行政院國家科學委員會專題研究計畫成果報告

多軸式觸覺感測器之研究二

A Study of Multi-Axial Tactile Sensors

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中文摘要

本報告之第一部份為利用預蝕步驟做晶向對準。為了對壓阻之阻值作精確之分析與校準，將圖樣精準地對齊晶向是非常重要的，休德提出的方法是個不錯選擇，但此方法與光罩製作機之解析度有相當的關係，本文將針對光罩製作機之解析度所造成之對準誤差加以分析與模擬，並在本文最後提出改進誤差的可行方法。

第二部分為在{100}矽晶片上製作{110}垂直壁。傳統的非等向性溼式蝕刻缺乏有效的蝕刻停止機制，故需更大的努力在{100}矽晶片上製作{100}垂直壁。在此介紹利用雷射控制蝕刻停止的新方法，用以在{100}矽晶片上製作{110}垂直壁。

Abstract

The first part of the report is to align the mask to crystal orientation by pre-etching. To achieve smooth etched sidewall surface and minimal time expense are basic disciplines of the task of accurate alignment. While aligning etch-masks to <110> crystal orientation on (100) wafer, a consideration is proposed by Schröder who uses a dial pattern for pre-etching to determine the <110> crystal orientation. But that performance depends strongly on the resolution of the mask pattern generator. In this paper, we analyzed Schröder's method by mathematical modeling and computer simulation. Finally, we proposed an improvement for Schröder's limitation according to our analytic results. The second part present the {110} vertical sidewalls on a {100} wafer. Anisotropic wet-etching for conventional {100} vertical sidewalls on {100} Si wafers needs much effort to ensure the desired dimension of the micro structure since the lack of effective etching stop mechanism. In this paper, a new method for etching {110} vertical sidewalls on a {100} silicon wafer by laser controlled etching stop is presented.

The first part: Alignment of mask patterns to crystal orientation

Introduction

Having accurately aligned etch-masks to <110> crystal orientation on (100) Si can save time to get smooth sidewall surface. Schröder proposed an improved method from Ensell's research to accomplish the task [1][2]. Instead of sophisticated approach, his method can be used together with an optical microscope to find the <110> crystal orientation without any other special equipment [3]. Schröder's works use the dial pattern with its orientation O at the center of the wafer and its radius r_0 that is slightly smaller than that of the wafer for pre-etching masks. The small circles of dial pattern are separated equally with an angle pitch $\delta\phi$. The X-axis of the mask is aligned to be parallel with the edge of the primary flat. The dial pattern spans for $\pm 2^{\circ}$ that is enough to account for the aligning error and the variation of <110> orientation. The patterned wafer is then etched by an anisotropic etching solution such as KOH etc. A target etched square can be found according to some criterion. The label besides the target etched square indicates the error angle between the mask orientation system and the <110> orientation.

In our studies, we found that the performance of the

Schröder's method depends strongly on the accuracy of the coordinates of the small circles' origin of the dial pattern. But that is limited by the resolution of the mask pattern generator. The typical resolution of the mask pattern generator for MEMS application is about 0.1μm [4]. But this is large enough to significantly degrade the accuracy of Schröder's method.

Modeling

The mnemonics defined below are used in this work.

θ : the error angle between the mask coordinate system and <110> orientation.

H_ϕ ,T_ϕ ,B_ϕ : three kinds of spacings between R_ϕ and adjacent squares.

The etched square $R_{\phi I}$ is the target square that should be found by the microscopic inspection and comparison of the etched squares. Then ϕ_I can be identified from the label besides $R_{\phi I}$. For an etched square R_ϕ, H_ϕ, T_ϕ and B can be found from the microscopic inspection. The mathematical equations for H,T, and B were derived as shown in Eq.(1)-(3).

$$H_\phi = (D_{PL}(C_{\phi-\delta\phi}, L_{<110>}) - r_G) - (D_{PL}(C_\phi, L_{<110>}) - r_G \quad (1)$$

$$T_\phi = (D_{PL}(C_{\phi+\delta\phi}, L_{<110>}) - (D_{PL}(C_\phi, L_{<110>}) - 2r_G) \quad (2)$$

$$B_\phi = (D_{PL}(C_\phi, L_{<110>}) - (D_{PL}(C_{\phi-\delta\phi}, L_{<110>}) - 2r_G) \quad (3)$$

Three kinds of criteria by comparing H_ϕ, T_ϕ, and B_ϕ can be applied to determine $R_{\phi T}$ .Criterion 1 is that $R_{\phi I}$ is the most far away from the origin of the dial pattern O. This criterion can be applied by finding the last R_ϕ of which H is positive from $\phi = 2^\circ$ counting back.

Simulation Results

According to the model derived from the previous section and considering of 100mm wafers for processing, some simulation works were done in order to show the effects of the finite resolution of the mask pattern generator on the performance of Schröder's method.

The simulation result of the relations between the accuracy and round-off precision for the three criteria with $r_0 = 50000\mu m$ and $\delta\phi = 0.05^\circ$ .Criterion 1 is the most insensitive to the round-off precision among the three criteria.

A basic approach to reduce the round-off effect on the coordinate of C_ϕ is to increase the radius of the dial pattern r_0.

The second part: The laser controlled anisotropic etching to form vertical sidewalls on {100} silicon wafers

Introduction

Because of providing the maximal deflection in the horizontal direction, the vertical beam of a wafer is very attractive in the work of the sensor design. Some research have utilized anisotropic wet-etching for {100} vertical sidewalls when they fabricate vertical beams on a {100} silicon wafer[6]-[8]. Due to the lack of effective etching stop mechanism, they need accurate control of etching time or to take the wafer in and out from the etching solution repeatedly for visual inspection in order to get the desired dimension. In order to earn reliable control of vertical sidewall etching, a new method of laser controlled etching stop mechanism is introduced. Moreover, this method has been demonstrated by our experimental results.

Etching mechanism

An anisotropic wet-etching process on {100} silicon wafers will start from {100} crystal planes certainly and then {111} crystal planes grow up gradually during etching progressing. The resultant {111} planes which have relatively slow etching rates can stop wet-etching from the creation of vertical sidewalls [9]. The key point of the etching method we proposed is to etch the silicon wafer besetting by {111} planes and monitor the process simultaneously.

The proposed process steps are illustrated in Fig. 1 for cross-section view. The first step is to grow protected layers on both sides of the wafer and then open the coincident square windows respectively as depicted in Fig. 1(a). The edges of the square etching windows have been aligned to the <110> direction. The etching process will nearly stop at {111} planes and progress toward the bottom of the pits until the wafer is etched through as shown in Fig. 1(b). When the wafer is etched through, we apply a laser beam to detect the surface of the {111} plane. The laser beam detector is used for detecting the intensity of the reflected beam from the {111} plane. As indicated in Fig. 1(b), The small {110} plane can be found at the boundaries of the two etched {111} planes. The etching rate of {110} planes is much faster than that of {111} planes[4]. Therefore, the main etching surface turns into the {110} plane as shown in Fig. 1(c). The intensity of the reflected laser beam from the {111} plane will decrease gradually, and will vanish when the etched pit coincides with the etching window. The vertical sidewalls are created as illustrated in Fig. 1(d) finally when the readout of the detector becomes zero.

Experiments

We adopted a Pyrex 7740 glass etching tank because of its availability and capability in resisting thermal shock. The reflux condenser was introduced and the temperature of the etching tank is maintained. For the laser part, we used a laser distance meter for this etching process control. The module LC-2220[10], which consists of a laser and an optical detector, was mounted on a moving stage whose X, Y, Z axis and inclined angle can be adjusted. The output signal of the module was processed by the readout unit LC-2101.

The etching solution was aqueous KOH. After an initial clean, both sides of the {100}silicon wafer was deposited by LPCVD Si_3N_4 at 800 °C with the thickness 2000A. Then the top side and the back side of the wafer was patterned. Then the wafer was then etched by aqueous KOH (80 °C, 40% KOH). Having been etched for six hours, the wafer was etched through. Then the module LC-2220 was arranged for in-situ monitoring. Although the bubbles generated from the etched surface resulted about ±30% variation on the readout of the laser intensity during etching. That did not interfere our decision when to stop etching since the bubbles did not cause any offset error on the readout. The etching was stopped when the intensity of the reflected laser beam from the {111} plane vanished totally. At that moment, the readout of the module LC-2200 was zero.

Results and discussion

The photo in Fig. 2 shows one of the etched sidewalls we have made. From the view of it, we can see the etched sidewall are not exactly vertical to the {100} plane as we depicted in Fig. 1. We speculate that the result is owing to the non-uniform etching rate on the intersection of the {110} plane and {111} plane. Referring to Fig. 1(c), the {110} planes are beset by the {111} planes. In the vicinity of the {111} planes, the etching rate varies extremely with the little angular changes[4]. So around the intersection of the {110} and {111} plane, the etching rate is not uniform. The slant of the sidewall will appear as the photo Fig. 2 shows. Besides the surface of the vertical sidewall is not very smooth. The roughness of the surface may come from the metallic impurities in aqueous KOH solutions[11].

Conclusions

The finite resolution of the mask pattern generator has significant influence on the accuracy of Schröder's method. Improving the situation by using more precise mask pattern generator is insignificant even with resolution as small as 0.025μm. The accuracy of Schröder's method can be improved by applying the criterion 1 described in section 2 to find $R_{\phi T}$ and increasing r_0. The origin of the dial pattern can be chosen such that the dial pattern can fit into the requiredarea on the wafer besides choosing the wafer's center as the origin of the dial pattern in Schröder's works.

In contrast with the conventional time control or off-line visual inspection method, we proposed a reliable alternative to get vertical sidewalls on {100} wafers by the aids of a laser. The etching stop mechanism has been described and the experimental agreement is obtained. Some non-ideal effects and constraints have also been discussed. By the laser controlled anisotropic etching , we can form the desired micro structures of vertical sidewalls on {100} wafers more precisely.

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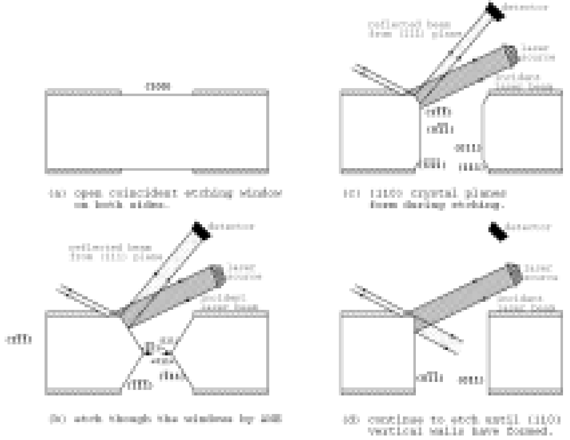

Figure 1: The cross-section view of the proposed etching process.

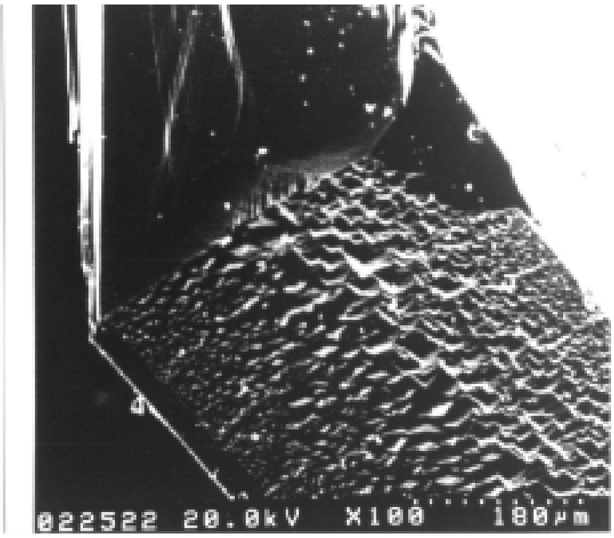

Figure 2: An etched vertical sidewall in the middle of the photo.