

## **PARTICLE-FREE SEMICONDUCTOR DICING USING THE WATER JET GUIDED LASER TECHNOLOGY**

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### **Abstract**

Separation of semiconductors is a challenge for laser based cutting techniques since many years, because of the sensitive material. Until recently, the standard process for dicing semiconductor wafers was abrasive sawing that has been optimized for this application over more than 2 decades. However, the demands of new emerging types of semiconductor devices, like those based on thin wafers and on compound semiconductors, can no longer be fulfilled by abrasive sawing and new separation methods are investigated. The water jet guided laser showed some years ago to be a good alternative for dicing and free-shape cutting of thin semiconductors including GaAs, and is now qualified in terms of particle generation.

Particle generation and redeposition is an important problem for all classical laser-cutting techniques. The water jet guided laser already features an inherent rinsing by the water jet and thus produces much smaller amount of particles than any other laser process. Recently, particle-free dicing of wafers could be achieved by covering the whole work piece with a well-controlled thin water film during the entire cutting process. This paper will compare the particle quantities after usage of different laser dicing processes. For the Laser Microjet<sup>®</sup> the benefits of a clean surface are discussed in more detail.

### **Introduction**

In conventional cutting processes, particles and dust (size between 0.1 and 5  $\mu\text{m}$ ) are spread over the surface of the work piece, which gives an unacceptable result, especially in the case of laser-based technologies. Small particles are very difficult to clean as the adhesion forces (capillary, electrostatic and Van der Waals) are very strong compared to the force that can be applied by a wiping or rinsing device. Additionally, in classical laser cutting, droplets of molten material are "soldered" to the surface of the work piece.

In the case of wafer processing the most problematic consequences of particle contamination are generation of short-circuits and prevention of reliable wire bonding contacts on metal pads. More generally, they cause problems in all manufacturing steps.

As cleaning of these small particles is difficult and expensive or even impossible (for example when employing laser cleaning), the usually applied approach is to keep the wafer clean by avoiding the particles to attach to the surface during the cutting step. The various singulation methods apply today different implementations of this idea and this paper presents a realization of this principle for the water jet guided laser and discusses the results.

### **State of the Art**

In abrasive sawing of semiconductors a strong rinsing with DI-water is used in order to make sure that the generated particles are swept away before they can attach to the wafer surface. A method showing a high impact on the cost of ownership of the saws, as the DI-water consumption is very high.

In classical laser cutting, particle contamination is extremely high. Even when cutting under light atmosphere or in raw vacuum, the required cleanliness of semiconductor samples can by far not be reached (see Figure 1).

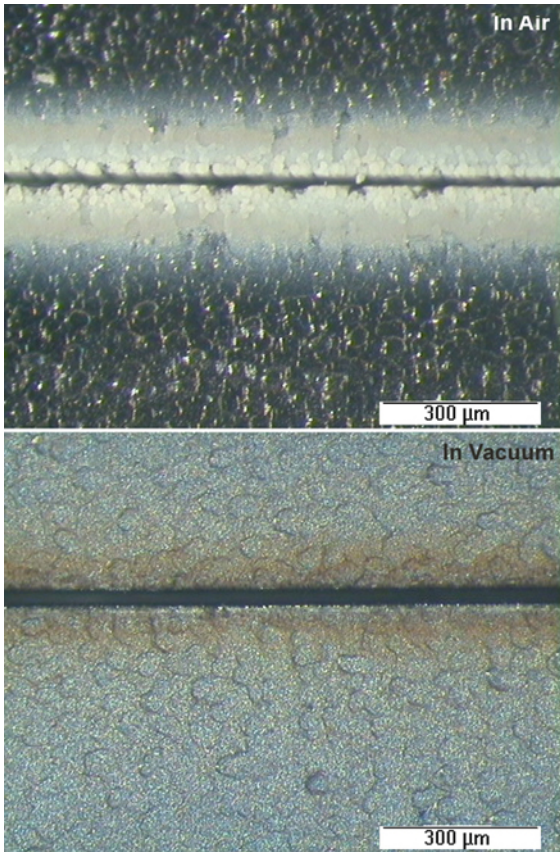


Figure 1 Particle contamination in classical laser cutting: in air (top) and in vacuum (bottom) [1]

If classical laser cutting is applied all the same to semiconductor dicing, a sacrificial protection layer is needed on the wafer. In semiconductor applications, the protection layer is mostly realized by a thick layer of photo resist. The particles thus deposit on the protection layer, which is removed by etching after the dicing step. This solution greatly increases the cost of ownership of the dicing process, as two supplementary process steps must be added.

As mentioned above, classical laser cutting is not an alternative to abrasive sawing. Nevertheless, more and more dicing applications require a force-free and particle-free cutting process, featuring very small kerf widths and therefore a minimization of the zone of damaged material (chipping upon sawing and heat-affected zone upon laser cutting). Mostly the dicing of thin Silicon and III-V wafers, both being at the base for devices with an increasing market share, is problematic with saws and the semiconductor industry is looking for alternative technologies.

## Laser Microjet Principle

The concept of the Laser Microjet is to couple a pulsed laser beam into a low-pressure water jet in order to cut, scribe, drill holes, etc. in any kind of materials. 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 Figure 2).

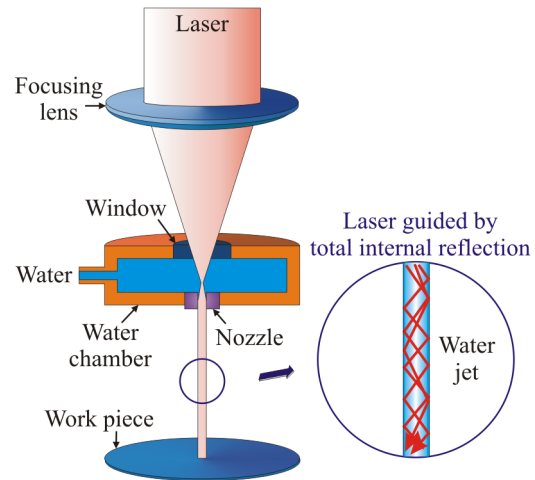


Figure 2 Principle of the coupling unit: coupling the laser beam into the water jet

The water jet acts thus as a stable fluid optical waveguide of variable length; it has three process critical functions:

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

The LMJ is a very fast, efficient alternative 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.

## Particle contamination and Laser Microjet

Compared to conventional laser-based technologies, the water jet guided laser technology produces a much smaller amount of particles, since the water jet used to guide the laser beam onto the work piece also removes efficiently most of the molten material. However the

development of a new cleaning device was necessary in order to reach a particle contamination level close to zero.

The aim in this development was to avoid the sacrificial layer technique that can be employed with the water jet guided laser too. Simply implementing a strong rinsing is not possible with the water jet guided laser technique, because of the sensitivity of the micron sized water jet that has to be stable and cylindrical until it touches the work piece.

During laser micro jet cutting a part of the high-speed jet is deviated and builds up a thin water film on the sample surface. Once the cut goes through the sample a part of the water film will be sucked into the vacuum chuck. Usually in the middle of the chips a part of the water film remains. When cutting wafers the remaining water may evaporate and the particles that are held in suspension in this water film can then attach to the sample. Anyway the particle contamination caused by this mechanism is negligible compared to the particle contamination caused by classical laser techniques.

### Water Film Device

If the water jet guided cutting process itself shows already excellent results, the cleanliness of the processed wafers has even more been improved with the development of a new device to complete the system. The water film device makes sure that a continuous water layer of controlled thickness covers the wafer. The presence of the water layer avoids that the particles in suspension can attach to the wafer surface after evaporation of the water dispensed by the micro-jet. Removing the water layer after cutting in a controlled way then also removes the particles in suspension.

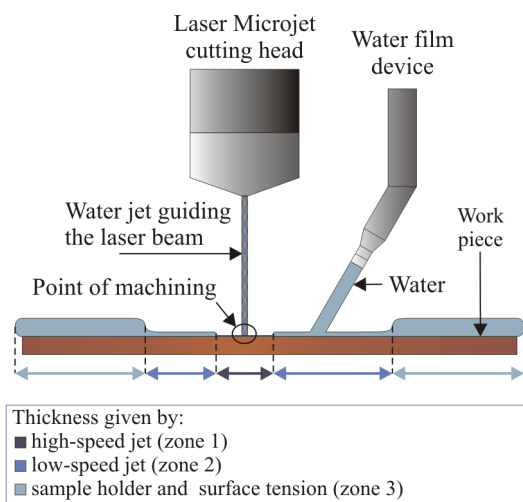


Figure 3 Principle of the Water Film Device (one water source)

Usually the low-speed water jet has a pressure of typically 0.5 to 2 bar (relative to the atmospheric pressure) and a jet diameter of 0.5 to 4 mm. This water jet impinges onto the surface of the work piece close to the machining point (where the laser water jet hits the surface) and creates a zone of intermediate water film thickness around it (see Figure 3).

The water film is composed of three zones:

1. The thickness of the film in zone 1 is given by the parameters of the laser guiding high-speed jet, mostly its flow rate. Only the high-speed jet feeds zone 1.
2. The thickness of the water film in zone 2 (0.1 to 0.5 mm) is mostly determined by the parameters of the low speed jet, namely the angle of impingement of the low-speed jet (typically in the range of 45-90 degrees) and its input pressure. Both jets feed zone 2.
3. The thickness of the water film in zone 3 (0.5 to 5 mm) is given by the geometry of the sample holder and the surface tension of the liquid.

The liquid dispensed by the low-speed jet can be adapted to the particular application and may contain buffer molecules in order to adjust the PH. The liquid film can thus be used to control the chemistry on the wafer and protect the wafer from electrostatic discharge (ESD) damage. This additional advantage is due to the fact that the water emerging from the water film device cannot penetrate zone 1 of the liquid film on the wafer.

At least one low-speed water jet source is needed but more water sources can be added. This can be very useful when the wafer presents many cut lines, because in that case the vacuum that fixes the chips tends to absorb the water, drying the wafer by suction through the already finished cuts.

### Quantitative Particle Reduction Tests

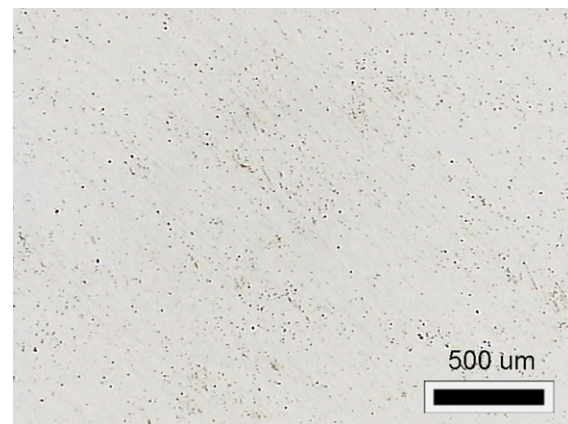


Figure 4 Inverted picture of the sample after preparation prior to cutting

The following tests have been generated using 100- $\mu\text{m}$  thick bare silicon wafers that were stored in a usual office for several weeks. Prior to the test, the wafers have been cleaned by wiping subsequently with acetone and isopropanol, but still many particles were visible under the optical microscope (see Figure 4).

Particle counting was performed using LabView IMAQ Vision software. Figure 5 shows an example of an input image and the result.

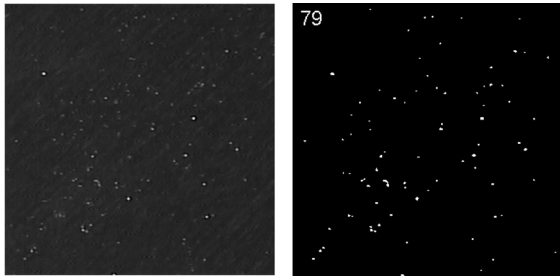


Figure 5 Input picture (left) and processed picture (right) with the number of particles counted

Figure 6 shows the situation after normal cutting without water film device. The cutting parameters were: wavelength 532 nm, average power 24 W and pulse repetition 40 kHz for the laser; nozzle diameter 50  $\mu\text{m}$ ; water jet pressure 350 bar; chip size 2x2  $\text{mm}^2$ .

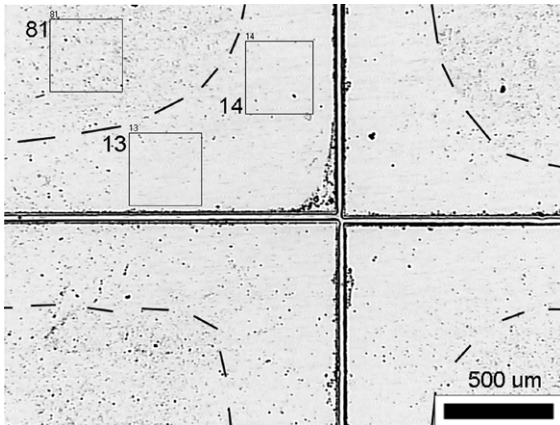


Figure 6 Sample after cutting without water film device

One can observe a line of changing particle density on figure 6, which is indicated by the interrupted line. It is generated under the influence of the water suction through the finished cuts. Only a part of the water film dispensed during cutting was removed, generating a zone of few particles in the vicinity of the cuts except in a region right near the cut where water drops remain due to pinning effects.

Figure 7 shows the sample after the same cut but this time with the DI-water fed water film device used. No clear line of changing particle density can be seen. As before, the cut is perfectly stable and the cut quality is unchanged compared to the “dry” cut (Figure 6).

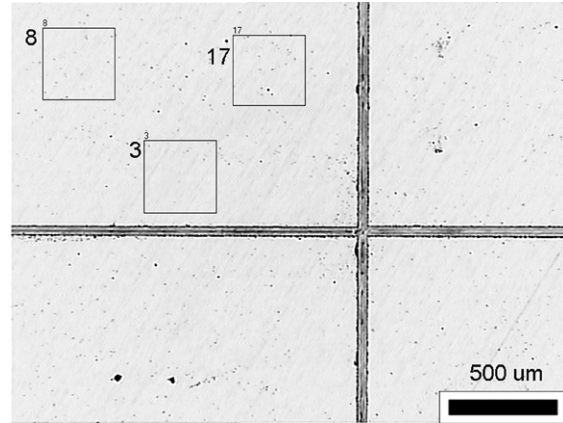


Figure 7 Sample after cutting using the water film device with pure DI-water

Compared to the initial state of the wafer (Figure 4) the number of particles is not enhanced. Comparing the dry cut (Figure 6) with the water-film cut (Figure 7) and considering the fact that the samples were not completely clean prior to cutting we can state that with the water film device, the particle contamination has been reduced by at least 90 percent compared to the usual laser micro jet cut which in turn is already much cleaner than any other laser cut. These are the first preliminary quantitative results. For a final analysis it will be necessary to use perfectly clean wafers and perform an analysis of large surfaces. Partially, the following sections show what can be expected from a more detailed study.

### Results on Clean Samples

After removing the water layer and using a standard cleaning station no contamination is observed under the optical microscope. The microscope photos below show the surface quality after a cutting process with the Laser Microjet with three different types of material: Silicon, Gallium Arsenide and metal.

#### Silicon

Silicon can be diced by through cutting or scribe and break method. The quality and cleanliness of the material can be seen on Figure 8 below. It shows scribing of a 100  $\mu\text{m}$  silicon wafer for a water jet guided Nd:YAG laser, wavelength 1064 nm, average power 50 W, and pulse repetition rate 50 kHz. The nozzle diameter was of 40  $\mu\text{m}$ , and the water jet,

guiding the laser beam, had a pressure of 400 bar. The scribing was done in one pass at 100 mm/s.

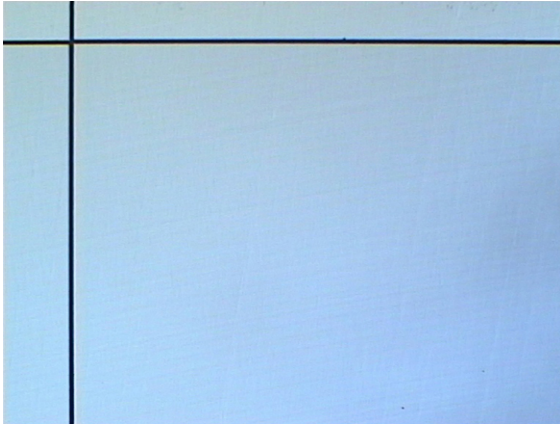


Figure 8 Blank Silicon, thickness 100  $\mu\text{m}$

### Gallium Arsenide

Conventional laser ablation of GaAs creates a lot of debris, hard to remove, that can even damage nearby active components. Using the water film device keeps GaAs wafers clean and free of particles. The resulting level of chip contamination is as low as with a conventional saw, but the cut is much faster.

Figure 9 shows results of complete dicing of a thin GaAs wafer for a YAG laser, wavelength 1064 nm, average power 50 W, and pulse repetition rate 35 kHz. The water jet diameter was of 25  $\mu\text{m}$ , and the water pressure 400 bar. The resulting cutting speed was 60 mm/s.

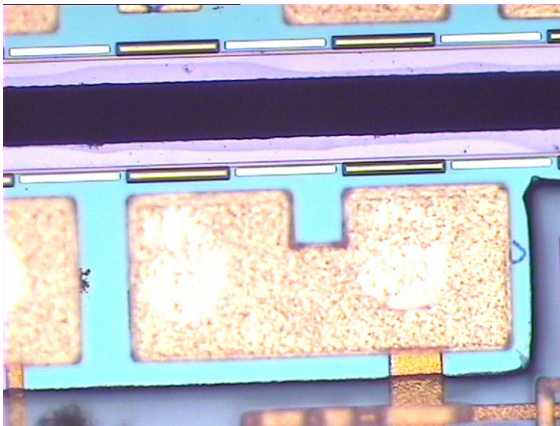


Figure 9 Dicing of a 100  $\mu\text{m}$  thick GaAs wafer (kerf width 26  $\mu\text{m}$ )

### Metal

Metals can be cut with the Laser Microjet as well. A potential application is drilling of stainless steel stencils. The water jet combined with the water film device avoids any deposition; there is no oxidation. The metal surface is perfectly clean. The backside is completely burr-free, without any post-treatment.

Figure 10 shows results of holes cutting in a thin stainless steel sheet (50  $\mu\text{m}$ ) for a pulsed YAG laser, wavelength 1064 nm, average power 55 W, and pulse repetition rate 700 Hz. The water jet diameter was of 40  $\mu\text{m}$ , and the water pressure 300 bar. The average resulting cutting speed was 20'000 holes/hour.

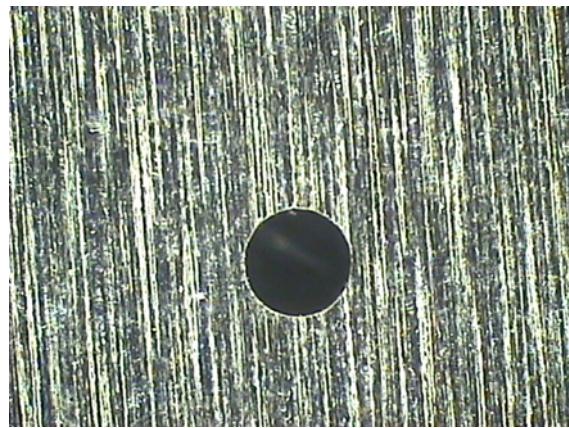


Figure 10 Hole (diameter 250  $\mu\text{m}$ ) in 50- $\mu\text{m}$  thick stainless steel (stencil)

### Conclusion

Contamination is a serious problem of any cutting process. The new device developed by Synova, using a thin water film to avoid redeposition of particles generated by the laser ablation, is very efficient. The Water Film Device consists in a continuous flow of water that provides a film of inert liquid on the work piece in order to build a protection layer against the particles that might be generated in the machining process. The results for a wide range of different materials show that the particle number is strongly reduced. The processed work pieces are clean and practically free of particles. The level of chip contamination is low.

### References

[1] Klotzbach, U., Mälzer, S., Panzner, M., Kuntze, T., Sonntag, F. & Dötschel, M., Fraunhofer Institut for Material and Beam Technology (2004) Influence of gas for structuring silicon, in Proceedings of SPIE (Photonics West), San Jose, USA, Vol. 5339.