High Resolution Technology of FPD Exposure Tools and a New Broadband Illumination Technique to Achieve 1.0 µm L&S Resolution

Toru Okubo, Manabu Hakko, Nobuhiko Yabu, Kazuki Toyoda, Miwako Ando, Takeo Oyanagi, Yusuke Miyoshi, Ryousuke Fukuoka, Nozomu Izumi, Fumiyasu Ono, Takaaki Terashi, Yoshinori Osaki

okubo.toru610@mail.canon
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, RET

ABSTRACT

To meet the demand for high resolution in flat panel display (FPD) market, we have developed Gen. 6 exposure tools "MPAsp-E903T" for 1.2 µm L&S. With the use of resolution enhancement techniques (RETs), the resolution performance extends to 1.0 µm L&S patterns.

1 INTRODUCTION

To manufacture displays, fine patterns are fabricated on substrates by optical lithography using exposure systems. To improve performance of displays, the industry demands exposure tools with higher resolution [1].

Canon's exposure system uses mirror projection exposure tool, which can use broadband illumination source. Broadband illumination source, which is called Deep UV (DUV), has wavelength shorter than the i-line (~365 nm) of a mercury lamp. The shorter wavelength provides higher resolution, and the greater exposure light energy results in higher productivity. A primary optical benefit of Canon FPD systems is the ability to apply broadband illumination to achieve higher resolution and productivity. [2,3,4,5,6]

2 MPAsp-E903T

2.1 Concepts of New Exposure Tools

We have released exposure tools which apply DUV technology. MPAsp-E903T as shown in 1, apply DUV broadband exposure light for higher resolution and productivity [7]. The specifications are shown in Table 1. Plate size is 1500 mm x 1850 mm. Resolution is 1.2 um line and space (L&S) pattern and 1.8 um hole with a binary mask (BIM), and 1.5 um hole with a phase shift mask (PSM). Overlay is ±0.25 µm.

Figure 1. MPAsp-E903T

Table 1. Specs of MPAsp-E903T

Plate Size	1500 mm x 1850 mm (Gen. 6)
Resolution	1.2 um L&S (BIM) 1.8 um hole (BIM) 1.5 um hole (PSM)
Overlay (Single machine)	±0.25 µm

Three major concepts of MPAsp-E903T are described below.

Concept 1: High resolution

Resolution of MPAsp-E903T is 1.2 µm for line and space pattern and 1.8 µm for hole pattern with a BIM.
As mentioned in the Introduction, our exposure tools adapt mirror projection optics, which basically has no chromatic aberration. Therefore, broadband light can be used as exposure light even in DUV region. As a result, both high resolution by shorter wavelength and high productivity by high light power of broadband can be achieved.
The resolution performance can be improved by using resolution enhancement techniques (RETs), explained in chapter 3.

Concept 2: Process adaptability

Exposure tools need high level of process adaptability. In other words, a single exposure tool exposes both of layers which need high resolution and ones which need high exposure power.

For this purpose, we have developed an automatic switching function for switching 3 illumination and 2 numerical aperture (NA) modes.

Users can choose preferable illumination mode and NA for each exposure recipe as they like according to necessary exposure dose and depth of focus (DOF), which can be affected by photomask design and resist properties.

Table 2. Examples of exposure modes

Expo. Mode	NA Mode	Illumination Mode		Process
Mode 1	High	Annular		High resolution Line & Space
Mode 2	Normal	Small-σ		High resolution contact hole
Mode 3	Normal	Large-σ		Organic Insulation Film Rough Layer

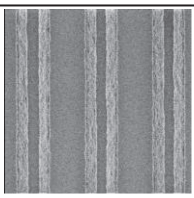
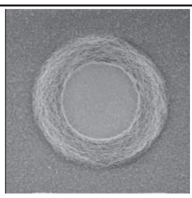
Concept 3: Compatibility with conventional exposure tools

Size of photomasks and positions of alignment marks for MPAsp-E903T are the same as our conventional tool MPAsp-E813H. The footprint is also almost the same. Therefore, it is possible to use both of these tools in an already existing fab without major renovation.

2.2 Experimental results of MPAsp-E903T

Table3 shows experimental results of MPAsp-E903T. Illumination mode was annular and small-σ as shown in Table 3. Mask was a binary mask. NA was high for 1.2 μm L&S pattern and normal for 1.8 μm hole pattern. Prototype novolak resist which was specially designed for DUV broadband illumination, was utilized. SEM images showed enough resolution both L&S and hole patterns.

Table 3. Experimental results with binary mask

Illumination	Annular	Small- σ
mask	Binary mask	
NA	high	normal
Pattern	1.2 μm L&S	1.8 μm Hole
SEM image (best focus) ×20k (L&S) ×30k (hole)		

3 Resolution Enhancement Technique (RET)

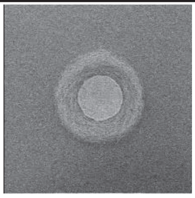
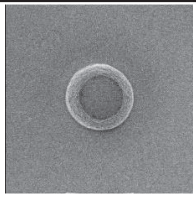
3.1 Phase Shift Mask (PSM)

PSM technique is one of the RETs [8]. 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. A design method of PSMs specialized in DUV broadband illumination was reported at IDW’17, IDW’19 and IDW’20 [9,10,11].

Table 4 shows experimental results of 1.5 μm hole pattern with BIM and PSM. Prototype novolak resist and the PSM, which were specially designed for DUV broadband illumination, were utilized.

SEM images shows the side wall angle of PSM is larger than that of BIM. This means that PSM improved the resist profile. SEM image shows satisfying profile with PSM.

Table 4. Experimental results of 1.5 μm hole with binary and phase shift mask

Illumination	Small- σ	
mask	Binary mask	Phase shift mask
NA	normal	
Pattern	1.5 μm Hole	
SEM image (best focus) ×20k		

3.2 Divided Spectrum Illumination (DSI)

We developed an original RET, named divided spectrum illumination (DSI), to achieve both high resolution and large DOF.

The key concept of DSI is source wavelength optimization according to the illumination angle. A method to optimize the illumination angle is widely known as an off-axis illumination (OAI) method for narrowband illumination. DSI involves optimization with respect to both the source wavelength and illumination angle to achieve both high resolution and large DOF [12,13].

The theoretical equation of the illumination angle to achieve large DOF is as follows [14]:

$$\sigma_c = \lambda/(2NA \cdot P). \quad (1)$$

where σ_c corresponds to the optimized illumination angle, λ is the wavelength of the exposure light. NA is the numerical aperture of the exposure tool, and P is the pitch of the exposed pattern. This equation derived from the condition in which the transmission (zeroth order diffraction) light and first order diffraction light propagate symmetrically with respect to the optical axis. According to equation (1), image contrast is maintained with increasing defocus when the longer illumination wavelength is utilized for the larger illumination angle.

Figure 2 shows a conventional OAI example. OAI does not vary the wavelength of the exposure light according to the illumination angle.

Figure 3 shows a design example of DSI, which has two illumination source areas: DSI_{in}, the source area with σ = 0.45–0.65 and wavelengths of 290–350 nm, and DSI_{out}, the area with σ = 0.65–0.85 and wavelengths of 290–385 nm. These parameters are designed to eliminate the i-line, which corresponds to the 350–385 nm region, with wavelength filter in the area of DSI_{in} (σ = 0.45–0.65), as shown in Fig. 3. As described above, longer illumination wavelength is utilized for the larger illumination angle, so the longer wavelength in smaller illumination angle, which corresponds to σ = 0.45–0.65, is eliminated by wavelength filter.

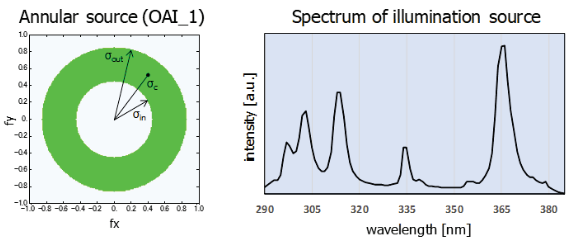


Fig. 2 A design example of traditional OAI

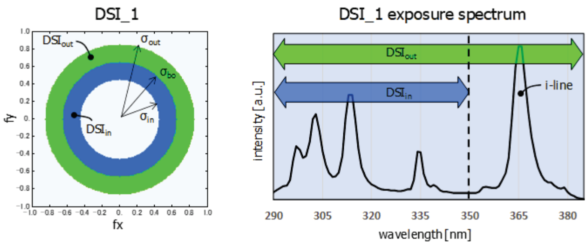


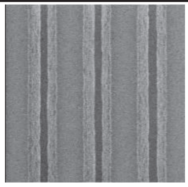
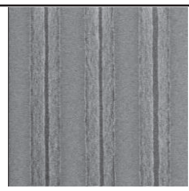
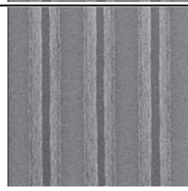
Fig. 3 A design example of DSI

Table 5 shows the MPAsp-E903T experimental results of OAI and DSI for a CD 1.0 μm L&S pattern. We reported 1.0 μm L&S pattern results with DSI and BIM [12,13] and with DSI and PSM [11]. But these results were obtained by using a test exposure tool which cannot expose Gen. 6 glass plate. The results in this section was obtained by using MPAsp-E903T.

OAI and DSI are shown in Fig. 2 and Fig. 3 respectively. Prototype novolak resist and the PSM, which were specially designed for DUV broadband illumination, were utilized in the same way in 3.1.

The SEM images shows the top width of the line using DSI is wider than that using OAI at the best focus. This means that DSI improved resolution. Adding to this, the SEM images shows the top width of the line using DSI is wider than that using OAI at the defocus 12 μm. This means that DSI improved DOF. Thus, DSI improved both resolution and DOF. DSI has the ability to pattern 1.0 μm L&S, which is one of the targets to produce next-generation high definition FPDs.

Table 5. Experimental results of 1.0 μm L&S with OAI and DSI

Illumination	OAI	DSI
mask	Phase shift mask	
NA	high	
Pattern	1.0μm L/S	
SEM image (best focus)		
SEM image (defocus12μm)		

4 CONCLUSIONS

To meet the demand for high resolution in FPD market, we have developed Gen. 6 exposure tools "MPAsp-E903T" using DUV broadband illumination. Specially designed techniques for DUV broadband illumination, which contains mercury lamp, DSI, PSM, mirror projection exposure tool and photo resist, achieved high resolution and productivity. Especially, to achieve higher resolution and larger DOF, we developed a new RET, DSI. Experimental results showed DSI improved both resolution and DOF, for a CD 1.0 μm L&S pattern. Installation of MPAsp-E903T makes next-generation high definition patterning possible.

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