A Novel Etching Method of Silicon Nozzle Plate Manufacture for Monolithic Inkjet Print Head

Chi-Ming Huang, Chia-Tai Chen, Chou-Lin Wu, Lai-Chen Chen, Yung-Hsiang Wu, Ching-Yi Mao, and Chun-Jung Chen
K200/OES/ITRI, Industrial Technology Research Institute
Chutung, Hsinchu, Taiwan, R. O. C.

Abstract

The aim of this work is to develop a novel silicon etching method in the manufacturing of a silicon nozzle plate for a monolithic inkjet print head. The nozzle plate was etched by inductively coupled plasma (ICP) etching for orifice definition and wet etching for bulk surface definition. Depth of the wet etching process for thickness deviation of nozzle plate is less than 4 µm and the surface roughness is less than 40 Å. After the deep wet etching step with etching depth around 370µm and the ICP dry etching process, electrical characteristics of the driver circuits still work normally. The etching methods on silicon nozzle plate manufacture for monolithic inkjet print head in this study provide a better surface roughness of outlet surface of nozzle plate and keep the good thickness uniformity of nozzle plate.

Introduction

In recently years, there is a trend for MEMS (Micro-Electrical-Mechanical System) device to combine with the CMOS digital circuit, so that the device has high operation frequency and intelligent control, such as thermal bubble inkjet print head,[1] micro mirror[2,3] and other MEMS devices. In the MEMS application, anisotropic etching of bulk silicon is an important process for manufacturing microstructure. Therefore, anisotropic silicon wet etching with CMOS devices is an important technology.

In the high resolution and high operation frequency monolithic inkjet print head, the silicon etching process is following the MOSFETs device processes. In this study, we would like to present a novel silicon etching method, which integrates the dry etching method to form nozzles and the chemical wet etching method to define the thickness of the nozzle plate.

In this study, the influence on the characteristics of MOSFET device, the surface roughness on the etched surface and variation of thickness of nozzle plate (variation of the etching stop point) was discussed.

For anisotropic wet etching process, the most frequently used etchant is potassium hydroxide solution (KOH) (reference) and tetramethyl ammonium hydroxide (TMAH) solution. Especially for the TMAH solution, it has gained more and more attention because of its lower toxicity and the absence of metal ions. Recently, there is a need of flatness control after deep etching process such as pressure sensor and micro flow channel device. Although there have been many research about how to improve the etched surface quality,[4-7] we provide an etching mechanism whose surface quality is almost as better as a polished wafer.

For ICP etching, it is the large variation of the thickness on a wafer after deep etching that it is not an appropriate tool to control the thickness of the nozzle plate. For this reason, the ICP etching method is replaced with the wet etching method and only can it be used to drill through the wafer. In this study, we will compare the etching results of the thickness variation and the surface roughness between the ICP method and the wet etching method.

Experimental

(1) The wet Etching Process

The etching experiments were carried out on p-type (0.4~0.7 Ωcm) silicon wafer (100) with 400µm thickness. And it is double sides polished for depositing thin films on one polished side and deep wet etching on another one. The etching solution is composed of TMAH with 25% and IPA etc. For manufacturing the inkjet print head with driver circuits, we need a silicon membrane with 30µm thickness and good surface quality of the etched surface. So we set up an etching equipment (in figure 1) including a Teflon wafer holder, adjustable ultrasonic power, constant temperature water bath, and a motor to rotate the wafer holder. For good surface quality, the ultrasonic power is adjusted to a suitable power, and the temperature is controlled at 80°C. The masking layer is used a SiNx film with 7000Å, which is deposited on the back polished side by PECVD, and opened a series of 3.5mm × 4.5mm windows by lithography and RIE etching processes. After the wafer is handled well with the etching instruments, the uncovered windows will be etched by the TMAH etchant and the process will not be ended until the rest of the thickness is about 30µm. The results of the characteristics of the MOSFET device, the surface roughness, the etching variation of the thickness, and the reason to replace the ICP deep etching with the wet etching method will be discussed later.

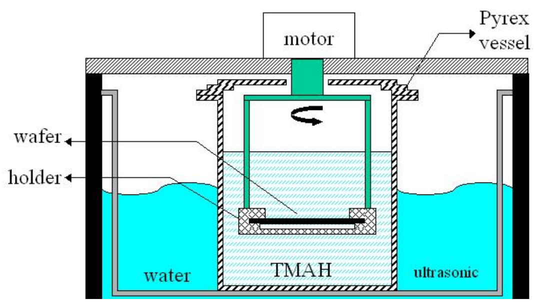

Figure 1. The equipment of chemical wet etching.

(2) The ICP Etching Process

After the thickness definition of the silicon plate, the next step is drill through the silicon wafer to define nozzle by using the ICP dry etching process. For a convergent nozzle shape, the etching process must etching from the top of the wafer. It is the suspended structure that results in the poor heat dissipation and the lower etching rate. Therefore, the thicker photoresist layer will be used to ensure the enough thickness from etching the other areas.

Results

(1) The Characteristics of the MOSFETs

In this study, the MOSFET devices and other thin film structures on the top surface of wafer, these devices and thin film structures should be protected in the etching solution at least fifteen hours under the process of etching rate is 24µm per hour.

The compare with characteristics of etching and without etching process of MOSFET device was shown in figure 2 and 3. In the figure 2, the characteristics curve of Id versus Vds is not have any difference between curve of etching and without etching. Furthermore, in the fig. 3, the threshold voltage of MOSFET is not variation after the etching process. And both of the turn on current and the off current (leakage current) are also not had any shift after the etching process. Following the results of figure 2 and 3, the etching process had not influence on MOSFET device.

(2) The Surface Roughness of the Etched Plate

In this study, we study on the different surface quality by using different of etching solutions, and compare with the chemical wet etching and ICP dry etching.

At first, the etched plate was etching by the ICP dry etching. As shown in figure 4(a). The etching surface of etched plate is very rough. Due to the poor surface roughness in nozzle plate surface, puddling effect will occur and affect on print quality.

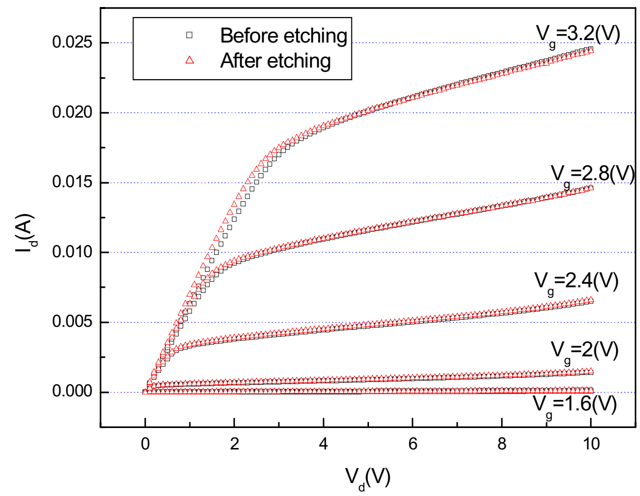

Figure 2. Vds versus Ids curve of MOSFET with etching and without etching.

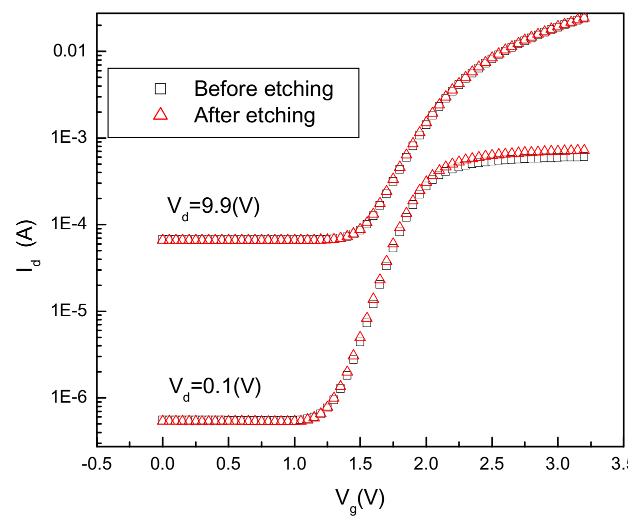

Figure 3. Turn on current and off current of MOSFET with etching and without etching.

Second, we used chemical wet etching to etch the plate surface of silicon nozzle plate and etching time is 7 hours. In this study, we changing the agitated etching method and adjusting the ingredients of the etchant to improve the surface topography gradually. Method 1 is the magnetic stirring method to perturb the KOH etchant (as shown in figure 4 (b)). Method 2 is used the ultrasonic method to agitate the KOH etchant (shown in figure 4 (c)) and method 3 is used the ultrasonic method to agitate the IPA+KOH etchant (as shown in figure 4 (d)). In the table 1, we measurement the roughness of the different etching method of etched plates by the α-stepper. The ultrasonic to agitate the IPA+KOH etchant method have best surface performance (surface roughness ~ 400 Å).

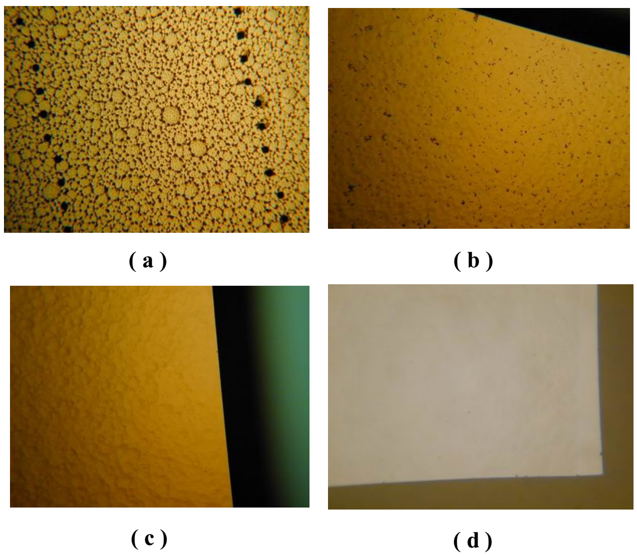

Figure 4. Photography of etched surface with various etching methods. (a) ICP dry etching (b) magnetic stirring + KOH wet etching (c) ultrasonic + KOH wet etching (d) ultrasonic + IPA + KOH wet etching

Table 1. Surface Roughness of Etched Surface with Various Etching Methods. (Unit: Å)

	1	2	3	4	5	Average
ICP etching	6160	6819	6173	6524	6734	6482
Magnetic stirrer	1095	1113	1138	1036	1269	1130
Ultrasonic	661	607	740	694	762	692
Ultrasonic + IPA	430	384	411	350	458	406

Figure 5. Pyramid-free etched surface.

On the basis of the experience in KOH solution, the etching solution is in place of TMAH solution. After a period of time for tuning the operation parameters and the ingredients of the etchant, the smooth and pyramid-free surface was achieved (in figure 5). And the roughness of Ra was obtained by using a surface profiler similar to the α-stepper. For examining the uniformity of the roughness, we measure 17 chips on wafer from one side to the other one. The value of roughness is from 34 to 45 Å and the results were shown in figure 6. If we use the AFM instrument to measure the roughness in a square area (5×5μm^2), the value of Ra is only about 5 Å because of the small scan area. If the scan area is 60 × 60 μm^2, the value of Ra is about 30 Å. (as shown in figure 7).

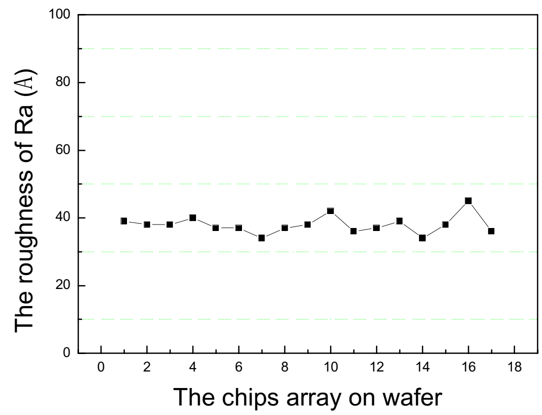

Figure 6. The roughness arrangement

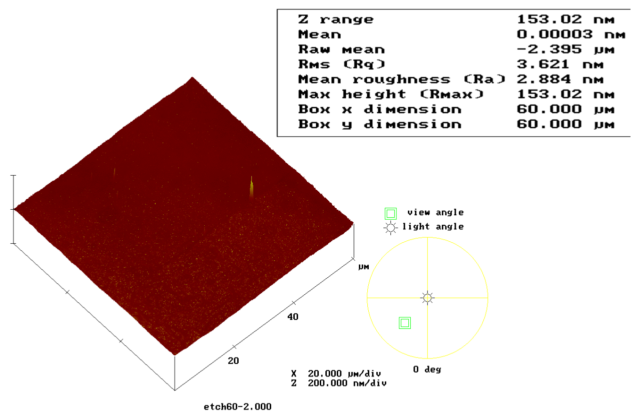

Figure 7. Surface roughness measurement by AFM. (scan area: 60×60 μm^2)

(3) The Variation of the Thickness Control

The next important issue is the thickness deviation after the deep etching (370 μm). In this study, it is compared with the dry etching and the wet etching methods. At first, the dry etching method was preferred to reduce the thickness of the nozzle plate to verify the work function of the back-shooter print head because of its convenience. However, in spite of the careful control of etching rate, the thickness of the nozzle plates were widely distributed from 50 μm to 25 μm, which target was 30 μm. In the chemical wet etching, the etching uniformity is better than ICP dry etching. The difference between the two etching methods was shown in figure 8. From the results of the wet etching method, the variation of the thickness is within 3.85 μm. It is easily to meet the specification of the metal nozzle plate and provide the uniform length of nozzle.

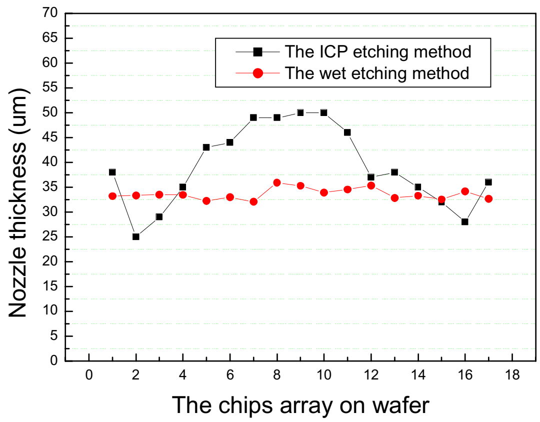

Figure 8. Compare with thickness of nozzle plate by ICP and wet etching method.

Conclusion

In this study, we provide a novel etching method to manufacturing the silicon nozzle plate of monolithic inkjet print head. This etching method provides a polish like etched surface and accurate etching stop point. Especially in the characteristics of MOSFET device, it is not have any influence by this etching method.

Although in the fabrication of nozzle plate, the cost of this method is higher than convention method of electroforming. This method could be providing a bench process of nozzle plate fabrication and mounting. Therefore, this method providing a new choice for monolithic inkjet head manufacturing.

Reference

1. David Westberg and Gert I. Andersson, "A Novel CMOS-Compatible Inkjet Head", Transducers 97, pp.813-816
2. Sjoerd Haasl, Frank Niklaus, and Göran Stemme, "Arrays of monocrystalline silicon micromirrors fabricated using CMOS compatible transfer bonding", Micro Electro Mechanical Systems, 2003. MEMS-03 Kyoto. IEEE The Sixteenth Annual International Conference on 19-23 Jan. 2003, Pages:271 - 274
3. C. Strandman, L. Rosengren and Y. Backlund, "Fabrication of 450 Optical Mirrors on (100) Si Using Wet Anisotropic Etching", IEEE Micro Electro Mechanical Systems, Amsterdam, Netherlands, 1995, PP.244-249
4. C. Mihalcea, "Improved anisotropic deep etching in KOH-solutions to fabricate highly specular surfaces", Microelectronic Engineering, 57-58, 2001, 781-786
5. R. Divan, "Limiting roughness in anisotropic etching", Semiconductor Conference, 1997. CAS '97 Proceedings, 1997 International , Volume: 2 , 7-11 Oct. 1997, Pages: 553 - 556 vol.2
6. H Schröder, "Micropyramidal hillocks on KOH etched {100} silicon surfaces: formation, prevention and removal", J. Micromech. Microeng. 9, 1999, 139-145
7. Jing Chen, "Study of anisotropic etching of (100) Si with ultrasonic agitation", Sensors and Actuators. A , 2002, 152-156

Biographies

Chi-Ming Huang joined the printing Technology Division of OES/ITRI in 2002. He received his M.S. degree from Institute of Applied Mechanics of National Taiwan University, Taipei, Taiwan. His current research includes MEMS technology, thin film process and the study of monolithic inkjet head.

Chia-Tai Chen joined the printing Technology Division of OES/ITRI in 1999. He received his M.S. degree from Institute of Material Science and Technology of National Tsing Hua University, Taiwan. His current research includes MEMS technology, the design of inkjet head and the study of monolithic inkjet head.

Chou-Lin Wu joined the Printing Technology Division of OES/ITRI in 2001. He received his M.S. degree from Department of Mechanical Engineering of National Central University, Taoyuan, Taiwan. His current research includes MEMS technology, thin film process and print head testing technology.

Lai-Chen Chen joined the ITRI in 1987 and focus on the clean room engineering. He was joined the Printing Technology Division of OES/ITRI in 2000. He has researched print head process and test equipment for several years.

Yung-Hsiang Wu received his M.S. degree in Institute of Mechanical Engineering from National Chung Hsing University, Taichung, Taiwan, in 2002. He joined the Printing Technology Division of OES/IRTI in 2002. His current research includes MEMS technology, inkjet process for industrial application, and the study of monolithic print head.

Ching-Yi Mao received his M.S. degree in Institute of Electronic Engineering from National Tsing Hua University, Hsinchu, Taiwan, in 1999. He joined the Printing Technology Division of OES/ITRI in 2000.

His current research includes thin film process, ink jet print head chip design and failure analysis of ink jet head He is the section manager of Print Head Development and Manufacturing Section in OES/ITRI.

Chun-Jung Chen joined the Printing Technology Division of OES/ITRI in 1990. He received his M.S. degree from Department of Power Mechanical Engineering of National Tsing Hua University, Hsinchu, Taiwan. His interest lies in electro-photography, media handling of printer and magnetic damper. He is the department manager of Printing Device Department in OES/ITRI.