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Influence of Coaxial CW Laser Heating on the Ablation of Silicon with Ultra-fast lasers

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Abstract

These days most common way to produce electrical components like LEDs, solar cells or transistors is a batch process. Therefore a lot of identical components are processed parallel on one big wafer and eventually each chip has to be singulated. Currently two dicing technologies have established themselves, which can be devided in mechanical blade sawing and laser based processes with nanosecond lasers. In contrast to these technologies, laser dicing with picosecond lasers offers fundamental advantages like smaller kerf width and marginal heat effected zones. However the process efficiency and the attainable aspect ratio are limited and thus some deep cutting or drilling processes are not feasible. In this paper the influence of coaxial laser heating on the cutting process of Si wafers with ps lasers is investigated. It turns out that already with cw average powers in the range of 20 W a significant decrease of the ablation threshold can be obtained. Furthermore the aspect ratio can be increased by approx. 20 %.

Keywords: Cutting; Dicing; Singulation; Si Wafer, picosecond Laser, UKP

1. Motivation / State of the Art

Mechanical sawing with diamond blades have been used for a long time but as the wafer material is getting thinner and the chip size smaller, this classical process is replaced by laser based dicing processes. Especially the mechanical load and the relatively large kerf width are serious disadvantages of a mechanical dicing process. A reduction of the kerf width leads to a much higher yield.of chips per wafer and therefore to an increase in efficiency and resource conservation at the same time. Furthermore diamond blades are basically not suitable to cut thin wafers in the range of 100 µm or less, because they cannot resharpen themselves at the thin wafer edge.

Thus several laser dicing technologies are currently available on the market:

- Full cut with ns laser at UV-Wavelength [1]
- Stealth dicing with ns at IR-Wavelength [2]
- Full cut with a water-jet guided ns laser at IR-Wavelength [3]

Although these developed technologies overcome some of the problems connected with a mechanical sawing process, there is still a lot of optimization potential. For example the kerf loss in a ns laser cutting process is still in the range of 50 µm. Stealth dicing has shown great potential, but gets problems if metallic layers on the wafer surface occur. In a water-jet guided laser cutting process it could be rather difficult not to damage the polymer tape, which is typically sticking below the wafer. Taking all this into account it is worth to investigate the suitability of a picosecond laser ablation process for the dicing of thin Si wafers.

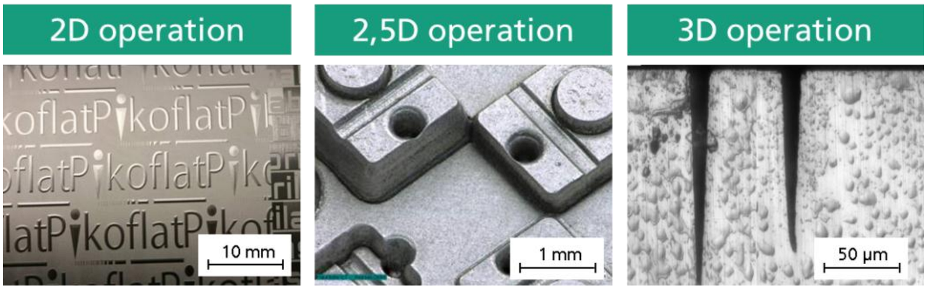


Figure 1 Difference between laser ablation process according to their aspect ratio

However the process efficiency and the attainable aspect ratio are limited and thus some deep cutting or drilling processes are not feasible. As Figure 1 shows 2D operations are in most cases quite easy to realize. But when it comes to 2,5D and especially t 3D operation with aspect ratios of more than 1:10, it is very challenging to use a ultrafast laser. Thus in this paper the influence of coaxial laser heating on the cutting process of Si wafers with ps lasers is investigated in order to increase the feasible aspect ratio and parallel also the ablation rate in very deep geometries.

2. Experimental

The experiments are carried out with a Coherent Rapid (1064nm, 15 ps, 10 W, 15 µm Spotsize) and a Northrop cw Laser (1064 nm, 100W, 100 µm Spotsize). Both lasers are coupled via a polarization cube and afterwards focused with a 50 mm focusing lens. Relative motion between laser and silicon wafer is realized with a x-y-z-axis system, compare Figure 2. In contrast to the thin wafers, which are in the focus of the process development, the fundamental ablation experiments are carried out with 500 µm thick boron doped silicon wafers. This wafer thickness is much easier to handle and furthermore it possible to break the material in and perpendicular to the cutting direction with a result of clean break lines without cracks. The comparability of both material thicknesses has been already investigated and is in the range of a few micrometers.

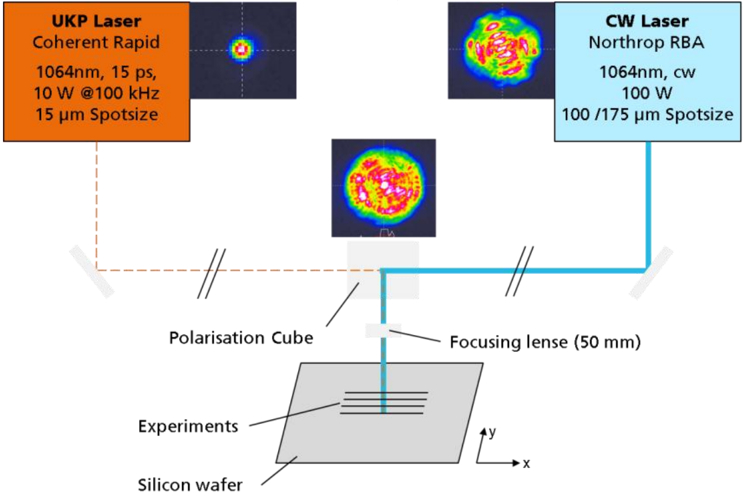
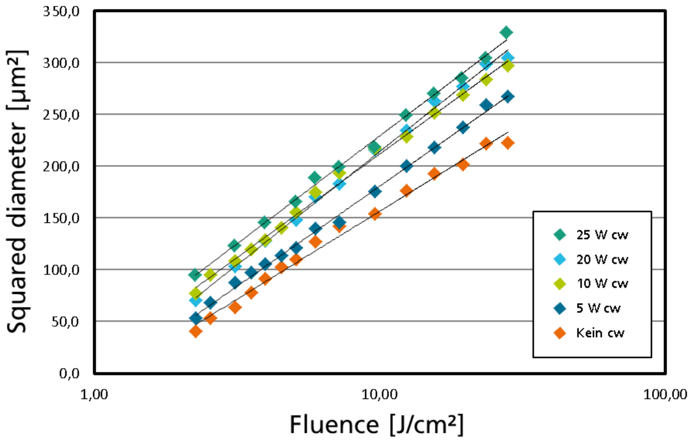


Figure 2 Experimental setup

3. Results and Discussion

Before the actual cutting experiments are done, firstly the ablation threshold under various cw conditions is investigated. Thus the threshold is determined with the method provided by J. M. Liu [4]. In this method the radius of a single pulse ablation is measured while the pulse energy is varied. Eventually this measured radius is squared and plotted over the logarithm of the fluence. Figure 3 shows ablation threshold for different cw laser powers. Orange is the reference threshold without any assistant cw laser heating. In this case the ablation threshold amounts 0,6 J/cm².With increasing cw laser heating this value can be decreased to finally 0,38 J/cm² at 25 W average power. This is a decrease of 36 %.



	0W	5W	10W	20W	25W
Threshold [J/cm²]	0,6	0,55	0,5	0,44	0,38

Figure 3 Ablation threshold of silicon with different cw average power

Figure 4 shows results of cutting experiments with 150 mm/s feed rate, a 100 µm cw Spotsize, 25 kHz repetition rate and 2 µJ pulse energy for the ultrafast laser. The left side shows the ablation depth while the right side represents the ablation width (both measured in cross sectional view under a light microscope). The colors again indicate whether cw laser heating was used and if so which average power was adjusted. Starting from the orange line, which show the reference experiments without any cw laser heating, going further to the green line, which shows maximum heating, a significant increase in the attainable cutting depth can be observed. However the main development over increasing repeats remains the same. A heating with 25 W cw laser power leads to a cutting depth of 88 µm instead of 66 µm for the reference experiment. This means an increase of 30 %. When also the cutting width is considered it turns out that a heating with 25 W already leads to serious heat damage at the sides and thus increased cutting width. With 25 W average power the width amounts 27 µm instead of 19 µm for the reference line. In contrast to that such a situation cannot be observed for 20 W heating.

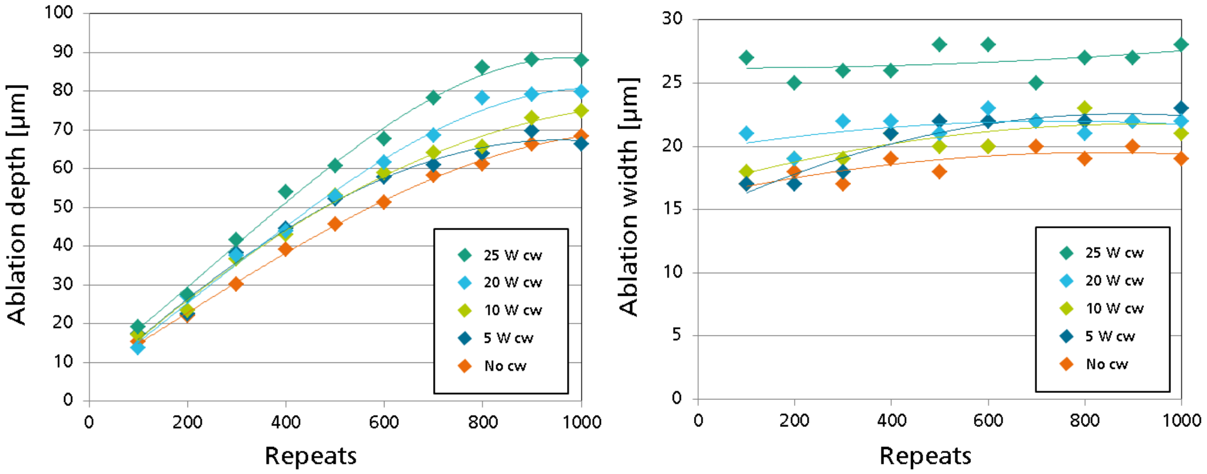


Figure 4 Ablation threshold of silicon with different cw average power, pulse energy 2 µJ

Figure 5 shows a similar diagram as figure 4 does with the difference that now 14 µJ pulse energy is adjusted for the ultrafast laser. As expected the overall cutting depth is bigger due to the higher pulse energy. 25 W average power for heating is not used anymore, since the previous results already showed negative thermal effects. In terms of the ablation depth the difference between cw heating with 20 W and no heating is 135 µm compared to 117 µm which means 17 % difference. For the ablation width no real difference can be measured. Due to different grinding conditions the values are more or less spread around 23 µm +-2 µm.

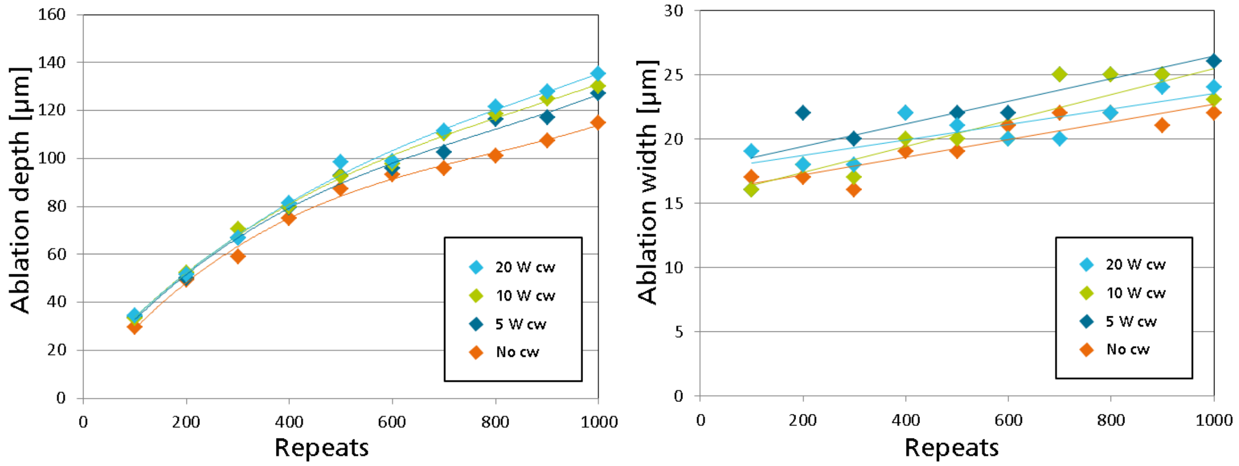


Figure 5 Ablation threshold of silicon with different cw average power, pulse energy 14 µJ

Figure 6 shows ablation geometries in the cross section for the reference experiments (orange) and cw laser heating with 20 W (blue). From left to right the development from 400 up to 1000 repeats is shown. The pulse energy is set to 14 µJ. No significant difference in terms of quality or heat affected zone can be measured or obtained while comparing the pictures. The geometry remains also very similar, with the exception that the depth is increased.

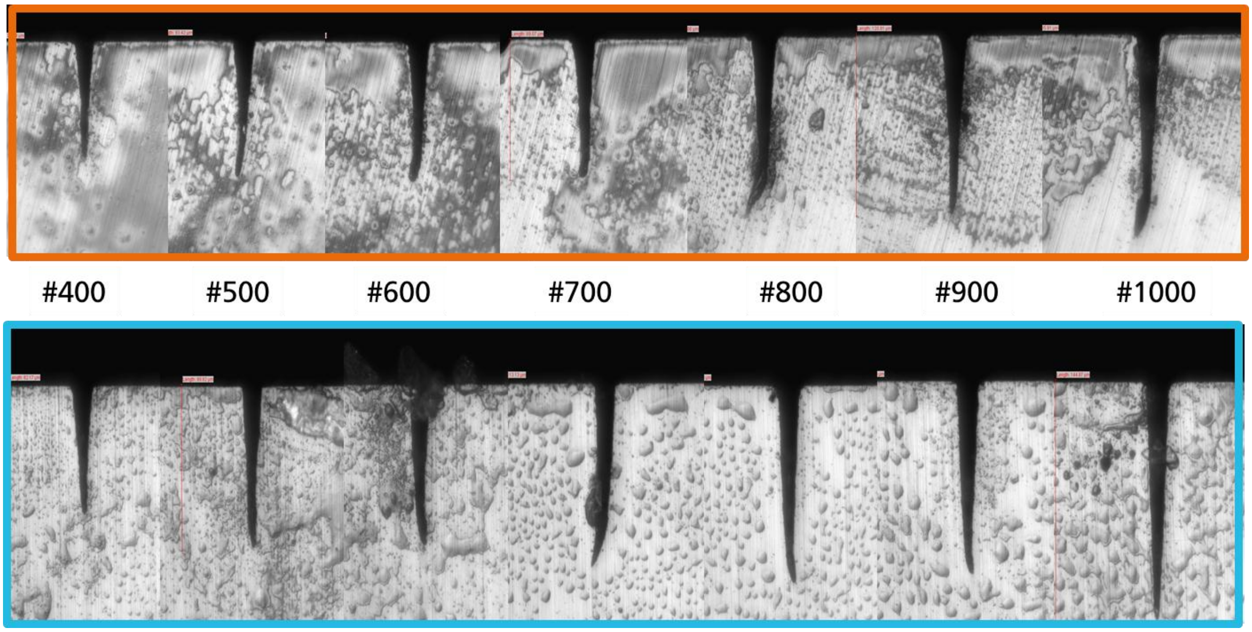


Figure 6 Ablation geometries for no cw (orange) and 20 W cw (blue) for different repeats

4. Summary

Laser ablation experiments are carried out with a hybrid experimental setup which includes an ultrafast laser and also a cw laser for heating of the silicon specimens. During the experiments it turns out that the ablation threshold can be decreased by 30 % when the cw laser power amounts 25 W. However the first cutting experiments show thermal damage at the cutting edge which leads to increased cutting width and thus no advantage in the aspect ratio. For this kind of experimental setup the optimal cw laser heating power amounts 20 W which delivers an increase in depth of 17 %, while the ablation width remains the same. Investigations of cross sectional pictures do not show any heat affection or melting zones, which could be expected from the heating process. For future experiments it is planned to reduce the spot size of the cw laser to heat the silicon more locally and increase the intensity. Also the coupling of both lasers shall be realized via a sharp edge filter, to keep the polarization as a degree of freedom.

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