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Precision alignment of mask etching with respect to crystal orientation

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Abstract. For most micro-mechanical devices, a high precision alignment of mask pattern to crystal orientation is preferred. Such alignment even becomes critical for devices that simultaneously require a smooth sidewall and minimal undercut. In this article, we present an innovative pre-etching pattern to determine the ⟨110⟩ crystal orientation on [100] silicon wafers. This pattern etched on the wafer allows us to determine the crystal orientation within an accuracy of 0.01°. Such a pre-etching pattern can be used as a valuable reference for all subsequent mask patterns.

1. Introduction

A mask accurately aligned to the ⟨100⟩ crystal orientation on a (100) Si wafer can reduce the time deemed necessary to obtain a smooth etched sidewall surface and the minimal undercut during the anisotropic etching process. Several methods have been proposed to align mask patterns to crystal orientation [1–5]. Schröder *et al* [1] proposed a method based on Ensell's investigation [2] to achieve accurate alignment. Instead of the complex approach given by Steckenborn *et al* [4], the method of Schröder *et al* can be applied with a simple optical microscope to obtain the ⟨110⟩ direction with no other special equipment needed. However ensuring the performance of the Schröder method heavily relies on coordinate accuracy of the small circle origins of the dial pattern, which is determined by the resolution of the mask pattern generator. In addition, the method of Schröder *et al* can not easily yield an accurate alignment with an ordinary optical microscope. In this article, we present an aligning set which consists of a rectangle and a square; the angle between two neighbor aligning sets is 0.01°. A series of aligning sets is etched into the wafer, allowing us to easily determine the set which is the closest to the ⟨110⟩ direction with the optical microscope. This alignment method can be easily realized, and the alignment accuracy is as high as ±0.01°.

2. Principles of the alignment pattern

When (100) Si wafers are etched in anisotropic etching processes, i.e. etched in KOH, through an arbitrarily shaped window, the slowest-etching planes, i.e. {111} planes, become exposed. In addition, the fact that the {111} planes intersect the surface of the wafer along the ⟨110⟩ direction accounts for why the outline of the etched feature on the wafer surface is a rectangle.

Figure 1(a) illustrates the mask layout of the proposed pattern. The mask layout consists of an oblique clear rectangle and square windows in the dark- field mask. Each pair of a rectangle window and a square window is used as a unique alignment set of the mask layer. In the alignment set, the widths of both the square and the rectangle are W as shown in figure 1(a). The length of the rectangles is L. The distance between the square and the rectangle is D. The alignment sets are positioned annually on an arc of radius R_0 which may be greater than the diameter of the wafer. The dimension of the alignment sets depends on the pre-alignment accuracy. As shown in figure 1(b), we had fabricated the alignment sets on one side of the wafer and the auxiliary alignment sets which are square windows on the other side of the wafer. The alignment sets and the auxiliary alignment sets form arcs of concentric circles. The corresponding pre-etching patterns are collinear. When provided with the alignment pattern, the subsequent masks can be aligned in accordance with the pre-etching pattern with selected direction.

Interestingly, rectangles form on the wafer's surface when the silicon is etched through these windows of the alignment sets. If the angle between the direction of an alignment set and the ⟨110⟩ direction is θ, the edges at the alignment set are misaligned by Δy, as shown in figure 2.

$$\Delta y = (D + L)\sin\theta. \tag{1}$$

Therefore, we can easily compare Δy of the alignment sets to determine the set which is closest to the ⟨110⟩ direction with simply an optical microscope.

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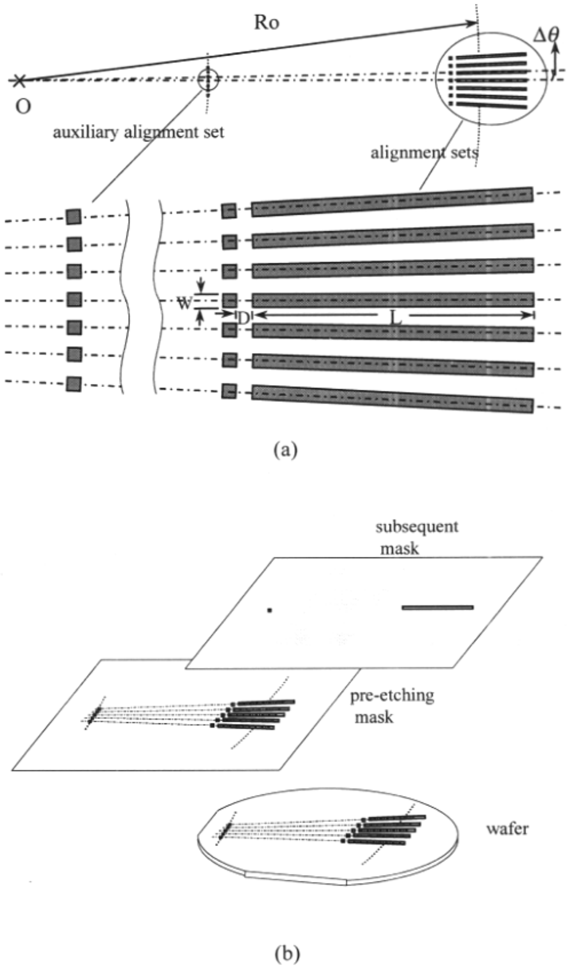

Figure 1. (a) Mask layout; the angle between two neighboring sets is $\Delta\theta$. (b) Subsequent mask alignment.

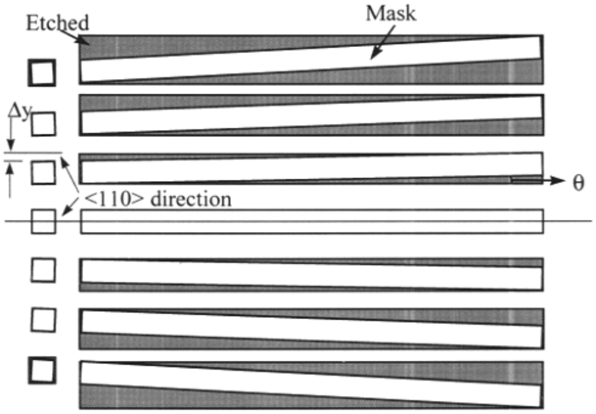

Figure 2. Etched profile of the mask layout without undercut.

3. Processes and results

Four inch (100) Si wafers are used in this study, and 200 nm Si_3N_4 is used as the etching mask for KOH solution. The wafer is then etched in 40 wt% KOH solution at 80 °C for a time sufficient to expose {111} planes. In this article, the pre-alignment accuracy is 0.01°. The variable W of the alignment pattern is 15 μm, and L is 1000 μm. In addition, D is equal to 16 μm, and R_0 is 180 mm. According to equation (1), the value of Δy is around 0.18 μm for each 0.01° misaligning angle of the alignment set.

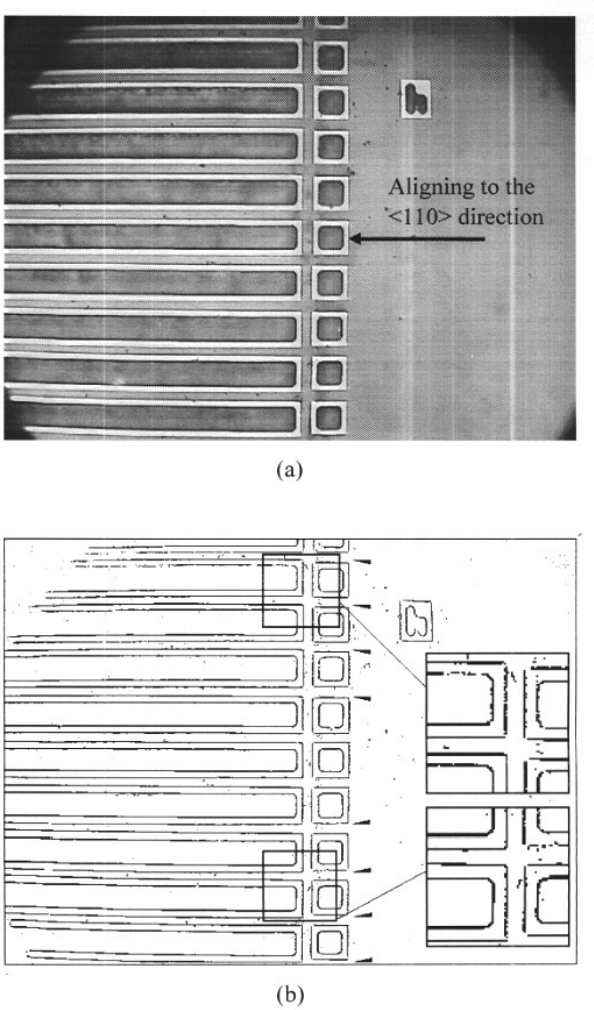

Figure 3. (a) A photograph of the etched patterns. (b) A photograph of (a) with image processing. The alignment of their edges indicates that the center pattern is aligned to the ⟨110⟩ direction.

Pre-etching patterns on the ⟨110⟩ direction can usually be visualized after the etch time of an hour. Figure 3(a) illustrates the neighboring etched patterns before the silicon nitride is stripped; the result is however obtained after a six hour etch time for demonstration purposes. The photograph is captured by a 10 × 40 microscope. This observation indicates that the patterns are nearly all aligned when only the central pattern is exactly aligned with the ⟨110⟩ direction. When aligning masks to the ⟨110⟩ direction, the central pattern is used. Figure 3(b) illustrates the observation in Figure 3(a) after a series of image processing steps which primarily include edge enhancement and the contour tracing. Figure 3(b) depicts a clear picture of the mask effect, which is unnecessary in an actual process.

4. Conclusions

This article presents an innovative pre-etching pattern to determine the $\langle 110\rangle$ crystal orientation on [100] silicon wafers. According to this pre-etching pattern, the crystal orientation can be easily determined within an accuracy of 0.01°. This pre-etching pattern provides a valuable reference for all subsequent mask patterns, which is useful in fabricating a micro-mechanical system.

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