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Novel metrology methods for image quality control

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Abstract

New metrology methods have been developed to characterize exposure tool performance: SPIN for monitoring lens aberration, *Z*-SPIN for focus measurement, and EFSCP for checking effective light source profile. These methods, with design intention directed to measurement accuracy, measurement speed, and process robustness, provide increased accuracy and reduced time by a factor of 15 and 1/6, respectively, compared to traditional SEM metrology. SPIN allows direct measurement of lens aberration, achieving reproducibility of 0.8 mλ RMS. *Z*-SPIN translates focus (i.e. displacement in *Z*-axis direction) into an *X*–*Y* shift. Reproducibility of *Z*-SPIN measurement mostly depends on repeatability of the metrology tool, i.e. overlay metrology tool, which is ~1 nm, and the measurement time of *Z*-SPIN is 1/8 of the conventional SEM measurement. EFSCP is a function to measure effective light source profile with high precision, achieving the repeatability of 0.00028 NAill for light source shift. While the traditional exposure tool performance inspections using SEM provide measurement reproducibility of 20 nm for IFD, 15 nm for astigmatism, and 2 nm for LR-CD, the new metrology methods provide 7 nm, 1 nm, and 0.3 nm, respectively, when estimated on the same scale. Also, the measurement result using the new methods shows very good agreement with the average of five SEM measurements for all the three inspection items. From this fact, it can be said that the traditional SEM-based inspection can be replaced by the new methods. To insure exposure tool quality in an appropriate manner, we at Canon recommend employing the new metrology methods in characterizing the exposure tool performance.

Keywords: Lens aberration monitor; Focus control; Effective light source; Exposure tool; Metrology

1. Introduction

The endless drive toward smaller geometries, as represented by ITRS [1], requires continuous efforts to enhance CD control capabilities of exposure tools. Key contributors to CD control are lens aberration, focus, and effective light source profile of the illuminator. Traditionally, inspections of these CD control factors are performed based on SEM measurements; lens aberration is examined by measuring astigmatism, image field deviation (IFD), and left–right CD difference (LR-CD). SEM-based inspections, however, provide measurement repeatability of 3.6 nm for CD and 20.7 nm for focus, which accuracy is unsatisfactory for the inspection of the CD quality currently required of the exposure tool. It is therefore necessary to establish alternative inspection methods with higher speed, higher accuracy, and greater process robustness which can replace SEM-based inspections. Considering this, Canon have developed the following new inspection methods:

(1) SPIN (Slant projection through a PINhole): Lens Aberration Monitor
(2) *Z*-SPIN (Zex type of SPIN): Focus Monitor
(3) EFSCP (Effective source check plus command): Effective Light Source Monitor

Astigmatism is characterized by Zernike coefficients [2] using SPIN [3], and IFD is checked by obtaining focus values at each field position using *Z*-SPIN [4]. Also, LR-CD is characterized by Zernike coefficients using SPIN and by effective light source profile using EFSCP [5]. In this paper, we will describe the principle and performance of the new methods and present some experimental results in comparison with conventional SEM tests.

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2. Metrology methods

The SPIN aberration monitoring method (SPIN method) allows representing lens aberrations as Zernike coefficients (36 terms) by measuring the positional shift of the rays passing through the wavefront with aberrations. The advantage of the SPIN method is that it enables aberration measurement made on an actual exposure tool instead of the use of PMI (Phase Measurement Interferometer). The *Z*-SPIN focus monitoring method (*Z*-SPIN method) determines the focal position based on the fact that the image of oblique incident beam is shifted by defocus. It has a benefit of extremely reducing exposure time per shot as well as measurement time, thereby realizing greater ease in averaging of multiple point measurements, resulting in high accuracy focus measurement. Also, it involves actual wafer exposure, so the exposure tool can be inspected in a state closer to the real process. The EFSCP function (EFSCP) observes the light flux from a point source at a defocused position using a photodetector located on the stage, and measures the effective light source profile. EFSCP has the advantage of remarkably reduced measurement time and improved repeatability. The details of the methods will be presented in the following sections.

2.1. SPIN (Slant projection through a PINhole)

The outline of the theory of SPIN aberration measurement is illustrated in Fig. 1. If wavefront is in an ideal state, namely a sphere, the beam converges on the optical axis at the image plane no matter where it passes through on the wavefront. However, if wavefront has aberrations, the image location is shifted from the optical axis at the image plane according to the amplitude of aberrations. By measuring this shift, the aberrations can be quantified in Zernike polynomials.

The actual SPIN method utilizes a SPIN mask. Fig. 2 is a schematic of SPIN measurement. The SPIN mask has unique YAMATO patterns on its bottom with pinholes on the top surface. The entire exposure area is covered with groups of the YAMATO patterns and pinholes so that lens aberrations can be measured across the field. When the mask is illuminated, the light passes through the pinholes and then illuminates the YAMATO patterns, which are arranged in a grid shape, and forms a grid pattern on the wafer. As the position of the grid pattern is shifted when the lens has aberrations, such displacement relative to the reference mark is measured to calculate Zernike coefficients. The YAMATO pattern is designed so that the diffraction light is kept to a minimum and the image is formed with the 0th order light alone to realize high sensitivity. As shown in Fig. 3, the YAMATO pattern has reduced diffraction light, compared to dense lines and isolated line features. With the YAMATO pattern and the dense lines, the ±1st order light goes outside the pupil aperture and the 0th order light only passes through the pupil.

Fig. 4 shows the linearity of Zernike terms C5 (astigmatism), C7 (coma), and C9 (spherical) of aberration measurement accuracy using SPIN. The experiment was done using Canon FPA-5000ES4.

The exposure tool allows arbitrary input of spherical aberration anywhere in the field and astigmatism and coma anywhere off-axis of the lens, and the graph represents SPIN measurements with respect to the input value. It shows that the SPIN measurement is almost linear to the

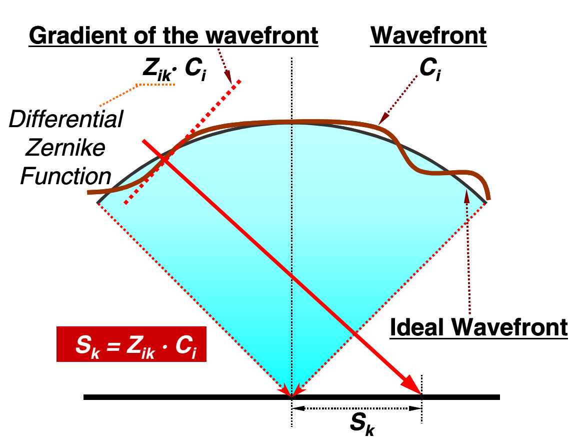

Fig. 1. Theory of aberration monitoring.

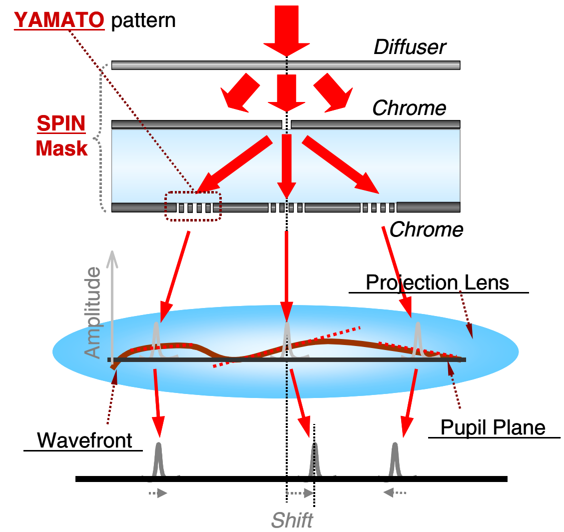

Fig. 2. Schematic diagram of SPIN method.

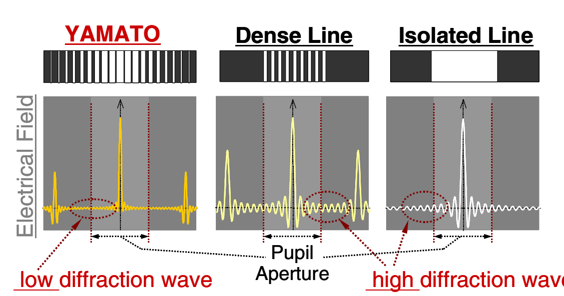

Fig. 3. Object spectrum at pupil plane.