# Dicing of High-Power White LEDs in Heat Sinks with the Water Jet-Guided Laser

Tuan Anh Mai[1], Roy Housh, Arnaud Brulé, Bernold Richerzhagen,
Synova S.A., Chemin de la Dent D'Oche, 1024 Ecublens, Switzerland

## ABSTRACT

High-brightness LEDs are compound semiconductor devices and distinguish themselves from conventional LEDs by their exceptional luminosity. Today they are increasingly used as light sources, replacing conventional incandescent and fluorescent lamp technologies. HB LEDs are difficult to manufacture, as they must be grown by sophisticated epitaxial growth techniques such as MOCVD. They are packaged like power semiconductors, using surface mount technology and thermal pads.

After having been successfully applied to GaN scribing for side-emitting LEDs, the Laser MicroJet® is used today for cutting heat sinks of HB white LEDs. Due to the high-emitted light power, the generated heat must be dissipated through a heat sink. Materials typically employed are metals with high heat conductivity, notably CuW and molybdenum. Applying the Laser MicroJet®, the achieved cutting quality in these metals is outstanding – smooth edges, no contamination, no burrs, no heat damage, no warping – all this at high speed.

**Keywords:** Heat sinks, wafer, laser, dicing, water jet-guided laser

## 1. INTRODUCTION

High-Power White LEDs (HPWL) are compound semiconductor devices. They distinguish themselves from conventional LEDs, as they present several advantages, including higher brightness levels, having an even longer life span, generating lower costs to the end-user through increased energy savings, and being compatible with lead-free processing.

HPWL are being increasingly adapted as light sources to replace conventional incandescent, as well as fluorescent lamp technologies. Application fields range from automotive, industrial, commercial lighting, to even general usages. Some key examples of expanding end-user applications are elevator lights, airline cabin illumination, freezer lighting, and portable electronic displays.

The market for High-brightness LEDs has grown nearly 50% per year since 1995 and is projected to top $500 million in 2007, according to Strategies Unlimited (Mountain View, CA). Declining natural resources providing traditional energy sources in parallel with a building demand of energy from emerging markets in Asia, South America, the Indian Subcontinent, and Africa are obliging LED's to step up and respond to the ever increasing lighting demands, as all countries heed the call to respond to growing energy resource restraints.

## 2. ISSUES WITH CONVENTIONAL MANUFACTURING PROCESSES

High-brightness LEDs are difficult to manufacture, as they must be grown by sophisticated epitaxial growth techniques such as MOCVD. They are packaged like power semiconductors, using surface mount technology and thermal pads. While fabricating HPWL in wafer packages is practical for the semiconductor industry due to the equipment lines and processes available; the heat sinks required to maintain long life and optimal luminosity output levels, engender die

---

[1] mai@synova.ch, phone 41 21 694 3512, fax 41 21 694 3501

separation issues that defy today's conventional back end solutions, described hereafter in this paper, along with solutions found by applying the Synova water jet-guided laser, known as Laser MicroJet® or LMJ (registered trademark).

## 2.1 Thermal management

Effective heat sinking is a key factor in ensuring stable LED performance over a long lifetime. The LED junction temperature influences the luminous flux of the device, its lifetime, wavelength and efficiency. As described by James Hooker of Lighting Equipment News, the junction temperature is influenced by the drive current, the provision of heat sinking, and the ambient temperature. LEDs are generally rated in terms of their output at a junction temperature of 25ºC, although several people questioned why this was the case, when that value was unlikely ever to be attained in practice. The actual junction temperature can be calculated by adding the temperature of the mounting board to the product of the board's thermal resistance and the wattage of the LED. Hooker gave a practical demonstration of the effect of temperature on LED brightness levels, using Luxeon devices from Lumileds. A few minutes after switching on the LEDs, the package became hot to the touch and the intensity of the light output dropped appreciably. When the LED package was taped to a large, aluminum plate that acted as a heat sink, the light output returned to its original level.

## 2.2 Current Problems in the Backend (Wafer Dicing)

Traditional wafer dicing is carried out using the following processes in order of frequency, diamond blade sawing, scribe and break, conventional dry laser cutting. While these processes still work well in certain cases for more conventional standard wafers made out of silicon and III-V materials, more accommodating to conventional processing equipment, these processes quickly show their limitations when cutting heat sinks.

## 2.3 Heat Sinks Changing the Rules of the Game

In order to preserve the long lifetime, as well as maintaining maximum luminosity output, heat sinks made out of Cu, Cu/Wc, Mo and CVD are necessary for preserving temperature consistency of the HPWL arrays. The nature of these materials render wafer separation impossible, or at best, inefficient, hence economically non-viable.

## 2.4 Scribe and Break

This process is not under any consideration due to the metallic composition of the wafers, inherently lacking a crystal structure to break after scribing.

## 2.5 Diamond Saw Blades

The metals used in heat sinks wear down the grains of the diamond blade saws much more rapidly than in conventional wafer packages, obliging frequent, costly blade changes. Furthermore, soft material such a Cu gum around the saw spindles, requiring frequent, time-consuming maintenance, lowering productivity and financial return on the equipment. WC and CVD are simply too hard for diamond blade sawing to be competitive.

## 2.6 Dry Laser Cutting

Cu, Mo, WC, and CVD do not lend themselves easily to dry laser cutting. Cu, Mo, and WC do not disperse easily after being transformed into a plasma state and remain within the kerf, either as burrs or recast spanning the kerf width, consequentially impeding the die separation. Increasing the blow jet does not increase the plasma removal efficiency and tends to distribute recast from the kerf on to the active areas of the HPWL arrays, lowering yields. The first HPWL array manufacturers, becoming customers of Synova for this application, had problems of burring and recast within the kerfs.

The difficulty of CVD cutting with conventional laser methods brought additional major account customers to Synova. The edge quality of CVD cut with conventional lasers due to the heat-affected zones was sub-standard when put against market requirements. In hard materials, Synova customers have regularly documented a minimum heat affected zone of 60 um. Synova's Laser MicroJet® process has regularly reduced this occurrence to < 6 um, a ten-fold improvement in quality, rendering post-processing unnecessary. As Cu and Mo reserves worldwide are being quickly depleted, the CVD option in the long term is more promising, being a process that can be synthesized by industry.

A leading emerging markets consultant, Tony L. Housh, Owner of East European Consultants Ltd., and board member of the American Chamber of Commerce in Poland offered the following insight. "Emerging markets in Eastern Europe, the former Soviet Republics and Asia, in an unprecedented economical expansion, have the opportunity in constructing new infra-structures and manufacturing new wares, to by-pass current conventional incandescent lighting at lesser cost than in the western group of nations where considerable costs will be incurred to accommodate HPWL, due to the fact that everything is already built. Remodeling costs more than building. Emerging markets are already leading the West in wireless applications. HPWL's market development will follow the same path, as all the market conditions, as with wireless and are in place for efficient, economical adoption. Consulting with fabs in Eastern Europe, CVD may very well be the choice, and Synova's quality and economical advantages in backend processing make the Laser MicroJet® the unquestionable partner in CVD and other heat sink material separation."

## 3. WATER JET-GUIDED LASER ACHIEVING MAJOR IMPROVEMENTS

### 3.1 Technological background

When challenged in an interview that the incumbent technologies will not hand over the market, Housh responded by saying, "The technology market will not be sold anything. It will simply evolve towards economical efficiency. For centuries, the horse was the undisputed means of transportation worldwide. Within a period of ten years, the automobile transformed the horse into nothing more than an expensive hobby. Synova will not have to sell itself, the advantages of its technology are self –evident. The technology sells itself. It's a simple market evolution." Synova has become a supplier in each of the following applications described hereafter, following the brief description of the Laser MicroJet® process. This article will describe Synova's experiences with the heat sink materials.

The water jet-guided laser (also called Laser MicroJet®) was developed in the nineties for medical applications and is currently used for precision micro machining in a wide range of industrial fields, such as semiconductors and electronics. The basic principle of this technology is to use an ultra-thin, low-pressure water jet to guide a laser beam to the work piece. To achieve this, the laser beam is focused through a transparent window into a nozzle placed at the bottom of a water-filled chamber. The cylindrical water jet produced below the nozzle guides the laser beam by means of total internal reflection at the water/air interface, similarly to conventional glass fibers (see Fig. 1).

The capabilities and performances of this process are different from those of conventional dry lasers. First, because the water jet is cylindrical and the laser beam parallel, kerf walls are parallel. The working distance – corresponding to the stable length of the jet – can be several centimeters long, depending on the jet diameter. Therefore, there is no need of focus control. The laser remains focused in the water jet.

Second, heat damage is nonexistent, since the water jet cools the edges between the laser pulses. The temperature of the cut edge rapidly decreases to the water temperature and heat generated by the laser is not conducted further into the material. The negative effects of heating, such as micro cracks, oxidation, structural changes or low fracture strength, do not appear.

Contamination is greatly reduced, as the water jet, whose pressure ranges from 50 to 500 bars, develops a high kinetic energy fully dedicated to the removal of the molten material. Additionally, a thin water film is generated on the wafer surface during the process, preventing particle deposition. Since the water jet is very thin (diameter ranging from 20 to 100 microns), the mechanical force applied on the wafer is negligible (less than 0.1 N). As a result, the process does not generate chipping or micro-cracks. [1]

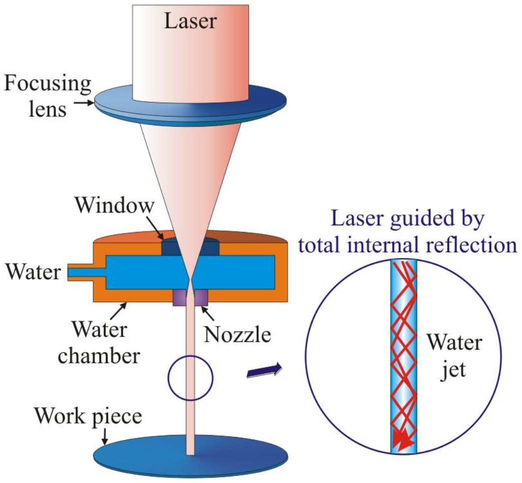


Fig. 1: Basic principle of the water-jet-guided laser technology

For several years, the water jet-guided laser technology has been successfully used for semiconductor micro machining (dicing and grooving). The process is especially efficient on thin wafers and on brittle materials (such as GaAs) since it is a damage-free tool. High process rates are reached, virtually no chipping on the wafer front and backside can be observed, heat damage to the material is negligible and surface contamination is low. The technology has therefore an important potential for manufacturing high-power white LEDs.

After having been successfully applied to GaN scribing for side-emitting LEDs, the Laser MicroJet® is today used for cutting heat sinks for HB white LEDs. Indeed, since the emitting light power is high, the generated heat must be drained off through a heat sink. Typical materials are metals with high heat conductivity such as CuW and molybdenum. Using the Laser MicroJet®, the achieved cutting quality in these metals is outstanding – smooth edges, no contamination, no burrs, no heat damage, no warping – all this at high speed. Moreover, Laser MicroJet® process allows highest die fracture strength of diced wafers.

### 3.2 Satisfactory experimental results with the processing of relevant materials

Experimental wafer dicing of several materials was investigated on Synova LDS200A. This dicing machine is based on the Laser MicroJet® technology, combining the advantages of the high energy pulsed Q-switch Nd:YAG laser with a hair-thin water jet. While the laser is used for material ablation, the water jet is used for guiding the laser light, cooling the edges and preventing the sample from particle contamination, advantages that are essential for dicing of thin material with high quality. The Laser MicroJet® technology has been tested for dicing both Molybdenum & CuW wafer samples (thickness 250 µm, Ø 50 mm, chip size of 2800 x 4200 um). For these experiments, the LDS200A equipped with a Nd:YAG infra-red, Q-switch laser has been selected as the most suited machine. It is a fully automatic cassette-to-cassette clean-room compatible machine, allowing to cut, drill, groove, scribe, trench, mark, or grind wafers of any kind of semiconductor material. Cutting these materials with Laser MicroJet® allows us to obtain an excellent chip quality (sharp edges and free of contamination and heat damages) with a high cutting speed.

### 3.3 Molybdenum 2” wafers (blank & patterned)

The cutting of Molybdenum wafers with Laser MicroJet® produces very high quality. The main problem encountered during the first trials was the warping of the material due to thermal effect, which made it hard to cut through (see Fig. 2). One line out of two was not cut through due to the “negative warping effect” which creates a water jet perturbation. The positive warping effect allows cutting through easily as you can see on the drawing.

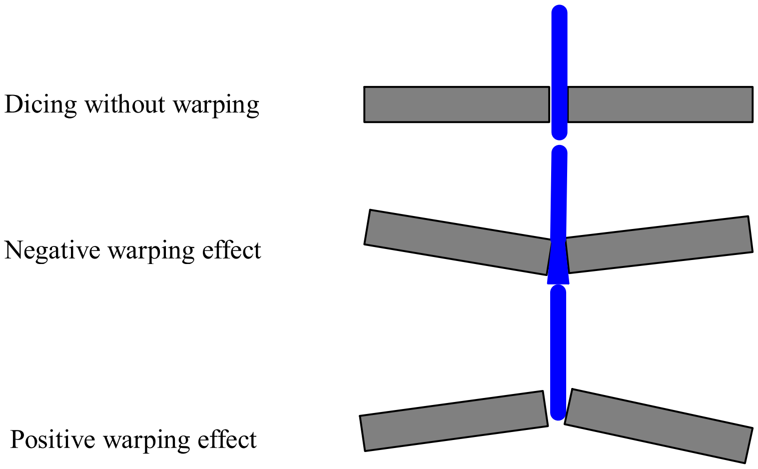
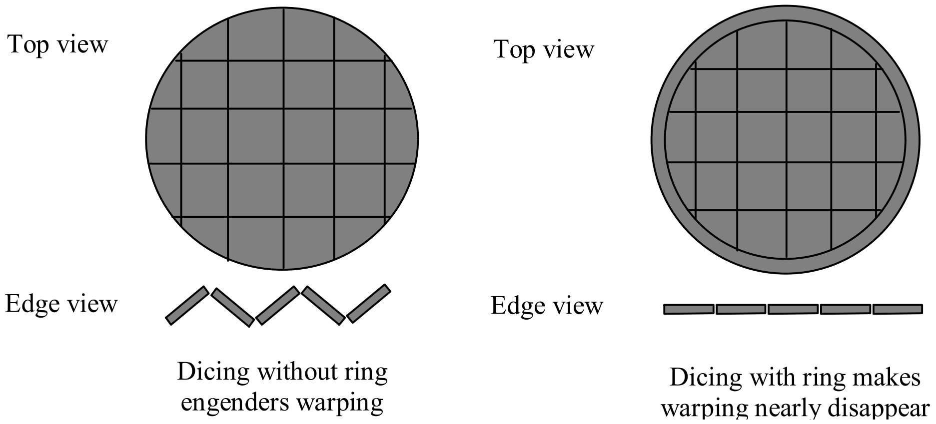


Fig. 2: Comparison of warping effects depending on process

In order to solve this warping problem, a second series of tests was done, keeping a non-diced ring around the 2” wafer (see Fig. 3). This part of the wafer is not used anyway (partial chips; no coating on backside). The dimension of the ring does not seem to be very critical.



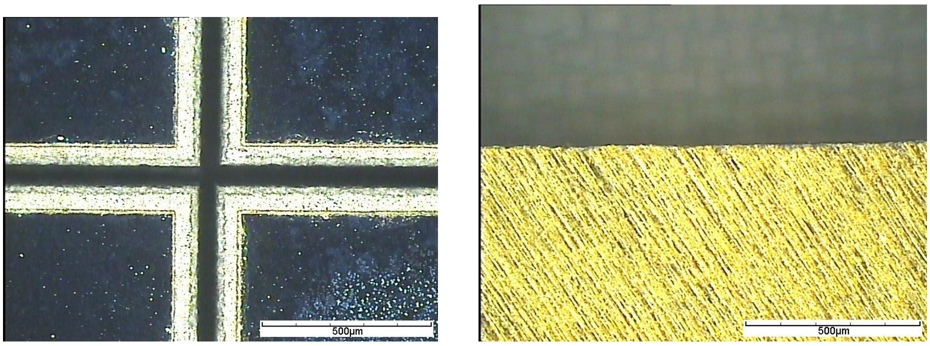
Dicing without ring engenders warping

Dicing with ring makes warping nearly disappear

Fig. 3: Comparison of dicing methods with / without ring

The first tests with the ring were done on the non-processed molybdenum wafers and produced a 100% effective dicing, which shows that the ring can solve the problem. When the processed wafers were diced, a few chips were not 100% cut through, but the results were much better than without the ring, which is very encouraging and shows that we can completely solve the problem with further tests on processed wafers. The parameters should be different for processed and non-processed wafers.

Here below are some pictures of the cuts (Fig.4).



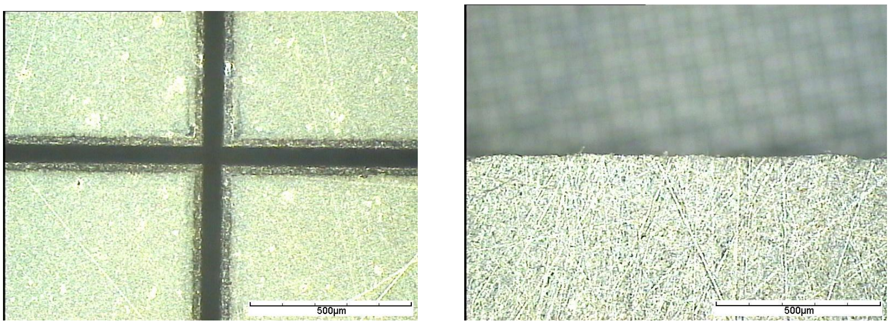
a) b)

Fig. 4: Dicing on Molybdenum wafer; a)  top surface; b) backside surface

### 3.4 CuW 2” wafers (blank)

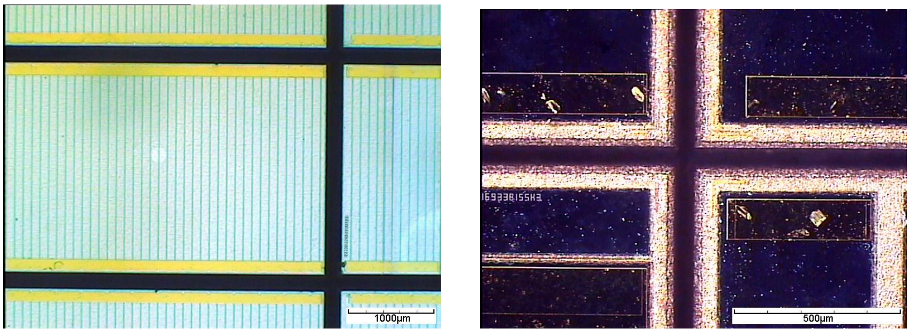
The cutting of CuW is not as critical as Molybdenum in terms of a warping effect. It was decided to cut the wafers in the traditional way, which means without maintaining the ring around. The achieved speed was a bit lower than the one used for molybdenum dicing, but it can also be due to the fact that fewer CuW wafers were diced. Nevertheless, the cutting quality was good and the cutting speed is already very encouraging. An additional series of CuW has been used for optimization.

Here below are some pictures of the cuts (Fig.5 & 6).



a) b)

Fig. 5: Dicing on CuW wafer; a) top surface; b) backside surface



a) b)

Fig. 6: Dicing on CuW wafer; a) bright-field illumination, top view; b) dark-field illumination, top view

## 4. CONCLUSION

The water jet-guided laser technology has proved its capabilities by matching the demanding requirements of dicing High-Power White LEDs with heat sinks. The dicing of Molybdenum and CuW wafers was investigated on the Synova LDS200A machine. While the laser is used for material ablation, the water jet is used for guiding the laser light, cooling the edges and preventing the sample from particle contamination, advantages that are essential for the dicing of metal with a high quality level. The overall cutting speeds are high and could be increased further with additional optimization. The warping effect has been diminished with the ring solution. Further tests can undoubtedly make the Molybdenum dicing 100% reliable with a high rate on the Synova LDS200A machine.

As mentioned earlier, in the future CVD Diamond will most likely be the favorite material for heat sinks. Several experiments have already been done to process this very hard material with Laser MicroJet® and the results are extremely promising for a heat sink dicing application.

The major advantages of the water-jet-guided laser technology with regards to this application are:

- Cutting of arbitrary shapes
- Negligible heat damage to the material
- Parallel and smooth cut walls
- No slag/burr formation
- Excellent wall surface quality
- Parallel cut
- Advantageous process rates
- Low surface contamination
- High fracture strength

## REFERENCES

1. D.Perrottet, B.Richerzhagen, Laser MicroJet® dicing – the only process to dice thin and thick wafers, European Semiconductor, vol. 28, March 2006