Bessel Vortex Filaments for Laser Material Processing

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The field of femtosecond beam shaping is undergoing rapid expansion for numerous applications since intense-light-matter interactions are used in both fundamental and applied science. Laser processing of transparent materials is currently an important technological topic, because transparent materials have an increasing number of applications in consumer electronics, microelectronics, photonic chips or next-generation displays. Single-shot machining by structured beams is attractive for such applications, but only void nanochannel fabrication has so far been demonstrated from Bessel beams [1]. The challenge in laser structuring of dielectrics is that the high intensities required (>10^{13}W/cm^2) are associated with strong spatio-temporal nonlinear distorsions of the laser pulses.

Here, we report a new regime of tubular filamentation, where energy can be deposited on a very long hollow tube. This regime is seeded by ultrashort higher-order nondiffracting Bessel beams, which carry an optical vortex charge. We have analytically predicted the existence of a stationary regime, behaving as an attractor, where nonlinear Bessel vortices propagate at high intensity without deformation, and exist over a wide range of parameters [3]. This is very different to other areas of nonlinear optical localization such as solitons where a very delicate balance is required.

To experimentally investigate these solutions, we have developed a novel approach allowing 3D imaging of filaments in transparent solids with, for the first time to our knowledge, direct quantitative comparison to numerical simulations.

At low Bessel cone angle, we also report transitions from stationary regime (Fig 1.(b,e)) to other nonlinear regimes: rotating –where several filaments are generated and rotate around the optical axis (Fig 1.(c,g)) and "speckle-like" where multiple hot-spots appear and disappear along the propagation in absence of rotation (Fig 1.(d,h)) [4]. Higher conical angles maintain the quasi-stationary regime at higher energy, thus opening the possibility of high-quality tube machining inside the glass sample (shown in Fig. 1(i, j)).

This new tubular regime at high intensity allows for generating waveguides and cylindrical compression in single shot. We anticipate that our results will foster new advances in several areas of ultrafast laser science and laser material processing.

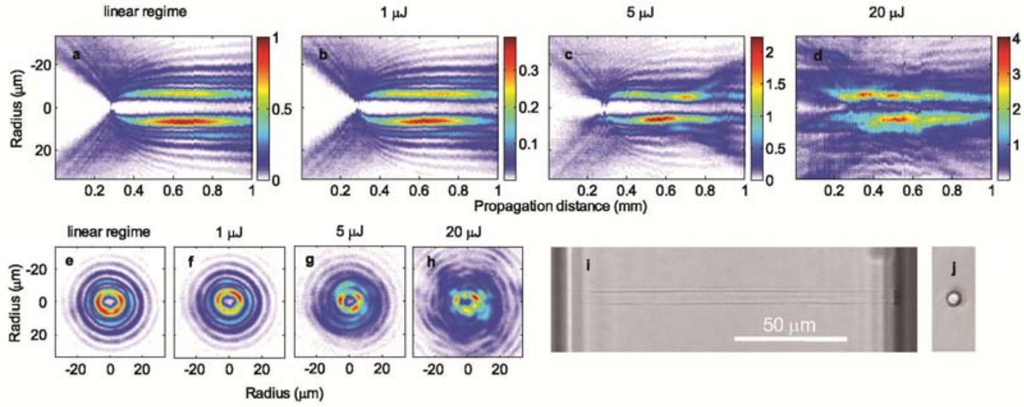

Fig. 1 Fluence distribution of the Bessel vortex beams with a conical angle of 6.8° a) in the linear regime, b) in the stationary regime, c) in the rotating regime and d) in the speckle-like regime and e) – h) corresponding beam profiles at z = 1 mm. The i) side view and j) cross section view of the material modification in glass (single shot).

References

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