The waterjet-guided laser in wafer cutting

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ABSTRACT

The results yielded to date by the waterjet-guided laser in the field of wafer dicing have shown that the semiconductor industry now has a new technology at its disposal that displays decisive advantages over classic cutting processes, and which will quickly make it a widely used tool. Granted, it won't be able to fulfil every expectation right away, but its development potential is vast, and the limits of this new technology with regard to kerf width, cutting speed and edge quality are unknown.

1. Introduction

The technology of using diamond-edged blades to saw wafers has been pushed to its absolute limits during the last ten years. And with today's demands increasing incessantly, conventional mechanical sawing techniques are quite simply no longer up to the job.

In the past, no competitive technique has been able to stand the test of wafer dicing. Lasers have failed repeatedly to cater to the high demands encountered in the field of semiconductor manufacture, largely on account of the collateral thermal damage they produce. Indeed, the laser has only been used for cutting silicon wafers in very few applications, such as high-voltage conductive devices.

Now, a solution is on hand. Over the last year, a new cutting technique has been causing a minor sensation among those in the know, particularly in the field of micro-electronics: the Laser-Microjet, in which a hair-thin jet of water guides the laser beam much like an optical fibre, yielding a combination that rules out the thermal damage familiar from conventional lasers. At last, the cool laser cut has become reality.

Exhaustive tests have shown that the waterjet-guided laser beam is able to cut silicon wafers of 25 to 5000 microns in thickness at speeds of up to 120 mm/sec, with a cutting width of 50 microns and in any conceivable contour. What's more, this technique can justifiably be called force-free, due to the low pressure of the actual waterjet. It is also non-abrasive, as there is no mechanical contact between the material and the tool.

The Microjet will most likely find its first applications in the cutting of round shapes, such as wafer edges, but also in cutting and drilling applications for which the mechanical saw is unsuited.

2. Wafer-dicing by sawing and alternatives

The cutting of silicon wafers is an indispensable process in the manufacture of semiconductors. In recent years, the established method of separating the silicon chip by sawing it with a diamond-edged blade has been perfected into a high-tech process by the ever growing demand of the semiconductor industry for faster cutting speeds, greater accuracy, smaller kerf widths and enhanced cutting quality. Nevertheless, the possibilities of abrasive cutting would seem to have reached their limit as far as the above-mentioned criteria are concerned. However, these demands continue to grow, and more often than not, the saw is no longer able to deliver the goods.

Table I. The indisputable problems of the saw today

A lack of constant cutting quality due to wear of the saw-blade
No reliable forecast of the service life of a saw-blade
High consumption of saw-blades leading to high consumption costs
Chipping (front and back side)
Mechanical stress and the formation of cracks
Less suitable for very thin wafers
Only straight contours can be cut
Speed and cutting quality have reached their limits

In the past, the search for alternative cutting processes has failed to come up with a suitable solution:

Laser light is characterised by lightwaves of equal frequency and phase, which can be bundled at high intensity on account of their negligible divergence. The focussed laser beam is able to heat material to temperatures of several thousand degrees, thus causing it to melt and evaporate. An additional jet of gas can expel the molten material from the cut.

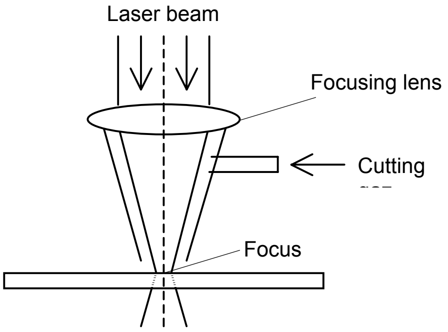


Fig. 1: Cutting with laser

Although the laser is able to compete with the diamond-edged saw-blade in terms of speed and width of cut, it lags far behind when it comes to quality. The laser's intense thermal effect on the silicon, in particular, gives rise to cracks, structural changes, bur and deposits on the wafer surface. A high-precision tool in all other respects, and certainly one that has increasingly replaced conventional cutting processes, the laser has been unable to establish itself in the field of semiconductor technology, with the exception of a few applications.

The laser is familiar in the field of silicon processing for marking wafers or cutting round silicon components, such as high-voltage thyristors and diodes. Yet a host of compromises have to be accepted even in these applications. Two such compromises are the need to apply a special protective coating, which has to be removed after the laser processing stage with solvent, and the time-consuming necessity of reprocessing the cut edges.

The abrasive waterjet is able to ablate material by means of its kinetic energy alone. In this context, water is forced through a nozzle at high pressure (3000 bar) and subsequently mixed with abrasives to create a water-particle mixture.

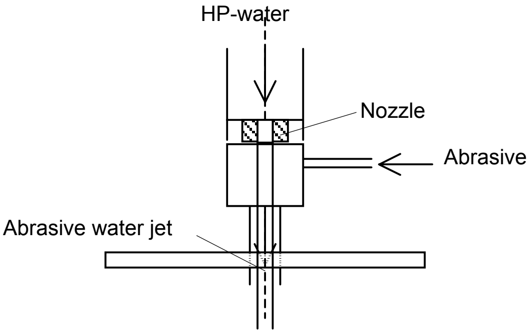


Fig. 2: Cutting with abrasive water jet

In contrast to the laser, waterjet processing has the inherent advantage of being a low-temperature process. However, the high degree of kinetic energy renders the process unsuitable for use on sensitive silicon wafers.

Both cutting processes date back to the 1960s and have established themselves as reliable cutting tools, particularly in the metalworking industries.

However, because both processes have their limits, caused by “hot” cutting on the one hand (laser) and high kinetic forces on the other (abrasive waterjet), thought has been given for some time now as to whether both processes could be combined, with the advantages of each individual process being retained: the „cold“ cutting of the waterjet and the „low-force” cutting of the laser.

Cutting with laser and water?

Now, this may at first sound like a physical contradiction, but it is possible! Thirty years after the discovery of the laser and the high-pressure waterjet, scientists at the Institute for Applied Optics at the Lausanne University of Technology in Switzerland succeeded in creating a laser light guiding waterjet.

To this end, the Swiss scientists used a solid-state laser (neodymium – YAG) that emits at approx. 1 μm and is commonly used in material processing.

The laser beam was focussed in a nozzle while passing through a pressurised water chamber. The geometry of the chamber and nozzle are decisive to coupling the laser beam in the energy-rich waterjet. The waterjet emitted from the nozzle guides the laser beam by means of total reflection at the transition zone between water and air, in a manner similar to conventional glass fibres. The waterjet can thus be referred to as a fluid optical waveguide of variable length.

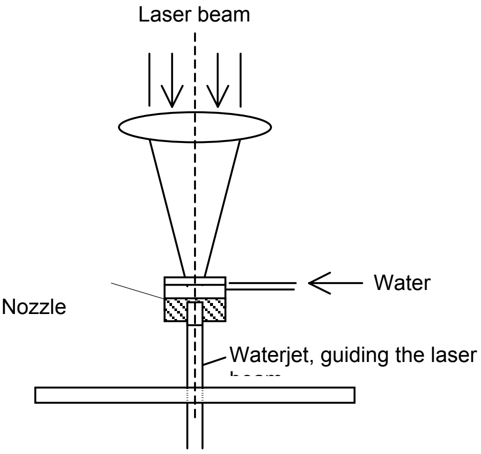


Fig. 3. Cutting with water jet guided laser

3. Material Ablation by water jet guided laser

This question is justified when considering that the laser beam heats the material and the waterjet cools it. The following physical phenomenon assisted the scientists in overcoming this problem: the waterjet is essentially transparent for the laser beam. However, if the laser beam encounters a body which absorbs it, the surface of the material is heated to such an extent that a plasma is created that separates the waterjet and the material from one another. The plasma shields the water, but the laser is able to penetrate.

But how does the cooling effect arise? The plasma only remains as long as the laser beam is activated. Because a pulsed laser was used, the continuous waterjet was able to immediately re-cool the cut, resulting in only a very slight depth of thermal penetration.

The laser-waterjet was thus born, and the goal attained of rendering a cold laser beam suitable for use in industrial applications.

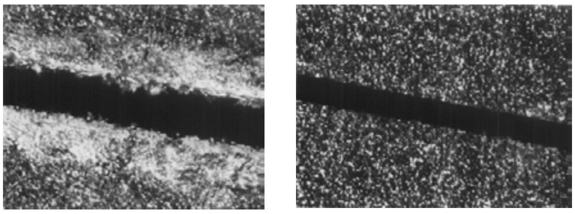
The following list shows the most important parameters of the laser-waterjet, christened the Laser-Microjet by its inventor:

Table II. Parameters of the Laser waterjet

Wavelength of the laser:	1.064 μm
Laser pulse refresh rate:	max 1000 Hz
Laser pulse duration:	0.1 – 0.3 ms
Average laser output:	300 W
Waterjet pressure:	50 – 400 bar
Waterjet diameter (= laser beam diameter):	50 – 150 μm
Water quality:	filtered to 0.2 μm, deionised
Waterjet length:	50 mm
Water flow rate:	20 ml/min on average

Since the first results from the Lausanne laboratories were released in 1997, the microelectronics industry, in particular, has shown keen interest in this development, hoping that the many unsolved problems of –high-precision processing can be overcome using this technology.

And it soon became apparent that the Microjet is eminently suitable for cutting silicon, as convincingly testified to by a comparison with conventional lasers:



conventional laser cutting Laser-Microjet cutting

Fig. 4 Comparison between conventional laser cutting of silicon and Laser-Microjet cutting

From this time on, extensive tests were performed on silicon wafers and the following performance data have now been determined.

Table III. Performances of wafer dicing by laser

Maximum cutting speed:	120 mm/sec
Minimum width of cut:	50 µm
Maximum material thickness:	5 mm

However, these results by no means represent the absolute limits of this technology, and even narrower cuts and higher speeds will be possible in future.

4. Quality of the laser cut

One of the most major problems of conventional saw cutting is the resultant chipping, which can lead to destruction of the die:

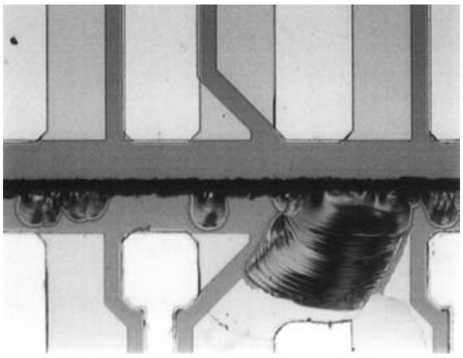
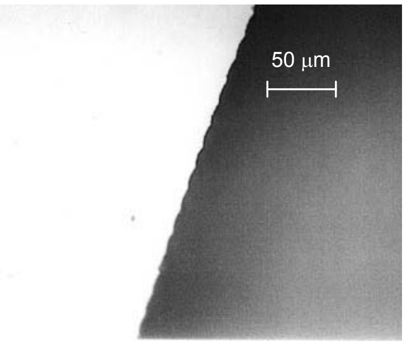
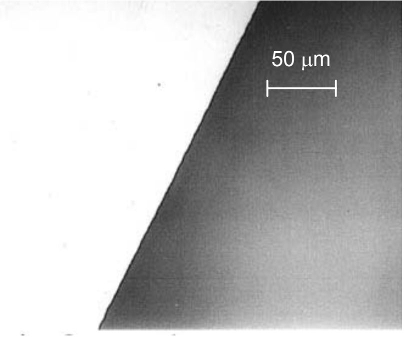


Fig. 5 Chipping by sawing

The following pictures show the edge of a cut produced with the Laser-Microjet at a magnification of 160x:



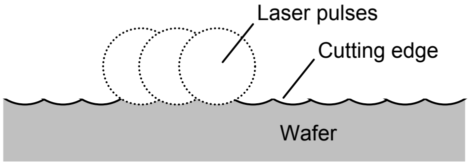
Small overlap



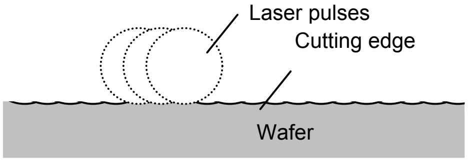
Large overlap

Fig. 6 Edge quality with Laser-Microjet

The irregularities at the edge of the cut – comparable with the edges of a stamp – result as a function of the selected laser pulse overlap, which is yielded by the traversing speed and laser pulse refresh rate.



Small overlap (= low speed, high pulse refresh rate)



Large overlap (= high speed, low pulse refresh rate)

Fig. 7 Effect of small and large overlap of laser pulses

The edge on the rear of the wafer is only minimally poorer.

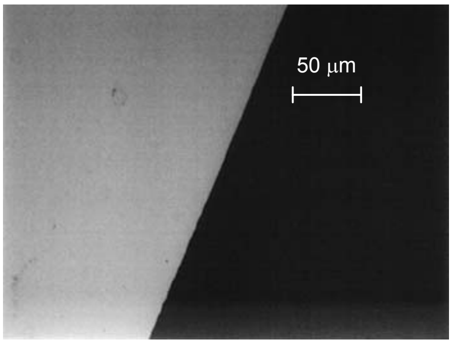


Fig. 8 Edge quality back side

Chipping is thus almost thoroughly dispensed with in the case of the Laser-Microjet.

The cutting speed essentially depends on the wafer thickness, as the thicker the material, the greater the requisite laser pulse energy.

Table IV. Dicing speed in function of wafer thickness

Wafer thickness	Cutting speed (no limit value!)
100 µm	120 mm/sec
200 µm	80 mm/sec
300 µm	40 mm/sec
500 µm	20 mm/sec
700 µm	10 mm/sec
1000 µm	6 mm/sec
1500 µm	3 mm/sec
2000 µm	1 mm/sec

The maximum cutting speed at a given wafer thickness depends only on the pulse refresh rate and the mean output of the laser, thus ruling out technical limit values.

5. A comparison between laser dicing and sawing

In the case of the diamond-edged saw-blade, the quality of the cut deteriorates with an increasing cut length on account of wear to 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. The laser, in contrast, is not subject to mechanical stress, thus yielding constant cutting quality.

The diamond saw-blade exerts extremely high forces on the wafer during the sawing process, which make it necessary to fix the wafer firmly in place and can lead to parts becoming chipped at the edges and corners and cracks occurring in the wafer, which can subsequently lead to circuit failure.

The most significant problem of abrasive sawing is the chipping at the upper and lower edges of the cut – chipping across the width of the line and into the die will inevitably lead to rejection. Laser processing on the other hand, being virtually force-free, means that chipping is not a problem. The irregularities on the rear of the wafer generally do not exceed 5 µm. The force exerted on the wafer by the waterjet is far lower than that of the saw. Indeed, it is even 10 times less than the force exerted by the cutting gas jet of a conventional laser. This is due to the very small cross-section of the waterjet.

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

This also renders the rotary axis required for orienting the wafer during sawing superfluous.

A Z-axis is also no longer needed, as the laser-waterjet 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-force laser cutting process is its ability to dice very thin wafers, as the wafer thickness has no lower limit.

The running costs of the saw are very high on account of the consumption of diamond-edged saw-blades. Furthermore, the manufacturing process has to be stopped for a tool change, and the actual change performed manually. Although somewhat more expensive to purchase, the laser is characterised 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. All in all, this equates to considerably lower consumption costs for the laser.

The Laser-Microjet is also just as suitable as the saw for grooving. The depth of the groove is determined by the laser pulse energy and is very constant.

Table V. Advantages of laser dicing compared to sawing

Constant cutting quality
No mechanical stress, force-free
No chipping
Omnidirectional cutting
Cutting of straight and round shapes
Drilling holes
No Z-axis, no rotary axis
Ideal for ultra-thin wafers (smart cards)
Wafer thickness between 25 µm and 5 mm
No tool-wear
Very few consumption parts, low running costs

And what about the limits of waterjet-guided lasers?

The laser isn't interested in the mechanical properties of the workpiece, such as its hardness. However, the optical parameters do have a great effect on its efficacy. As a result, some materials can only be cut to a limited extent, if at all:

Glass, for instance, is a material that is very transparent to the YAG laser. Other materials reflect the laser beam intensely, such as gold and copper, meaning that only very thin specimens of these materials can be cut.

However, the gold and copper vapour deposits of just a few 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 takes the energy it uses for ablating the material from the laser, and not from the pump. The waterjet serves the sole purpose of cooling the workpiece, guiding the laser beam and expelling molten material from the cut. The actual ablation process is thus thermal, although the depth of thermal penetration is very low on account of the waterjet. The edges of the cut thus display a molten surface.

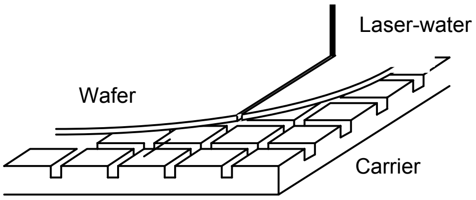
The resultant structure is very fine, but increases proportionally with a large wafer thickness. The roughness in Ra for a wafer roughly 660 µm thick is 3 µm.

The surface of the edge cannot, therefore, be compared with that cut by a diamond-edged blade. Nevertheless, the surface roughness is generally of no consequence unless it leads to impaired fracture strength.

In addition to the high purchase costs, a laser also requires more floor space than a saw, which is merely driven via a spindle. A 300 W laser unit requires between 0.4 and 0.8 m^2.

6. Wafer fixation in laser dicing

There are two possible solutions: the first solution is to use recyclable carriers, such as those used when singulating µBGAs.



*F*ig. 9 Carriers for wafer cutting

The plastic carriers have cutting slits corresponding to the grid of the wafer. These slits allow the waterjet to penetrate the material and to be suctioned out of the cut. In order to achieve a good cutting quality, it is necessary to leave an empty space below the edge of the cut. The dies are secured on the carrier with adhesive up to the pick and place process, with the carrier subsequently channelled back in to the cutting process.

The disadvantages of this solution are the necessity of providing carriers with precisely the same grid dimensions as the wafer and the increased transport weight and volume (wafer + carrier).

The second solution is to use a tape, albeit one that differs from conventional tape in quite a few respects. The prerequisites of such a tape are that it must not be cut with the laser but the waterjet must be able to pass through it. Such so-called laser-tape has already been developed and is currently in the test phase. Laser-tape will fulfil the same prerequisites as conventional tape, so that it can be used in existing environments without modification.

7. The laser dicing machine

Not a great deal will actually change regarding the outer appearance, which is also true of the auxiliary equipment currently required for a dicing saw, such as cleaning unit, video alignment system, loading station, etc.

Only the spindle is replaced by the laser resonator and waterjet coupling unit:

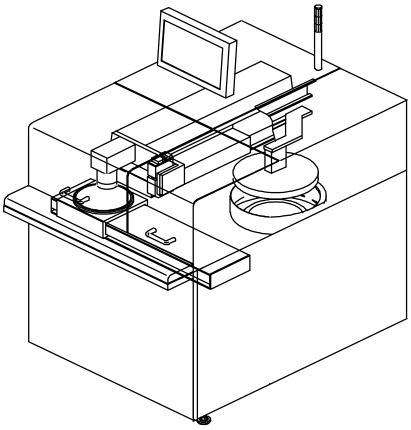


Fig. 10 Laser dicing system

8. First applications

Initially, it will be used in applications where the existing solutions have proven to be either inadequate or totally ineffective:

Table VI. First applications for the new dicing technology

Drilling and slot cutting (inkjet printers)
Cutting of round dies (high-voltage thyristors, diodes)
Dicing of very thin wafers (smart cards)
Wafer edge cutting
Cutting of solar cells