Process development and characterization towards microstructural realization using laser micromachining for MEMS

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Abstract

This paper presents the process development and characterization towards microstructural realization using laser micromachining for MEMS. Laser micromachining technique is environmental friendly, fast patterning and able to avoid multi steps in conventional lithography based microfabrication techniques. This research focuses on understanding the dimensional properties of materials of the laser beam on the silicon wafers where microstructures were fabricated. Four main parameters like rectangular variable aperture (RVA-XY) size, number of pulse, stage/table feed rate and laser energy play important role in laser ablation process. The pattern of the microchannel or line with 1 cm length was drawn by AutoCAD software or any CAD software. The pattern in the CAD software is then transferred onto the silicon wafer by using laser micromachining. Finally, high power microscope (HPM) and Stylus Profiler will be used as measurement tools for observing and analysing the width and depth of the microchannel structures fabricated by laser micromachining. When using bigger size of RVA, it will lead to bigger microchannel width. There are a little effects or almost comparable in term of microchannel depth if varying all parameters' value. Surface roughness test also needs to be considered before choosing the best setting for the laser ablation.

Keywords Laser · Micromachining · Parameter · Microstructure

1 Introduction

Chip design and fabrication are getting more complex and compact due to their size. It starts from small scale integrated (SSI) circuit to very large scale integrated (VLSI) circuit and then integration with microelectromechanical system (MEMS). Standard steps to fabricate MEMS like using microelectronic manufacturing methods such as photolithography, etching and deposition [1–5]. Further study should be carried out for looking alternative technique to produce 3 dimension (3D) micro-components with less cost, better durability, better surface roughness and better strength [6–10].

One of the methods that can be used is micromachining methods. Some of micromachining methods consist of MEMS lithography, deep reactive ion and wet etching,

vapour phase etch process, porous silicon-based MEMS, micro 3D technologies, laser-based micromachining, surface and bulk micromachining. Laser ablation also known as laser micromachining, is usually used to remove material from solid state by laser irradiation. There are several types of laser that can be used for micromachining, for examples like yttrium–aluminium–garnet (YAG), carbon dioxide (CO₂) and excimer [11, 12]. In this study, KrF excimer laser micromachining with wavelength of 248 nm will be used. In laser micromachining, a laser beam is aimed firmly on the surface of the material to form a desired pattern.

Nowadays, excimer laser is widely used in academic and industry. The gain medium of KrF excimer laser is a gas mixture of noble gas such as krypton with reactive gas (fluorine). A pseudomolecule which is named Excimer will

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be generated under high pressure and electrical stimulation. Laser micromachining belongs to top-down, subtractive approaches. It has great potential and flexibility in term of 3D structure microfabrication and possible to be a mainstream fabrication technology. Laser micromachining technique is environmental friendly, fast patterning and able to avoid multi steps in conventional lithography based microfabrication techniques. Besides, it is said that 3D laser micromachining can advance the visionary top-down approach of micro/nanofabrication technology. This research focuses on understanding the dimensional properties of materials of the laser beam on the silicon wafers where microstructures were fabricated. Silicon is a common semiconductor material that used widely in microelectronic fabrications. There are four main parameters that will be manipulated to study the dimensional properties of the laser beam like rectangular variable aperture (RVA-XY) size, number of pulse, stage/table feed rate and laser energy to a certain range (Fig. 1).

2 Materials and methods

In this research, microchannel structure will be used to study the characteristics and trend of the laser beam. All micro channels with length of 1 cm will be fabricated on top of the silicon wafer by firing one laser shot of RapidX 250 KrF excimer laser micromachining. Each micro channels will be produced by using different parameter setting of laser micromachining tool. RVA-X (rectangular variable aperture-X) and RVA-Y (rectangular variable aperture-Y) are x-axis and y-axis of the lens in the RapidX 250 KrF excimer laser micromachining. Number of pulse is the number of laser pulses exposed onto the wafer surface that leads the ablation result. Laser energy (J) is the capacity of the excimer laser gas charging voltage [13, 14].

Process starts with cleaning the wafer surface from any contaminations or particles that might disturb the result

of the study by using buffered oxide etchant (BOE). The pattern of the microchannel or line with 1 cm length was drawn by AutoCAD software or any CAD software. The pattern in the CAD software is then transferred onto the silicon wafer by using laser micromachining. Finally, high power microscope (HPM) and Stylus Profiler will be used as measurement tools to observe and analyse the width and depth of the microchannel structures fabricated by laser micromachining (Fig. 2) [15, 16].

3 Result and discussion

Initially, settings for all micro channels or lines in a CAD software was set up as 1 cm length before run the laser tool. Four main parameters were studied or manipulated to see the dimensional properties of the laser beam on the silicon wafer where focusing on shape, width and depth size of the microchannel structures. Before run the experiment, reference or default setting was chosen to compare the result. Table 1 shows reference/default setting for main parameters.

After micromachining process, all microchannel structures of the fabricated silicon wafers will be measured and analysed by using HPM and Stylus Profiler. Figure 3 shows graph of microchannel dimension (μm) vs laser energy (mJ) where there are few effects to the width of micro channels when manipulating or varying the laser energy between 10 and 18 mJ. Both HPM and Stylus

Fig. 1 RapidX 250 laser micromachining [16]

Fig. 2 AutoCAD design of 1 cm microchannel/line structure [16]

Table 1 Reference/default setting for main parameters

Parameter	Reference/default setting
Laser energy	16 mJ
Rectangular variable aperture (RVA)	0.4 mm $\times$ 0.4 mm
Number of pulse	200 pulses
Stage/table feed rate	0.5 mm/s

Fig. 3 Graph of microchannel dimension (μm) vs laser energy (mJ)

Fig. 5 Graph of microchannel dimension (μm) vs number of pulse

Fig. 4 Graph of microchannel dimension (μm) vs rectangular variable aperture (RVA, mm × mm)

Fig. 6 Graphs of microchannel dimension (μm) vs table feed rate (mm/s)

Profiler graph show same trend even have a bit different in term of width value. For microchannel depth, the value showed almost comparable around 2 μm depth even varied the laser energy value.

Figure 4 shows graph of microchannel dimension (μm) vs RVA (mm × mm) where manipulating RVA can give big effect to the width of the microchannel. The graph shows increasing trend when RVA size increase. But, depth of microchannel not much different when manipulating RVA size around 1.6 μm per laser shot.

In Fig. 5 below shows graph of microchannel dimension (μm) vs number of pulse where the graph show trend of microchannel widths were almost comparable even varying number of pulse between 100 and 250 value. For microchannel depth, the graph shows microchannel depth less than 2 μm depth per shot when varying number of pulse from 100 to 250.

Figure 6 shows graphs of microchannel dimension (μm) vs table feed rate (mm/s) where there was slightly fluctuated in trend of microchannel width and depth when varying table feed rate. Figures 7 and 8 show photo as well as profile of micro channel structure by using reference/default setting; captured by HPM and Stylus Profiler.

Fig. 7 Photo of micro channel structure by using reference/default setting; captured by high power microscope (HPM)

Based on this result, there are a little effects or almost comparable in term of microchannel depth if varying all parameters' value. When using bigger size of RVA, it will lead to bigger microchannel width. As predicted the etched surface (microchannel width) increase with size of RVA, as bigger size of RVA, a larger exposed area of the targeted femtosecond beam of laser has energy higher than the machining threshold. When using different technique of measurement, tolerance of the tool's performance should be considered. Surface roughness test also needs to be considered before choosing the best setting for the

Fig. 8 Profile of micro channel structure by using reference/default setting; captured by Stylus Profiler

laser ablation. It can be seen from the photo and profile of reference micro channel structure captured by HPM and Stylus Profiler (Figs. 7, 8) where at bank of the micro channel structure is not completely clean as several residues and recast can be detected at the bank of the micro channels. The residues are the materials produced during the ablation process, and the vaporization of the targeted material fall back onto the targeted substrate and accumulated around the ablation area. These problems can be reduced by cleaning the ablated area immediately after the ablation. This cleaning process maybe will increase the processing time of the laser micromachining [16–20]. At the same time, the laser micromachining process needs to be carried out in stable condition and avoid firing of the debris or residue.

4 Conclusions

Nowadays, laser micromachining process is one of the important processes in MEMS fabrication. Understanding the dimensional properties of materials of the laser beam on the silicon wafers where microstructures were fabricated is very important for getting better results. Four main parameters like rectangular variable aperture (RVA-XY) size, number of pulse, stage/table feed rate and laser energy play important role in laser ablation process. When using bigger size of RVA, it will lead to bigger microchannel width. There are a little effects or almost comparable in term of microchannel depth if varying all parameters' value. When using different technique of measurement, tolerance of the tool's performance should be considered. Surface roughness test also needs to be considered before choosing the best setting for the laser ablation.

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Compliance with ethical standards

Conflict of interest The authors also declare that they have no conflict of interest.

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