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Bare Wafer Inspection using a Knife-edge Test

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We present a very simple and efficient bare-wafer inspection method using a knife-edge test. The wafer front surface and inner structures are inspected simultaneously. The wafer front surface is inspected visually using a knife-edge test while the inner structure is simultaneously inspected by a camera in the infrared region with a single white-light source. This paper presents a laboratory implementation of the test method with some experimental results.

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I. INTRODUCTION

In semiconductor manufacturing, quality control is crucial to ensure the reliability of the end product. Accordingly, the identification and elimination of wafer defects at all manufacturing stages is necessary. As wafer sizes have continued to increase, feature sizes have decreased. Consequently, the production of high quality bare silicon wafers is of great importance and subsequent processing and bare wafer inspection have become critical.

Bare-wafer inspection systems inspect surface defects such as contaminations and scratches and inner defects such as cracks. Most inspection systems use optical techniques [1-8] while a few systems apply electric field propagation [9] and electron beam techniques [10]. The optical inspection systems use a combination of a bright-field microscope, dark-field microscope, DIC (differential interference contrast microscope), and laser beam reflection/scattering. Applications of dark-field and DIC microscopes have increased owing to their higher edge contrast compared to the bright-field microscope. The latter meanwhile is employed to take images of the illuminated surface. Laser beam reflection/scattering basically focuses a laser beam onto a spot of certain size on the wafer surface with/without an inclination angle and then detects the directly reflected beam and/or scattered beams.

This paper proposes a new, simple, high-speed wafer-inspection method using a knife-edge approach [11]. This method basically corresponds to a bright-field microscope except the light reflected from the wafer surface is partially cut by a knife-edge, which increases edge contrast in the cutting direction. In addition, the knife-edge test does not depend on the light wavelength and thus the light can have any wavelength as far as it is reflected by the wafer surface. Therefore, the knife-edge test, which uses visible light, can be employed simultaneously with a looking through inspection technique, which uses infra-red, with a single white-light source. The knife-edge method in tandem with a looking through inspection is implemented at a laboratory level and preliminary experimental results demonstrating edge enhancement are presented.

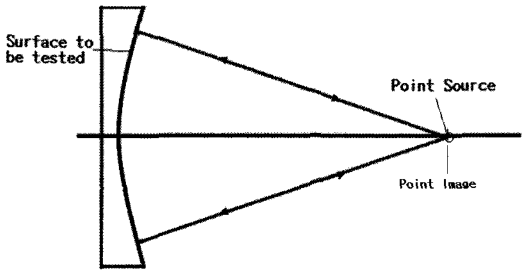
II. TEST SETUP

2.1 Introduction to a knife-edge test

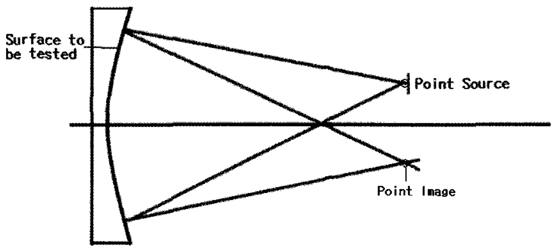
When a point light source is located at the center of the radius of curvature of a mirror, all light from the point shall be reflected back to the point source, as shown in figure 1 (a). When the point source is moved off the axis, the mirror reflects the light from the source to an off-axis image point localized on the other side of the center of the curvature of the spherical mirror, as shown in figure 1 (b).

A knife-edge test or Foucault Test places an illuminated point (or pinhole size) source at one side of the center of curvature of a spherical concave mirror and the image of the illuminated point source is formed at the other side, as shown in figure 1 (b). A knife-edge is then introduced to cut the illumination beam that forms the image. An observer sees a shadow pattern appearing over the otherwise uniformly illuminated surface of the mirror [11].

Previous studies of the knife-edge test in terms of diffraction theory show that the irradiance variations in the image plane are related to the inverse Fourier transform of the derivative of the Fourier spectrum of the aberration function, which describes the aberrations present over the optical surface [11]. In some sense, the knife-edge test can be interpreted as a means to emphasize the derivative or variations of the surface aberrations or surface errors [12].



(a) When a point source is located at the center of the radius of curvature of the surface to be tested



(b) When a point source is moved off-axis from the center of the radius of curvature of the surface to be tested

FIG. 1. Point reflections by a spherical mirror.

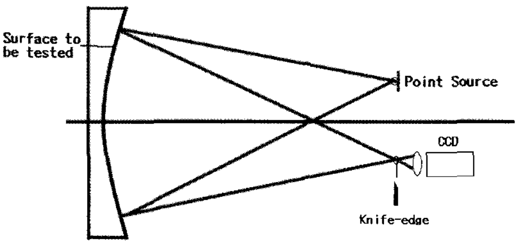


FIG. 2. Schematic layout of a knife-edge test.

2.2 Wafer inspection test

The presented test setup for wafer inspection is a modified knife-edge test, as shown figure 3. Since wafers are flat rather than concave or convex, we place a collimating lens (doublet) with a focus located at the pin-hole source. White light from a pin-hole is collimated to a wafer, which is slightly tilted in order to tilt the reflected beam. The wafer reflects only the visible band of the incoming light and the IR band passes through the wafer and reaches a CCD through a CCD lens.

The reflected visible light is folded 90° by a mirror located in front of the conjugated image of the source followed by a CCD lens. A knife-edge located is at the source image plane to modulate the irradiance of the incoming beam. The CCD lens is conjugated to the front surface of the wafer. The He-Ne laser shown in figure 3 is for alignment, not for the knife-edge test. Figure 4 shows a picture of the test setup.

III. TEST RESULTS

3.1 Test specimens

We performed the knife-edge test for bare-wafers with and without polishing tool marks. A wafer with

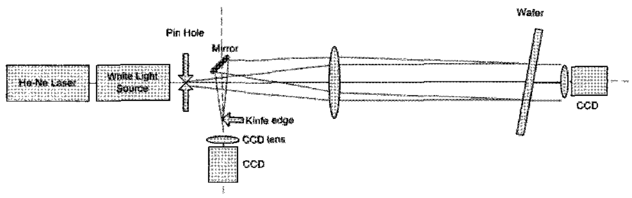


FIG. 3. Test setup for the wafer inspection.

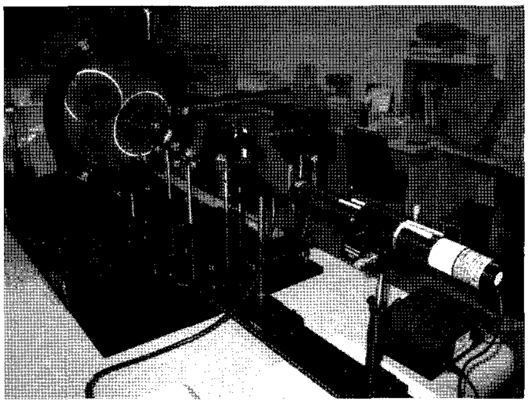


FIG. 4. Picture of test setup.

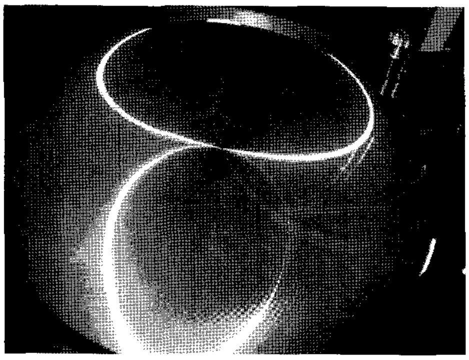
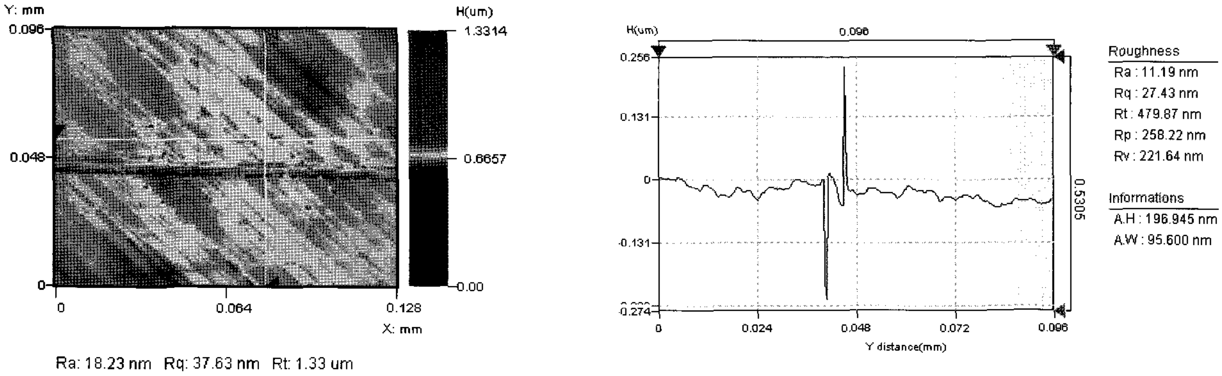


FIG. 5. Picture of a test specimen: bare wafer with tool marks.

tool marks has a crack, which is circled in figure 5. Figure 6 shows an interferometer measurement and the height profile of the crack. The crack is shown to have ~480 nm PV and ~1 μm width.

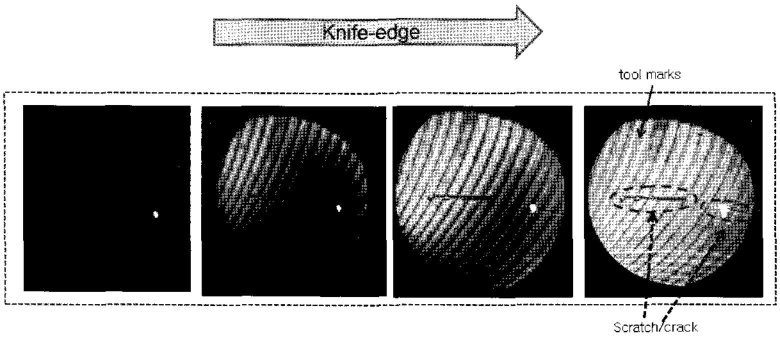
3.2 Knife-edge test results

Figure 7 shows the knife-edged images of two bare-wafers with and without tool marks. In the figure, the images from the left to the right were taken by the CCD as the knife-edge was moved from left to right i.e. full blocking to full open. The rightmost pictures are equivalent to the images of a bright-field micro-

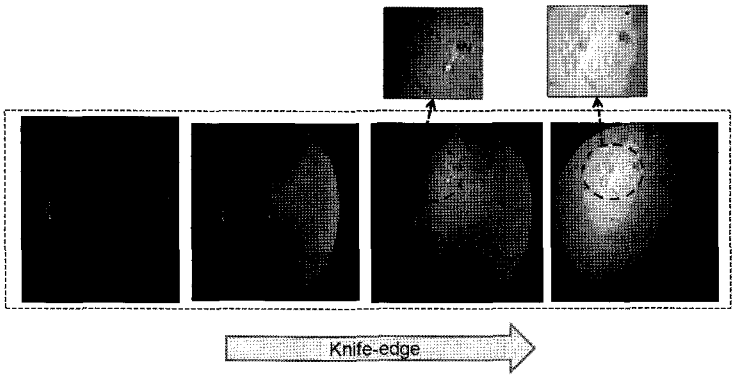


(a) Interferometer measurement (b) Height profile across the crack

FIG. 6. Crack located in a bare wafer with tool marks.



(a) Bare wafer with tool marks and scratch/crack



(b) Bare wafer without tool marks

FIG. 7. Knife-edged images of two bare wafers with/without tool marks.

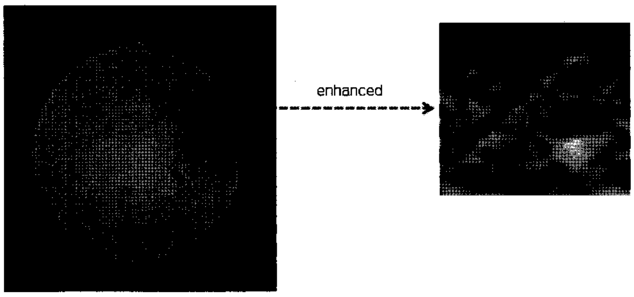


FIG. 8. Transmitted IR image.

scope, since the knife-edge did not block any light. From the figure, it can be said that the knife-edge test emphasizes features on bare wafers that would be unclear or unnoticeable via a conventional bright-field microscope.

3.3 IR image

Figure 8 shows the knife-edged images of the bare wafer without tool marks. Features in figure 7 (b) and figure 8 might be regarded as dust due to their shapes; however, after several trials to remove these features, it was determined that they were indeed intrinsic to the wafer. IR images show similarity to the visible images but some features unseen in the visible images are shown in the IR images. In figure 8, a thin line suspected to be a crack is newly seen. Further investigation utilizing the visible and IR images provided further information on the surface and inner structures of the wafers.

IV. CONCLUSION

We proposed a knife-edge test method that could be used to simultaneously inspect defects on the surface and in the interior of bare wafers with very simple instrumentation. The method was evaluated for two bare wafers and its capacity to clarify irradiance features that would be otherwise unclear or undetectable was demonstrated.

Further research should be followed to investigate irradiance variation due to different types of defects so that the similarities and differences between visible and IR images can be effectively utilized.

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