Amphibian XIS: An Immersion Lithography Microstepper Platform

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ABSTRACT

Recent advances in immersion lithography have created the need for a small field microstepper to carry out the early learning necessary for next generation device application. Combined with fluid immersion, multiple-beam lithography can provide an opportunity to explore lithographic imaging at oblique propagation angles and extreme NA imaging. Using the phase preserving properties of Smith Talbot interferometry, the Amphibian XIS immersion lithography microstepper has been created for research and development applications directed toward sub-90nm patterning. The system has been designed for use at ArF and KrF excimer laser wavelengths, based on a fused silica or sapphire prism lens with numerical aperture values up to 1.60. Combined with a chromeless phase grating mask, two and four beam imaging is made possible for feature resolution to 35nm. The approach is combined with X-Y staging to provide immersion imaging on a microstepper platform for substrates ranging up to 300mm. The Amphibian system consists of single or dual wavelength sources (193nm and 248nm), a 2mm exposure field size, stage accuracy better than 1 um, polarization control over a full range from linear polarization to unpolarized illumination, full control of exposure dose and demodulation (to synthesize defocus), and the ability to image both line patterns as well as contact features. A fluid control system allows use of water or alternative fluids, with the ability to change fluids rapidly between wafers. The Amphibian system is fully enclosed in a HEPA and amine controlled environment for use in fab or research environments.

Keywords: Immersion, Lithography, Microstepper, Excimer Laser, Talbot, Interference

1. INTRODUCTION

Advances in UV optical lithography will extend toward the nanoscale for applications in the fields of semiconductor devices, nano and microstructures, advanced packaging, bio devices, and optical components. We have a developed a small field immersion lithography tool for research into materials and processes extending toward the 32nm device generations. The system provides the early learning required for applications identified by the International Technology Roadmap for Semiconductors (ITRS) out to the year 2013. The design of the system addresses several desirable goals for an immersion lithography research and development tool. These include:

- Excimer laser based immersion interferometric exposure
- NA values from 0.54 to 1.60
- Automated step-and-repeat exposure
- 150mm, 200mm, and 300mm wafer capability
- Robotic wafer handling
- Automated fluid dispense to accept water or alternative fluids
- 193nm (ArF) or 248nm (KrF) capability
- Chromeless PSM lithography with commercial PSM gratings
- Full polarization control
- Automated single beam attenuation for Modulation/Exposure matrices
- Exposure times 0.5 to 5 second range
- Multiple exposure arrays on a single wafer
- Two-pass exposure for contact arrays

2. SYSTEM DESCRIPTION

The Amphibian XIS imaging approach is based on Smith-Talbot interferometry, as shown in Figure 1, which has been described previously [1, 2]. The lens is based on a fused silica prism with surfaces polished and coated allow imaging through a fluid meniscus interface.

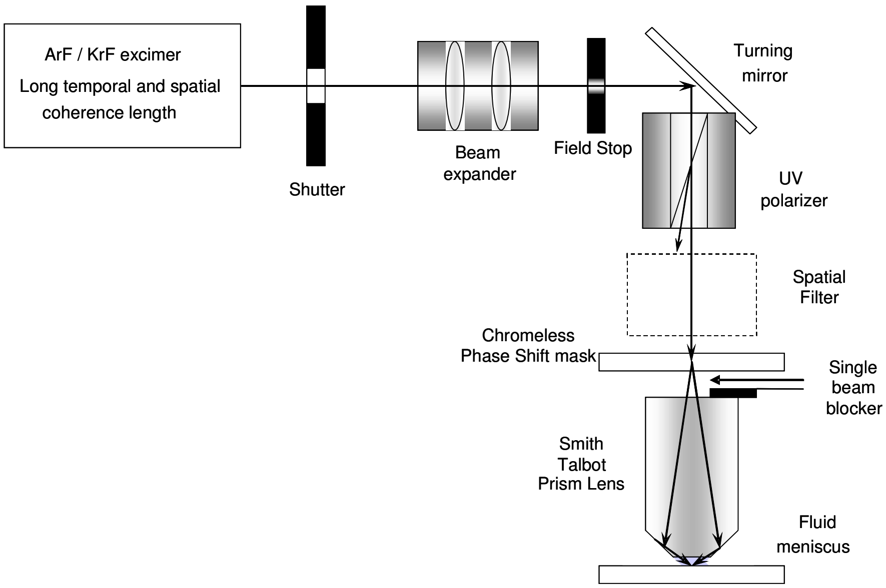


Figure 1. Schematic of Smith-Talbot interferometric lithography

2.1 Lens options

Smith Talbot lenses between 0.54 and 1.40 NA are designed using ArF grade fused silica material for use with water as the imaging media. However, the Amphibian XIS and the Smith Talbot lens design approach are not limited to 1.40NA. By designing fused silica lenses for use with a high index fluid (HIF), numerical apertures up to 1.50 are possible. Furthermore, by designing the Smith Talbot lens for aluminum oxide (Al_2O_3 or sapphire) and a HIF, numerical apertures up to 1.60 can be obtained. Table 1 shows an example of the available lenses. Most values of numerical aperture between 0.54 and 1.60 are possible. The standard lens NA range is between 0.54 and 1.35.

NA	Half-pitch	Lens Material	Fluid	Standard / Optional
0.54	90 nm	Fused Silica	Water	Standard
0.80	60 nm	Fused Silica	Water	Standard
1.05	45 nm	Fused Silica	Water	Standard
1.20	40 nm	Fused Silica	Water	Standard
1.35	36 nm	Fused Silica	Water	Standard
1.40	34 nm	Fused Silica	Water	Optional
1.50	32 nm	Fused Silica	HIF	Optional
1.50	32 nm	Al_2O_3	HIF	Optional
1.60	30 nm	Al_2O_3	HIF	Optional

Table 1. Smith Talbot lens examples available for 193nm imaging.

Three configurations of the basic system design are shown in Figure 2

1. Amphibian XIS – SW (Single Wavelength) with Lambda OPTEX Pro for single source exposure.
2. Amphibian XIS – SW (Single Wavelength) with Tui BraggStar for single source exposure.
3. Amphibian XIS – DW (Dual Wavelength) for dual source and dual column exposure.

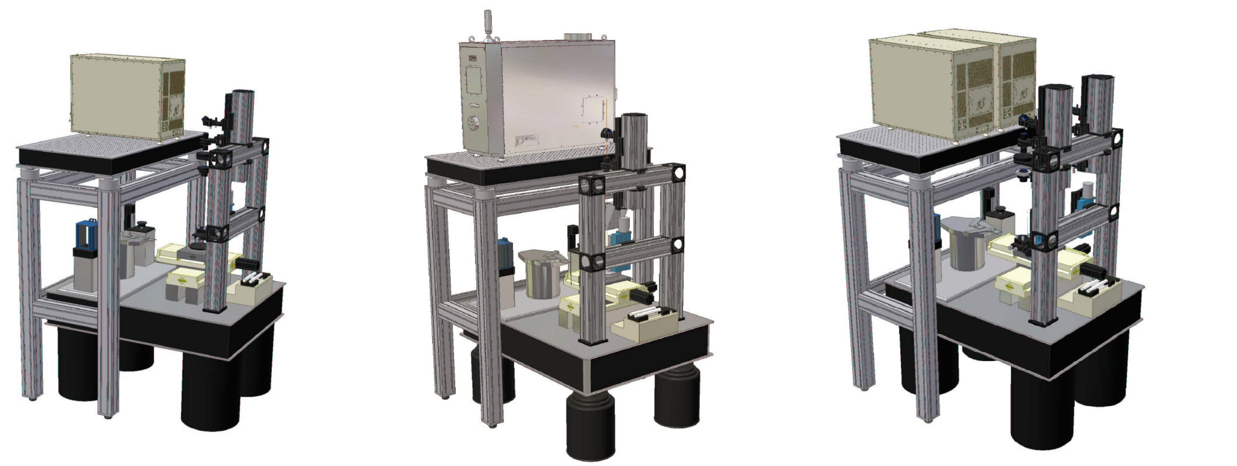


Figure 2. Possible configurations of the Amphibian XIS-SW (left) with OPTEX PRO (center) with BraggStar and (right) with a dual wavelength option.

2.2 Laser source

The Amphibian XIS tool is designed for use with a compact excimer laser running with the following minimum conditions:

- Compact to fit into framework of Amphibian XIS (<1m^2)
- Repetition rate > 80Hz
- Output energy >0.5 mJ/pulse all repetition rates
- Temporal bandwidth <10 pm
- Spatial coherence > 100 μm
- Beam uniformity better than 10% over 0.5mm^2 area

These specifications have been achieved with two compact excimer lasers that have been modified to meet the specific needs of the tool. The laser sources available for the tool are given below.

1. Lambda Physik OpTexPro TROM. The OpTexPro is a self contained, compact laser with a modular design that facilitates serviceability and provides maximum flexibility in the working environment. The air-cooled OpTexPro features a maintenance-free solid-state switch, smooth pre-ionization, and optimized gas flow. The laser can be operated at 200 Hz with unlimited duty cycle, and operated up to 500 Hz with limited duty cycle. Output energy is >1mJ/pulse. A line-narrowing assembly has been incorporated into the laser to achieve the performance specifications listed above. The TROM unit includes three-prism beam expansion with a grating, externally mounted to the back of the laser frame. The laser footprint remains unchanged and a nitrogen purge exists to assist optic lifetime and reduce ozone.

2. Tui BraggStar Industrial-LN. The Tui BraggStar Industrial-LN is a long temporal coherence length compact laser designed for fiber Bragg grating writing and interferometric applications. The laser features up to 1000 Hz repetition rate, >1 mJ/pulse energy output using metal / ceramic tube technology.

2.3 Fluid delivery system

Fluid delivery is carried out in a static mode using a software controlled syringe pump to dispense a meniscus of fluid at a user-determined location on the wafer surface. Upon fluid dispense, the wafer stage automatically centers the meniscus under the optical column, at which time the column is precisely lowered to create a fluid gap between the prism lens and wafer of 0.1 to 5mm (as determined by the user). The fluid is stepped with the lens and held in place via surface tension, where the fused silica prism surface provides hydrophilicity and the resist surface provides hydrophobicity for an aqueous immersion fluid. The approach is not limited to aqueous fluids, however, as several alternative fluids have been tested successfully using this design. The design of the fluid delivery system also allows for rapid changing of fluids by replacing the syringe, delivery line, and syringe needle assembly with a new assembly preloaded with a new fluid.

The removal step can be performed to dispose of an immersion fluid or to collect the sample for analysis. Once the multiple field exposures are complete, the stage is moved out from under the prism lens as the column is raised away from the wafer substrate. A collection syringe is used to remove the fluid for sampling or the fluid is wicked from the prism lens for disposal. The exposure operation can then be followed by an automated lens cleaning operation, where clean water is dispensed to several locations on a bare, clean silicon wafer and the optical column is successively lowered into the menisci to remove contaminants.

2.4 Changing effective numeric aperture (NA_{eff}).

The Smith-Talbot prism lens design is based on Talbot interferometry, where the approach forces the path length of the interfering beams to be equal at the center of the image field. A phase grating produces a pair of beams with identical coherence properties and only these +1st and –1st diffraction orders are used in the imaging interference (the effect is equivalent to coherent "strong" phase shift mask lithography). Recombination of the beams occurs at the internal reflective surfaces of the prism lens, created via the reflective coating of the prism facets. The angle of the facets, combined with the phase grating pitch, defines the arrival angle at the wafer. The bottom surface together with the wafer forms the fluid gap. The top surface has an anti-reflective coating to minimize stray light. A schematic of the arrangement for the prism lenses is shown in Figure 3.

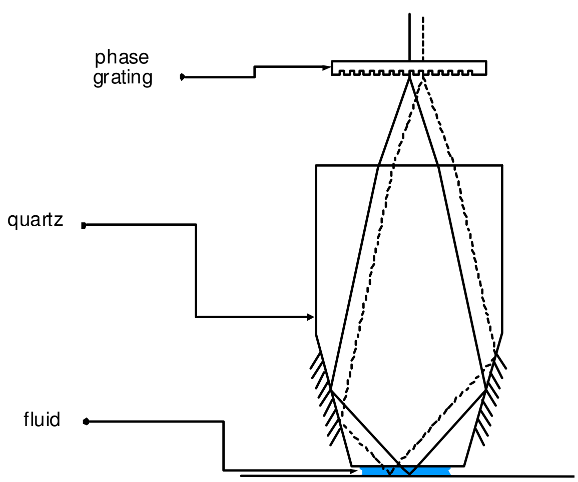


Figure 3. The Smith-Talbot prism lens

The advantage of this unique design for interference imaging is the inherent preservation of coherence between the two interfering imaging beams. By using a phase grating to create the two optical paths, left-to-right beam coherence is guaranteed with the approach, allowing for the use of a source with relatively poor spatial and temporal coherence properties. This allows for the use of an excimer laser and the imaging source. Alternative interferometric approaches using conventional methods for beam-splitting require a highly coherent source because of the poor phase relationship between reflected and transmitted beams (as with Michelson and other similar interferometry). The illuminated prism approach to interferometry also possesses the same problem, where a highly coherent laser source must be used. The coherence preserving aspect of the Smith Talbot and Amphibian designs allow for a very robust, cost effect imaging system based on a compact excimer laser (vs. a more expensive solid-state, frequency shifted laser source). An additional benefit of the Smith Talbot approach is the reduction of interference artifacts including speckle and ringing anomalies.An example of two such lenses (1.05 and 1.25) is shown in Figure 4.

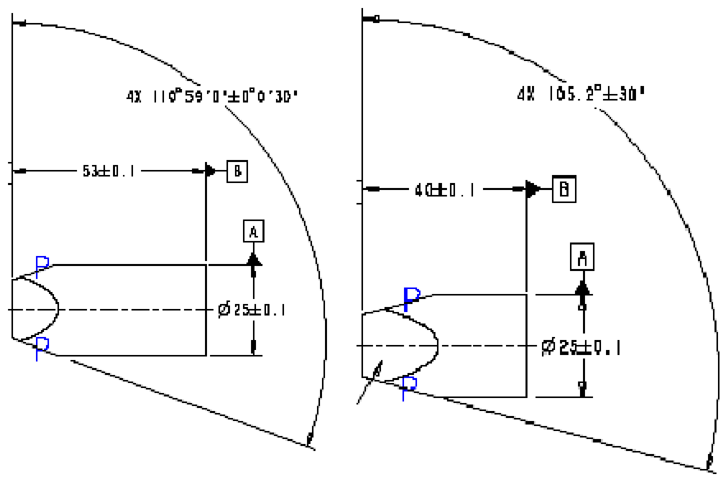
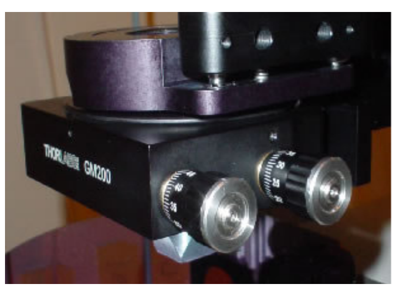


Figure 4. A schematic of the Smith-Talbot lenses for 1.25 NA and 1.05 NA.

The Amphibian XIS Smith-Talbot lenses are mounted in threaded collars and held in individual gimbal mount assemblies for quick-change removal and replacement. Mounts are designed for exact positioning performance, which eliminates angular or positional crosstalk. The working distance is computer controlled by z-axis stage control to < 0.50µm. The total time between required to change lenses is less than five minutes. Figures 5 show views of the lens assembly and gimbal mount.



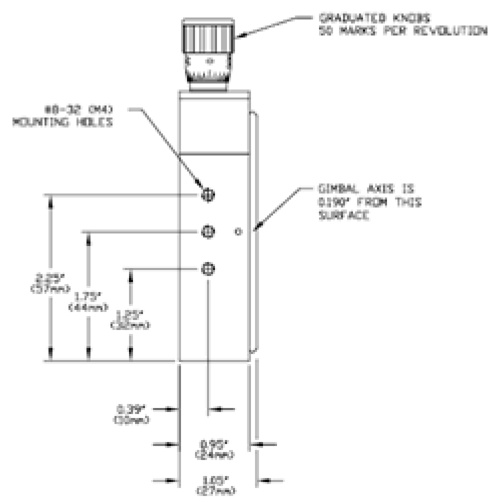


Figure 5. The lens assembly for the Amphibian tool, showing the Quick-change gimbal mounted Smith-Talbot prism.

2.5 Adjusting image modulation

The Amphibian tool can utilize interferometric lithography to synthesize the functions of conventional projection photolithography. The approach is fully automated and programmed into the software user interface. The method employed with this system involves the blocking of one of the first diffraction orders during part of the resist exposure. This results in background energy with zero modulation added to the two-beam interference pattern. By controlling the ratio of two-beam to single-beam exposure, the system is able to produce varying modulation conditions. The approach is shown in Figure 6. A small stepper motor mounted in proximity to the prism lens is used to control a blocking blade, which covers one of the diffraction order beams. Through software control, the user determines the level of desired demodulation, which splits the full exposure time into portions of single and two-beam imaging. The user selects the projection lithography condition to synthesize, based on a look-up table created from lithography simulations (such as with Prolith). Such a look up table is used for example in Figure 7 to create a four-zone transfer plot correlating single beam exposure contribution to defocus. By choosing the level of defocus to produce (in linear increments), the software selects the level of demodulation to match (using the non-linear look-up function). The wafer is exposed in an array varying exposure and (synthesized) defocus to produce a conventional FE matrix using interferometry.

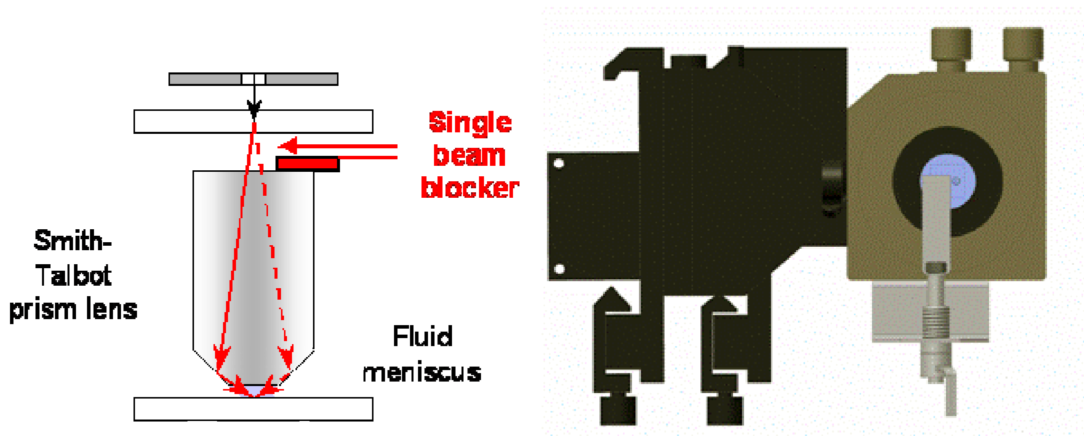


Figure 6. Single beam blocking for the Amphibian tool.

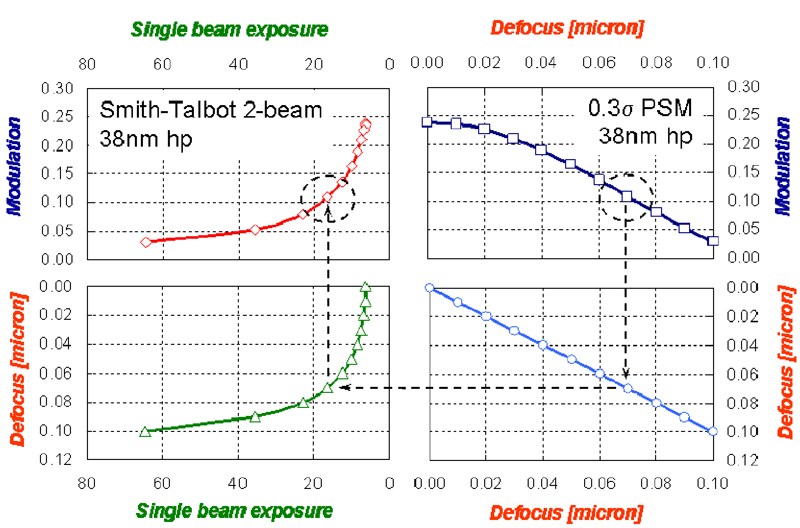


Figure 7. A four-zone transfer plot correlating single beam exposure to defocus for the Amphibian tool.

2.6. Contact hole imaging

Contact hole exposure can be approximated using a double pass exposure. It should be noted that the diffraction pattern and subsequent intensity image for a contact array from a conventional projection lithography system cannot be strictly matched using interferometric lithography. This is primarily because of the presence of zero order in the contact array diffraction pattern. The use of a single beam secondary exposure to match image modulation between interferometric imaging and projections imaging, as describe for one dimensional patterns, is not sufficient for matching in this two dimensional case. The approach used to synthesize contact arrays with the Amphibian tool is a two-pass exposure, where line features in the Y direction are printed over line features in the X direction. This is accomplished by a first pass exposure of the wafer, removal of the wafer from the wafer chuck, and replacement of the wafer after a 90-degree rotation. The placement accuracy of the LUDL robot is better than 3 micrometers. The rotation accuracy is better than 2-arc minutes. This operation is fully automated using the software interface, where the user defines an X-Y array for the first pass exposure and Y-X translation of the array is carried out for the second pass exposure. This approach ensures symmetrical polarization for each exposure, whether TE (similar to azimuthal polarization), TM (similar to radial polarization), or unpolarized. An example of the resist intensity pattern for two-pass TE polarized contact array is shown in Figure 8. Additionally, an interferometric lithography simulation program (ILSim) is provided with the Amphibian tool for testing various imaging scenarios prior to exposure.

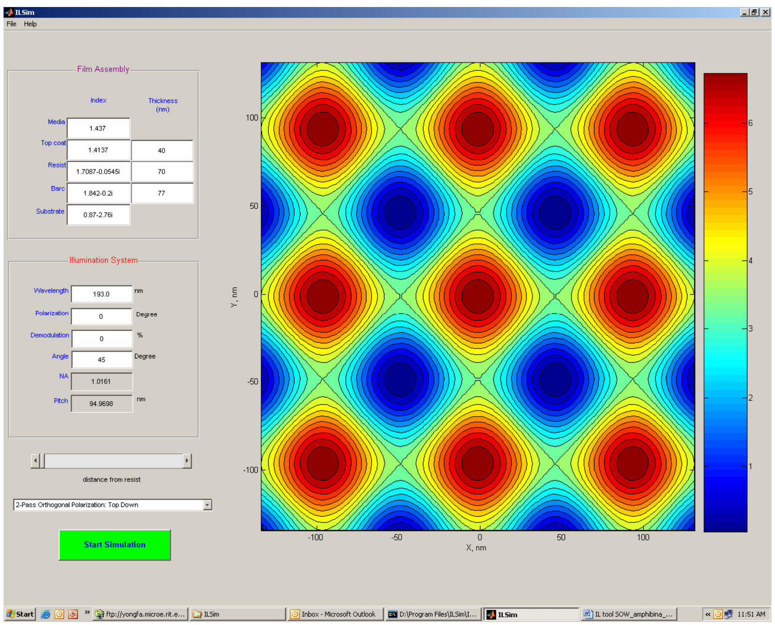


Figure 8. ILSim simulation results showing two-pass contact array exposure using TE polarization and1.02NA for 48nm contacts in resist over BARC and under topcoat.

3. LITHOGRAPHIC PERFORMANCE

Lithographic performance of the Amphibian XIS with a 1.05NA lens for 45nm half-pitch imaging is shown in Figure 9. Images are shown from 45kX to 7kX magnification to demonstrate the uniformity that can be achieved across a 2 mm field. Figure 10 shows a low magnification image of the entire image field, spanning over 2mm in diameter. Figure 11 shows CD uniformity over a 2mm field at 7 sites for four separate exposure fields, resulting is

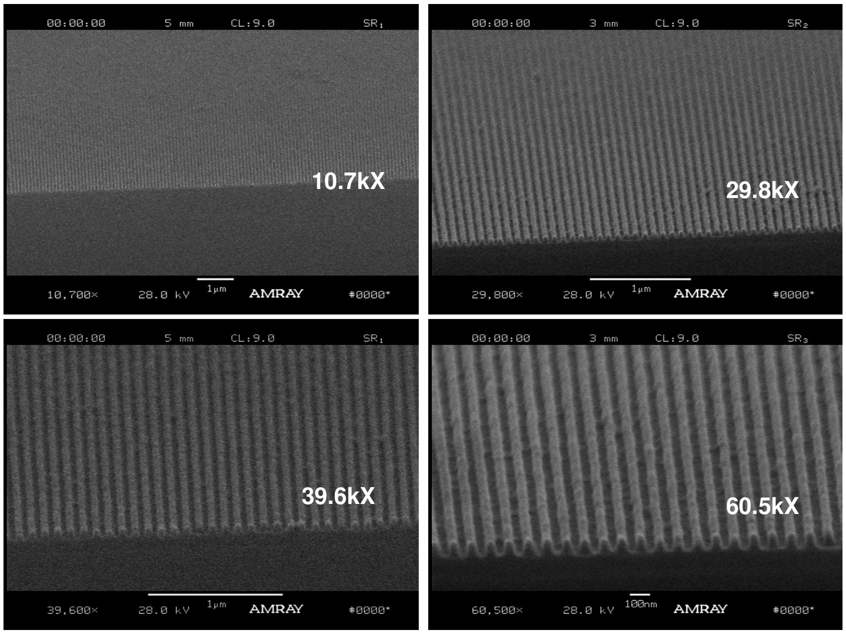


Figure 9. Imaging results using a 1.05NA lens for 45nm half-pitch resolution.

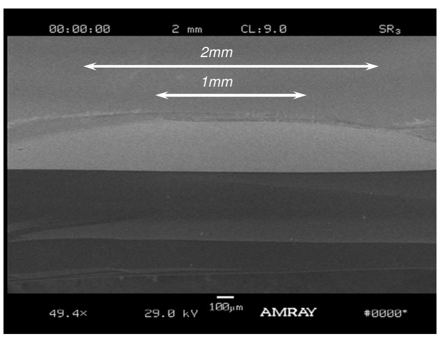


Figure 10. Full field exposure uniformity over 1mm and 2mm.

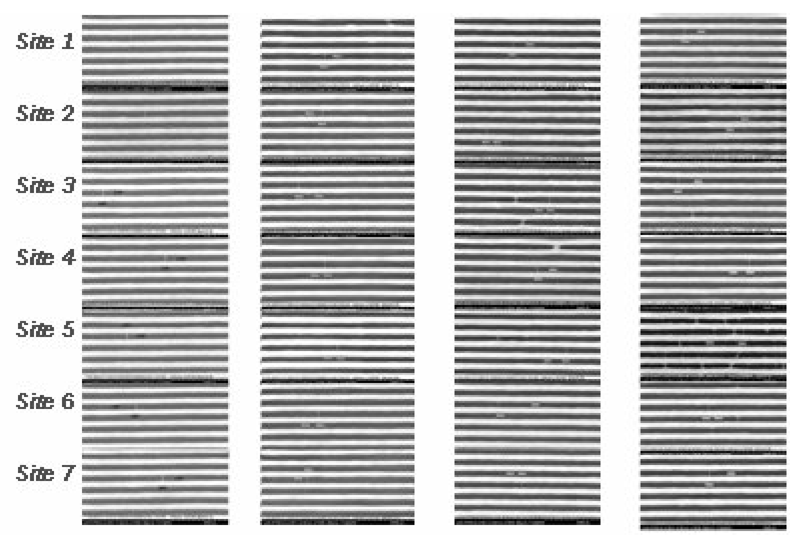


Figure 11. CD uniformity for 45nm features across four fields and 2mm field diameter.

4. CONCLUSIONS

The Amphibian XIS excimer immersion microstepper has been designed to meet the immersion lithography research and development needs required to pursue the 65nm, 45nm, and 32nm device generations. By using Smith Talbot interferometry for phase mask interference lithography, a simple robust system has been achieved. The system allows for numerical apertures up to 1.60 with water and alternative high index fluids. Robotic wafer handling has been designed into the tool for 150-300mm substrates and the system can operate at 193nm (ArF), 248nm (KrF) or in a dual wavelength set-up. Full polarization control is allowed as is two-pass exposure for contact array emulation. By meeting the design goals set out for the tool, the Amphibian XIS is a versatile immersion lithography research and development exposure system.

5. REFERENCES

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[2] A. Bourov, Y. Fan, Frank C. Cropanese, N. Lafferty, L. Zavyalova, B. W. Smith, "Immersion microlithography at 193 nm with a Talbot prism interferometer," Proc. SPIE 5377 (2004).