High Resolution Technologies of 1.0 µm L/S Using PSM Specialized in DUV Broadband Illumination

Kanji Suzuki, Manabu Hakko, Miwako Ando, Koichi Takasaki, Nobuhiko Yabu, Kouhei Nagano, Nozomu Izumi

Optical Products Operations, FPD Production Equipment PLM Center 4, Canon Inc.,
20-2, Kiyohara-Kogyodanchi, Utsunomiya-shi, Tochigi 321-3298, Japan

Keywords: Lithography, FPD, High resolution, DUV, Phase shift mask

ABSTRACT

To meet the demands for high resolution, we designed a PSM specialized in DUV broadband illumination and evaluated resolution performance with the PSM. In this paper, we present the ability of 1.0 µm L/S pattern resolution with our PSM based on simulation results and exposure test results.

1 INTRODUCTION

In recent years, flat panel display (FPD) exposure tools of high resolution are strongly demanded from the FPD market. It is predicted that over 1000 ppi display panels will be used in next generation smartphone and virtual reality (VR). Such advanced products will need resolution of 1.0 µm L/S. However, as described below, a trade-off relationship exists between resolution and depth of focus (DOF). Thus, higher resolution may lead to smaller DOF. In this point, keeping DOF as well as improving resolution should be carefully worked on.

Fig. 1 shows machine configuration of a mirror-projection exposure tool produced by Canon [1][2]. Illumination light from illumination optics irradiates a mask, copying patterns on the mask to a plate below. The projection optical system mainly consists of three components, which are a convex mirror, a concave mirror, and a trapezoidal mirror. This allows using broadband light as exposure light because mirror elements, in principle, don't generate chromatic aberration.

Resolution and DOF of exposure apparatus can be expressed by Rayleigh equations as follows:

$$(\text{Resolution}) = k_1 \times \lambda / NA \qquad (\text{eq.1})$$

$$(\text{DOF}) = k_2 \times \lambda / NA^2 \qquad (\text{eq.2})$$

where k_1 and k_2 are constants, λ is wavelength of exposure light, and NA is a numeric aperture of projection optics. Eq. 1 indicates that high resolution can be obtained by small k_1, short λ, and large NA. However, large NA has a great influence on shrinking DOF since DOF is in inverse proportion to NA^2. Consequently, for getting higher resolution and keeping DOF, shorter wavelength illumination is preferable to larger NA.

Fig. 2 illustrates an example of spectral distribution of mercury lamps. For conventional FPD exposure tools, the ghi wavelength region (350-450 nm) is used as exposure light. Fig. 2 shows that mercury lamps have several peaks in the wavelength region under 350 nm, which has not been used for conventional exposure tools. The wavelength region under 385 nm is hereinafter referred to deep ultra violet (DUV). To achieve higher resolution, the use of DUV as exposure light is desirable.

Recently, we have developed a high resolution technique with DUV broadband illumination [3]. At IDW '14, we reported that 1.2 µm L/S pattern was resolved with DUV exposure using a binary intensity mask (BIM) and Novolak resist [4]. At the same time, we reported that 1.0 µm L/S pattern was not resolved under this condition.

To achieve further higher resolution, the use of a phase shift mask (PSM) is effective. This leads to smaller k_1 in eq. 1. At IDW '17, we reported the design techniques of PSMs to increase DOF for contact hole (CH) for DUV broadband illumination [5]. In this paper, we present our study on the ability of 1.0 µm L/S pattern resolution with a PSM designed based on the design methods specialized in DUV light.

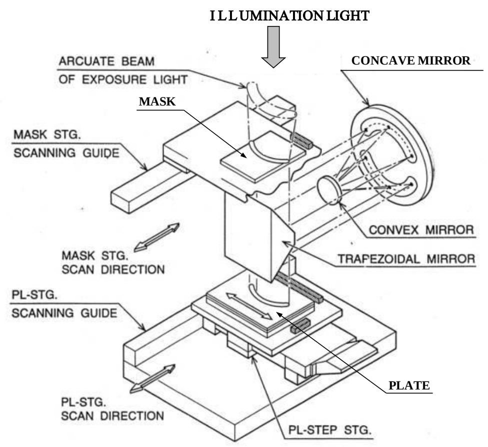


Fig. 1 Configuration of a mirror-projection exposure tool

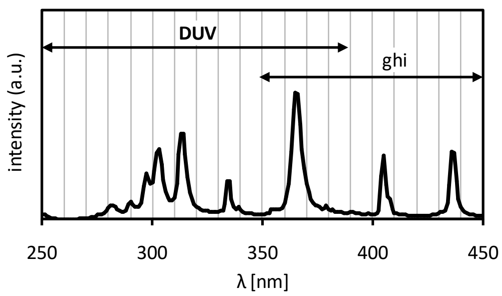


Fig. 2 Illumination spectrum

2 ATTENUATED PSM

This section describes general properties of attenuated phase shift masks (Att. PSMs) and calculation results concerning resolution enhancement with Att. PSMs.

2.1 Principle of Att. PSM

PSM is one of the resolution enhancement techniques (RETs) to improve aerial image contrast on a plate by modulating phase of illumination light on a mask. There exist two types of PSMs: alternating PSMs (Alt. PSMs) and attenuated PSMs. Because of the easiness of manufacture and defect inspection, the latter ones are extensively used in production processes of semiconductor devices [6]. Fig. 3 shows the principle of resolution enhancement with Att. PSMs. Att. PSMs consist of phase-shifting film, which induce phase shift of 180˚ and attenuation of light intensity to the light passing through the film. The interference between phase-shifted background light and non-phase-shifted diffraction light results in improving contrast of image intensity on an image plane, when parameters such as the transmittance and the phase shift are appropriately tuned.

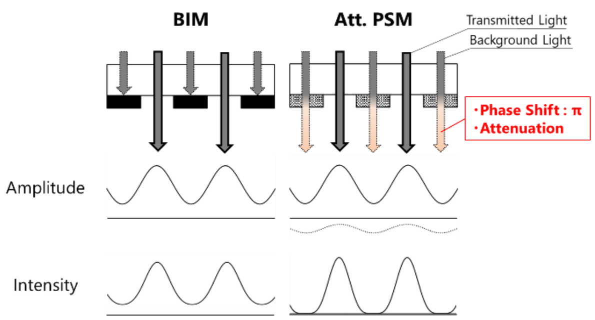


Fig. 3 Principle of resolution enhancement with Att. PSMs

2.2 Resolution Enhancement with Att. PSM

The resolution enhancement effect of PSMs is explained based on a calculation result of aerial images. Fig. 4 shows aerial image contrasts for BIMs and PSMs as a function of defocus. Calculation conditions were as follows: mask pattern was 1.0 µm L/S (alternating pattern of 1.0 µm line and 1.0 µm space), transmittance of PSM was 7 %, wavelength was 340 nm (single wavelength), and illumination mode was annular. In the defocus range of -25 to 25 µm, PSMs have higher contrast than BIMs. In particular, PSMs gain contrast improvement of 30 % compared to BIMs at best focus, which shows great enhancement of resolution with PSMs.

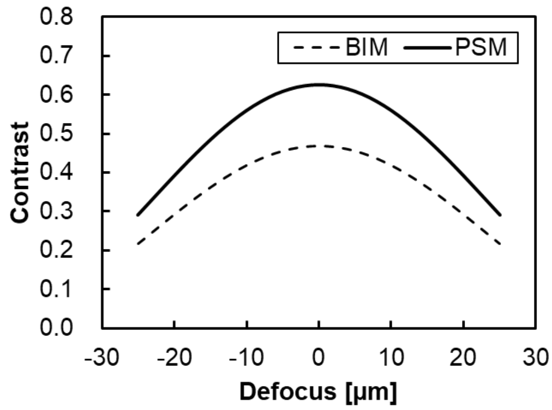


Fig. 4 Aerial image contrasts as a function of defocus

3 SIMULATION AND EXPOSURE RESULTS

In this section, simulation results and exposure test results concerning the resolution improvement effect of PSMs are shown.

A prototype of resist for DUV exposure was provided by Tokyo Ohka Kogyo CO., LTD. An test Att. PSM and BIM for 6-inch wafers were manufactured by SK-Electronics CO.,LTD, according to our design specialized in DUV.

3.1 Simulation Results

Since transmittance and phase shift amount of PSMs vary according to wavelength, the impact of the variation must be considered to use PSMs for broadband illumination. The illumination spectrum used in simulations was the spectral distribution illustrated as ‘DUV’ in Fig. 2, which were formed by cutting off the light in the unnecessary wavelength region from illumination light of mercury lamps.

Resist image simulations with PSMs for DUV broadband light were carried out as described below. At first, the DUV spectrum was divided into 5 regions. Each region had a different spectrum region. Transmittance and phase shift amount were determined as values of centroid wavelength in each region. Then, aerial image intensities were calculated for each region and summed incoherently. Finally, a resist image was simulated using the aerial image intensity and the resist data.

Simulation conditions were as follows: Mask pattern was 9 lines of 1.0 µm L/S and illumination mode was annular. For comparison, simulations for both the BIM and PSM were carried out.

Fig. 5 shows aerial image contrasts and resist profiles.

The center line in 9 lines was evaluated. The aerial image contrast of the BIM is so low that the top of resist doesn't remain. In contrast, the aerial image contrast of the PSM is larger than that of the BIM, and large part of the top of resist remains. Thus, simulation results clearly show that PSMs specialized in DUV enables to resolve 1.0 µm L/S pattern.

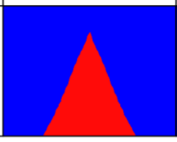
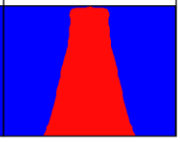
	BIM	PSM
Aerial Image Contrast	0.48	0.64
Resist Profile		

Fig. 5 Simulation results of 1.0 µm L/S

3.2 Exposure Results

Exposure tests of 1.0 µm L/S pattern were carried out using a test exposure tool. DUV light source was a mercury light. To cut off the light in the unnecessary wavelength region, a band-pass filter was inserted in the light path before a mask. The spectral distribution is as shown in Fig. 2.

Fig. 6 shows experimental results. The center line in 9 lines was evaluated. DOF was calculated as the range of focus in which variation of bottom critical dimension (CD) was less than 10 % of the target CD (1.0 µm). Resist profiles were obtained with a scanning electron microscope (SEM).

Similarly to the simulation results, the resist profile for the BIM didn't resolve with retaining the top of resist, while that for the PSM was sharp enough to retain the top of resist. DOFs for the BIM and PSM were (17.1 µm) and 19.5 µm, respectively. Here, it is noted that the DOF for the BIM is shown with parentheses as a reference value because the resist profile for the BIM didn't resolve even at its best focus.

Fig. 7 illustrates CD curves for the BIM and PSM, and Fig.8 illustrates a comparison of top view images at best focus and defocus of 10 µm. For the PSM, CD variation with defocus was small compared to the BIM, resulting in higher DOF. It should be noted that the resist profile for the PSM retained the top of resist at defocus of 10 µm, while that for the BIM didn't even at its best focus. This means that the PSM could form the resist profiles with retaining the top of resist, in the full range of DOF.

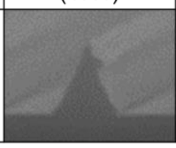
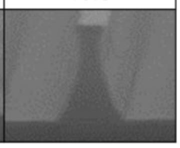
	BIM	PSM
DOF [µm]	(17.1)	19.5
Profile (SEM Image)		

Fig. 6 Exposure results of 1.0 µm L/S

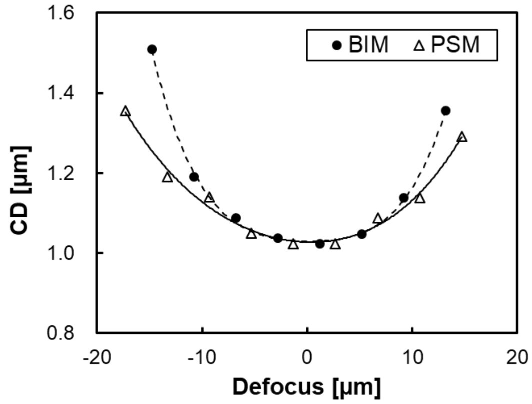


Fig. 7 CD curves for the BIM and PSM

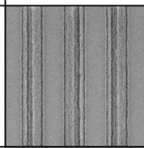
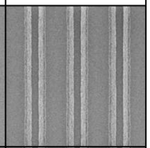
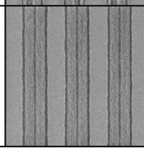
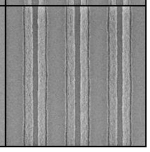
	BIM	PSM
Best Focus		
Defocus 10 µm		

Fig. 8 Comparison of top view images at different focus positions

In addition to 1.0 µm L/S, exposure tests were carried out for 1.1 and 1.2 µm L/S. Fig.9 shows DOFs as a function of CD. DOFs for the PSM were larger than those of the BIM at any CDs, and the difference between DOF of the PSM and that of the BIM increased as the CD was reduced. This result indicates that the improvement of DOF with the PSM increases in smaller CD.

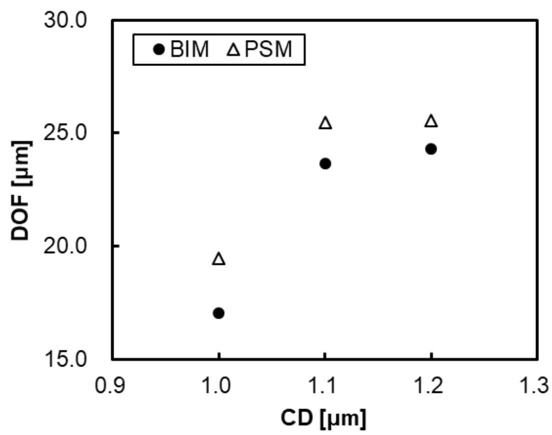


Fig. 9 DOFs as a function of CD

4 CONCLUSION

To enhance resolution for fine L/S pattern, we examined the application of Att. PSMs in DUV broadband illumination. The simulation and exposure test results clarified that our PSM can enhance resolution much enough to resolve 1.0 µm L/S pattern.

We have presented the concept of ‘DUV Exposure’ for resolution enhancement. In this study, we have verified that using RET masks for DUV exposure enables the unprecedentedly high resolution of 1.0 µm L/S. In the near future, our new techniques will become indispensable for mass production of high resolution display panels of over 1000 ppi.

However, the shrink of DOF with the CD reduction from 1.2 µm to 1.0 µm exists. To manufacture high resolution display panels with high productivity, further studies on DOF enhancement techniques or other techniques to obtain sufficient focus margins are needed.

REFERENCES

[1] A. Suzuki, “Complete analysis of a two-mirror unit magnification system. Part 1,” Applied Optics, Volume 22, Issue 24, pp.3943-3949 (1983).

[2] Michio Kohno, Kiyoshi Fukami, Hitoshi Yoshioka, Shu Watanabe, Akiyoshi Suzuki, "Catadioptric projection optical system for flat panel exposure tool," Proc. SPIE 6342, International Optical Design Conference 2006, (2006).

[3] Nagano K, Yabu N, Hakko M, Ando M, Izumi N, Osaki Y, “Development of G6 exposure tool for 1.2 µm resolution,” J Soc Inf Display, 2019;1-8, (2019).

[4] Nobuhiko Yabu, Kouhei Nagano, Nozomu Izumi, “High Resolution Technology for FPD Manufacturing,” Proc. IDW ’14 (2014).

[5] Manabu Hakko, Nobuhiko Yabu, Miwako Ando, Nozomu Izumi, Kouhei Nagano, “To Specialize an Attenuated Phase Shift Mask in DUV Broadband Illumination,” Proc. IDW ’17 (2017).

[6] T. Ii and M. Otaki, “Development of High-Quality Attenuated Phase-Shift Masks,” Yield Management Solutions, Volume 3, Issue 1, pp.41-45 (2000).