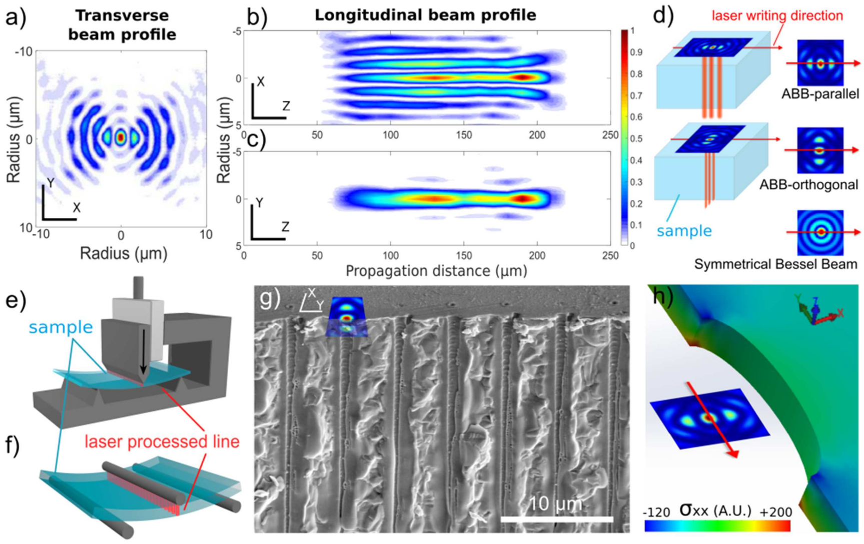

Fig. 1: a, b, c) Experimental transverse and longitudinal profiles of Asymmetrical Bessel beam in air. d) Different processing methods employed in our study. e) 3-point bending test and f) schematic sample bending. g) SEM picture of a cleaved sample edge (tilted view at 52°). Inset: scaled laser transverse intensity profile. h) FEM simulation of transverse stress at main elliptical channel vicinity (only a half shown here; stress in arbitrary units).

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References

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