Measurement of microstructures to super resolution by focus probe

Kuang-Chao Fan, Liang-Chia Chen

Department of Mechanical Engineering
National Taiwan University
1, Sec. 4, Roosevelt Rd., Taipei, 10617, Taiwan
Tel.: +886 [2] 2362-0032 Fax: +886 [2] 2364-1186 E-mail: fan@ntu.edu.tw

Abstract

The edge detection of microstructures by microscopes is poor in resolution due to the effect of diffraction limit. This paper proposes a new technique by using the focus probe in association with a nanopositioning stage. The edge is detected by the total energy reflection principle and the step height is detected by the astigmatic principle. Both methods can realize the resolution of 1 nm. Experimental results show that for the edge detection of micro cavities and the measurement of micro linewidth, the standard deviation is less than 40 nm. For the step height measurement, the standard deviation is less than 22 nm. This novel super resolution technique is a breakthrough of the conventional diffraction limit.

Keywords: Focus probe, nanopositioning stage, super resolution, edge detection, step height

1. Introduction

As the miniaturized microstructures are fabricated by advanced processes, such as MEMS, micro machining, lithography, nano-imprinting etc., conventional methods are no more capable to measure the physical dimension. Diffraction limits around half the wavelength in the far-field physically inhibits imaging of nanostructures with visible light [1]. Many superresolution methods to extend the limit are all of the image-based optical metrology, such as the through-focus technique [2, 3], scatterfield microscopy [4], stimulated emission depletion (STED) microscopy [5], fluorescence photoactivated localization microscopy (PALM) [6], absorbance modulation imaging (AMI) [7], phase modulation microscopy [8], etc. These are either based on the statistical approach or required complicate optical system. Although electron and X-ray microscopy could provide nano-scale imaging, vacuum requirement is a necessary condition.

In this paper, a new technique by using the focus probe in association with a nanopositioning stage is presented for the edge detection of micro cavities and the step-height measurement of a thin film. The edge is detected by the total energy reflection principle and the step height is detected by the astigmatic principle. Both methods can realize the resolution of 1 nm. Experimental results show that for the edge detection of micro cavities and the measurement of micro linewidth, the standard deviation is less than 40 nm. For the step height measurement, the standard deviation is less than 11 nm. This novel super resolution technique is a breakthrough of the conventional diffraction limit.

2. Measurement principle

2-1 Microcavity measurement

The principle of edge detection of a cavity is simply based on the light reflection theory. When a beam spot is focused on the surface, the total light will be reflected back to the receiver. While the spot is moved across the edge of the surface, only partial light will be reflected back. Fig. 1 shows the situation when the spot has passed a distance (x) from the edge (CD) of the surface W. The amount of reflected light is proportional to the remaining spot area on the surface. Let the radius of the spot be r (x < 2r), the sector area of OAF is $r^2 \theta$.
and the triangular area of AOF is $r(r-x)\sin \theta$. The remaining area of the spot on the surface can be expressed by Eq. (1).

\[
A(x) = \pi r^2 - r^2 \theta + r(r-x)\sin \theta
\] (1)

![Diagram](image)

Fig. 1. (a) The focused spot moving across the edge, (b) spot area at edge.

The total reflected light intensity received by the photodetector is proportional to the reflected area of the spot. Its relationship is plotted in Fig. 2. It shows that when the spot is on the surface ($x = 0$) the received light intensity is 100%. This intensity will decay gradually and vanish when the spot is entirely out of the surface. The theoretical slope of this characteristic curve can be plotted in Fig. 3. It can be seen that the ideal edge position corresponds to the minimal slope point ($x = r$).

![Graph](image)

Fig. 2. Optical intensity of received light.  
Fig. 3. The slope of the intensity curve.

2-2 Step-height and linewidth measurement

The step height measurement of a thin film is based on the astigmatic principle of the focus probe. As shown in Fig. 4, if the measurement surface is near to or far away from the focal point, the image of the beam on the photodiode becomes elliptically shaped in different orientations (Fig. 4, plane1 and plane3). If the measured surface is in focus, the image becomes circular (Fig. 4, plane2). The photodiode outputs focus error signals (FES) based on the astigmatic principle, as expressed by Eq. (2) [9].

\[
FES = (V_A + V_C) - (V_B + V_D)
\] (2)

According to the beam spot distribution among the four quadrants, the linear part (1-2-3 in Fig. 4) of the focus error signal (FES) is used to measure the height of the object after calibration.
For the edge detection of a step-height when the focusd spot is passing through the edge, a sequence of steps is illustrated in Fig. 5. Before contacting the edge, the total reflected intensity of the light remains, while crossing the edge partial light will be blocked by the height of the side wall so that the total reflected intensity decreases. When the focused spot moves into the edge by a distance $d$, the total reflected intensity is a function of $d$ and is minimum when the focal point reaches the edge, as shown in Fig. 6.

3. Experimental results

Several microstructures were measured. The focus probe was modified from a blue ray DVD pickup head and the movement of the object was carried out by a nanopositioning stage, which has 1 nm resolution and 15 mm travel range [9]. The stage was moved at an incremental step of 0.1 μm. For the edge detection of a cavity, a mirror having sharp edge was tested. Figure 7 shows quite a good repeatability for five times of measurement. The detected average edge position within the EF zone is 2301.8 nm and the standard deviation is 26.1 nm.
This demonstrates the capability of edge detection of the developed system. Figure 8 shows the results of a trench width measurement for four times. The average value is 30.016 μm with the standard deviation of 26.3 nm. Figure 9 shows the step-height and linewidth measurement of a VLSI thin film template. The measured linewidth is 101.318 μm on average with standard deviation of 31.5 nm, and measured step-height is 1.954 μm on average with standard deviation of 21.1 nm.

4. Conclusion

In this paper, a new method for edge detection, linewidth and step-height measurements are proposed based on the astigmatic principle and total reflected intensity of a focus probe assisted by the nanomotion of a linear stage. Experimental results show good accuracy and repeatability. The system is simple in structure. It has the potential for on-line practice.

References