Experimental EUV Exposure System using a Synchrotron Source

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Extreme ultraviolet lithography (EUVL) is an candidate for lithography technology to be used for the fabrication of the future-generation semiconductor devices with the design rule of 100nm and below. Till date few extreme ultraviolet (EUV) exposure experiments, which demonstrate a high resolution of less than 100nm using small field optics, have been performed. However, such a high resolution in the case of practical large-field exposure has not yet been reported. We designed a 3-mirror ring-field projection optics, which enabled large-field exposure. An EUV exposure experiment will be performed using an EUVL beam line to be constructed at the new synchrotron ring named New Subaru, which is now under construction by Hyogo Prefecture. In this paper the details of the EUV exposure tool will be described.

Key words: extreme ultraviolet lithography (EUVL), synchrotron radiation, multilayer mirror, aspheric mirror

1. Introduction

Shortening of the exposure wavelength and enlargement of the numerical aperture used in projection optics have resulted in the improvement of the resolution of optical lithography. Optical lithography resolution has been reduced by $1/\sqrt{2}$ every 3 years. The exposure machines using KrF excimer laser (wavelength of 248nm) have recently been introduced for the manufacture of 250nm-devices. ArF excimer laser (wavelength of 193nm) is expected to enhance the resolution of optical lithography down to 130nm [1]. The development of an exposure machine using ArF excimer laser is currently being aggressively pursued. However, in the wavelength region shorter than 193nm transparent materials are limited [2] and therefore, it will become difficult to maintain the past trend of optical lithography resolution improvement.

On the other hand, molybdenum/silicon (Mo/Si) multilayers exhibit high reflectivity near 70% in normal incidence at a wavelength of 13nm [3]. Extreme ultraviolet lithography (EUVL) is an exposure scheme using all-reflection optics constructed with multilayer mirrors with short wavelength radiation of 13nm [4-6]. By adopting EUVL, the trend of resolution improvement for the

manufacture of below-100nm devices can be recovered. High resolution of EUVL down to 50nm has already been confirmed [7, 8]. The development of large-field exposure optics is now required. Ring-field optics using aspheric mirrors with scanning exposure is the solution for meeting this requirement [9-11].

In the United States, EUV-LLC (a limited liability company) was established in Autumn 1996. EUV-LLC started the research and development program of EUV lithography systems in collaboration with national laboratories and private companies [12]. On the other hand, several fundamental research studies on EUVL have been performed by NTT [4, 13-17], Hitachi [18-20], SORTEC [8, 21-23] and Nikon [24-27], but systematic research and development on EUVL has not yet been organized in Japan.

2. EUV exposure tool

2. 1. Outline of the EUV exposure tool

Hyogo Prefecture is presently constructing a new synchrotron radiation ring named New Subaru at the Spring-8 site. Himeji Institute of Technology (HIT) is presently constructing a beam line for the research of EUVL. We have started the

development of a ring-field EUV exposure system using aspheric mirrors in collaboration with HIT, Hitachi, and Nikon [28]. It is planned to start the exposure experiments at this Autumn. The target of this research is high-resolution (100nm) and practical large-field (30x20mm) exposure using aspheric ring-field optics and scanning stages. The exposure system is equipped with a wafer-alignment system. We are planning to demonstrate device fabrication using EVUL. The specifications of the exposure system are listed in Table 1.

Table 1. Specifications of EUV exposure system.

Numerical aperture	0.1
Magnification	1/5
Resolution	0.1 μ m ($\lambda=13$ nm)
Depth of focus	1.9 μ m (0.1 μ m resolution)
Resolution limit	0.06 μ m
Ring field on wafer	30mm x 1mm
Alignment accuracy	30nm (3 σ)
Mask size	6inch
Wafer size	8inch
Scanning stage	In vacuum

2. 2. Light source and illumination optics

The parameters of the New Subaru synchrotron radiation ring are the circumference of 119m, electron energy of 1.5GeV and beam current of 500mA. The EUVL beam line is set up at a bending magnet of the ring. Photon flux of 10^{11} photons/sec/mrad²/mA/1%BW can be obtained. The ring-field illumination optics consists of an ellipsoidal grazing incidence mirror as shown in Fig. 1 [20]. The rays reflected from the ellipsoidal mirror converge with a cone shape on an entrance pupil of projection optics. A mask is placed so as to intersect the cone. The illumination area on the mask is arc shaped.

Fig. 1. Ring-field illumination optics using ellipsoidal mirror.

2. 3. Projection optics and exposure chamber

Figure 2 shows a schematic diagram of the projection optics. The projection optics constructed with 3 aspherical mirrors is a ring-field optics with the magnification of 1/5 and the numerical aperture of 0.1 [29]. On the wafer side the optics comprises a telecentric configuration, which prevents the image displacement in the occurrence of defocus. On the mask side the optics comprises a non-telecentric configuration in order to employ a reflection mask. The modulation transfer function (MTF) of the optics is over 75% at the spatial frequency of 5000 lines/mm. The image contrast is sufficient for resolving 100nm patterns. The depth of focus at this frequency is 1.9 μ m. The distortion of the optics is less than 10nm within the width of 1mm of the ring-field. Mo/Si multilayers, which reflect EUV radiation with the wavelength of 13nm, are coated on the reflection surfaces of each mirror.

Fig. 2. 3-mirror ring-field projection optics.

The maximum permissible root mean square (RMS) wavefront error of diffraction limited optics is $\lambda/14$ [30]. λ is the wavelength at which the optics is used. For the projection optics of EUVL, which is used at 13nm, the wavefront error should be less than 1nm RMS. In the case of extremely precise optics, the deformation of the mirrors due to gravity or stress of the multilayers cannot be neglected. We examined these deformations by the finite-element method (FEM) using a commercially available simulation code; I-DEAS. Figure 3 shows the examples of the calculated results [31, 32]. Figure 3 (a) shows the calculated deformation due to gravity. The deformation is concentrated in the neighborhood of the support point indicated with a triangle in the figure. The deformation due to the stress of the multilayers cannot be calculated directly, because boundary conditions are given as calculation parameters in FEM. Therefore, we employed the technique to replace stress deformation with thermal expansion.

Fig. 3. Deformation of mirrors calculated by FEM.

(a) Deformation due to gravity (M3),

(b) Deformation due to stress of multilayers (M2, M3)

Figure 3 (b) shows the calculated results. The maximum deformation was over 1nm when the stress of the multilayers was 100MPa. The deformation exceeded the permitted value, but a major part of the deformation occurs in the form of the change of the radius of curvature, which can be compensated by the alignment of the optics.

Figure 4 shows the schematic diagram of the EUV exposure chamber. The housing of the projection optics is a rigid cylinder, which is equipped with gimbaled support mechanisms and differential micrometers coupled to taper blocks that demagnify the motion. A reflection mask which consists of absorber patterns on a multilayer reflector is employed [19, 27, 33, 34]. A mask stage and a wafer stage, which are mechanical

scanning stages in vacuum, provide synchronous scanning motion. A fine alignment wafer stage with 6 degrees of freedom is also equipped. It employs piezoelectric transducers coupled to elastomechanical elements exclusively, which can withstand small displacements with no backlash. A wafer can be exchanged through the load-lock chamber. The housing of the projection optics, the wafer stage and the mask stage are supported on a vibration isolation bench, which is separated from vibration sources of the vacuum chamber and pumping unit [35].

Fig. 4. EUV exposure system.
(exposure chamber)

2. 4. Alignment system

Figure 5 shows the wafer-alignment system and focus detection system. TTR (through the reticle) alignment scheme, by means of which an alignment mark on a mask and an alignment mark on a wafer are observed simultaneously, is employed [36]. Visible light from a halogen lamp is introduced through a window in the vacuum chamber, and illuminates the wafer alignment mark and the mask alignment mark through the projection optics. An optical microscope and a CCD camera are used to observe the mask alignment mark by overlapping the projected image of the wafer alignment mark magnified by the projection optics. These alignment marks are coarse gratings. The Moire pattern generated by overlapping the two gratings is utilized for the displacement detection. As the projection optics is

telecentric on the wafer side, one half of the numerical aperture is used to pass the incident light rays and the other half is used to pass the reflected light rays on the wafer. The optics on the source side and the detector side in vacuum are placed on slide stages, which can move to the outside of the projection optics in order to prevent the interruption of the exposure radiation. The target alignment accuracy of the system is 30nm (3σ). Generally, chromatic aberration of projection optics is an error factor to be considered for the TTR alignment in an optical lithography tool. There is no chromatic aberration in the case of all-reflection EUVL optics. Therefore, TTR alignment is suitable for EUVL.

A glancing angle optical focus detector was employed. It detects the wafer height from the lateral deviation of the reflected light on the wafer.

Fig. 5. Alignment and focus detection system.

3. Conclusion

The EUV exposure system, consisting of ring-field illumination optics, ring-field projection optics with 3-aspheric mirrors, mask and wafer synchronous scanning stages and a wafer-alignment system, was designed. The construction of the EUV exposure system will be completed and the exposure experiments will be started this Autumn. We are planning to demonstrate large-field (30 x 20mm) and high-resolution (100nm) exposure, and device fabrication using EUVL.

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