Femtosecond laser micro and nano processing with nondiffracting Bessel and accelerating Airy beams

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Femtosecond laser micro and nano-processing is a versatile material processing tool which has opened up a broad range of technologies and applications. However, in the particular context of the fabrication of deep trenches and channels, precise control of profile of the ablated structure is extremely challenging. We have recently developed a novel approach to fabricate controlled high aspect structures using novel Bessel and Airy beams, and this contribution will review our recent work in this field.

The key concept behind the use of Bessel and Airy beams in controlled femtosecond fabrication is to control the direction of the incident light field rather than simply shaping the laser intensity pattern in one plane. With Bessel beams, light propagates along a cone and for sufficiently high conical angles, the nonlinear propagation of femtosecond Bessel filaments is stationary [1]. In this regime, we have reported high aspect ratio (100:1) nanochannels drilled in glass using single femtosecond laser shots [2]. Numerical simulations of the nonlinear propagation of femtosecond Bessel pulses allow us to accurately reproduce the experimental results [3], confirming that the propagation of Bessel filaments during nanochannel drilling is stationary. In addition, we report extremely high plasma densities, even higher than the optical critical density on long propagation distances. This arises because of the very specific Bessel beam conical structure that allows the pulse to propagate with minimal dynamical effects, thus generating a high aspect ratio cylinder of plasma.

Airy beams and more generally accelerating beams constitute another family of beams that possess quasi-nondiffracting behaviour. Their primary intensity lobe propagates along a curved trajectory that can be arbitrarily shaped [4] (Fig. 1(a)). These beams can be described and designed conveniently using the notion of optical caustics and the tools of mathematical catastrophe theory, and we have recently applied this to show fs pulses accelerating on non-paraxial circular trajectories [5]. Significantly, the region of maximal intensity in accelerating beams is adjacent to a region where no light propagates. This has been used for direct curved edge profiling of silicon and diamond (Fig. 1(b)) and we also report direct curved trench machining [6].

Our results show that the control of the nonlinear propagation of ultrashort femtosecond laser pulses by nondiffracting beams is a key new technological approach for laser processing allowing precise control of the profile of laser-processed structures in the longitudinal direction.

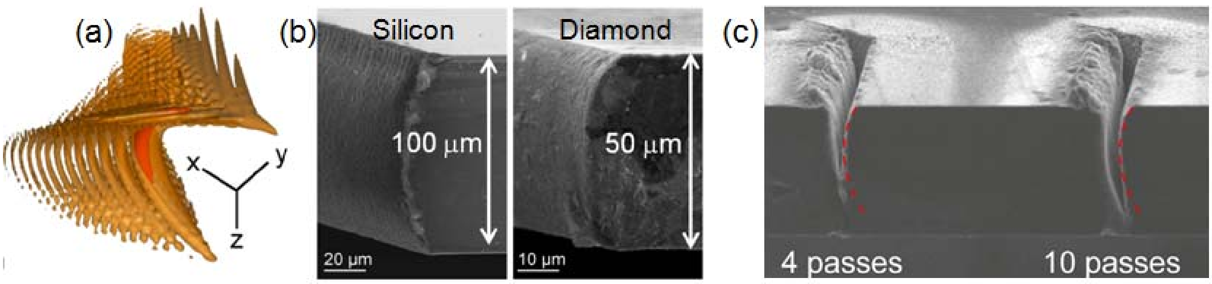

Fig. 1 (a)3D iso-intensity surfaces at 5%(gold) and 50%(red) of a beam accelerating on a circular trajectory. (b) typical results of edge profiling with circularly accelerating beams. (c) direct curved trench processing in silicon.

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