Chemical etching of Si-p-type wafers using KOH

Intessar K.abd, Abtisam K.al-Bity, Ahmed A.Esmael, Salah A. Bayat

College of Education / Al –Raze

Abstract

In this paper wet etching was used to etch Si-wafers by chemical solution KOH at different temperature and concentrations, the results showed: - decreasing of the etching rate at higher KOH concentrations producing smooth surface, on the other hand by observing the etching rate as a function of temperature it shows that the etching rate increases with the increase of the etching temperature producing roughness surface.

الخلاصة

في هذا البحث تم استخدام الحفر الرطب لعينات السيليكون بأستخدام المحلول الكيميائي KOH بأختلاف التراكيز ودرجة الحرارة ، لقد تم الحصول على معدل حفر قليل بأستخدام التركيز العالي للمحلول KOH مع ملاحظة نعومة سطح العينات المحفورة ، كما لاحظنا حصول زيادة في معدل الحفر لعينات السيليكون عند زيادة درجة حرارة المحلول KOH مع ملاحظة خشونة حاصلة على سطح العينات المحفورة .

Introduction

Wet etching technologies can produce complicated Micro-Electro-Mechanical Systems (MEMS) structures onto a Si wafer with a batch process by combing a photolithography. Generally, MEMS structures are produced by three steps, a thin film deposition, a patterning of the film defining the etching region by the photolithography, and the etching to create the 3D structure with Si wafer. The etching process, especially anisotropic wet one, becomes a key technology and requires know-how in the fabrication of MEMS.[1]

Two alkaline solutions, potassium hydroxide (KOH) and tetramethl ammonium hydroxide (TMAH), are normally used as the etchants for the anisotropic wet process. The former has an excellent uniformity and reproducibility, but not-compatible with an electrical circuits. To overcome this drawback, TMAH used in the development process in photolithography became to be applied in the anisotropic wet etching. Generally, the usage of KOH becomes the best choice in the case of that the engineers simply produce the micro-structures onto the Si wafer. Therefore, the etching characteristics by KOH are focused in this study. The detail information of the differences between the two solutions is described in. [3]

The etching rate by KOH strongly depends on the crystallographic orientations of the Si material. That is the why we are able to produce the 3D micro-structure by the KOH anisotropic wet etching. The overall chemical etching reaction by alkaline solution is given by [3].

$$Si + 2OH^- + 2H_2O \rightarrow SiO_2(OH)_2^{2-} + 2H_2$$

Silicon reacts with water and an OH^- ion and produces hydroxide ion and hydrogen gas bubbles. The dependency of the etching rate on the crystallographic orientation said to be the differences of the number of dangling bond at the surfaces and of the atomic step structures [4-5]. However, the mechanism of the orientation dependency remains inconclusive and still mystery in the present.

Properties of ER in silicon are highly anisotropic. Hence, single crystal silicon has different mechanical characteristics with respect to orientation. In order to understand basic mechanism of anisotropy in silicon crystal, one should understand activation energy. Activation energy of a reaction is the amount of energy needed to start. The rate of reaction depends on the temperature at which it runs.

ER and surface morphology are macroscopic results (James, 1998). As the moving surface reaches a steady state it seem to fixes etch rate. As a result, final shape of the etched wafer depends on relative etching speed along the crystallographic planes. Etch rate (ER) depends on average of the microscopic activation energy and existence of fluctuation in fraction of particles at a fixed temperature i.e. on *pi* and *T* (Gosalvez and Nieminen, 2003) as:

The chemical mechanism behind it is removal of silicon atom in KOH solution takes place in two steps (Wenspoek and Jansen, 1998; Ashcroft and Mermin, 1988).

First, four electrons are affected in bulk silicon

$$Si + 4(OH)^{-} \text{-----} Si(OH)_4 + 4e^{-}$$

In second step, the electrons are released back into the solution accordingly

$$4e^{-} + 4H_2O \text{-----} 4(OH)^{-} + 2H_2$$

Products in first step *Si (OH)*$_4$, is supposed to soluble in water. But actually, *Si (OH)*$_4$ is decompose into water and silicon-dioxide, as a result of supplied thermal energy and hence there is removal of silicon atom with release of oxygen gas. The probability of removal of particular silicon atom depends on temperature and microscopic activation energy.

Experimental

Wet chemical etchants by two case first, by immersing the samples into bath of solution ($KOH + H_2O$) with the change of the concentrations at room temperature for 30 min. Second, by immersing the samples into bath of solution ($KOH + H_2O$) with the change of the temperatures for 30 min. Several types of Si wafers (2-2.5 cm^2) were obtained from 3-inch p-type standard wafers

Results and Discussion

The rate-limiting factor in KOH etching said to be changed with the change of the concentration. That is, the chemical reaction happened on the Si surface limits the overall systems in the case of the high concentration. On the other hands, the system is dominated by the diffusion of reacting species and reaction products at low concentration.

The etching rate in the case of higher KOH concentration decrease, because the high Potassium is an extremely fast-diffusing alkali metal which will have disastrous effects on the performance of any electronic device it should come into contact with any wafers contaminate. Thereby, the throughput in the etching process will be down .The etching rate by KOH becomes the maximum around the border of 10 wt. %, the results is shown in Fig.1.

The etched surfaces become smooth with the increase of the KOH concentration as show in Fig.3-a. The etching-rate- and the surface-roughness-dependency on the orientation by KOH etching are described in [6] and [7], respectively.

The anisotropic wet etching is depend on an Arrhenius equation [4]. It means that the etching rate drastically increases with the maximally increase of the etching temperature. Results are displayed in Fig.2 which tells about ER is a linear function with temperature. The temperature of the system increases, the number of molecules that carryout enough energy to react also increase, this means the molecules move faster and therefore collide frequently. The proportion of collision that can overcome the activation energy for the reaction increases with temperature. Temperature is a factor of surface roughness as show in Fig.3-b. The quantitative characterization of the activation energy with temperature follows an Arrhenius nature (James, 1998)

Conclusions

- By using low KOH concentration we obtain an etching rate greater than etching rate for high KOH concentration with a smooth surface of Si wafers.
- The etching rate increase with the increase of the etching temperature with a roughness surface of Si wafers.

References

1. M. Shikida ,"Overview of KOH etching in microfabrication of MEMS structures" Forum for MEMS Technology, Sensors and Systems,2010.

2. M. Shikida, et al., "Differences in anisotropic etching properties of KOH and TMAH", Sensors & Actuators: A80, 2, 179-188, (2000).

3. H. Seidel, et al., "Anisotropic etching of crystalline silicon in alkaline solutions, 1. Orientation dependence and behavior of passivation layers, J. Electrochem. Soc., 137, 3612-3626, (1990).

4. M. Elwenspoek, et al., "Silicon micromachining", Cambridge studies in semiconductor physics and microelectronic engineering, Cambridge University Press, (1999).

5. Y. Gianchandani, et al., "Comprehensive microsystems", 1, 183-215, (2007).

6. K. Sato, et al., "Characterization of orientation dependent etching properties of single-crystal silicon: Effect of KOH concentration", Sensors & Actuators: A64, 87-93, (1998).

7. K. Sato, et al., "Roughening of single-crystal silicon surface etched by KOH water solution", Sensors & Actuators: A 73, 1-2, 122-130, (1999).

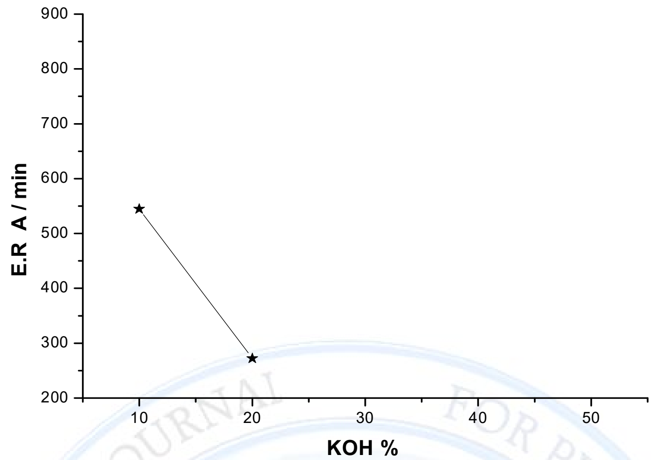

Fig.1. etching rate vs. KOH concentrations

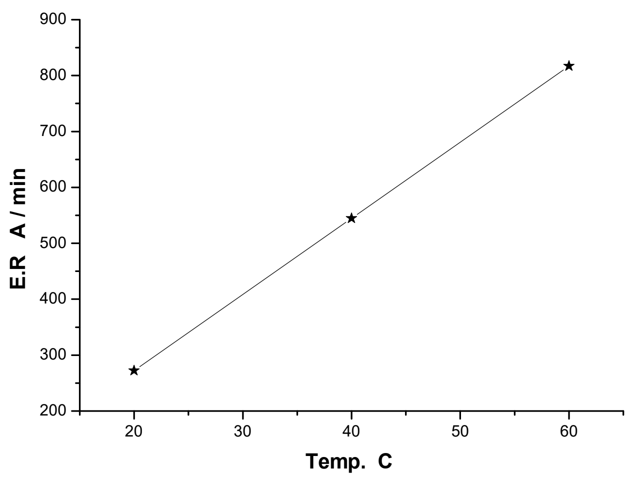

Fig.2. etching rate vs. temperature

a- a smooth surface

b- a roughness surface

Fig.3. Si wafers of surface which etched by

a. KOH of different concentrations.
b. KOH of different temperatures.