Sensors and Materials, Vol. 14, No. 8 (2002) 407–413
MYU Tokyo

S & M 0500

LETTER

Anisotropic Etching of <100> Silicon Using a Novel UV-HNA Technique

K. Zandi, S. Haji, S. Mohajerzadeh,* K. Naeli, M. Mozafari
and E. Asl Soleiman

Thin Film Laboratory, Department of Electrical and Computer Engineering
University of Tehran, Tehran, Iran

(Received June 28, 2001; accepted September 4, 2002)

Key words: anisotropy, ultraviolet, HNA solution, orientation, silicon

Anisotropic etching of <100> silicon is typically accomplished using an alkali-OH solution such as potassium hydroxide (KOH) where (100) faces are preferably etched relative to (111) faces, which are exposed. In the technique proposed in this paper, silicon is anisotropically etched under ultraviolet exposure in a solution containing hydrofluoric/ nitric/ acetic acids (HNA). This solution is typically used for polishing silicon as well as for etching polysilicon due to its isotropic etching property. In this technique, which we refer to as UV-HNA, the etching of silicon is enhanced in the direction determined by UV exposure. A mixture of HF/HNO_3/CH_3COOH with a relative composition of 1:15:5 seems suitable for revealing (111) planes with an etch rate of 10 μm/h at 35°C. Etch rates as high as 60 μm/h can be achieved using a higher concentration of HF acid in HNA solution. In the latter case the etching is less anisotropic and mask undercut is observed.

1. Introduction

Anisotropic etching of <100> silicon is a crucial step in the fabrication of bulk micromachined devices. The fabrication of gas flow meters, pressure sensors, thermocouple-based infrared arrays and gas sensors lends its success to the accurate definition of membranes on silicon chips.(1,2) Conventional micromachining of silicon is carried out using alkali solutions,(3–5) and compatibility with CMOS fabrication is achieved with

---

*Corresponding author, e-mail address: smohajer@sunl.vlsi.uwaterloo.ca

TMAH.(6) In all cases hillocks are present at the base of etched cavities, which undermine surface smoothness.(7–9) The smoothness appears to be enhanced by the addition of sufficient quantities of isopropyl alcohol into the solution.(10)

In this letter, we report anisotropic etching of <100> silicon by means of an external source of energy, i.e. ultraviolet (UV) illumination. The etching solution is a combination of hydrofluoric, nitric and acetic acids. This mixture is typically used for isotropic etching of silicon and polysilicon, as well as surface polishing. In the presence of UV illumination, however, the etching process is dramatically altered in favor of the directional removal of exposed silicon atoms, providing a form of anisotropic etching. The concentration of hydrofluoric acid in HNA solution is a crucial factor in terms of etching parameters such as the etch rate and selectivity of crystal orientations.

In the following sections, we describe the etching arrangement along with some of the early results obtained in this study. We first review the isotropic etching behavior of HNA followed by the effect of UV exposure on the etching process. Although the mechanism of etching is not yet fully understood, our initial understanding of the etch process is propounded. While a volume mixture of 2:15:5 of HNA solution has a high etch rate, the evolution of (111) planes is more significant using a volume solution with 1:15:5 composition. The HF and nitric acids used here are aqueous solutions of 41% and 65% in water. By proper selection of different solution compositions, it may be possible to achieve vertical craters or trenches with an insignificant mask undercut.

2. Experimental

Figure 1 depicts the experimental setup used in this study. The etching system consists of a non-glass container placed in a controlled temperature basin. The system features a UV light source equipped with a back reflecting mirror on top of the container. For this experiment we have used 1 Ωcm N-type silicon wafers. The <100> silicon sample is held close to the surface of the solution by means of a Teflon holder, which also protects the back surface of the sample from being exposed to chemicals (Fig. 1). The temperature of the etchant is in the range 35 to 50°C. Due to the energy transferred from the UV source to the solution, there is a rise in the temperature of the solution, particularly after extended operations. The UV source used in this setup is a 400 W mercury high-pressure UV lamp, whose intensity is 15 mW/cm^2 at a wavelength of 360 nm and at a distance of 10 cm from the sample surface. The sample was held close to the surface of the solution for good UV exposure. The setup was vented by air or nitrogen to keep the lamp cold and to prevent hydrogen from burning close to the UV lamp. Also, a silicon-nitride-coated Corning glass lid was placed between the UV source and the solution to prevent the extreme heat created by the lamp from being transferred to the solution.

The masking of the exposed surface is achieved by means of a bilayer of Si_3N_4 and Cr films deposited using consecutive sputtering in a multi-target-sputtering unit. In all the experiments conducted in this study, this bilayer has a total thickness of 1.8μm, consisting of equal-thickness deposited films. Chromium is important to prevent UV exposure of unwanted areas. Also it is not significantly affected by the HNA solution and can be used for long etching periods. Figure 2 shows an isotropic profile indicating the mask undercut,

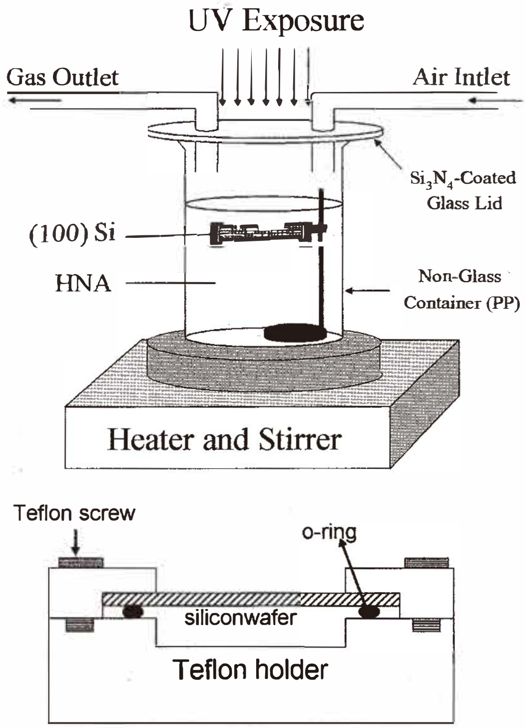
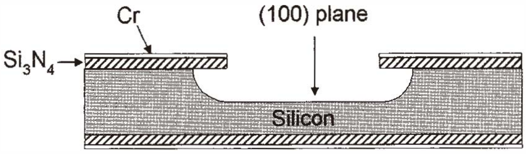
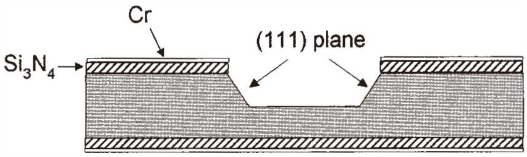


Fig. 1. Experimental setup used for this study. The figure at the bottom shows the Teflon holder used.



Isotropic Wet Etching



Anisotropic Wet Etching

Fig. 2. Schematic isotropic and anisotropic etching of Si samples, illustrating the mask undercut. A bilayer of C/SiN is used as the mask.

as well as the anisotropic etching in the presence of UV illumination. In all cases the back surface is physically protected from the etchant.

3. Results and Discussion

Results for two of the samples prepared in this study are presented in Fig. 3. For both specimens, a solution containing a mixture of (1:15:5) of HNA components has been used. Figure 3(a) illustrates the isotropic etching of a silicon wafer in HNA solution without UV exposure. As indicated in the etch profile, the etching undercut leads to a suspended Cr masking layer. Figure 3(b) depicts the etch profile of a similar sample etched under UV exposure at a temperature of 35°C. Planes with (111) orientation are evident from this figure and no significant undercut of the masking layer is observed. The depth of the crater formed in the latter case is around 70 μm and duration of etching is around 7 hours, yielding an average etch rate of 10 μm/h. Also in Figure 3(c) one can see the SEM micrograph of the cleaved Si sample corresponding to Fig. 3(b) where etching has been performed under UV illumination. The (111) surface is evident in this figure and the mask edge remains sharp and intact.

Figure 4 illustrates the anomalous behavior of the emergence of (110) planes, which is a characteristic not usually observed in OH-based systems. The reasons for this anomalous behavior are presently unclear, although further investigations on this unique characteristic are underway. Perhaps the freshness of the solution at the initial stages of the reaction is a factor; fresh solutions are more reactive, rendering the etching process less sensitive to crystal planes and thus providing the vertical anisotropy induced by the UV illumination. As time elapses and the solution becomes less reactive, a crystal orientation with stronger bonding energy is exposed. Also, the variation of solution temperature during etching could be partly responsible. Mask undercut is observed for this sample with a value of about 5 to 8 μm.

Shown in Fig. 5 is a sample prepared using a (2:15:5) HNA volume fraction solution with a higher concentration of hydrofluoric acid. The temperature during the etching process is maintained at 35°C. An etched pit with a depth of 180 μm is observed. Here, the average etch rate is 80 μm/h. Although the shape of the crater is non-crystallographic, as compared to previous samples, the etch rate in the direction of UV exposure is higher than that in the lateral directions. The mask undercut observed in this sample is around 20 μm. The addition of hydrofluoric acid to the solution leads to a more isotropic etching behavior with the etch rate increasing from 10 μm/h to 80 μm/h. The observed etched profile suggests an etch rate in the vertical direction which is about 8 times higher than that in the lateral directions.

4. Conclusions

In summary, this paper reports preliminary experimental results, which demonstrate that we have successfully manipulated the etching chemistry of silicon by HNA solutions by means of external UV illumination. While the etching of silicon in HNA is isotropic, anisotropic etching is achieved under UV illumination. The addition of HF to the solution

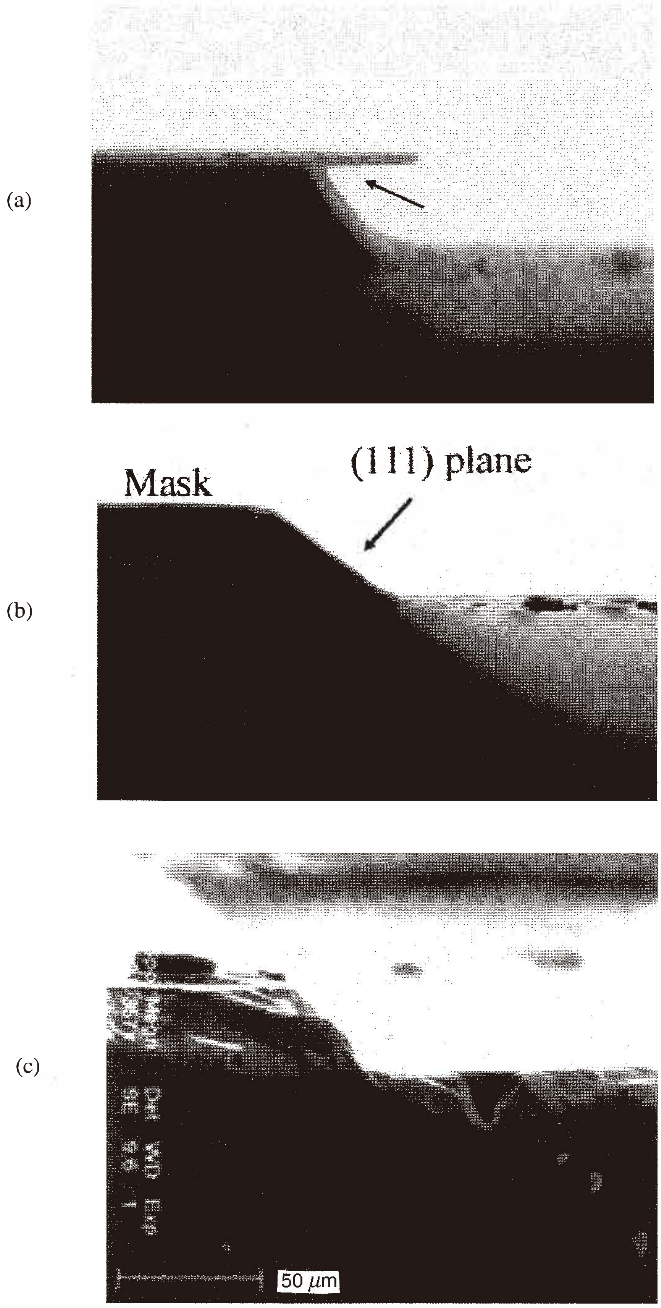


Fig. 3. Etching of (100) Si in HNA (1:15:5), (a) without UV, (b) with UV exposure. (c) SEM micrograph of the sample in (b).

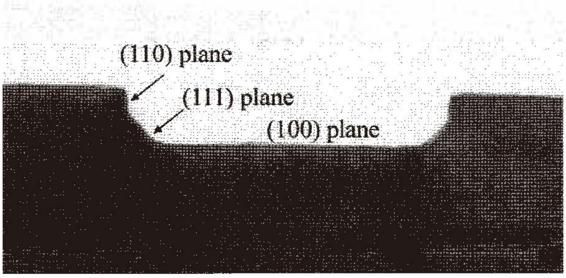


Fig. 4. Emergence of (110) planes in the anisotropic etching of (100) Si under UV exposure in (1:15:5) HNA.

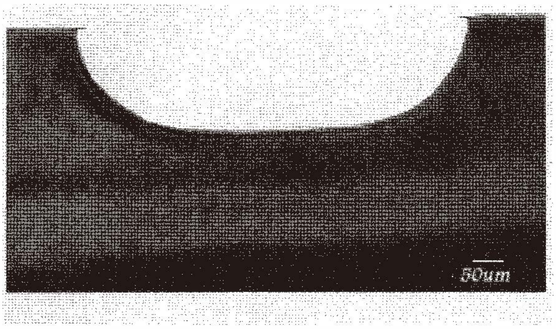


Fig. 5. Etching of (100) Si under UV exposure in (2:15:5) HNA showing the mask undercut.

increases the etch rate, at the expense of lower anisotropy. It is believed that etching with appropriate composition of HF may lead to the emergence of (111) planes with little mask undercut. Through a more critical study of the underlying etch chemistry, one may achieve straight and vertical trenches in silicon, which in turn allows a significant reduction in the size of the back surface mask opening as compared with ordinary OH-based systems. A more thorough investigation of the effect of light intensity, the etch solution temperature and composition is currently in progress.

Acknowledgments

This work has been supported by a grant from the Faculty of Engineering, University of Tehran and partially by the Institute of Electrotechnique of the University of Tehran, Tehran, Iran. The comments given by Prof. A. Nathan from University of Waterloo, Canada are sincerely acknowledged.

References

1 K. E. Bean: IEEE Trans Electron Devices ED-25 (1978) p. 1158.

2 T. Fukuda and W. Menz: Micro Mechanical Systems, Principles and Technology, Handbook of Sensors and Actuators. (Elsevier, 1998) Vol. 6.

3 H. Seidel, L. Csepregi, A. Heuberger and H. Baumgartel: Journal of Electrochemical Society **137** (1990) 3612.

4 V. Lehmann and H. Foll: Journal of Electrochemical Society **137** (1990) 653.

5 G. T. A. Kovacs, N. I. Maluf and K. E. Petersen: Proceeding of the IEEE Vol. 86, no. 8. (1998).

6 O. Tabata, R. Asahi, H. Funabashi, K. Shimaoka and S. Sugiyama: Sensors and Actuators A **34** (1992) 51.

7 P. M. M. C. Bressers, J. J. Kelly, J. G. E.Gardeniers and M. Elwenspoek: Journal of Electrochemical Society **143** (1996) 1744.

8 S. A. Campbell, K. Cooper, L. Dixon, R. Earwaker, S. N. Port and D. Jschiffirin: J. Micromech. Microeng. **5** (1995) 209.

9 K. Ohwada, Y. Negoro, U. Konaka and T. Oguchi: Proc. IEEE Micro Electro Mechanical System Conf., Amsterdam, The Netherlands, Jan. 29–Feb. 2 (1995) p. 100.

10 J. B. Price: Semiconductor Silicon, eds. H. R. Huff and R. R. Burgess and N. J. Princeton: Journal of Electrochemical Society (1973) p. 339.