Development of wafer singulation technique for MEMS and MOX gas sensors using 355 nm UV laser ablation process

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Summary:

This work presents a 355 nm UV laser ablation process for singulation of silicon wafers. The process may be suitable for singulation of wafers that are sensitive to water and particle contamination such as specific MEMS and MOX micro-hotplate gas sensors. Conventional dicing using a rotating blade and constant water flow can damage and contaminate delicate structures and functional layers. In contrast, the proposed UV laser method requires no liquids, minimizes particle generation near the dicing street, and offers a cleaner, safer alternative for singulating sensitive wafers.

Keywords: UV laser ablation, laser micro-processing, wafer singulation technique, MEMS and metal-oxide (MOX) micro-hotplates gas analyzer, assembly gas sensors, alternative wafer singulation technique.

Introduction

A large majority of silicon wafers [1] are singulated using a sawing process that consists in mechanical cutting of the silicon wafer by a diamond blade rotating typically from 30,000 to 60,000 rpm, and with a feeding speed between 1 and 100 mm/s. The width of the dicing blade usually ranges between 20 and 200 µm, defining the width of the dicing kerf. This mechanical cutting process generates silicon dust and employs a high-pressure water flow directed into the dicing area to remove said dust while simultaneously cooling down the blade and the wafer. The process works very well on the majority of CMOS ICs and is successfully extended to MEMS-wafers. However, the presence of high-pressure water and the unavoidable occurrence of silicon dust generated during sawing imposes additional limitations on this process' applicability. For example, the high-pressure water can mechanically damage movable parts of MEMS devices such as beams, micro-mirrors, RF switches and micro-heaters of metal-oxide (MOX) micro-hotplates gas analyzers. Additionally, silicon dust can contaminate the micro-features of these components. Specifically, in the case of MOX-gas sensors, the sensing materials deposited on the micro-hotplate can be also affected by water and silicon dust. It has been previously shown [2] that silicon wafers can be ablated using various laser techniques, but extensive research is needed to adapt the process to specific applications. In this paper, we investigate the feasibility of singulating silicon wafers using a direct ablation process using a 355nm UV laser.

Materials and methods

The study was carried out on a polished silicon wafer with a diameter of 100 mm, a standard thickness of 525 ± 25µm, crystal orientation (111), N-type, and a resistivity of 0.0020–0.0045 Ohm.cm. We performed the study using a WS Flex optomechanical system from Optec. It is equipped with a Talon 355-12 W (Spectra Physics) 12 W Nb: YAG Q-switched DPSS laser, with a wavelength of 355 nm (UV). The laser beam spot size diameter at target is 8 µm. The laser has several parameters that can be adjusted within the operating range (laser repetition rate, laser spot speed, laser pulse energy, number of repetitions, etc.), however some of them are interdependent. We adjusted the laser speed to obtain a 50% diameter overlap between successive laser spots, as well as other parameters to obtain maximum laser fluence [3]. The variable parameter during the study was the number passes or repetitions, which is the number of times the laser beam moves through the programmed pattern. The chosen pattern is a 5 mm x 5 mm square, which is a typical size for a silicon die or MEMS device. We explored the impact of the number of repetitions starting from 1 to 5,000 (0, 10, 20, 50, 100, 500, 1000, 2000, 5000 and 10000). Using 1000 or more repetitions, a complete cut of a 525 µm thick silicon wafer was achieved.

Results

We performed the analysis and characterization of the laser ablation process. We investigated singulated dies and areas of the wafer in proximity of the laser cut by means of optical inspection using a visible light optical micro-scope Leica Z6APO and performed profilometric scanning using a stylus type profilometer DektakXT from Bruker. The kerf width is about 30-40 µm and the area near to the kerf has specific features originated by the laser processing. They have distinct hard ridges with an average height of 5-7 µm, and a width (a1 and a2) extending up to 10 µm (Fig.1).

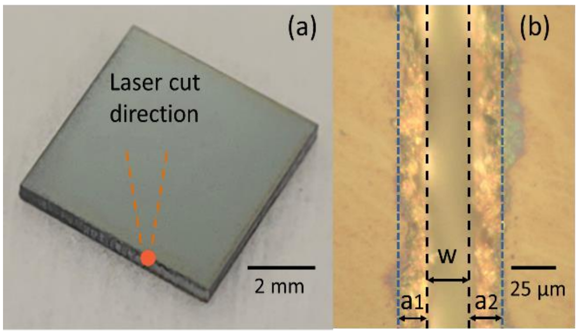

Fig. 1. An individual singulated die (a), a top sideview of the laser cut and area affected by the laser processing (b), where w is the kerf width, and a1 and a2 are the widths of the left and right area affected by the laser processing.

Outside of this area, the surface remains smooth with average roughness of 0.02 µm, which is typical for an unprocessed wafer. The nature of these ridges remains to be studied, but they are likely formed from silicon evaporating during laser ablation and re-depositing on the surface. The more laser passes, the wider the area next to the laser kerf affected by the laser processing. Remarkably, we did not detect any chipping near the laser cut, which typically occurs during a conventional saw dicing process.

We have also analyzed the sidewall of singulated silicon dies, presented in Fig.2.

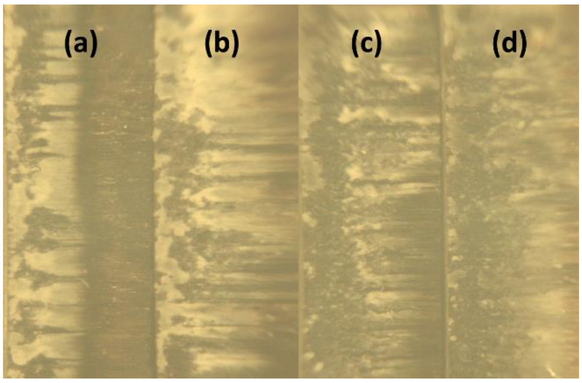

Fig. 2. Sidewall microscopic observation of laser ablated wafers using 1000 (a), 2000 (b), 5000 (c) and 10000 (d) passes. Laser cut direction from right to left.

We characterized the sidewall roughness in terms of R_a and R_q (roughness average and root mean square roughness correspondingly). The results are presented in Table 1.

Tab. 1: Sidewall roughness versus number passes.

Passes	# *10^3	1	2	5	10
Roughness	R_a, µm	0.45	0.85	1.49	1.84
	R_q, µm	0.54	0.99	1.74	2.14

The roughness variation is most likely due to the laser induced damage along the cut sur-face. The more laser passes, the rougher sur-face of the sidewall. Despite this, the sidewall surface is smoother than that obtained by the saw dicing process and does not exhibit chipping (neither topside nor back-side chipping), which is typically around 5 - 10 µm under optimized saw dicing process parameters with a dicing kerf of 50-60 µm wide.

In our study, we demonstrated that it is possible to singulate a silicon wafer into individual dies using a UV laser. The 1000 laser passes (repetitions) allow to obtain a repeatable and good quality full through-cut on a 525 µm thick silicon wafer. This results in less damage (sidewall and area near the laser cut) compared to a conventional saw dicing technique, and a smaller kerf width. Meanwhile, various technical challenges remain to be solved. The laser dicing process must be further optimized to increase processing speed and reduce material redeposition.

References

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