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The Fabrication of Megasonic Agitated Module (MAM) for the Improved Characteristics of Wet Etching

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Abstract – The MAM (Megasonic Agitated Module) has been fabricated for improving the characteristics of wet etching. The characteristics of the MAM are investigated during the wet etching with and without megasonic agitation in this paper. The adoption of the MAM has improved the characteristics of wet etching, such as the etch rate, etch uniformity, and surface roughness. Especially, the etching uniformity on the entire wafer was less than ± 1% in both cases of Si and glass. Generally, the initial root-mean-square roughness (R_{rms}) of the single crystal silicon was 0.23nm. Roughnesses of 566nm and 66nm have been achieved with magnetic stirring and ultrasonic agitation, respectively, by some researchers. In this paper, the roughness of the etched Si surface is less than 60 nm. Wet etching of silicon with megasonic agitation can maintain nearly the original surface roughness during etching. The results verified that megasonic agitation is an effective way to improve etching characteristics of the etch rate, etch uniformity, and surface roughness and that the developed micromachining system is suitable for the fabrication of devices with complex structures.

Keywords : Anisotropic Etching, Boundary Layer, Etching Characteristics, Megasonic Agitation, Surface Roughness

1. Introduction

With the increase of the MEMS market, the accurate control of bulk micromachining based on wet anisotropic etching of silicon has received greater attention. The roughness variations of the etched surfaces can be one of the most dominant factors in the commercialization of MEMS devices. Also, smooth and defect-free surfaces are needed to manufacture micro devices using bonding techniques. The initial root-mean-square roughness (R_{rms}) of the single crystal silicon was 0.23nm [1].

Ultrasonic agitations have been used widely to remove contaminant particles during the wet process. In a few studies, etch characteristics have been improved by ultrasonic agitation [2-7]. These studies suggest that the surface roughness mainly depends on the masking of hydrogen bubbles or silicate etch products. Cavitations from ultrasonic wave may cause some damages to the wafer surface or the structures of the devices. Because megasonic wave may cause less wafer damage and acoustic streaming flow, it is considered very suitable for improving etching characteristics. The thickness of the boundary layer and the local microstreaming flow are important factors that affect the easy removal of attached hydrogen during the etching process. The applied megasonic wave causes a vortex flow in the thinner boundary layer, and the shear stress from the vortex flow can easily remove the attached bubbles on substrates. Because the boundary layer created by a megasonic wave is thinner than the one created by a hydrodynamic flow or an ultrasonic wave, small bubbles can be removed more effectively [8~10]. Therefore, the adoption of the megasonic wave in the etching process can improve the characteristics of etch rate, etch uniformity, and surface roughness.

In this paper, the MAM (Megasonic Agitated Module) has been fabricated and the characteristics of wet etching with MAM have been improved during the etching process.

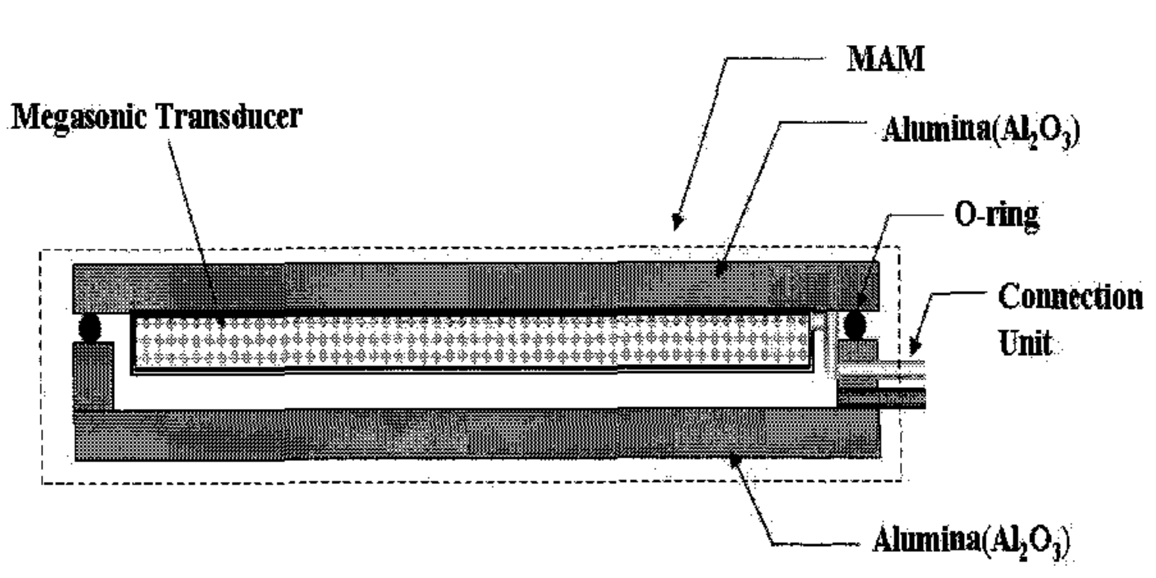

Fig. 1. Schematic view of MAM

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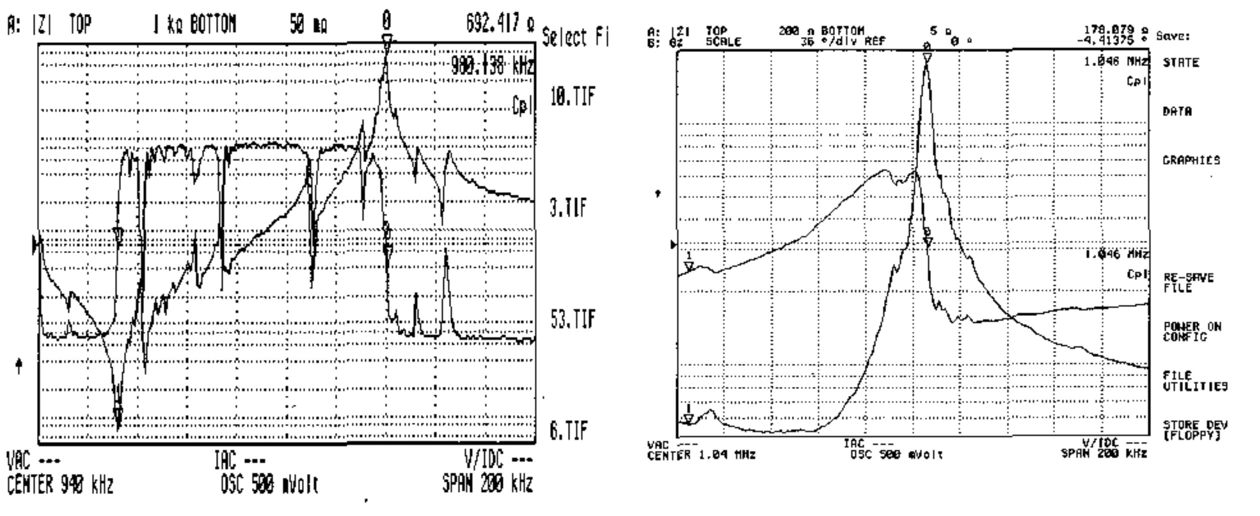
2. MAM (Megasonic Agitated Module)

2.1 Design of MAM

Figure 1 shows the schematic view of MAM (Megasonic Agitated Module) for the wet etching process. The MAM consists of 1MHz megasonic transducers, a packaging unit, and a connection unit. To transfer the acoustic energy uniformly, megasonic transducers have been arrayed on the plate. The roles of the packaging unit are to protect the megasonic transducers in the etching solution and to transfer the energy from the megasonic transducers into etching solution effectively. An alumina (Al_2O_3) plate is used as the packaging unit. In this case, a plastic plate such as PTFE, PEEK, and quartz are not suitable. The acoustic energy through a plastic plate decreases strongly. Quartz is a good material for transferring the acoustic energy but is not good for the etching process. On the other hand, alumina is a suitable material for both cases. In this paper, a 5 mm thick alumina plate is used to fasten the megasonic transducers. The connection unit consists of an electronic connection component and an air connection component. The electronic connection component supplies power to the megasonic transducers and the air connection component protects the megasonic transducers from etch solution leakage and breakdown by temperature during the etching process.

2.2 Fabrication and test of MAM

The thickness of the alumina plate is important in the transfer of uniform energy from the megasonic transducer effectively without distortion. In this paper, rectangular 1 MHz megasonic transducers are used. Alumina plates of 4.68 mm and 5 mm in thickness have been used. To optimize the thickness of the alumina plate, frequency characteristics have been measured with the impedance analyzer before and after adhesion in Fig. 2 and Fig. 3. With a 4.68 mm thick alumina plate, the anti-resonant frequencies of the megasonic transducer were 980 kHz and 1,046 kHz before and after adhesion, respectively. The difference in the anti resonant frequency is 66 kHz. In the case of a 5 mm thick alumina plate, the anti-resonant frequencies of the megasonic transducer were 980 kHz and 1,046 kHz before and after adhesion, respectively, and the difference of the anti resonant frequency was 38 kHz. When megasonic energy was transferred into D.I water from each transducer, there was the difference of acoustic distribution between two cases visually as shown in Fig. 4. In Table 1, the frequency characteristics are summarized. Because the difference of anti-resonant frequency before and after adhesion was smaller, the energy transfer was more uniform.



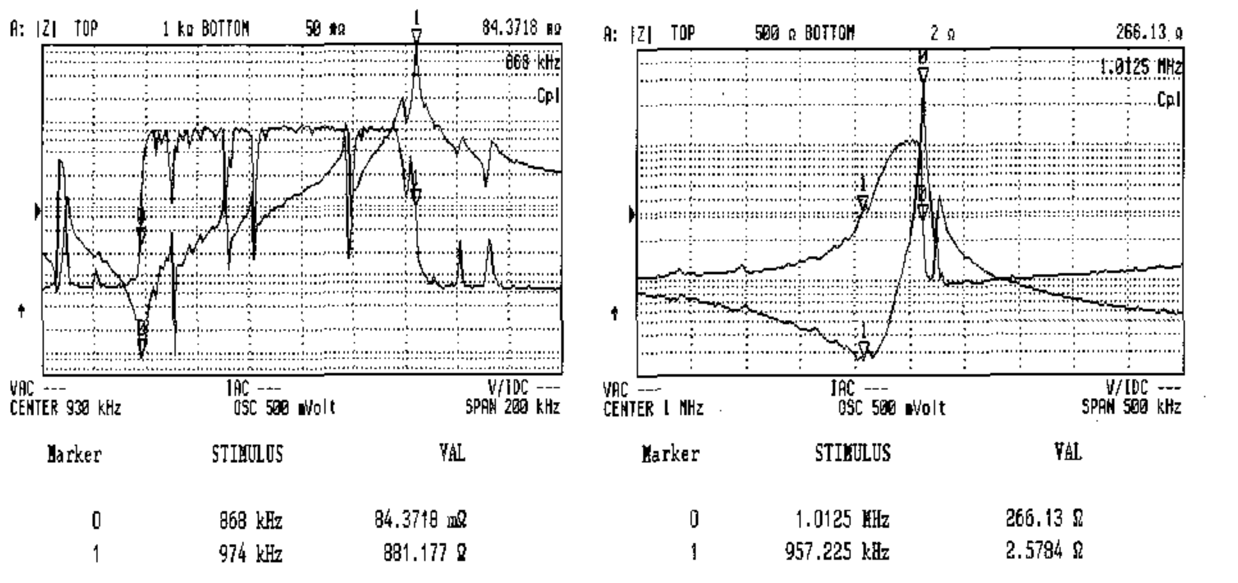
(a) (b)

Fig. 2. Frequency characteristics

(4.68 mm thick Alumina plate)

(a) before adhesion (anti resonant frequency : 980kHz)

(b) after adhesion(anti resonant frequency : 1,046kHz)



Marker	STIMULUS	VAL
0	868 kHz	84.3718 mΩ
1	974 kHz	881.177 Ω

Marker	STIMULUS	VAL
0	1.0125 MHz	266.13 Ω
1	957.225 kHz	2.5784 Ω

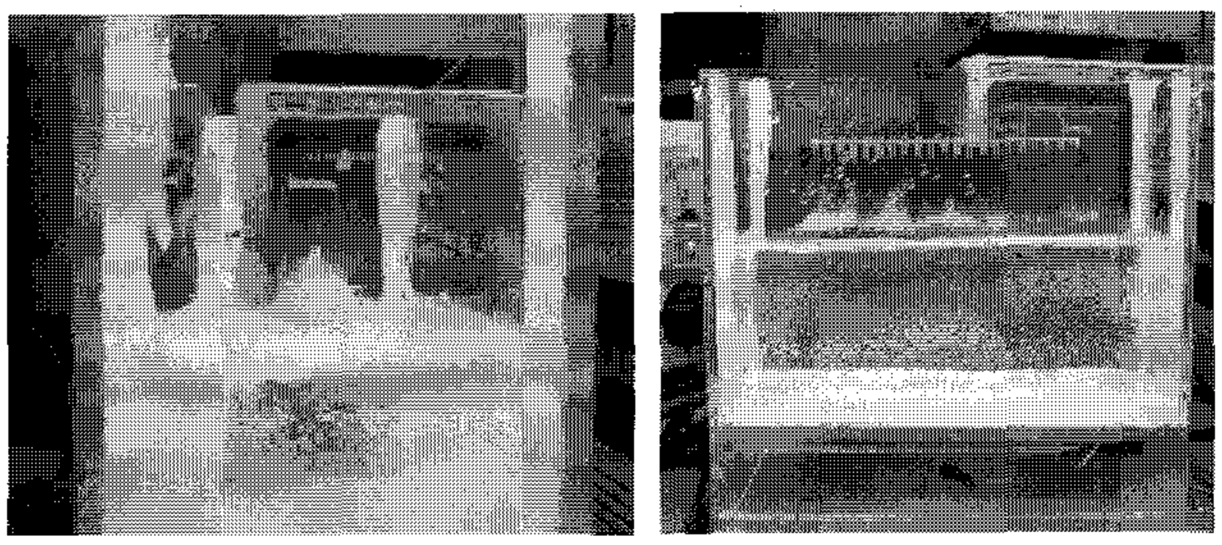
(a) (b)

Fig. 3. Frequency characteristics

(5 mm thick alumina plate)

(a) before adhesion (anti resonant frequency : 974kHz)

(b) after adhesion (anti resonant frequency : 1,012kHz)



(a) 4.68 mm thick (b) 5 mm thick

Fig. 4. Distribution of megasonic energy

Table 1. Frequency Characteristics of Megasonic Unit

Thickness		4.68 mm	5 mm
Anti-resonant Freq. (kHz)	Before	980	974
	After	1,046	1,012
Freq. Variation (kHz)		+66	+38
Distribution of Acoustic Energy		Non-uniform	Uniform

Figure 5 shows the fabricated MAM. To transfer the acoustic energy uniformly, megasonic transducers have been arrayed on the 5 mm thick alumina plate. Four megasonic transducers stick to a 5 mm thick alumina plate.

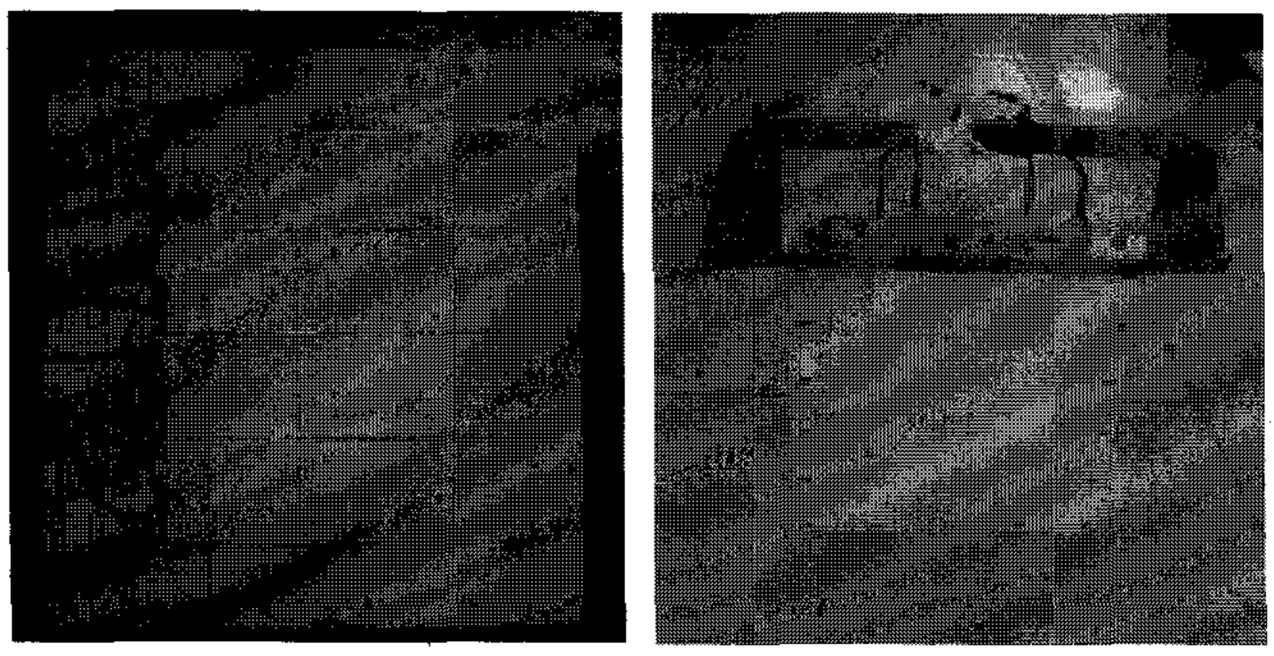


Fig. 5. MAM (Megasonic Agitated Module)

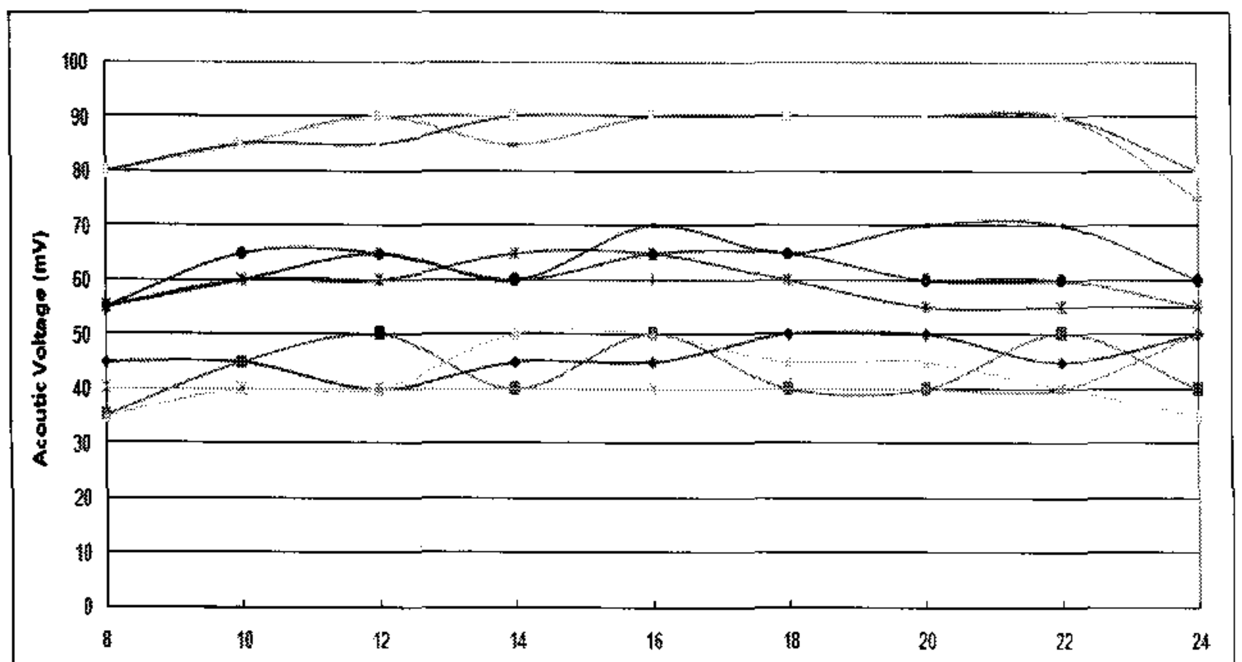


Fig. 6. Energy distribution near the surface of MAM

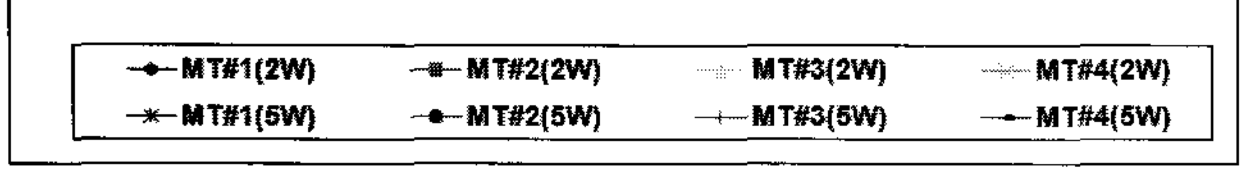


Fig. 7. Energy distribution along the distance from MAM

The anti-resonant frequency was 1 MHz after adhesion at each megasonic transducer.

The characteristics of the fabricated MAM were measured with an ultrasonic meter in the etch bath filled with D.I water. The output voltage from the ultrasonic meter is the relative acoustic energy. Megasonic energy is related to the removal energy of the bubble (hydrogen gas) on the etched surface during the etching process. Therefore, the uniform megasonic energy from MAM is an important parameter for the etching process.

The energy distribution near the surface of MAM is uniform in Fig. 6. At 10W, the uniformity is ± 4.1%. As the applied power increases, the acoustic voltage increases regardless of the location. Figure 7 indicates the distribution of energy along the distance from MAM in the etch bath. The energy remains uniform within ± 5%. In this case, the energy is not dependent on the distance because acoustic streaming occurs. As the applied power increases, the acoustic voltage increases regardless of the location.

3. Performance

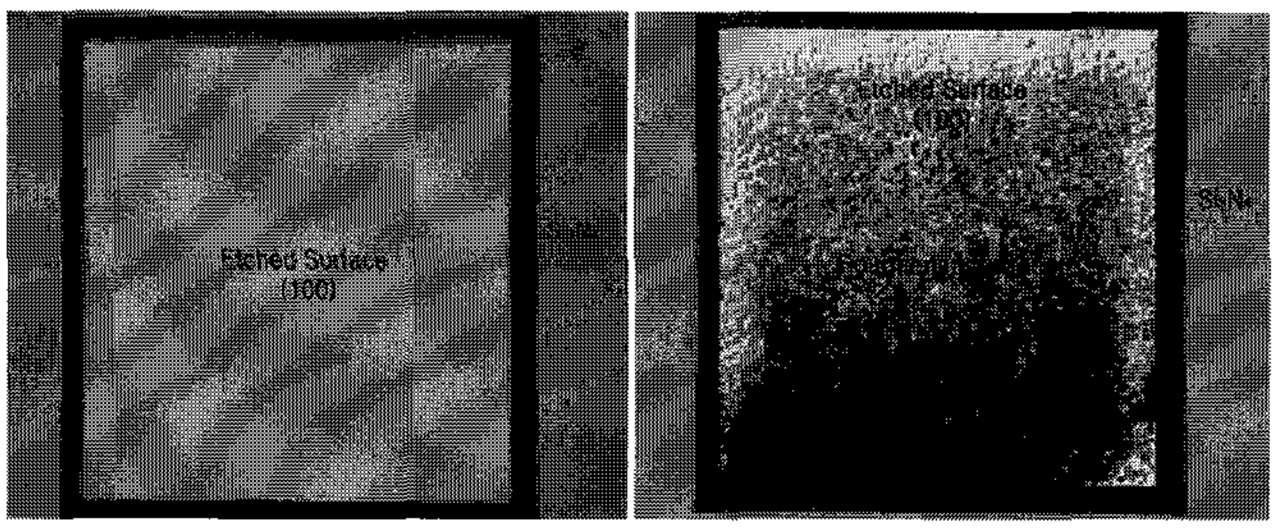
The performance of MAM has been evaluated by using samples of Si and glass. The starting material of the samples is a single-sided-polished p-type (100) 6 inch silicon wafer and a 4 inch quartz wafer. To etch Si and glass selectively, silicon nitride and poly-Si film were used as the etch mask.

Si samples and glass samples have been etched respectively in a 30 wt% KOH solution at 66 ℃ and in 10:1 HF solution at room temperature. The applied megasonic energy is 4.4 W/cm^2. The etched surfaces were inspected with a microscope and a scanning electron microscope (SEM) as shown in Figs. 8 and 9. A stylus profilemeter (Tencor Alpha step) and an atomic force microscope (AFM, Autoprobe-CP) were used for surface measurements. Table 2 summarizes the characteristics of the etching process through MAM. The characteristics with MAM are better than the characteristics without MAM. Especially, the etching uniformity becomes within ±1% in both the Si and glass samples. As revealed in Fig. 8(a) and Fig. 9(a), the etched surfaces are smooth and defect-free. With megasonic agitation during the etching process, bubbles on the surface can be easily exposed to the larger current of the solution with megasonic agitation. And then, the bubbles can be more easily detached. But, as in Fig. 8(b) and Fig. 9(b), the etched surfaces become very rough. The roughened surfaces probably originate from micromasking of hydrogen bubbles or silicate etch products. Figure 10 shows an AFM image of 37 ㎛ etched surface with megasonic agitation. The roughness is lower than 2 nm.

4. Conclusions

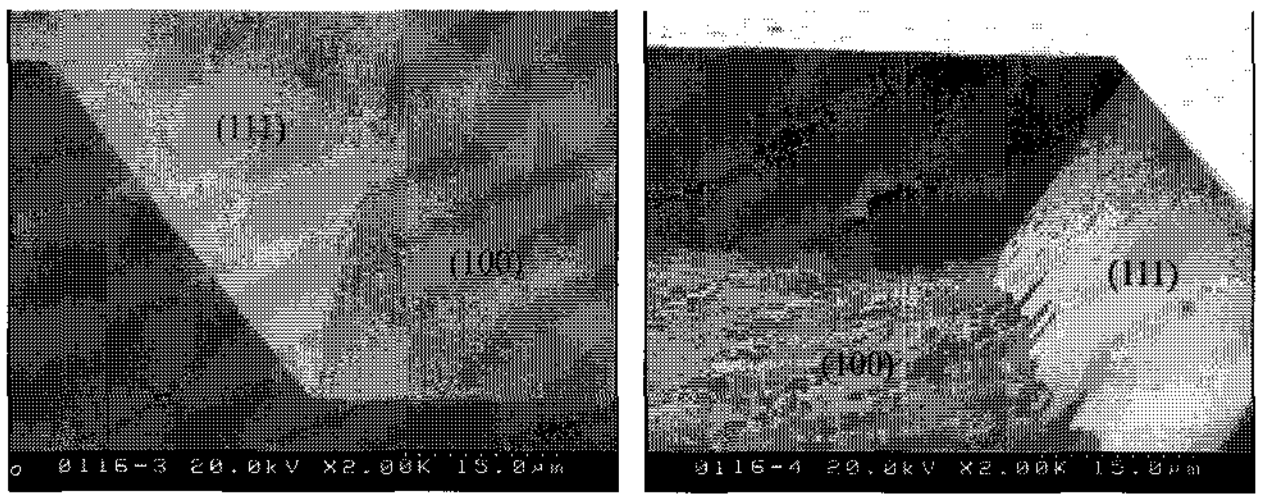
For the fabrication of MEMS or BioMEMS devices, it is essential that the etched surface is smooth and defect-free with high dimensional uniformity. In this paper, the fabricated MAM (Megasonic Agitated Module) improves the etching characteristics - etch uniformity, etch rate, surface roughness, and defect-free surface - by megasonic agitation. The characteristics of the system were evaluated by the wet etching of (100) Si in KOH solution and quartz wafer in HF solution.

Especially, the megasonic energy from MAM improved the roughness and the uniformity of the etched surface. In the near future, the effects of the incident angles of megasonic energy and the fabrication for high dimensional structured devices will be further evaluated.



(a) (b)

Fig. 8. The Microscope images of etched surface (Si)
(a) with megasonic agitation
(b) without megasonic agitation



(a) (b)

Fig. 9. The SEM images of etched surface (Si)
(a) with megasonic agitation
(b) without megasonic agitation

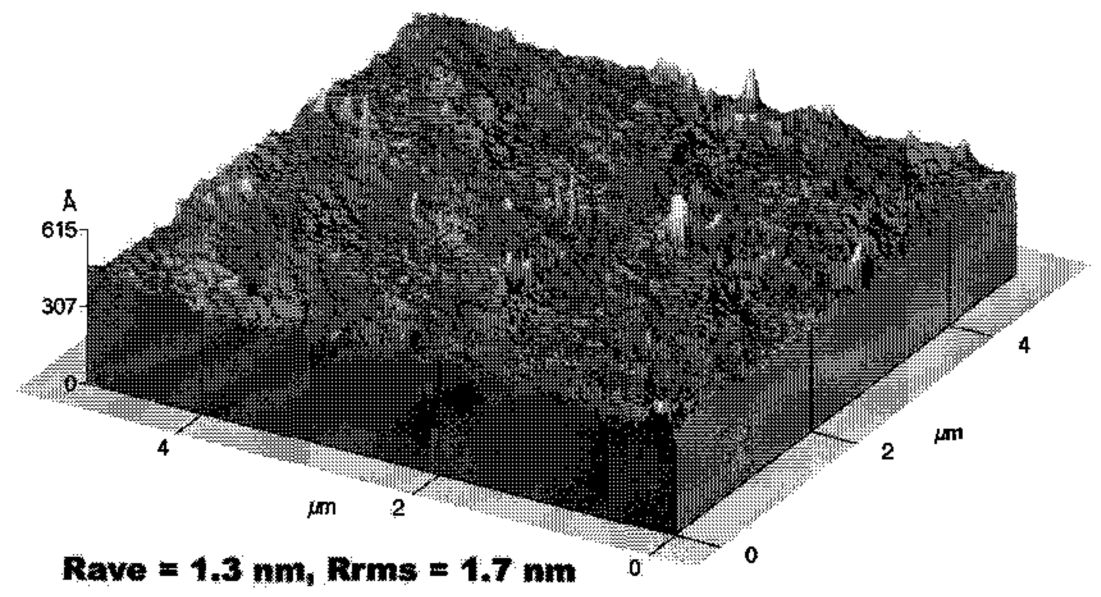


Fig. 10. The AFM image of etched surface with megasonic agitation

Table 2. Performance of MAM

			With Megasonic	Without megasonic
Si wet etch	Etch rate (um/min)		0.48	0.46
	Uniformity		± 1 %	± 21 %
	α-step	Rave	53 nm	770 nm
	AFM	Rave	1.3 nm	-
Glass wet etch	Uniformity		± 0.7 %	± 6 %
	α-step	Rave	1.5 nm	1.6 nm

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