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Fabrication of MEMS cantilever using laser micromachine

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Abstract. This paper presents the fabrication of MEMS cantilever using laser micromachine. This technique of micromachining is able to overcome the problem limitations of conventional lithography. It also facilitates three-dimensional (3D) microfabrication rather than two dimensional (2D) microfabrication of conventional lithography. Prior to fabrication process, wet etching process using KOH solution are carried out on silicon wafer. Etching process is necessary to thin the silicon wafer for the laser micromachine purpose. The etch performance on silicon wafer was investigated by varying the concentration of potassium hydroxide (KOH) solution with respect to time. It can be seen that with higher KOH concentration and higher KOH solution temperature, the etch rate is higher and it will thin the silicon wafer faster. Even though it is beneficial when the time taken for the etching process is faster, this also resulted in a rougher wafer surface. The optimized etch rate is approximately 1µm/min which yield in low surface roughness. The optimized parameters of laser micromachining were implemented to produce MEMS cantilever. Silicon wafer is used because most of the MEMS devices are silicon-based substrate. Three types of microcantilever were fabricated using laser micromachine namely rectangular cantilever, T-shaped cantilever and triangular microcantilever. Scanning electron microscope (SEM) and high power microscope (HPM) were used to obtain the surface morphology on the ablated area of the microcantilevers.

1. Introduction

Device miniaturization is imperative towards the production of micro-electro-mechanical system devices. The existing fabrication process encompass series of manufacturing process such as deposition, etching, mask patterning, then followed by etching and post baking. This is time consuming and costly as it requires various chemicals. For example, for a certain device fabrication process, several layers of photoresist, followed by oxide layer and metal layer have to be deposited on a bare substrate. In addition, the conventional fabrication technique is restricted to only one material surface for bulk etching in three silicon planes directions.

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Laser micromachining process has been widely adapted to develop microstructures where it utilizes laser ablation as the fundamental fabrication step [1-5]. The process of laser micromachining encompass the interaction between laser and material, where when the targeted material is exposed to laser radiation, the substrate/material will absorb the energy from the laser. The absorbed laser energy is transformed into lattice vibration energy (thermal). This will result in rising of the temperature, hence heating the targeted surface. The repetition of this process will ultimately melt and vaporize the targeted material (Figure 1). The interactions of laser and its substrate depends on both the substrate material and the laser parameters, such as the laser wavelength, the pulse duration and laser intensity. The process of laser micromachine has been established for various types of materials. Patterning using laser allows direct prototyping of materials without the use of additional mask, photoresist molds and further post-processing treatment.

Fabrication process using laser micromachine will give complex three-dimensional structure without a mask. In addition, laser micromachining will give good quality in high resolution, high precision, high process speeds and less fabrication processing steps. Silicon wafers are favourites materials for MEMS devices since it is easily available and compatible with the processing technology in the microelectronic industries. Moreover, silicon is widely used since it has good electrical conductivity and very wide functional range in the semiconductor dopants

A microcantilever is a device that can be used for physical, chemical or biological sensor by detecting the changes in cantilever bending or vibrational frequency. In terms of sensitivity, microcantilever-based sensing devices has good sensitivity as opposed to existing sensors as their response time is shorter and they required minimal operational power. However, the sensitivity can still be improved by modifying the shapes of the microcantilever. The sensitivity depends on the microcantilever stiffness, and the stiffness can be affected by the geometrical structure of the cantilever, namely its width, length and thickness.

In this paper, we aim to use laser micromachine as an alternative method for the development of arrayed microcantilever towards biomedical application. Previously we have reported on the fabrication of microfluidic structure using both laser micromachine and soft lithography technique [6].

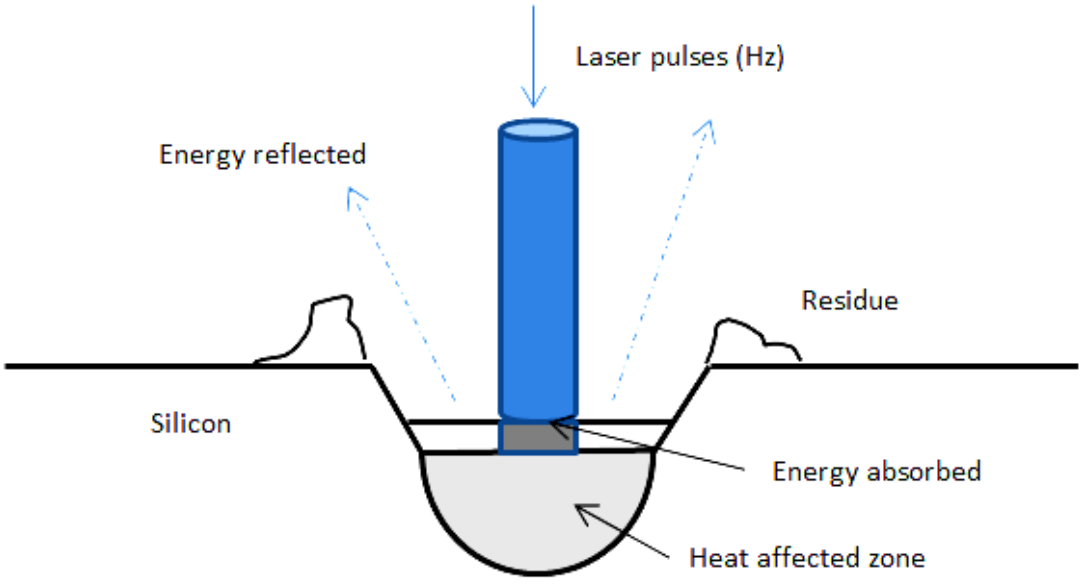

Figure 1. Laser-material interaction [7].

2. Methodology

Three types of cantilever design are initially drawn using AutoCAD software. The cantilever design are rectangular, T-shaped and triangular and the cantilever structure was designed in 4mm^2 area. These cantilever design were created on a surface of silicon wafer with the thickness of 100 um. Initially, silicon wafer with the diameter and thickness of 100 mm and 550 µm respectively is cut into 20 mm x 20 mm dimension using a wafer scriber. Next, the wafer is dipped in the buffered oxide (BOE) solution for 30 to 60 seconds. This is to eliminate native oxide on the surface of the wafer. After that, the surface of silicon wafer is rinsed with deionized (DI) water to remove the BOE residue on the surface. The wafer is then placed on a spinner (30 seconds and 3500 rpm) for drying purposes. In order to thin the wafer to the desired thickness which is below 100 µm, the wet etching process have to be done. The thickness is chosen based on the application of the microcantilever and that it is the approximation for the optimum thickness of microcantilever [8]. Mixture of Potassium hydroxide (KOH) and isopropy alcohol (IPA) solution is prepared for wet etching purposes. The thinning process is conducted based on different parameters as depicted in Table 1, where the solution concentration and its baking temperature are varied. The etching time is fixed for one hour.

For laser micromachining process, RapidX-250 series KrF excimer is used to pattern/etch directly the microcantilever on the wafer. The machine consists of a microscope camera that is used to point the sample on the stage. This enable the sample to be monitored live during the etching process. The stage where the sample is put is a moveable three-axis in X, Y and Z direction. In order to control the laser, a specific software called Laser Control 4 Valve is used. The software includes Atlex control software (ATL), which functions are to stabilize the pulse energy or average power, repetition rate adjustment, high voltage adjustment, trigger modes, auto gas exchange, menu guided mirror exchange, transport & storage function, menu guided gas cylinder exchange, and safety interlock functions.

When using laser micromachine, there are five primary parameters that have to be taken into consideration. They are number of pulse, laser energy, number of laser shots and rectangular variable arperture (RVA) in both x- and y- direction. These parameters were varied to a certain range based on our previous work [9]. Energy (Joule) is directly directed to the volume of the excimer laser gas charging voltage. RVA-X (Rectangular Variable Aperture-X) is the x-axis of the lens in the Rapid X laser micromachining and RVA-Y (Rectangular Variable Aperture-Y) is the x-axis of the lens in the Rapid X laser micromachining. Number of shot is the number of laser shot required to obtain the desired microstructure, while number of pulse is the number of laser pulses exposed onto the wafer surface leading to ablation effect.

The silicon wafer is placed on the wafer stage and is adjusted to the center of the laser lens. Then to avoid contamination on the sample, the exhaust gas is opened to clear the dust on the surface of the silicon wafer. Next, BobCAD software is opened and the design of desired microcantilever from AutoCAD is loaded.

3. Results and discussion

During the wet etching process, the concentration of the KOH solution and its temperature were varied. The concentrations were varied at 20%, 25% and 30%, while for the temperature were increased from 60˚C, 80°C and 100°C. At the end of the etching process, the result of the wafer surface should be low in surface roughness and the etch rate should be low approximately 1µm/min. The etch rate is the time taken for the silicon wafer to etch. The wafer thickness prior to wet etching is 550 µm.

Referring to the high power microscope images of wafer surface (Table 1), the higher the temperature of the solution, the roughness will be increased also. But for 25% and 30% KOH concentration, at 100°C etching process temperature, the silicon wafer was completely etched during 60 minutes. So, the etching process for them is carry out at 30 minutes only. It can be concluded that with higher KOH concentration and higher KOH solution temperature, the etch rate will be higher and

it will thin the silicon wafer faster. Even though it is beneficial when the time taken for the etching process is faster but they will give a rougher wafer surface.

Table 1. Images of substrates after wet etching process at different concentrations and temperatures.

	60°C	80°C	100°C
20%			
25%			
30%			

The best parameter for etching process should be low etch rate approximately 1µm/min and low in surface roughness. From the parameter obtained, the relationship between the temperature and the etch rate can clearly be seen in the graph of temperature and etch rate as depicted in Figure 2. From the graph below, the result can be summarized that with higher temperature, etch rates will be higher also. Therefore, from the result obtained of the etch rate and the surface roughness of the wafer surface, at 80°C will give the best result for the wafer thinning at 30% KOH concentration because it will give low etch rate and less surface roughness.

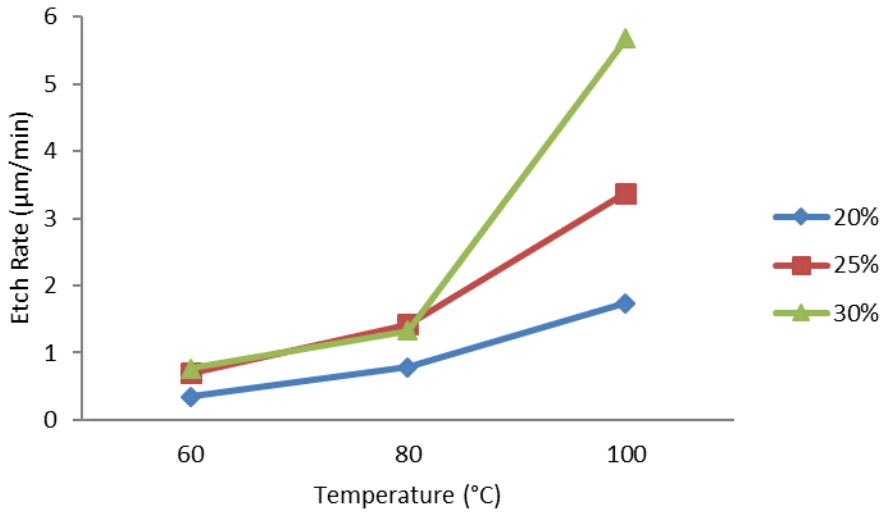

Figure 2. Etching rate of substrate with respect to temperature for different concentration

During the fabrication process using laser micromachine, the operational parameter of the machine were varied according to [8]. The number of pulse used was 300, laser energy was set to 15mJ, and the frequency, RVA-X and RVA-Y were set to 400 Hz, 5mm and 5mm respectively. The laser energy

and laser pulse rate gave direct impact to the etching depth while the rectangular variable aperture (RVA) either "X" or "Y" gave direct effect to the cantilever surface dimension, or simply the width. As expected the etched area increase with laser energy, as at higher laser power, a larger part of the focused femtosecond beam has energy exceeding the machining threshold.

We found that the number of laser pulses do not have any significant effect on the etching performance of the structure. We also established that, when the pulse rate is higher, the ablated surface will be smoother.

The optimized laser micromachined parameter used in previous works to fabricate different materials are summarized in Table 2. It can be seen that the laser parameter of the micromachine depends highly on the ablated materials. The material parameters include its type and thickness, substrate reflectivity and density, and its spectral absorption. For instance, the laser energy required for the fabrication of PDMS is very low compared to the energy required to micromachine other materials. This is because the elastic properties of PDMS is lower compared to other materials. If the laser energy used is low, the frequency of the laser micromachine has to be increased. In order to effectively fabricate transparent materials with femtosecond laser pulses, the laser pulse energy must be higher than the damage threshold of the ablated material.

Table 2. Laser parameters of previous works

Frequency (Hz)	Laser energy (J)	Material
250k	2.4u	Silica [9]
250k	3u	Glass [9]
100	1.2-1.6u	PDMS [9]
100	12-40	Silicon [10]
100	12-47.5	PZT [10]
100	12-20	Pyrex [10]
400	15m	Silicon [This work]

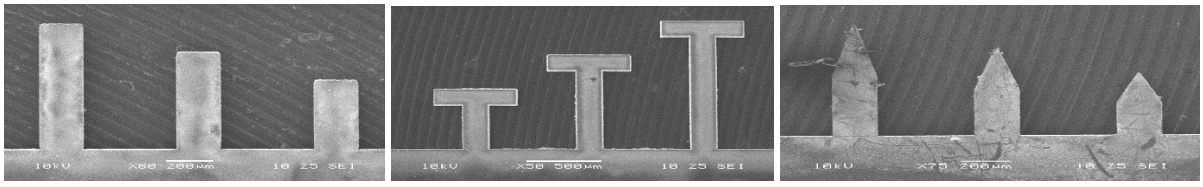

Figure 3. SEM images of rectangular, T-shaped and triangular microcantilver array

The fabricated cantilevers were inspected and measured using SEM and High power microscope, as shown in Figure 3. It can be seen from the SEM micrographs that the edge of the microcantilever structure is not completely clean as several remains and recast can be observed around the edge of the microcantilever. The remains are the materials produced throughout the ablation process, and the vaporization of the targeted material fall back onto the target substrate and accumulated around the ablation area. According to [7], these remains can be reduced by cleaning the ablated area immediately after ablation or alternatively, gas jets can also be used to remove it. This however will increase the processing time of the laser micromachining. A different suggested method to eliminate the remains is to coat the ablated area with photoresist prior to laser micromachining process. Then, photoresist developer will be used to remove the photoresist. This somehow is opposing the laser micromachine process, where the additional steps of etching should be avoided.

4. Conclusion

Laser micromachining process have the potential to contribute significantly to the development of MEMS devices. In addition, the ability of manipulating materials could also provide further improvement in the field of MEMS packaging and assembly. We have demonstrated the process of fabricating three different types of microcantilever namely rectangular, T-shaped and triangular using laser micromachine. The results were observed using high power microscope and SEM. Initially silicon substrate was etched in order to obtain the desired thickness of the cantilever. It was found that optimized etch rate is approximately 1µm/min, which yield in low surface roughness. Future works include performing experiment to measure the stiffness of the fabricated microcantilever and also to investigate the bending effect of the cantilever by applying input force and measuring its displacement.

Acknowledgments

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