The Novel Solution for Negative Impact of Out-of-band and Outgassing by Top Coat Materials(OBPL) in EUVL

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EUV lithography (EUVL) is the most promising candidate of next generation technology for hp20nm node device manufacturing and beyond. However, the power of light source, masks and photo resists are the most critical issues for driving the EUVL. Especially, concerning about deterioration of the patterning performance by Out-of-Band (OoB) light existing in the EUV light, and contamination problem of exposure tool due to the resist outgassing are the key issues which have to be resolved in the material view point toward the high volume manufacturing by EUVL. This paper proposes the solution for these critical issues by applying the top coat material. The key characteristics for top coat, name as OBPL(Outgassing and Out-of Band Protection Layer) material are the protection of the OoB effect, the prevention of the outgassing from resist as a barrier layer and enhancement of photo resist performance, like resist profile and process window.

This paper describes the material design and performance. The optical property needs having the high absorbance of DUV light in OoB range and high transmittance for 13.5nm wavelength. Outgassing barrier property needs high broking property against non contamination chemical species from photo resist outgassing. The study of TOF-SIMS analysis indicates how much the polymer chemistry can impact for outgassing barrier property. Regarding the Lithography performance, using OBPL showed the prevention for OoB irradiation negative effect such as sensitivity variation, LWR and resist profile deterioration. The lithography performance using OBPL showed good process window and resist profile in PTI and NTI process.

Keywords: EUV lithography, resist, outgassing, Out-of-Band, Outgassing & Out-of-Band protection layer (OBPL)

1. Introduction

EUV lithography (EUVL) is one of the next generation lithography candidates for hp20nm node device manufacturing and beyond, however there are many critical issues to solve in the light source, tools, mask and photo resist. Regarding the development of resist for EUV, it is necessary for high volume manufacturing (HVM) to improve LWR (10% of CD size), resolution limit and sensitivity ($E_{op} < 10 \text{ mJ/cm}^2$).

Meanwhile, some recent reports discuss that Out-of-Band (OoB) light which is wide range wavelength presents in EUV light. It is concerned

to be the cause of deterioration of lithographic performance [1-4,9]. Moreover, outgassing from resist remains a significant problem for exposure tool optics.

In order to solve these problems, top-coat material as Outgassing & Out-of-Band Protection Layer (OBPL) on resist has been developed to protect the OoB and prevent the outgassing from resist [5]. It is advantage to able to keep the material design of resist [8]. This paper describes this challenging experiment with details of design concept and material performance of OBPL.

2. Experimental

2.1 OBPL material lineup

Properties required for OBPL are no-intermixing with resist and alkaline or organic solvent dissoluble in development process. Several types of OBPL were prepared. Each property are measured with 90degC/60sec baked film, and showed in Table 1. OBPL-1, 2, 3a and 3b are used as specific for methacrylate type resist, OPBL-4 has applicability to all types of resist. In addition OBPL-4 applies to NTD (Negative Tone Development) process.

OBPL material has been designed from rigid polymer and showed high film density and T_g except for OBPL-2. These OBPLs were studied about outgassing barrier, OoB protection and lithographic performances.

Table 1. Polymer type, film density, T_g and feasible resist type of OBPL.

	Polymer type	Film density (g/cm ³)	T_g (degC)	Feasible resist type
OBPL-1	Rigid	1.21	200	Methacrylate for PTD
OBPL-2	Flexible	1.15	165	
OBPL-3a	Rigid	1.33	260	
OBPL-3b	Rigid	1.2	250	
OBPL-4	Rigid	1.44	240	All resist including for NTD

2.2 Evaluation condition

The film density and T_g were measured by XRR (D8 DISCOVER, BLUKER). The DUV transmittance was measured by UV-visible spectrophotometer (UV-2550, SHIMADZU). The performance of outgassing was evaluated by Residual Gas Analyzer (RGA) in IMEC.

The performance of contamination was evaluated by Witness Sample (WS) in CNSE. The EUV flood exposure was carried out in Osaka Univ. The behavior of S atom concentration was detected by TOF-SIMS (TOF-SIMS 5, ION-TOF). The performance of EUV transmittance was calculated by CXRO [6]. The EUV patterning was completed with Micro Exposure Tool (MET) in LBNL. The EUV patterning was completed with the ASML NXE:3100 installed in IMEC (NA=0.25, s0.81 conventional).

3. Results and Discussion

3.1 Outgassing property

Outgassing related resist is known to be a

potential risk for optics degradation in EUV exposure tools. In developing an OBPL, it is important that an OBPL generates very low amount of outgassing and blocks the contamination from resist by application of it on resist [7].

For the examination of the impact of OBPL polymer backbone on outgassing barrier property, OBPL-1 and 2 were tested. Firstly, these two OBPLs with 10nm and 30nm film thickness were measured RGA in IMEC.

These OBPLs gave low outgassing rate within a specified limit, nevertheless 30nm film thickness showed higher amount compared to 10nm film thickness (Table 2).

Table 2. Outgassing rate of OBPL with 10nm and 30nm film thickness.

Film thickness	Outgassing rate (mol/cm ² s)	
	10nm	30nm
OBPL-1	1.61E+13	1.78E+13
OBPL-2	3.26E+13	7.18E+13

Secondly, outgassing barrier property was evaluated. Fig.1 and Fig.2 show resist outgassing rate through each OBPL which was spin-coated on 60nm thickness resist. OBPL-1 showed good barrier performance against benzene-derived species regardless of OBPL thickness. On the other hand, OBPL-2 is not sufficient to block the contamination, especially 10nm thickness.

Fig 1. Resist outgassing rate through OBPL about benzene-derived species.

Fig 2. Resist outgassing rate through OBPL about all outgass chemical species.

Machine time of RGA and WS measurement are very limited. Hence, the different measurement approach was established by TOF-SIMS. OBPL / resist stacked wafer was exposed by EUV flood exposure system with $30\text{mJ}/\text{cm}^2$, depth profile estimated the barrier property from variation of S atom concentration in OBPL (30nm film thickness). Fig. 3 and Fig.4 show that S atom is detected at surface of OBPL-2 which has low barrier property by RGA measurement. Several OBPLs were screened by this TOF-SIMS method, OBPL-3a showed that variation of S concentration was dramatically increased at interface between OBPL and Resist-B. This indicates that polymer backbone of OBPL-3a is promising candidate of barrier layer.

Fig 3. Variation of S atom concentration after EUV exposure with OBPL-2.

Therefore, OBPL-3a / Resist-B stacked film was measured by WS in CNSE. OBPL-3a was successful in blocking not only the cleanable but also the non-cleanable contamination from resist as expected (Table 3). It was found that TOF-SIMS method is highly correlated with RGA / WS

measurement.

It is necessary to know the film density and/or T_g that develop an OBPL which has high barrier property against outgassing.

Fig 4. Variation of S atom concentration after EUV exposure with OBPL-3a on Resist-B.

Table 3. Contamination rate.

	Cleanable contamination thickness (spec: < 3.0nm)	Non-cleanable reflectivity loss by S atom
Resist-B	0.50nm	0.014
OBPL-3a / Resist-B	0.21nm	0.007

3.2 Optical property

In this topic, an effect of OoB protection is described. OBPL has been designed with consideration for OoB light absorbance and EUV light transmittance. Transmittance of OBPL-3b at DUV range was measured as Fig. 5. It shows around 25% transmittance with 30nm film thickness OBPL. This result predicts that OBPL-3b decreases the risk of pattern degradation by OoB. On the other hand, transmittance of EUV was calculated 88% as a low loss. 30nm film thickness provides the best balance of OoB absorbance and EUV transmittance.

Fig 5. Transmittance of OBPL-3b with 30nm at DUV range.

In this study, demonstration about OBPL efficacy was experimented by patterning. First of all, to estimate the OoB contribution, resist pattern was compared with OoB exposed pattern before MET hp26nm patterning. This result shows that number of smooth pattern is dramatically decreased by OoB exposure (Fig.6). Next, the same test was repeated for applying OBPL, there is no significant variation in pattern margin, sensitivity and LWR (Fig. 7). Meanwhile, OBPL is very effective material to protect the OoB irradiation. The sensitivity and LWR comparison at each condition were summarized in table5. Using OBPL-3b showed stable sensitivity, LWR and resist profile at each condition (Table.4).

The OoB imaging studies were completed by using pre-OoB exposure tool inline system with MET in LBNL. The OoB exposure dose was set as 20% of the E0 at EUV exposure patterning.

Fig 6. Pattern margin comparison of Resist-C.

Fig. 7. Pattern margin comparison of OBPL-3b/Resist-C.

Table.4 The impact of OBPL against OoB effect.

	Resist-C		Resist-C+OBPL-3b	
	without OoB	with OoB	without OoB	with OoB
Sensitivity	26.8	18.7	28.6	26.8
LWR	4.17	6.32	4.25	4.10
X-SEM				

3.3 Lithographic performance

The impact of OBPL to lithographic performance is shown in Table 5 with ASML NXE:3100 in IMEC. It is found that there are almost the same performances between using OPBL and just resist condition as reference. From result of cross-section image, Methacrylate type EUV resist (Resist-D) shows rectangular shape at top but little footing. On the other hand, OBPL-3b / Resist-D stacked sample got straight pattern with slightly top-rounding. But these two resist profile is quite similar. It is believed that OBPL-3b didn't show the negative impact for lithographic performance. Furthermore, OBPL-3b is very close to OBPL-3a which has high barrier property against outgassing. This means, OBPL makes it possible to protect the OoB irradiation and prevent the outgassing from resist.

Table 5. Lithographic test result.

hp28nm	Resist-D	OBPL-3b on Resist-D
Top-down image		
Cross-section image		
CD (nm)	27.73	27.38
Dose to size (mJ/cm ²)	11.20	11.52
LWR (nm)	6.38	6.57
LER (nm)	4.51	4.64
DOF at 10% EL (um)	0.20	0.16
Max DOF (um)	0.20	0.22
Max EL (%)	14.30	12.90

The lithography performance with NTI was investigated^[10]. OBPL-4 designed as compatible to all kind of EUV resist such as Hydroxyl styrene

including resist and pure Methacrylate type resist and also compatible for PTI and NTI process. The lithography performance with NTI showed no RLS performance degradation. Almost same process window, LWR and slightly improved the sensitivity (Fig.8).

Fig 8. NTI image with OBPL-4 and reference (no OBPL).

4. Conclusion

OBPL materials were investigated outgassing barrier, OoB protection and lithographic performances. It is found that rigid OBPL has sufficient barrier property against outgassing. And TOF-SIMS method which is highly correlation with RGA / WS was successfully established by detecting S atom concentration variation after EUV exposure.

Regarding the basic property, OBPL has compatibility with high OoB absorbance and high EUV transmittance. OoB deteriorated the lithographic performance seriously, but OBPL defended it.

As a result of full field scanner NXE:3100, OBPL got a smooth pattern without any negative effects to resist.

Additionally, state-of-the-art OBPL-4 has applicability to all types of resist including NTI process.

From these results, OBPL is an essential material for HVM.

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