Particle-free semiconductor cutting using the water jet guided laser

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ABSTRACT

For many years, wafer cutting has posed a challenge to laser-based cutting techniques because of the brittle nature of semiconductors and the exacting requirements for cleanliness. Since conventional laser cutting generates a strong heat-affected zone and a large amount of particles, abrasive sawing is currently the standard process for semiconductor wafer dicing. However, abrasive sawing can no longer fulfill the demands of new, emerging types of semiconductor devices like those based on thin wafers and compound semiconductors. New separation methods are investigated here. The water jet guided laser is a relatively recent technology that offers not only a significantly reduced heat-affected zone but also a cleaner wafer surface. This is due, first, to the water jet, which cools the material between the laser pulses and removes a significant amount of molten material generated by laser ablation. However, the system has recently been upgraded by adding a device that covers the entire wafer surface with a well-controlled thin water film throughout the cutting process. The few generated particles are thus kept in suspension and will not deposit on the wafer surface.

Keywords: Water-jet guided laser, silicon, laser cutting, debris, particle generation

1. INTRODUCTION

In conventional cutting processes, small particles – between 0.1 and 5 µm – are spread over the wafer surface. This effect is especially important in the case of laser-based technologies. Additionally, in conventional laser cutting, droplets of molten material adhere to the wafer surface. These particles cause problems in all manufacturing steps and can generate short-circuits and prevent reliable wire bonding contacts on metal pads.

Such small particles are very difficult to clean, as the adhesion forces are stronger than the force that can be applied by a wiping or rinsing device. Cleaning devices, such as laser cleaning, are expensive and do not always provide satisfying results. Therefore, the approach usually applied is to completely avoid the particles to attach to the surface during the cutting step. The current range of singulation methods relies on different approaches to implementing this idea. This paper presents an application of this principle using the water jet guided laser and discusses the results.

2. STATE OF THE ART

Particle contamination is extremely high in conventional laser cutting. Even when cutting under slightly reduced pressure or in a coarse vacuum, it is very difficult to achieve the cleanliness required of semiconductor samples (see Fig.1). Therefore, the wafer needs a sacrificial protection layer during laser processing. In most semiconductor applications, a thick layer of photo resist is used. The particles thus deposit on the protection layer, which is removed by etching after the dicing step. This solution greatly increases the operating cost of the dicing process, as it requires the addition of two supplementary processes.

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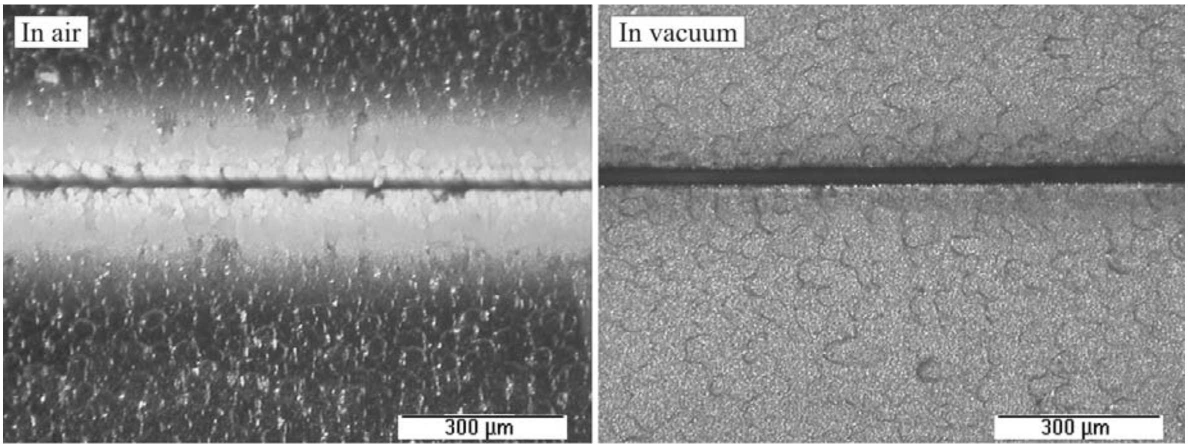

Fig.1. Particle contamination in conventional laser cutting: in air (left) and in vacuum (right) [1]

In the semiconductor field, conventional 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 street widths and, therefore, minimization of the zone of damaged material (chipping resulting from sawing and heat-affected zone resulting from laser cutting). Both thin wafer dicing and III-V semiconductor processing are problematic with saws. Both are the basis of devices with an increasing market share.

3. LASER-MICROJET 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).

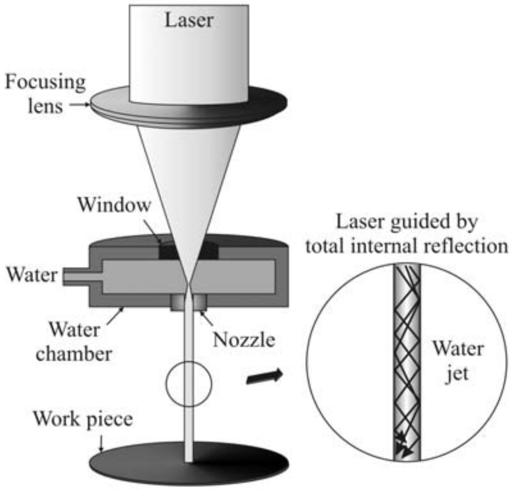

Fig.2. Principle of the coupling unit: coupling the laser beam into the water jet

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

The Laser-Microjet 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 to III-V semiconductors.

4. PARTICLE CONTAMINATION AND LASER-MICROJET

During Laser-Microjet cutting, part of the water jet is deviated and builds up a thin water film on the wafer surface. Once the cut passes through the wafer, part of the water film is sucked into the vacuum chuck. Part of the water film usually remains in the middle of the chips. When cutting wafers, the remaining water may evaporate and the particles held in suspension in this water film can then attach to the wafer surface. In any event, particle contamination caused by this mechanism is negligible compared to that produced by classical laser techniques.

However, it was necessary to develop a new cleaning device to reduce particle contamination. The goal was to avoid the sacrificial layer technique that could also be used with the water jet guided laser. It is not possible to simply perform a strong rinsing because of the sensitivity of the micron-sized water jet that must be stable and cylindrical until it touches the wafer.

4.1 Water Film Device

While the water jet guided cutting process already demonstrates excellent results, the cleanliness of the processed wafers could be improved further by developing a new device to complete the system. The water film device ensures that a continuous water layer of controlled thickness covers the wafer. The presence of the water layer prevents the particles in suspension from attaching to the wafer surface after water dispensed by the micro-jet evaporates. Removing the water layer after cutting in a controlled way then also removes the particles in suspension.

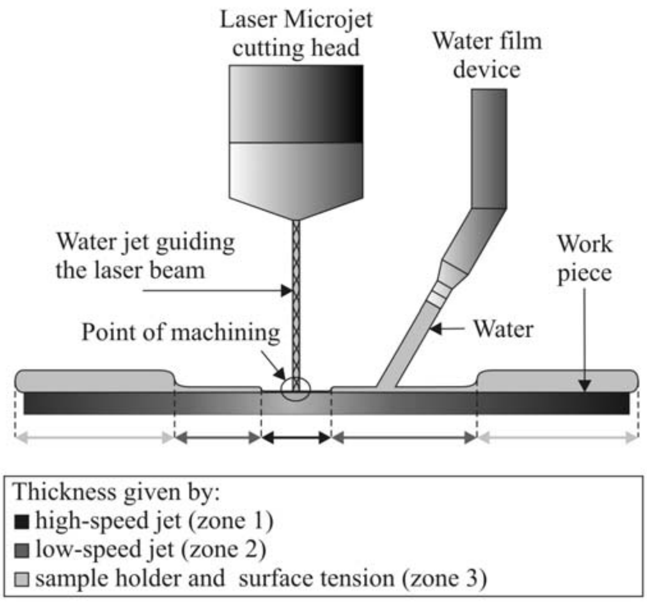

Fig.3. Principle of the Water Film Device (one water source)

The low-speed water jet pressure typically ranges from 0.5 to 2 bar (relative to the atmospheric pressure) and its diameter ranges from 0.5 to 4 mm. The water jet impinges onto the surface of the work piece close to the machining point (where the water jet guiding the laser hits the surface) and creates a zone of intermediate water film thickness around it (see Fig.3). This water film is composed of three zones:

- Zone 1 is fed by the high-speed jet; the parameters of the laser guiding high-speed jet (mostly its flow rate) determine the thickness of the film;
- Both jets feed zone 2; the film's thickness (0.1 to 0.5 mm) is 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;
- The thickness of the film in zone 3 (0.5 to 5 mm) is determined 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 specific applications and may contain buffer molecules to adjust 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 provided because 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.

4.2 Quantitative Particle Reduction Tests

The wafers used for the following tests were 100-µm thick bare silicon wafers stored in a typical office for several weeks. Prior to the tests, the wafers were cleaned by wiping with acetone and isopropanol. However, many particles were visible under the optical microscope (see Fig.4).

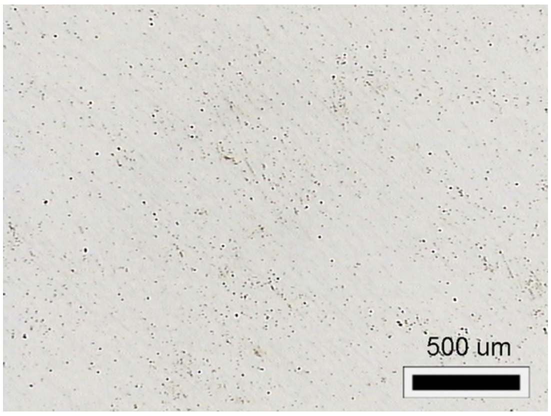

Fig.4. Inverted picture of the sample after preparation prior to cutting

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

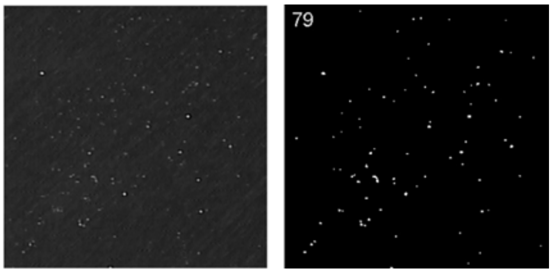

Fig.5. Input picture (left) and processed picture (right) with the number of particles counted

Fig.6 shows a wafer after normal cutting without the 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 μm; water jet pressure 350 bar; chip size 2x2 mm^2. The interrupted line indicates a line of changing particle density, generated under the influence of the water suction through the finished cuts. Only 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 near the cut where water drops remain due to pinning effects.

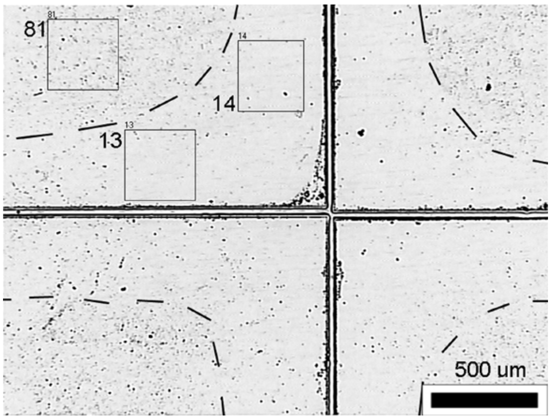

Fig.6. Sample after cutting without water film device

Fig.7 shows another cut wafer, but this time the DI-water fed water film device was 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 first cut (Fig.6).

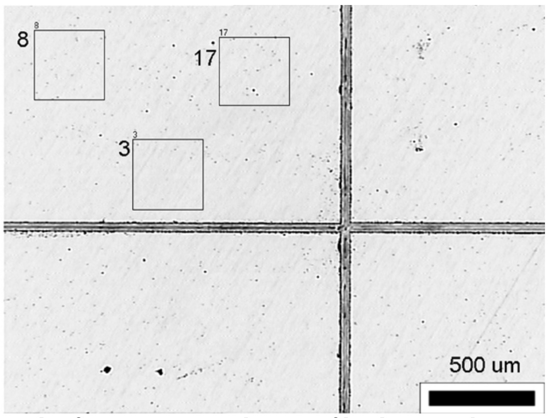

Fig.7. Sample after cutting using the water film device with pure DI-water

Compared to the initial state of the wafer (Fig.4), the number of particles is not increased. Comparing the "dry" cut (Fig.6) with the water-film cut (Fig.7) and considering that the samples were not completely clean prior to cutting, we can state that using the water film device reduced particle contamination by at least 90 percent compared to the usual Laser-Microjet cut, which already produces a much cleaner result than any other laser cut.

These are the preliminary quantitative results. A final analysis would require the use of perfectly clean wafers and an analysis of large surfaces. The following sections show, in part, what can be expected from a more detailed study.

5. 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 Laser-Microjet cutting of two semiconductor materials – silicon (Si) and gallium arsenide (GaAs).

5.1 Silicon

Silicon can be diced by through cutting or scribe and break method. Fig.8 shows the quality and cleanliness of a 100-µm thick silicon wafer after Laser-Microjet scribing. The parameters were: wavelength 1064 nm, average power 50 W, and pulse repetition rate 50 kHz for the Nd:YAG laser; nozzle diameter 40 µm; water-jet pressure 400 bar. The scribing was done in one pass at 100 mm/s.

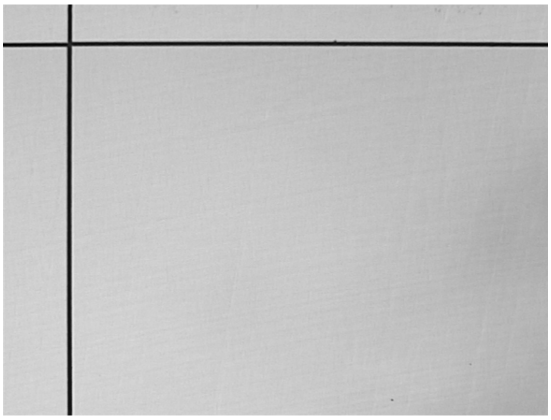

Fig.8. Blank Silicon, thickness 100 µm

5.2 Gallium Arsenide

Conventional laser ablation of GaAs creates considerable debris that is hard to remove and may 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 abrasive sawing, but the cut is much faster. Fig.9 shows a thin GaAs wafer completely diced with the Laser-Microjet. The parameters were: wavelength 1064 nm, average power 50 W, and pulse repetition rate 35 kHz for the laser; water-jet diameter 25 µm; water pressure 400 bar. The resulting cutting speed was 60 mm/s.

Fig.9. Dicing of a 100-μm thick GaAs wafer (kerf width 26 μm)

6. CONCLUSION

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

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