Adjustable plane mirror interferometer adapted for microelectronic mask with different thickness

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Abstract: Plane mirror interferometers are usually utilized to nano-position large-range scanning stage in microelectronic mask measurement systems. To avoid Abbe-error the centerline of measurement light beams of X Y Z should be intersected at the upper surface of the mask. But the different thickness of masks can also lead to Abbe-errors. In this paper a novel plane mirror interferometer is designed, in which the measurement centerline can be accurately adjusted in coincidence with the upper surface of the mask according to their different thickness. The Abbe arm of this interferometer can be decreased to zero and the Abbe-error is avoided completely. The range of different thickness that can be adapted in this interferometer is ±3mm. In this paper a quadrant photoelectric cell adapter is used to measure the centerline of the measurement light beams and the uncertainty of this method is better than 0.02mm, which can meet the needs of nano-positioning of microelectronic mask measurement.

1. Introduction

As the semiconductor industry moves toward 90-nm silicon technology, more and more efforts have been made in the area of profile measurement such as inspecting the line width, step height, film thickness, etc.\textsuperscript{1,2} In a 2-d microelectronic mask measurement system plane mirror interferometers are utilized for precision positioning. The molecular measuring machine was designed in the National Institute of Standard Technology(NIST) in 1990s, and the coupling and differential interferometers, which have a resolution of about 75nm, are employed to position the stage.\textsuperscript{3} 2-d microelectronic mask measurement system LMS-2020PTB, which used 2-d plane mirror interferometers to position the stage, was developed by PTB in 1990s.\textsuperscript{4}

In a 2-d microelectronic mask measurement system the centerline of measurement light beams of X Y Z should be intersected at the upper surface of the mask to avoid Abbe-error. But the different thickness of masks can also lead to Abbe-errors. In this paper a novel plane mirror interferometer is designed, which has a measurement centerline that can be accurately adjusted in coincidence with the upper surface of the mask according to their different thickness. The Abbe arm of this interferometer can be decreased to zero and the Abbe-error is avoided completely.

2. Principle and System Setup

In this paper the configurations of the plane mirror interferometer, which can be utilized to position the 2-d microelectronic mask measurement system is demonstrated in Fig 1. We use a transverse...
Zeeman He-Ne laser as the light source, which emits an orthogonally linear-polarized beam including P component and S component. Part of the beam is directly polarized and received inside of the Zeeman laser to act as reference signal \(S_r\) (Not demonstrated in Fig. 1). P component and S component are separated by polarized beam splitter (PBS). P component is reflected by PBS acting as reference light and S component passes through PBS on the spot of \(S_1\) acting as measurement light.

Suppose the P and S component of the emitting light from the laser can be expressed as:

\[
E_p = E \cos \omega_p t
\]

\[
E_s = E \cos \omega_s t
\]

And \(S_r\) and \(S_m\) can be got as:

\[
S_r \propto E^2 \cos((\omega_p - \omega_s)t)
\]

\[
S_m \propto E^2 \cos((\omega_p - \omega_s)t + (\Phi_p - \Phi_s))
\]

\[
\varphi_p = \psi_{p1} - \psi_{p2}
\]

\[
\varphi_s = \psi_{s1} - \psi_{s2}
\]

Where \(\Phi_p\) and \(\Phi_s\) are the phase delay of reference light and measurement light separately. The displacement \(L\) of the table of the microelectronic mask measurement system corresponds to \(\Phi_p\) and \(\Phi_s\), as is demonstrated by:

\[
L = \frac{\Phi_p - \Phi_s \cdot \lambda}{2\pi} \cdot \frac{1}{4}
\]

From Eq.(6) we can get a resolution of 0.05nm for displacement discrimination when the phase meter with a resolution of 0.1° is adopted.

3. Characteristic of the plane mirror interferometer

The height of the plane mirror interferometer can be adjusted according to the thickness of the mask specimen. So the centerline of the measurement light can be accurately adjusted in coincidence with the upper surface of the mask and the Abbe arm of this interferometer can be decreased to zero and the Abbe-error is avoided completely.
Figure 2. Demonstration of the spot on plane mirror and cube corner

For a special mask specimen (default mask specimen of the measurement system) adjust the height of the plane mirror interferometer to make the centerline of the measurement light in coincidence with the upper surface of the mask. The spot of the measurement light on the plane mirror and that of the reference light on the cube corner are demonstrated in Fig.2 (1). Dashed line A means the upper surface of the mask specimen. A different mask specimen has a different thickness. When the upper surface of the mask specimen is higher (demonstrated as dashed line B in Fig.2) or lower (demonstrated as dashed line C in Fig.2) than that of the default specimen mask, adjust the interferometer to make the spot of the measurement light on the plane mirror and that of the reference light on the cube corner are shown in Fig.2 (2) or Fig.2 (3).

As the size of the beam is about 6mm and the clear aperture of this interferometer is about 20mm, the height of the mask specimen which can be measured is \( H_d \pm 3\text{mm} \) (\( H_d \) is the default height of the system). So the working range of this microelectronic mask measurement system can achieve \( 150 \times 150 \times 6\text{mm}^3 \), meeting the needs of most of the mask specimens’ measurement.

4. Experimental Results

4.1. Light centerline measurement

When the upper surface of the mask is higher than that of the default height of the specimen, just like the demonstration in Fig.2 (2), the height difference of the measured mask and default mask must be equal to half of the vertical distance between two measurement lights projecting on the plane mirror shown as Fig.3.

A quadrant photoelectric cell (QPC) adapter is used to measure the centerline of the measurement light beams. The QPC can be fixed on the micromotion unit. Adjust the micromotion unit to make the difference of U1 and U4 be zero, so the light beam projects on the center of the QPC exactly. From this kind of measurement the vertical distance between centerlines of two light beams can be achieved as shown in Table 1.

|   | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | sd  |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| d | 3.14| 3.18| 3.16| 3.19| 3.21| 3.17| 3.18| 3.16| 3.16| 3.17| 0.02|
The uncertainty of this method is better than 0.02mm, which means that the Abbe-arm caused by different thickness of the mask specimens is less than 0.02mm.

Figure 5. Stability test of the interferometer in one hour

4.2. Stability test of the interferometer
First we investigate the stability of the plane mirror interferometer, which is achieved by keeping the 2-d stage unmoved and recording the output of the interferometer automatically. The stability result in one hour is shown in Fig. 5. The drift is less than 4.0nm.

5. Conclusion
In this paper a novel plane mirror interferometer is designed, in which the measurement centerline can be accurately adjusted in coincidence with the upper surface of the mask, according to their different thickness. The Abbe arm of this interferometer can be decreased to zero and the Abbe-error is avoided completely. The range of different thickness that can be adapted in this interferometer is ±3mm. In this paper a quadrant photoelectric cell adapter is used to measure the centerline of the measurement light beams and the uncertainty of this method is better than 0.02mm, which can meet the needs of nanopositioning of microelectronic mask measurement.

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