LASER IN CERAMICS PROCESSING

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LASER, an acronym for Light Amplification by Stimulated Emission of Radiation have unique properties, Which make it differ from ordinary light such as it is highly coherent, monochromatic, negligible divergence and scattering loss and a intense beam of electromagnetic radiation or light. It also occur in a wide range of wavelength/frequency (from Ultraviolet to Infrared), energy/power and beam-mode/configurations ; Due to these unique properties, it have use in wide application of *ceramic processing* for industrial manufacturing, fabrication of electronic circuit such as marking, serializing, engraving, cutting, micro-structuring because laser only produces localized heating, without any contact and thermal stress on the any part during processing. So there is no risk of fracturing that occurs during mechanical sawing and also reduce Cost of processing. The discussion in this paper highlight the application of laser in ceramics processing.

1. Introduction

New laser technology is improving the economics and convenience of ceramic processing. Ceramics has been used in electronic applications for many years. However, with the recent commercial boom in electronic devices and the trend toward miniaturization, ceramic fabricators have sought more efficient and precise manufacturing methods and tools. The laser is one tool that has recently received much attention, in large part because advances in laser technology have improved the economics, efficiency and convenience of ceramic processing.

Laser processing of ceramics has a long history. However, laser use has primarily been limited to scribing applications involving fired alumina (Al_2O_3) substrates using fast- and slow-flow carbon dioxide (CO_2) lasers. In the past, the size, reliability and operating cost of CO_2 lasers prevented their widespread use in ceramics processing. But in recent years, technological advances have led to the development of entirely new sealed- CO_2 and solid-state lasers that have overcome the drawbacks of early lasers, creating new applications and possibilities in ceramic processing.

2. Laser Applications

Ceramic processing applications for lasers have increased since the development of several new industrial lasers. Lasers are now used to scribe, drill and profile, as well as for selective material removal and marking/serializing applications. They are used to process fired substrates of alumina, aluminum nitride (AlN) and beryllium oxide (BeO), as well as unfired (green) substrates (see Table 1).

Table 1. Ceramic Processing applications and corresponding laser sources.

Process	Type of Laser
Scribing, Drilling and Profiling Fired Substrates (Alumina,AlN,BeO)	CO ₂ Laser
Scribing, Drilling and Profiling Green Substrates	CO ₂ Laser/UV-DPSS Laser
Selective Material Removal	IR-/Green-/UV-DPSS Laser
Marking/Serializing	CO ₂ Laser/IR-/Green-/UV-DPSS Laser

3. Selecting the Right Laser

A laser is a non-contact, zero-wear tool capable of precisely delivering enormous amounts of photon energy to a specific and highly localized area for drilling, cutting, scribing or welding. The type of interaction that takes place depends on the properties of the material to be processed, as well as the wavelength and energy of light emitted by the laser. Figure 1 shows the wavelength of light and range of output power emitted by various types of lasers.

Figure 1. In general, output power increases with wavelength, and each type of laser only emits in a specific wavelength region. DPSS lasers are an exception, since they can be engineered to emit in the UV, visible and NIR portions of the electromagnetic spectrum.

Modern ceramic processing uses two types of lasers: CO₂ lasers that emit in the far-infrared (FIR) region of the spectrum, and diode-pumped solid-state (DPSS) lasers that are available at output wavelengths ranging from the ultraviolet (UV) through the visible to the near-infrared (NIR).

3.1. CO₂ Lasers

CO₂ lasers emit in the FIR at a wavelength of 10.6 microns, which is easily absorbed by most ceramics. CO₂ lasers also have high output powers, which allow high-speed processing and the processing of thick materials. Consequently, these lasers have been used by the ceramic industry for many years. However, in the past, only fast- and slow-flow CO₂ lasers using flowing-gas technology (where the lasing gas mixture flows through the laser cavity) were employed in these applications.

Flowing-gas lasers exhibit excellent output laser beam properties with M₂ (a parameter indicative of beam quality) values ranging from 1.1 to 1.3 (the ideal value being 1.0). However, despite the fact that flowing-gas laser beams are suitable for ceramic processing, several factors have prevented their widespread use and acceptance by the ceramic industry. First, flowing-gas lasers are relatively large devices (in excess of 8 ft in length) that occupy a considerable amount of shop floor space. Second, they are maintenance-intensive systems that require routine expert upkeep, including the replacement of optics and laser gases. Finally, the daily operating expenses of these lasers are high. For many years, these limitations made laser technology appear to be inconvenient, expensive and difficult to integrate.

By virtue of the slab-discharge design, sealed lasers are rugged and compact. They also require no replacement gases, and the head typically requires no maintenance for up to 20,000 hours (two and a half years) of continuous operation. Furthermore, the operating cost of sealed lasers is lower than that of flowing-gas lasers (see Table 2).

Table 2. Comparison of operating costs for CO₂ lasers.

CO ₂ Laser Type	Sealed	Slow-Flow	Fast- Flow
Typical Average Power	500Watts	1000Watts	1000Watts
Peak Power	1500Watts	10000Watts	3000Watts
Maximum Repetition Rate	100kHz	2 kHz	5 kHz
Laser Gas Consumption	0	40 liter/hour	73 liter/hour
Electrical Consumption	8.5kV A	12 kV A	35 kV A
Cooling-Water Flow	9.5 liter/hour	38 liter/hour	77 liter/hour
Maintenance Period	2.5years	6month	3month
Average Hourly Operating Cost	\$1.20	\$2.50	\$7.00

Another advantage of the sealed, slab-discharge design for ceramic processing is its fast pulsing capability. Slab-discharge lasers emit high-frequency pulses (up to 100 kHz) with up to 1.5 kW of peak power. The combination of high frequency and high peak power results in faster material processing, minimal thermal degradation and a smaller heat-affected zone (HAZ).

Figure 2. Sealed slab-discharge CO_2 laser concept. Recent technological developments have led to the invention of a different type of CO_2 laser incorporating sealed slab-discharge technology that overcomes the limitations of earlier lasers.

The shape of pulses emitted by sealed CO_2 lasers also improves the quality of the drilled holes. Compared to flowing-gas lasers, sealed laser pulses exhibit short rise and fall times relative to the duration of the pulse, as well as a more square-wave pulse profile (see Figure 3). When pulse rise-times are long, the ceramic is needlessly heated before the pulse energy reaches the threshold required for material processing. When fall-times are long, the ceramic continues to be heated after processing. The result is an excessive HAZ. With sealed-laser pulses, energy is efficiently delivered for cutting or drilling, rather than for merely heating the material to be processed. The result is a cleaner cut or hole, better feature resolution and no heat-induced collateral damage.

Figure 3. The fast rise and fall times of slab-discharge, sealed CO_2 laser pulses result in a more efficient use of energy, thereby causing less thermal damage and improving both hole quality and feature resolution. Conventional CO_2 lasers with slow rise times and long fall times needlessly heat the ceramic before and after processing.

Laser scribing is an application where the shape of laser pulses is very important. Laser scribing of a ceramic substrate consists of drilling a series of shallow, closely spaced holes. A pulse with slow rise and fall times leaves debris around the holes, glassy phase buildup around the sidewalls, and microfractures caused by thermal damage that extend into the surrounding substrate. In contrast, Figure 4 shows a 1 mm thick substrate of 96% alumina scribed with a sealed CO_2 laser. The substrate was scribed with a series of 0.35 mm deep, 60 mm diameter holes. No microcracking occurred, and there was no glassy phase debris.

Figure 4. A 1-mm-thick substrate of 96% alumina scribed with a sealed CO₂ laser reveals no microcracking and no glassy phase debris.

High-frequency pulsing also allows sealed lasers to quickly scribe and cut materials. Although scribing and cutting speeds are dependent on thickness, scribe depth and material, scribing speeds up to 12 m/minute and cutting speeds up to 500 mm/minute for 1.5 mm-thick fired ceramic and 3.0 mm green ceramic are typical for a 100-watt sealed CO₂ laser. Figure 5 graphs the scribing speed of a 100-watt sealed laser for various scribe depths in 96% alumina.

Figure 5. A 100 W sealed CO₂ laser can scribe 96% alumina to a depth of 0.35 mm at a speed of 6.6 m/minute.

Via (or hole) drilling is another ceramic processing application where sealed CO₂ lasers are commonly used. Their high-frequency output allows sealed lasers to drill vias with speeds up to 200 holes/second in green ceramic and 1 to 4 holes/second in fired ceramic. Of course, drilling speed also depends on the thickness of material and the diameter of the vias. Due to the long emission wavelength of CO₂ lasers, they are only used to drill vias down to 50 microns in diameter. For smaller features, short wavelength UV lasers are used with compatible materials.

In general, the average output power of sealed CO₂ lasers is lower than that of flowing-gas lasers. However, in most ceramic processing applications only 20% of the usable power of flowing-gas lasers is used. This is because the use of the full power would increase both thermal damage and the HAZ. Consequently, 1-kilowatt flowing-gas lasers are usually replaced with 250 or 150 W sealed lasers. In some cases, 500 W sealed

lasers are used, with the output of the laser split four ways to simultaneously process four ceramic machining stations.

3.2. Diode-Pumped Solid-State (DPSS) Lasers

DPSS lasers used in ceramic processing are available in a variety of wavelengths, including 355 nm in the UV, 532 nm in the green portion of the visible spectrum, and 1064 nm in the near-infrared (NIR) region. The latest DPSS lasers contain one or more diode laser arrays that are used to continuously pump a rod of neodymium-doped vanadate (Nd:YVO₄), and an acousto-optic Q-switch that is used to generate pulsed output. The fundamental output wavelength of Nd:YVO₄ is in the NIR, at 1064 nm. A second and third harmonic crystal is then used to transform the beam from 1064 to 355 nm wavelength.

The latest DPSS lasers are typically air-cooled units and have lower facilities requirements than CO₂ lasers. With their all-solid-state design, they are also highly compact and rugged devices. Originally, solid-state lasers were flashlamp-pumped devices with low reliability, due to their aging and the thermal degradation of flashlamps, which had to be replaced every few hundred hours at great expense. However, leading manufacturers of today's DPSS lasers offer a minimum guaranteed time-to-service of 5,000 to 10,000 hours.

DPSS lasers are used for a variety of applications in the ceramic industry. Marking and serializing are most commonly performed with NIR DPSS lasers at 1064 nm, due to their high processing speeds and minimal thermal damage. However, marking and serializing are sometimes performed with green (532 nm) and UV-DPSS (355 nm) lasers as well. DPSS marking speeds on a variety of materials range between 100 and 500 mm/second at 1064 nm wavelength.

UV-DPSS lasers are used in ceramic processing applications where CO₂ and other long wavelength lasers are unsuitable. These applications usually involve small feature sizes or require high-quality processing where no thermal degradation is tolerated and where speed of manufacturing is not the primary concern. The short wavelength of UV-DPSS lasers (355 nm) compared with CO₂ lasers (10,600 nm) allows them to focus down to smaller spots. Therefore, UV-DPSS lasers can more reliably drill smaller features (25 mm), such as vias, than CO₂ lasers (70 mm).

3.2.1. Comparing CO₂ LASER with UV-DPSS lasers

Compared to CO₂ lasers, UV-DPSS lasers have relatively low output powers. Consequently, they are only used for processing thinner, uncured green ceramics. However, UV-DPSS lasers with a 50% increase in output power have recently been developed. These units have average output powers in excess of 4.5 W at 355 nm. In the future, units with even higher output power are expected, making these devices even more cost-effective.

4. Bringing Laser Mainstream

New CO₂ and DPSS laser technology has provided the potential to improve the economics and convenience of ceramics processing. Modern, no-maintenance sealed CO₂ lasers featuring slab-discharge technology offer high-frequency pulsing and pulse shaping that improve feature quality and reduce HAZ. DPSS lasers are also now available in UV, visible and wavelengths with higher output powers. The convenience and cost effectiveness of these new lasers are making laser processing of ceramics a mainstream technique.

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