Fast cutting of ceramics with the water jet guided Nd:YAG Laser

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ABSTRACT

Many devices aiming at high temperature operations use ceramics. A well-known example is high power semiconductor packages such as RF-amplifiers for mobile communication. They offer high performance for small dimensions. For integrating ceramics into a device, several operations are required: scribing, cutting, drilling holes (for vertical connections). These processes can be quite challenging because of the material properties of ceramics. These materials are indeed very hard and brittle. The main problem when dicing ceramics is the formation of cracks leading to material breaks. Conventional sawing, even in scribe and break technique, strains to avoid this crack formation. Other criteria, such as chipping, speed, kerf width or costs, are unsatisfying when using blades for this particular application. However, a recent technology achieves high quality processing of ceramics: the Laser Microjet. This innovative concept is based on coupling a laser and a low-pressure water jet. With water cooling the work piece, cracks formation, heat damage and contamination are avoided.

Keywords: Nd:YAG, Water jet guided laser, Laser cutting, Ceramics, Hybrid Circuits, LTCC

1. INTRODUCTION

Ceramics hold an important place in the semiconductor and electronic industries. Indeed, they are characterized by excellent dielectric properties with very good thermal stability and thermal conductivity, and low thermal expansion. They are mainly used as substrates for packaging integrated circuits, mostly in high temperature applications. In this case, the ceramic substrate acts as the interface between the integrated circuit (IC) and the printed circuit board (PCB). The chip is placed on the substrate that is then soldered to the final PCB. The vertical connections are created by very thin gold wires or tiny solder balls (in the case of flip chip technology). Besides the task of realizing these electrical connections, the ceramic has to protect the chip and to maintain it in good operating conditions, where one of the most critical topics is thermal management. Especially, the LTCC (Low Temperature Co fired Ceramic) technology is widely used because it enables manufacturers to use low resistive materials (such as gold or silver) for connections. This is due to the low firing temperature (about 850°C) during the manufacturing process. This technology has reduced circuit dimensions, as well as time losses and costs.

Different tasks are needed when preparing ceramic substrates: scribing, grooving, drilling holes (vias) and cutting. As substrates become thinner (with new circuit design), smaller vias, closer vias locations, denser circuit patterns and denser multi layer interconnects are required. Because ceramics are very hard and brittle, and often contain internal stresses from manufacturing, these tasks require extreme accuracy of design. The frozen stresses may cause the sample to warp and some of them will be released during the singulation process, which may cause cracking or small shape changes during cutting.

Conventional methods, such as dicing saw, punch or ultrasonic cutter, are not able to achieve complex geometries and high quality; they are very slow, produce low quality and have high running costs. Punching typically becomes unusable between 0.008 and 0.015 inches diameter; furthermore small diameter punches wear and break too easily. Conventional CO_2 laser provides significant benefits but is still problematic. Material cracking has been observed, as well as a formation of a brittle recast layer, and edges of bad quality. New techniques are required. The Laser Microjet obtains unmatched results.

2. CLASSICAL SINGULATION OF CERAMIC SUBSTRATES

Ceramics are very hard and brittle. Avoiding cracking and shape changes due to internal stresses during cutting is the main problem of the process. Usually a scribe and break technique is employed because of the hardness and high thickness of the ceramics substrate (see Fig.1).

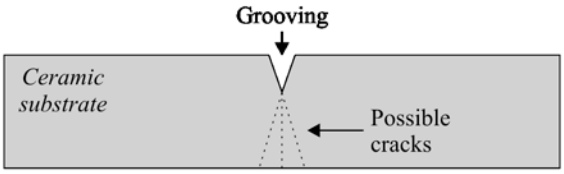

Fig.1. Schematic of scribe and break singulation process

The classical method is sawing. The grooving of the substrate is performed using a thin diamond blade in order to obtain a precise starting location for the crack that will separate the parts. In this step most of the difficulties arise from the hardness of the sample and the release of internal stresses during sawing. Table 1 summarizes the problems that arise when grooving ceramic substrates with the diamond saw.

1	Very low grooving speed (2-3mm/s)
2	Chipping of the ceramics close to the groove
3	Crack formation due to mechanical shear stress
4	Varying cutting quality due to the blade wear
5	Short and unpredictable blade lifetime (typically 60m grooving length)
6	High running costs because of high blade consumption
7	Unsatisfying positioning precision of front and backside cuts

Table 1: Summary of the problems arising during ceramic substrate singulation with a diamond saw

Short and unpredictable blade lifetimes, as well as the bad positioning accuracy, and crack formation are most important concerns of the production managers. These problems can only be solved using a flexible tool that is not affected by the hardness of the material.

3. WATER-JET GUIDED LASER PROCESSING

Water jet guided laser processing is a unique world wide patented technology relying on the use of a thin stable water jet as an optical wave guide. In order to couple the light into the water jet, the laser beam is focused into a nozzle while passing through a pressurized water chamber (see Fig.2). The water jet will guide the light until the sample, where the ablation takes place. The main advantages of this method compared to conventional laser cutting are:

- Very low thermal load of the sample due to the cooling between the laser pulses exactly at the place where it was heated before;
- An efficient expulsion of the ablated material due to the high momentum of the water-jet;
- Absence of redeposit material on the sample;
- Low-temperature since the measured temperature during any working conditions does not exceed 160°C [1].

The laser is coupled to a core step-index fiber (100 to 200µm core diameter) and then the fiber exit is imaged onto the nozzle entry with variable demagnification depending on the used collimator lenses (see Fig.2, left). Using a fiber between the laser and the machine tool is more practical for placing laser and machine in the production environment. Further the intensity profile of the light on the nozzle is more flat-top like, resulting in a longer nozzle lifetime than observed with a Gaussian beam profile.

The used lasers are either flash lamp pumped pulsed Nd:YAG lasers with pulse durations of less than 120µs or multi-mode Q-switched lasers operating at 1064nm, 532nm, or 355nm. Pure de-ionized and filtered water is pressurized at 50 to 500 bars for the water jet. The nozzles are made out of sapphire or diamond in order to generate a long stable water-jet. The laser beam is focused through a quartz window into the nozzle, very much like a usual fiber coupling and is thereafter reflected in the water-jet at the air-water interface due to the refractive index step (see Fig.2, right). Due to the flow separation the water-air interface extends until the nozzle edge, and respecting the jet retraction factor of 83% in diameter, none of the injected light is lost.

The samples are clamped onto one translation stage (x-stage), the optical setup is implemented in a "optics head" that is mounted on another translation stage (y-stage). The z-variation of the optics head is only necessary in order to adapt to the different working distances of different nozzles sizes and water pressures and is not used during the cutting procedure.

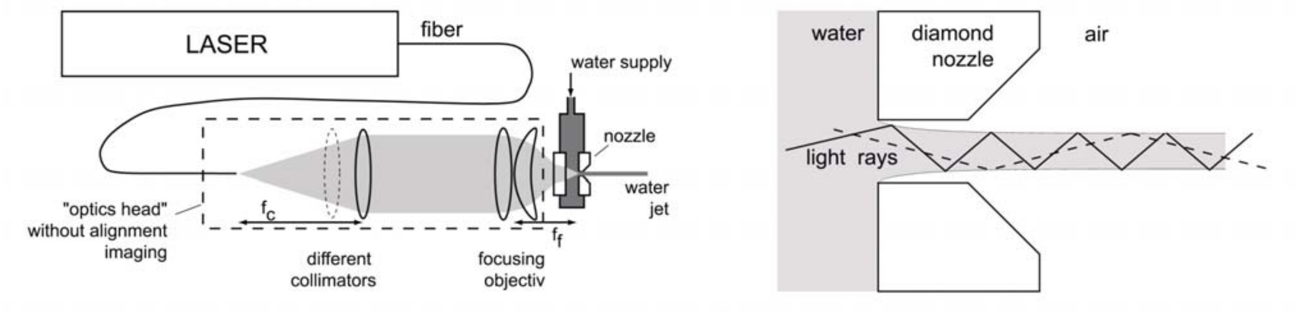

Fig.2. Sketch of the coupling between laser and waterjet (left); jet formation through the nozzle (right)

This hybrid system allows to join the force of a powerful Nd:YAG laser and the softness of a low pressure water jet. The Laser Microjet (LMJ) is, in other words, particularly adapted for critical applications where the fragility of the material or its brittleness complicates the machining with other methods.

3. APPLYING THE LASER MICROJET TO CERAMICS CUTTING

The water jet guided laser was applied to ceramics cutting using the same scribe and break approach as the sawing process (see Fig.1). Ceramics were grooved, then the samples were broken and evaluated.

Ceramic are difficult to cut because of their low absorption coefficient for infrared and visible light, and their tendency to scatter the light might cause damage in nearby structures. Three different types of ceramic substrates, 900µm thick, have been processed. For each one the cutting parameters were adapted (see Table 2) in order to achieve the best quality for a 300µm grooving depth. For this application the water pressure was kept at the moderate value of 280 bars, and a 60µm nozzle was chosen. A high power frequency doubled Nd:YAG laser yielded the best results.

Ceramic	Average power	Pulse repetition rate	Pulse lenght	Peak power	Speed	Passes	Resulting speed
LTCC	26.3 W	20 kHz	175 ns	7 kW	100 mm/s	20 x	5 mm/s
LTCC	26.3 W	20 kHz	175 ns	7 kW	100 mm/s	16 x	6.25 mm/s
Al2O3	28.6 W	15 kHz	145 ns	12 kW	60 mm/s	16 x	3.75 mm/s

Table 2: Experiments' parameters

Fig.3 and Fig.4 show the edge quality of the grooves in the three different ceramics. A picture of the final edge quality is shown in Fig.4 (right). The groove in the ceramics has a V-like shape, which favors controlled crack propagation starting at the lowest point of the V.

Fig.3. Grooving of two different types of LTCC

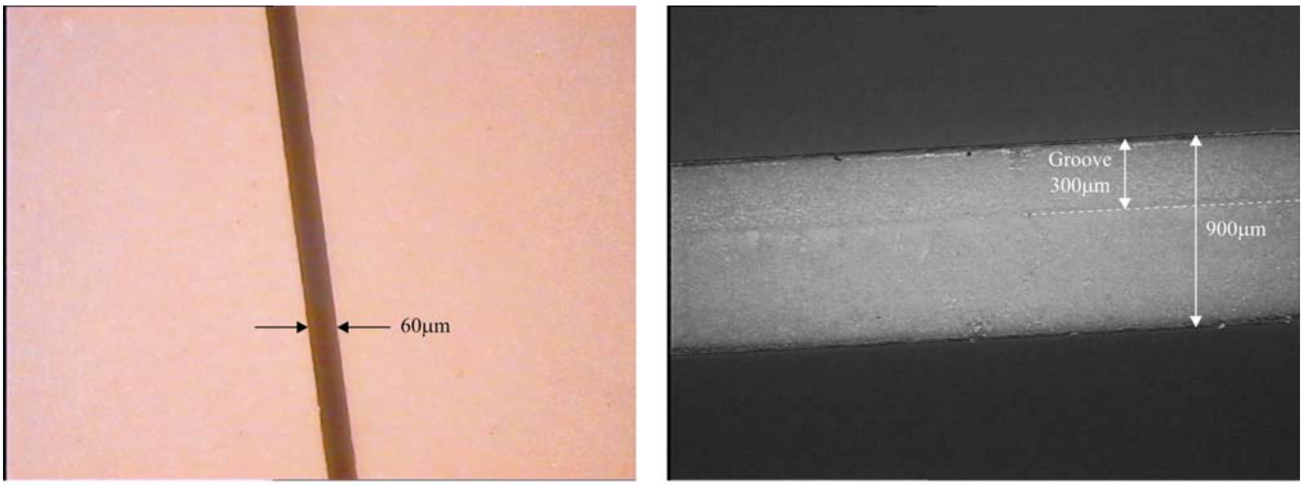

Fig.4. Grooving of Al2O3: top view (left) and side view (right)

Using an infrared laser at 1064 nm, it was possible to reach a speed of 10 mm/s, with the same high groove quality. A LTCC ceramic substrate, 900μm thick, has been processed. As before, the cutting parameters were adapted (see Table 3) in order to achieve the best quality for a 300μm grooving depth. Fig.5 shows the edge quality of the groove.

Nozzle diameter	Average power	Pulse repetition rate	Pulse lenght	Peak power	Speed	Passes	Resulting speed
60 µm	100 W	17 kHz	700 ns	8 kW	400 mm/s	40 x	10 mm/s

Table 3: Parameters with the infrared laser

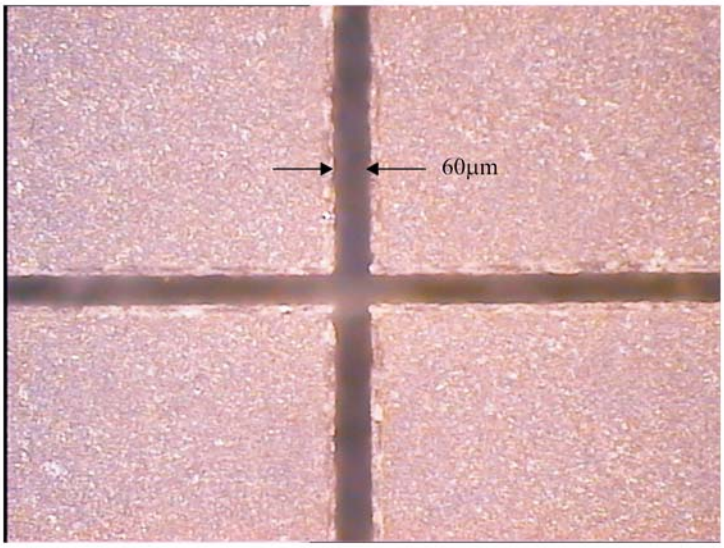

Fig.5. Grooving of an LTCC substrate using an infrared laser

Applying a three-head system, a total speed of 30 mm/s has been realized for the same groove depth.

4. SUMMARY AND CONCLUSIONS

In summary, a very efficient grooving of ceramics was demonstrated using the Laser Microjet technology. The applied process was the usual scribe-and-break process grooving 1/3 of the substrate thickness. Comparing the performance of the laser process to sawing it can be stated that a higher speed can be reached at lower cost of ownership and chipping free edge quality. Applying a parallel process, a multiple of machining speeds of 10mm/s are obtainable.

Comparing the results to conventional laser processes the strongly decreased thermal load of the sample has to be mentioned, improving the edge quality in the ceramic and finally avoiding cracking of the sample. Another advantage of the water jet guided laser is contamination free surfaces after the grooving.

It should also be noted that ceramics-based packages (i.e. substrate, chip and mold compound) can be singulated by the Laser Microjet. A first step cuts the mold compound. Then the package is flipped. Finally, the ceramic substrate is grooved as seen before. The packages are separated by breaking them.

It can be concluded that the Laser Microjet is a cost efficient alternative for high-quality singulation of ceramic substrates, and has high potential for further speed improvement.

REFERENCES

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