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An Automatic Mask Alignment System Using Moirë Sensors

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Abstract

An alignment system in the X- and Y- directions using an X-Y-θ stage driven by piezoelectric actuators is presented. A pair of quadruple gratings and a quadruple photo-detector are used. The difference between the two 0-th order moiré signals in reflection with a relative spatial phase of 180° is used in each direction to control the alignment of the X-Y-θ stage. The stage is aligned at the position where the difference is zero. The quadruple gratings are 10 mm × 10 mm, and of a binary square-type with a 1/2 duty cycle. Their pitches are 16 μm. Alignment accuracy of ±20 nm was obtained in this system.

1. Introduction

There are many demands for high resolution in the lithographic processes to reduce the minimum feature size of micro-circuits for VLSI. X-ray lithography is a promising method for these demands. For the use of X-ray lithography as a practical VLSI fabrication, highly accurate alignment of successive masks is required. Therefore, several methods have been proposed as the alignment systems.

King and Berry[1] first applied the moiré technique to photo-lithographic mask alignment and obtained an alignment accuracy of 200 nm. Since then, several alignment methods were proposed using moiré technique in different ways and an alignment accuracy better than 100 nm was obtained.[2] The alignment is usually carried out by detecting a minimum point of the intensity of the moiré fringe. However, the change of the intensity is not sensitive to the relative displacement around this point. On the other hand, it has been shown that sensitivity is considerably improved by using the difference between two moiré signals 180° out of phase.[3-6] Since the detection of the correct alignment is determined at the position where the variation of the moiré signal intensity relative to the displacement of the gratings is at a maximum, the alignment accuracy is very high.

They were aligned in the one direction by using a stage driven by a stepping motor. This paper presents an alignment system in the X- and Y- directions using an X-Y-θ stage. The stage is driven by piezoelectric actuators. It is aligned at the position where the difference of two moiré signals, 180° out of phase, is zero. A pair of quadruple gratings and a quadruple photo-detector are used. Therefore, this alignment system is highly accurate. Either a transmission method or a reflection method for the detection of the moiré signals is practically usable in the above system. In this experiment a reflection method was used.

2. Alignment Method

Figure 1 shows the fundamental of the alignment system. Transmission method and reflection method are shown together. Two pairs of gratings with spatial phase difference of 180° between them are used. The beams diffracted by the two grating pairs. The 0-th order beams from the two pairs of gratings are received by two photo-

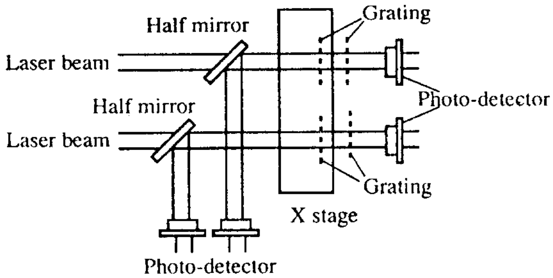


Fig. 1 Fundamental of the alignment system.

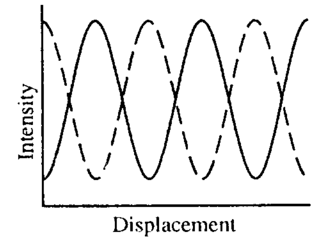


Fig.2 Intensities of the moiré signals 180° out of phase each other.

detectors. When the X stage is moved, two moiré signals which are 180° out of phase with each other appear as shown in Fig.2. The maximum contrast of the moiré signal is obtained under the Fourier image conditions. [7] The contrast varies periodically within the Fresnel zone with an increase in the gap between the two gratings. When two gratings are set at the vicinity of a gap value of mP^2/λ, most contrary sine-wave moiré signals are obtained. Here, m is an integer, P is the pitch of the gratings, and λ is the wavelength of the light. The position where two moiré signals are equal in intensity is a reflection point of the moiré signals and the slope of the signals is steepest at that point. Therefore, high sensitivity is obtained in alignment. Furthermore the position is not influenced by the minor change of the gap length between the two gratings.

3. Development of the Alignment Apparatus

Figure 3 shows the construction of the alignment apparatus. The first grating is fixed on the X-Y-θ stage driven by piezoelectric (PZT) actuators, and the second grating is fixed on the rough stage. The X-Y-θ stage is supported by parallel wire springs. Two PZT's and two compressive springs are located perpendicularly at each apex of the stage. Four sets of PZT's and compressive springs push against each other. The stage is controlled with three degrees of freedom in the X, Y, and θ directions with high resolution by controlling the voltages applied to the PZT actuators. For example, the PZT_A is activated and the PZT_C is deactivated simultaneously to move the stage in the X direction. Similarly, the PZT_B and the PZT_D are used to move the stage in the Y direction. The PZT_A and the PZT_C are activated or the PZT_B and the

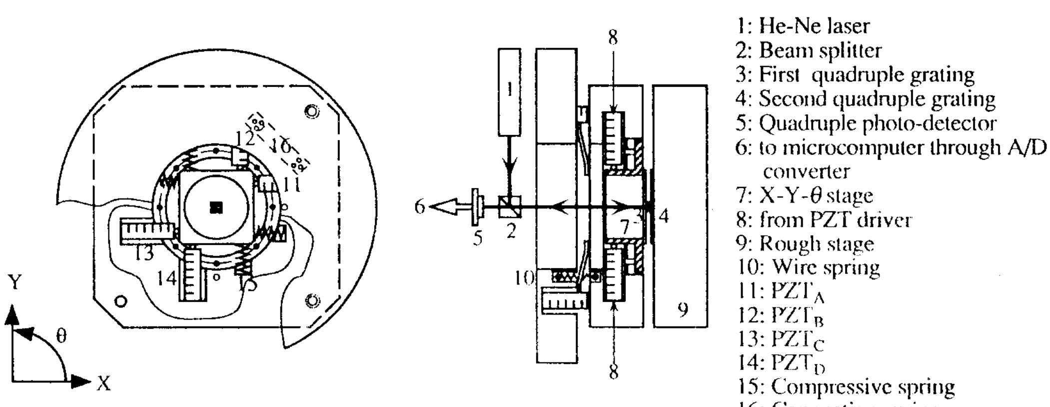


Fig.3 Construction of the alignment apparatus.

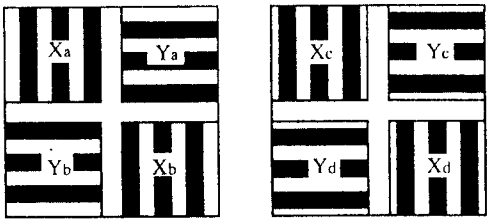


Fig.4 Quadruple gratings. The pitches of each grating are magnified.

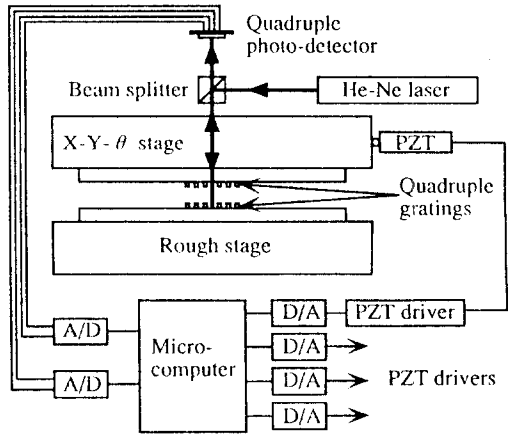


Fig.5 Schematic diagram of the alignment system.

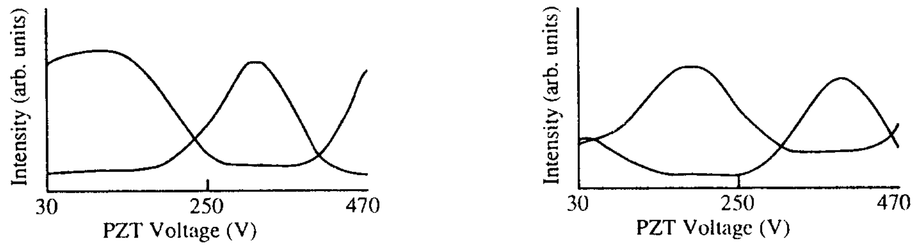
PZT_D are deactivated simultaneously to move the stage in the θ direction.

Figure 4 shows the first and second quadruple gratings fixed on the X-Y-θ stage and the rough stage, respectively. The pitches of each grating are magnified in this figure. They are 10 mm × 10 mm, and of a binary square-type with a 1/2 duty cycle. Their pitches are 16 μm. Each grating is formed by electron beam lithography under the same conditions. The gratings are fixed at the position that the gratings X_a, X_b, Y_a and Y_b overlap the gratings X_c, X_d, Y_c and Y_d, respectively. The grating pairs $X_a X_c$ and $X_b X_d$ are spatially out of phase 180°, and they are used for the alignment in the X direction. The grating pairs $Y_a Y_c$ and $Y_b Y_d$ are also out of phase 180° spatially, and they are used for the alignment in the Y direction.

Figure 5 shows the schematic diagram of the alignment system. A light beam of the He-Ne laser (632.8 nm) is diffracted by the quadruple gratings. The 0-th order beams from the two gratings are detected by the quadruple photo-detector. The four signals are amplified by pre-amplifiers. RC filters with a time constant of 0.4 s is introduced to reduce the noises present in the pre-amplifier outputs. The signals are converted into digital signals by the A/D converters. The converted signals are transferred to the computer. The difference between the moiré signals by the two grating pairs $X_a X_c$ and $X_b X_d$ is calculated, and the X-Y-θ stage is controlled by the PZT_A and the PZT_C in the X-direction in order to compensate the difference of the two signals. Similarly, the X-Y-θ stage is controlled in the Y-direction by the PZT_B and the PZT_D in accordance with the difference between the moiré signals by the two grating pairs $Y_a Y_c$ and $Y_b Y_d$. The differences between the signals are compared with predetermined upper and lower reference values. The stage is moved stepwise until the difference between the signals comes within the reference values simultaneously in the X- and Y-directions. Therefore, the alignment precision of the present system depends on the reference value and one step displacement of the stage. The resolutions of the A/D converters are 12 bits. The PZT's are controlled in the range of the applied voltage from 20 V to 500 V.

4. Results and Discussions

The moiré signals obtained by moving the stage in the X- and Y-directions are shown in Fig.6 (a) and (b). The horizontal axis shows the voltages applied to the PZT's and the vertical axis shows the intensities of the moiré signals. Good contrast and a high S/N ratio have been



(a) X-direction.

(b) Y-direction.

Fig.6 Moiré signals obtained by moving the stage in X- and Y-directions.

obtained for the intensity of the 0-th order moiré signal. Since the moiré signal changes with the pitch of 16 μm, the pre-alignment range is 16 μm. The asymmetry of the moiré signal is due to the well known hysterysis phenomena in PZT.

Figure 7 shows an example of the automatic alignment. The horizontal axis and the vertical axis show the time and the displacement calculated using the data of the moiré signals, respectively. The solid line and the broken line show the alignment in the X-direction and the Y-direction, respectively. The two broken lines show the upper and lower pre-decided reference values. The actual displacement corresponding to the reference value is given by the following equation.

$$\Delta x = k \cdot I_{ref} \qquad (1)$$

Here I_{ref} is the reference value, and k is the gradient of the difference value between the two moiré signals to the displacement. In this system, it is calculated to be ±20 nm, and the noise amplitude of error signal is included between them. As shown in Fig. 7, the stage is controlled toward the desired position automatically, and even if the system gets out of the correct position by disturbance or vibration, it is again controlled toward the desired position automatically. The alignment time is about 3 minutes. The alignment accuracy of this system is concerned with the pre-decided reference values I_{ref} and the value k. The reference values are restricted by the noise amplitude of error signal. Therefore, to improve the alignment

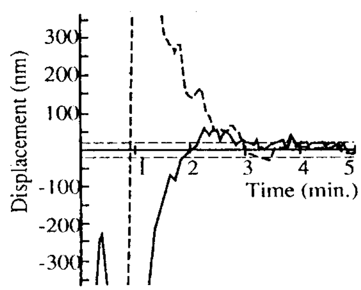


Fig.7 Example of the automatic alignment.

accuracy of the system, it is necessary to improve the *S/N* and stability, and to decrease the pitch of the gratings. The alignment time depends on several factors of the system. The main factor is the noises present in the pre-amplifier outputs, which determines the time constant of the RC filters. Therefore, to improve of the alignment time, it is again necessary to improve the *S/N* and stability of the system.

5. Conclusions

An alignment system in the X- and Y- directions using an X-Y-θ stage driven by piezoelectric actuators has been developed. A pair of quadruple gratings and a quadruple photo-detector has been used. The difference between the two 0-th order moiré signals in reflection with a relative spatial phase of 180° has been used in each direction. An alignment accuracy of ±20 nm was obtained.

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