Dicing of thin Si Wafers with a picosecond laser ablation process and high-speed polygon scanner system

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Keywords: USP, ultra-short pulsed Laser, picosecond Laser, micro machining, dicing, silicon, polygon scanner, semiconductor

Abstract

Currently, electrical semiconductor components such as LEDs, solar cells or transistors are commonly produced in a batch process. This way, many identical components can be processed in parallel on one big wafer; subsequently, each chip has to be singulated. In contrast to state-of-the-art technologies like blade sawing and nanosecond-based laser processes, laser dicing with picosecond lasers offers fundamental advantages [1]. Due to the short interaction time between laser and material, small kerf widths, marginal heat affected zones and minimal edge damaging are attainable. While a reduction of the kerf width leads to a higher yield per wafer, minimal thermal and mechanical damage increases the breaking strength of each die [2]. Though ablation processes with ultra-short pulsed lasers deliver best results in terms of quality, the production speed mostly suffers due to a missing technology to distribute the average power on the workpiece.

In this paper an ablation cutting process of thin Si wafers with an ultra-short pulsed laser system (22.5W@5MHz, 5 ps, 532 nm) is investigated in order determine the most suitable process parameters. Beside a conventional Galvo scanner we use a novel high-speed polygon scanner to guide the laser beam to the wafer surface. With an in-house developed software and control system it is possible to obtain scanning speed higher than 200 m/s and thus the operation of high repetition rate lasers.

1. Experimental Setup

The experiments were carried out with a Coherent HyperRapid at a wavelength of λ = 532 nm, an average power of maximum 22.5 W @ 5 MHz and pulse duration of τ = 5 ps. In this setup, the laser beam is deflected to the workpiece either by a Scanlab

IntelliScan 14DE or a polygon scanner, see figure 1. Afterwards the beam is focused onto a spot diameter of 14 µm (1/e²) by a 100mm f-Theta lens. The polygon mirror has 7 facets and allows a rotation speed of 10,000 rpm. In combination with the 100 mm focussing lense this offers scanning speeds up to 200 m/s.

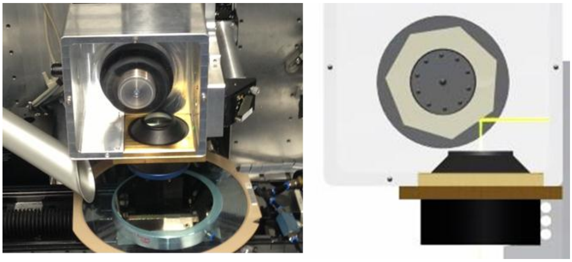

Figure 1: Image and scheme of the 7 facet polygon scanner setup

The cutting test were performed at 120 µm thick 6" boron doped silicon wafers. While the process parameters pulse overlap, pulse energy and number of repetitions were varied, every cutting line was investigated if the substrate is completely cut through or not. During all the experiments the focal plane always remained on the workpiece surface and the polarisation was kept perpendicular to the scanning (cutting) direction.

2. Reference experiments with a galvo scanner

To get a reference for the experiments with the polygon scanner and furthermore an impression about the parameter frame, first of all experiments with a galvo scanner were performed. Figure 2 shows the results of these experiments.

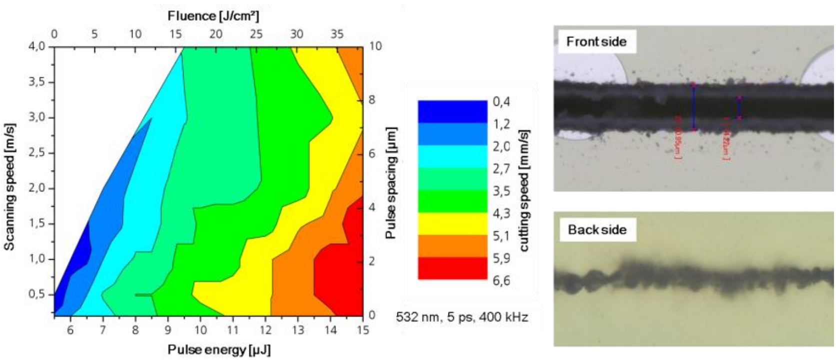

Figure 2: Attainable cutting speed with a galvo scanner

At a repetition rate of 400 kHz, different pulse energies starting at 5.5 µJ up to 15 µJ together with different scanning speeds from 250 mm/s up to 4 m/s. The coloured scale shows the attained cutting speed (scanning speed / number of repetitions). The upper left white triangel shows the parameter combinations which were not suitable to cut through the wafer; even after great number of repetitions. The cutting speed strongly depends on the pulse energy. For example at a scanning speed of 1 m/s a pulse energy leads to a cutting speed of 0.4 mm/s. At 10 µJ the cutting speed amounts 4 mm/s and at 15 µJ 6.6 mm/s. But the scanning speed has also an influence. Low scanning speeds and thus small spacing from puls to puls leads to a high thermal impact during the ablation process. At the highest cutting speed the process quality, e.g. cutting width and heat affected zone are clearly worse, compared to results at 10 µJ and 2 m/s. So a good trade off between quality and cutting speed delivers around 3 mm/s cutting speed, compare the microscope pictures on the right side of figure 2. Higher pulse energies lead to worse quality in terms of melt and cutting width.

3. Results of ablation process with a high speed polygon scanner

To take advantage of the high available scanning speed of a polygon scanner, the laser repetition rate is switched to 5 MHz and therefore the available repetition rate decreases to 4.5 µJ. The highest attainable cutting speed amounts 20 mm/s at 4.5 µJ and 2 m/s scanning speed, see Figure 3. Similar to the reference experiments this operating point is not reasonable due to the poor cutting quality, resulting from the strong thermal impact. Much better qualities are obtained if the scanning speed is increased to more than 20 m/s. In this case the cutting speed drops to 12 mm/s.

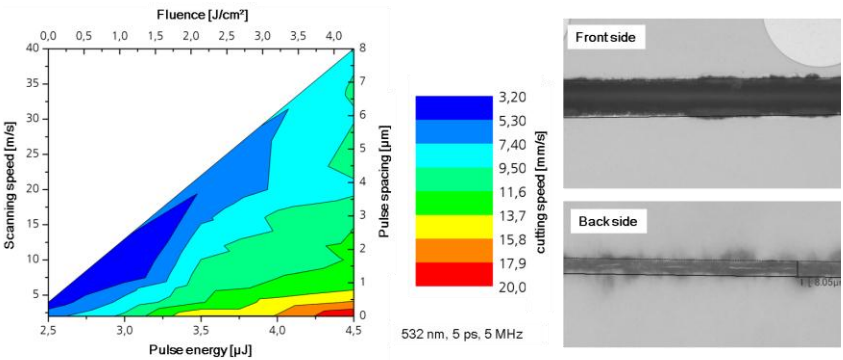

Figure 3: Attainable cutting speed with a high speed polygon scanner

Compared to the conventional process the cutting speed is 4 times higher (3 mm/s → 12 mm/s) with even better cutting quality, compare right side of figure 3. However it has to be considered that the average power due to the high repetion rate of 5 MHz is also higher. The distribution of high average powers on many pulses in combination with high scanning speeds is obviously an effective way to increase the cutting speed. Figure 4 shows SEM pictures of the cutting edge at 4.5 µJ, 5 MHz and 20 m/s, processed with the polyon scanner. The cut surface has a relatively smooth structure with some particles sticking on it. The wavelike lines parallel to the cutting edge indicate the cutting progress over the repetitions. The magnification in the lower part of figure 4 shows a very clear and sharp edge of the chip backside. No chipping and no cracks are to be found, which are usuallly the most critical defects.

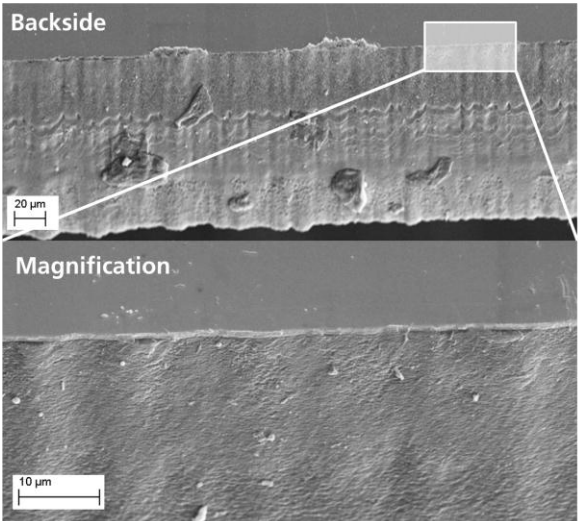

Figure 4: SEM picture of the cutting edge at 4.5 µJ, 5 MHz and 20 m/s

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