Scribing of GaN wafer for white LED by water jet guided laser

T. Nilsson, F. Wagner, B. Richerzhagen*
Synova SA, Ch. De la Dent d'Oche, CH-1024 Ecublens, Switzerland

ABSTRACT

In 1993, a laser light guiding water jet was successfully developed at the Institute of Applied Optics (EPFL, Lausanne, Switzerland) and patented as Laser Microjet®. The laser beam is focused into a nozzle from which a thin low-pressure water jet is emitted. The laser beam is injected in the water jet and guided in it by total internal reflection at the water/air interface similarly to a standard optical fiber. Normally a pulsed laser is used, so the continuous water jet is able to immediately cool the cut, reducing efficiently the heat-affected zone. The result is a very narrow, parallel, burr-free, clean cut, without detectable thermal damage. LED manufacturing is one example where thin layers need to be removed from well-defined regions on a wafer without damaging the neighboring structures. Compared with diamond saw cutting for which chipping and delaminating of the wafer cannot be avoided due to the strong shear forces; or compared with conventional laser cutting where low power irradiation of nearby functional structures occurs, the laser Microjet® offers better edge quality and high precision. Compared to the main competitor, etching techniques combined with subsequent sawing of the substrate, the water jet guided laser is faster at similar edge quality.

Key words: Laser cutting, water-jet, scribing, grooving, LED, GaN

1. INTRODUCTION

Laser Microjet® is a water jet guided laser beam, a combination that makes a precision tool for heat-free material processing. After its invention ten years ago at the Institute of Applied Optics at EPFL in Lausanne, Switzerland, the growth of new applications has been very intense, fueled by the ever-increasing quality specifications and material flow requirements from the industry.

There are today three major areas wherein the Laser Microjet® is established as a mature industrial process: precision cutting and drilling of *thin metals* (for instance stencils), dicing, cutting, scribing and drilling *semiconductors* (mainly thin wafer Si and GaAs) and *heat-free precision cutting* and grooving (ceramics, CBN, air-gaps in ferrite cores etc). The medical field, including direct surgery with the water jet guided laser, is currently in the development phase, and this field promises a lot for the future. The Water Jet Guided Laser provides solutions where traditional laser processing is relegated to a sub-satisfactory treatment method.

The semiconductor field is in perpetual motion. The expanding market for optic-semiconductors, encompassing diode lasers, flat screens, white LED's etc., requires ways to process the material with high precision, high speed, and zero or minimal mechanical stress and heat. The optic-semiconductor applications are, as a rule much more sensitive to this, compared to the relatively forgiving silicon applications.

Spanning ten years with the Laser Microjet®, a broad range of laser sources have been guided by the water jet, giving industries a new tool, as well as new capabilities. Infrared Nd:YAG lasers in continuous wave mode, long-pulsed or Q-switched. Nd:YAG lasers, frequency doubled green Nd:YAG, and now the frequency tripled ultraviolet Nd:YAG, are all being guided to the work piece by the water jet.

Scribing the optic-semiconductor gallium nitride (GaN), without heat damage and at high speeds has proven itself to be a very good application for the Laser Microjet. The water jet cools the workpiece, paramount for avoiding thermal damage, and by employing a short laser wavelength, 355 nm, the quality achieved is unrivaled compared to other laser processes.

---

* richerzhagen@synova.ch; phone +41 21 694 35 00 ; fax : +41 21 694 35 01

2. SYSTEM SET-UP

Water and high power laser? Will it not start boiling? The answer is no, not at all. When using a laser with wavelength in the visible or close to it, the light is transmitted almost perfectly. As can be seen in the absorption spectrum of water in figure 1; the best wavelength interval for the water jet guided laser is somewhere from 300 nm up to 700 nm. The 355 nm laser (and 532 nm laser as well) are transmitted virtually loss free by the water jet.

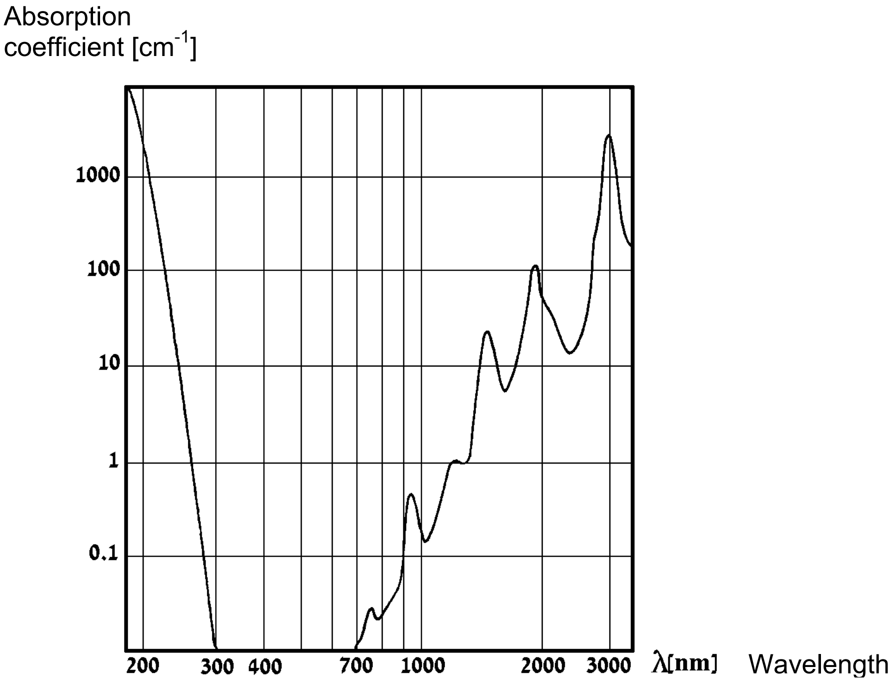

Figure 1. The optical absorption spectrum of water.

The practical limit for LMJ is about 0.3-0.5cm^{-1}, which gives a 250-1100 nm working range for the water jet guided laser. The most commonly used lasers for cutting without water jet assistance are the CO_2 laser, the Nd:YAG laser and the frequency doubled (green) Nd:YAG laser. The CO2-laser has a far-infrared wavelength (10600 nm) and is absorbed by the water, but both Nd:YAG lasers can be guided by the water jet, and the frequency tripled (UV) Nd:YAG as well.

The coupling unit is the heart of the Laser Microjet® technology. A low-pressure water jet is formed by a diamond nozzle with an aperture of typically 30-100 µm, see figure 2. The laser beam is then focused on the point where the water jet separates from the nozzle and the jet origins. The laser power can be applied either as continuous wave or as pulsed light. For many applications, pulsed laser power is the preference, as the water jet will be able to cool the workpiece in the cut and on the side walls between the pulses. With CW power only the side walls are cooled, but this is still very useful in many applications.

De-ionized water is used for the jet to make sure that there is nothing else in the water that either absorbs laser light or makes depositions on the window of the coupling unit. The nozzle is a diamond with a precision-drilled circular hole for the water to exit through. As the jet itself is only ‘hair thin’, 48 µm, the water consumption is surprisingly low although the speed is 200 m/s (at 230 Bar chamber pressure). It is only in the order of 1 liter per hour. The water jet speed is proportional to the square root of the pressure and not dependent on the jet diameter. Directly after the nozzle, the water jet contracts to 83% of the diameter of the opening diameter of the nozzle, which makes it an even thinner and more precise tool for cutting and drilling.

Low heat input in the material is an advantage of laser material processing in general. With Laser Microjet® the heat input reduction is enhanced as the surroundings of the laser processed area are efficiently cooled by the water jet. The coolest process uses pulsed power, so permitting the water jet to cool the workpiece where the microjet impacts the sample during the time between the pulses. In addition there is no problem with surface contamination due to sputtering from the process. The removed material is instantly cooled by the water jet and will not attach to or heat damage the GaN surface. The particles caused by the scribing process are washed off with water.

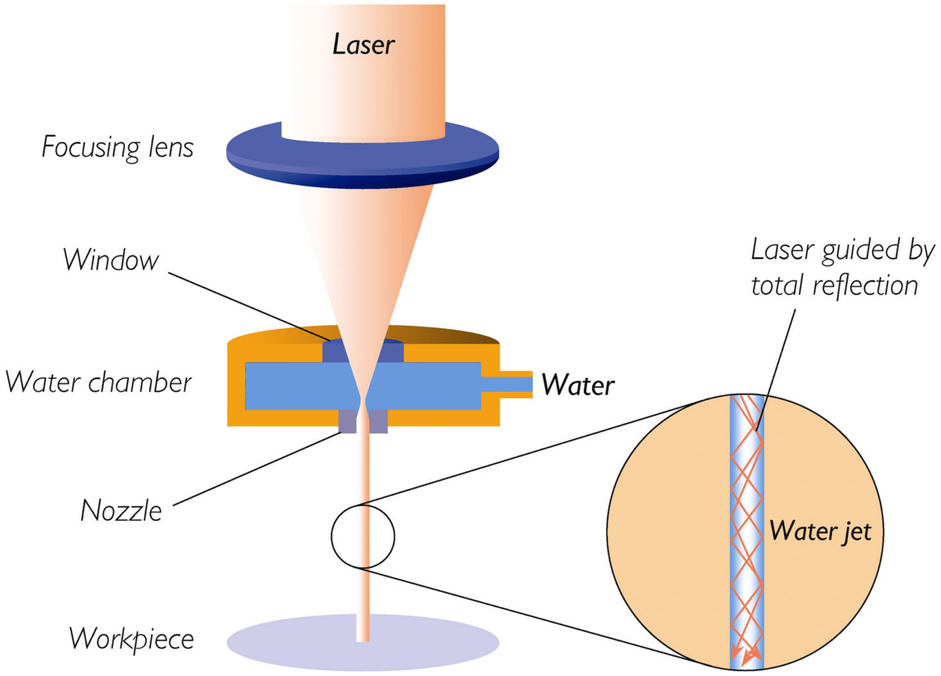

Figure 2: The principle of the coupling unit: coupling the laser beam into the water jet.

The water jet acts as a liquid fiber that remains coherent while penetrating into the material, which means that the spot size impacting the material is always constant, resulting in an excellent kerf parallelism. By controlling the laser pulse parameters; the shape of the bottom of the groove can be well controlled. 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). The LDS200 is the Laser Microjet® machine for wafer dicing and includes cleaning and drying steps of the wafer, see figure 3 (left). The laser wavelength can be chosen freely as long as it fits the water transmission spectrum, see figure 1.

The water jet has three process critical functions:

- To guide the laser beam to the workpiece
- Efficiently removing all molten material, thus ensuring no deposition build-up on the components
- Cooling the edges of the scribe line, i.e. the temperature gradient from the groove where material was melted to the remaining material at room temperature is extremely thin.

At high power and short wavelength, one can see with the naked eye, a phenomena called Raman Scattering. Due to this process, a small fraction of the laser power is converted into longer wavelength light (in this case visible light) and phonons. The visible light is scattered in all directions and may escape from the jet, see figure 3 (right).

Figure 3. left: LDS200, the Laser Microjet® machine for wafer dicing.
right: Scattered light from the water jet (mainly longer wavelengths from Raman scattering in the water) photographed without camera flash. The water jet has a diameter of 48 µm and leaves the coupling unit with a speed of approximately 200 m/s (pressure 230 Bar). The laser peak power is 20 kW and intensity ~1 GW/cm^2.

3. GALLIUM-NITRIDE SCRIBING FOR LED FABRRICATION

This scribing application uses the Laser Microjet® to singulate white LEDs. The process is similar for the Laser Diodes (LDs). The active part of the LED is a thin GaN-layer on a support. The support can be, for instance, a sapphire wafer. The task for the scribing step is to cut along the component side where the diode emission will exit the component, see figure 4. The precision demands are extreme; the LED needs a very straight and smooth edge to have good performance. The total kerf tolerance for positioning, plus edge roughness, is a few wavelengths (1-2 µm). The cut edge can only be a few microns from the active component. Avoiding heat damage is key issue for this application.

After the scribing step, another method can be used to cut the thicker substrate. As the components are already defined in the scribing process, the demands for precision and edge smoothness are now much lower, which makes it relatively easy for a diamond saw for instance, which efficiently cuts the substrate, but would leave a wafer with a lot of chipping (pieces from the edge break off) and delamination (the GaN layer partly separates form the substrate) if it was applied directly without the Laser Microjet scribing process

The main competitor for the Laser Microjet® in this and its related applications, are etching processes that provide good quality, but that are very time consuming with its masking, etching and de-masking steps. Due to the literally exploding market for white LEDs and blue laser diodes, cycle time is now crucial.

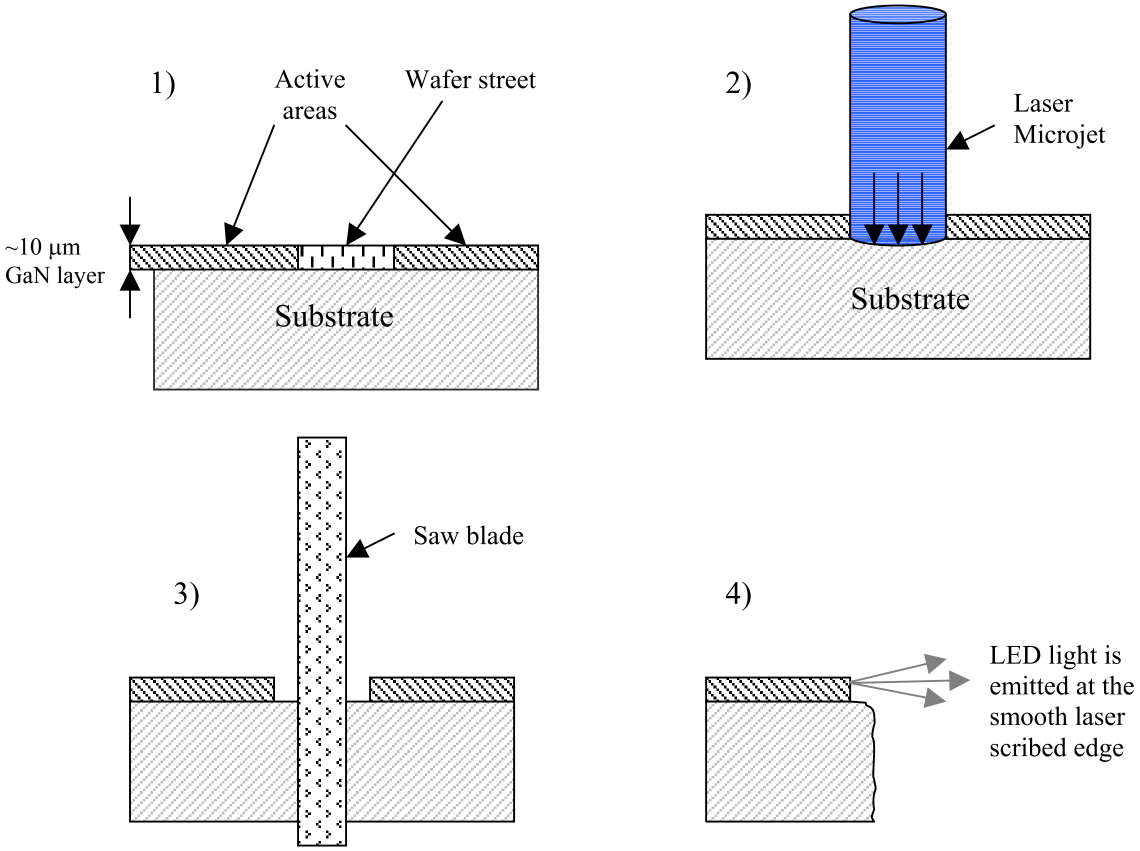

Figure 4. A schematic sketch of the task with the wafer seen from the side.

4. EXPERIMENTS

In these experiments we scribed 50-micron streets on a transparent wafer with an approximately 10 µm thick coating of GaN. The laser and water jet parameters were tuned for a perfect edge quality and a depth of >10 µm to be sure that the chips would be singulated electrically. The frequency-tripled Nd:YAG with its 355 nm wavelength (UV) suits this application well as the absorption in the material is optimal (better than for green and near infrared).

The most critical parameter was the laser power density, which can be modulated by changing the average power, the pulse repetition rate or the water jet diameter. As the water jet diameter was chosen to match the wafer street width; (the line width between the components on the wafer), the main parameters to be optimized were laser power related, but water pressure and working distance were optimized as well for best edge quality. The speed is primarily a result of how efficient the power is coupled into the workpiece. Excessive high peak powers result in lower speeds due to plasma shielding. A plasma is built up during the laser pulse when molten material is evaporated and its vapor is ionized. Laser power is absorbed in the plasma and this continues until the end of the pulse after which the plasma collapses quickly. The higher the energy, the shorter the interaction time with the workpiece, which means less energy finally coupled into the GaN layer. In conclusion, there is an optimum peak power to give the highest speed.

The material removal was more efficient when the pressure was high, and low pressures resulted in a kerf with more ripple/roughness. 200-250 Bar (20-25 MPa) is a fairly commonly used pressure for Laser Microjet when using the 60 micron nozzle, it is neither “high”, nor especially “low”. When the pressure is increased significantly, the jet becomes shorter and less stable. 230 Bar gave the best result when optimizing in the interval 100-300 Bar. In order, to keep the translation speed high, a high average power is useful. The pulse repetition rate will also have to be high enough to give sufficient overlap between the pulses. The result of the parameter optimization is in table 1. With 33 kHz pulse repetition rate and a speed of 9 mm/s, the step between two consecutive pulses will be only 0.27 µm, which equals 1/176 of the water jet diameter.

The pulse length is also important, as it determines the peak power and consequently how efficient the laser power is coupled into the GaN layer (referring to the discussion above of the plasma shielding effect). The pulse length is normally increasing with increasing pulse repetition rate for Q-switched lasers. As the spatial overlap of the pulses was very high; the pulse repetition rate was used here to vary the pulse length. An overlap of 1/50 can be considered as a "perfect" overlap in this application at the given parameters, so changes of the pulse repetition rate would not cause a problem if the ratio of translation speed / pulse repetition rate was not more than tripled.

Process parameters for scribing through a 10 µm GaN layer on a substrate with Laser Microjet®		
Average power	4.4	W
Pulse length	77	ns
Pulse repetition rate	33	kHz
Translation speed	9	mm/s
Diameter of nozzle	60	µm
Diameter of water jet	48	µm
Water pressure	230	Bar
Working distance from nozzle	35	mm
Speed of water jet	200	m/s
Scribe depth	10	µm

Table 1: The result of the parameter optimization.

The best result was achieved with a laser pulse length of 77 ns, average laser power 4,4 W and translation speed of 9 mm/s. This is a good speed for the application. Figure 5 and figure 6 show the result seen from the front side. For example, a 4" wafer (Ø 100 mm) with 1x1 mm2 LED chips will take only 1 h 14 min to scribe with perfect quality. The main alternative for the scribing method is different etching techniques, which necessitate considerably more time.

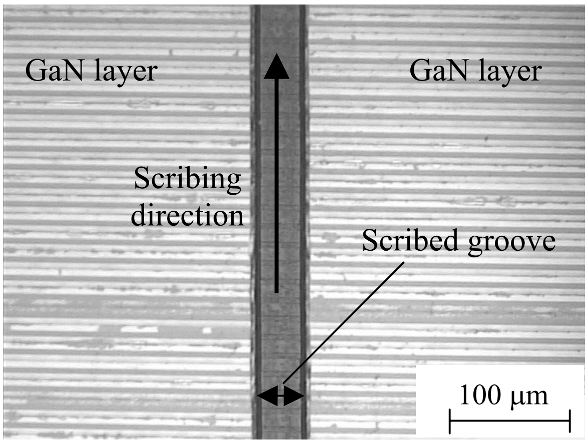

Figure 5. A top view showing a 10 µm deep and 49 µm wide groove (measured at half-depth) where the GaN layer is completely removed from the substrate with very smooth edges. The picture is taken with an optical microscope.

The demanding tolerance for the edge smoothness is valid for the upper part of the GaN layer (which is the active part). This corresponds to the brighter part of the edge (the region between the arrows in fig. 5). The deeper parts of the edge should be very smooth to avoid cracking and delaminating, however, the positioning may be made with a little larger tolerance The edge smoothness and straightness is very good and the scribing result keeps within the tolerances.

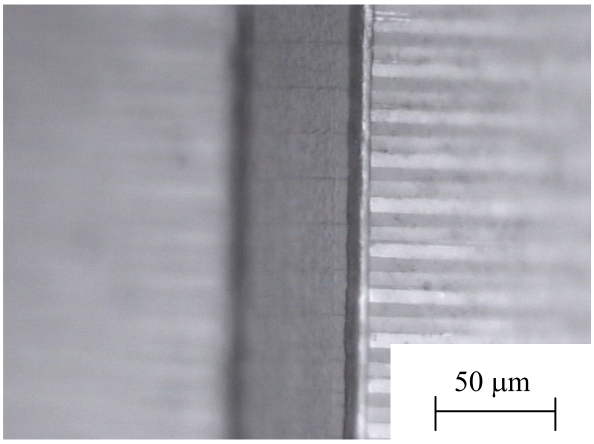

Figure 6. The same groove in higher magnification, but with tilted sample to give better view on one edge.

5. SUMMARY AND CONCLUSION

The water jet guided laser was invented in 1993, and since then near-infrared and green lasers (wavelengths 1064 and 532 nm) have been used to cut, groove and drill materials. This study shows that also the ultraviolet frequency tripled Nd:YAG with 355 nm wavelength works well with the liquid-fiber principle of the Laser Microjet® and has potential to be used for high volume applications.

GaN layers can be scribed without heat damage in the remaining material using the Laser Microjet®. An important use of GaN is for short-wavelength LEDs and LDs, and this study shows that a 10 μm deep and 49 μm wide groove can be scribed at a speed of 9 mm/s in a GaN coated sapphire wafer. For a 4” (100 mm) wafer with chip size of 1x1 mm^2 this corresponds to a processing time of only 1h 14 min, or approximately 2½ chips per second.

Due to the high scribing speed and good edge quality the laser Microjet® is thus an alternative to much more time consuming etching techniques.

ACKNOWLEDGEMENTS

The authors would like to thank Lightwave Inc. (USA) and Soliton GmbH (DE) for supplying Synova with the UV-laser source, Lightwave Q302-HD, that was used for the tests.