6-axis alignment based on analysis of far-field patterns diffracted from cross grating pair

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A novel 6-axis alignment technique based on image analysis of far-field patterns diffracted from two adjacent cross grating sensors is proposed in this paper. Two cross gratings with different groove density are attached to the mask and substrate respectively. Collimated monochromatic laser beam impinges onto the abutted boundaries of the two gratings and the diffraction beams in no less than 3 diffraction orders are focused by a lens. Rayleigh interference far-field patterns (RIFFPs) are formed on the focus plane of the lens and recorded with a CCD detector. The intensity distributions of the RIFFPs are analyzed for separating and detecting the 6 alignment errors between two cross gratings. The alignment procedure is designed after theoretical analysis and simulation.

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1. Introduction

Positioning and Alignment with ultrahigh resolution (submicron or even nanometer scale) is of great importance in precision engineering, especially in the field of microelectronics and nanotechnology. Proximity- or contact-lithography systems are prospective micro-manufacturing systems because they can help reduce the feature size of integrated circuits to less than 10 nm. In these systems, alignment in X and Y direction, and controlling of the azimuth, tip, tilt angle and gap of the mask relative to the substrate, i.e. six-axis alignment is essential. However, most of the current alignment schemes, including image processing, interferometry adopting gratings, or Moire technique, only focused on X-Y-θ 3-axis alignment. A novel 6-axis alignment technique based on diffractions from two adjacent cross grating sensors is proposed in this paper. Image processing of the so-called Rayleigh interference far-field pattern (RIFFP) is adopted for the phase difference detection of two adjacent laser beams instead of interferometry.

2. Cross grating diffraction and Rayleigh interference far-field pattern

2.1 Systematic structure

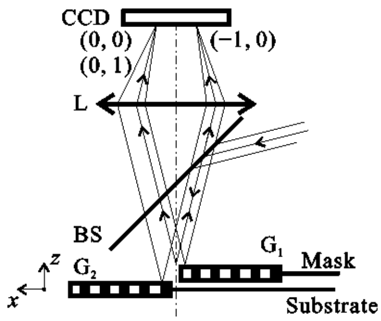

Fig. 1 Layout of the alignment system

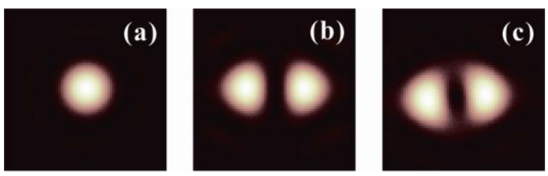

Fig. 2 Variation of the RIFFP with phase differences
(a) $\Phi=0$, $\varepsilon_x=0$, $\varepsilon_y=0$; (b) $\Phi=\pi$, $\varepsilon_x=0$, $\varepsilon_y=0$; (c) $\Phi=\pi$, $\varepsilon_x\neq0$, $\varepsilon_y\neq0$

As shown in Fig. 1, two grating sensors G_1 and G_2 are fixed in the surface of the mask and substrate respectively. They are set to overlap or be adjacent to each other in *x* direction. A collimated laser beam incident onto the adjacent boundaries after reflected by BS will be diffracted by the grating pair in different orders. We take orders (0, 0), (0, 1) and (−1, 0) for further detection, where i and j in the note (i, j) mark the order of diffraction because of the periodic structure along x and y direction, respectively. A lens L is inserted into the beams through BS and help generate Frounhofer far-field patterns on the focal plane. The patterns are the far-field interferences of two adjacent beams, and regarded as the Rayleigh interference far-field patterns. The RIFFPs are picked up with CCD and sent to computer for image processing.

2.2 Principles

6-axis alignment errors make different phase contributions to different diffraction orders from a cross grating. The diffraction rules of cross grating is the key to obtaining and distinguishing 6-axis alignment errors. Cross grating has periodic structure along two directions, typically perpendicular directions. Thus the diffraction from cross grating will be complicated than a normal grating. The 3 kinds of phase differences between 2 beams diffracted from 2 cross grating with 6-axis alignment errors denoted as θ_x, θ_y, θ_z angularly, and Δx, Δy, Δz positionally around and along the corresponding axes are as follows.

, (1)

where $\Delta\varphi$, ε_x and ε_y denote the piston phase and angular dispersions in two perpendicular directions, respectively; the subscripts (i, j) still marks the order of diffraction; , , , ; (or) and (or) are the incident and diffraction angles in x (or y) direction, which can be conducted from the conical diffraction formula; and are the grating constant relative differences along x and y direction. Generally speaking, with comparison of (0, 0) and (0, 1) order diffractions, the effects of θ_y / θ_z and $\Delta y/\Delta z$ can be distinguished. Similarly, the effects of θ_x / θ_z and $\Delta x/\Delta z$ can be distinguished with (0, 0) and (1, 0) order diffractions. Therefore, only 3 diffraction orders are monitored for 6-axis alignment.

As to phase measurement, interferometry is a conventional approach but unfortunately the system will become too complicated if more than 3 pairs of wavefronts are monitored simultaneously. Image processing of RIFFPs similar with the method in Ref. [1] is adopted in this paper for phase difference measurement. Variations of RIFFP intensity with the phase difference are simulated and drawn in Fig. 2. The ideal RIFFP is an Airy disk (Fig. 2a). Generally two kinds of shape changes may appear. The split inside the pattern (Fig. 2b) implies the piston phase is not equal to integer multiple of 2π and a symmetric split is corresponding to odd multiples of π piston phase. If piston error exists with angular dispersions in two directions, the split across the pattern will incline (Fig. 2c). However, if piston error is present with angular dispersion in only one direction, the split will not incline. As a result, for preserving angular dispersions in two directions and detecting the angular alignment errors, the grating constants of the two gratings in both directions are preset to be slightly different from each other.

3. Alignment procedure

According to the above analysis, alignment error separation can be done through the following alignment processing.

Step 1: null θ_x with (0, 0) order -- adjust Δz to make a centered split in (0, 0) pattern; adjust θ_x to make the split vertical;

Step 2: null θ_z with (−1,0) order -- adjust Δx to make a centered split in (−1, 0) pattern; adjust θ_z to make the split vertical;

Step 3: fix Δz to be $(2n+1)\lambda/4$ with (0, 0) order – adjust Δz to make an exactly centered split in (0, 0) pattern;

Step 4: fix Δx to be $m_1 d_x$ with (−1, 0) order – adjust Δx to make an exactly centered split in (−1, 0) pattern;

Step 5: null θ_y with (0, 1) order – adjust Δy to make a centered split in (1, 0) pattern; adjust θ_y to make the split vertical;

Step 6: fix Δy to be $m_2 d_y$ with (0, 1) order – adjust Δy to make an exactly centered split in (0, 1) pattern.

4. Conclusions

A novel 6-axis alignment technique based on image analysis of far-field patterns diffracted from two adjacent cross grating sensors is proposed. The alignment procedure is designed after theoretical analysis and simulation.

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