Etching Behavior of KOH at the Convex Corner

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Abstract – *Anisotropic etchants produce a hole consisting of (100) and (111) planes onto a (100) silicon wafer through a rectangular opening in a mask. In this case the upper corner of the hole is sharp. If the whole surface is etched by maskless wet anisotropic etching process the upper corners become rounded. The corner round up is essential for example in case of realization of wafer through – hole interconnects. The sharp corner increases the risk of a photoresist break up which is used for patterning of the metal underneath. Therefore it is important to know the etching behaviour of the most common anisotropic etchants – KOH and the shape of the rounded convex corners. This paper explains the rounding effect of KOH at the convex corners by the etching rate distribution of the etchant for the different crystal planes. To determine the fast-etched plane simulation of the shape of the corner round up has been made. The performed experimental results are very similar to the simulated shape of the etched corner.*

Introduction

It is known that the packaging is the most expensive part of the IC production. To produce cheaper and smaller IC devices, new packaging technologies should be discovered. The strategy is to reduce the packaging area and look for cheaper alternatives materials, which can be used, without decreasing the reliability and stability of the devices. The packaging area of some specific devices, for example solar cells, can be reduced by wafer through-hole interconnections [1]. The idea is based on the realization of metallic interconnection lines on the inclined sidewalls of anisotropically etched through-holes in <100>-oriented silicon wafer (Fig.1). The through-holes are etched by KOH, one of the most popular anisotropic etchants. The photoresist is used to define the metallic interconnection lines. The problem is that the photoresist layer is very thin across the corners of the hole [2]. To solve this problem all convex corners should smoothed. The corner round up usually is made by two-step maskless anisotropic etching and the wafer through-holes are etched through a protection mask (Fig.2). Then the protection mask (SiN) is stripped and the wafer is dipped for a short time (a few minutes) again in KOH. This will smooth all convex corners and will make possible the uniform photoresist coverage of the convex corners [3]. Since the rounding of the convex corner has been of big interest we decided to study the shape of etched corner.

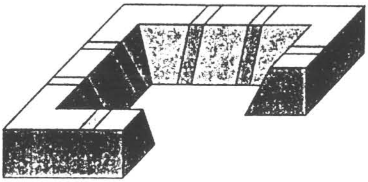


Fig.1: Art drawing of a through-hole metallization

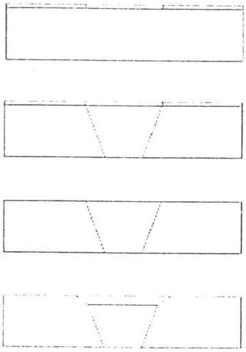


Fig.2: Two step maskless anisotropic etching

Theory

The rounding of the corner by the anisotropic etchant, for example KOH, could be explained by its anisotropy and etch rate distribution. To study the etching behaviour, which occurs at the corners and to simplify the task, we work with a cross-section of the corner made in <110> direction (Fig.3). In order to find the fast etch plane at the corner we need to know the etching rates in <n11> direction. In [5] we found some of the etching rates for KOH (30wt%, 70°C):

- (100) 0,797 μm/min
- (111) 0,005 μm/min
- (211) 1,319 μm/min
- (311) 1,436 μm/min

The points O and O_1 in Fig.3 define the corner before and after the etching in the case that only (100) and (111) planes are considered. The vectors OR_{100} and OR_{111} define the etch rates per unit time in <100> and <111> directions. Both OR_{100} and OR_{111} could be expressed as:

$$OR_{100}=\lambda.r_{100} \quad (1)$$

$$OR_{111}=\lambda.r_{111} \quad (2)$$

where λ is a linear coefficient, r_{100} is the etching rate in <100> direction and r_{111} is the etching rate in <111> direction.

Every plane at the cross-section in <110> direction between (100) and (111) planes is a (n11) plane (for example (211),(311),(411) plane, etc.). If the (n11) plane is passing through O_1 (Fig.4) and R'_{n11} is the etching rate of the plane per unit time ($R'_{n11}=\lambda.r_{n11}$), then R_{100}, R_{111} and R'_{n11} form three different triangles. These triangles have common side OO_1 and angle of 90^o against this side. Therefore all three points R_{100}, R_{111} and R'_{n11} are lying on a circle with diameter OO_1.

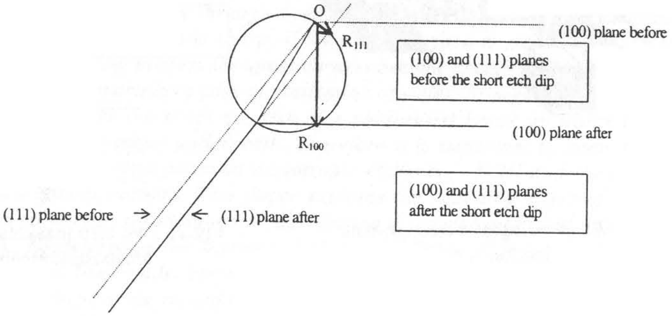


Fig.3: Sketch of the hole without corner round up after etching

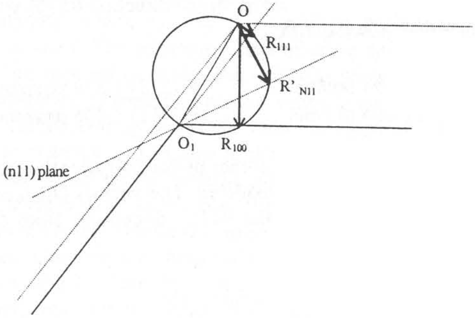


Fig.4: Formation of the corner

Regarding the corner round up formation, two criterias should be discussed:

- Criteria of no corner round up (Fig.5)

If the etching rate in the <n11> direction is R_{n11} and $R_{n11}<R'_{n11}$, then the corner will be not rounded up. Therefore if the point R_{n11} is inner for the circle, then the corner is preserved and it is not rounded up by this <n11> plane.

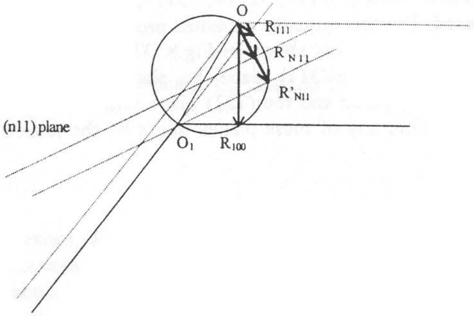


Fig.5: Case of no corner round up

- Criteria of corner round up (Fig.6)

If the etching rate in the <n11> direction is R_{n11} and $R_{n11}>R'_{n11}$, then the corner will be rounded up by the (n11) plane. Therefore if the point R_{n11} is outer for the circle, then the corner is rounded up by this plane.

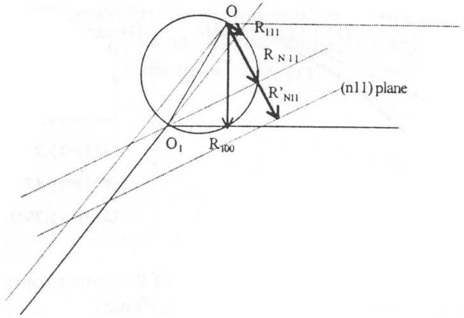


Fig.6: Case of corner round up

Experimental result and simulation

The corners round up experiments with KOH 33wt% (70°C, 10min) show that the fast-etched plane is about 18-25 deg-off angle from the (100) plane (Fig.7). Theoretically the (311) plane is about 25,24 deg-off angle from the plane (100) and the (411) plane is about 19,47 deg-off angle. Because the angles of the (311) plane to the (100) plane and (411) plane to the (100) plane are very close, and the measurement of the angle of the fast-etched plane could not be made accurate enough, a simulation of the etched profile has been made. For this purpose the etching rate data in <100>, <111>, <211>, <311>, <411>, <511> directions from [5] has been used. The theoretically estimated profile of the corner round up with KOH 33wt% (70°C, 10min) is shown in Fig.8. The simulation results show that the fast-etched plane is the (311) plane, but the range of 18-25 deg-off angle covers also the (411) plane and the (722) plane with 22 deg-off angle from the (100) plane. Therefore any of these planes might be the fast-etched plane at the convex corner.

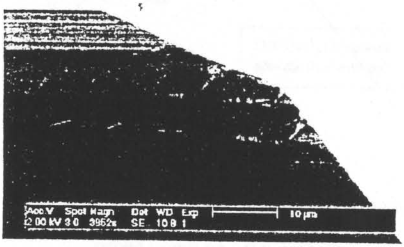
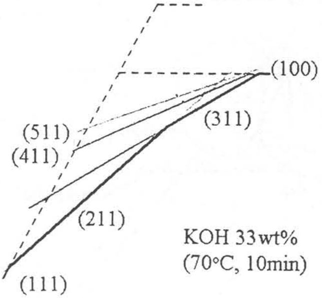


Fig.7: Cross section of a corner round up with KOH 33wt% (70°C, 10min)



Theoretical angles between
(100) and other planes

(111)=54,73561032
(211)=35,26438968
(311)=25,23940182
(411)=19,47122064
(511)=15,79316905

Fig.8: Theoretically estimated profile of the corner round up with KOH 33wt% (70°C, 10min)

Conclusions

The simulation curve of the round up of the convex corner shows that the (311) plane is the fast-etched plane. Although, all estimations in this paper are based on published elsewhere etching data it is possible that this data is not accurate enough. Therefore, it is very likely that the (411) plane might be also the high-index plane. Moreover, we do not have the etching rate in <722> direction in order to take this plane into account in our simulation. Hence, the (722) plane might be also the high-index plane at the convex corner.

Acknowledgments

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References:

1. C. Christensen, P. Cersten, S. Henke, S. Bouwstra, "Wafer Through-Hole Interconnections with High Vertical Wiring Densities", IEEE Transactions on Components, Packaging, and Manufacturing Technology - Part A, Vol. 19, No.4, December 1996, pp. 516-522
2. S. Linder, H. Baltes, F. Gnaedinger and E. Doering, "Photolithography in Anisotropically Etched Grooves", Proc. IEEE MEMS, 1996, pp. 38-43
3. V.G. Kutchoukov, J.R. Mollinger, A. Bossche, "New Photoresist Coating Method for 3-D Structured Wafers", Sensors and Actuators, Vol. A85, No.1-3, 2000, pp. 377-383
4. M. Shikida, K. Sato, K. Tokoro, D. Uchikawa, "Differences in Anisotropic Etching Properties of KOH and TMAH Solutions", Sensors and Actuators, Vol. A80, 2000, pp. 179-188
5. K. Sato, M. Shikida, Y. Matsushima, T. Yamashiro, K. Asaumi, Y. Iriye, M. Yamamato, "Characterization of Orientatation – Dependent Etching Properties of Single – Crystal Silicon: Effects of KOH Concentration", Sensors and Actuators, Vol. A64, 1998, pp. 87-93