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A New Mask-To-Wafer Alignment Technique for A-Quarter-Micron SR Lithography

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A new optical-heterodyne detection method of mask-wafer displacement has been developed. This method measures the phase difference between light beams diffracted from three gratings arranged symmetrically. With a 0.76 μm-grating system and a He-Ne laser, the sensitivity better than 0.005 μm was obtained independently of the mask-wafer gap variations. With this method, a prototype aligner system having vertical mask and wafer stages was constructed. The alignment accuracy better than 0.01μm was achieved.

1. Introduction

Lithography using synchrotron radiation (SR) is a promising replication technology for a-quarter-micron patterns. Precise alignment between the mask and the wafer is a key technique for the SR lithography.

The alignment using two gratings with the same period was first proposed by Flanders *et al.*.[1] The alignment signal in this method, however, is strongly affected by the mask-wafer gap variations.[2,3] A holographic method[4] using two coherent laser beams is independent of the gap variations. This method, however, only align the mask or the wafer to the interference fringe generated by the beams; direct alignment is impossible.

We report the performances of a fine alignment system constructed with a newly-developed displacement-detection method. The displacement-detection method uses three gratings and has high precision independently of the mask-wafer gap variations.

2. Displacement-detection method

The principle of the present detection method is schematically illustrated in Fig.1. A transmission grating G_1 with a period d_1 is formed on the mask and two reflection gratings G_2 and G_2' with a period d_2 are formed on the wafer with an interval S. The periods of the gratings G_2 and G_2' are the same with each other. The period of G_1 is 1.5 times as large as that of G_2 and G_2'. The whole grating system is normally illuminated by a light beam u_i consisting of two orthogonally-polarized components with respective frequencies of f_1 and f_2. These components are mutually coherent; by making them interfere, beat with a frequency of $|f_1-f_2|$ is obtained. The frequency $|f_1-f_2|$ is selected so small that the beat signal is easily detected. The light u_i is diffracted by G_2 or G_2' ($u(\pm 1)$ in the figure), and

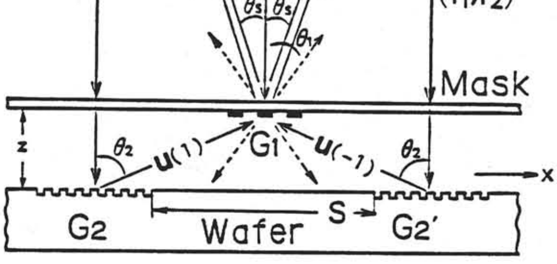

Fig. 1 Principle of displacement measurement.

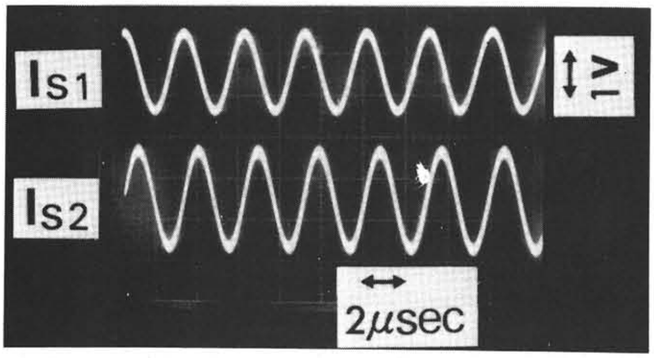

Fig. 2 Photograph of the beat signals observed by an oscilloscope. Beat frequency is 344 kHz.

then diffracted by G_1 in the direction of θ_s ($u(\pm 1,\mp 1)$, $u(\pm 1,\mp 2)$ in the figure). The angle θ_s is obtained from the following equation,

$$2d_1\sin\theta_s=\lambda\ , \qquad (1)$$

where λ is the wave length of u_i.

The present method measures the path-length difference between $u(\pm 1,\mp 1)$ and $u(\pm 1,\mp 2)$ through the intensity and the phase of the light signals, I_{s1} and I_{s2}, which beat with a frequency of $|f_1-f_2|$ after the analyzers. In this configuration of gratings, this path-length difference depends only on the relative displacement in the lateral direction x but does not depend on the mask-wafer gap z, in principle. The amplitudes of the beat signals vary sinusoidally with x with a period a half of that of the gratings G_2 and $G_{2'}$[5]. The phase difference between the beats in I_{s1} and I_{s2} is expressed as,

$$\phi=2\tan^{-1}[(\alpha-\beta)\sin 2\delta\ /\ \{1+(\alpha+\beta)\cos 2\delta+\alpha\beta\}], \qquad (2)$$

where, $\delta=2\pi x/d_2$. The coefficient α is the diffraction amplitude ratio of G_1 (the second order to the first order) for the f_1 component and β is that for the f_2 component. For $x \ll d_2$,

$$\phi=8\pi x(\alpha-\beta)/\{1+\alpha+\beta+\alpha\beta)d_2\}\ . \qquad (3)$$

We can detect the lateral displacement x by measuring the intensity of the light signals or the phase difference ϕ. The zero displacement is judged by the maximum of the intensity or the zero in the phase difference. The reverse arangement of the gratings, where G_1 is formed on the wafer and G_2 and $G_{2'}$ are formed on the mask, gives the same result and can be used for displacement detection.

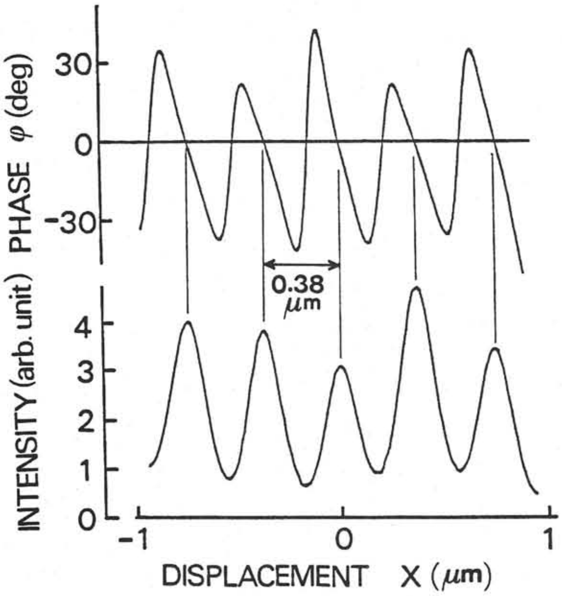

Fig. 3 The intensity and the phase difference measured as a function of the lateral displacement between the mask and the wafer. The mask-wafer gap is 62.2 μm.

In order to evaluate the present displacement-detection method experimentally, the following gratings were prepared. The transmission grating G_1 consists of 21 lines of tungsten formed[6] on a 400 μm-thick quartz plate. The reflection gratings G_2 and $G_{2'}$ consist of 40 grooves formed on a Si wafer. The periods

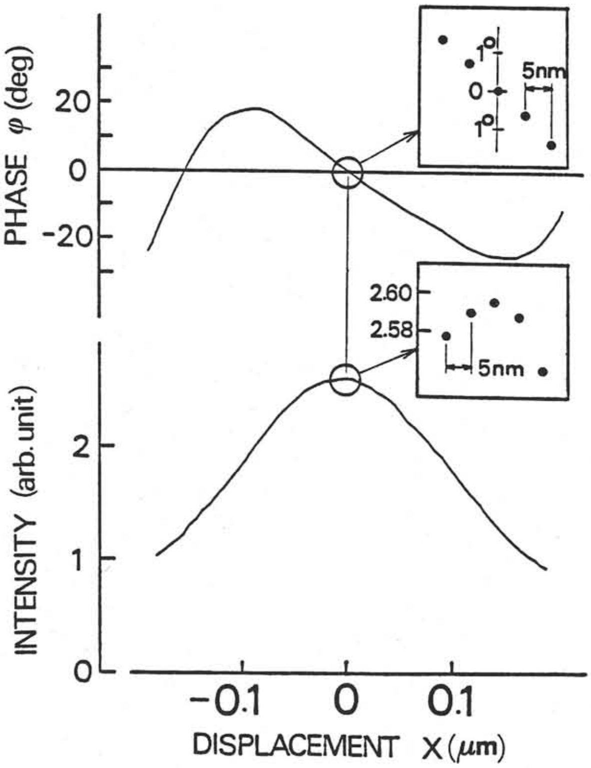

Fig. 4 Detailed results of the displacement measurement. The mask-wafer gap is 60.0 μm.

of G_1 and $G_2(=G_2')$ are 1.14 and 0.76 μm, respectively. The interval S is about 58 μm. In this period condition, the direction of the signal light, θ_s, is 16.1° for the wave length λ =0.6328 μm of a He-Ne laser.

A transverse-mode He-Ne Zeeman laser (Asahi Bunko, STZL-II) was used for a light source of u_i; the beat frequency $|f_1-f_2|$ is 344 kHz. The light signals were measured with photomultipliers. A universal counter was used for the phase measurement.

An example of the beat signals, I_{s1} and I_{s2}, are shown in Fig.2. A band pass filter for 344 kHz was used to reduce the electrical noise. The shape of the signal is so clear that the error in the phase measurement is within ±0.2°

The phase difference ϕ measured as a function of the displacement x for the gap of 62.2 μm is shown in Fig.3 together with the intensity of I_{s1}. As seen in the figure, the position where $\phi=0$ exactly coincides with the position where the intensity is maximum. This feature is advantageous for precise alignment, because the error in the phase measurement decreases with the increase of the signal intensity. Figure 4 shows the details of the signal intensity and the phase difference for the gap of 60.0 μm. As shown in the figure, the present method has a detection sensitivity better than 0.005 μm. The sensitivity is not affected by the mask-wafer gap variations.[5]

3. Mask-to-wafer alignment

We have constructed a prototype aligner system. This system has vertical mask and wafer stages because SR is horizontally emitted. The schematic diagram of the system is shown in Fig.5. The mask stage has four fine-movement mechanisms (z and three rotations around x, y, z axes in the figure) and three coarse movement mechanisms (x, y and z translation). The wafer stage has an x-direction fine movement and four coarse movement mechanisms (x, y, z and rotation around z axis). The mask and the wafer are held by vacuum chucks.

All the fine movements are performed with piezoelectric transducers (PZT) controlled by a micro-computer through GPIB interface bus. The movement of the wafer stage in x-direction is con-

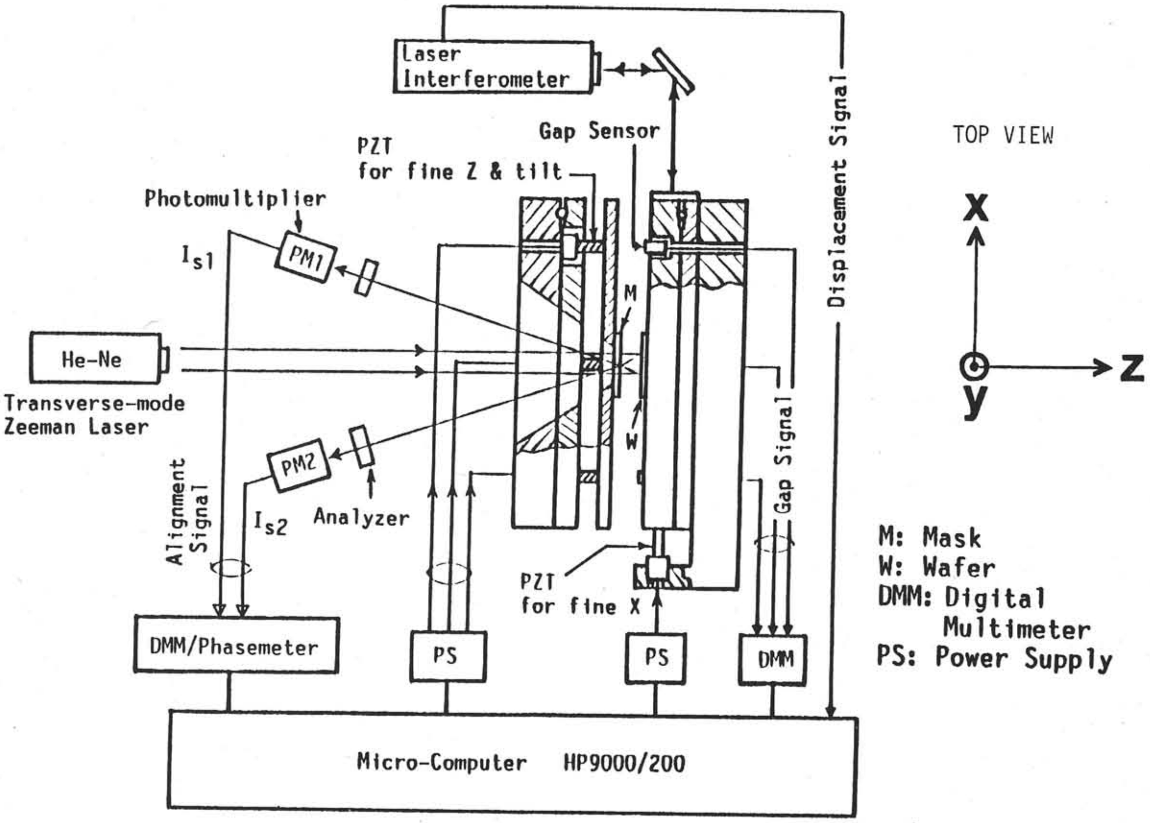

Fig. 5 Schematic diagram of the prototype aligner system.

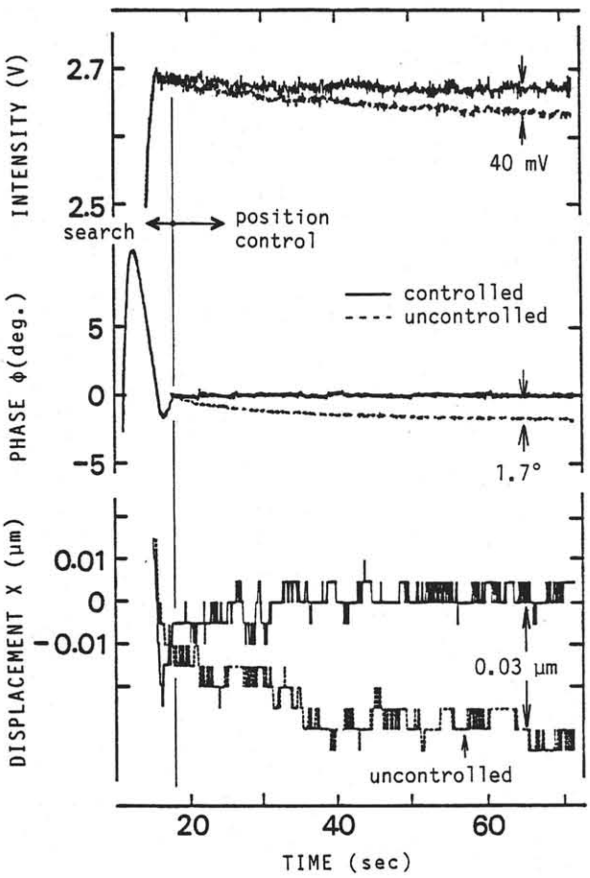

Fig. 6 Result of an alignment experiment. The mask-wafer gap is 62.2 μm.

trolled with a step of 0.0025 μm and is monitored with a laser interferometer (HP, system 5527A) of 0.005 μm-resolution. The gap between the mask and the wafer stages is controlled with three PZTs having 18 μm stroke attached to the mask stage and is detected by three gap sensors with 0.1 μm resolution, which measure the inductance change due to eddy currents.

In advance of the fine alignment, the mask and the wafer are prealigned manually by observing them through an optical microscope with a TV monitor. The fine alignment is performed by the following procedure; the wafer stage is first moved with the PZT to maximize the intensity of the light signal (position search) and then finely feedback controlled to keep the phase difference φ zero (position control).

An example of the alignment experiments in x direction at the gap of 62.2 μm is shown in Fig. 6. In the figure, the movement of the wafer stage is shown as a function of time, together with variations of the intensity and the phase difference. In the experiment, the threshold in the phase difference for the feedback action was set ±0.25°, which is slightly larger than the fluctuation (±0.2°). One can see in the figure that the alignment accuracy is better than 0.01 μm.

4. Summary

We have developed a new detection method of the lateral displacement between the mask and the wafer using the three-grating system and have succeeded in fine alignment with an accuracy better than 0.01 μm.

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