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A Design of Anisotropic Wet Etching System to Reduce Hillocks on Etched Surface of Silicon Substrate

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Abstract**—**This research aims to design and build a wet etching system, which is suitable for anisotropic wet etching, in order to reduce etching time, to reduce hillocks on the etched surface (to reduce roughness), and to create a 45-degree wall angle (micro-mirror). This study would start by designing a wet etching system. There are four main components in this system: an ultrasonic cleaning, a condenser, a motor and a substrate holder. After that, an ultrasonic machine was modified by applying a condenser to maintain the consistency of the solution concentration during the etching process and installing a motor for improving the roughness. This effect on the etch rate and the roughness showed that the etch rate increased and the roughness was reduced.

Keywords**—**Anisotropic wet etching, wet etching system, Hillocks, ultrasonic cleaning.

I. INTRODUCTION

IN the electronics industry, chemical etching can be found in the fabrication of electronic devices, such as components of the head (slider) on the hard disk drive, etc. Because of the smooth etched surface [1], there are very few errors of wall angle and produced at a low cost [2]. The etched surface must be smooth (with low roughness) since the roughness of the etched surface is affected by the product's reliability. The anisotropic wet etching is an essential process in the fabrication of many components [3], and it is the etching process and accordance to the structure of the atomic arrangement which can control the direction and keep the etched surface smooth. Additionally, this technique can control the wall angle. However, the limitation of this technique is a long processing time which is not suitable for mass production. If the etching time is reduced, it can be applied in the actual process. However, the etching time reduction leads to hillocks on the etched surface which causes a high roughness.

The dimension of the wall angle is not only dependent on the direction of the crystal plane, but also depends on the mask alignment and the mask pattern. Normally, the 54.74 degree of wall angle is from (111) plane. It has the lowest etch rate which is called the etch stop [4]. Besides, there are other dimensions of the wall angle which are affected by new conditions such as a mask alignment, a high concentration of an etching solution and using a surfactant, etc.

The wall angles which are widely used in the electronics industry are 45 degrees and 90 degrees [5]. The 45-degree wall angle is always used as a micro-mirror for reflecting the light [1] as shown in Fig. 1 with an optical switching, an optical interconnecting [6], and a housing of a slider to increase hard disk drive capacity [7].

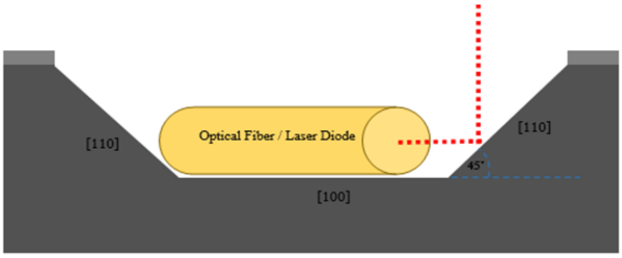

Fig. 1 An example of a light reflection

From the above mentioned, researchers have realised that there are essential problems in the electronics industry. Thus, the objectives of this research are to reduce the etching time and decrease the roughness of an etched surface by removing hillocks on the etched surface along with preserving a 45-degree wall angle.

II. LITERATURE REVIEWS

The design of the wet etching system is shown in Fig. 2. The main components consist of an ultrasonic cleaner, which has 40 kHz of frequency and 50 W of power, a condenser, a motor and a substrate holder.

Frequency waves from ultrasonic cleaners cause vibrations between the sodium hydroxide (NaOH) solution and H2 bubbles. This creates hydrogen bubbles on the substrate surface, called "Psudo-mask", which interferes with the chemical reaction between an etchant and the silicon atoms on the surface which affects a low etch rate and separates from the substrate surface [2], [7]-[10]. Hence, the sodium hydroxide bombards the substrate surface faster and this results in a higher etch rate.

The condenser was applied in the wet etching system in order to keep the concentration of the solution stable. Furthermore, it can prevent the evaporation of the vapor solution into the environment [8]. Many researches state that

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using rotation or stirring the solution during etching helps the etched surface remain smoother [5], [10]-[14]. Therefore, a motor was adopted together with ultrasonic cleaning by assembling a motor to the substrate holder as shown in Fig. 3. The vibration from ultrasonic cleaning and stirring from rotation created waves in the etching process and helped to remove H2 bubbles on the substrate surface faster. Because of this, the quality of the work surface can be improved [5], [10]-[14].

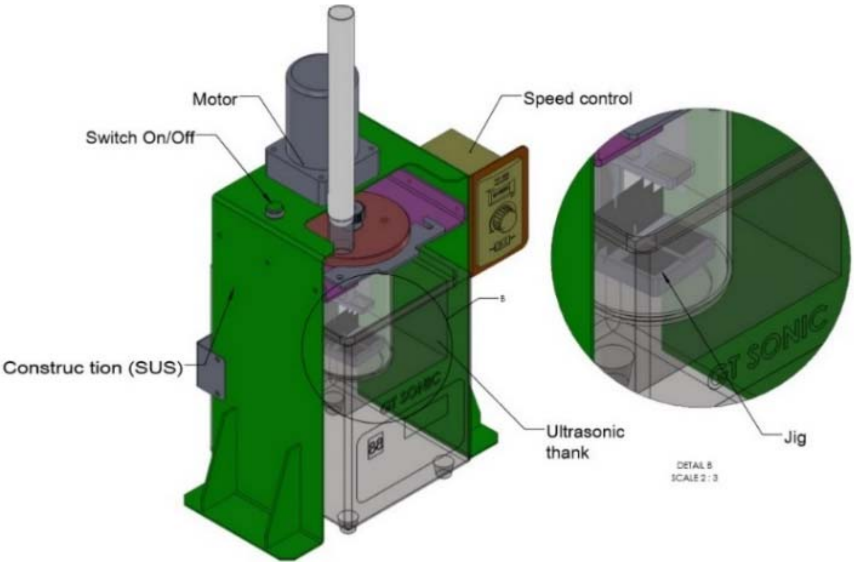

Fig. 2 The wet etching system design

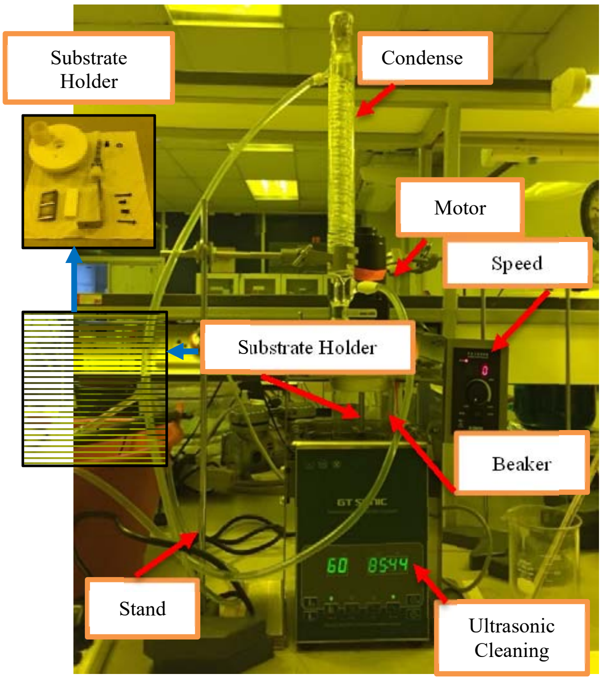

Fig. 3 The wet etching system with a main components description

The silicon substrates were etched in a solution concentration of 20% wt. sodium hydroxide (NaOH), isopropyl alcohol (IPA) 20 ml/DI, and 100 ml. of water at a 60° C solution temperature for 90 minutes per etch in a wet etching system (an ultrasonic wet etching unit appropriate for wet etching systems). In this work, the condition of the wet etching system, which was the soft mode of the ultrasonic, applied a motor speed of 5 rpms and a vertical orientation. This condition was determined by using the Design of Experiment (DOE) technique and the full factorial is applied in previous experiments. There were three responses in this research which were the etch rate, surface roughness (Sa) and wall angle. The experiments were performed and the etched substrates were measured. The surface roughness and etched depth were measured by a 3D Optical Microscope (Contour GT, Bruker). The wall angle and image, including the physical characteristics of the etched surface, were inspected by using an Optical Microscope and Scanning Electron Microscope (SEM).

III. DISCUSSION

The etching experiments were performed following the conditions as shown in Table I for the three replications and the experiment's results are shown in Table II.

After the implementation of the wet etching system in the experiment, the average etch rate was 202.06 nanometers per minute (nm/min) and the average roughness (Sa) was 19.604 nanometers (nm) or Ra was 9.23 nm. The roughness from this technique is lower than the target which was 15 nm (Ra). There are many researches which tried to reduce the roughness to less than 15 nm (Ra) as shown in Table III, so this became the target for this work. Then, the results from the wet etching system were compared with the results of the room temperature experiment (28 °C) and the results at 60 °C with IPA, which were from the previous experiments, and it showed that the etch rate was 13.57, 195.71 and 202.06 nm/min. The roughness of the work surface is as follows:

roughness on the surface height (Sa) was 670.68, 89.58 and 19.60 nm. The wall angle was 48.42, 45.54 and 45.05 degrees, respectively as shown in Table IV. From the results of the experiment, it was disclosed that the higher the etching temperature, the higher the etch rate and the etching time was reduced. The hillocks were decreased by adopting the ultrasonic with rotation and this created a low roughness as the hillocks were the cause of the roughness. Accordingly, the substrate has a smoother etched surface as shown in Fig. 4.

TABLE I
THE CONDITIONS OF THE WET ETCHING SYSTEM

Parameters (Unit)	Condition
Concentration of NaOH (%)	20
Solution Temperature (°C)	60
Time (minutes)	90
Ultrasonic Mode	Soft
Motor Speed (rpm)	5
Sample orientation	Vertical

TABLE II
THE EXPERIMENTS' RESULTS OF THE CONDITION: SOFT MODE, 5 RPM AND VERTICAL ORIENTATION

No.	Results			
	Etch Rate (nm/min)	Roughness (Sa) (nm)	Roughness (Ra) (nm)	Wall Angle (degree)
1	196.80	15.292	7.91	45.05
2	206.03	18.249	9.74	45.09
3	203.36	25.272	10.04	45.41
Average	202.06	19.604	9.23	

IV. CONCLUSION

According to the study, the etch rate was approximately increased by 3.24 percent and the roughness declined by 78.12 percent from the etching at 60 °C. This meant that the etching time could be decreased and the roughness could also be improved. For the wall angle, it can be controlled to be 45 degrees. In conclusion, the findings disclosed that the substrates etched in the wet etching system had a smooth etched surface and maintained a 45-degree wall angle. Moreover, the etching process occurred faster. Consequently, this technique is suitable for mass production and can be an alternative to further develop the manufacturing process in the electronics industry.

TABLE III
A REVIEW OF ROUGHNESS (RA) BY USING THE WET ETCHING TECHNIQUE

Researcher	Year	Country	Roughness (Ra) (nm)
Baum & Schiffrin [15]	1997	UK	10
Chen [16]	2002	China	66
Su et al. [17]	2005	Taiwan	14.29
Tang [18]	2009	Japan	20
Xu et al. [19]	2009	Australia	2.06
Dutta [20]	2011	India	9.4
Zubel [21]	2012	Poland	32.2
Prakash et al. [22]	2013	India	40
Pakpum & Pussadee [23]	2014	Thailand	701.48
Rola et al. [24]	2014	Poland	15.6
Chutani et al. [25]	2014	-	14
An [26]	2014	South Korea	7.83
Pakpum & Pussadee [27]	2015	Thailand	10.58
Fu et al. [27], [28]	2018	China	15.1
Savkina et al. [26], [29]	2018	Mexico	33

TABLE IV
THE WET ETCHING RESULTS AT ROOM TEMPERATURE (28 °C) AND NO ULTRASONIC, AT TEMPERATURE 60 °C WITH IPA AND NO ULTRASONIC AND THE WET ETCHING SYSTEM CONDITION

A Solution Concentration of 20% wt. Sodium Hydroxide (NaOH)			
Response/Etching Method	Room Temperature (28 °C)	Heating (60 °C) with IPA	The Wet Etching System
Etch Rate (nm/min)	13.57	195.71	202.06
Roughness (nm.)	Sa = 670.68	Sa = 89.58	Sa= 19.60
Wall Angle (degree)	48.42	45.54	45.05

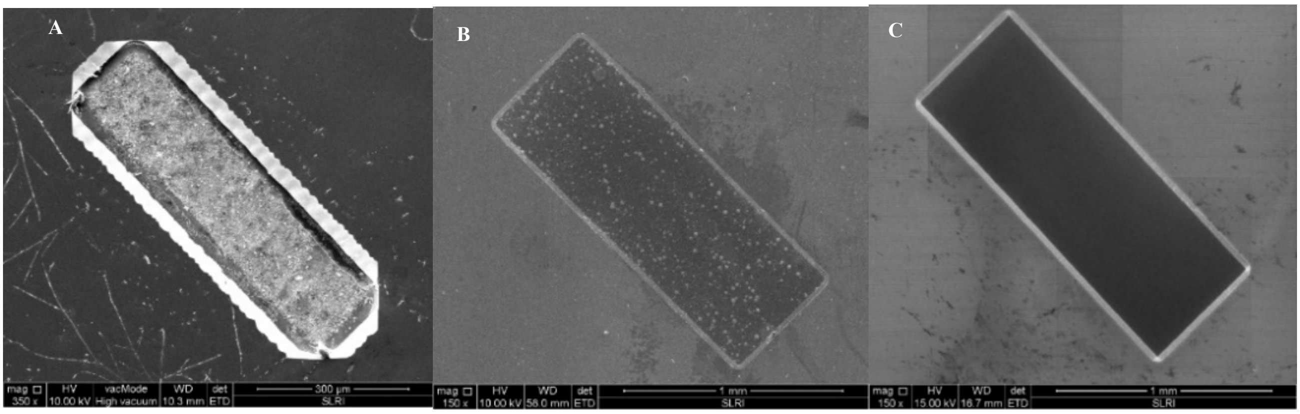

Fig. 4 Top view of SEM image (A) showing etched surface of NaOH wt.20%, room temperature (28˚C) and no ultrasonic (B) showing etched surface of NaOH wt. 20%, Temperature 60˚C and no ultrasonic (C) showing etched surface of the wet etching system condition

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