Qualitative Edge Topology Inspection and Interpretation by Enhanced Knife-Edge Interferometry

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INTRODUCTION

Edge topography measurement technology is vital in many engineering applications such as cutting tool inspection, photomask inspection, or corrosive wear inspection. Although those applications require high-level sharpness or smoothness of the edges to achieve their needs, there is little measurement and inspection technology available. Most of the current surface metrology and inspection technology is primarily focused on planar surface characterization [1-3], and sometimes indirect methods such as measuring the cutting force or acceleration to interpret tool wear propagation during the machining process are used [4]. This paper presents the enhanced knife-edge interferometry (KEI) that measures optical scattering behaviors that originated from the edge. KEI utilizes the optical interference of incident light and scattered light at the edge and produces the fringe patterns proportional to edge quality [5-7]. Analysis of such fringe patterns enables monitoring edge quality. We recently improved KEI performance by shaping the beam with the objective lens (4×, 10×). The incident plane wave was turned into a spherical wave by the objective lens, and the spherical wave and the diffracted wave at the edge interfered. As a result, the strong interference effect was observed, and over 3 times fringe patterns were obtained compared to the interference results of no objective case. The enhanced KEI was employed for edge quality inspection of sharp edges (razor blade), cutting tools, and photomask.

MEASUREMENT PRINCIPLE

The principle of enhanced KEI can be easily explained in geometrical optics. When we are using the objective lens in the system, the output plane wave will first focus on the focal point of the objective lens and then disperse. Now the light source can be viewed as a point source and the diffraction can simplify as a Fresnel number modal. In Fresnel number modal. In this modal, the number means the half-period zones in the plane. Each zone implies the constructive/destructive light intensity effect to our on-axis observation point. The equation for Fresnel number is listed as follows:

$$F = \frac{a^2}{\lambda \times Z_{eff}} \qquad (1)$$

In this equation, a means the radius of the light beam at the plane, λ means the wavelength of the laser, Z_{eff} is the effective distance, which equals to:

$$\frac{1}{Z_{eff}} = \frac{1}{Z_o} + \frac{1}{Z_{src}} \qquad (2)$$

Where Z_o is the distance between the edge plane and the sensor and Z_{src} is the distance between the edge plane and the focal plane. The experiment principle can be seen in Figure 1. Another adventure for the enhanced KEI system is its high sensitivity. Ideally, the simulation result is just the output intensity of the on-axis point, but in a conventional KEI system, the output plane wave from the laser will be fully emitted to the sensor, which normally has its size in units of ~100 μm. Unfortunately, those off-axis points on the sensor will also receive the light intensity and will be recorded in data collection. The intensity from those off-axis points will decrease the sensitivity of recorded data and generate the attenuated fringe pattern from a diverse beam. But in the enhanced KEI system, the light will diverge after the focal point and only a small amount of light will be recorded since the light was scattered.

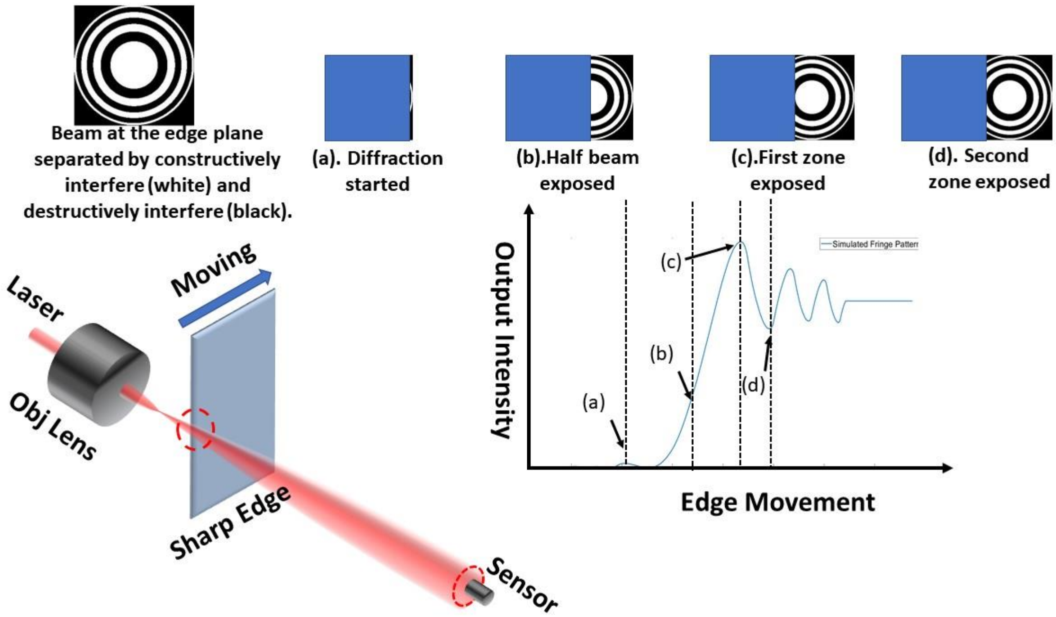

FIGURE 1. Principle of experiment

EXPERIMENTAL RESULTS

Experiment Setup

As shown in Figure 2, a 10× objective lens was mounted at the front of the edges to shape the beam, and an avalanche photodiode (APD) recorded the output fringe pattern by scanning the razor blade. The four different edge conditions were prepared by using the grinding tools to wear out the edge sequentially. After each worn-out process, the edge will be scanned by the laser and the edge profile will be captured by the microscope for verification.

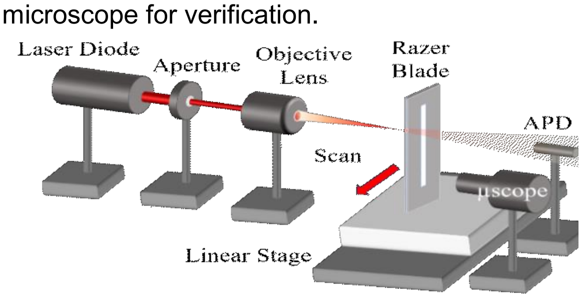

FIGURE 2. Experimental setup.

The measurement fringe pattern result for each stage can be seen in Figure 3. The data were analyzed by using cross-correlation. After that, we will get two parameters: the lag and the similarity. While the similarity illustrates the edge defect in microscale (less than 10 micron), the lag shows the edge damage in macro scale (over 10 micron).

Experiment Results

Compared with the conventional knife-edge diffraction method, the similarity of the experiment results with 10× objective lens decreases from 1 to 0.98 while the conventional knife-edge diffraction system gives us less than 0.01 changes in the value of similarity. The photomask patterns (width, line-edge roughness) were also tested. By adding the defect to the photomask pattern, the width of the transparent area decreases from 0.995 mm to 0.668 mm, and the similarity changes from 0.987 to 0.907 after adding the defect. The fringe pattern for the experiment group and the control group can be seen in Figure 4. This study has the potential to be used in high-resolution optical metrology systems for edge topography characterization, such as photomask inspection or micro-machining verification. Its improved resolution and highly sensitive features may bring another low-cost, in situ, direct testing method into the industry of precision engineering.

ACKNOWLEDGEMENTS

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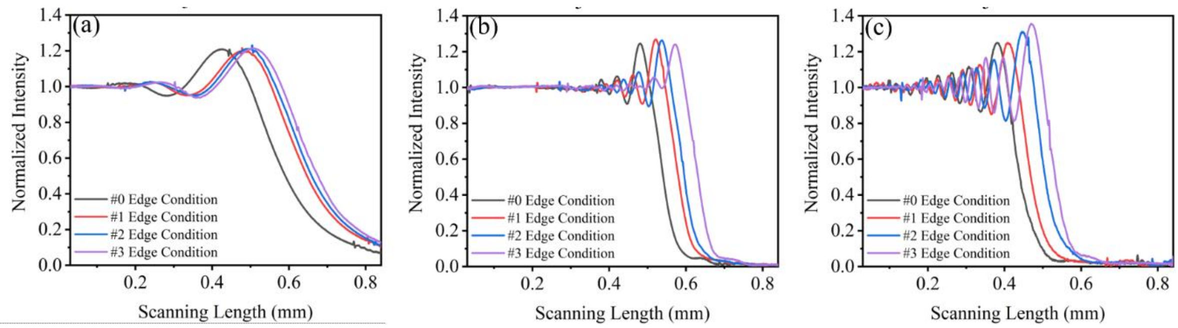

FIGURE 3. Knife-edge interferograms for (a) no objective lens case, (b) 4× objective lens case, and (c) 10× objective lens case.

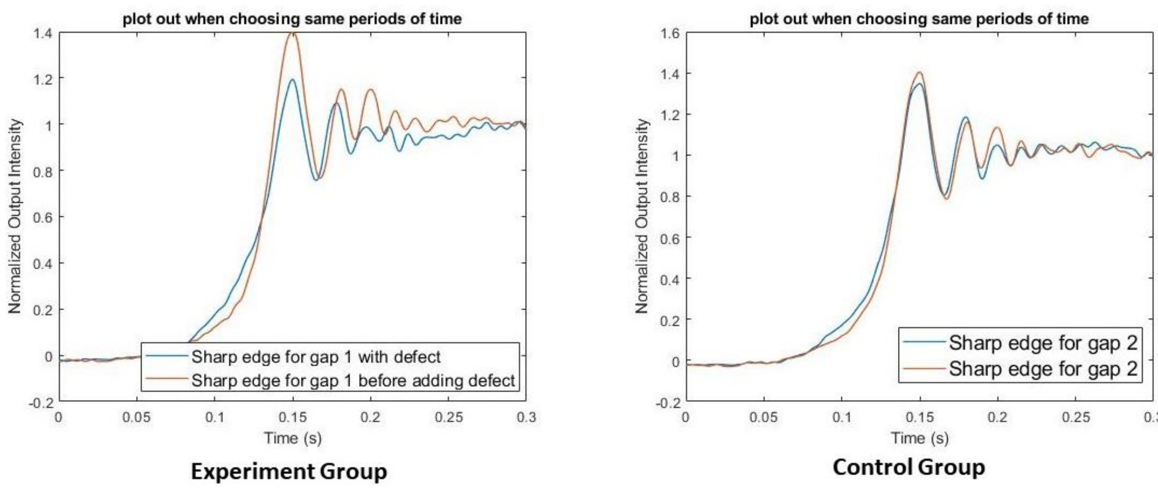

FIGURE 4. Knife-edge interferograms for (a) clear edge and defected edge on the photomask, (b) clear edge scanning twice for the control group.

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