

# Heat damage-free Laser-Microjet cutting achieves highest die fracture strength

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## ABSTRACT

Unlike conventional laser-based technologies, the water jet guided laser does not generate heat damage and contamination is also very low. The negligible heat-affected zone is one reason why die fracture strength is higher than with sawing. This paper first presents the water jet guided laser technology and then explains how it differs from conventional dry laser cutting. Finally, it presents the results obtained by three recent studies conducted to determine die fracture strength after Laser-Microjet cutting.

**Keywords:** Water jet guided laser, silicon, laser cutting, heat-affected zone, die fracture strength

## 1. INTRODUCTION

Less than 5% of today's semiconductor wafers are thin (< 150  $\mu\text{m}$ ). However, in the next two years that percentage is expected to increase to 20 or 30%. Wafer thickness should also decrease over time. In addition to offering thinner packages, thin wafers also provide improved heat evacuation and a certain degree of flexibility. Thanks to these advantages, dies based on thin wafers are today used for smart cards, stacked packages and diodes. However, the flexibility achieved for thin dies depends significantly on fracture strength. This is the result of two factors: surface fracture strength and edge fracture strength. After applying precise stress release methods like chemical mechanical polishing (CMP), spin etching and dry polishing, which remove damage on the backside of the wafer after grinding, die fracture strength is currently determined primarily by edge fracture strength. The next step toward increase die strength is, thus, to improve dicing.

Dicing generates edge damage resulting in low die fracture strength. At first, dicing was performed after back grinding (DAG); that is, directly on thin wafers. However, to reduce chipping and thus improve die fracture strength, dicing can also be performed before grinding (DBG) through grooving of thick wafers (see Fig.1).

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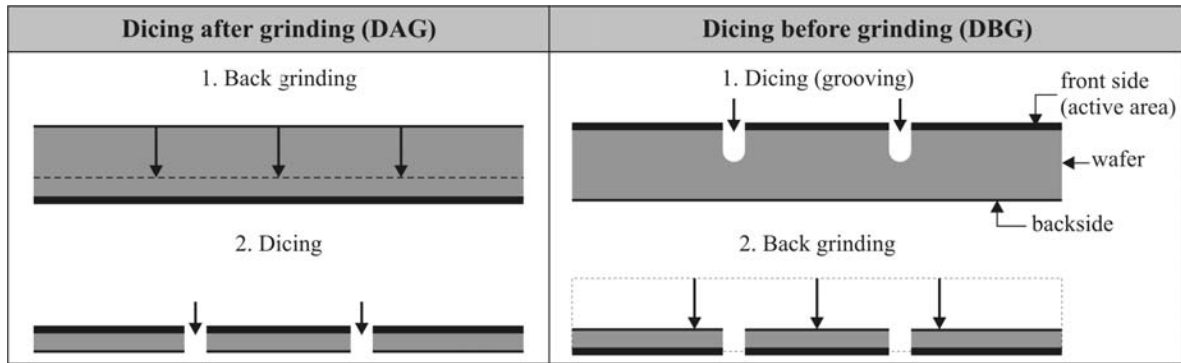


Fig.1. The two dicing methods for thin wafers

Today, conventional processes strain to dice thin wafers. Conventional lasers generate heat damage and abrasive saws generate chipping and micro-cracks. A new damage-free technology is therefore required to improve die fracture strength.

## 2. WATER JET GUIDED LASER

### 2.1 Basic principle

The concept of the water jet guided laser (Laser-Microjet) is to couple a pulsed laser beam into a low-pressure water jet to cut, scribe, drill holes and perform other functions in any kind of material. Its basic principle is to focus a laser beam into a nozzle while passing through a pressurized water chamber. The low-pressure water jet emitted from the diamond nozzle guides the laser beam by means of total internal reflection at the water/air interface, in a manner similar to conventional glass fibers (see Fig.2).

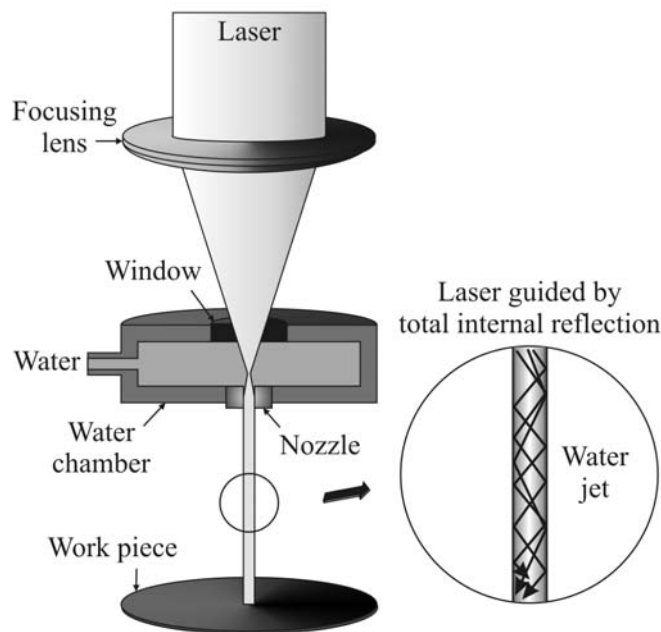


Fig.2. Principle of the coupling unit: coupling the laser beam into the water jet

The water jet thus acts as a stable fluid optical wave-guide of variable length. It has three process-critical functions:

1. Guiding the laser beam to the work piece;
2. Removing molten material; and,
3. Cooling the work piece, i.e. the heat-affected zone is negligible.

Furthermore, the force applied by the micro-jet is negligible (less than 0.1 N) because the jet is very thin (between 25 and 100  $\mu\text{m}$ ). The Laser-Microjet is today a very fast, efficient tool for thin wafer dicing (thru-cut), scribing and edge grinding (where the outer 1-2 mm of the wafer is cut off to ensure a crack free wafer edge). It can be applied to silicon as well as III-V semiconductors.

## 2.2 Technical parameters

The lasers used are either flashlamp-pumped pulsed Nd:YAG lasers with pulse durations of less than 120  $\mu\text{s}$  or multimode Q-switched lasers, operating at 1064 nm, 532 nm, or 355 nm. Pure deionized and filtered water, pressurized at 50 to 500 bars, is used for the waterjet. As the jet is only “hair thin,” water consumption is very low – about 1 liter per hour. The nozzles are made out of sapphire or diamond in order to generate a long stable waterjet, and their diameter ranges from 25 to 100  $\mu\text{m}$ .

## 3. LASER-MICROJET DICING

### 3.1 Advantages over conventional dry lasers

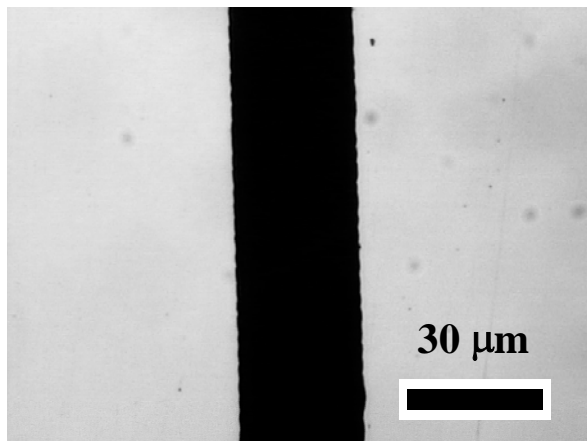
The water jet guided laser should not be confused with a conventional dry laser (see Table 1). Indeed, several major differences exist between the water jet guided laser and the dry laser, which explain the significant dissimilarities that can be seen regarding cutting results. These fundamental differences all result from the concept of the technology itself: the use of water as a wave-guide in laser processing.

In conventional dry laser cutting, the laser beam is focused directly on the work piece. The beam has a conical shape between the focal point and the focusing lens. The laser ablates the material by heating in the focal point, where the intensity is sufficiently high. An assist gas, coaxial to the laser beam, removes the molten material.

With the water jet guided laser, the laser beam, passing through water, is focused in a waterjet-nozzle. The laser beam is then contained inside the produced water jet by total reflection and guided to the work piece, where it ablates material by heating. The waterjet cools the work piece between the laser pulses and expels the molten material from the cut.

Laser-Microjet	Conventional dry laser
<ul style="list-style-type: none"> <li>• Through-cutting</li> <li>• Unlimited wafer thickness (up to 20 mm)</li> <li>• Maintenance-free fiber lasers</li> <li>• Robust, field-proven IR lasers</li> <li>• High dicing speed of up to 300 mm/s (for 50-<math>\mu\text{m}</math> thick Si)</li> <li>• Parallel kerf</li> <li>• Omnidirectional cutting (hexagonal chips, round chips, rounded corners)</li> <li>• No thermal damages thanks to the waterjet</li> </ul>	<ul style="list-style-type: none"> <li>• Scribing mainly, as through-cutting is slow</li> <li>• Limited wafer thickness</li> <li>• Maintenance costs (diodes)</li> <li>• Delicate lasers (UV)</li> <li>• Low scribing / dicing speed</li> <li>• V-shape kerf</li> <li>• Omnidirectional cutting (with single beam)</li> <li>• Thermal damages with any kind of dry laser</li> </ul>

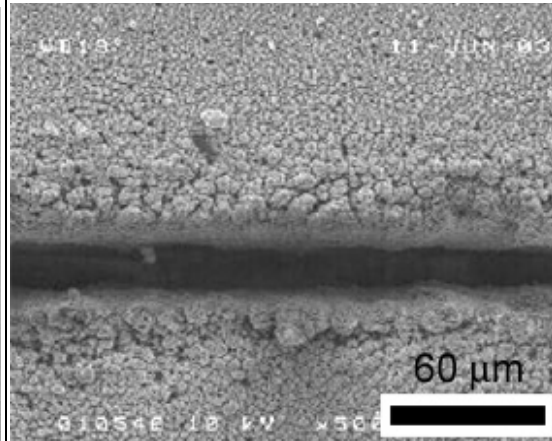
- No contamination thanks to the use of a water film
- Protective layer not required, unlike the conventional laser
- Any semiconductor material (including III/V composites)
- LaserTape for through-cutting
- Low-k wafer compatible
- Highest fracture strength, higher than DBG with surface- and edge- stress release



**Laser-Microjet cutting**

- Kerf width: 26 µm
- Kerf shape: parallel kerf
- Cutting speed: 80 mm/s

- Always contamination; cutting through water impossible
- Protective layer needed
- Dangerous with toxic III/V materials (arsen-oxides for example)
- No tape available
- Incompatible with low-k wafers
- Poor fracture strength, lower than standard dicing



**Conventional dry laser cutting**

- Kerf width: 10-30 µm
- Kerf shape: V-shape
- Cutting speed: 6 mm/s

Table 1 Comparison between Laser-Microjet and conventional dry laser processing

The last pictures in Table 1 show the difference in quality between the two cutting technologies; the sample, a thin silicon wafer (thickness 150 µm), was completely cut in each case.

### 3.2 Samples

Because the Laser-Microjet does not generate thermal or mechanical damages, it is a perfect tool for thin wafer dicing. The very low contamination is also a significant advantage, as the effect of the waterjet is strengthened by the use of a thin water film on the wafer surface. Even brittle semiconductor materials can be processed with high quality. Table 2 shows three samples completely diced with the Laser-Microjet. For each material, wafers are very clean and free of heat damage.


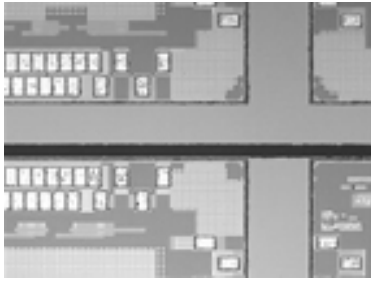

		
<p style="text-align: center;"><b>GaAs wafer</b></p> <ul style="list-style-type: none"> <li>• Kerf width: 23 <math>\mu\text{m}</math></li> <li>• Cutting speed: 20 mm/s</li> </ul>	<p style="text-align: center;"><b>Low-k wafer</b></p> <ul style="list-style-type: none"> <li>• Kerf width: 26 <math>\mu\text{m}</math></li> <li>• Cutting speed: 60 mm/s</li> </ul>	<p style="text-align: center;"><b>SiC wafer</b></p> <ul style="list-style-type: none"> <li>• Kerf width: 30 <math>\mu\text{m}</math></li> <li>• Cutting speed: 50 mm/s</li> </ul>

Table 2 Laser-Microjet dicing of sensitive semiconductor materials. All three samples are 100- $\mu\text{m}$  thick, and were completely cut

## 4. FRACTURE STRENGTH

### 4.1 Setup

A 3-beam bending method was chosen for die fracture strength tests, because it is well suited to measuring the influence of edge damage, allowing even small chips to be checked. The die's extremities rest on two parallel pins, while a vertical force is applied through a third pin located in the middle of the die (see Fig.3). The force is increased consistently until the die breaks and is recorded on a PC, together with the bending radius, as these information determine the die strength.

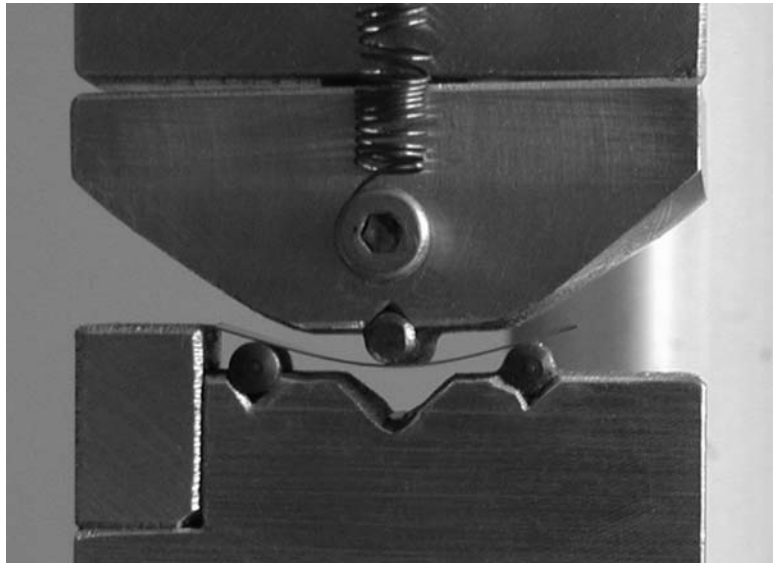


Fig.3. Die bending under the effect of the vertical force during the breaking process on a 3-point bending test

All test samples were 125- $\mu\text{m}$  thick production silicon wafers from the same batch and were ground and polished. After using the different methods to dice them into 10 x 10 mm chips, the samples were removed carefully from the dicing support (dicing tape, grinding tape or LaserTape), avoiding any damage to edges. All tested wafers were then analyzed on both sides, since front and backside values may change based on the dicing process. Around 25 dies were tested for each parameter to determine representative average values.

The first observation noted during the tests was that dies cut with the Laser-Microjet broke into hundreds of small pieces, suggesting that the strength may be very high. The three independent measurements summarized below confirm that initial impression.

#### 4.2 Results from Synova

Fig.4 compares Laser-Microjet trenching (LMJ) and standard sawing (DAG). For an equivalent kerf width, the force – corresponding to the fracture strength – is around 50% higher with the LMJ than with saws for both sides. Moreover, the dicing speed is higher with the Laser-Microjet because in contrast to laser-based technologies, saws are slower when working on small thicknesses.

Dicing technology	Dicing speed	Kerf width	Fracture strength (average force)	
			Front side	Back side
Saw	25 mm/s	45 $\mu\text{m}$	6.7 N	6.8 N
LMJ	50 mm/s	46 $\mu\text{m}$	10.1 N (1.5x)	11 N (1.6x)

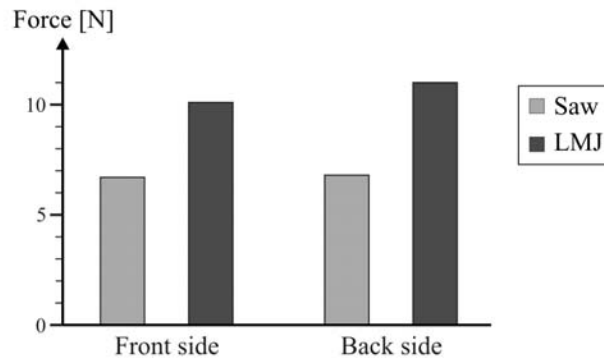


Fig.4. Die fracture strength: comparison between the saw and the Laser-Microjet (LMJ) [source: Synova]

#### 4.3 Results from Fraunhofer-Institute for Mechanics of Materials

Another interesting analysis concerns Weibull distributions, which characterize fracture probability. The Weibull strength (Fig.5) is the strength required to break 63% of dies. The Weibull modulus describes the distribution spread of the breaking probabilities: high value corresponds to low deviation in strength. This parameter is equivalent for sawing and Laser-Microjet dicing, and is thus not represented on the graph.

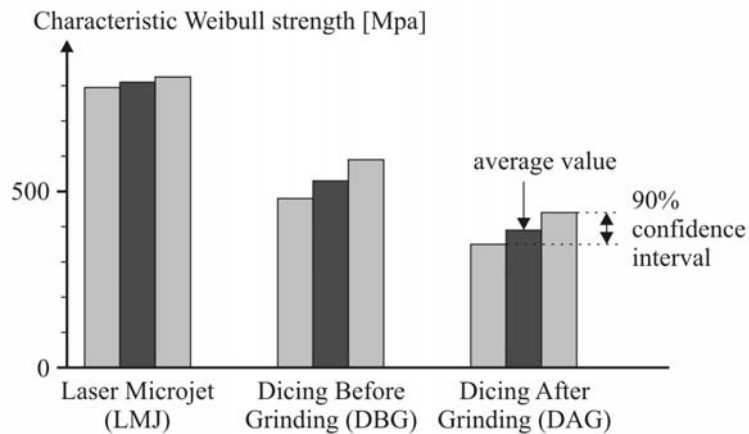


Fig.5. Characteristic Weibull strength for three dicing techniques [source: Fraunhofer-Institute for Mechanics of Materials]

With respect to strength, the Laser-Microjet reaches 810 MPa (front side) while the DBG method remains at around 530 MPa. These results confirm the previous conclusion, which found that the Laser-Microjet increased the die fracture strength by 50%.

#### 4.4 Dicing of etched thin wafers

The last analysis compares Laser-Microjet and traditional dicing of grinded and etched thin wafers. DBG is not studied since, for many wafers, it is not applicable (due to backside processes). Fig.6 (left) illustrates the process: first, the thick wafer is thinned with back grinding; then backside etching is applied, which removes stress from the backside caused by the previous step; finally, the dies are singulated from the front side. As no stress release method is applied after dicing, the 3-point bending test (see Fig.6, right) shows damages generated by dicing only.

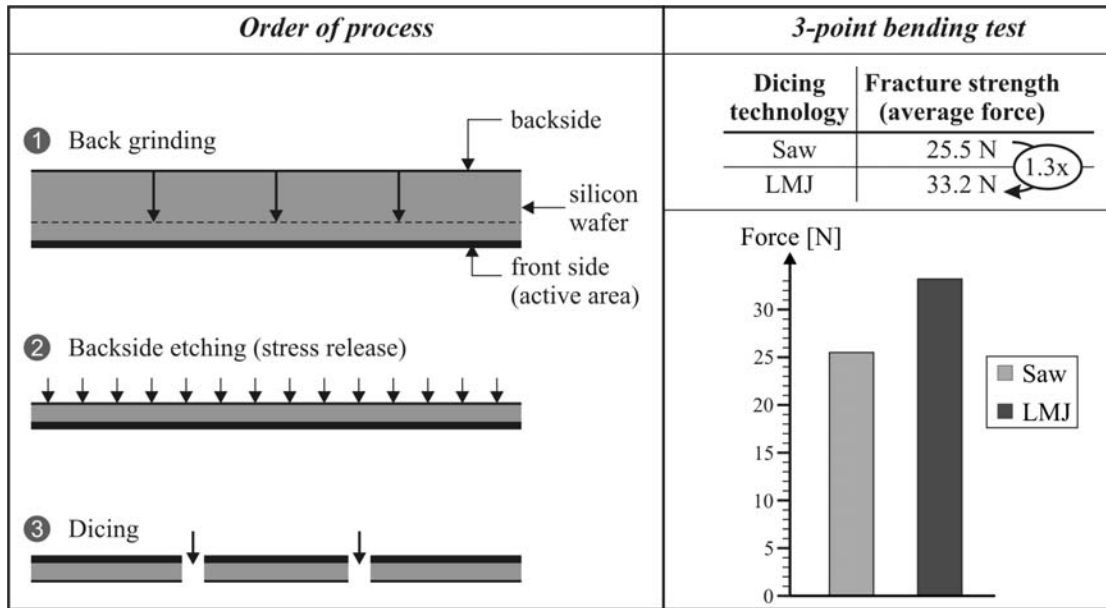


Fig.6. Dicing on etched thin wafers: process (left) and results on a 3-point bending test (right) (absolute values differ from those in Table 1 because those depend on the setup) [source: Infineon Technologies]

Coherent to the results of the previous tests, the Laser-Microjet process generates a die fracture strength significantly higher than sawing (1.3 times higher).

## 5. CONCLUSION

The three independent studies comparing different singulation methods have reached the same conclusion: trenching by water jet guided laser technology achieves the highest die strength. While dicing before grinding (DBG) does improve die fracture strength compared to conventional sawing, it still produces damage and is not applicable for wafers with backside processes. The stress release by etching after grinding improves die strength. However, the advantage of the Laser-Microjet process compared to traditional sawing remains nearly the same. This is due to the specific characteristics of the process, which differentiate the Laser-Microjet from the conventional dry lasers. Thanks to the waterjet, thermal and mechanical damage is negligible, and contamination is very low. The cut quality on sensitive semiconductor materials, especially on thin wafers, is quite high.