HIGH-INDEX GLASS FOR AUGMENTED REALITY EYEWEAR CUT WITH INFRARED PICOSECOND LASERS

While augmented and mixed reality technology has reached adoption in certain industrial applications, general consumer use remains limited. Some uses, such as visual aids for complex assembly tasks overlaid directly onto the user's field of view, are gaining traction. However, technical and aesthetic improvements are needed to drive growth in broader markets. Some augmented reality (AR) applications can be served by a smartphone, but these are limited by the need to hand-hold the device, the relatively small display size, and having to divert attention away from the task at hand. By comparison, AR eyeglasses provide a seamless and minimally obtrusive display that leaves the user's hands—and focus—free. As explored in this Application Focus, laser cutting of the AR eyeglass lens material shows promise to bring these products to consumer markets.

AR eyewear presents the challenge of combining the functionality of conventional eyeglasses with the benefit of context-based graphics. To do this, graphical content is first generated by discrete micro-displays, then coupled into and guided by transparent lenses, and finally projected onto the human eye. Given this design complexity, the adoption of AR eyewear is limited due to a tradeoff between bulkiness and field of view (FOV). Ongoing developments in high-refractive index ("high-index") glass material are enabling waveguide-based devices with a greater FOV and thinner, lighter lenses, thus removing this tradeoff and paving the way towards more widespread consumer acceptance. Figure 1 illustrates the basic design concepts for AR eyewear and summarizes the benefits of using high-index glass. Such glass, however, is difficult to cut with good edge quality, even using IR picosecond lasers that are commonly used with more conventional glasses.

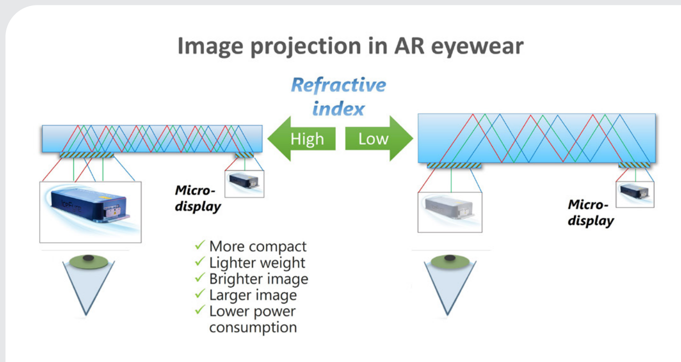

Figure 1. Image projection in AR eyewear and the advantages of using high-index glass.

Using an IceFyre® IR50 ultrashort pulse (USP) infrared (IR) laser combined with Bessel beam technology, MKS industrial laser applications engineers processed high-index glass for AR eyewear. Building on previous work (Application Notes 46, 54) that employed TimeShift™ ps pulse-tailoring to cut standard and ultrathin glass, here we expand the process to cutting small-radius rounded corners in high-index glass. We also show how cut quality is further improved using the more advanced capabilities of TimeShift ps.

Process parameters for cutting 0.7-mm thick glass with a refractive index of ~1.8 were adapted from our previous work, with only minor adjustments required (the pulse-to-pulse spacing on the material, for example). Operating at a 50-kHz pulse repetition frequency (PRF), parameters were developed for making straight-line cuts at a speed of 200 mm/s. This speed is extendable to >1.6 m/s when using the full laser power available at higher PRFs. For processing small-radius curves, the stage speed and laser PRF were scaled down proportionally to accommodate the motion system capability while keeping the correct spacing between pulses. After parameter fine-tuning, corner radiuses of 0.5 mm were processed at 10 mm/s using ~0.3 W at a PRF of 2.5 kHz. Figure 2 shows a processed corner before and after mechanical separation from the glass wafer.

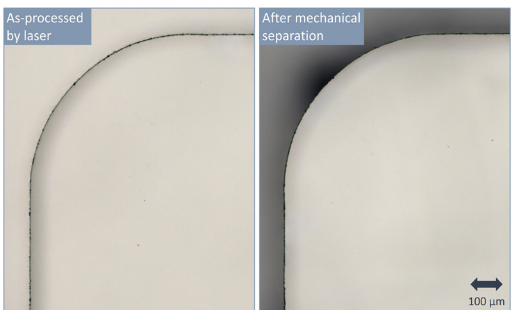

Figure 2. Microscope images of a 0.5-mm radius rounded corner processed in high-index glass. (Left) Top surface view before manual separation, (Right) top surface view after separation.

The images in Figure 2 show that the process is consistent along the straight segment, going through the corner, and then back out again. After separation, the edge roughness was measured to be approximately 0.6 µm R_a, with chipping at the entry and exit surfaces below 5 µm.

Though the above results demonstrate superior Bessel beam cutting of contoured paths, there is further potential and need for improved cut quality, particularly in the reduction of sidewall roughness. To achieve this, we used TimeShift technology to vary both the intra-burst sub-pulse separation time and the relative energy of the sub-pulses within the burst. For this work, the number of sub-pulses comprising the burst was kept at two, which was found to be optimal in most circumstances. The burst sub-pulse separation time was varied from 10 ns (used in previous work) to 100 ns. Other parameters remained fixed, including a 200-mm/s stage speed, 50-kHz PRF, and an average power of ~5.5 W. The processed samples were manually separated and the edge roughness (R_a) was measured, producing the plot in Figure 3.

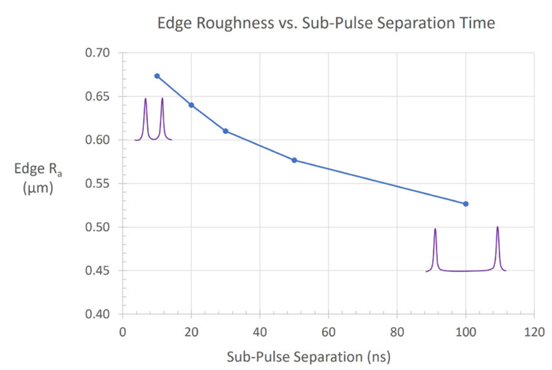

Figure 3. Plot of the edge R_a vs. the intra-burst sub-pulse separation time, showing a distinct trend towards lower roughness with increasing separation time.

From Figure 3, we see that by increasing the burst sub-pulse separation time the edge roughness is reduced, from 0.67 µm R_a at 10 ns separation to 0.53 µm R_a at 100 ns separation. This equates to a decrease in roughness of ~20%.

In further testing, we studied the effect of varying the energy ratio between the two sub-pulses in the burst, with the energy in the trailing sub-pulse adjusted incrementally downward from 100% to 30% of that in the first sub-pulse (the default used in our previous work was ~70%). All other parameters were kept constant except for average power, which was adjusted as needed to maintain a fixed modification depth of ~500 µm. The resultant data is plotted in Figure 4, showing edge roughness vs. trailing-pulse relative energy. The average power (P_{avg}) required for structuring is also noted for select data points.

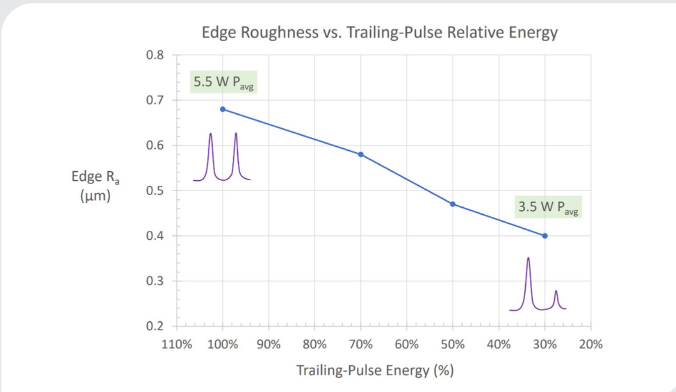

Figure 4. Plot showing the improved edge roughness that accompanies a reduction in the relative energy of the trailing sub-pulse.

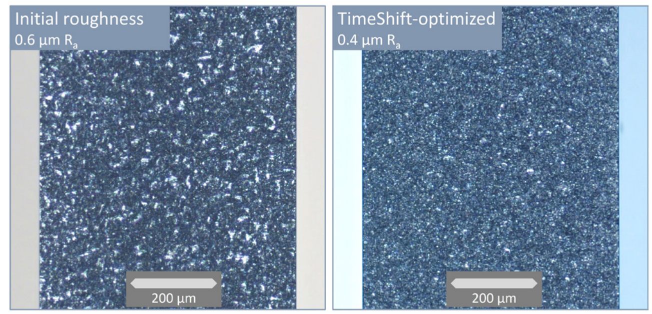

Figure 5. Visual comparison of sidewall surfaces having of 0.6 µm R_a (left) and 0.4 µm R_a (right) roughness values, with full-length structuring of the entire glass thickness.

From these results we see that by reducing the energy in the trailing sub-pulse from 100% to 30%, the edge roughness decreases from ~0.7 µm R_a to ~0.4 µm R_a, or about 40%. Of further note is that the reduced roughness comes at a lower average power level (3.5 W vs. 5.5 W), implying that higher overall throughput can be achieved along with the improved quality. The magnitude of the difference in surface roughness is readily apparent in a side-by-side edge-view comparison, which clearly shows the overall finer surface appearance that accompanies the lower measured roughness (Figure 5).

The work presented here demonstrates that Bessel beam processing with an IceFyre IR50 excels at cutting high-index glass used for AR eyewear and can accommodate contoured processing with very tight radiuses. In addition, significant quality improvements are gained when using TimeShift ps to tailor the pulse intensity within the burst envelope, reducing the need for costly and time-consuming post-processing. These techniques allow for finely-tuned glass processing—achieving high quality results while at the same time maintaining highest throughput—thereby enabling high-volume manufacturing for consumer AR eyewear.

PRODUCT

IceFyre® Industrial Picosecond Lasers

The IceFyre UV50 is the highest performing UV ps laser on the market, providing >50 W of UV output power at 1.25 MHz (>40 µJ) with 100's µJ pulse energies in burst mode, and pulsewidths of 10 ps. The IceFyre UV50 sets new standards in power and repetition rates from single shot to 10 MHz. The IceFyre UV30 offers >30 W of typical UV output power with pulse energy >60 µJ (greater pulse energies in burst mode) and delivers exceptional performance from single shot to 3 MHz. The IceFyre IR50 provides >50 W of IR output power at 400 kHz single pulse and delivers exceptional performance from single shot to 10 MHz.

IceFyre laser's unique design exploits fiber laser flexibility and Spectra-Physics' exclusive power amplifier capability to enable TimeShift™ ps programmable burst-mode technology for the highest versatility in the industry. A standard set of waveforms is provided with each laser; an optional TimeShift ps GUI is available for creating custom waveforms. The laser design enables true pulse-on-demand (POD) and position synchronized output (PSO) triggering with the lowest timing jitter in its class for high quality processing at high scan speeds, e.g. when using a polygon scanner.

	IceFyre IR50
Wavelength	1064 nm
Power	>50 W @ 400 kHZ
Maximum Pulse Energy, typical (greater pulse energy per burst possible with TimeShift ps)	>200 µJ @ 200 kHz
Repetition Rate Range	Single shot to 10 MHz
Pulse Width, FWHM	<15 ps (13 typical)
TimeShift ps	Yes
Pulse-to-Pulse Energy Stability	<1.5%, 1 σ
Power Stability (after warm-up)	<1%, 1 σ, over 8 hours
Spatial Mode	TEM_{00} (M^2 <1.3)
Beam Diameter (D4σ)	3.0 mm ±0.3 mm
Beam Divergence, full angle	<0.75 mrad
Polarization	>100:1, vertical

Application Note_65_03/17/2023