Core size, zone length and axicon tip tolerance of a Bessel beam shaper for glass cutting

Ultrashort-pulse laser at 1030 nm, fused-silica axicon and a reducing telescope, after Balage et al. [1]; wave-optics field computed plane by plane along the Bessel zone

Application

Glass is cut with ultrashort pulses focused into a Bessel beam: a narrow core that keeps its size over the whole thickness of the sheet. The machine builder has to know three things before buying the optics. How narrow is the core, how long is the zone, and how much does an imperfect axicon tip disturb it?

Modelling approach

The Gaussian beam was propagated as a field through the axicon and the two telescope lenses. The axicon was crossed by its exact radial ray map, the lenses as ideal thin lenses. The field was read on planes every 12.5 to 40 µm along the zone. Real rays traced through a glass sheet give the length of the zone inside the glass.

1 The shaper

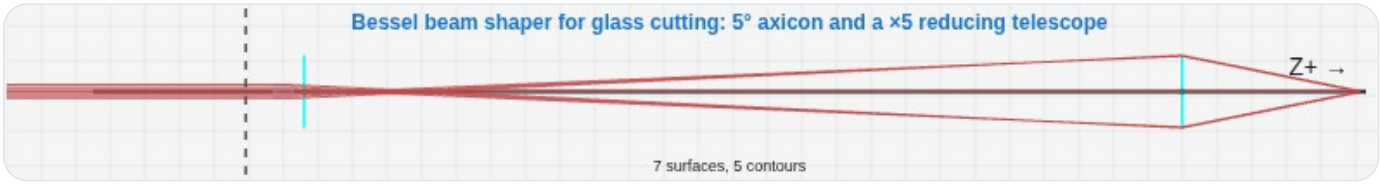


Figure 1. The shaper in the 2D view of the App, laser on the left: the axicon turns the collimated beam into a cone, the first lens focuses it into a ring, and the second lens forms the reduced Bessel zone on the right, 30.3 mm after it. The drawing is to scale in both directions. **Table 1.** Main parameters.

PARAMETER	VALUE
Laser	1030 nm, Gaussian, beam radius 0.75 mm (1/e²)
Axicon	Fused silica, 170° apex (5° base angle)
Telescope	f1 = 125 mm, f2 = 25 mm, reduction ×5
Cone half-angle	11.2° in air, 7.4° in glass
Zone centre	30.32 mm after the second lens

2 The Bessel zone along the beam

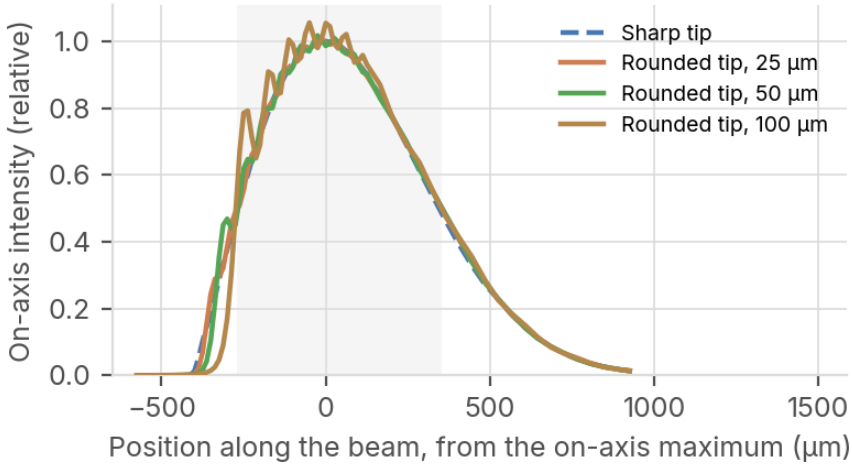


Figure 2. Intensity on the axis along the zone, for a sharp axicon tip and for three rounded tips, relative to the maximum of the sharp tip. The grey band is the zone above half maximum with the sharp tip.

2.06 µm

Radius of the Bessel core at its first zero, at the centre of the zone. The cutting study we follow measured 1.9 ± 0.66 µm [1].

0.61 mm

Length of the zone in air, where the on-axis intensity stays above half its maximum. In a glass of index 1.51, the zone grows to about 0.94 mm.

3.5 %

Share of the beam power inside the core at the centre of the zone. The rest flows in the rings that feed the core along its length.

What glass the shaper cuts, and what axicon tip to accept

Table 2. Zone length against the glass to cut

Glass sheet	Beam radius (mm)	Zone in air (mm)	In glass (mm)	Air length ≥ sheet
alkali-free borosilicate, 0.3 mm	0.75	0.61	0.94	pass
soda-lime, 1 mm	0.75	0.61	0.94	fail
soda-lime, 1 mm	1.00	0.82	1.25	fail

Zone length at half maximum of the on-axis intensity. In glass: the length in air times 1.53, from real rays traced through a soda-lime sheet. Judged in air (conservative).

Table 3. Rounded axicon tips

Rounded zone (µm)	Apex radius (mm)	Largest change in the zone (%)	Core radius (µm)	Within 20 %
0 (sharp)	0	0	2.06	pass
25	0.29	3	2.08	pass
50	0.57	11	2.12	pass
100	1.14	40	2.21	fail

On-axis intensity against the sharp tip, plane by plane, inside the zone. The rounded tip is a hyperboloid whose slope tends to that of the 5° cone [2, 3].

Why a rounded tip modulates the zone

The centre of a rounded tip acts as a weak lens. Its light travels almost along the axis and beats with the cone, which gives fringes along the axis with a period of λ / (1 − cos θ) [2].

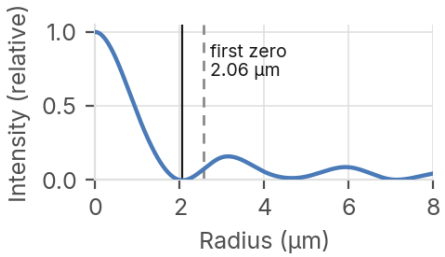
What to ask from the axicon supplier

A rounded zone up to 50 µm across the tip keeps the on-axis intensity within 20 % of the sharp tip inside the zone. A rounded zone of 100 µm does not. A tolerance on the tip belongs in the axicon specification.

The ring focus inside the telescope

The first lens focuses the cone into a ring of 4.9 mm radius, in air. Its peak irradiance is about 3 × 10^4 times lower than in the core. No ray crosses the axis inside the axicon: no focus in the glass of the optics.

Figure 3. Core profile, zone centre



Dashed: largest radius accepted, 2.56 µm [1]. An ideal Bessel beam at the same cone angle has its first zero at 2.04 µm.

In etendue

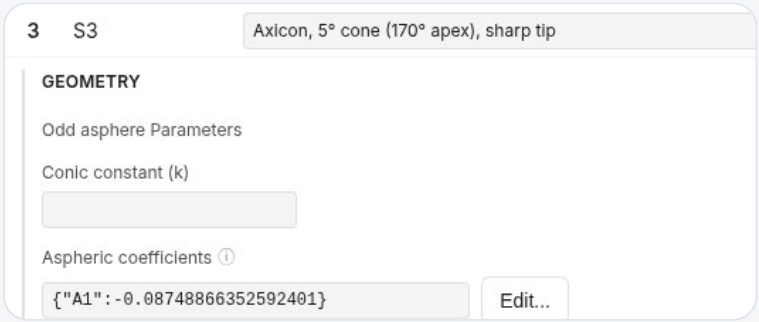


Figure 4. The axicon cone in the surface table: an odd asphere whose only term is in r, A1 = −tan 5°. Library project « LAS11 – Bessel Beam Shaper for Glass Cutting »: Projects → Laser → Open, then Execute.

Conclusions. With a 0.75 mm beam, the shaper covers the 0.3 mm sheet with margin, and its core meets the published radius. The zone grows in proportion to the beam radius (0.61 mm at 0.75 mm, 0.82 mm at 1 mm, in air): a 1 mm soda-lime sheet needs a beam radius above 1 mm under the conservative criterion. The axicon tip should be specified: a rounded zone up to 50 µm is acceptable, 100 µm is not.

Limits of the study. Ideal thin lenses. The second lens is 25 mm instead of the 10 mm of [1], so the cone half-angle is 11° instead of 27°: at that angle, the zone would need a wave-optics grid beyond the memory budget of this study. Field computed in air, not in the glass; no process model.

References. [1] P. Balage et al., Bessel beam dielectrics cutting with femtosecond laser in GHz-burst mode, Micromachines 14, 1650 (2023). [2] O. Brzobohatý et al., High quality quasi-Bessel beam generated by round-tip axicon, Opt. Express 16, 12688 (2008). [3] S. Akturk et al., Intensity distribution around the focal regions of real axicons, Opt. Commun. 281, 4240 (2008). [4] D. McGloin, K. Dholakia, Bessel beams: diffraction in a new light, Contemp. Phys. 46, 15 (2005).