APPLICATION NOTE 68

CUTTING AND SCRIBING ALUMINA CERAMIC WITH HIGH-POWER GREEN DPSS LASERS

Ceramics are commonly used in areas such as rugged-environment printed circuit board (PCB) substrates and high-thermal dissipation LED packaging, as well as in biomedical applications including implants and medical devices. Their hardness, chemical inertness, and overall resilience in harsh, high-temperature environments make them an excellent choice across various industries. When manufacturing ceramic components, laser processing in the form of cutting, scribing, or drilling is commonly used, and therefore it is beneficial to understand the impact of various laser technologies that are available on the marketplace.

Sintered aluminum oxide (Al_2O_3, "alumina") is a frequently used industrial ceramic that poses various challenges for laser processing. To start, it has a high ablation threshold, requiring a high fluence to efficiently remove material. It is also very brittle, with thinner substrates prone to fracturing with excessive heating. Finally, the relatively high cost of alumina encourages narrow kerfs and closely packed features, which can make brittleness a serious yield and production cost problem. A well-known approach to overcome these challenges is the use of nanosecond-pulse, diode-pumped solid state (ns DPSS) lasers, particularly at green and ultraviolet (UV) wavelengths.

UV lasers have several advantages over green lasers for processing alumina: stronger absorption in the binder material promotes enhanced ablation efficiency, and smaller spot sizes with longer Rayleigh ranges are beneficial for machining higher density and greater aspect ratio features. Despite these advantages, green lasers are a competitive option due to their higher output power and lower overall cost (initial and ownership) compared with UV lasers.

The MKS Spectra-Physics® Talon® ns DPSS laser platform, in both green and UV wavelengths, has demonstrated excellent quality and throughput when cutting and scribing industrial ceramics (Application Note 36). To expand on this body of data, tests were performed with a Talon GR70, a green nanosecond laser that delivers >70 W average power at a pulse repetition frequency (PRF) of 275 kHz and maintains >60 W up to 700 kHz, with shorter ns pulse widths. For these tests, the laser is focused by an f = 100 mm f-theta lens to a diameter of approximately 16 µm ($1/e^2$). Cutting and scribing was achieved using high-speed, multi-pass processing with a scan speed of 4 m/s and a variable number of passes used to control the scribe depth.

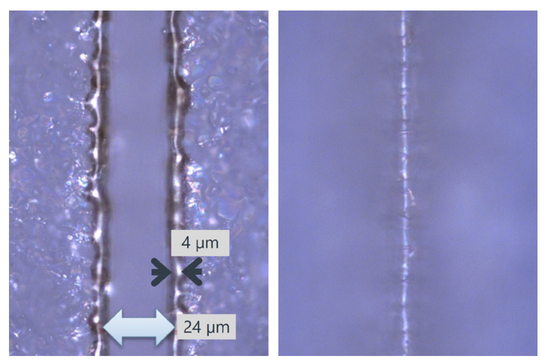

Figure 1. Top-down view of the scribe with focusing on the top of the surface (left) and bottom of the scribe (right). The scribe width is 24 µm with a HAZ (heat-affected zone) of 4 µm. The view of the scribe bottom shows a smooth trench with uniform depth.

Scribes were processed in 200-µm thick alumina plate material operating the laser at 65 W and 500 kHz, delivering a pulse energy of 130 µJ. Figure 1 shows the result of a 25 µm deep and 24 µm wide scribe, processed with 10 overlapping scans at 4 m/s for a net speed of 400 mm/s. There is little to no debris around the scribe, and the heat affected zone (HAZ) is minimal and consistent at <5 μm. Additionally, the scribe floor is smooth, with uniform depth, indicating optimal combination of scan speed and PRF.

To achieve full cutting of the alumina plate, it was necessary to widen the kerf by applying additional adjacent and parallel scribes at a fixed lateral spacing. This helps compensate for the reduced scribing efficiency (depth per scan) that occurs as the scribe becomes deeper. Due to the natural tendency of a scribe to become narrower ("taper") with increasing depth, the number of adjacent scribe lines can also be reduced in a manner that matches this narrowing. This taper matching technique, refined by MKS Spectra-Physics, improves overall scribing efficiency by progressively eliminating the outermost scans since they ablate less sidewall material of a deepening groove.

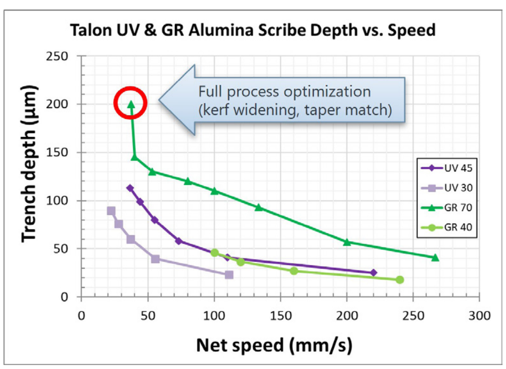

Figure 2. Trench depth vs. net processing speed with four different Talon lasers: UV30, UV45, GR40, and GR70. The chart shows significant improvement in net speed with the Talon GR70, achieving 37.5 mm/s to cut 200 μm thick alumina.

Figure 2 shows a comparison of trench depth versus net speed for several different nanosecond DPSS lasers. Dramatic throughput improvement of the Talon GR70 over lower-power green and UV Talon series lasers with power levels of 30 W and 45 W is evident. The red circle indicates a fully optimized result using combined kerf widening and taper matching, achieving full cutting of the 200 μm thick alumina plate at a net speed of 37.5 mm/s. This doubles the depth compared to results achieved with the Talon UV45 at the same net speed. All other data points represent the scribe depth with multiple overlapping scans, without kerf widening or taper matching.

The substantial improvement in scribe depth with the Talon GR70 compared to lower-power green and UV lasers cannot be explained by average power arguments alone. For example, at a net speed of 100 mm/s, the depth with the GR70 operated at 65 W, is nearly 2.4× that of the GR40 and UV45 lasers while having a 1.63× and 1.44× power advantage, respectively. Additional efficiency gains may be due to the higher PRF (3.3×) and longer pulse width (2×), which induce increased material heating that can be beneficial for throughput, provided the material remains cool enough to avoid thermal stress failures such as fracturing and lower HAZ. Interestingly, the depth advantage for the GR70 compared to the UV45 laser decreases for deeper scribes. This is likely due to the longer Rayleigh range associated with the shorter UV wavelength, which is beneficial for machining higher-aspect ratio features.

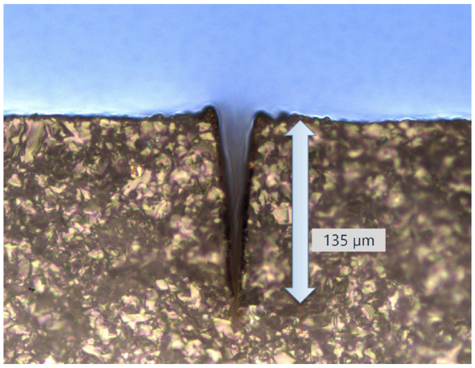

Figure 3. Cross section of a 135 μm deep, high aspect ratio (5:1) scribe showing minimal debris accumulation within the scribe, and low HAZ. No post-processing or cleaning has been applied.

Deep, high-aspect ratio scribes in ceramic are challenging to fabricate, due in part to the reduction in fluence resulting from the angled side walls, as well as the difficulty to exhaust debris. Debris tends to accumulate as scribe depth increases, inhibiting and eventually stalling ablation. Cross-sectioning a relatively deep scribe produced by Talon GR70 reveals a consistent 6° taper with an overall aspect ratio of 5:1 (Figure 3). The quality is excellent for an as-processed scribe with no post-processing applied, showing low HAZ and minimal residual debris.

Due to their advantageous material properties, industrial ceramics like alumina are used in many applications from medical devices to electronics packaging, however they pose several processing challenges. Alumina has a high ablation threshold requiring high laser fluences and is prone to fracture from thermal stress. The presented results have established that the Talon GR70 is an excellent candidate for alumina processing as it is able to achieve excellent quality with high throughput, substantially outperforming lower-power green and UV lasers. Scribe results show smooth trench floors, minimal HAZ, and little to no debris deposition. Through kerf-broadening and taper-matching optimizations, a net cutting speed of 37.5 mm/s was obtained for 200 µm thick alumina plate.

Product-application performance takeaways:

- Alumina scribing and cutting at high throughput with excellent quality is demonstrated by industry leading cost-performance Talon GR70 ns lasers.
- Talon GR70's high-PRF optimization point (70 W at 275 kHz, and >60 W out to 700 kHz) is ideal for micromachining of ceramics at higher speeds.
- Talon GR70 pulse to pulse stability can yield optimal fluence in each pulse for superior quality, with an exceedingly high pulse rate for elevated throughput.
- The throughput increase with the Talon GR70 outperforms the expected gains compared to lower-power green and UV DPSS lasers.
- The overall benefit is a cost-performance productivity increase for high-quality laser processing of challenging industrial ceramics.

PRODUCT

The Talon® UV and Green Lasers

The Talon laser platform is a family of UV and green diode-pumped solid state (DPSS) Q-switched lasers that deliver an unprecedented combination of performance, reliability, and cost. Talon is based on Spectra-Physics' *It's in the Box*™ design, with the laser and controller combined in a single, compact package. Talon exhibits high pulse-to-pulse stability and excellent TEM_{00} mode quality for tens of thousands of operating hours. The Talon laser is designed specifically for micromachining applications in a 24/7 manufacturing environment where system uptime is critical. As presented in this Application Focus, there is a strong advantage to having available a broad range of powers and wavelengths, which is provided with the complete Talon portfolio. The Talon provides disruptive cost-performance: lowest cost-of-ownership in the industry with no compromise in features, performance, or reliability.

	Talon UV45	Talon UV30	Talon UV20	Talon UV15	Talon UV12	Talon UV6	Talon GR70	Talon GR40	Talon GR20
Wavelength	355 nm	355 nm	355 nm	355 nm	355 nm	355 nm	532 nm	532 nm	532 nm
Power[2]	>30 W @ 100 kHz	>15 W @ 50 kHz	>10 W @ 50 kHz	>15 W @ 50 kHz	>12 W @ 50 kHz	>6 W @ 50 kHz	>70 W @ 275 kHz	>20 W @ 50 kHz	>20 W @ 50 kHz
	>45 W @ 150 kHz >35 W @ 200 kHz	>30 W @ 100 kHz >23 W @ 200 kHz	>20 W @ 100 kHz	>13 W @ 100 kHz	>10 W @ 100 kHz	>4 W @ 100 kHz		>40 W @ 100 kHz >36 W @ 200 kHz	>18 W @ 100 kHz
	>23 W @ 300 kHz	>17W @ 300 kHz	>11 W @ 300 kHz	>3 W @ 300 kHz	>3 W @ 300 kHz	>1 W @ 300 kHz		>30 W @ 300 kHz	>13 W @ 300 kHz
Repetition Rate	0-500 kHz						0-700 kHz	0-500 kHz	
Pulse Width	<35 ns @ 150 kHz	<25 ns @ 100 kHz					<43 ns @ 550 kHz	<25 ns @ 100 kHz	
Pulse-to-Pulse Energy Stability	<2% rms @150 kHz	<2% rms @100 kHz, typical				<2% rms @50 kHz, typical	<3% rms up to 550 kHz	<2% rms @ 100 kHz, typical	
	<3% rms up to 300 kHz <5% rms above 300 kHzl	<3% rms up to 150 kHz <5% rms up to 300 kHz, typical						<3% rms up to 300 kHz <5% rms above 300 kHz	

		Talon HE UV500	Talon HE UV275	Talon HE GR1000
Wavelength		355 nm	355 nm	532 nm
Power[2]	15 kHz	—	—	15 W typical
	20 kHz	>10 W	5.7 W typical	>15 W
	40 kHz	7.7 W typical	>11 W	13 W typical
	100 kHz	4.2 W typical	5.9 W typical	10 W typical
Repetition Rate		0 to 150 kHz		
Pulse Width		25–40 nsec @ 20 kHz	40–60 nsec @ 40 kHz	25–40 nsec @ 20 kHz
Pulse-to-Pulse Energy Stability		<3% rms		

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