

High Quality, High Throughput Glass Processing with the IceFyre® 1064-50 Picosecond Laser

As lasers become more advanced, delivering higher power and energy along with shorter pulse widths at a range of wavelengths, the application space for industrial manufacturing continues to grow. In particular, lasers with shorter pulse widths in the picosecond and femtosecond regime are increasingly being used in manufacturing across various industries. These ultrashort pulse (“USP”) lasers are unique in both their ability to machine materials with exceptional quality as well their ability to machine transparent materials, both on the surface and through the bulk of the material as well. For many years, USP lasers were too costly and unreliable for high volume manufacturing. Over the years, however, laser manufacturers have improved the quality and reliability of such products while at the same time reducing their cost. Today, one of the leading cost-performance USP lasers is the MKS Spectra-Physics® IceFyre® 1064-50 laser, delivering high power and high pulse energy along with industry-leading pulse burst flexibility with its TimeShift™ ps capability.

In addition to the laser, supporting equipment such as beam delivery optics, motion control systems, and beam scanning equipment play important roles in any successful laser-based manufacturing process. In particular, beam shaping optics can be important in the context of USP lasers processing transparent materials. Due to the intensity-dependent absorption of the light in transparent materials such as various polymers, glasses and crystals, tailoring the distribution of light as it travels through the medium can be critical for some applications.

Since their development in the late 1980's, research into Bessel beams (or “non-diffracting” beams) and their applications has continued. For several years Bessel beams have been used in conjunction with lasers in many ways, including for optical tweezers for biological cell micromanipulation [1], optical coherence tomography [2], and sub-micron scale micromachining [3]. Their elongated small focal diameter along with the ability to self-reconstruct beyond a small central occlusion have interesting ramifications for processing transparent materials such as glass. A simple and low cost way to generate a Bessel beam is with the use of an axicon (conical) lens which presents a flat but angled refractive surface to the incoming beam, as opposed to the curved surface of a spherical lens.

As early as 2003, researchers recognized the value of processing glass with USP laser output shaped into a Bessel beam [4]. Another early

(2006) application of Bessel beam processing of transparent materials involved photopolymerization to create very long and narrow polymer fibers by using an axicon-generated Bessel beam that was reduced to much smaller dimensions using a conventional 4F optical system for demagnification [5]. Similar Bessel beam optical set-ups have also been employed for other laser processing tasks, including structuring of glass plates for subsequent cleaving along a pre-determined path [6].

MKS Spectra-Physics applications engineers used a Bessel beam optical setup to shape the beam of an IceFyre 1064-50 laser to structure 700 μm thick aluminosilicate glass for subsequent mechanical cleaving. This glass is commonly used as a cover glass for mobile devices and is typically chemically strengthened in downstream processing. The optical components were chosen according to the systems described in Ježek et al. [5] and Duocastella [7] with minor changes in focal lengths, etc., so as to demagnify the Bessel beam length to approximately match the 700 μm thick glass. A schematic of the optical components used to shape the IceFyre picosecond pulses for structuring the glass for subsequent use is shown in Figure 1.

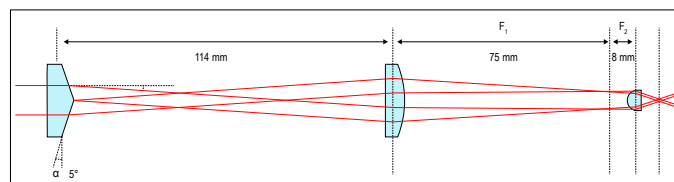


Figure 1: Optical schematic showing optics and distances used for the glass processing tests

Using the set-up in Figure 1, the Bessel beam intensity distribution in space can be modeled showing the elongated, highly intense central spot having a very small beam diameter ($\sim 4 \mu\text{m}$) as well as a series of lateral side-lobes. This intensity distribution is described by the zeroth-order Bessel function, J_0 .

Figure 2 is viewed from the side, orthogonal to the propagation (z) axis. The side lobes are of constant intensity for a given radial distance from the central bright spot. They comprise a series of concentric rings with increasing diameter and decreasing peak intensity and converge toward the center of the beam as they propagate through any transparent medium, thus reconstructing the small central bright spot along the way.

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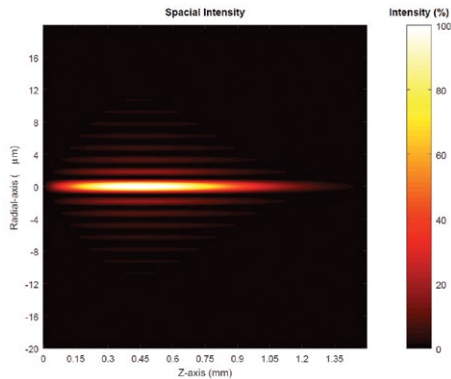


Figure 2: Side view of intensity distribution of a Bessel beam generated with IceFyre laser and optical components in Figure 1.

The intensity of the central bright spot of the Bessel beam is not constant along the z-axis, in part due to the Gaussian beam distribution of the incident beam. The relative intensity of the central bright spot is plotted in Figure 3.

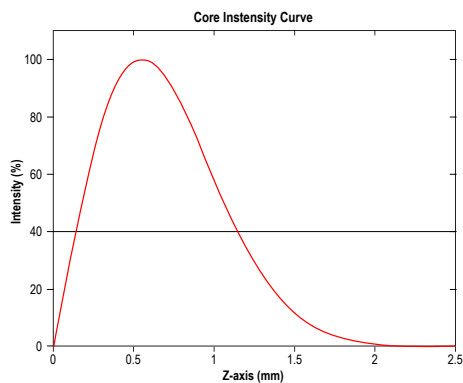


Figure 3: Data plot shows the intensity of the Bessel beam along the propagation axis with a targeted length of ~1.0 mm which was effective for processing glass with thicknesses of up to about 0.7 mm.

Because there is a smoothly varying intensity distribution along the z-axis, one might expect that there is a thresholding phenomenon which limits the effective modification length for a given amount of pulse energy, etc., applied to the workpiece. In this case the length over which the intensity is >40% of the maximum is ~1 mm, and this was found to be sufficient for uniform processing of the 700 µm thick glass.

When processing glass, the picosecond pulses from the IceFyre laser, having been tightly focused with the Bessel beam optical setup, create a series of fine, circular structural modifications in both the top (entry) and bottom (exit) surfaces of the glass. Generally, the appearance of these features is similar on both surfaces. In Figure 4, the entry surface is shown both before (left) and after (right) a mechanical cleaving process. Using the IceFyre laser's high power and high pulse frequency capability allowed this feature to be processed with a single pass at 1 m/s scan speed. Best results were typically achieved using the IceFyre's TimeShift ps capability to output a burst of 2-4 pulses with an intra-burst pulse separation time of 10 ns.

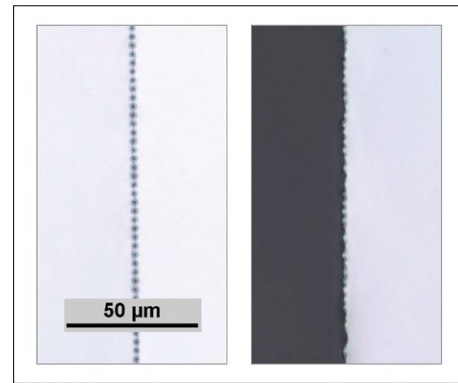


Figure 4: Optical microscope images showing the surface of aluminosilicate glass processed at 1 m/s scan speed with an IceFyre laser before (left) and after (right) mechanical cleaving of the glass.

The laser-processed features have diameters of 2-3 µm and are fairly uniform along the length of the processed region. After cleaving the processed glass, the variation of the cleaved edge is of similar dimension, as one might expect.

Compared to a Gaussian beam of the same ~4 µm diameter, the length along the z-axis is significantly higher (~1 mm with a Bessel beam compared to ~100 µm with a Gaussian beam). Given the reconstructive property of Bessel beams behind occlusions in the propagation media, one might expect the modification features to be relatively consistent throughout the full thickness of the 700 µm thick glass. This is confirmed in Figure 5, which shows a microscope image cross-section of a cleaved glass plate processed with the IceFyre laser and a Bessel beam optical setup.

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Figure 5 shows that the cleaved laser processed sidewall is fairly uniform across the entire thickness of the glass. Using scanning white light optical profilometry, the roughness of the surface was measured to be $R_a = 0.5\text{-}0.6\ \mu\text{m}$ (typical). The surface appears lightly granular in texture which is typical when using USP lasers to process brittle transparent materials because the short pulse width allows for material removal before melting occurs.

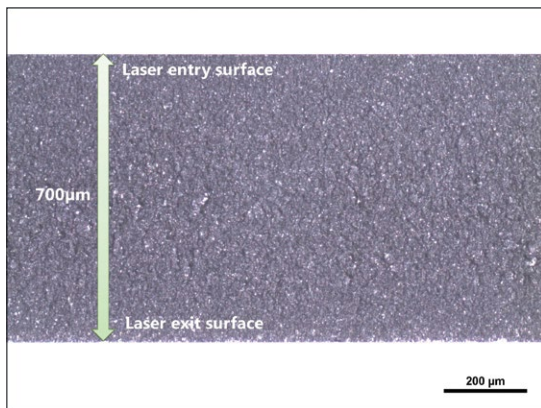


Figure 5: Optical microscope image showing cross-section of aluminosilicate glass processed with an IceFyre laser; roughness R_a is 0.5-0.6 μm .

The MKS Spectra-Physics IceFyre 1064-50 laser in conjunction with a typical Bessel beam optical system has been proven to be a good combination for processing relatively thick glass materials commonly used in flat panel display manufacturing, particularly for mobile devices. With suitable optics selection and process parameter optimization, high quality and high throughput results have been achieved. The optical support equipment to achieve such results has been known and available for many years. Very recently, however, USP laser technology has made great strides in terms of cost, quality, and performance, and with these developments, the combination of USP lasers such as MKS Spectra-Physics IceFyre 1064-50 and Bessel beam delivery optics provides an effective solution for high volume glass manufacturing.

Note:

MKS Spectra-Physics hereby disclaims any and all representations and warranties, express, implied or statutory, including warranties of merchantability, fitness for a particular purpose or use, and non-infringement of third party intellectual property rights regarding the use of a Bessel beam optical system in conjunction with an MKS Spectra-Physics IceFyre 1064-50 laser for any particular application.

References:

1. J. Arlt, V. Garces-Chavez, W. Sibbett, K. Dholakia, "Optical micromanipulation using a Bessel Light beam", *Optics Communications* 197 (2001), 239-245.
2. Z. Ding, H. Ren, Y. Zhao, J. Nelson, Z. Chen, "High-resolution optical coherence tomography over a large depth range with an axicon lens", *Optics Letters* Vol. 27, No. 4, (2002), 243-245.
3. F. Courvoisier, P.A. Lacourt, M. Jacquot, M.K. Bhuyan, L. Furfaro, J.M. Dudley, "Surface nanoprocessing with nondiffracting femtosecond Bessel beams", *Optics Letters* Vol. 34, No. 20 (2009), 3163-3165.
4. J. Amako, D. Sawaki, E. Fujii, "Microstructuring transparent materials by use of nondiffracting ultrashort pulse beams generated by diffractive optics", *Journal of the Optical Society of America B* Vol. 20, No. 12 (2003), 2562-2568.
5. J. Ježek, T. Čížmár, V. Neděla, P. Zemánek, "Formation of long and thin polymer fiber using nondiffracting beam", *Optics Express* Vol. 14, No. 19 (2006), 8506-8515.
6. J. Dudutis, P. Gecys, G. Raciukaitis, "Non-ideal axicon-generated Bessel beam application for intra-volume glass modification", *Optics Express* Vol. 24, No. 25 (2016), 28433-28443.
7. M. Duocastella, C. Arnold, "Bessel and annular beams for materials processing", *Laser Photonics Rev.* 6, No. 5, 607-621 (2012)

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PRODUCT: ICEFYRE 1064-50

IceFyre redefines picosecond micromachining lasers with a patent-pending design to achieve exceptional performance and unprecedented versatility at industry leading cost-performance. Based on Spectra-Physics' It's in the Box™ design, IceFyre integrates laser and controller into the industry's smallest package. IceFyre's unique design exploits fiber laser flexibility and Spectra-Physics' exclusive power amplifier capability to enable TimeShift ps programmable burst-mode

technology and wide adjustability of repetition rates. A standard set of waveforms is provided with each laser; an optional TimeShift ps GUI is available for creating custom waveforms. The laser provides pulse-on-demand triggering with the lowest jitter in its class for high quality processing at high scan speeds, e.g. when using a polygon scanner.

	IceFyre 1064-50
Wavelength	1064 nm
Power	>50 W
Maximum Pulse Energy, typical	>200 μ J single pulse at 200 kHz
Repetition Rate Range	Single Shot to 10 MHz
Pulse Width, FWHM	<20 ps
Pulse-to-Pulse Energy Stability	<1.5% rms
Power Stability (after warm-up)	<1%, 1 σ over 8 hours
Spatial Mode (TEM ₀₀)	<1.3
Beam Asymmetry	1.0 \pm 10%
Beam Pointing Stability	< \pm 25 μ rad/ $^{\circ}$ C



www.spectra-physics.com

3635 Peterson Way, Santa Clara, CA 95054, USA
PHONE: 1-800-775-5273 1-408-980-4300 **FAX:** 1-408-980-6921 **EMAIL:** sales@spectra-physics.com

Belgium	+32-(0)0800-11 257	belgium@newport.com	Korea	+82-31-8021-1600	korea@spectra-physics.com
China	+86-10-6267-0065	info@spectra-physics.com.cn	Netherlands	+31-(0)30 6592111	netherlands@newport.com
France	+33-(0)1-60-91-68-68	france@newport.com	Singapore	+65-6664-0040	sales.sg@newport.com
Germany / Austria / Switzerland	+49-(0)6151-708-0	germany@newport.com	Taiwan	+886 -(0)2-2508-4977	sales@newport.com.tw
Japan	+81-3-3794-5511	spectra-physics@splasers.co.jp	United Kingdom	+44-1235-432-710	uk@newport.com

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