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Pulsed laser processing of ceramics in water

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A new method for defect-free processing of ceramics is presented. This method consists of processing ceramics in water with a Q-switched yttrium aluminum garnet (YAG) laser. In laser machining, a recast layer and cracks are usually formed in the machined part. Using this method, these defects are not formed.

The laser is a tool applicable for efficiently machining ceramics. In laser machining, however, it is difficult to avoid the formation of a recast layer and the appearance of cracks in the machined part. These defects significantly hinder some functions of ceramics,[1] and limit the application of laser machining in the production of ceramic components. The authors have investigated the feasibility of laser processing as a defect-free processing method for ceramics.

For defect-free processing, a water environment was examined. The reason for processing in water is that water has an effect on cooling and recycling. Water was circulated to restrain convections and bubbles from fluctuating at the laser condensing spot.

In the experiment, a Q-switched yttrium aluminum garnet (YAG) laser was used. This type of laser can produce short pulses of about 100 ns and high peak power above 50 kW when used with a Q-switching modulator. Short pulses are essential to minimize recast layer thickness and crack size. YAG lasers also retain high transmittance through water. The spot diameter was about 0.3 mm. The laser power density was below 7.1×10^7 W/cm^2.

For the ceramic material work pieces, silicon nitride was used. Silicon nitride is sublimated into silicon and nitrogen without melting through usual heating. Therefore, silicon nitride has the potential of laser machining without the formation of a molten layer. However, as is later described, a molten layer is formed through laser machining.

Figure 1 shows cross sections of work pieces drilled in air and water. By machining in air, a recast layer about 20 μm thick is generated and microcracks spread within this layer. In the Si $K\beta$ x-ray emission spectrum of the recast layer measured with an electron probe microanalyzer, a silicon spectrum and a silicon oxide spectrum[2] were observed. This indicates that the recast layer consists of silicon and silicon oxide. In contrast, by processing in water,[3] no recast layer and cracks were observed. Only a silicon nitride spectrum was observed on the processed surface. This indicates that the processed surface is similar to the matrix. In this way, a combination of YAG laser and water is an effective method for processing ceramics without causing the generation of a recast layer and cracks.

As the disappearance of a recast layer achieved in water was peculiar to Q-switched power (with a pulse duration of 100 ns), this effect could not be obtained with a continuous power laser nor a long-pulsed power laser (with a pulse duration greater than 100 μs). Figure 2 shows photographs of holes drilled in water using 1 ms pulses. A thick recast layer is formed and cracks spread into the matrix. The same result was obtained in processing experiments using various laser power densities. These results indicate that, in order to carry out defect-free machining, it is necessary to process in water using Q-switched power from an YAG laser.

Using this method in Q-switching frequencies (the pulse repetition rate) above 10 kHz, a recast layer and cracks were formed [Fig. 3(b)]. Again, in contrast, using various laser power densities at a Q-switching frequency of 1 kHz, the work piece was processed without any recast layer and cracks [Fig. 3(c)]. This test demonstrates that an increase

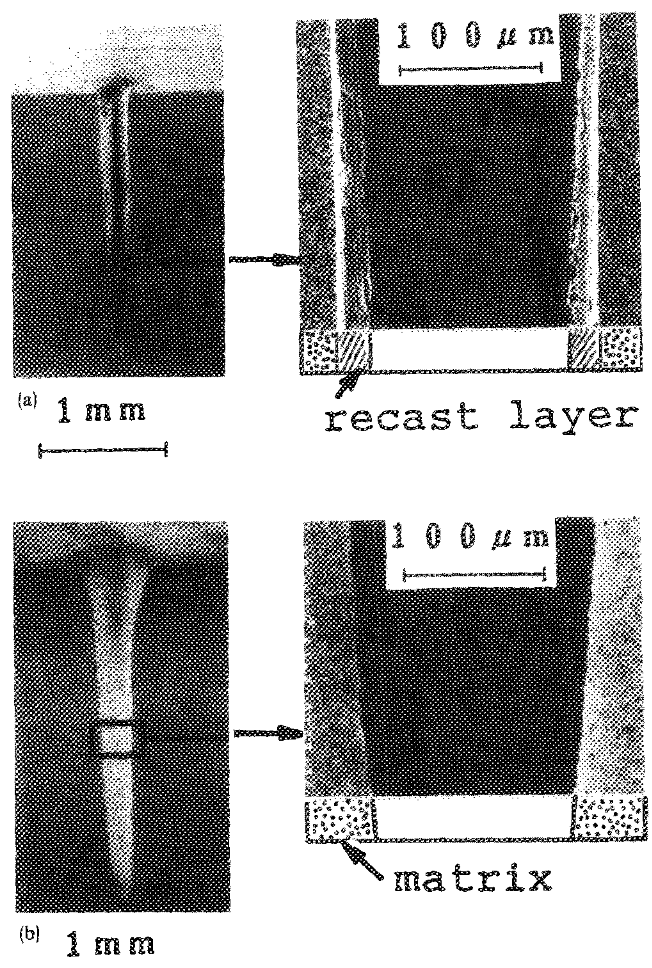

FIG. 1. Pictures of a cross section of a silicon nitride ceramics drilled in air (a) and water (b) with Q-switched power (pulse duration = 100 ns, laser energy = 5 mJ/pulse, Q-switching frequency = 1 kHz, processing time = 60 s, laser power density = 7.1×10^7 W/cm^2). A recast layer and cracks are generated in air, but they are not generated in water.

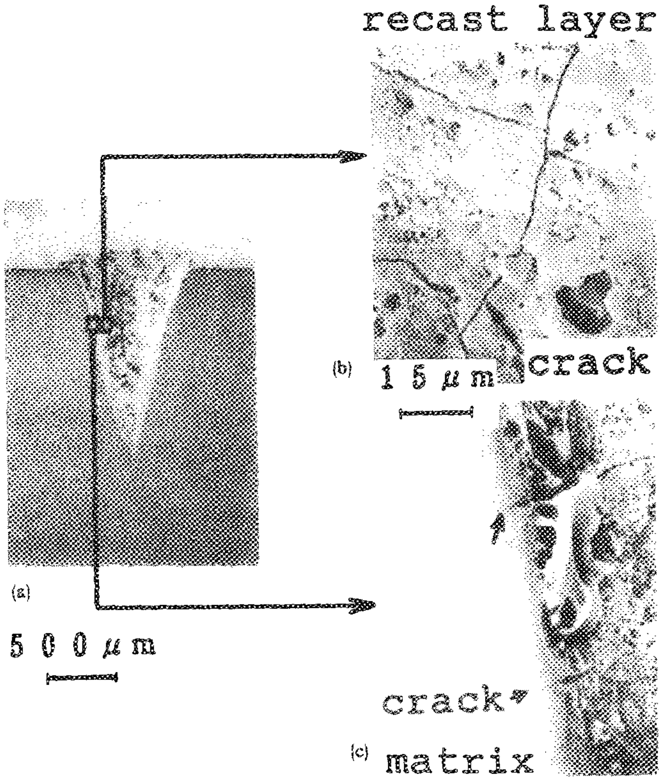

FIG. 2. Pictures of a hole drilled in water using a long-pulsed power (pulse duration = 1 ms, laser energy = 0.5 J/pulse, pulse repetition rate = 120 Hz, processing time = 60 s, laser power density = 6.4×10^6 W/cm^2). A thick recast layer is formed and cracks spread into the matrix.

in the pulse repetition rate leads to the generation of a recast layer. Therefore, an increase in the pulse repetition rate is similar in result to an increase in the pulse duration.

It can be inferred that an intermittent process in water using 100 ns short pulses (with the frequencies below 10 kHz) has the effect of preventing the pressure of silicon vapor from reaching the saturation level. At pressures above the saturation level, the molten silicon would appear on the processing surface. In this process, the effects of water are to solidify the vaporized silicon and to remove the microsolid

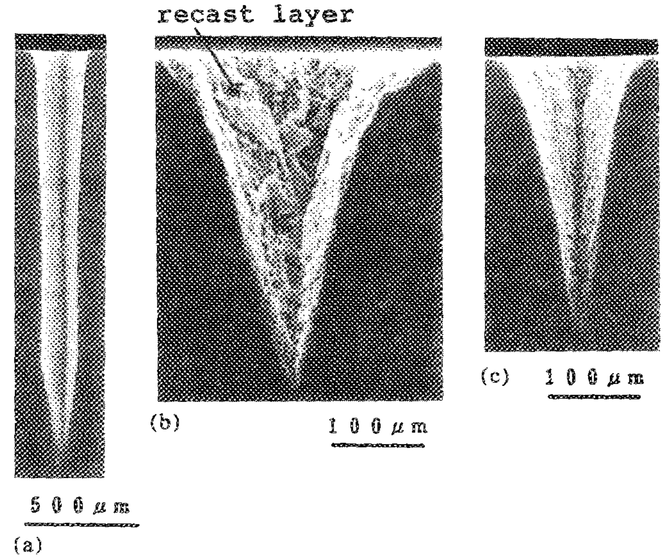

FIG. 3. Pictures of a hole drilled in water with various Q-switching frequencies and laser peak power. (a) Q-switching frequency = 1 kHz, laser peak power = 50 kW, laser power density = 7.1×10^7 W/cm^2, (b) 50 kHz, 5 kW, 7.1×10^6 W/cm^2, (c) 1 kHz, 5 kW, 7.1×10^6 W/cm^2.

silicon through recycling in water.

A similar effect can also be obtained with aluminum nitride ceramics which sublimate much like silicon nitride. However, alumina ceramics, which fundamentally have a melting point, cannot be processed without creating a recast layer.

The method of processing ceramics in water using a Q-switched YAG laser as a heat source is effective as a defect-free processing method. This method can be used to successfully scribe, cut, and drill without damaging the inherent characteristics of ceramics.

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