New Approach in MEMS Integration with UV Laser Micro-cutting

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Abstract

This paper presents laser micro-cutting through-holes in 300 µm thick silicon wafers with a nanosecond UV laser under freely definable angles. The key process is the deflection of the laser beam by a front surface mirror with an aluminium coating and the associated challenge of focusing.

1 Introduction

In order to be able to meet the demands of the microtechnology, modern MEMS must be more and more powerful. Therefore it is necessary to increase the efficiency not only of the system itself but also of the connections from the micro into the macro world. The growing number of applications on top of the chips demand more connections on the chip backside. To simplify their installation, the corresponding through-holes have to be further apart, as shown in Figure 1. Standard through-holes are fabricated with dry as well as with wet etching technologies. Both allow the processing at least on wafer level but need expensive and time-consuming preparations, e.g., mask based photolithography. Furthermore the etch rates are very slow (dry: 2-4 µm/min, wet: up to 6 µm/min [1, 2]) and there is no possibility of an inclined material removal as well as of rapid prototyping (RP). Laser micro-cutting eliminates all these disadvantages.

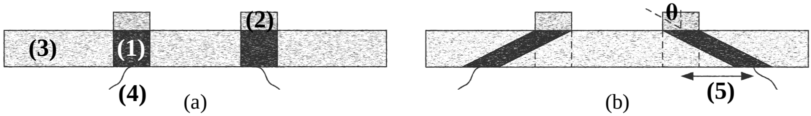
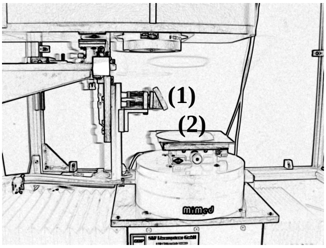


Figure 1: Schematic diagram of (a) vertical through-holes (1) for applications (2) on the chip (3) with the corresponding connections (4); (b) through-holes under a freely definable angle θ with declaration (5) of the extra space for easier assembly.

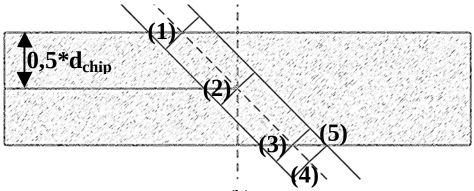
2 Experimental procedure

2.1 Experimental apparatus

A galvanometer scanner from Arges and a Nd:YAG laser from Lambda Physik are used. The oscillator produces 15 ns pulses with an average power of 2 W. The laser beam is deflected by an inclination adjustable front surface mirror from OWIS with a high reflectivity of 80 %, as shown in Figure 2 (a). The focus position is automatically moved by the optical height axis of the scan head into the chip in four steps during the machining process. The last focus position (4) is designed to insert more energy at the most turned away side from the laser beam (see Figure 2 (b)).



(a)

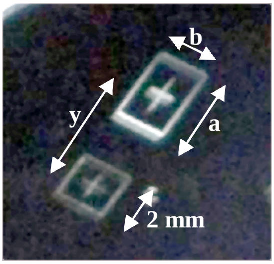


(b)

Figure 2: (a) the laser beam is deflected by the front surface mirror (1) and is directly impinged on the chip (2); (b) schematic diagram of the four focus positions (1) - (4) with declaration of the most turned away side from the laser beam (5).

2.2 Challenges in focusing the laser beam and adjusting the mirror

The focus position depends on the adjusted angle θ of the mirror. Therefore a two-stage process, to define the focus position as well as to examine the adjusted angle, is implemented. At first a square with a cross in the middle is lasered with the focus on the chip. The second step is to manufacture this square under deflection of the laser beam by the mirror without changing the position of the chip. Both, the value for the required angle and for the focus on the chip are coarsely adjusted via the two micrometer screws on the mirror as well as via varying the mechanical height axis of the scan head about the factor Δf_{coarse}. A shape is faithfully produced by the laser if the image plane is vertical to the laser beam. By tilting this plane about one axis, the resulting axis in the other direction is elongated. To counteract this, a compressed circle with the factor cos(θ) is implemented as cut shape. By the measurement of the side lengths a and b as well as the distance y of the two crosses, the value for the adjusted angle and for the focus position is determined (see Figure 3). Formula 1 calculates the resultant value f_{tilted} for the mechanical scan head height axis. Therefore the focus is centered in the chip, which is on a protector plate. $F_{standard}$ is the mechanical height axis value for focusing on the underlying plate of the XY-table.



$$\cos(\Theta) = \frac{b}{a}$$

$$f_{tilted} = f_{standard} + (1 - \cos(\Theta)) \cdot \left(\frac{y}{\tan(\Theta)} + \Delta f_{coarse} \right) - d_{protection} - \frac{d_{chip}}{2}$$

$d_{protection}$ = *thickness of the protection plate*

d_{chip} = *thickness of the chip*

$f_{standard}$ = *focusing on the XY-table plate; present system: -6,78 mm*

"The higher the axis the more negative this value"

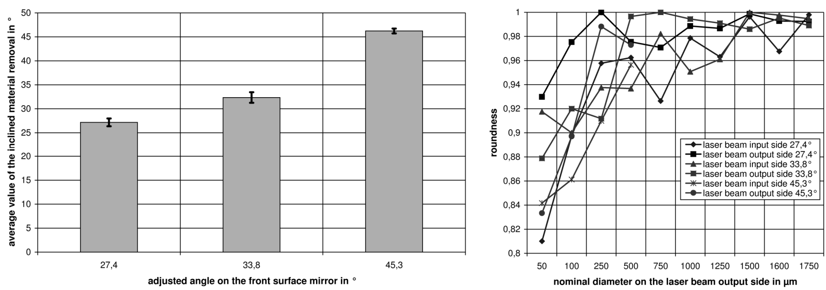
Δf_{coarse} = *factor for the coarse adjustment of the height axis*

Figure 3: Two-stage process for adjusting the angle and the focus.

Formula 1: Determination of the mechanical height axis value f_{tilted} after deflecting the laser beam by the front surface mirror.

3 Results and discussion

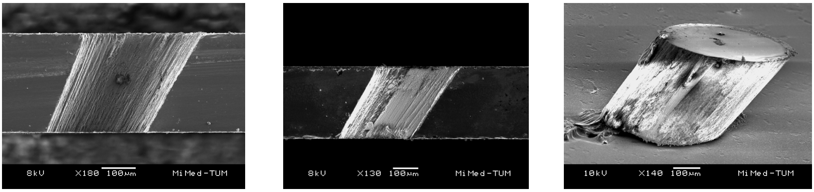
Up to now, through-holes between an angle of 27,4° and 45,3° are realizable. Due to the precise process for focusing the laser beam and for adjusting the mirror, a high accuracy is reached for the inclined material removal (see Figure 4 (a)). The implementation of a compressed circle as cut shape leads to high values for the roundness using formula R=(x*y)/(max(x,y)); x and y are the measured values for the half-axes (see Figure 4 (b)). Only in manufacturing through-holes with small diameters the values for the roundness are reduced because small deviations in the micrometer range have already enormous influence.



(a) (b)

Figure 4: (a) adjusted angles have a low standard deviation; (b) the laser beam input as well as the output sides show high roundness values.

The diameters on the output side are on average 64 µm larger in comparison to the nominal values. The reason is that the laser beam is reflected multiple times on the sidewall and the kerf gets a steep slope. Until now, this taper is compensated too large. With this procedure all investigated diameters (50 to 1750 µm) can be fabricated up to an angle of 33,8° (see Figure 5). Through-holes under an angle of 45,3° can be fabricated up to a diameter of 500 µm because the irradiated side is too far away from the focus. Investigations with laser micro-drilling instead of laser micro-cutting lead to an adjustable angle up to 55° but to a decrease of the roundness.



(a) (b) (c)

Figure 5: SEM cross-sectional images of through-holes under an angle of (a) 27,4° and (b) 33,8°; (c) out-cutted part of a through-hole.

4 Summary and outlook

In this paper the foundation for the inclined material removal is set by the implemented process. It would be possible to enlarge the adjusted angle by using a laser with higher power and shorter pulse duration. This would enable us to fabricate anisotropic etch geometries and opens up new opportunities for the RP of silicon.

Acknowledgement

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