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An Improved Angle Polishing Method for Measuring Subsurface Damage in Silicon Wafers*

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Abstract: We present an improved angle polishing method in which the end of the cover slice near the glue layer is beveled into a thin, defect-free wedge, the straight edge of which is used as the datum for measuring the depth of subsurface damage. The bevel angle can be calculated from the interference fringes formed in the wedge. The minimum depth of the subsurface damage that can be measured by this method is a few hundred nanometers. Our results show that the method is straightforward, accurate, and convenient.

Key words: silicon wafer; subsurface damage; angle polishing; defect etching; wedge fringes
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1 Introduction

Single crystal silicon is the most important substrate material, upon which over 90 percent of semiconductor devices are manufactured. Silicon wafer preparation requires a series of processing steps in order to attain high performance semiconductor devices. Many processing steps, such as slicing, lapping, and grinding, induce surface and subsurface damage to silicon wafers. The subsurface damage may significantly alter the electric properties of the semiconductor and endanger its proper operation by distorting the doping profiles, and it must be removed in subsequent processes[1]. Furthermore, a substantial percentage of silicon wafers are thinned by back grinding prior to dicing and packaging. As wafers become thinner and more fragile, the subsurface damage of back grinding creates increasingly significant risk of yield loss during de-taping, handling, dicing, and package assembly processing[2]. Therefore, the evaluation of the subsurface damage is important for optimizing machining processes and ensuring the quality of silicon wafers.

Many methods have been used to measure and evaluate subsurface damage in silicon wafers, such as angle polishing, cross-sectional transmission electron microscope (TEM), X-ray diffraction, and Raman spectroscopy[3,4]. SEMI MF950-02 provides a standard test method for measuring the crystal damage depth of a mechanically worked silicon slice surface by angle polishing and defect etching[5]. In this method, the silicon specimen must be deposited with silicon nitride first. The minimum measurable damage depth is about 5μm. It is difficult to obtain an appropriate measuring datum since material intermixing on the etched interface is intrinsically unavoidable. It is also hard to measure the bevel angle accurately. These disadvantages make this method unsuitable for slightly damaged silicon wafers. Subsurface damage could be examined by cross-sectional TEM, but it is very difficult to prepare TEM samples of non-metallic materials. To get the sample thin enough for electrons to go through (< 500nm), the method most commonly used is mechanical lapping and polishing, followed by ion milling. The sample preparation is tedious, and artifacts may be induced during lapping, polishing, or ion milling. Sometimes, densities of micro cracks are so small that the likelihood of having a micro crack in a typical TEM sample is practically zero; as a result, a false conclusion may be obtained. X-ray diffraction is widely used as a nonde-

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structive method to determine residual stress from the lattice deformation of a crystal[6], but the spatial resolution of X-rays is so poor that the result measured by this method is only an average over a specified zone. Raman spectroscopy has been used for the analysis of phase transformation and residual stress in machined silicon wafers[7]. A main advantage of Raman spectroscopy is its high resolution. However, the method cannot identify cracks and dislocations.

In the present investigation, an improved angle polishing method is developed to measure the subsurface damage of machined silicon wafers.

2 Principle

The reason that angle polishing can be used to measure subsurface damage depth is that the sample region under investigation is multiplied by angle beveling. The subsurface damage depth is then obtained by scaling down the acquired image in the direction perpendicular to the bevel edge by a factor of $\sin\beta$, where β is the bevel angle. Samples beveled at angles ranging from 5°44″ to 2°52″ produce a magnification from 10 to 20 times with respect to the cross section[5]. As mentioned above, a main disadvantage of conventional angle polishing is that the interface becomes illegible after defect etching, which makes it difficult to get an accurate measurement due to lack of an appropriate datum. However, the measuring accuracy can be greatly improved on the condition that a sharp measuring datum is used. We have successfully achieved this after much experimentation. Figure 1 is a schematic illustration of the improved angle polishing method. Two silicon slices were glued together face to face, as shown in Fig. 1(a). One was a sample slice cut from the silicon wafer to be measured; the other was a cover slice that was cut from a finely polished silicon wafer. After angle lapping and chemical mechanical polishing, an angle beveling was formed. The end of the cover slice near the glue layer was beveled into a defect-free, thin wedge, and the edge of the thin wedge was straight and parallel to the glue line, as shown in Fig. 1(b). After defect etching, the wedge edge can be kept unaltered, because the silicon in the wedge has a perfect crystal structure and the etching speed is much slower than in the damaged region. Therefore, the wedge edge of the slice can be used as a perfect datum for measuring the depth of the subsurface damage.

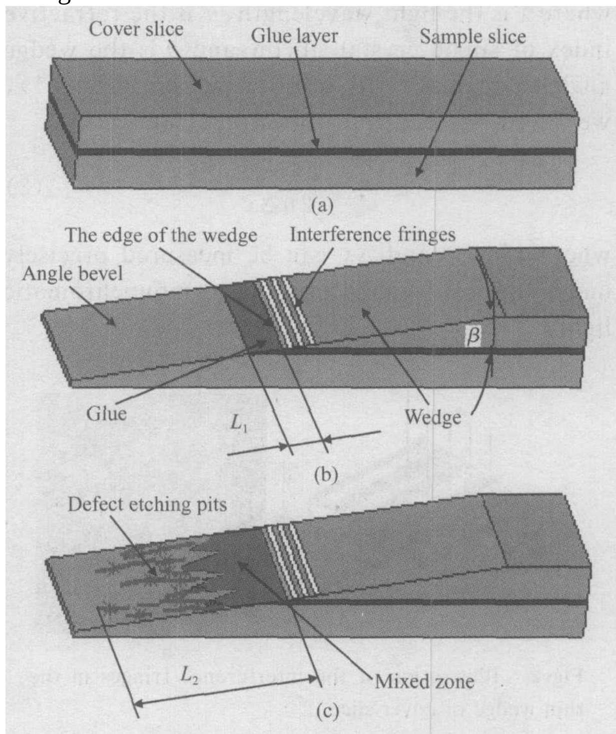

Fig. 1 Illustration of the improved angle polishing method (a) Two silicon slices were glued together face to face; (b) After chemical mechanical polishing; (c) After defect etching

If the width of the glue layer is denoted by L_1 and the distance from the wedge edge of the cover slice to the farthest etching pits along the direction perpendicular to the wedge edge is denoted by L_2, then the depth of the subsurface damage is

$$d = (L_2 - L_1)\sin\beta \qquad (1)$$

The bevel angle β can be defined by the angle polishing fixture; it can be measured precisely by using the interference fringes produced in the thin wedge as well. Since the wedge is so thin as to become transparent, interference fringes will appear after chemical mechanical polishing, as shown in Fig. 2. The interference pattern is composed of a series of alternating bright and dark fringes of the same color when created by monochromatic light. The fringes are straight and parallel to the edge of the wedge. The optical path difference between two adjacent bright fringes or dark fringes is $\lambda/2n$. The distance between two adjacent bright fringes or dark fringes, Δx, is

$$\Delta x = \frac{\lambda}{2n\sin\beta} \quad (2)$$

where λ is the light wavelength, n is the refractive index of single crystal silicon, and β is the wedge angle in degrees[8]. By substituting β into Eq. (1), we obtain the depth of subsurface damage:

$$d = \frac{\lambda(L_2 - L_1)}{2n\Delta x} \quad (3)$$

where L_1, L_2, and Δx can be measured precisely under optical microscopy with monochromatic light.

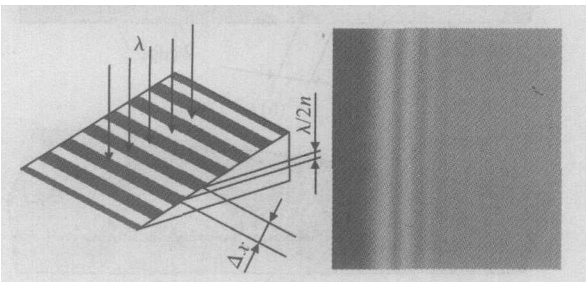

Fig. 2 Illustration of the interference fringes in the thin wedge of cover slice

3 Experimental procedures

In this study, two machined silicon wafers were measured by the newly developed method. One was silicon wafer lapped with alumina abrasive slurry, and the other was ground with a #3000 resin bond diamond grinding wheel. The procedure is as follows.

3.1 Gluing

A sample slice was cut from the silicon wafer and was measured to be 5mm wide and 10mm long. A similarly sized cover slice was cut from a polished silicon wafer. After ultrasonic cleaning, the two slices were glued together face to face with epoxy.

3.2 Lapping

The sample was mounted onto an angle polishing fixture with a bevel angle for lapping and subsequent chemical mechanical polishing. The polishing fixture was then transferred to a polishing machine to be lapped using a succession of water proof silicon carbide abrasive papers in the order of 30, 9, 6, 3, and 1μm. After the final lapping step, the sample should have a mirror finish with no visible lapping marks.

3.3 Chemical mechanical polishing

After lapping, chemical mechanical polishing was conducted. A firmly backed polishing pad and slightly alkaline polishing slurry are recommended. While polishing, the sample should be placed with the wedge of the cover slice facing the direction of the polishing pad in order to prevent chipping. After polishing, a very smooth, defect-free angle beveling should appear. The end of the cover slice near the glue layer should be beveled into a thin wedge, and the edge of the thin wedge should be straight and parallel to the glue line without any chipping or scratching. In this instance, the wedge of the cover slice is so thin as to become transparent. Interference fringes can be seen clearly near the edge of the wedge; these are what are called "wedge fringes" in physics.

3.4 Etching

The damaged region cannot be examined by chemical mechanical polishing alone. However, measurement and evaluation become possible after defect etching. The basic idea behind defect etching is to mark defects such as cracks and dislocations intersecting the surface by small pits or grooves so they become visible[9]. In this study, the silicon slices were placed into a defect etching solution (H_2O : HF49% : $K_2Cr_2O_7$ = 500ml : 1000ml : 22g) for 10s at a room temperature.

3.5 Measuring the length L_1, L_2, and Δx

To accurately measure the depth of the subsurface damage, an optical DIC microscope with a camera and image measuring capability is necessary. The length L_1 was measured before defect etching, which is the distance from the edge of the wedge of the cover slice to the interface between the sample slice and glue along the direction perpendicular to the edge. The length L_2 was measured after defect etching, which is the distance from the edge of the wedge of the cover slice to the farthest etching pits along the direction perpendicular to the edge; Δx is the distance between two adjacent bright fringes or dark fringes. The depth of the subsurface damage d was then calculated according to Eq. (1) or Eq. (3).

4 Results and discussion

Figures 3 and 4 are images of the improved angle polishing before and after defect etching under DIC microscopy. As shown in Fig. 3(a) and Fig. 4(a), after chemical mechanical polishing, the cover slice near the glue layer was beveled into a thin, defect-free wedge, the edge of which was straight and parallel to the glue line without any chipping or scratching. After defect etching, subsurface damages were revealed, but the interface between the sample slice and glue layer became illegible, and thus it was impossible to measure accurately the the subsurface damage with the traditional angle polishing method. However, in the improved angle polishing method, the straightness and completeness of the wedge edge were unaltered even after defect etching. Therefore, the edge of the cover silicon slice was a perfect measuring datum with negligible datum uncertainty, as shown in Fig. 3(b) and Fig. 4(b).

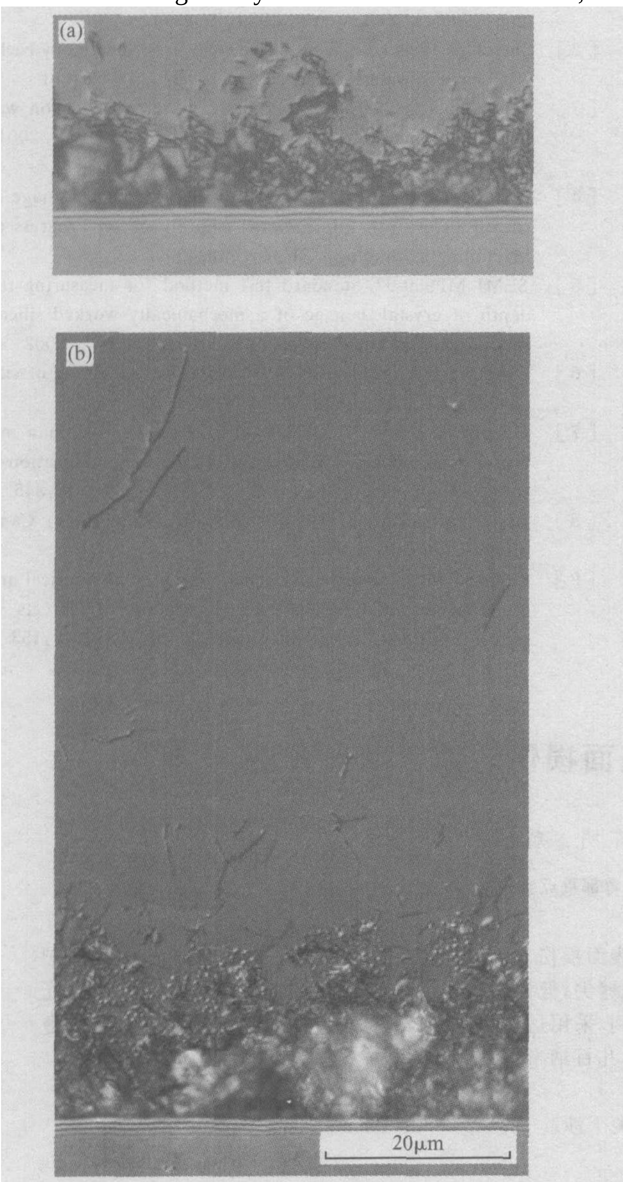

Fig. 3 Subsurface damage of the lapped silicon wafer (a) After chemical mechanical polishing; (b) After defect etching

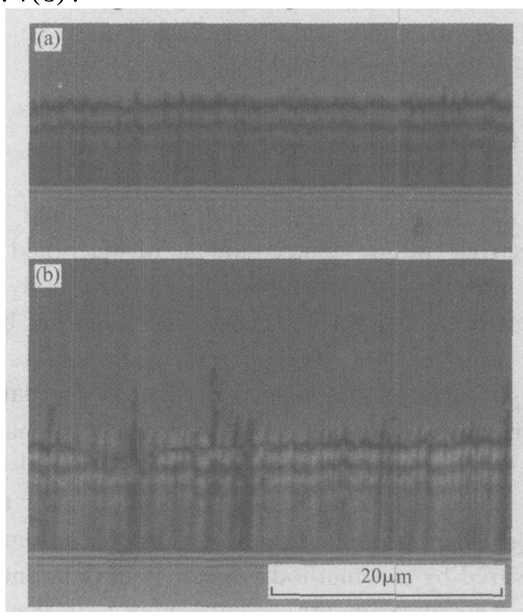

Fig. 4 Subsurface damage of the ground silicon wafer (a) After chemical mechanical polishing; (b) After defect etching

The interference fringes, composed of a series of alternating bright and dark fringes, can be seen clearly in the wedge under DIC microscopy, and the bevel angle can be calculated from the relationship between the bevel angle and the spacing of the interference fringes formed in the thin wedge. By our method, the depth of the subsurface damage in the lapped silicon wafer was measured to be 9.45μm, as shown in Fig. 3. The depth of subsurface damage in the ground wafer was 693nm, which is beyond the measuring capability of the traditional angle polishing method.

For the heavily damaged silicon wafers such as lapped wafers, due to uneven surface topography, as shown in Fig. 3(a), the interface between sample slice and glue layer of the lapped silicon wafer was irregular, which may have a negative influence on measurement accuracy. However, the disturbance is limited, since the glue layer is very thin, less than 500nm.

From Fig.3(b) and Fig.4(b) we find that the subsurface damage induced by lapping and grinding is not distributed evenly. Because of a large sampling length up to 5mm, the depth of the subsurface damage variation may be detected by this method, which is good for a more accurate measurement. However, since the sample area is much smaller than in the angle polishing method, cross sectional TEM can hardly detect the heavily damaged region, and a false conclusion may be obtained.

5 Conclusion

An improved angle polishing method for measuring the subsurface damage of machined silicon wafers was developed. In this method, the end of the cover slice near the glue layer was beveled into a thin, defect-free wedge, and the straight edge of the wedge was used as the datum for measuring the depth of subsurface damage. The bevel angle can be measured accurately by using the interference fringes formed in the thin wedge. The minimum depth of subsurface damage measured by this method is a few hundred nanometers. Our experimental results show that the improved method is straightforward, accurate, and convenient, and could be an economical and technical alternative to the conventional angle polishing method.

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一种改进的测量硅片亚表面损伤的角度抛光方法*

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摘要: 提出了一种改进的角度抛光方法来测量硅片的亚表面损伤. 其原理是: 经过研磨和化学机械抛光后, 起保护作用的陪片靠近胶黏剂的一端形成一个无损伤的、完整的劈尖, 劈尖的棱边作为测量亚表面损伤的基准; 角度抛光的倾斜角可通过劈尖上面产生的干涉条纹准确地测量得到. 采用这种方法可以方便、准确地测量硅片由切割、研磨和磨削引起的亚表面损伤, 其能够测量的最小损伤深度为几百纳米.

关键词: 硅片; 亚表面损伤; 角度抛光; 缺陷腐蚀; 劈尖干涉

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