High-speed singulation of electronic packages using a frequency doubled Nd:YAG laser in a water-jet and realization of a 200 W green laser

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ABSTRACT

Each electronic chip is packaged in order to connect the integrated circuit and the printed circuit board. In consequence high-speed singulation of packages is an important step in the manufacturing process of electronic devices. The widely used technique of abrasive sawing encounters problems due to the combination of different materials used in packages such as copper and mold compound. The sawing blade rapidly blunts because of the copper adhering to the saw blade and covering the diamonds. In fact, the abrasive saw, well adapted to silicon wafer sawing, has problems to adapt to package materials.

It has already been shown that the water jet guided laser can be used for efficient high quality singulation of leadframe based packages. In this technique a low-pressure water jet guides the laser beam like an optical fiber, providing efficient cooling of the cutting kerf at exactly the point that was heated during the laser pulse.

We present new cutting results using a frequency doubled Nd:YAG laser with 100 W average power, and the combination setup for generating a 200 W green laser beam. The timing between the two lasers can be precisely controlled.

Keywords: Laser cutting, electronic packages, copper, mold compound, 532nm, CSP, QFN, beam combination.

1. INTRODUCTION

Electronic packages are the interface between the printed circuit board and the silicon chip, containing the extremely miniaturized electrical elements. The chip is placed on a substrate that will be soldered to the final circuit board, the connection between the chip and the package substrate is realized by very thin gold wires or tiny solder balls (flip chip technology). The substrate itself is usually a copper lead frame or a thin glass fiber enhanced polymer circuit board with solder-balls. The whole assembly is protected, rigidified and isolated by mold compound. This material is normally a brittle, black polymer (epoxy, Bakelite) with different filler materials. These electronic packages are produced by numerous manufacturers and are referred to by different abbreviations. The most general designation is CSP (Chip Scale Package), which comprises the various types like such as BGA, QFN, and MLF[1]. Hereafter, they will be referred to simply as “electronic packages”.

The biggest volume of mostly cheap components with relatively few in/out pins is packaged on copper leadframes. This type of package is often produced using a Matrix-Array Process, enhancing productivity roughly by a factor of 3[1]. If the packages are produced in this way, both materials, mold compound and copper, must be cut during the singulation process. Low-cost, high quality singulation of these packages is especially difficult because of the very different mechanical, thermal, optical and electrical properties of the materials involved. Nevertheless, the precise, burr free singulation of copper only, in the case of separately molded packages, is still a topic.

Today, mechanical sawing is primarily used to singulate these packages. The main problem with this method is the inherent softness of the copper, leading to important burr formation and rapid wear of the sawing blade due to smearing. The burr formation is a considerable disadvantage, because too big burrs limit the pitch of the packages, and, in the worst case, cause bad contact to the printed circuit board. Another approach for package singulation is conventional laser cutting, but it leads to poor cut quality, as the thermal and optical properties of the used materials are very different.

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Therefore, we use since approximately one year an alternative method for package singulation[2]: the water-jet guided laser cutting[3]: With this unique laser cutting technique a free laminar water-jet is used as an optical wave guide in order to guide a high power laser onto the sample. The main advantages of this method compared to conventional laser cutting are: (i) parallel sidewalls (even in thick mold compound layers), (ii) low thermal load of the sample due to the cooling of the sample between the laser pulses exactly at the place where it was heated before, and (iii) an efficient expulsion of the melted copper due to the high momentum of the water-jet. Compared to sawing, burr free cuts of copper can be achieved and the mechanical force on the sample is much lower.
We report here on the advances we obtained during the last year where we mostly addressed the formerly still relatively low cutting speed by using a laser with higher average power and the development and realization of a combined laser source.

2. WATER-JET GUIDED LASER PROCESSING

The schematic of the used setup is shown in Figure 1. It differs from the setup used in reference[2] by the method to guide the light from the laser to the water-jet nozzle. In [2] we used simple direct focusing, here we opted for a fiber injection right after the laser and then we image the fiber exit onto the nozzle entry with a variable demagnification. This is more practical for placing laser and machine in the lab, and the intensity profile of the laser on the nozzle entry is more flat-top like resulting in a longer nozzle lifetime than observed with a Gaussian beam profile. The used lasers are multimode Q-switched lasers operating at 532 nm. We use pure de-ionized and filtered water at 50 to 500 bars for the water jet. The nozzles are made out of sapphire or diamond in order to generate a long stable water-jet. The laser beam is focused through a quartz window into the nozzle, very much like a usual fiber coupling and is thereafter reflected in the water-jet at the air-water interface due to the refractive index step (Figure 2).

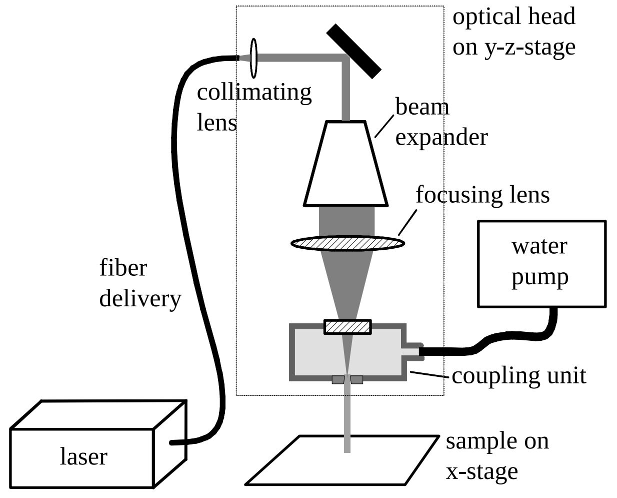

Figure 1: Schematic of the water-jet guided laser setup

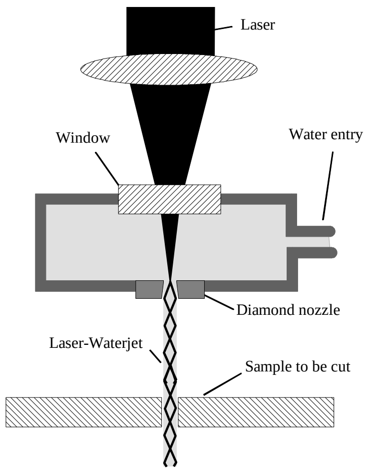

Figure 2: Detailed sketch of the coupling unit

The samples are clamped onto an x-stage, the optical setup is implemented in a “optics head” that is mounted on the y-stage. The z-variation of the stage is only necessary in order to adapt to the different working distances of differently sized nozzles at different water pressures[4] and is not used during the cutting procedure.

3. CUTTING RESULTS WITH THE 100 W LASER

The process of water-jet guided laser singulation of copper based electronic packages was already described elsewhere in detail[2]. Briefly, a two step process is applied: first the mold compound is cut with a 100 micron nozzle at low laser peak intensity, and in the second step the sample is flipped and the copper lead frame is cut with a 60 micron nozzle and higher laser peak intensity. At the time, we used a 70 W frequency-doubled diode pumped Nd:YVO_4 laser from Coherent Inc. (model Corona) and obtained approximately 20 mm/s cutting speed in the 0.9 mm thick mold compound, and 5 mm/s cutting speed in the 200 micron thick copper leadframe.

In a first step, in order to enhance the process speed, we used a laser with higher average power and choose the 100 W green laser from Quantronix (model: 532-CQE). This laser is a lamp pumped Nd:YAG laser with an intra-cavity frequency doubling and similar beam quality as the Corona, $M^2 = 35$. Average output powers and pulse peak powers of the 532-CQE are presented in Figure 3 at 10 kHz and 20 kHz pulse repetition rate.

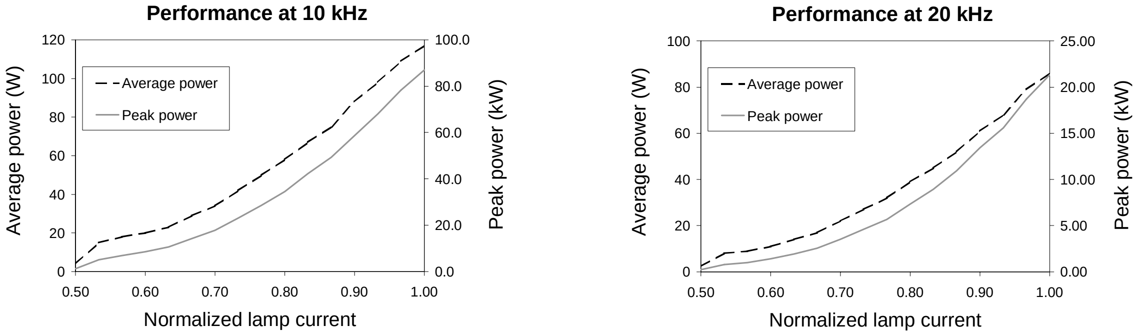

Figure 3: Laser performance at 10 kHz and 20 kHz pulse repetition rate (Quantronix, 532-CQE)

In spite of the lower pulse repetition rate and higher peak power, compared to the $Nd:YVO_4$ laser system, we could increase the cutting speed without decreasing the final edge quality. Cutting parameters and speeds for a package with a total thickness of 0.8 mm based on a 180 μm thick copper lead frame are presented in Table 1. Figure 4 shows microscope images of the obtained cutting quality.

Material	**Cutting speed**	$\mathbf{I_{peak}}$ **(MW/cm²)**	**ν / (kHz)**	**τ (ns)**	$\mathbf{E_{pulse}}$ **(mJ)**	$\mathbf{P_{av}}$ **(W)**	$\mathbf{P_{wa}}$ **(bar)**	$\mathbf{D_{nozzle}}$ **(μm)**
Mold compound 0.8 mm	80 mm/s, 2 passes = 40 mm/s	94	20	210	1.9	38	150	100
Copper 0.18 mm	50 mm/s, 6 passes = 8.3 mm/s	477	20	190	3.0	60.9	150	60

Table 1: Optimal processing parameters for copper and mold compound for a typical chip scale package. (I_{peak}: peak intensity, ν: pulse repetition rate, τ: Full Width at Half Maximum (FWHM) pulse duration, E_{pulse}: energy per pulse, P_{av}: average laser power, P_{wa}: water pressure, D_{nozzle}: diameter of water-jet nozzle)

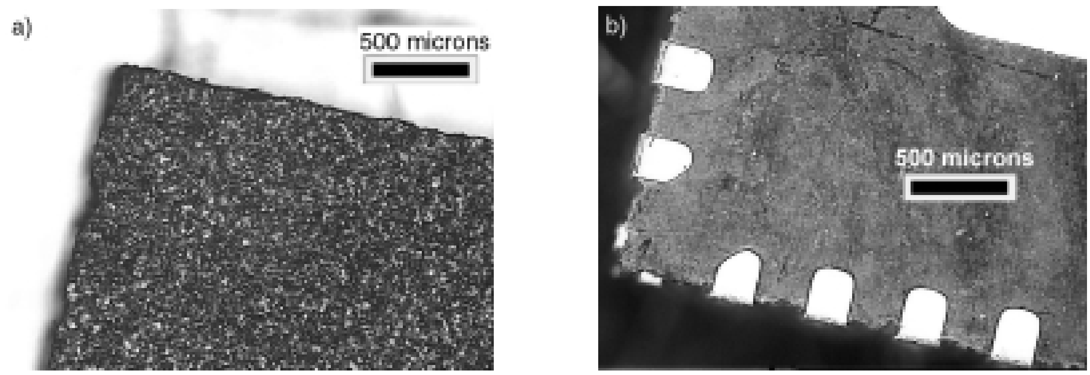

Figure 4: Optical microscope images of the edge quality obtained with the parameters given in Table 1. a) front side, b) backside. The higher peak intensities of the 100 W Nd:YAG laser, compared to the 70 W $Nd:YVO_4$ laser, did not alter the quality of the final cutting result. (c.f. reference[2])

The mold retraction, which has been discussed in [2], is shown to reduce if the cutting street of the package stripe does not contain copper at the surface (Figure 5). This is understandable reminding that the mold retraction has been shown to be caused by reflections of the light on the copper surfaces.

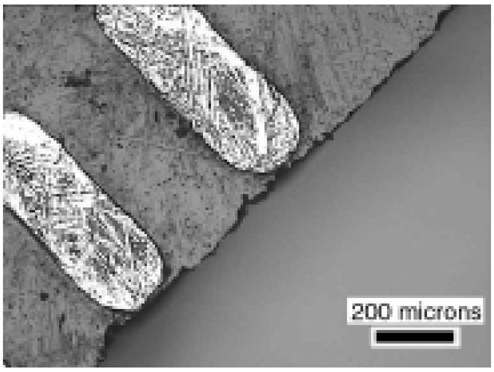

Figure 5: Mold retraction is no longer observed if the street does not contain copper at its surface.

4. THE 200 W DOUBLE LASER

These good cutting results and the good experience with the higher pulse repetition rates of the YVO_4-laser encouraged us to realize a 200 W green laser source by combining two YAG-lasers with crossed polarizations. A sketch of the setup is shown in Figure 6 and a photograph of the combination optics is visible in Figure 7a.

Both lasers normally emit vertically linearly polarized light. We included a half wave plate in one of the systems in order to turn the polarization and combined both beams, after the same optical path length, with a thin film polarizer as polarization sensitive element. It is critical for the fiber-coupling that the beams are perfectly aligned to one another in near-field and far-field. The field lens, fl, together with the focusing objective generates the beam waist with the appropriate focus diameter and divergence for the fiber coupling.

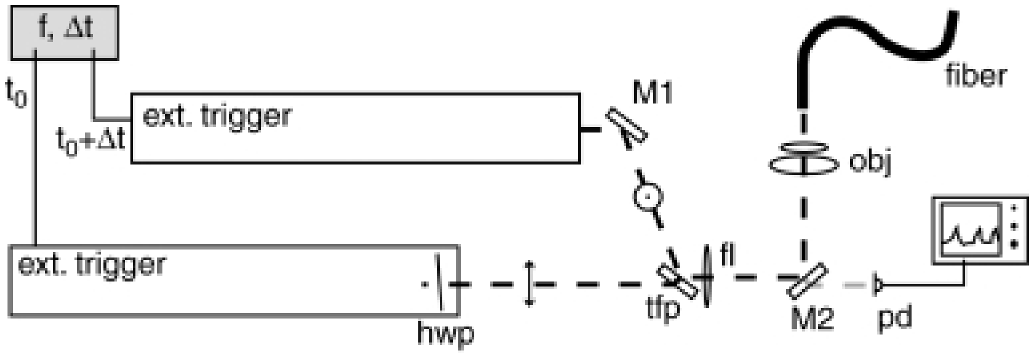

Figure 6: Schematic of the laser combination setup. Hwp: half wave plate, M1, M2: 90° edge mirrors, tfp: thin film polarizer, fl: field lens, obj: focusing objective for the fiber coupling.

Both lasers are triggered externally by a Stanford delay generator, allowing an adjustable delay time between both trigger signals. The effect of the chosen delay time is monitored using a fast photodiode and an oscilloscope.

Concerning the timing of the laser pulses and the power settings for each laser, we can distinguish 4 different cases which are interesting for laser material processing:

1. Same laser settings, equidistant spacing of the pulses: In this case we virtually double the pulse repetition rate of the system without changing peak power or pulse duration.
2. Same laser settings, simultaneous triggering: Here the peak power of the pulses is doubled, pulse repetition rate and pulse duration are not affected.
3. Same laser settings, pulses separated by one pulse length: The temporal pulse shape is influenced, the most important change will be the doubling of the pulse duration. Nevertheless peak power is also affected, because

of the typical slightly asymmetric temporal pulse shape of these lasers (Figure 7 b). The pulse repetition rate is not influenced.

4. Different laser settings, pulses separated by less than two pulse durations: This configuration allows to use a configuration where a pre-pulse prepares the material and the ablation pulse removes efficiently the material.

The setup was tested at 10 kHz pulse repetition rate and we obtained the expected 200 W average power of 532 nm output with 2% stability (Figure 7b).

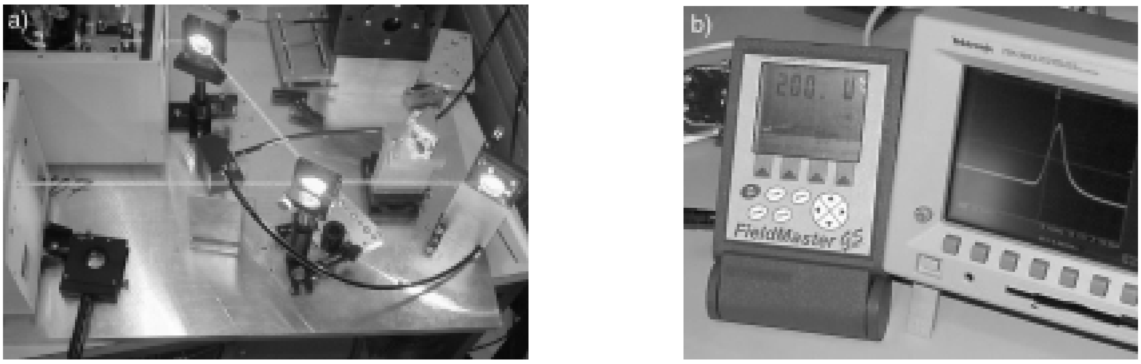

Figure 7: a) Photo of the setup and b) photo of power meter and temporal pulse shape (right), both at maximum average output power.

We are still about to gain experience with the fiber coupling of this laser, but presumably it will be possible to use all settings up to maximum power for the fiber transmission, as long as the pulses are not superposed. An energy transmission of more than 85% has been obtained over the full range of presently tested settings.
Cutting results with the double laser will shortly be presented elsewhere.

5. FUTURE WORK

The first step to follow is the proof for the proportionality between pulse repetition rate and cutting speed in this particular application. As a matter of fact, the cutting speed can be limited either by the melt expulsion (performed by the water-jet) or by the laser pulse repetition rate. It is expected that increasing the laser repetition rate will increase significantly the cutting speed, but it is important to know to which extend the melt expulsion dynamic limits this increase. An hint that the melt expulsion is also an important point is the fact that the cutting speed in copper foils is slightly enhanced by the use of higher water jet pressure.
The next interesting topic will be the study of a pre-pulse influence on the mold retraction. The mold retraction was shown to be caused by light that is reflecting from the copper surfaces. Assuming that the copper reflectivity decreases with increasing temperature as it does at the fundamental Nd:YAG and CO_2-laser wavelength[5,6], it will be beneficial to use a pre-pulse of relatively low pulse energy. The pre-pulse will heat the copper surface and will thus increase the absorption of the following ablation pulse which removes the material efficiently.

6. CONCLUSIONS AND SUMMARY

Data on the cutting speed improvement due to the application of a lamp pumped 100W Nd:YAG based laser was given and compared to the data obtained with the diode pumped 70W Nd:YLF based laser. The cut quality improvement due to better package design was shortly mentioned. The combination of two high power lasers is presented and the potential of the system in micro machining is discussed. Finally, two precise projects for future work are presented. The realization of these studies will further enhance the package singulation capabilities of the water-jet guided laser technology.

7. ACKNOWLEDGEMENTS

We acknowledge the support of Sascha Häuser (Laser Care Europe) who spent a lot of time with the 200 W (world record) laser.

8. REFERENCES

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