Challenges and solutions for transferring a 248 nm process to 365 nm imaging

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ABSTRACT

In order to minimize manufacturing costs, lithographers have to extend the capabilities of KrF and i-line tools working with low k1 factor. In this paper we present results of a successful transfer of several lithographic processes from KrF to i-line.

During the process transfer, the optimal conditions for 365-nm technology were first determined by simulation and then verified by exposure of real production layers on a 0.65 NA i-line tool. The goal of the process optimization was to find settings for 365-nm process, which can match the performance of the 248-nm process. Proximity matching, CD uniformity, tool throughput and process costs were chosen as the main criteria for successful transfer.

Encountered challenges, the applied methodology and the experimental results have been discussed. Based on the results, we conclude that low k1 i-line lithography is feasible for mass production with CD as small as 210 nm. The process does not require additional preparation for 248-nm masks.

Keywords: Lithography, process transfer, i-line, 365 nm

1. INTRODUCTION

In order to minimize manufacturing costs, lithographers have to extend capabilities of KrF and i-line tools working with low k1 factor [1-4]. To satisfy the low-cost market demand, the manufacturers of lithographic tools develop new 365 nm and 248 nm tools with extended imaging capabilities. Advanced tool capabilities make it possible to postpone transferring litho process to smaller wavelength or sometimes even move non-critical products back from ArF to KrF and from KrF to i-line.

In Table 1 the main parameters of ASML's KrF and new i-line scanner are shown. It can be noticed that with respect to overlay and throughput they have comparable capabilities. It means that if the product exposed at lower wavelength is far enough from the resolution limit of the tool, it may be possible to manufacture it on the tool using higher wavelength.

The major driver of process transfers is a better cost efficiency: the estimated benefits per layer can be up to 40%. In order to illustrate it we show the results of the value of ownership (VOO) calculations that are based on PAS 5500/750G (KrF) and PAS 5500/450F (I-line) exposure tools, taking into account fixed cost, support cost, exposure cost, chemicals cost and reticle cost. The following examples are based on VOO with total benefit of 3$ per layer on 5500/450F tool with 2100 aligns/day.

Example 1: Tool in mix layer situation.

In the case of 180 nm logic process with 28 layers, 10 KrF and 18 i-line layers transferring 4 layers from KrF to i-line results in savings of about 38 k$/month.

Example 2: High volume situation with an i-line tool fully dedicated to hi-end layers transferred from KrF results in a cost benefit of about 189 k$/month.

The process of transferring litho production to lower wavelength is very well known (see, e.g., Ref. 5), but transferring process back to higher wavelength was not discussed earlier. In this article we publish results of a successful transfer of 0.18 µm, 0.25 µm and 0.35 µm lithographic processes from KrF to i-line with minimal k1 factor of 0.37.

Table 1 ASML PAS 5500/450F and PAS 5500/750H tools datasheet

Tool type	PAS 5500/450F		PAS 5500/750H	
Configuration	Base	High Performance	Base	High Performance
Wavelength (nm)	365	365	248	248
NA (max)	0.58	0.65	0.65	0.70
Resolution (nm)	≤ 350	≤ 220	≤ 180	≤ 130
SM Overlay (nm)	≤ 30	≤ 20	≤ 20	≤ 15
MM Overlay (nm)	≤ 50	≤ 40	≤ 35	≤ 30
Throughput (46shots)	124	150	130	165
Dose (mJ/cm^2)	200	200	50	50
Intensity(mW/cm^2)	≥ 3500	≥ 5000	≥ 3300	≥ 3300

2. PROCESS TRANSFER

The most important items of lithographic process transfer are the following:

1. *Proximity matching in the whole range of pitch size*
The critical dimension (CD) of the imaged structures should match the target within prescribed tolerance for specified pitch values. It may become a serious issue because the resist parameters and illumination conditions at higher wavelength usually differ from ones at lower wavelength. The optical proximity correction (OPC) also works in a different way. Generally it is difficult to transfer layers with assisting features such as scattering bars because they are designed for defined numerical aperture (NA) and wavelength. However, other OPC tricks such as line biasing or end-of-line hammerheads may secure a substantial yield even with different illumination scheme. If CD through pitch curve does not represent all proximity effects the original reticle layout or multiple test structures e.g. brickwall, end-of-line, elbow shape, etc. should be considered.

2. *Resist profile matching*
The ultimate proof of the transfer success is matching of the resist profile. Since resist profile may be affected by standing waves, it is not sufficient that CD value is on target, and, therefore, it should be verified.

3. *CD uniformity optimization*
In order to guarantee CD uniformity (CDU) for the mass production the process window (PW) for defined illumination settings should be large enough.

The process condition and performance on the reference tool is used as the input data for the process transfer. This includes CD through pitch and process window data, information concerning original illumination conditions, resist stack and substrate parameters. The main aim of transfer is to get a comparable or better process performance with respect to the reference tool.

Based on the described process items the following approach to process transfer has been used. First, the proper resist stack should be chosen. Then the illumination conditions are determined that allow to match CD to target with appropriate resist profile. Finally, the process window limits for the chosen illumination settings should be determined. Exposure latitude (EL) and depth of focus (DOF) should then satisfy specification.

This approach was applied to transfer processes with parameters given in Table 2. We transferred in total nine layers of 0.18 µm, 0.25 µm and 0.35 µm technologies with minimal CD value varying from 0.21 µm to 0.55 µm. The CD tolerances and process performance requested by customer specification are specified in Table 2 as well.

Table 2. Product datasheet

Product	Layer Name	Main feature		CD Target [µm]	CD tolerance, +/- [µm]	248 nm (original)		365 nm (simulation)		365 nm (measured)		EL required [µm]	DOF required [µm]
		Type	CD&Pitch [µm]			EL [%]	DOF [µm]	EL [%]	DOF [µm]	EL [%]	DOF [µm]		
0.18 µm	Via	Dense Hole	0.26&0.52	0.26	0.02	>20	0.6	12	0.75	16	0.6	>10	>0.6
	Metal1	Dense Line	0.21&0.42	0.22	0.015	>18	1.2	9	0.7	12	0.7	>15	>0.6
	Metal2	Dense Line	0.25&0.50	0.26	0.02	>21	0.9	13	0.75	13	0.9	>10	>0.6
0.25 µm	Poly	Dense Line	0.24&0.48	0.276	0.02	>25	0.6	10	0.5	15	0.9	>20	>0.8
	Contact	Dense Hole	0.28&0.56	0.32	0.03	>20	0.6	20	1.2	17	0.8	>20	>0.8
0.35 µm	Active	Dense Line	0.55&1.1	0.55	0.04	>30	1	42	1.6	38	1.6	>25	>1
	Poly	Dense Line	0.41&0.82	0.41	0.025	>18	0.65	31	1.4	27	1.5	>25	>1
	Contact	Dense Hole	0.43&0.86	0.43	0.03	>10	0.7	27	1	30	1	>25	>1
	Metal	Dense Line	0.48&0.96	0.48	0.04	>18	0.9	42	1.4	33	1.2	>25	>1

In order to find the best resist/ARC combination the performance of different resist stacks (a number of resist and ARC combinations) was analyzed with the help of resist/ARC vendors. The best combination found is Rohm&Haas Ultra-I 123 resist and Clariant AZ Barli II BARC. The calibrated resist model for this combination was obtained at ASML. The resist thickness was taken the same as at 248 nm process, and the BARC thickness was adjusted for the best resist profile when possible. It was also investigated whether it is possible to replace BARC by less expensive TARC. The research shows that for 0.35 µm process this can be done without any damage for the resist profile.

For the optimization of illumination settings we used the following ASML's PAS 5500/450F tool illumination capabilities (available with high performance imaging pack):

- numerical aperture: 0.48-0.65
- conventional mode sigma range: 0.31-0.88
- annular mode sigma range:
  - σ_{out}: 0.38-0.88,
  - σ_{in}: 0.16-0.64
  - minimal ringwidth: 0.24

3. SIMULATION

Since multiple exposures with different illumination settings are time and resource consuming a simulation has been performed in order to determine proper illumination settings. Although it saves a lot of effort the experimental verification of the simulation results is always required.
Our goal for the simulation was to find optimal illumination settings for higher wavelength tool, which can match the imaging capabilities of the reference tool, in terms of optical proximity effect (OPE) and CD uniformity performance.

Because the CD through pitch and process window reference data for all transferred layers was not complete, we had to use simulation to supplement it. However, this approach is only possible if the resist model is well calibrated. In order to calibrate it, we performed an experiment and measured CD through pitch values and process window for all used KrF resists. A special ASML reticle containing multiple CD trough pitch structures has been used. An example of the experimental data along with simulated CD through pitch curve for one of the resists is shown in Figure 1.

Thereupon for the proximity matching of 248 and 365 nm processes, we optimized CD through pitch performance of the i-line process for all layers by varying illumination settings. Since the matched processes are very different in terms of wavelength, illumination conditions, resist, etc. a simulation with the aerial image model is not sufficient and the full "after develop" resist model has been used. An example of process matching for two layers: 0.18 μm Metal 2 and 0.35 μm Poly is shown in Figure 2 and Figure 4. It can be seen from the figures that two CD through pitch curves can be very well matched if proper illumination conditions are found. For 0.18 μm Metal 2 layer the illuminations settings had to be changed from 0.54/0.7/0.35 at 248 nm to 0.65/0.65/0.2 at 365 nm. For 0.35 μm Poly layer the illuminations settings changed from 0.58/0.78/0.46 at 248 nm to 0.6/0.8 at 365 nm. We show illumination settings in $NA/\sigma_{out}/\sigma_{in}$ format for annular mode and NA/σ for conventional mode. The CD matching for all layers was within the customer specification shown in Table 2.

After that, the resist profile for each layer was checked. The simulation results for the abovementioned layers are shown in Figure 3 and Figure 5. For all other layers the resist profile was also well enough for mass production.
Finally, in order to assure good CDU performance the process windows for optimal illumination settings was estimated. The EL and DOF limits given by simulation are shown in Table 2. It is found that for seven layers out of nine the process window was within customer spec, for other two layers (0.25 μm Poly and 0.18 μm Metal1) it was somewhat smaller but still large enough for the mass production.

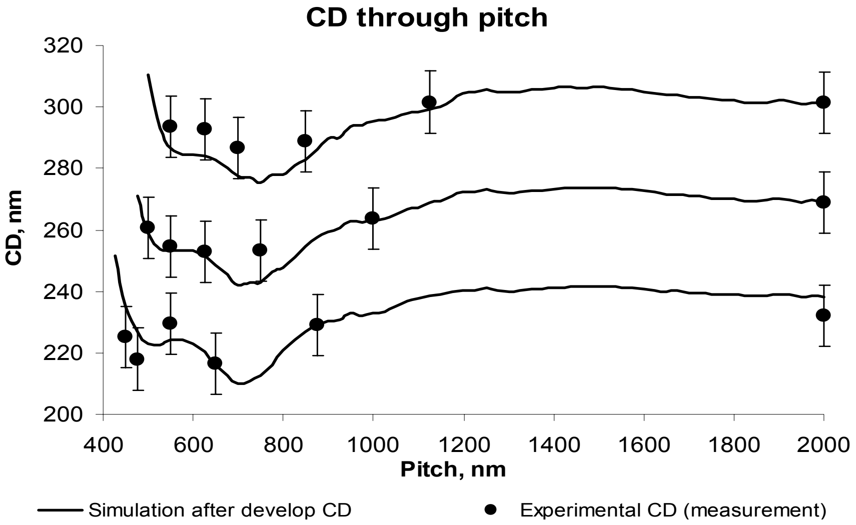
4. EXPERIMENTAL RESULTS

In order to verify simulation results an i-line process capable of imaging structures down to 220 nm, using Rohm&Haas Ultra-I resist and Clariant AZ Barli II Barc was successfully established at SMIC site. It was used by ASML to demonstrate the transfer of KrF layers to i-line.

We monitored the process parameters for all transferred layers. The measured process window limits are shown in Table 2. Six out of nine customer DUV layers show excellent imaging results on /450F, well within process window specified by customer. One layer is below the announced lens resolution (0.18 μm Metal 1 layer with CD/pitch of 0.21/0.42 μm). Nevertheless it showed a process window that is quite acceptable for mass production (EL of 12% and DOF of 0.7 μm), however out of customer spec (EL of 15%). For 2 other layers the process window is slightly less than the specified value, but it is believed that can be brought into customer specification after further process tuning. More production lots and some statistical data analysis are required for this.

An example of measured EL vs. DOF plot along with the reference 248 nm and simulated 365 nm plots for 0.18 μm Metal 2 layer and for 0.35 μm Poly layer are shown in Figure 6 and Figure 7. Small difference between simulated and experimental data confirms the validity of our approach.

During discussed process transfer the throughput and overlay performance was also examined. The matched machine overlay for pilot production was below 45 nm which is well within process specification. Nevertheless it can be further optimized which will improve the matching performance significantly. Apple to apple comparison of the raw throughput measured on actual jobs selected by customer was 35% to 45% higher. Batch throughput was 42% to 50% higher in comparison with previous generation of i-line tools. For customer i-line products a throughput showed an improvement from 34% to 79% and for layers transferred from KrF to i-line the throughput improvement of 79% has been measured.



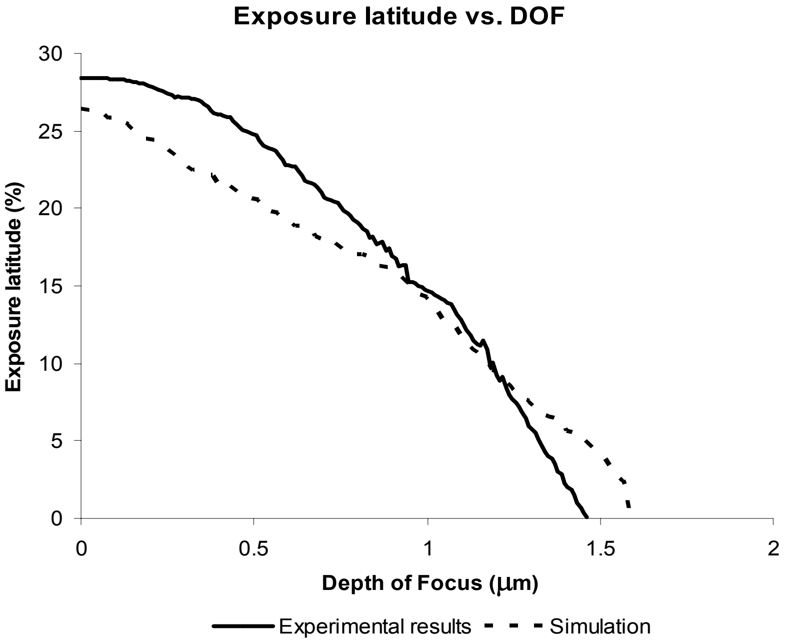


Figure 1. KrF resist model verification. The CD through pitch measurement was performed for several reference CD values. The measured curves are shown along with the simulated ones. The deviation between experiment and simulation is below 10 nm. Exposure latitude versus depth of focus plot is shown for experimental and simulated processes. The small difference between experiment and simulation confirms the model validity.

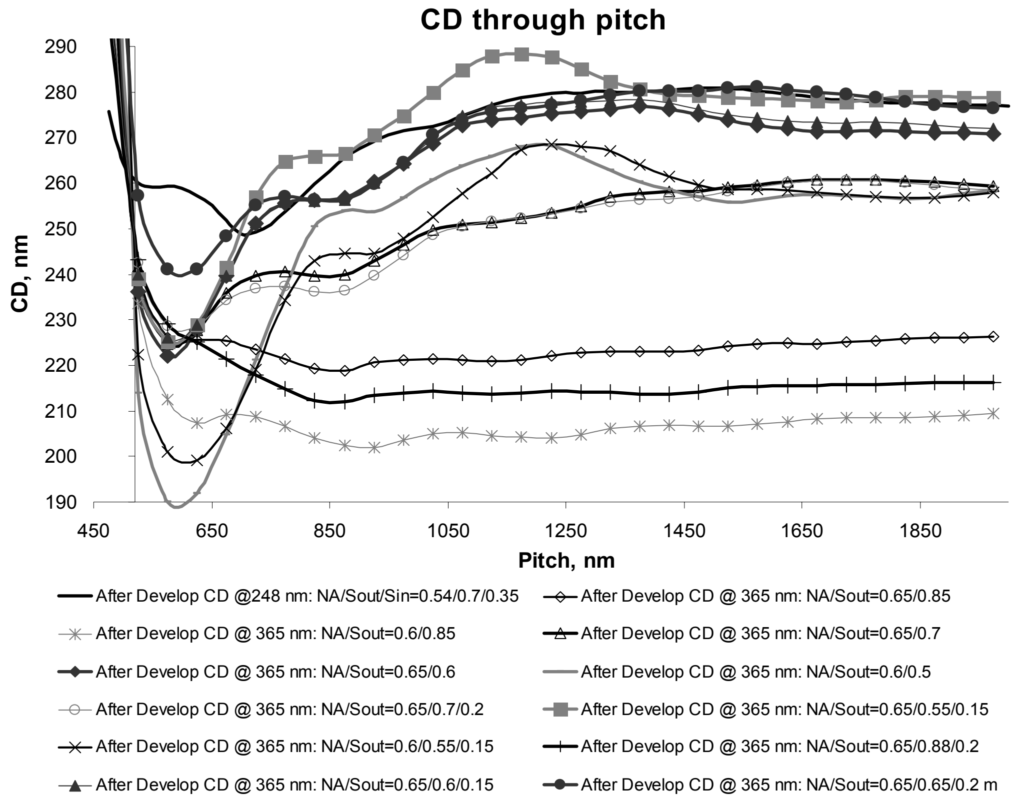


Figure 2. Proximity matching by optimization of illumination settings for 0.18 µm Metal 2 layer. The closest solution found for 365 nm process is 0.65/0.65/0.2.

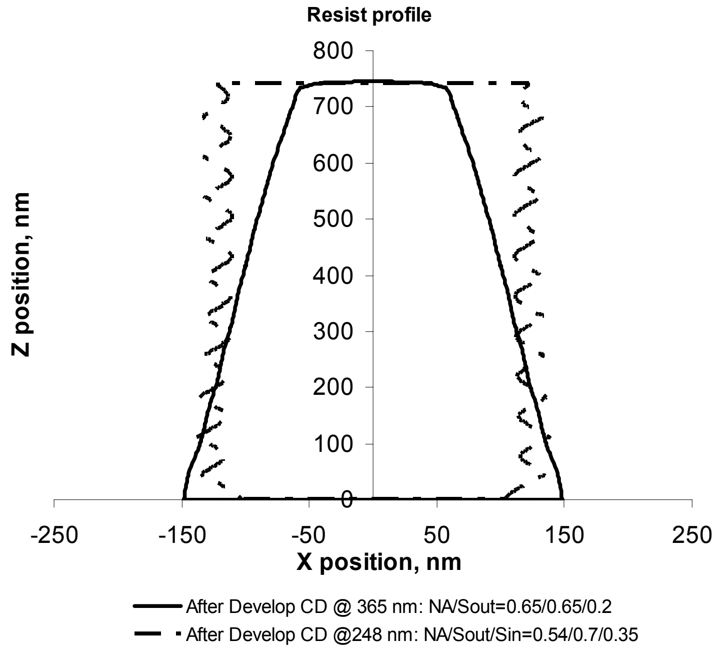


Figure 3. Resist profile matching for 0.18 µm Metal 2 layer. The profile is matched at 10% height.

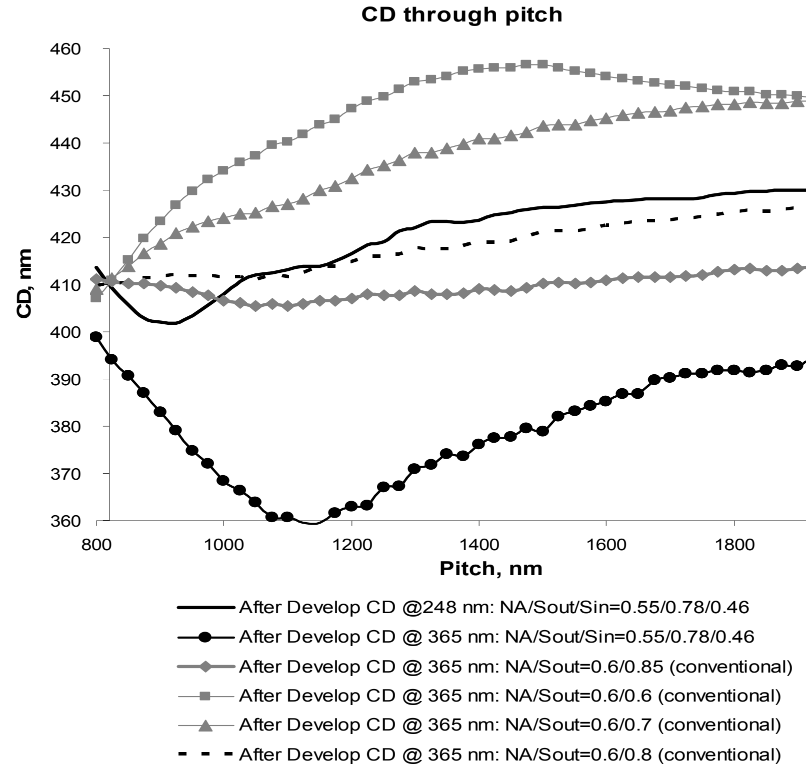


Figure 4. Proximity matching by optimization of illumination settings for 0.35 μm Poly layer. The closest solution found for 365 nm process is 0.6/0.8 (conventional mode).

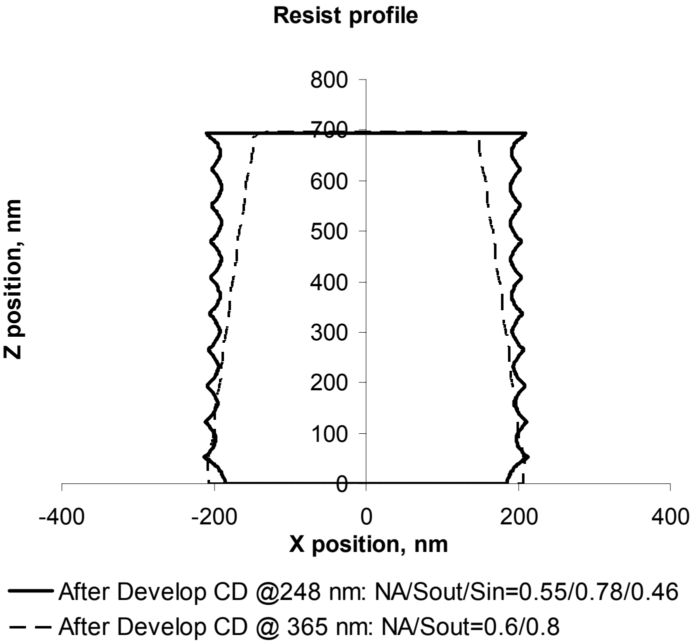


Figure 5. Resist profile matching for 0.35 μm Poly layer. The profile is matched at 10% height.

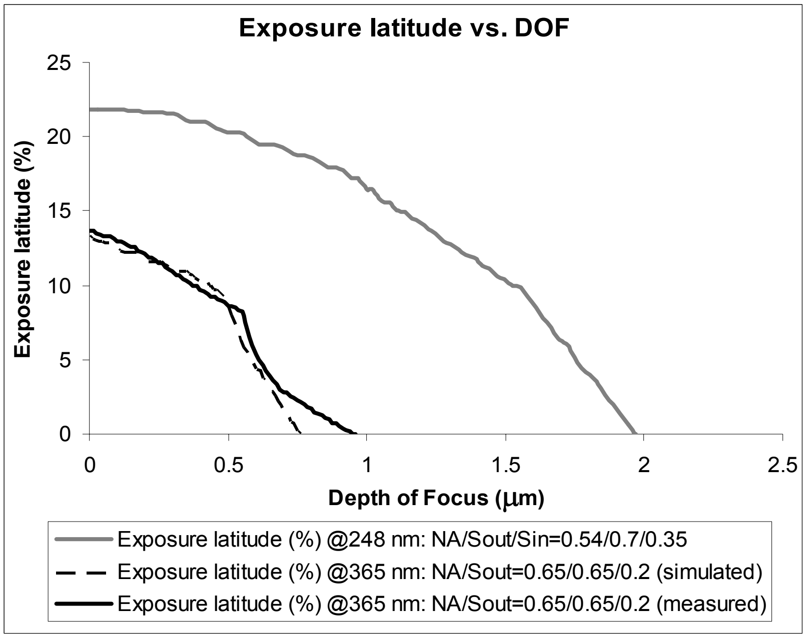


Figure 6. Experimental PW data for 0.18 µm Metal 2 layer along with reference 248 nm and simulated 365 nm curves. The process window size satisfies the customer specification (Exposure latitude > 10% and Depth of focus > 0.6 µm).

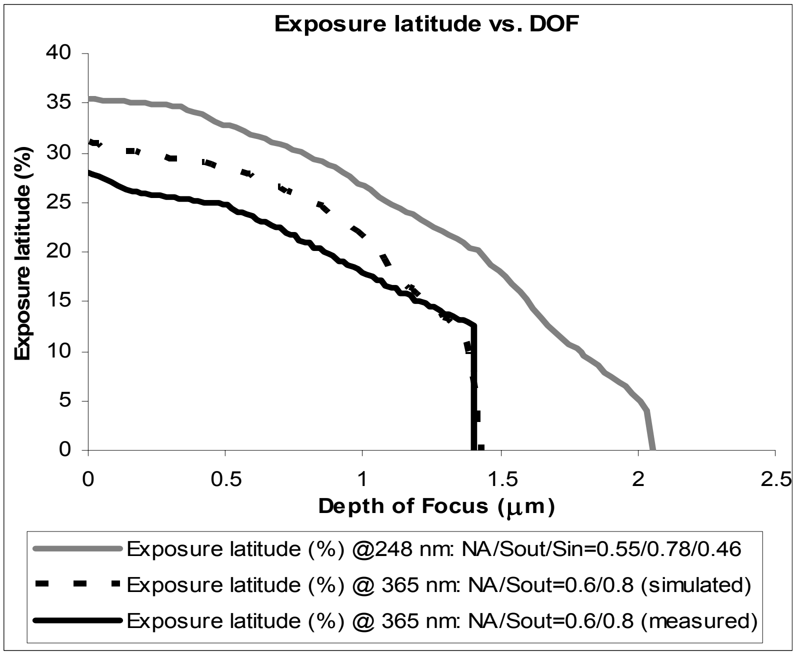


Figure 7. Experimental PW data for 0.35 µm Poly layer along with reference 248 nm and simulated 365 nm curves. The process widow size satisfies the spec (Exposure latitude > 25% and Depth of focus > 1 µm).

CONCLUSIONS

The KrF lithographic process was successfully transferred to i-line. The performance of all layers is adequate based on the typical customer requirements for the mass production. Additional process improvements are still possible. We demonstrated that ASML is capable to perform process transfer with high efficiency. It demonstrates the capability to transfer a number of customer production layers to i-line tools. Based on VOO calculations the benefit between exposure of an i-line layer versus a KrF layer can be up to 40%.

The success of process transfer has proved the applied methodology that will be applied to other process transfers required by customers such as ArF to DUV (193 nm → 248 nm), ArF wet to ArF dry and competitor high NA tool to less expensive ASML tool with a smaller NA (0.86NA→ 0.8NA).

ACKNOWLEDGEMENTS

We appreciate the support of Rohm & Haas Electronic Materials and AZ Electronic Materials which provided us with resist and ARC materials for experiment.

REFERENCES

1. *Extension of KrF lithography to sub-50-nm pattern formation*. Shuji Nakao, Jiroh Itoh, Akihiro Nakae, Itaru Kanai, Takayiki Saitoh, Hirosi Matsubara, Kouichirou Tsujita, Ichiriou Arimoto, and Wataru Wakamiya, Proc. SPIE Int. Soc. Opt. Eng. 4000, 358 (2000).
2. *Can DUV take us below 100 nm?* Jo Finders, Louis Jorritsma, Mark Eurlings, Richard Moerman, Henk van Greevenbroek, Jan B. van Schoot, Donis G. Flagello, Robert J. Socha, and Thomas Stammler, Proc. SPIE Int. Soc. Opt. Eng. 4346, 153 (2001).
3. *Feasibility of very low k1 (=0.31) KrF lithography*. Insung Kim, Byeongsoo Kim, Junghyun Lee, Hanku Cho, and Joo-Tae Moon, Proc. SPIE Int. Soc. Opt. Eng. 4181, 17 (2000).
4. *Optimization of multi-pole aperture for via patterning of 90 nm logic devices by KrF lithography*. Shu P. Fang, Hsiang Yang, Hsien-an Chang, Paul Chiang, Benjamin S. Lin, and Kuei-Chun Hung, Proc. SPIE Int. Soc. Opt. Eng. 5754, 1367 (2004).
5. *Process improvement of applying 193-nm lithography to 90-nm logic implant layer.* D.C. OweYang, Harrison Chen, R.M. Deng, and Bang-Ching Ho, Proc. SPIE Int. Soc. Opt. Eng. 5038, 1095 (2003).