The Development of 157nm Small Field and Mid-Field MicroSteppers

Ron E. Miller, Paul Bischoff, Roger Sumner, Steve Bowler,
Warren W. Flack, Galen Fong

Ultratech Stepper, Inc.
San Jose, CA 95134

The continuous advancement of optical lithography into the regime of sub-100nm patterning capability requires the utilization of shorter exposure wavelengths such as 157nm. This in turn requires modifications in lens performance and stepper body performance to meet the required system performance. Advances in index homogeneity have made it possible to develop 157nm lens systems suitable for investigating sub-100nm lithography. Recent advances in the transmission of modified fused silica as a reticle material have made it more desirable to pursue 157nm lithography tools. MicroSteppers are a necessary vehicle to obtain photoresist and process information pertaining to the efficacy of this technology for production at the 100nm and 70nm device nodes.

In this study we will discuss two MicroSteppers with two new lens designs: the first is designed for photoresist materials development and the second for device process development. The photoresist tool has a numerical aperture (NA) of 0.6 and field size of 1.5 mm X 1.5 mm. The second is a device and lithographic process development tool that has a variable NA of 0.75 and field size of 4 mm X 4 mm. The two MicroSteppers are designed with N_2 gas purging techniques to maintain low levels of O_2, hydrocarbon, and H_2O vapor contamination in the optical path. Experimental verification of the N_2 purge system at the reticle and wafer plane is presented. The illumination system is designed to maintain better than 2 percent illumination uniformity at the wafer plane over a large range of NA and partial coherence (σ) values. The illumination system supports off axis illumination filtering for annular, quadrapole, and similar pupil-fill modifications.

Key Words: 157nm lithography, microstepper, sub-100nm resolution

1.0 INTRODUCTION

1.1 Requirements for 100nm Lithography node

Smaller design rules and the resulting device shrinkage are the most economical means for semiconductor manufacturers to reduce cost and improve device performance. This economic driver has fueled advancement in optical lithography to extend each generation of technology to critical dimensions (CD) never before thought feasible [1]. Phase shift mask techniques and optical proximity correction has allowed the semiconductor industry to extend KrF (248nm) technology, first introduced for the 250nm node, down to sub-180nm design rules [2]. In similar fashion, it is expected that ArF (193nm) technology, just being implemented into production today, will be extendable down below 120nm [3].

As recently as last year, the industry expectation was that 193nm was the end of the progression to shorter wavelengths for optical lithography. This belief was held due to the limitations in the transmission of optical materials below 193nm. The likely choices for the next generation lithography (NGL) beyond 193nm are then e-beam lithography (SCAPEL) or extreme ultraviolet (EUV). However, the technical obstacles to implementing SCAPEL and EUV remain formidable in the areas of mask technology, light source, productivity, and requirement for operating in a vacuum environment. Neither technology is expected to be available for production use before 2007 [4].

This leaves a “technology gap” between 193nm optical lithography at 120nm and NGL at 65nm as shown in Figure 1. This gap can be filled by 157nm lithography provided a number of critical issues are resolved. The International Technology Roadmap for Semiconductors (ITRC) shows 157nm lithography at the 100nm and the 70nm nodes [5]. For the 100nm node, development is indicated through year 2001 with qualification and pre-production extending to year 2004. This outlook is primarily addressing production requirements. Photoresist development however, generally precedes tool development. For the small field development tools the requirement is from early 2000 forward. Device development with 157nm lithography can not be pursued without a larger field and a greater NA. Device developers require a mid-field lithography tool with alignment capability. The requirements for this tool are consistent with patterning complete devices or test structures. A mid-field size of 4mm x 4mm is sufficient to develop IC devices of considerable complexity using 100nm to 70nm design rules. It is expected that at a wavelength of 157nm, an NA of at least 0.75 will be required. The timing for the mid-field systems follows the small field systems by about 12 to 16 months placing the need for the first mid-field tools in the range of late year 2000 to mid year 2001.

1.2 157nm Technology

In the past year significant progress has been made in 157nm technology. Much of the research has been done by a team lead by Dr. Mordechai Rothschild at MIT Lincoln Labs [6]. Advancement in the technology has progressed to the point where industry leaders voted for 157nm as the technology of choice for the 100nm and 70nm technology node. This vote was taken during a Sematech meeting on next generation lithography in December 1999 [4].

International Sematech has identified a number of critical issues that need to be resolved for 157nm lithography [7]. Advancement has been made on virtually all fronts as shown in Table 1. Lithography grade CaF_2 with transmission of greater than 99%/cm is available in sufficient quantities for technology development from multiple suppliers [8]. Availability of lithography grade CaF_2 blanks greater than 150 mm diameter is still very limited; however, this is expected to change dramatically within the next year. At least one anti-reflective coating material has been found which is sufficiently durable to exposures at 157nm. The projection lens issues are discussed in detail in section 1.5. 157nm lasers with sufficient power and reliability are available from at least two sources [9, 10]. The use of an un-narrowed F_2 laser for a 157nm small field lithography system is discussed in section 3.2. For research and development tools, it has been demonstrated at MIT Lincoln Labs that N_2 purge of the optical path is sufficient to control the contamination levels down to the level needed for exposure. The issues for contamination control are discussed in section 1.6.

To date there is no satisfactory pellicle material that can withstand exposure at 157nm. This does not impede the development of 157nm MicroSteppers. Research and development continues for a suitable solution before production implementation. The issues for 157nm photoresists and reticles are discussed in sections 1.3 and 1.4 respectively.

1.3 Photoresist

The initial characterization of a 157nm exposure tool requires a straightforward method for recording the image using a baseline photoresist process. Current photoresist materials, such as those used for 193nm lithography, are highly absorbing at 157nm wavelength, restricting their application to very thin (approximately 50nm) films. However, such photoresists have known properties and can provide valuable initial characterization for 157nm imaging processes. Issues limiting the practicality of thin photoresists include higher defect density and the higher costs of multilayer photoresist processing.

For production applications photoresist films greater than 200nm in thickness are desired, which requires the development and characterization of new photoresist materials. A number of promising polymer materials with sufficient transparency at 157nm have been identified [11]. At present, there are very limited ways to expose candidate photoresist materials. Mostly, photoresist chemists are limited to flood exposure techniques, which are unable to address resolution issues. For advanced materials, a flexible, high resolution exposure tool is crucial for imaging characterization and overall photoresist optimization. This is one of the strongest motivations for the development of a small field 157nm lithography tool. A small field lens with an NA of 0.6 is a good compromise between lens development time and the need to quickly produce results consistent with the ITRC roadmap.

1.4 Reticle

Current optical lithography systems with light sources operating at wavelengths down to 193nm use photomasks manufactured on synthetic quartz substrates with transmission values greater than 90 percent. At wavelengths below about 175nm, however, transmission falls off dramatically because of the high OH^- content in the fused silica. At 157nm, standard UV excimer grade quartz has almost zero transmission [12,13,14]. Initially, CaF_2 was tested for suitability as a reticle material for 157nm lithography and was found to have serious shortcomings [15]. Thermal expansion for this material is more than 30 times that of fused silica and is considered unmanageable. Several glass manufacturers have demonstrated that dry (OH^- removed) fluorine doped fused silica will transmit greater than 70 percent at 157nm with 250mil blanks. A theoretical transmission limit of 88.5 percent has been calculated using refractive index measurements. Thermal and mechanical properties of the modified fused silica are similar to those of the standard excimer grade fused silica. Tests for laser damage have shown only slight changes in absorption after rigorous exposure testing. MIT Lincoln Labs has tested fused silica with exposures up to 520 million pulses with energy density up to of $1.4mJ/cm^2$ with minimal damage [16, 17].

Other areas of concern are the optical density, adhesion properties and durability of the thin chromium layer currently used in photomask fabrication. B. W. Smith has shown that the typical Cr, CrO, CrN film stacks have sufficient absorption and optical density for use at 157nm [18]. Furthermore, absorption can be optimized by adjusting the components of the film. Chromium film adhesion to polished modified fused silica substrates has also been tested with good results [12].

For this study a major glass company was able to provide 6.0 x 6.0 x 0.250 inch substrates with 157nm transmission values greater than 78% with ±1% uniformity. The substrates were coated by DuPont Photomasks using their standard chromium film and 2000Å of PBS photoresist. A 10X test pattern was designed containing 0.60µm lines and spaces, and a series of contact arrays down to 0.80µm at a variety of pitches including 1.60µm at reticle dimensions. DuPont Photomasks wrote the reticle on a MEBES 4500 and processed it using their normal production conditions.

The International Sematech goal for pellicle transmission is 95 percent at 157nm [19]. The other issues are laser damage, mechanical stability, and adhesive integrity and outgassing. The MicroStepper described in this paper is designed to be used in a development environment and is intended to be used without pellicles.

1.5 Projection Lens

There are stringent requirements on the CaF_2 for lens blanks. Homogeneity, stability against 157nm laser exposure, birefringence, and optical axis alignment are all critical factors. Candidate material samples have been tested by MIT Lincoln Labs [16] with multiple samples meeting the laser stability requirements. Homogeneity on the order of 1 to 2 ppm or better is required for most lens designs. Birefringence values are similarly stringent, at 1nm/cm or better. In addition to the physical and chemical requirements, production of large lens blanks is currently problematic. The small-field and mid-field MicroSteppers in this paper utilize all-CaF_2 catadioptric lenses. The design, being catadioptric, does not require a second material for color correction. Both natural lines in the 157nm laser spectrum are utilized, thereby avoiding line narrowing. Regardless, the stringent requirements on homogeneity and birefringence still apply as the choice of catadioptric design gives relief mainly from chromatic aberrations.

The NA requirements for early photoresist development tools can be relaxed somewhat to allow the screening of photoresist samples to meet the very demanding requirements for the implementation of early production tools in approximately 2004. The mainstream of 157nm production will occur later, perhaps in years 2005 and beyond. Chip manufacturers will need higher NA production tools to cope with the needs of 70nm node lithography. Pursuing NA’s above 0.7 will allow the industry to push optical lithography to its limit. Pre-production MicroSteppers will need to have NA values at least 0.75 and therefore be able to contribute to the knowledge of very high NA performance at 157nm.

1.6 Contamination Control

Since O_2 and other contaminants such as hydrocarbons and H_2O absorb 157nm light very efficiently, provision must be made to remove all but trace amounts of those compounds from the beam path [19]. The most common ways of doing so are either to evacuate the path or to purge it with a gas which is optically inert at these wavelengths. N_2 purge is perhaps the easiest and least expensive approach. Typically, the concentration levels of O_2 that are acceptable are in the ppm range. Adsorbed H_2O on lens surfaces or incorporated into lens coatings also produces significant detrimental effects. Rothschild pointed out that 1nm of adsorbed H_2O vapor on one surface attenuates the beam by 2 percent and similar numbers pertain to familiar photoresist compounds such as polyethylene and polyhydroxystyrene [19]. Photoactivated chemical reactions such as ozone formation and chemical vapor deposition are also possible issues that must be addressed by purging. Purging requirements and design are discussed in section 3.3.

2.0 ULTRATECH MICROSTEPPER PROGRAM AND GOALS

Ultratech Stepper’s goal for the 157nm program is to provide the semiconductor industry with cost effective lithography systems for early photoresist and device development. This means limiting the technology risk by utilizing proven hardware and software designs wherever possible. The 157nm MicroSteppers will utilize Ultratech’s production-proven XLS stepper body.

Ultratech Stepper’s advanced MicroStepper experience began with the insertion of 193nm technology. Ultratech developed the first 193nm MicroStepper for early photoresist characterization in 1994. The objective lens for 193nm was a 10X catadioptic design, with 0.60 NA, and 1.5 mm by 1.5 mm exposure field. This same proven lens design is adapted by Ultratech Stepper for the 157nm program. The optical material used for the 157nm objective lens is CaF_2. The lens design for the small field MicroStepper is shown in Table 2. Both the small field and mid-field 157nm MicroSteppers are described in this paper.

Ultratech has developed a small field (1.5 mm by 1.5 mm) 157nm exposure to tool for photoresist and material characterization. This tool is in the final test stage at Ultratech's Wilmington, MA manufacturing facility. Ultratech Stepper will follow the 157nm small-field MicroStepper with a mid-field (4 mm x 4mm) exposure tool for device evaluation. This system will have fine alignment capability, along with automatic wafer and reticle handling. This system is expected to be available by the second half of 2001.

3.0 MICROSTEPPER DESIGN

3.1 Optical System

3.1.1 Beam Delivery System

The beam delivery system relays the radiation from the F_2 laser to the illuminator. Since all microlithographic grade F_2 lasers output a rectangular beam, the beam delivery system (BDS) has a cylindrical optic to convert this to a square beam. Three folds are used to relay and steer the laser beam to the correct angle and position required by the illuminator.

Since photoresist sensitivities may run from about 2 to 30 mJ/cm^2, and 50 or more pulses of the F_2 laser are needed to obtain good dose control, a variable attenuator is included in the BDS. If more precise dose control is required, the user can increase the attenuation and thereby increase the dose precision by averaging the dose over a larger number of laser pulses. If throughput is of greater importance, the attenuation can be reduced and thus fewer laser pulses will be required to provide the correct dose at the image plane. In this way the variable attenuator allows the user to have control over the compromise between throughput and dose stability.

One of the concerns for the BDS is durability. The cylindrical lens and fold mirrors are subjected to a high fluence, albeit similar to the fluence seen by the laser optics. The mechanical design was made to allow for easy replacement of these optical components if required. As the manufacturing process for CaF_2 matures, it is likely that durability will become less of an issue.

3.1.2 Illuminator Design and Performance

As with other laser based UV lithography tools, the main functions of the illuminator are to spatially homogenize the input laser light and to match the input requirements needed at the entrance pupil of the objective. This is accomplished with the use of a diffuser and a kaleidoscope in conjunction with several refractive elements. The systems studied here are designed to provide better than 1.5 percent uniformity across the image field.

The partial coherence or filling factor of the optical system can be varied from 0.3 to 1.0. Additionally off-axis illumination can be utilized on either of the 157nm tools. As with the Beam Delivery System, the first component of the illuminator is subjected to relatively high fluence levels and this component was designed to be replaceable.

3.1.3 Objective Lens

One of the main differences between lithographic lenses made in the past for longer wavelengths and the optics for a 157nm system is the limited choice of materials available. Currently CaF_2 is the only viable refractive material, so catoptric or catadioptric systems are required if chromatic aberration is to be corrected. Since CaF_2 of the quality required for microlithography had not been available in the past, one of the key elements of success is the ability to obtain and characterize crystals of sufficient quality and size.

Figure 2 depicts the lens design form selected for the projection objective for the 157nm systems. For this design there are five optical elements, the system is telecentric on the image side, there is a small axial obscuration, and the last optical element is a double Mangin mirror with a near normal incidence beamsplitter on one side and a mirror with a central hole on the other side. A summary of the major optical parameters is given in Table 2. The image field size and fixed numerical aperture of the objective lens for the 157 small field MicroStepper is consistent with the requirements for early photoresist characterization and materials development. The reduction ratio of 10:1 for the objective lens of the small field MicroStepper is chosen for ease of lens manufacturing and reticle fabrication.

Due to the excellent color correction of the objective, it is possible to print images using either a single line or both lines emitted by an F_2 laser. This ability is a major advantage in that the laser is not required to have the additional cost and complications of line narrowing. Use of both of the laser natural lines also increases the throughput potential of the system.

3.2 157nm Laser

The 157nm F_2 laser design is quite similar in its components to micolithographic KrF and ArF lasers. The key specifications for the F_2 laser are summarized in Table 3. One fundamental difference is that F_2 is a true excimer, with F_2 as the dimer. Some of the major differences from the KrF and ArF lasers are that helium is used as the buffer gas, the entire optical path must be purged or evacuated and there is a higher sensitivity to contaminants. As the spectral output is in the vacuum ultra-violet (VUV), the laser must be operated in a vacuum or in a purge of gas which does not absorb significantly at this wavelength. Since ultrapure N_2 is readily available in most semiconductor fabs and the absorption is quite low at 157nm, N_2 is a natural choice as the purge gas.

The spectral emittance of an F_2 laser is quite different than that of KrF and ArF lasers. First, there are two natural lines, separated by about 106pm. Secondly, each of the F_2 lines near 157nm is about 1pm full width at half maximum (FWHM), which is significantly narrower than the natural output of the KrF and ArF lasers. As a result, optical designs with spectral bandwidths less than 106pm, but greater than about 1pm will not require the full expense or complication of a line-narrowing component in the laser. It is not as difficult to isolate the stronger of the two lines as it is to monitor and maintain the required bandwidth and mean wavelength in a KrF laser.

3.3 PURGING REQUIREMENTS AND DESIGN

3.3.1 Zone Purging Concept and Design

For a 157nm exposure tool, an N_2 purge and control system had to be devised to maintain the appropriate environment for the 157nm beam path from laser to image plane. O_2, H_2O and Hydrocarbons are absorbers in this wavelength and care must be taken to displace or remove these elements. The purging concept consists of taking the 157nm beam track length and dividing it up into different zones as shown in Figure 3. In order to meet the required purge in each zone, ultra-clean N_2 is used to displace O_2 and H_2O. Careful consideration is given to material choice for components in order to not contaminate with hydrocarbons. Purge zone 1 is for purging of the F_2 laser and the pressure and flow rates are specified by the manufacturer of the laser. Zone five (above the reticle), zone six (below the reticle) and zone eight (wafer plane) are considered critical zones since they are open to the ambient environment and are the hardest to control. The gas delivery and monitoring system (GDMS) delivers the appropriate flow, pressure and purity of N_2 in order to maintain the proper environment within each zone. In addition, the GDMS has been designed to monitor O_2 in each zone. The GDMS consists of filters, mass flow controllers, pressure transducers, vibration control, O_2 monitors and error reporting. The GDMS is a standalone rack that interfaces serially with the stepper control system.

3.3.2 Critical Zones

Zone five is designed to provide a properly controlled environment for 157nm radiation at the top side of the reticle. The design uses a zone plate that is held off the top surface of the reticle by a small amount. The bore of the zone plate is large enough to accept the illumination for the prescribed field. The bore is flooded with ultra-clean N_2 delivered by the GDMS. Zone six is designed to provide a properly controlled environment for 157nm at the bottom side of the reticle. The design and requirements mirror those of zone five with the exception that the zone plate does not need to move for reticle loading. Zone eight is designed to provide a properly controlled environment for 157nm radiation between the top side of the wafer and the last element of the objective lens. The design uses a nose cone that is mounted to the end of the objective lens. The N_2 forms a column from the end of the nose cone to the image plane and is a suitable environment for relaying the aerial image to the wafer.

3.3.3 Experimental Results

A Delta F oxygen analyzer was used to measure the O_2 content in zone 6 (the reticle chamber) and zone 8 (the lens to wafer exposure area). The results for these zones are shown in Figure 4. The O_2 concentration required for 97.9 percent transmission in zone six is less than 53 ppm O_2 while the experimental values are all less than 25 ppm. The O_2 concentration required for a 97.9 percent transmission in zone eight is less than 420 ppm while the experimental values are all less than 250 ppm. It is apparent that the design of the purge system supports the transmission budget for these critical zones.

3.4 XLS BODY

The 157nm MicroStepper is based on the XLS Mercury platform. The Mercury platform is the latest family of i-line and DUV reduction steppers currently offered from Ultratech Stepper. Since the 157nm MicroStepper is based on a production system platform, it contains many features not normally found in a research-based development tool. Some of these features include in-situ metrology for rapidly measuring system focus, fully automated wafer and reticle handling, and an intuitive graphical user interface for job creation and execution. The 157nm MicroStepper body specifications are summarized in Table 4.

4.0 SUMMARY

Ultratech Stepper’s current 157nm stepper family is designed to meet two needs depending on the lens configuration. First, the small field lens is primarily for photoresist performance characterization. The lens field size, 1.5mm x 1.5mm, and NA of 0.6 are a compromise between fabrication risk factors, development time, and the field size and NA needs for photoresist characterization. The goal of this work is to produce a pre-production lithography tool for photoresist scientists to utilize in the development of candidate photoresist materials, thus lithographic processes can therefore be developed with minimum risk in a time frame consistent with the ITAR roadmap. Reticle data will also be obtained from the newly developed fluorine doped fused silica. This stepper is expected to pattern photoresist from 130nm downward to 70nm or even smaller, where 130nm patterns will require a K_1 factor of about 0.5 and the 100nm test patterns will require K_1 factor of about 0.4. Reticle and wavefront engineering techniques such as phase shifting may be required to achieve 70nm and below [20].

Increased resolution can be obtain from the mid-field version of the MicroStepper which utilizes a lens of NA 0.75 and has a field size of 4mm x 4mm. Using this NA one can expect to pattern 100nm geometries with a K_1 of approximately 0.5 and 70nm geometries with a K_1 of approximately 0.33. Tables 5 and 6 show solutions to the Rayleigh equation for comparison of the expected performance of the 157nm MicroStepper versus the 193nm

MicroStepper. If photoresist performance in 157nm candidate photoresists can reach K_1 factors of approximately 0.3 as it has in the 193nm case without reticle and illumination enhancements then 70nm performance can be expected using a NA of 0.75. Should K_1 factors not progress to that extent, a higher NA figure of 0.85 is included for comparison only. It is interesting to point out that 50nm line-space geometries would seem to require a K_1 factor below 0.3 and appear to be beyond the capabilities of 157nm lithography.

5.0 ACKNOWLEDGEMENTS

The authors would like to thank Mordechai Rothschild at MIT Lincoln Labs for his helpful discussions, Evan Mapoles of Ultratech Stepper for his calculations of the budget for the allowable contamination in each purge zone and David Markle of Ultratech Stepper for his discussions and support.

6.0 REFERENCES

1. B. Bruggeman et. al., “Microlithography Cost Analysis”, *Microlithography Interface ‘99 Proceedings*, 1999.
2. H. Liu, A. Wong, “150µm DRAM Optical Lithography Capability”, *ARCH Microlithography Interface ‘99 Proceedings*, 1999.
3. S. Lee et. al., “Feasibility Studies of ArF Lithography for sub-130nm Lithography”, *Optical Microlithography XII Proceedings*, SPIE **2679** (1999).
4. W. Wade, “Search for next -generation lithography scheme slows”, *Electronic Engineering Times*, November 22, 1999.
5. The International Technology Roadmap for Semiconductors, “Lithography Exposure Tool Potential Solutions” 1999, p. 154, International Sematech, Austin, TX.
6. T. Bloomstein, V. Liberman, M. Rothschild, “Optical Materials and Coatings at 157nm”, *Emerging Lithographic Technologies III Proceedings*, SPIE **3676** (1999).
7. R. Harbisin, NGL Workshop, Colorado Springs, CO.; Dec. 1999.
8. D. Lammers, “Contenders Crowd Lithography Arena”, *Electronic Engineering Times*, December 6, 1999.
9. T. Hofmann et. al., “Revisiting F_2 laser for DUV Microlithography”, *Optical Microlithography XII Proceedings*, SPIE **2679** (1999).
10. U. Stamm et. al., “Excimer Laser for 157-nm Lithography”, *Emerging Lithographic Technologies III Proceedings*, SPIE **3676** (1999).
11. R. R. Kunz et. al., “Outlook for 157-nm resist design”, *Advances in Resist Technology and Processing XVI Proceedings*, SPIE **3678** (13-23), March 1999.
12. Lisa A. Moore, Charlene Smith, “Properties of Fused Silica for 157nm Photomasks”, *19th Annual Symposium on Photomask Technology Proceedings*, SPIE **3873**, 1999.
13. Y. Ikuta et. al., “New Silica Glass for 157nm Lithography”, *19th Annual Symposium on Photomask Technology Proceedings*, SPIE **3873**, 1999.
14. Charlene M. Smith, Lisa A. Moore, “Fused Silica for 157nm Transmittance”, *Emerging Lithographic Technologies III Proceedings,* SPIE **3676**, 1999.
15. C. Smith, and L. More, 157 Lithography Data Review, MIT LL, Boston, MA; May 1999.

16. M. Rothschild, NGL Workshop, Colorado Springs, CO.; Dec. 1999.

17. Hiroki Jinbo et. al., “Dry & F doped fused silica for photomask substrate in 157nm lithography”, *19th Annual Symposium on Photomask Technology Proceedings*, SPIE **3873**, 1999.

18. B.W. Smith, A. Bourov, M. Lassiter, M. Cangemi, “Masking materials for 157nm lithography”, *19th Annual Symposium on Photomask Technology Proceedings*, SPIE **3873**, 1999.

19. M. Rothschild, NGL Workshop, Colorado Springs, CO.; Dec. 1999

20. K. Patterson et. al., “Improving Performance of 193 nm Photoresists Based on Alicyclic Polymers,” *Advances in Resist Technology and Proceedings XV Proceedings*, SPIE **3333**, 1998.

Technology	Risk Estimate	Comments
Small and Mid-Field lens	Low	CaF$_2$ polishing and coating, Catadioptic Design Proven
Lens Materials	Low/Medium	Material Quality at > 150mm diameter blanks
157nm Laser Source	Low	Commercially Available
Beam Delivery Optics	Low	CaF$_2$ small optics
Body Modification	Low	Minimum requirement
N$_2$ Purge	Low	Test results are available
Focus Stability	Low	Minimum requirement for resist development
Software	Low	Minimum modifications
Reticle Exchange	Low	Based on existing technology
Alignment	Low	No alignment for photoresist
Pellicles	Medium/High	Not required for MicroStepper
Wafer Handling	Low	Based on existing technology

Table 1: Technology risks and advancement for 157nm lithography.

Optical Design Parameters	157nm Small Field
Material	CaF$_2$
Reduction Ratio	10:1
Wavelength (nm)	157.6 prim; 157.5 second
Numerical Aperture (NA)	0.60 Fixed
Field Size (mm)	2.1 Ø (1.5 ❏)
Spectral Bandwidth (pm)	≤ 120 (twin)
Distortion (nm)	≤ ±15
Guaranteed Resolution (nm)	130 lines
Depth of Focus (nm)	≥ 300
CD Variation (nm)	≤ ±5 dense; ≤ ±7 isolated

Table 2: Lens specifications for the small-field 157nm MicroSteppers.

Parameter	Specification
Repetition Rate	≥ 600 Hz
Average Laser Power	≥ 4.8 Watts
Pulse to Pulse Energy Stability	≤ ±0.5 percent
Gas Lifetime	$10X10^6$ pulses

Table 3: F_2 Laser specifications for 157nm lithography.

Parameter	Specifications
Wafer Size	200mm with orientation to notch or flat
Dose Control	2 percent
Reticle Handling	Automatic load
Reticle Size	6 x 6 inch, 250 mil thickness
Chuck Flatness	consistent with 100nm resolution requirements
Stage Stepping Precision	≤40nm 3σ Small Field
Wafer Auto focus Repeatability	Small Field: 100nm TIR; Mid-Field: 50nm TIR
Environmental Chamber	Control temperature (±0.1^{o}C)
Illumination Filtering	Custom plate for circular, annular and quadrapole
N_2 Purge	Easy access to mask and wafer plane
Alignment	Small Field: 60nm 3σ; Mid-field: 35nm 3σ

Table 4: 157nm MicroStepper body specifications.

Critical Dimension Node (nm)	NA = 0.60	NA = 0.75	NA = 0.85
130	0.50	0.62	0.70
100	0.38	0.48	0.54
70	0.27	0.33	0.38
50	0.19	0.24	0.27

Table 5: Comparison of K_1 factors versus NA for critical dimension nodes using 157nm wavelengths.

Critical Dimension Node (nm)	NA = 0.60	NA = 0.75	NA = 0.85
130	0.40	0.51	0.57
100	0.31	0.39	0.44
70	0.22	0.27	0.31
50	0.16	0.19	0.22

Table 6: Comparison of K_1 factors versus NA for critical dimension nodes using 193nm wavelengths.

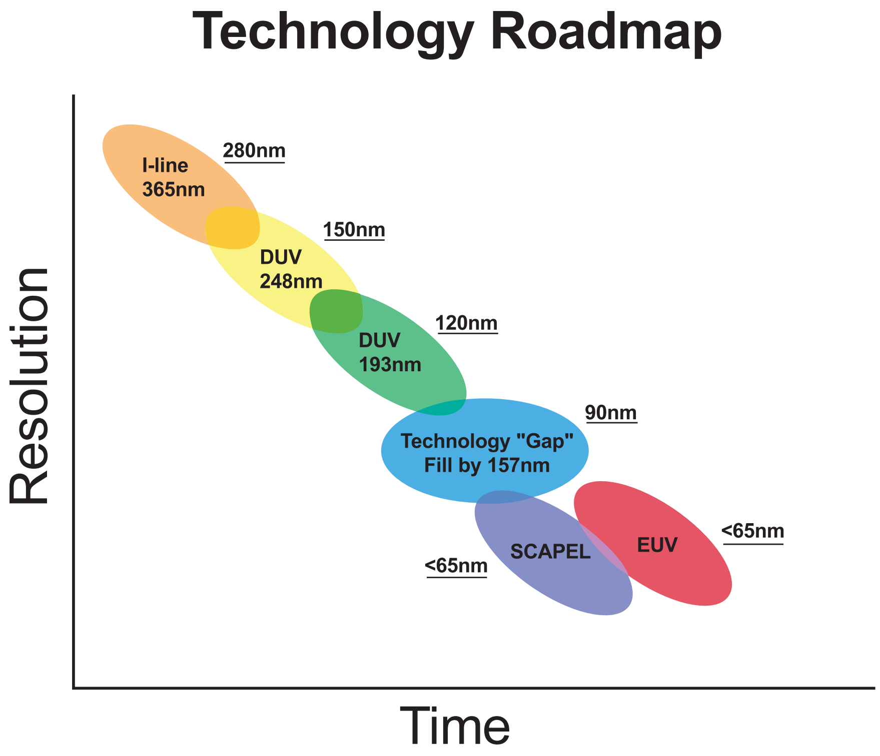


Figure 1: Technology road map for lithography resolution as a function of time.

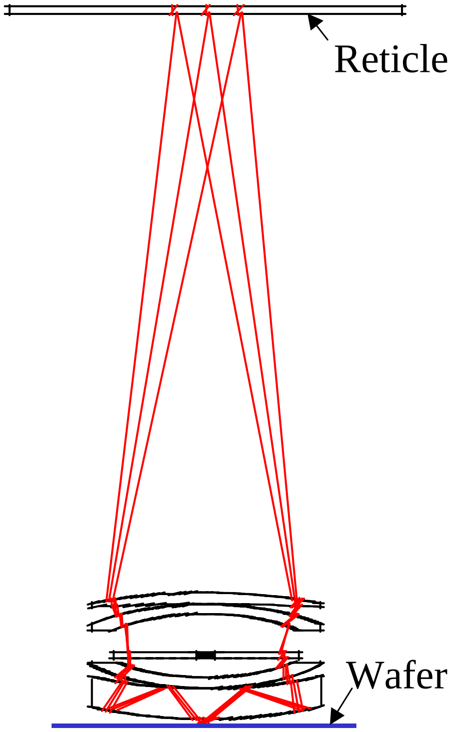


Figure 2: Catadioptric lens design for the 157nm MicroStepper objective.

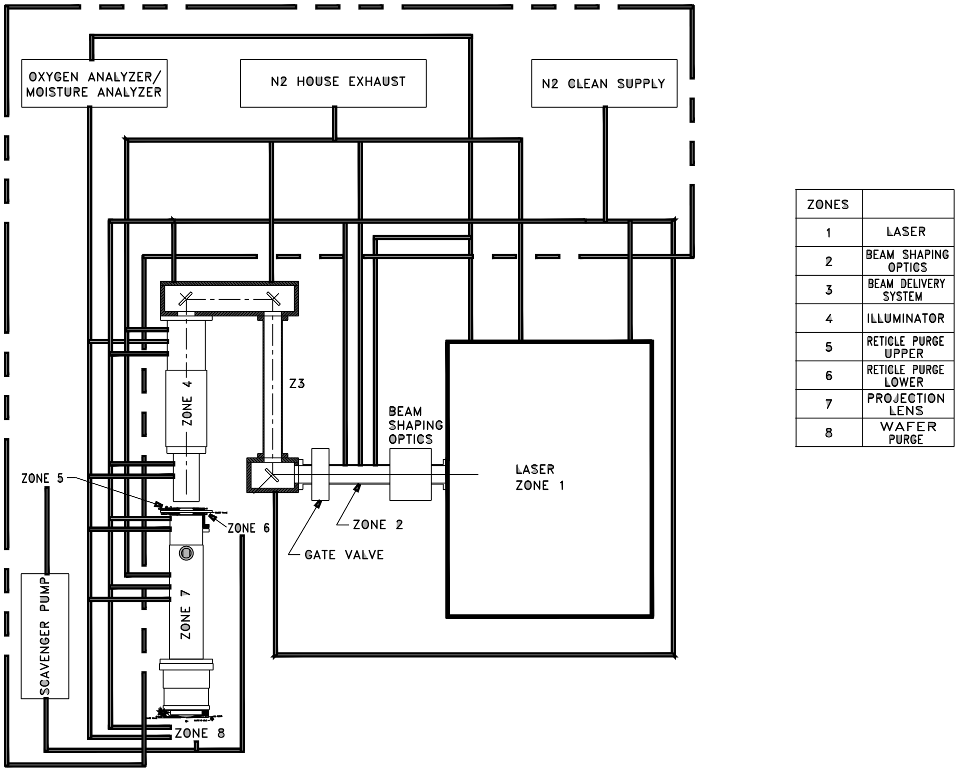
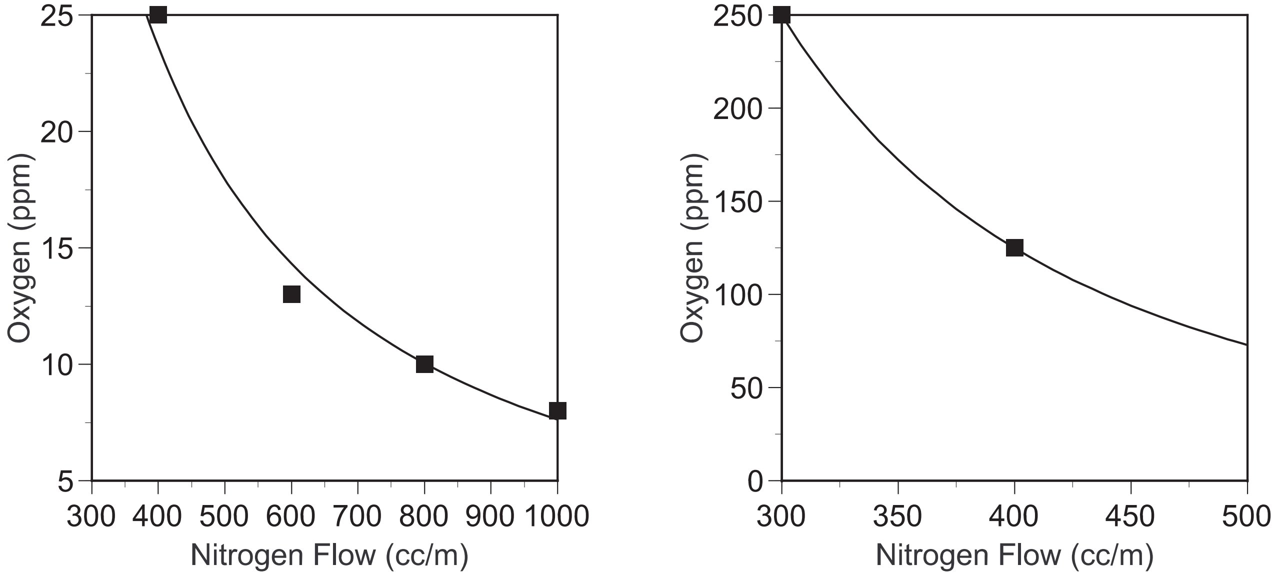


Figure 3: The N_2 purging concept divides the 157nm beam path into 8 zones.



(a) Zone 6

(b) Zone 8

Figure 4: Purge results for zone 6 (the reticle chamber) and zone 8 (the lens to wafer exposure area).