Stealth dicing with ultrafast Bessel beams with engineered transverse profiles

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Abstract: We investigate high-speed glass cleaving with ultrafast laser beams with engineered transverse intensity profile. We achieve accuracy of ~ 1 µm at 25 mm/s and drastically enhance cleavability compared to standard Bessel beams.

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1. Introduction

Ultrashort non-diffractive solutions such as Bessel beams have shown to be excellent tools for transparent material processing and cutting since they do not distort along the propagation and as they are robust to non-linear effects [1]. In addition they allow for high intensity deposition control over long distance [2]. This offers important opportunities for transparent material stealth dicing which is based on a two steps method [3]: first a single pass laser illumination induces defects that weaken a vertical plane in the medium to be cut and second, material separation occurs after slight mechanical bending (i.e. cleaving).

Here we highlight the possibility to control the energy deposition in volume even better than with conventional Bessel beams, allowing for high speed material separation. We engineer a multiple transverse intensity distribution that preserves non-diffractive properties and allow for enhanced cleaving ability of glass. We compare sample mechanical response after laser illumination for different beam shapes and energies, using a 3-point bending test and modeling data with Weibull cumulative distributions. Cleavability and edge toughness are measured and compared, showing that transverse intensity distribution strongly impacts stealth dicing properties. We finally demonstrate glass cleaving for laser writing speed as high as 25mm/s and with accuracy approaching 1 µm over the whole 20 mm sample length and 150 µm thickness.

2. Experimental setup

We use a 800nm Ti:Sa source which delivers pulses stretched to ~2.3 ps duration full-width at half maximum (FWHM). We generate a primary Bessel beam that we demagnify with a telescope in order to increase the focusing angle to 17° over a 120µm FWHM distance in air.

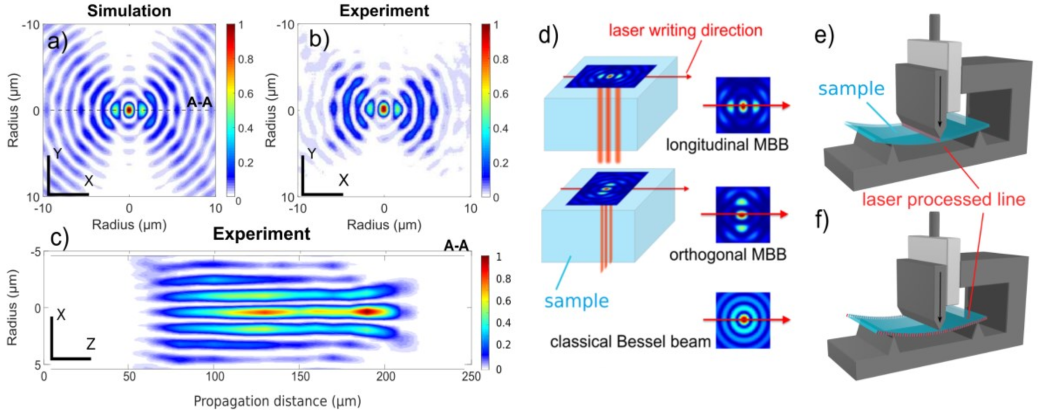

Figure 1: 3-spots Modified Bessel Beams (MBB) generation proof of principle and mechanical investigations methods. We compare simulated and experimental normalized intensity distributions respectively in a) and b), while longitudinal profile is shown in c) exhibiting non-diffractive properties over 120µm. d) presents the different processing cases related to MBB and in comparison to Bessel beams. e) and f) compare mechanical investigations methods using a 3-points bending test respectively in cleaving toughness and edge toughness cases

By spatial filtering in the Fourier plane of our telescope, we break the Bessel beam cylindrical symmetry and generate a novel beam shape (MBB) which features multiple hot spots (Fig 1.a and b) and non-diffractive properties

(Fig 1.c) A great agreement is obtained between simulation and experimental beam profiles. Polarization is set to circular to avoid any privileged direction.

We process the samples 2 configurations: longitudinal and orthogonal as shown in Fig 1.d and compare to Bessel beam processed samples. To quantify mechanical response after single pass laser illumination we bend the samples using a 3-points bending test (Fig 1.e and f) and measure the required deflection to fracture, from the first contact to sample failure. We distinguish nice “cleaving” (i.e. separation in 2 pieces) from “breaking” which means a non-guided failure resulting several pieces from the initial sample.

3. Results and discussions

Figure 2.a) shows the deflection needed to fracture the sample after single laser pass illumination for the different illumination schemes and energies. 6μJ processing does not provide sufficent defects for sample cleaving in all cases. For 12μJ and 18 μJ, we note a severe difference as longitudinal MBB provides mostly breaking while Bessel beams and orthogonal MBB systematically lead to nice cleaving (Fig 2b). In addition, we observe that for orthogonal MBB case, cleaving happens precisely along the laser processed path with an accuracy about 1μm over the whole sample length (Fig 2.b). Fracture propagates exactly at central channel middle that is induced by the most intense lobe of the MBB. Corresponding nanochannel is then open all over the edge thickness (Fig 2c).

Additional measurements have shown the cleaved edge is even more robust after processing by a MBB than with a classical Bessel beam. Edge toughness improvement is about 30% using orthogonal MBB. Numerical simulations further confirmed the strong enhancement of stress generated in the sample by the orthogonal MBB (right of Fig 2.a).

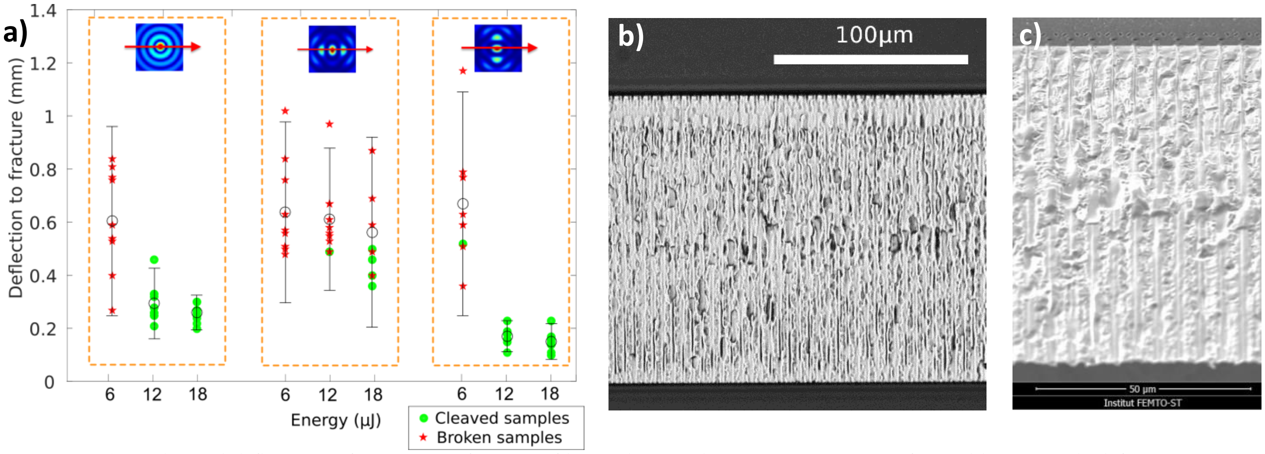

Figure 2: a) Mechanical deflection to fracture as a function of beam shape and energy. Comparison of Bessel beams on the left to MBB (resp. longitudinal case on middle; orthogonal case on the right). We distinguish cleaved samples (green disks) from broken samples (red stars). b) Optical microscope and c) Scanning Electron Microscope (tilt=52°) pictures of a sample edge, which was cleaved after illumination by orthogonal MBB.

4. Conclusion

We have demonstrated the feasibility of glass stealth dicing at extremely high precision with non-cylindrical diffractive-free beams. We have shown that stealth dicing of glass is controlled by the stress around laser-induced defects and not by the channels themselves and that transverse intensity profile strongly impacts the sample toughness. We believe this approach will foster new advances in ultrafast laser structuring of transparent materials.

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References

[1] M. K. Bhuyan et al., "High aspect ratio nanochannel machining using single shot femtosecond Bessel beams" Appl. Phys. Lett., **97**, 081102, (2010).

[2] F. Courvoisier et al. “Applications of femtosecond Bessel beams to laser ablation” Appl. Phys. A, **112,** 29–34 (2013)

[3] F. Ahmed, M. S. Ahsan, M. S. Lee and M. B. G. Jun, “Near-field modification of femtosecond laser beam to enhance single-shot pulse filamentation in glass medium”, Appl. Phys. A, **114,** 4, 1161-1165 (2013)

[4] A. R. Collins and G. M. O'Connor, "Mechanically inspired laser scribing of thin flexible glass" Opt. Lett., **40**, 120, 4811-4814, (2015).