Water jet guided UV laser for fast and precise GaN processing in LED manufacturing

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ABSTRACT

For the past few years, GaN-based LEDs have been used in an increasing number of applications, mainly due to their low production costs. Their market, according to the demand, has exploded. Nevertheless, the particular design of side-emitting GaN diodes raises difficulties for the delicate dicing step. Requirements are very high regarding to cut quality and precision. When using conventional dicing methods, scribe and break is mostly used in this case. Yet the choice of a scribing method is not easy. It is indeed essential to avoid heat damages (significant when using lasers), cracks (common with saws), while reaching high precision. Therefore, conventional techniques are not satisfying solutions. And dry etching, although providing good quality, is very time consuming and expensive. The Laser Microjet technology, coupling a laser into a water jet, is able to scribe GaN layers by complying all required criteria. The results are impressive: excellent scribe quality, no contamination, respected tolerances and low time consumption.

Keywords: Laser cutting, GaN, Water jet guided laser, InGaN, Blue LEDs, White LEDs

1. INTRODUCTION

The optic-semiconductor field is in perpetual motion. More particularly, the growth of the LED's market (encompassing diode lasers, flat screens, white LEDs etc.) these past few years is quite impressive, passing from \$30 million to \$420 million in 4 years (1995-1999). In 2000, the total worldwide LED market had reached ≈ \$3 billion, of which the nitride violet-blue-green (and white) LED market was ≈ \$0.5 billion. The predicted growth of GaN-LED market estimates \$2440 million in 2009. In 2002, the total global demand of blue and green LEDs represented ≈ 500 million units per month [1]. Today, GaN-LED's main applications are signal, display and illumination, but they also have a great potential in the following domains: medical and biophotonics; full color micro-display as alternatives of LC or OLED; data communications; sensing [2].

Optic-semiconductors require 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 silicon applications. Particularly in the case of LEDs, the gallium nitride (GaN) dicing is rather delicate. It is usually processed in two steps: GaN scribing and substrate cutting. The GaN scribing step requires no heat damage and high processing speeds. Moreover, in the case of side-emitting LEDs, which is discussed here, very precise dicing is required, in order to avoid shading of emitted light. Therefore, the scribing technique should be chosen carefully.

The conventional methods are not satisfying. The most usual way is saw dicing. The main problem in this case is important chipping created around the cuts. Moreover, if the dicing is precise, the yield is reduced. A new technology is required. Laser Microjet has proven itself to be a very efficient method for GaN scribing. It is a water jet guided laser beam, a combination that makes a precision tool for heat-free material processing. The water jet cools the work piece, paramount for avoiding thermal damage, and by employing a short laser wavelength the quality achieved is unrivaled compared to other laser processes.

2. THE LASER MICROJET

The concept of the Laser Microjet (LMJ) is to focus a laser beam into a nozzle while passing through a pressurized 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.1).

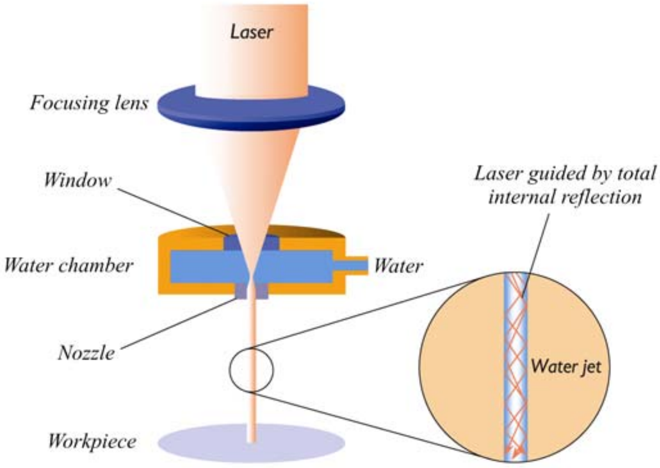

Fig.1. The principle of the coupling unit: coupling the laser beam into the water jet

The water jet acts thus as a liquid fiber that remains stable 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. LMJ is a very fast, efficient alternative for thin wafer dicing (thru-cut), scribing and edge grinding (where the outer 1-2mm of the wafer is cut off to ensure a crack free wafer edge).

Low heat input in the material is an advantage of laser material processing in general. With LMJ the heat input reduction is enhanced as the surroundings of the laser-processed area are efficiently cooled by the water jet. The cool process uses pulsed power, so permitting the water jet to cool the work piece where the Microjet impacts the sample during the time between the pulses. The measured temperature during any working conditions does not exceed 160°C [3]. 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 using a thin water film. Wafers remain clean and free of particles.

The laser wavelength can be chosen freely as long as it fits the water transmission spectrum. 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 work piece in the cut and on the side walls between the pulses. A broad range of laser sources have been used: 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.

The water jet has three process critical functions:

- Guiding the laser beam to the work piece;
- Efficiently removing all molten material, thus ensuring no deposition build-up on the components;
- Cooling the edges of the scribe line, i.e. the heat-affected zone is extremely thin.

De-ionized water is used for the jet to make sure that there is nothing else in the water that either absorbs or scatters the laser light. The nozzle is a diamond with a precision-drilled and polished circular hole for the water to exit through (aperture of diameter 30-100µm). As the jet itself is only 'hair thin', the water consumption is surprisingly low although the speed is 200m/s (at 300 bar water pressure). It is only in the order of 1 liter per hour. The water jet speed is 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.

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). The active part of the LED is a thin GaN layer which is deposited on a sapphire or SiC wafer. The task for the scribing step is to cut along the component side where the diode emission will exit the component (see Fig.2). The precision demands are extreme; the LED needs a very straight and smooth edge to have good performance. The total kerf tolerance (positioning plus edge roughness) is only a few wavelengths (1-2µm), in order to avoid shading of the emission (see Fig.2).

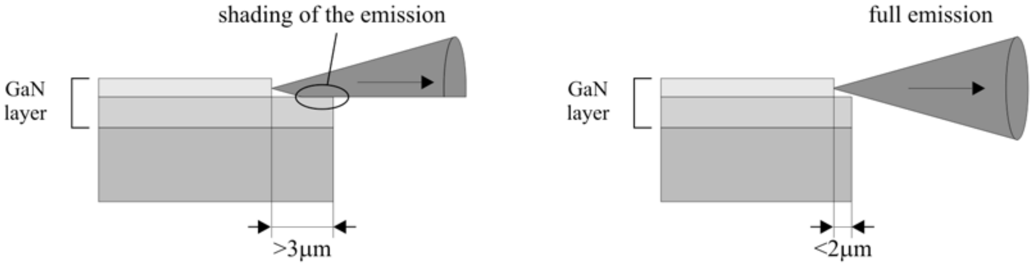

Fig. 2. Side-emitting diode: shading of the emission (left) - full emission (right)

The edge of the scribe being so close to the active emitting surface, it is essential for this application (heat affected zone required: 1-2µm) to avoid:

- Heat damage
- Cracking of edges
- Surface contamination

The second step, cutting the thicker substrate, can be done with another technique. Indeed, as the components are already defined in the scribing process, the demands for precision and edge smoothness are now much lower. For instance, a diamond saw can be used relatively easily and efficiently. However, the saw 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.

An alternative for the substrate cutting step are also laser based scribe and break technologies as they are employed more and more frequently. Fig.3 summarizes the process of side emitting GaN LEDs cutting.

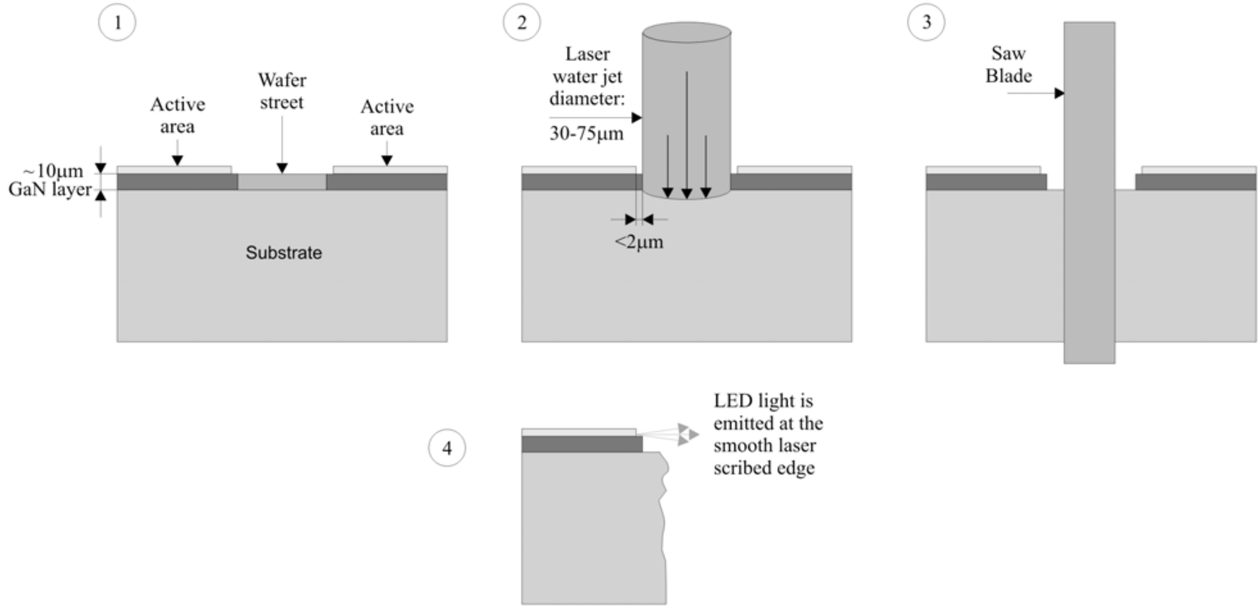

Fig. 3. A schematic sketch of the task with the wafer seen from the side

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

4. EXPERIMENTS

In these experiments 50µm streets on a transparent wafer with an approximately 10µm thick coating of GaN were scribed. The laser and water jet parameters were tuned for a perfect edge quality and a depth >10µm to be sure that the chips would be separated electrically. The frequency-tripled Nd:YAG (Lightwave Mode Q302) with its 355 nm wave-length (UV) suits this application well as the absorption in the material is better than for green and near infrared.

The most critical parameter is 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 work piece. Excessive high peak powers result in lower speeds due to plasma shielding.

The material removal was more efficient when the water pressure was high, and low pressure resulted in a kerf with more ripple/roughness. When the pressure is increased significantly, the jet becomes shorter and less stable. 230 bar gave the best result in terms of speed and quality 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 avoid high peak powers. The results of the parameter optimization are presented in Table 1. With 33kHz pulse repetition rate and a speed of 9mm/s, the step between two consecutive pulses will be only 0.27µm.

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. The pulse length is normally increasing with increasing pulse repetition rate for Q-switched lasers.

Process parameters for scribing through a 10µm GaN layer on a sapphire wafer 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
Scribe depth	10 µm

Table 1: The result of the parameter optimization

The grooving speed of 9 mm/s is a good speed for the application, compared to other methods. For example, a 4" wafer (Ø 100mm) with $1x1mm^2$ LED chips will take only 1h14min to scribe with perfect quality. The main alternative for the scribing method is different etching techniques, which necessitate considerably more time. Fig.4 and Fig.5 show microscope images of the grooves seen from the front side.

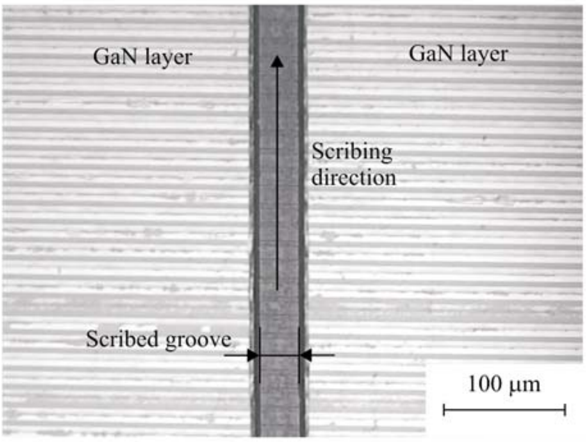

Fig.4. A top view showing a 10µm deep and 49µm wide groove (measured at half-depth) where the GaN layer is completely removed from the substrate with very smooth edges. The picture is taken with an optical microscope.

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.4). 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.

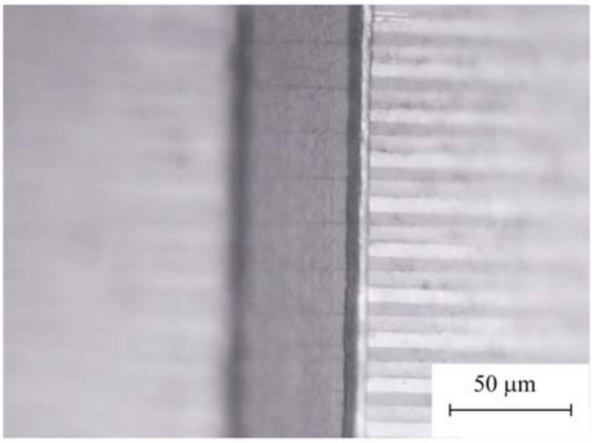

Fig.5. The same groove as in Fig.4 in higher magnification, but with tilted sample to give better view on one edge.

5. CONCLUSION

This study shows that the ultraviolet frequency tripled Nd:YAG with 355nm wavelength works well with the liquid-fiber principle of the Laser Microjet and has potential to be used for high volume applications in the LED fabrication.

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 laser diodes, and this study shows that a 10µm deep and 49µm wide groove can be scribed at a speed of 9mm/s in a GaN coated sapphire wafer. For a 4" (100mm) wafer with chip size of $1x1mm^2$ this corresponds to a processing time of only 1h14min, 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.

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