Fabrication of Smooth Silicon Based Microchannels by Anisotropic Etching

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ABSTRACT

Micro channels have been fabricated by silicon micromachining .The study of anisotropic etching of Silicon (100) in aqueous solution of KOH and IPA has been carried out so as to achieve defect free surface during the fabrication of Micro-channel. A series of experiment have been carried out using different concentration of KOH, and IPA. Surface profile-meter and optical microscopy has been employed for measurement of etching rate, and for study of surface morphology. The quantitative data so obtained on etching rate and surface roughness indicate that considerable improvement in surface quality is found for etchant comprising of 40% KOH with12.5 ml of IPA. This optimized etchant has been used to fabricate micro-channel system for biological as well as heat-sink applications.

Keyword: silicon micromachining, micro-channel, microfludics, anisotropic etching

1. INTRODUCTION

Recently, there has been increasing interest in the development of micro-electro mechanical system (MEMS) using Silicon micro machining technology [1, 2]. Due to its superior electrical and mechanical properties [3], single crystal Si has been applied to various MEMS devices. Micro machining technology has been key to many recent micro-fluidics applications such as- micro-coolers, micro-biochips, micro-reactors and chemical mixing etc [4-6]. Among these micro-fluidics systems, micro-channel has been identified to be one of the essential elements to transport fluid within the miniature area. It can also be used for reactant delivery, physical particle separation, chemical mixing, and chip cooling [7-8].

Silicon Micro-machining Technology comprises of surface micromachining and Bulk micromachining [6,7]. Surface micromachining involves building of layers on the substrate, using low stress films such as oxide and nitride while etching out the sacrificial layer, such as amorphous silicon. Bulk micromachining refers to the etching away of the bulk of silicon to generate the required microstructure. Bulk micro machining is widely used for making three-dimensional microstructures by anisotropic wet etching of silicon crystal. This provides unique etching characteristics and can be used to form the micro-channel in silicon. Micro-channels, fabricated by anisotropic etching, play very important role in all microfluidics devices. The smoothness of the etched surface is a critical factor in determining the characteristics of devices. Especially, it becomes difficult to achieve the desired functioning of devices, if smooth surface of etched micro-channel is not attained. For this reason, the role of surface smoothness on fluid flow in micro-channel has become increasingly important and of considerable interest in past several years [8, 9].

Anisotropic etchants frequently used for single crystal Si includes KOH, NaOH ethylene diamene pyrocatechol [EDP] and tetra methyl ammonium hydroxide (TMAH) [10-12]. KOH and NaOH have excellent etching properties. The studies of surface morphology etched in KOH solutions showed that the smoothness of the etched surface improves with the increase in KOH concentration. Isopropyl (IPA) has also been known as a very effective admixture to KOH solutions influencing the smoothness of resulted silicon surfaces [13-14]. However, the role and the amount of IPA ensuring the improvement in surface smoothness are still not fully understood. In this paper, a study has been conducted to investigate the influence of etchants, comprising of varying concentration of KOH and IPA on the etching rate and surface roughness. The etching process to obtain good surface smoothness of mono-crystalline silicon wafers with (100) crystallographic orientation has been optimized. Using optimized etchant, the complete system consisting of inlet & outlet ports along with micro-channels arranged in parallel has been fabricated.

2. EXPERIMENTAL

Silicon (100) samples were prepared by cleaning the wafer with RCA, and then 1-micron thickness of SiO2 is grown by oxidation in a quartz furnace at 1100 C. In this experiments p-type silicon wafers with (100) crystallographic orientation, and resistivity of 5-10 ohm cm have been used. Square window of 2.5 mm size were delineated using conventional photolithography. Buffered HF solution has been used to selectively remove silicon dioxide. The square patterns on SiO_2 mask enable the observation and measurement of etching rates.

The KOH solution was prepared by dissolving KOH flakes (Merk Germany) into DI water by varying its concentration from 20% to 60 % by weight, and then by adding IPA 12.5 cc in each KOH solution. The composition of prepared etchants is listed in **Table 1**. The samples were etched for each concentration of KOH in a constant temperature bath whose temperature stabilized within ± 1°Ċ. The etching process was carried out at 60 ^{o}C, as it was found that process condition can be controlled more accurately at this temperature. All etching experiments were performed under fume hood. After etching, the root mean square (RMS) surface roughness of the sample was evaluated using DekTak 3, by averaging the x and y scans at number of areas of each samples. The morphology of the etched surface was obtained by optical microscopy.

Table 1. Composition of Etchants

Etchants	KOH (gm)	DI (cc)	IPA (cc)
Etchant1	20	80	12.5
Etchant2	30	70	12.5
Etchant3	40	60	12.5
Etchant4	50	50	12.5
Etchant 5	60	40	12.5

3. RESULTS AND DISCUSSION

1.1 Relationship between Etching Rate and Concentration of KOH - The etch rate of (100) Si in five different etchant has been studied. Fig (1) shows the variation in etch rate for (100) Si with increasing KOH concentration. The gradual increase in etch rate with KOH solution concentration is observed up to certain value, then remarkable drop in etching rate curves occur. As shown in the Fig.1, the etching rate increases from etchant1 to etchant3 (etchant composition listed in table1), reaching to 0.39µ/min for etchant 3. The etching rate then begins to decline reaching to 0.19 µ/min. for etchants 5. The highest etch rate is obtained for the etchant 3, (KOH: DI: IPA: 40gm: 60 cc: 12.5 cc)

The mechanism of anisotropic etching of silicon as presented by Seidel et al [15], the etching rate of silicon depends on the product of hydroxide ions and water concentration. The K^+ and OH^- generated from the dissociation of KOH, undergo hydration in the solution, as given by following reaction equation:

$$KOH \rightarrow K^+ + OH^-$$

$$Si + 2H_2O + 2OH^- \rightarrow Si(OH)_4 + H_2$$

At low concentration of KOH, the OH ions are also low in concentration, hence etching reaction is low and it leads to low etching rate. With the increase in KOH concentration, the number of OH^- ions will also rise, hence the etching rate increases with the concentration of KOH. After reaching to certain level of KOH concentration, the hydration of OH^- ions in the solution consume large portion of water. Therefore, at higher concentration of KOH, there is remarkable reduction in availability of free water and that causes reduction in etching rate.

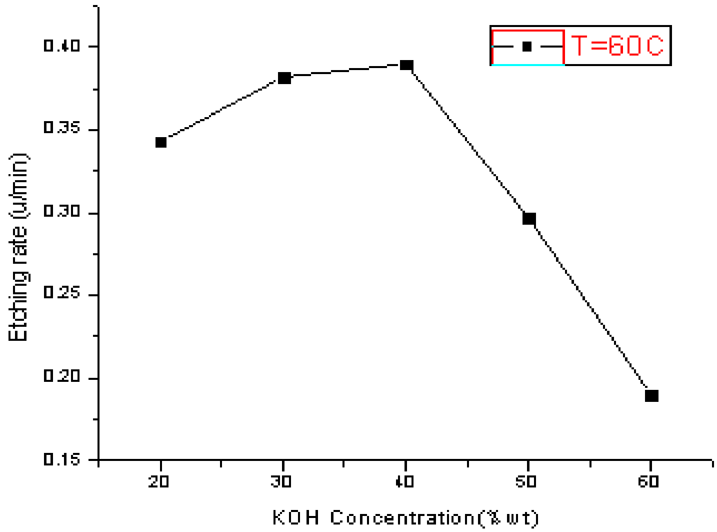
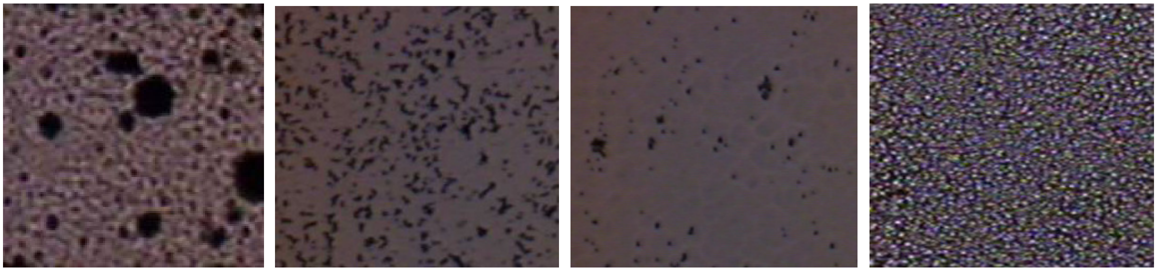


Figure 1. Etch rate as a function of KOH concentration

1.2 Relationship between Roughness and concentration of KOH - It has been confirmed by other authors [16-17] that etching process carried out in low concentration of KOH (below 30%) result in texturing of Silicon surface and is not suitable for channel fabrication. It has been also found that addition of IPA causes smoothening of etched Si (100) surface [16]. In our experiment we have presented the influence of different etchants (as listed in Table1) on the smoothness of etched surface of Si (100). The morphology of the etched surface as seen under optical microscope is shown in Fig2. The surface roughness of the etched surface is evaluated by Alpha step, and tabulated in Table2.

The surface roughness of etched surface is resulted due to hydrogen bubbles that remain attached with the Si surface during chemical reaction, and masked the surface from the etching solution. For etchant 1 (Fig 2), the density as well as the height of the hillocks is found to be very high, hence surface appears to be rough.

On further increasing the concentration of KOH (for etchant 2 and etchant3), the quality of etched surface improved in terms of smoothness. However, on further increasing the concentration of KOH (etchant 4 and etchant 5), there is significant detoriation in the flatness of the etched surface. The density as well as the height of hillocks both increases as compared to etchant 2 and etchant 3. The best surface morphology is achieved for etchant3 and it can be attributed to the rapid detachment of small size bubbles formed during etching reaction. Fig 3 shows the influence of surface roughness on etchants concentration.



Etchant1 **Etchant2** **Etchant 3** **Etchant 4**

Figure 2. Surface morphologies of etched silicon surface in KOH + IPA solution at 60 ^{o}C

Table 2. Etchants versus Roughness Measurement

S.No	Etchants	Average Roughness (A)
1	Etchant1	2540
2	Etchant2	520
3	Etchant3	315
4	Etchant4	1120
5	Etchant5	1515

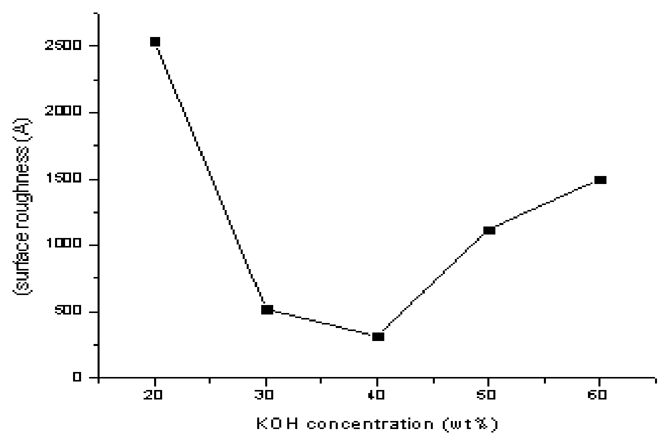


Figure 3. Surface roughness as a function of KOH concentration

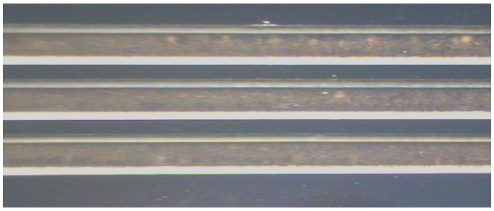
3.3 Fabrication of micro-channel - The above finding reveals that etchant 3 is ideal for fabrication of smooth surfaced micro-channel. Hence this etchant was used for successful fabrication of the micro-channels. The geometrical dimensions of the smooth micro-channels are presented in table 3.

Table3: Dimensions of micro channel

Characterization	Dimension
Channel length	10 mm
Channel width	300um
Channel depth	150um
Hydraulic diameter	166um

Pictures of the micro-channel are shown in Fig 4. The top view shows that channel configuration were etched sharply and cross sectional view shows that the channel has trapezoidal cross-section as expected from anisotropic etching.

Fluid flow was successfully activated through the micro-channel system shown in Fig 5.



(a)

(b)

Figure 4 (a). Top view and (b). Cross-sectional view of fabricated micro-channel

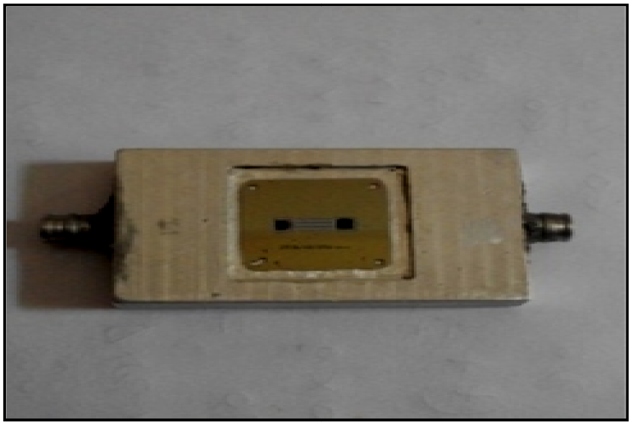


Figure 5. Package with microchannel system

4. CONCLUSION

The study of anisotropic etching characteristics of Silicon (100) in a solution of KOH and IPA for the purpose of micro-channel fabrication is carried out in this paper. Etching rate is closely connected with the concentration of etchants. The texture of etched silicon surface also depends strongly on concentration of etchants. The experimental results indicate that the best possible surface smoothness was achieved with etchant, comprising of 40% KOH (by wt) and 12.5 cc of IPA at 60^0C.A micro channel based system has been fabricated and experiments on fluid flow have been initiated.

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