

Waterjet-guided Laser Processing

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The waterjet-guided laser processing is a thermal cutting process in which the laser beam is used as the machine tool for cutting and the fine waterjet plays a role as an optical waveguide. The laser beam is guided in the waterjet stream with the full reflection that takes place at the boundary between water and air, in a manner similar to glass fibers. The waterjet also has the function of waveguiding and removing the cut products (see Fig. 1). The diameter of the waterjet can be controlled between 50 and 200 μm . The diameter of laser beam is completely utilised. The useful length of waterjet is usually approximately 50 to 100 mm. The type of laser used is a pulsed Nd:YAG laser. The advantages of waterjet-guided laser processing are (1) no Z-axis control, (2) narrower cut widths down to 50 μm , (3) very small heat affected zone, (4) a little oxidation of the cut edges, and (5) no assist gas for cutting. A research was carried out for the new industrial application which is unsuitable by conventional laser cutting.

Keywords: waterjet, waveguiding, coupling, working distance, Si wafer dicing

1. Coupling of water jet and laser beam

Waterjet-guided laser processing is an internationally patented technique which has been developed by Bernold Richerzhagen[1]. It is based on guiding a laser beam inside a fine water jet. Because of the difference in the reflection coefficient of water and air, the laser beam is fully reflected at the water jet surface, similar to an optical fiber. The fine water jet can be called as "liquid fiber with variable length"(see Fig. 2)[2].



Fig.1 Waterjet-guided laser processing

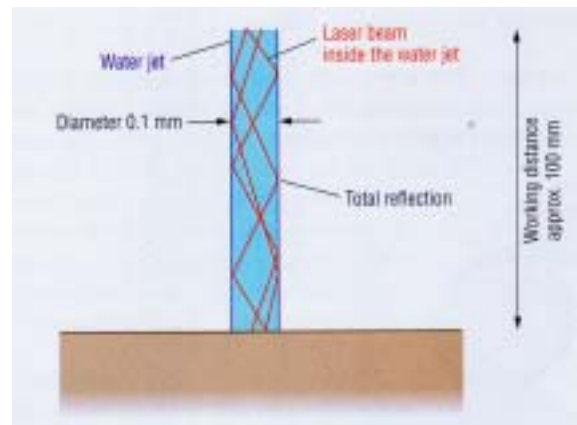


Fig.2 Coupling of water jet and laser beam

Although a high power laser beam normally vaporizes small volumes of water, a special geometry of the coupling system avoids thermal coupling of laser with water. The water jet at a pressure of about 100 bars (10 MPa), guides the laser beam and cools the material during the processing, and remove the cut products.

The typical diameter of waterjet-guided laser beam is 100 μm , which can be reduced to 50 μm . The useful length of water jet depends on the diameter and amounts to 100 mm in the case of a 100 μm water jet.

Another important characteristic of the technique is the fact that water jet is able to guide laser beam into the workpiece so that multilayered materials can be cut.

The process has some important advantages in comparison to conventional laser cutting, because of no focal point of beam, the large working distance and cooling by the water jet.

2. The Micro-waterjet laser machining system

The laser machining center consists of laser source with an optical fiber for laser transmission, a hydraulic unit to produce the required water pressure, a module for coupling laser beam into water jet, a workpiece handling system and CAD programming unit.

A pulsed Nd-YAG laser with average output power of 300-500 W and a peak power rating of 10 to 20 kW is used. The maximum pulse frequency is 1000 Hz. CW lasers can also be used for surface removal. The optical fiber used for laser transmission to coupling unit has a core of 400 μm in diameter.

The hydraulic unit was developed especially for the "Micro-waterjet". The reason for this effort was that although the systems is available on the market cover low pressure range up to 20 bar (2 MPa) and the high pressure range upward of 3000 bar (300 MPa), no system was found that was adequate for the middle pressure levels required.

A new concept was developed for the workpiece handling system, which is suitable to the demands of Micro-waterjet processing. Linear motors are integrated in the biaxial cross table. These offer considerably greater dynamics and precision over conventional drive techniques.

The table speed of 3 m/s can be achieved with a maximum acceleration of 3 g. The motors are mounted on a finely ground granite bed on a welded steel frame.

The greatest breakthrough was in developing bundling module which combines the two media of laser and water to form an extremely fine laser beam. The special geometry of the coupling device allows a laser intensity of more than 50 MW/cm² in a water jet with a diameter of 100 μm . The compact laser processing head contains optical lenses that focus the laser beam in special water jet nozzles. A mechanized beam expander matches the laser beam into water jet of any desired diameter between 50 and 1000 μm . In order to ensure flawless focusing, the beam is monitored with video camera and adjusted automatically.

3. The Waterjet-guided laser processing for wafer cutting

The technology of wafer sawing using a saw with diamond tips has been developed in last 10 years

In the case of saw blade with diamond tips, the quality of cut deteriorates with increasing cut length due to wear of the saw blade. In other words, two wafers can never be diced to the same degree of quality. In this context, it is up to the machine operator to decide when a tool change is due. On

the other hand, the laser processing is not subject to mechanical stress and wear, thus yielding constant cutting quality.

The diamond saw blade exerts extremely high forces on the wafer during the cutting, which make it necessary to fix the wafer firmly in place and can lead to chipping of the part at edges and corners and cracking of the wafer, which can subsequently lead to circuit failure.

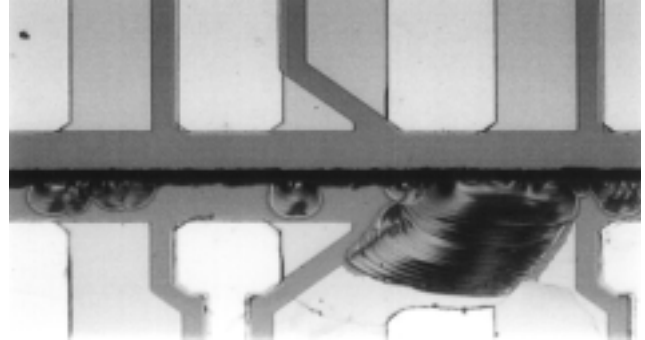
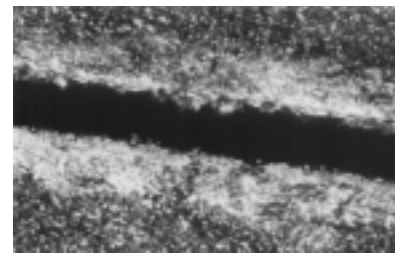
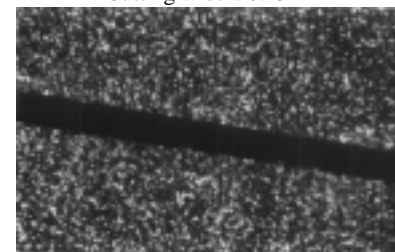


Fig.3 Chipping by sawing

The most significant problem of abrasive sawing is chipping at the upper and lower edges of the cut wafer (see Fig. 3) – chipping across the line and into the die will inevitably lead to rejection. Laser processing on the other hand, being virtually force-free, so that chipping is not occurred. The irregularities on the rear of wafer generally should not be less than 5 μm . The force on the wafer by waterjet is far lower than that of the sawing. Indeed, it is even 10 times more than the force caused by conventional laser cutting with assist gas. This is due to the very small cross-section of the waterjet. Fig. 4 shows the comparison between conventional laser and waterjet-guided laser processings.



(a) Conventional laser processing
Cutting width: 0.15mm



(b) Waterjet-guided laser processing
Cutting width: 0.085mm

Fig.4 Comparison between conventional laser and waterjet-guided laser processing for cutting Si wafer

The saw can only cut in straight lines, with the geometry of cut being limited to one dimension. The laser processing is punctiform and allows two-dimensional processing, thus meaning that any contour imaginables can be cut.

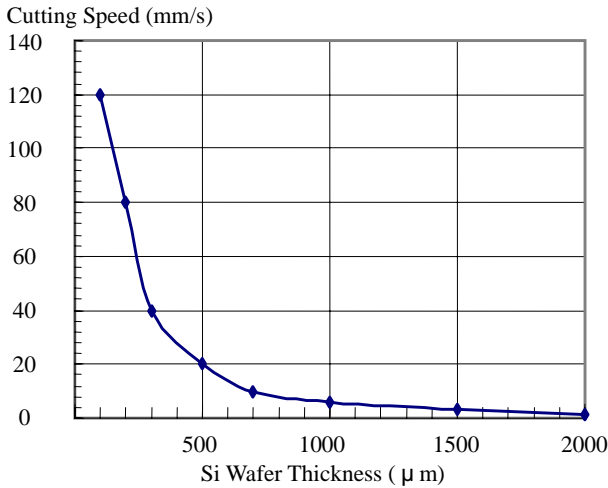


Fig.5 Relationship between Si wafer thickness and cutting speed by waterjet-guided laser processing

Fig.5 shows relationship between Si wafer thickness and cutting speed by waterjet-guided laser processing. The result that shows cutting speed is same or higher level compared with sawing with diamond tips.

This also renders the rotary axis required for orienting the wafer during sawing superfluous. A Z-axis is also no longer needs, as the waterjet-laser need not be focussed.

As a result of the punctiform laser, both holes and slots can now be drilled on one and the same machine – an application for which a particle jet with the associated compromises was hitherto used. A further advantage of the low pressure laser cutting process is its ability to dice very thin wafers, as the wafer thickness has no lower limit. Fig.6 shows slots.



Fig.6 Slots made in Si wafer (20x)

The running costs of sawing are very high on account of the consumption of diamond edged saw blades. Furthermore, the manufacturing process has to be stopped for tool change, and the actual change performed manually.

Although somewhat more expensive to purchase the facility, the laser is characterized by extremely low running costs. The laser flashlamps have to be replaced after approx. 800 to 1000 hours, and the diamond waterjet nozzles after approx. 200 hours. This equates to considerably lower consumption costs for the laser. Fig. 7 shows an example of cutting of IC devices for electric industry.



Fig.7 Cutting of IC devices for electric industry

The waterjet-guided laser processing is also suitable for grooving of wafer. The depth of groove is kept at constant due to laser pulse energy.

The laser processing can be applied easily to materials with different mechanical properties and hardness. However, the optical parameters such as reflectivity effects the process parameters. As a result, some materials can only be cut to a limited extent.

Grass, for instance, is a material that is very transparent to YAG laser. Metallic materials such as gold and copper reflect the laser beam intensively, therefore, only thin metal sheets can be cut.

However, the gold and copper vapour deposits of several micrometers in thickness that are used in silicon technology are not a factor in this context. Ceramics such as Al_2O_3 can only be processed very slowly when of high-grade purity, e.g. 99%.

The waterjet-guided laser has the energy used for cutting the material. The waterjet is useful for cooling the work-piece, guiding the laser beam and removing cut products from the cut. The actual cutting process is thus thermal one, although the depth of thermal penetration is very low on account of the waterjet. The edges of cut thus display a molten surface.

The resultant structure is very fine, but increases proportionally with a large wafer thickness. The roughness R_a is 3 μm for a wafer of 660 μm in thickness. Therefore, the surface of edge can be comparable with that cut by a diamond edged blade.

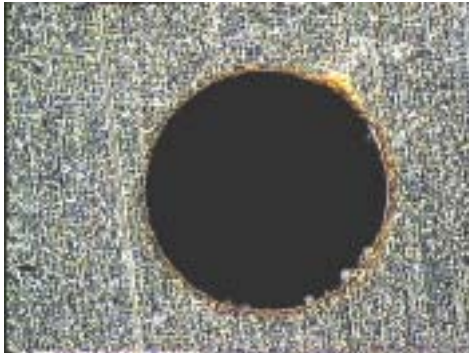
In addition to high machine costs, a laser processing system requires wide floor space than that of the sawing, which is merely driven via a spindle. A 300 W laser system requires between 10 and 20 m^2 .

Laser Dicing System, vacuum wafer chuck and Laser-Tape® (developed by Furukawa Japan) is developed last year.

4. Stencil cutting with waterjet-guided laser

Stencil is used solder paste mask for electric industry. Conventionally stencil is made by chemical etching process. Recently laser stencil cutting system is released. Debris is made around pattern edge because laser cutting is thermal process. After laser stencil cutting, acid washing or grinding is necessary for removing debris.

Waterjet-guided laser is cooling pattern edge while laser is cutting metal mask. Therefore acid washing and grinding is not necessary. And cutting speed is same as conventional laser stencil cutting. Fig.8 shows comparison laser and waterjet-guided laser.



(a) Conventional laser processing



(b) Waterjet-guided laser processing

Fig.8 Comparison between conventional laser and waterjet-guided laser processing for stencil cutting (80x)

5. Other applications

The applications of water jet-guided laser processing have been considered to the metal sheet industry. The waterjet-guided laser processing is for the high precision machining and micromachining. This includes a broad spectrum of processing metal sheet.

Of the host of applications successfully performed to date, the following two examples are intended to illustrate why waterjet-guided laser processing has been able to succeed where conventional laser technology has failed.

Fig.9 shows cutting sheet for nuclear industry. The demands of this application are slight drawing, close toler-

ances, slight structural changes, slight burring and parallel cutting edges.

Fig.10 shows microjet laser cutting of endoscopes for medical technology. The demands of this application are no structural changes, no drawing, clean cutting edges, narrow beam diameter and slightest mechanical load during processing.

In these cases, conventional laser processing is not applicable, because of thermal damage to the workpiece. Only the MicroJet laser processing could be applied to overcome all the problems.



Fig.9 Cutting sheet for nuclear industry



Fig.10 Cutting endoscopes for medical technology

6. Conclusion

Waterjet-guided laser processing has some important advantages in comparison to conventional laser cutting, because of no focal point of beam, the large working distance, and cooling by the water jet.

Now new machine is developing, which is used 120 W Q-switched YAG laser. The laser can irradiated very short pulse (400 ns). Neat future other new applications will be proposed.

References

- [1] Bernold Richerzhagen: Device for Machining Material with a Laser, International Patent WO 95/32834 Dec. 1995
- [2] Bernold Richerzhagen: Water-guided laser processing, Industrial Laser Review Nov. 1997 8