PHOTOLITHOGRAPHY At CNF

From Computer Aided Design (CAD) to Patterned Substrate

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Adapted from work by Graham M. Pugh

At CNF, many options exist for producing patterned substrates, but deciding which options are best for your application requires considerable ***planning***. Choosing the most appropriate lithography tool and technique depends upon what processes you will perform ***after*** exposure. The purpose of this manual is to provide you with the information necessary for you to design the best process for achieving the desired results.

Introduction to Nanofabrication

A Brief History

Transistors

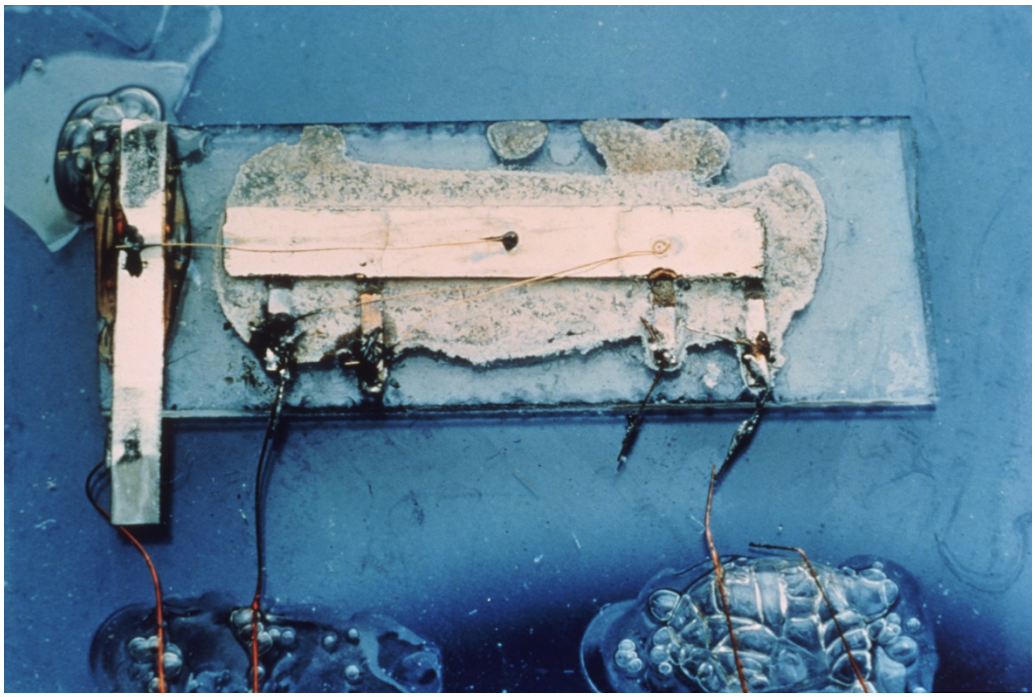
The first working transistor was demonstrated in 1947 at Bell Labs by researchers Bardeen, Brattain, and Shockley. This device was fabricated in Germanium and was rather large by today's standards:

The First Transistor
Courtesy Lucent Technologies

Transistors were manufactured as discrete devices beginning in the 1950's and continue to be produced and used in that and many other forms. The invention of the transistor revolutionized electronics by enabling smaller, lighter, cooler, cheaper, and more reliable products to be produced. It was the beginning of the end for vacuum tubes and the birth of portable consumer electronics.

Integrated Circuits

The first integrated circuit was demonstrated in 1959 at Texas Instruments by Jack Kilby.



The First Integrated Circuit
Courtesy Texas Instruments

At almost the same time, Robert Noyce was demonstrating a similar device at Fairchild Camera. Noyce's most important contributions to the future of IC fabrication were the use of planar technology, where all structures of the device are flat and in the plane of the substrate, and the use of silicon dioxide as an insulating material grown on a silicon substrate.

These innovations led to the development of nearly all the electronic products existing today. Manufacturing of integrated circuits began in the 1960's and continues to grow nearly exponentially.

Automation

The cost-effective manufacturing of modern IC's began in the 1980's with the advent of automated control of processing equipment.

Wafer Manufacturing Facility
Courtesy IBM

Previously, semiconductors were made on a scale reminiscent of laboratory experiments. Large-scale manufacturing was only made possible with the introduction of computer-controlled automation. As more and more aspects of the fabrication process were automated, higher yields and efficiencies were achieved; thus, smaller and cheaper devices were made possible. This continuous improvement of wafer processing through the statistical controls available with automated systems helps drive the race to higher performance products we benefit from today.

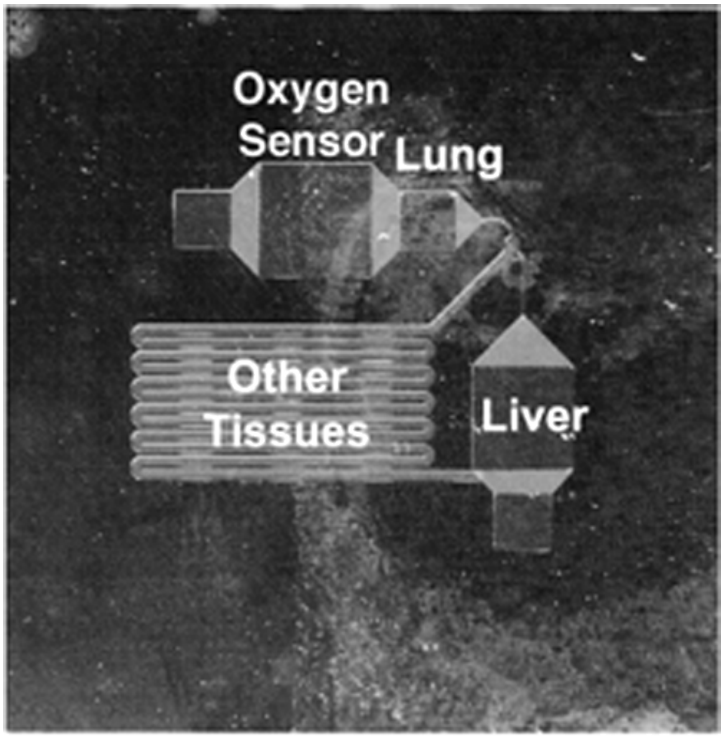
Applications

The international marketplace has driven the demand for faster, smaller, and cheaper devices in almost all applications. The first breakout product was the Personal Computer, and while this remains an important customer of IC's, the real growth areas are many: smartphones, automobiles, wireless networks, and personal entertainment to name a few. Even household appliances like thermostats and refrigerators are utilizing more and more electronic devices as size, cost, and power requirements are reduced, and capabilities and reliability improve.

The Future

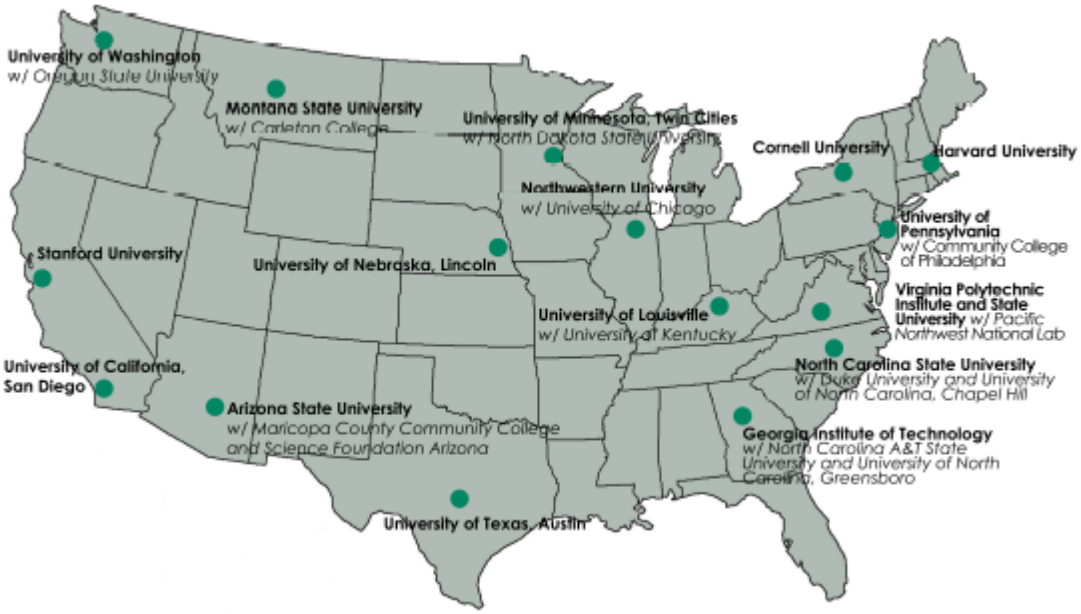
What does this mean to Me?

The technologies used to produce these devices were developed almost entirely within and for the electronics industry. Only recently have groups outside the realm of electronics considered applying these methods to constructing other devices. One of the most notable has been biologists, who now are making great strides by applying Nanotechnology to Biology; thus, Nanobiotechnology, which is an important and growing area of research.



Courtesy Cornell Nanobiotechnology Center

More researchers and industries are discovering new applications each year, and the National Science Foundation sees this as a trend worth supporting. The CNF is a part of the National Nanotechnology Coordinated Infrastructure (NNCI), which is an integrated partnership of nearly 30 associated user facilities supported by NSF, providing unparalleled opportunities for Nanoscience and Nanotechnology research.



NNCI Locations

Our purpose is to support researchers by providing access to state-of-the-art tools and technologies, combined with our experience and advice. We can teach you to use these tools and apply them to your project, as well as help you to find others who may assist with technologies outside of our scope. Our assistance can be as deeply involved or peripheral as you want, and any intellectual property is owned by the developer.

What follows is an introduction to Photolithography at CNF, and to some of the technologies available here. The discussions are general, with some of it more specific to the CNF tool set. More information is available from the staff associated with any specific area of the facility.

Lithography Basics

Manufacture of devices depends on selective processes:

Removal of material	--	**Etching**
Addition of material	--	**Deposition**
Modification of material	--	**Implantation, diffusion, etc.**

Defined areas of the substrate must be ***protected from*** or ***exposed to*** these processes. These areas become the pattern for one layer of the device.

Pattern definition takes place in the **resist** -- a thin layer of polymeric material that is usually spin-coated onto the substrate.

The resist is then modified so that it ***remains*** in some areas and is ***removed*** in others. This is a two-step process:

Exposure	--	Incident radiation, particles
Development	--	Selective removal in solvent or base liquid

TYPES OF EXPOSURE

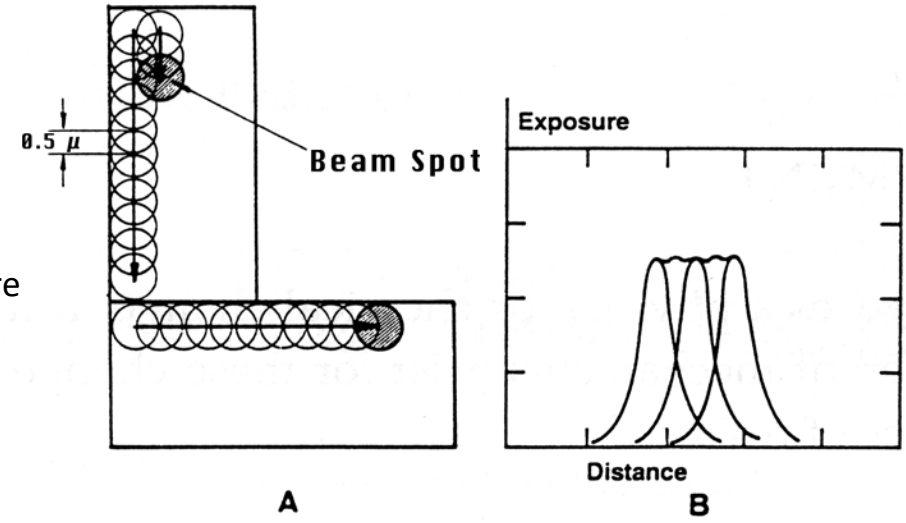
Light --	436 nm - 157 nm: Near-UV to Deep-UV Optical Lithography
EUV --	13.5 nm: EUV Lithography
X-rays --	5 nm - 0.4 nm: X-ray Lithography
Electrons --	10 keV - 150 keV: Electron Beam Lithography
Ions --	50 keV - 200 keV: Focused Ion Beam Lithography

METHODS OF EXPOSURE

Direct Write -- Electrons, ions, or photons are focused onto a small diameter spot which is scanned ***directly*** onto the resist; this is a ***serial*** exposure process.

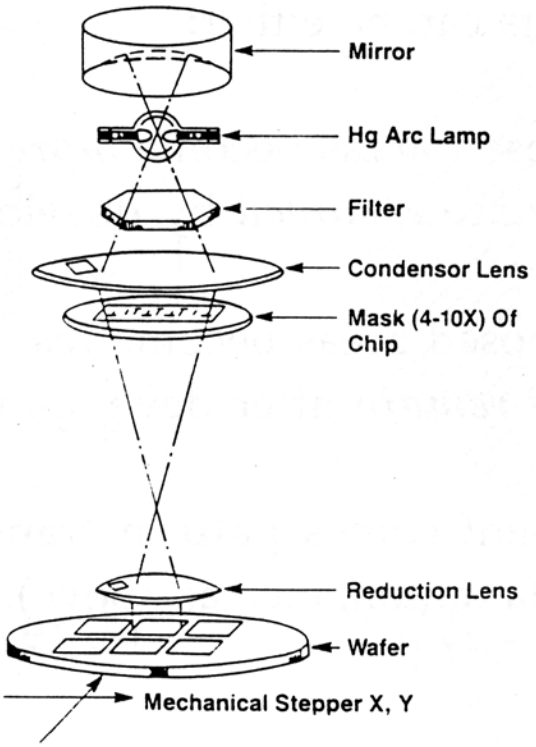
Masked Exposure -- Light, EUV, or X-rays are imaged onto the resist through a ***mask***; this is a ***parallel*** exposure process.

Serial Exposure



W. Moreau, **Semiconductor Lithography**, Plenum, New York, 1988, p. 423.

Parallel Exposure



W. Moreau, **Semiconductor Lithography**, Plenum, New York, 1988, p. 363.

DEVELOPMENT

Exposure causes a physical or chemical change in the resist. Different mechanisms are responsible for these changes in the various types of resist.

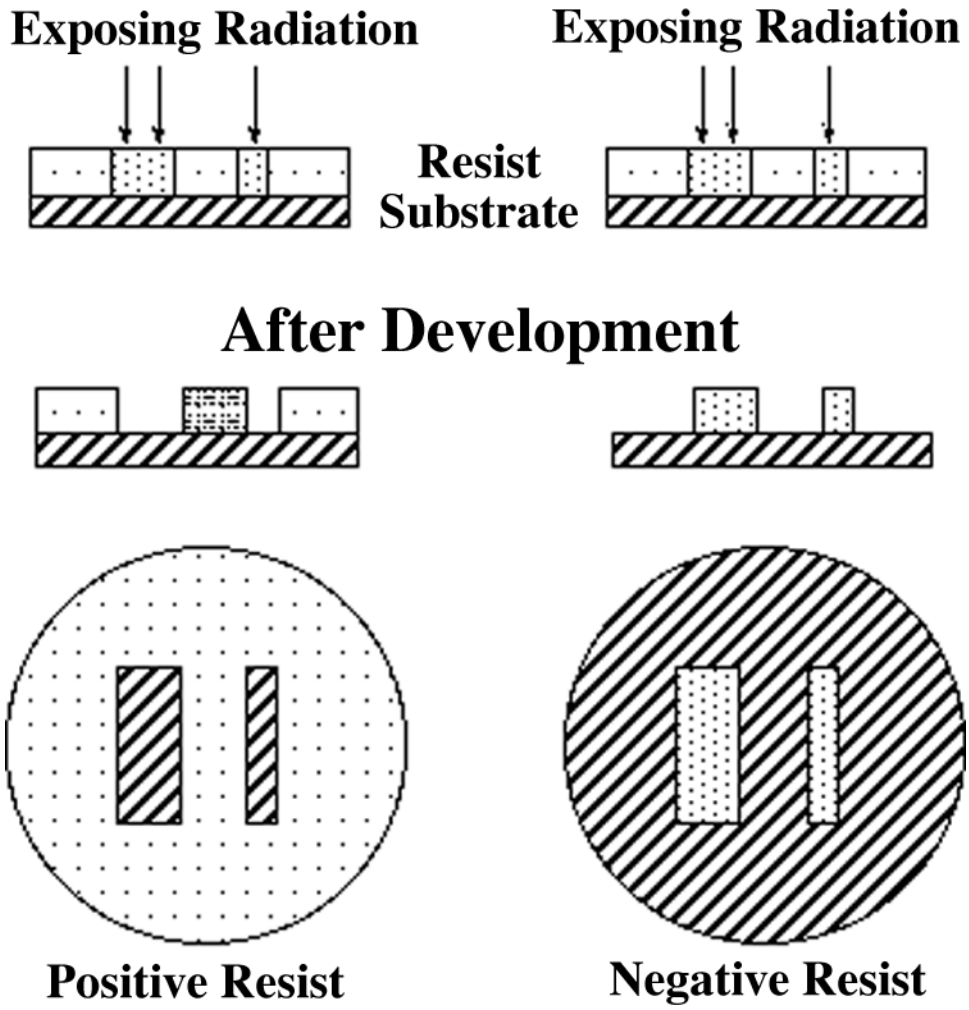
Development takes place in a liquid base or solvent, depending on the resist type.

In general, resists can be either:

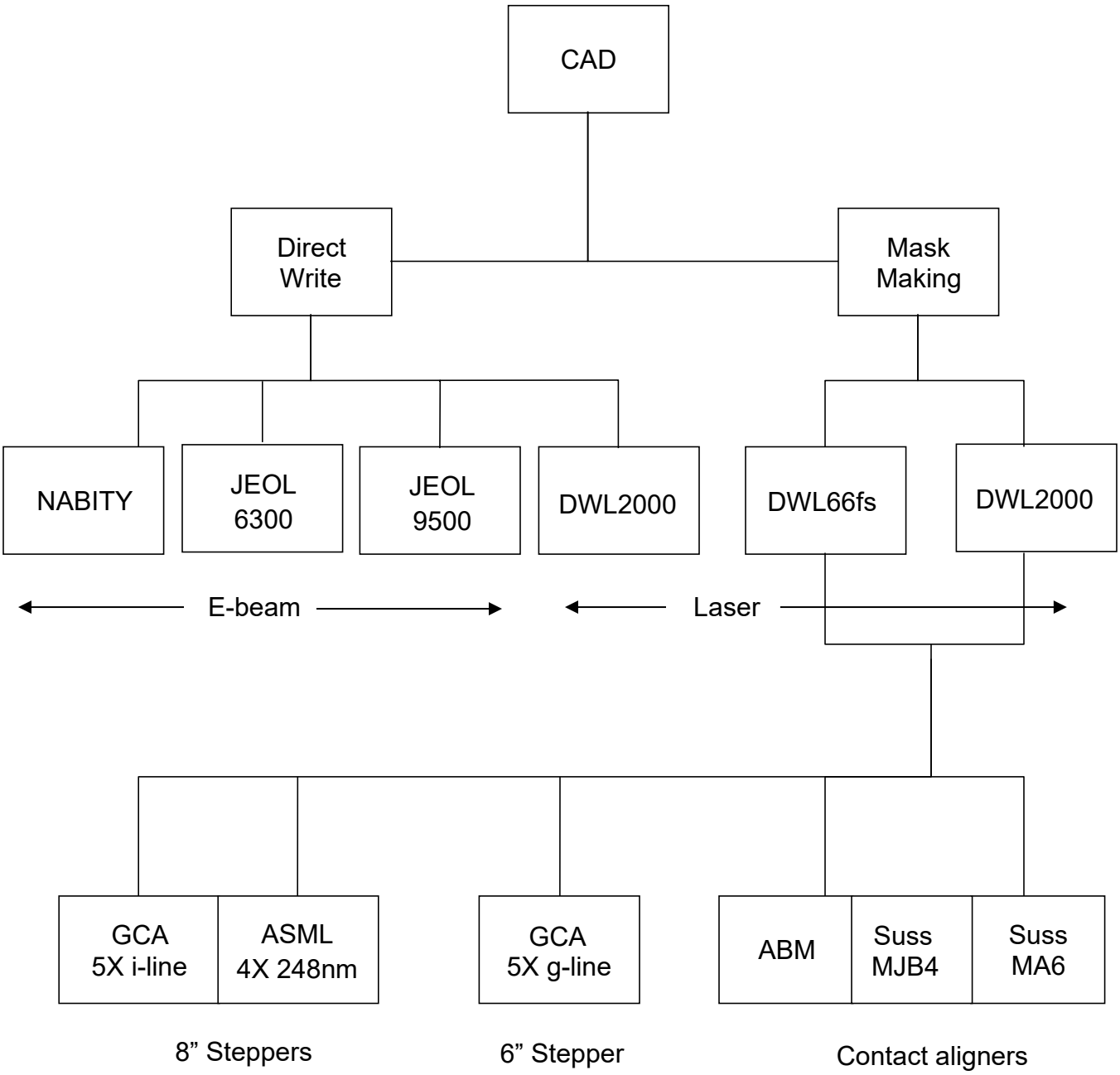
Positive -- exposed areas become ***more*** soluble in the developer; they are ***removed*** by development

Negative -- exposed areas become ***less*** soluble in the developer; they ***remain*** after development

After development is **pattern transfer** (etching, deposition, implantation, etc.).



Lithography at CNF



SOME SUGGESTIONS

The most difficult thing about lithography is that you must know what you want to accomplish and how you will do it ***before*** you design the lithography plan. In particular, you have to think about:

Your pattern requirements

The requirements of the lithography tools

The requirements of the techniques you will use for pattern transfer

These requirements will be discussed going forward.

HERE ARE SOME SUGGESTIONS BEFOR GETTING STARTED:

1. **Think** about what type of device you want and how to implement it.

2. **Gather information** from this manual, staff members, and other researchers about the best tools and techniques to use before you begin to design the pattern.

3. **Design the pattern** using the information you have gathered paying careful attention to the requirements listed above.

4. **Perform** lithography, pattern transfer, etc.

5. **Repeat steps 1 - 4** as many times as necessary to get it right.

HOW CNF WORKS: (A Staff Member's Perspective)

Your (usually) friendly local CNF staff member is balancing the requirements of local users, outside users, machine maintenance, process characterization, materials supply, and many other things. So, please keep in mind:

The more thinking and preparation you do, the more specific the questions you ask will be, and the more time you will end up saving yourself and the staff member.

The more advance notice you can give about when you would like to talk about your process or be trained on equipment, the better.

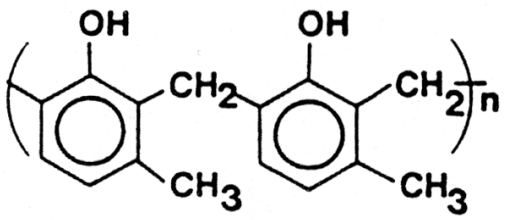
The more responsible you can be around the lab, the less we have to clean up after you, and the more time we have for answering your questions.

And, last but not least, please be patient!

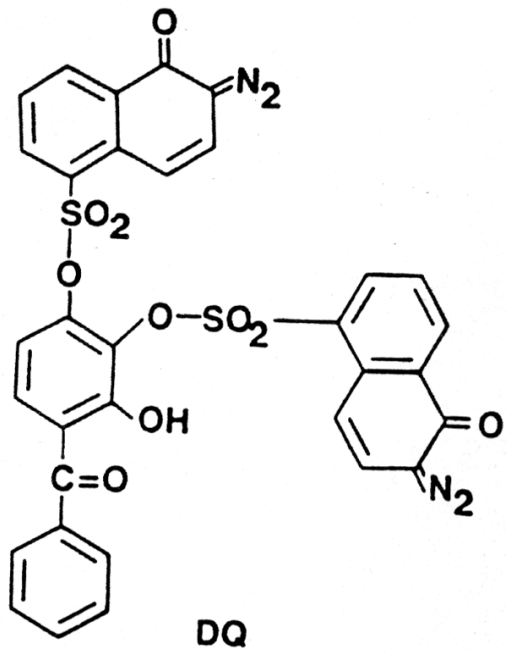
OPTICAL LITHOGRAPHY TECHNIQUES

OPTICAL RESISTS

The resist system used almost universally for **UV** (436-365nm) photolithography is the DNQ Novolak system: novolak resin with a diazonaphthoquinone sensitizer. The basic forms for the resin and sensitizer are shown below:



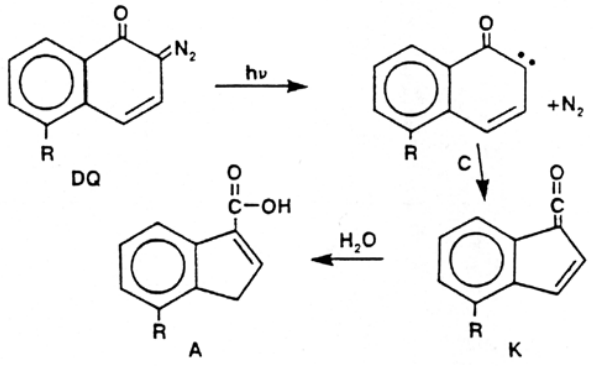
Novolak Resin



DQ

Moreau, p. 32.

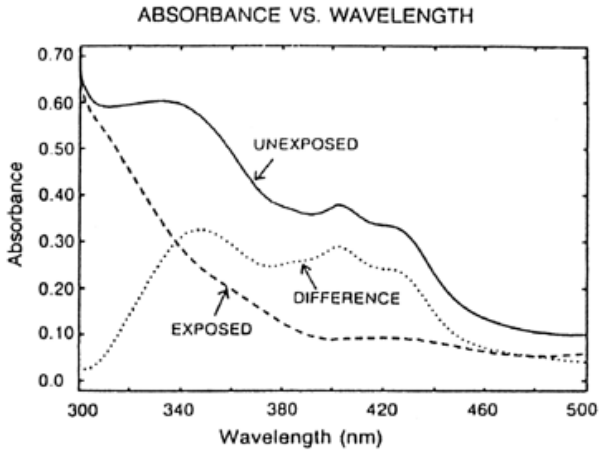
The novolak resin is rendered base-insoluble by the addition of the sensitizer, or photoactive compound (PAC). It remains insoluble until photo-exposure transforms the PAC into a base-soluble product. In this way the PAC acts as a ***dissolution inhibitor*** until transformed by exposure. The photochemical reaction in the sensitizer, known as the "Wolff rearrangement," is shown below:



Moreau, p. 35

The reaction product is **indene carboxylic acid** (seen again when discussing image reversal). Note that <u>water is required for the reaction to occur</u> (i.e. humidity).

The exact composition of each resist differs slightly, and the exact spectral sensitivity of every resist is different. Absorbance data is presented in manufacturer provided graphs as below:



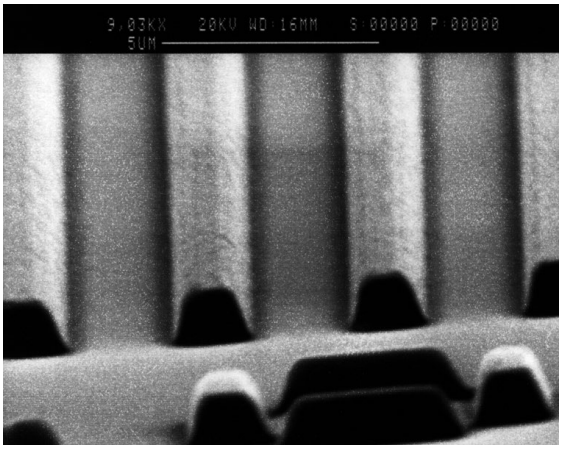
Shipley Product Information

The curve for unexposed resist shows the absorption of the resin and PAC. This must be high for efficient absorption of the exposing photons. The curve for exposed resist effectively shows the absorption of the resin alone. This must be low, so that once the film is exposed it is transparent all the way to the substrate. The difference between the two curves is a measure of the <u>contrast</u> of the resist.

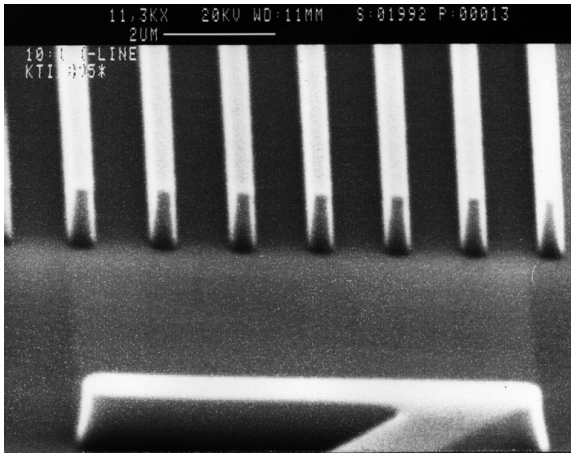
Every resist is designed to have high contrast over a specific wavelength range. If the resist is exposed with light of different wavelengths, higher absorption will result in a sloped sidewall profile as below:

Sloped Resist Profile

Even with the correct combination, there will always be some sidewall slope. The following pictures show the effect of using an i-line (365nm) stepper to expose both a photoresist designed for (mismatched) g-line (436nm) and a photoresist designed for i-line (365nm). Note the difference in sidewall slope:



2.0 µm lines and spaces in 1.0 µm Shipley 1400 g-line resist, exposed with an i-line stepper



0.7 µm lines and spaces in 1.0 µm thick OCG 895i i-line resist, exposed with an i-line stepper

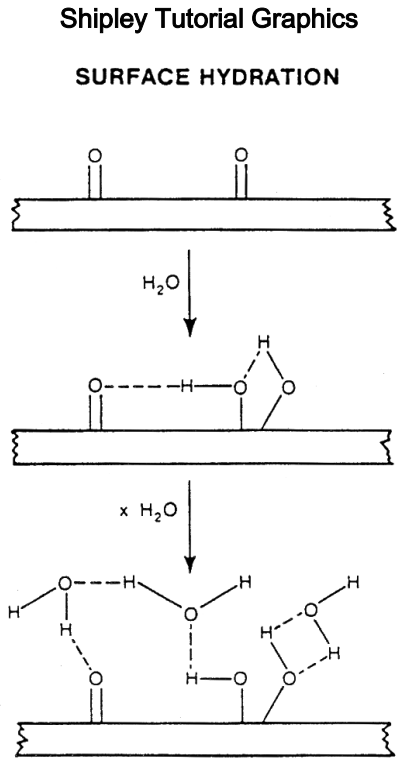
RESIST PROCESSING

Cleaning

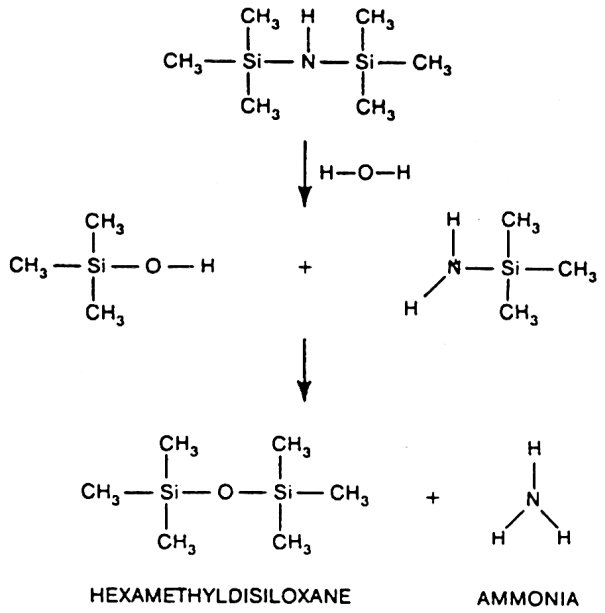
Cleaning a wafer before coating may be as complex as removal of the native oxide, or as simple as rinsing with solvents. A new wafer, however, often requires Standard Cleans 1 and 2 (aka RCA Cleans). If there is grease on a wafer, ***methylene chloride*** may be required to remove it. In post-processing, for example, Bosch-etched wafers require strong O_2 plasma cleaning. If the wafer has previously been coated with resist, this must be stripped before recoating, which in some cases can be difficult (see **Stripping**).

Priming

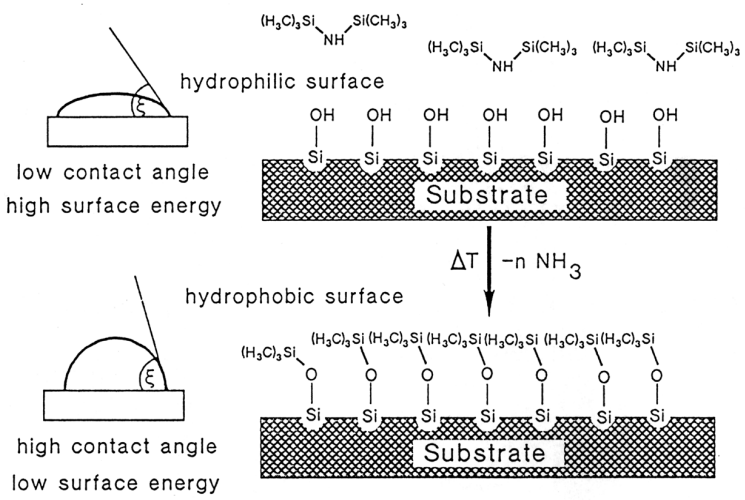
Unfortunately, the surfaces of most of the materials we coat with resist oxidize very easily. These surface oxides form long range hydrogen bonds with water adsorbed from the air. When resist is applied to such a surface, it adheres to the water molecules rather than to the oxide, resulting in poor adhesion. Adhesion to a hydrated surface is shown schematically below.



The figure below shows the chemistry of HMDS (hexamethyldisilazane), a chemical which acts to improve the adhesion of photoresist to the surface:



The diagram below shows how adsorption is reduced on surfaces silylated with HMDS.



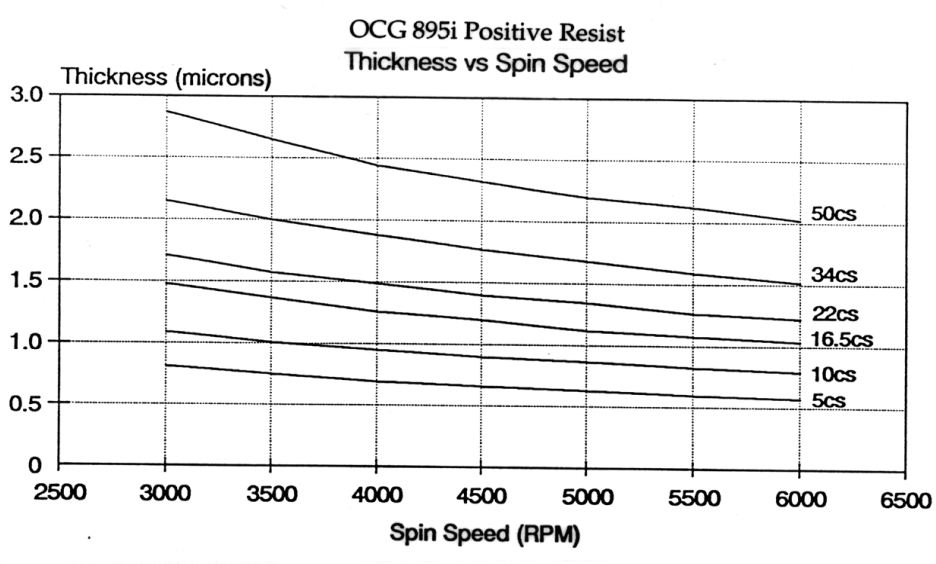
R. Dammel, **Diazonaphthoquinone-based Resists**, SPIE Press, 1993, p. 100.

Replacing the water with HMDS allows more uniform adhesion of the resist.

Liquid priming is the process of spinning HMDS, diluted in solvent, onto a ***dehydrated*** wafer. Typical dilutions are 10-20% HMDS in PGMEA, a common resist solvent. This is often effective but is not as good as ***vapor priming***. In a **Vapor Priming Vacuum Oven** during a 30-minute pre-programmed cycle the **150ºC** oven evacuates and refills the chamber with dry N_2 several times, and then fills with pure HMDS vapor, resulting in much better dehydration and priming than is possible otherwise.

Spin Coating

Spin coating is typically used to coat resist onto the substrate with uniform thickness. The physics of spinning is complicated and depends strongly on the evaporation rate of the solvent used, which is why there are only a few solvent systems in use. The process involves spinning for a fixed time, typically 30 seconds, at a speed selected to result in the desired thickness. Spin speed charts are used to select the appropriate speed and viscosity:



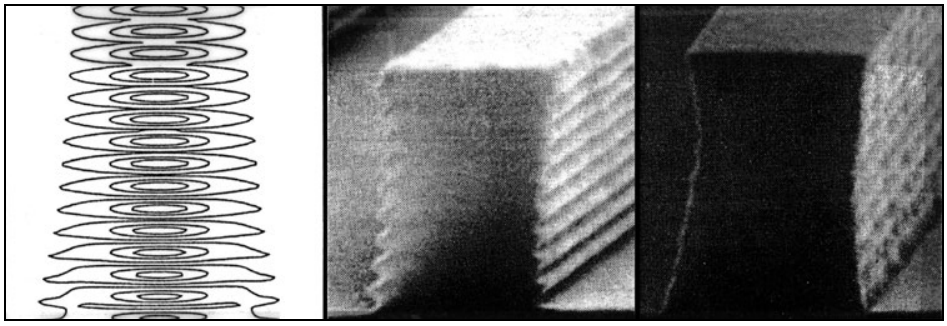
OCG Process Application Note

BAKING

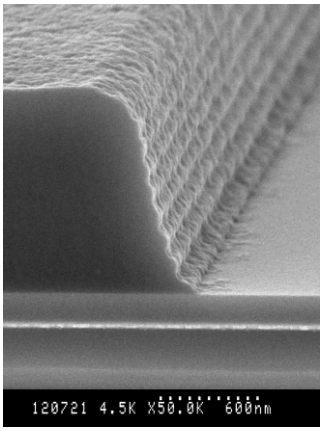
A post-apply bake, or ***soft bake***, is used to drive solvent from the resist. This is a critical step as failure to sufficiently remove the solvent will affect adhesion and the resist profile, as will excessive removal, which destroys photoactive compound and reduces sensitivity. A typical bake is 1 minute on a 90°-115°C vacuum hot plate or 30 minutes in a 90°-115°C convection oven. Thick resists often require longer bake times. **Repeatability** is very important once you have characterized your exposure for a given bake.

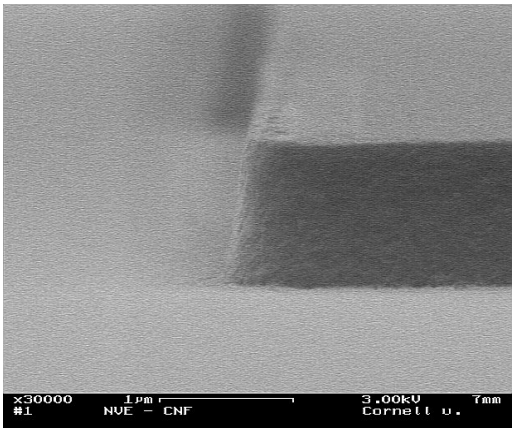
A post-exposure bake, or ***PEB***, is used to reduce standing waves in resist exposed on steppers, or to thermally activate certain chemical processes. It will also affect the resist profile (see the figure below.) An example of a PEB used for a positive resist is 115°C on a vacuum hotplate for one minute.

Calculated No PEB PEB, 115°C, 45 sec.



Dammel, p. 110.





Shipley 1813 no PEB Shipley 1813 115°C 60 sec. PEB

A post-develop bake, or ***post-bake***, is sometimes used to improve a resist's wet and dry etch resistance by hardening it and increasing adhesion. It may also make the resist more difficult to remove, or easier to remove in the case of some aggressive processes. In nearly all cases, temperatures above ~ 135°C will cause the resist to flow, so a DUV curing exposure can be performed first to retain the profile.

DEVELOPMENT

Development of exposed photoresist takes place in an alkaline solution. Simple solutions of NaOH (Dow 351), or KOH (AZ 412K) can be used, but because of mobile ion contamination issues in many materials, Metal Ion Free developers are typically used. These are most often TMAH, tetra-methyl ammonium hydroxide (AZ 300 MIF, Dow MF-322). Some developers also contain surfactants to improve wetting properties (AZ 726 MIF, Dow MF-321).

The developers used have different concentrations, and some can require longer development times. Developers are often recommended for particular photoresists. Although they are interchangeable to some extent, changing the developer used in a process will usually change the dose required to achieve the same feature sizes.

Important Note: All of these developers etch **aluminum**. In fact, some people prefer to do their aluminum etching in TMAH developer, since the etch rate is well controlled. If you are developing a pattern on aluminum, you should consider using **Dow Micro**(posit) **Dev**(eloper) **Concentrate** (MDC). This is a mixture of proprietary alkaline salts (mostly phosphates), and it has a much slower aluminum etch rate. You could also consider using an anti-reflective coating (ARC) to protect the surface.

STRIPPING

After pattern transfer it is necessary to remove or **strip** the resist. There are many ways to accomplish this. If no aggressive processing has damaged the resist, you could dissolve the resist in acetone or **n-methyl-2-pyrrolidone** (NMP)**,** which is more effective than acetone. Damaged resists can also be removed by **plasma stripping**, which can be done in a barrel asher**,** a downstream plasma tool**,** or in a reactive ion etcher. Sometimes a combination of soaking in remover and plasma stripping is required to remove damaged resist (it is often recommended to follow a wet strip with a plasma strip to remove resist residues). If this fails, you can resort to **Piranha** cleaning, or other acid etches used for removal of organics. However, some methods can also etch metals.

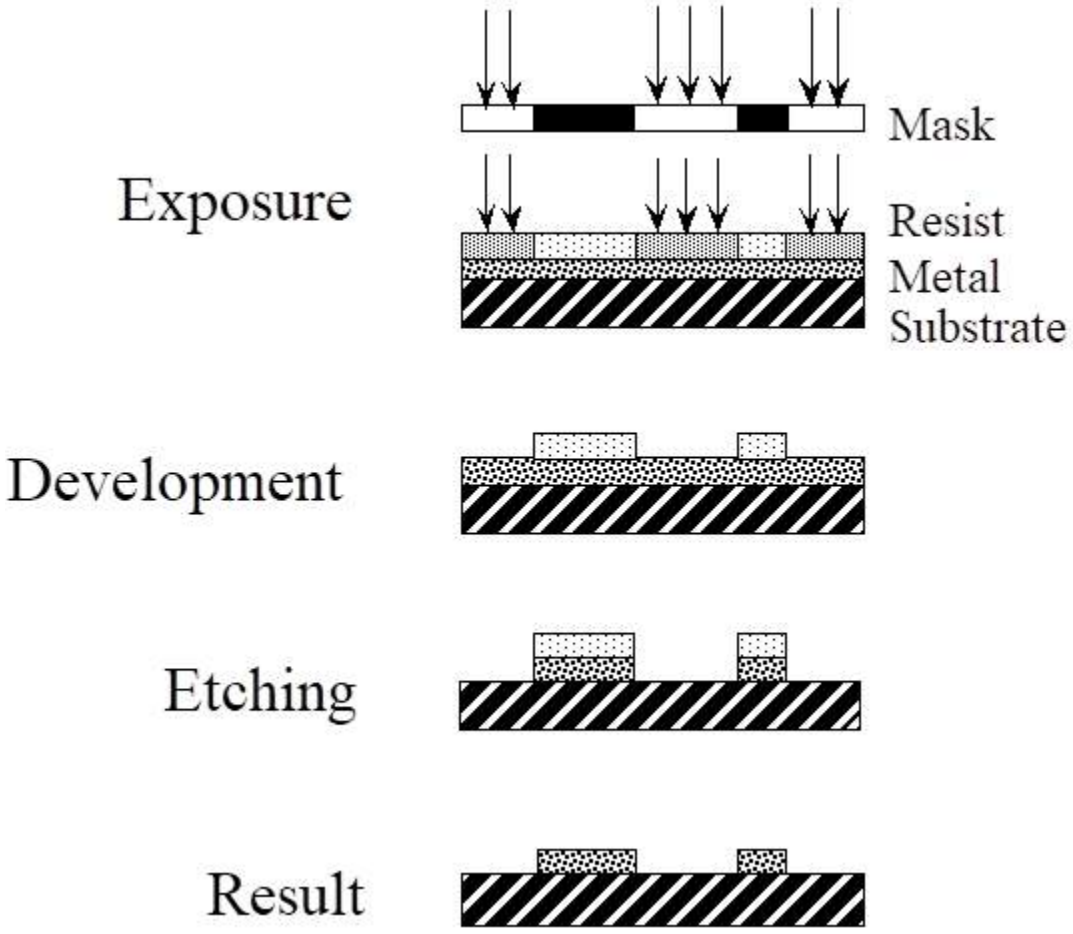
IMAGE REVERSAL

The resists used in photolithography are virtually all positive tone. Some negative resists have occasionally become available, but they are limited in application. Obtaining negative tone from positive resist can usually be done by performing **ammonia image reversal**. Although you can make photomasks to compensate for resist tone, write times and cost can increase. Another advantage of image reversal is that it creates an undercut profile which is very desirable for ***lift-off***.

LIFT-OFF

It is often necessary to form a metallized pattern on a wafer. If the metal used in the process can be etched, you can evaporate or sputter the metal film onto the wafer first, and then pattern the resist to perform the etch.

Process flow for patterning of resist after metal deposition:



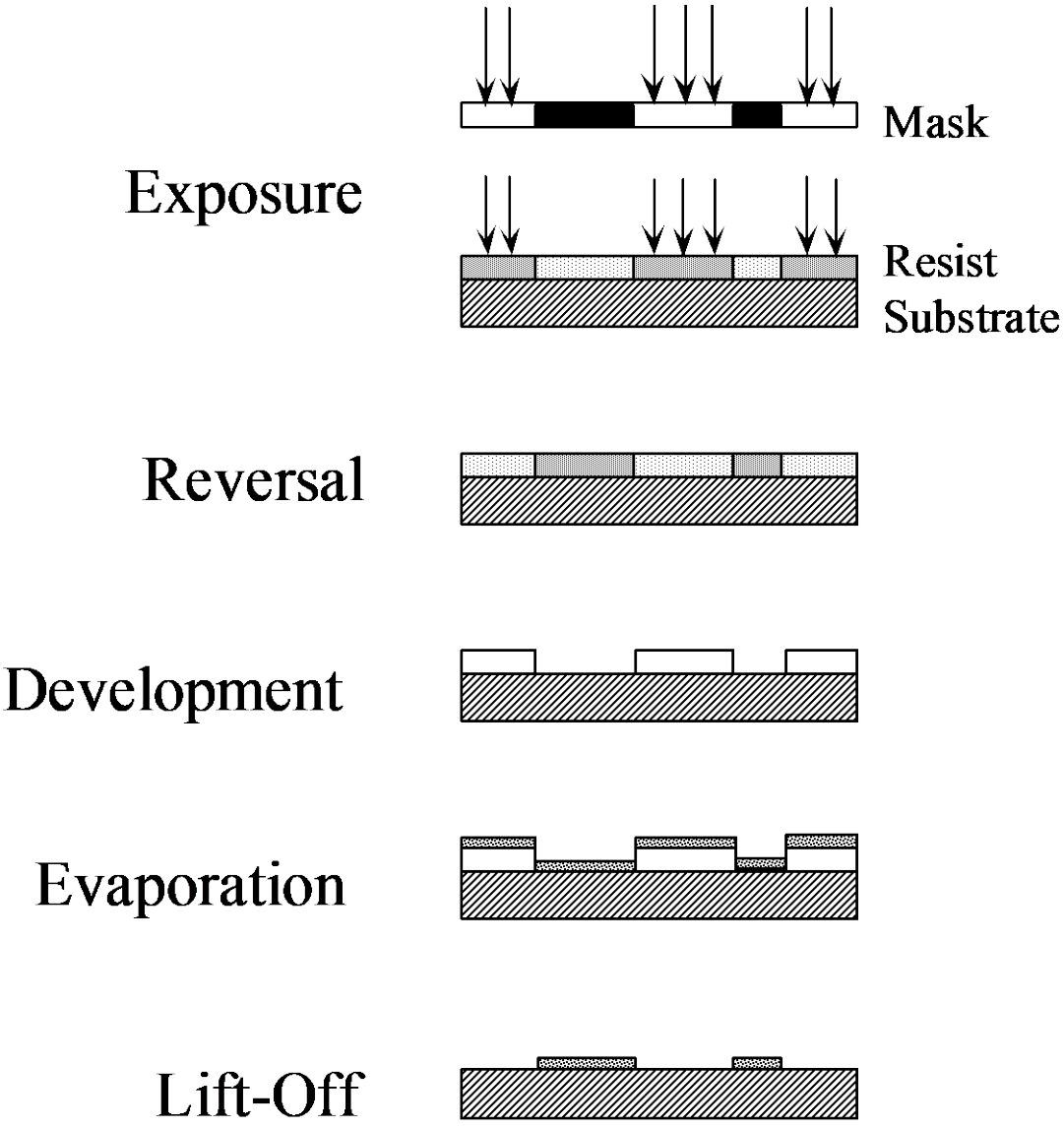
Unfortunately, some metals cannot be etched, or only wet etched (which lacks good control), or the surface cannot tolerate metal contamination. The recommended technique then is ***lift-off***. In lift-off, the resist is patterned first, then the metal is evaporated over the resist. The resist is then dissolved away in a solvent, carrying the unwanted metal with it. However, the normal positive resist profile presents a problem. Again, there is the issue of sidewall slope:

After evaporation, the metal would form a continuous film:

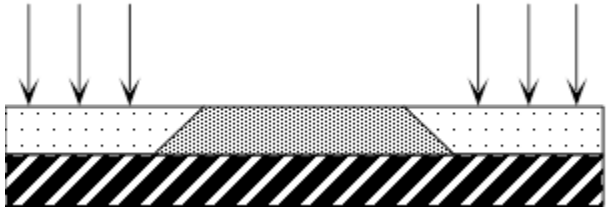
If the resist were removed, the edges of the metal film would tear leaving "fences", or sections of the pattern could be torn away.

Negative resists can produce the opposite, an **undercut** or **reentrant profile**. Unfortunately, there are very few negative resists available. For this reason, we sometimes use **image reversal** to create a similar undercut profile**.** The process flow is as follows:

Process flow for Metal Lift-off using Image Reversal:



A detailed look at the reversal step reveals why this technique is successful. Instead of exposing the features where you want to deposit the metal, you expose the areas surrounding the features. (This requires a reversed tone photomask, which is the same mask used for a metal etch process.)

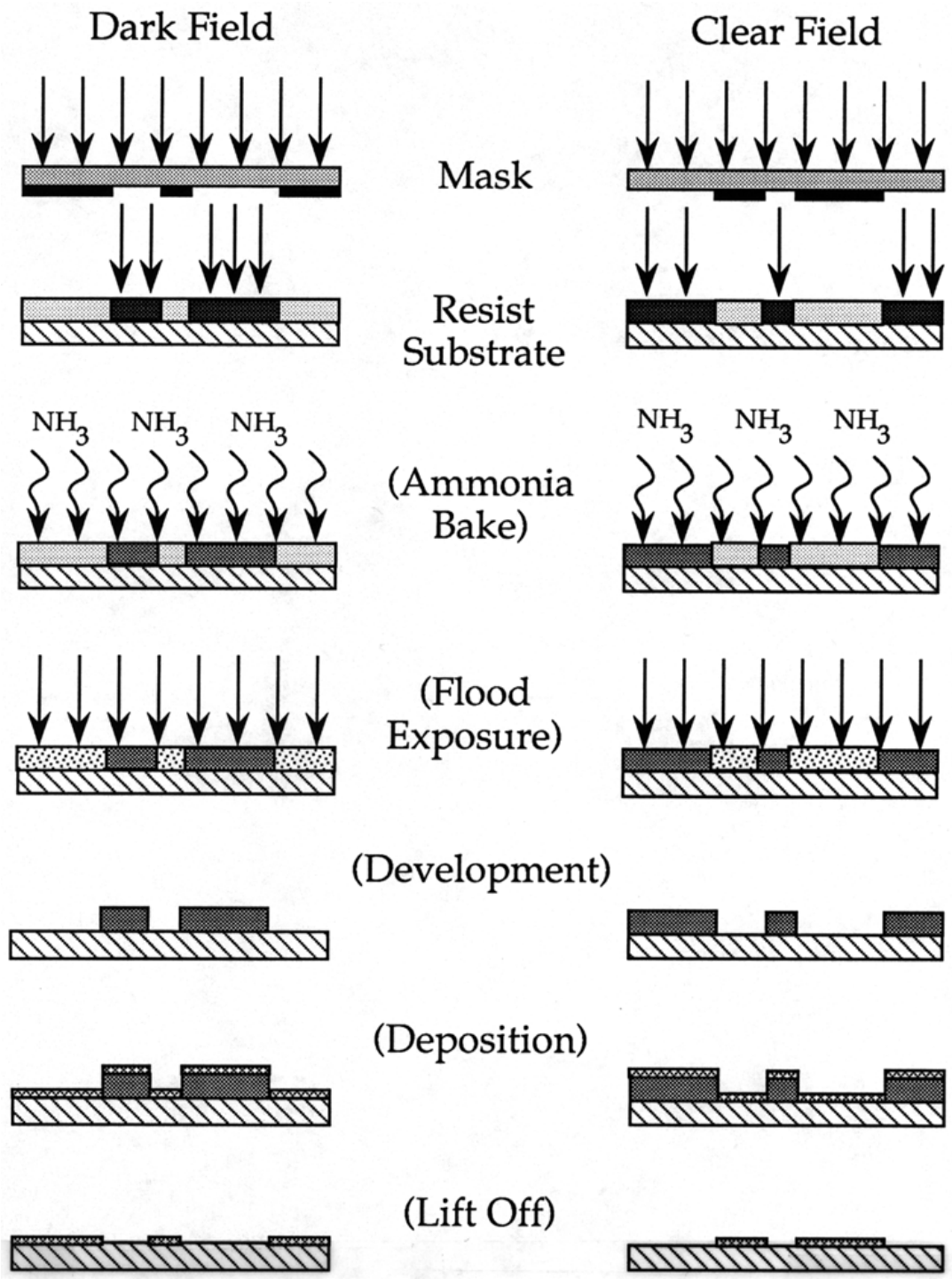


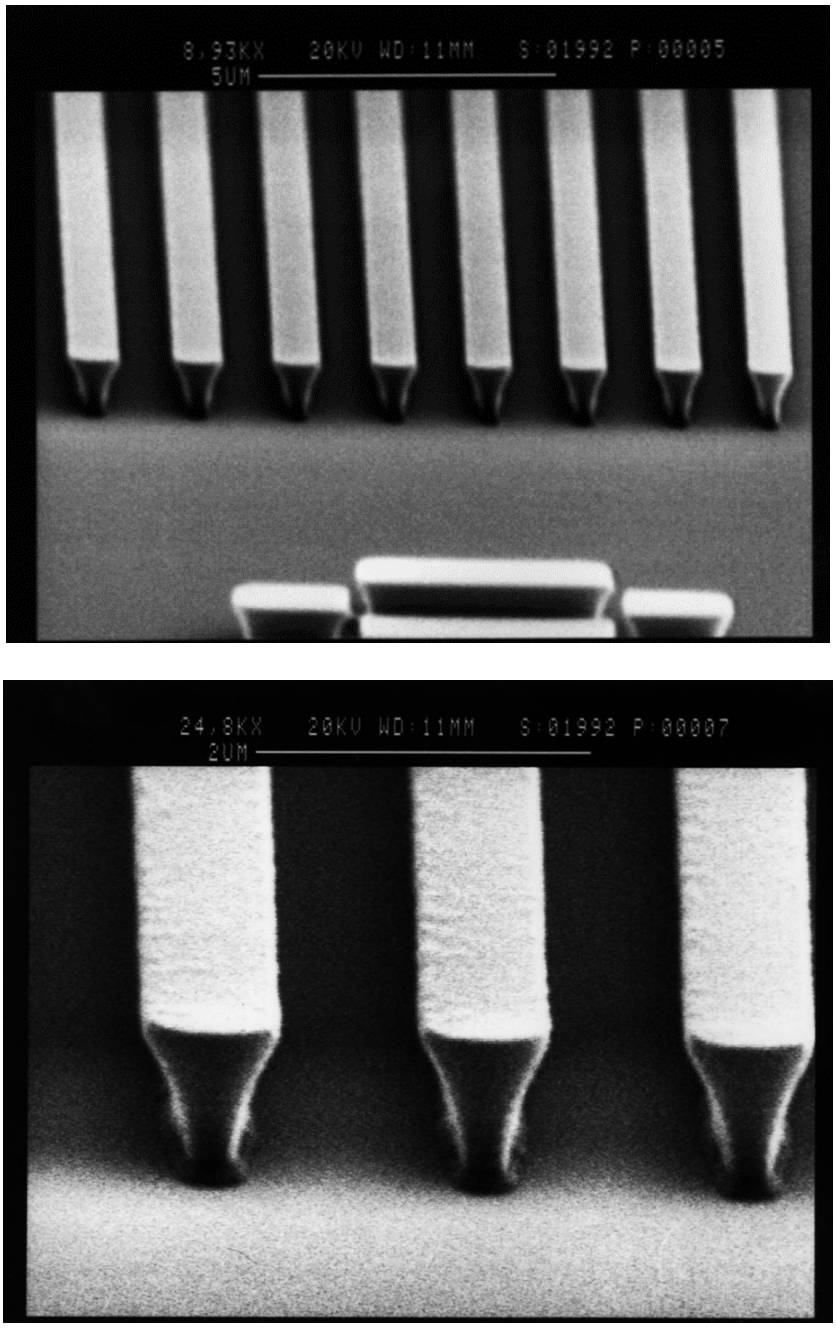
After reversal, the sidewall slope that worked against the process in positive tone now forms the undercut profile, which is much more desirable for lift-off. When the metal is evaporated, the film is discontinuous over the feature edges. The resist can be removed cleanly, leaving a well-defined metallization pattern behind.

Note: A good rule of thumb is to use a resist layer at least three times the thickness of the metal desired.

Image reversal can be accomplished using an **Ammonia Image Reversal Oven**. The ammonia method takes longer than a positive tone process but produces superior and more consistent results. In the reversal process, once the wafers are exposed, they are processed in the oven, where an ammonia diffusion bake takes place. The ammonia reacts with the exposed resist, where it binds to the **indene carboxylic acid** that was generated. The **exposed** areas are now rendered **insoluble**, while the **unexposed** areas are **not affected** by the ammonia. Following this process, a flood exposure is performed to expose the previously unexposed areas, rendering them **soluble**. Development is then performed using a weak (0.21N) developer. An O_2 plasma descum after development is strongly recommended before deposition to ensure good adhesion. This process is shown schematically on the next page. Photos of image reversed resist are shown on the page following.

IMAGE REVERSAL USING AMMONIA BAKE





Undercut profiles generated in OCG 895i resist using the Ammonia Diffusion Process.

Another method for performing lift-off is a **bi-layer process**. In this process a polymer layer which is soluble in developer is first deposited, then positive photoresist is applied on top of that layer. When the resist is developed after exposure, the bottom layer is dissolved at a faster rate than the resist leaving a recessed space under the edges of the photoresist. The proceeding process and result are very similar to the previously described ammonia process. It has the advantage of using a positive tone photomask and resist, simplifying the process design. One disadvantage is that most lift-off layers are spin bowl-incompatible with resist, so they must be applied in a separate room.

OPTICAL LITHOGRAPHY

EXPOSURE TOOLS

HISTORICAL PERSPECTIVE

"Optical lithography has been used for over 30 years as the preferred method of image formation in the manufacture of silicon devices and other semiconductor components. Its demise as the premier imaging technology was predicted at about 1 µm feature size by proponents of alternative imaging technologies and others who underestimated the ability of optical tool manufacturers to improve optical and mechanical system performance to the degree necessary to support the production of increasingly complex devices with ever smaller features.

"Nevertheless, optical lithography continues to be the dominant imaging technology used in manufacturing semiconductor components. It is used today for high volume production of products demanding features of less than 1 µm. There is a clear expectation in the industry that it will support several more generations of silicon technology . . . ."

(CWT Knight, The Future of Manufacturing with Optical Microlithography, **Optics and Photonics News**, Oct. 1990, p.11)

Historically, **lithographic resolution** has often been used to illustrate the progress of Semiconductor processing. The chart below shows the trend in feature size versus time:

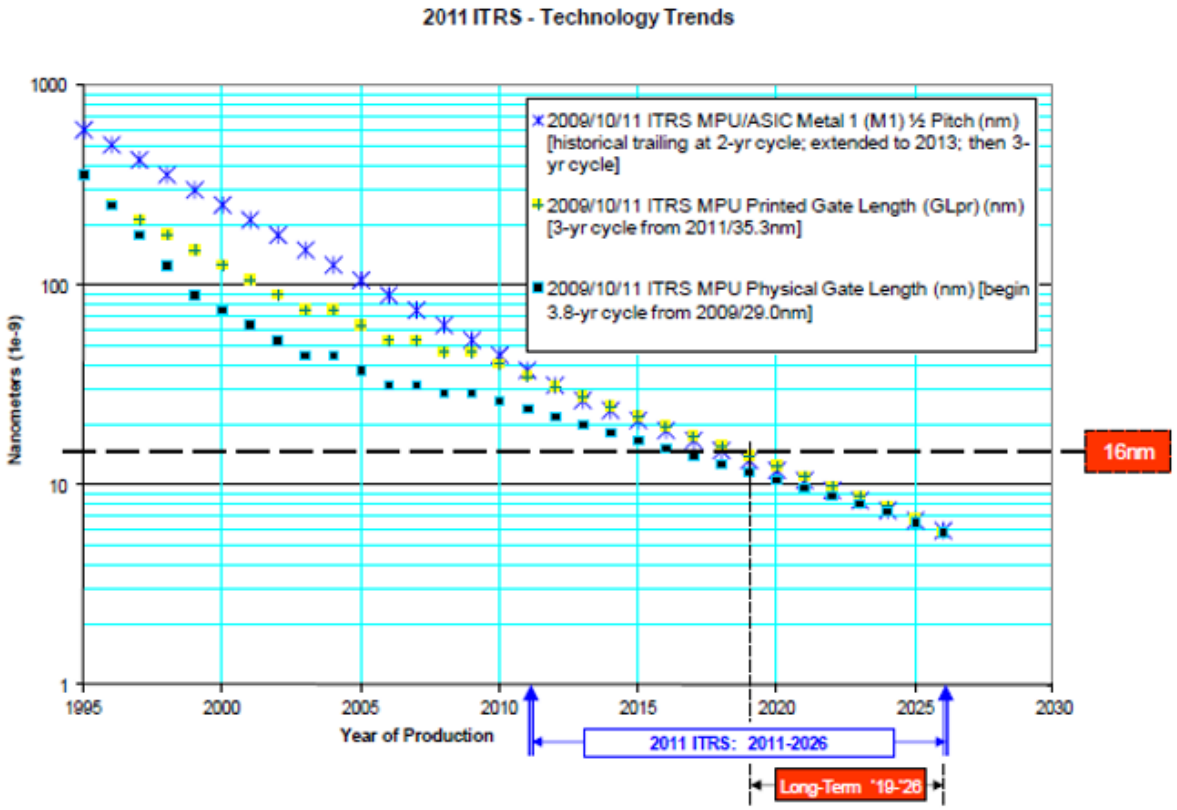


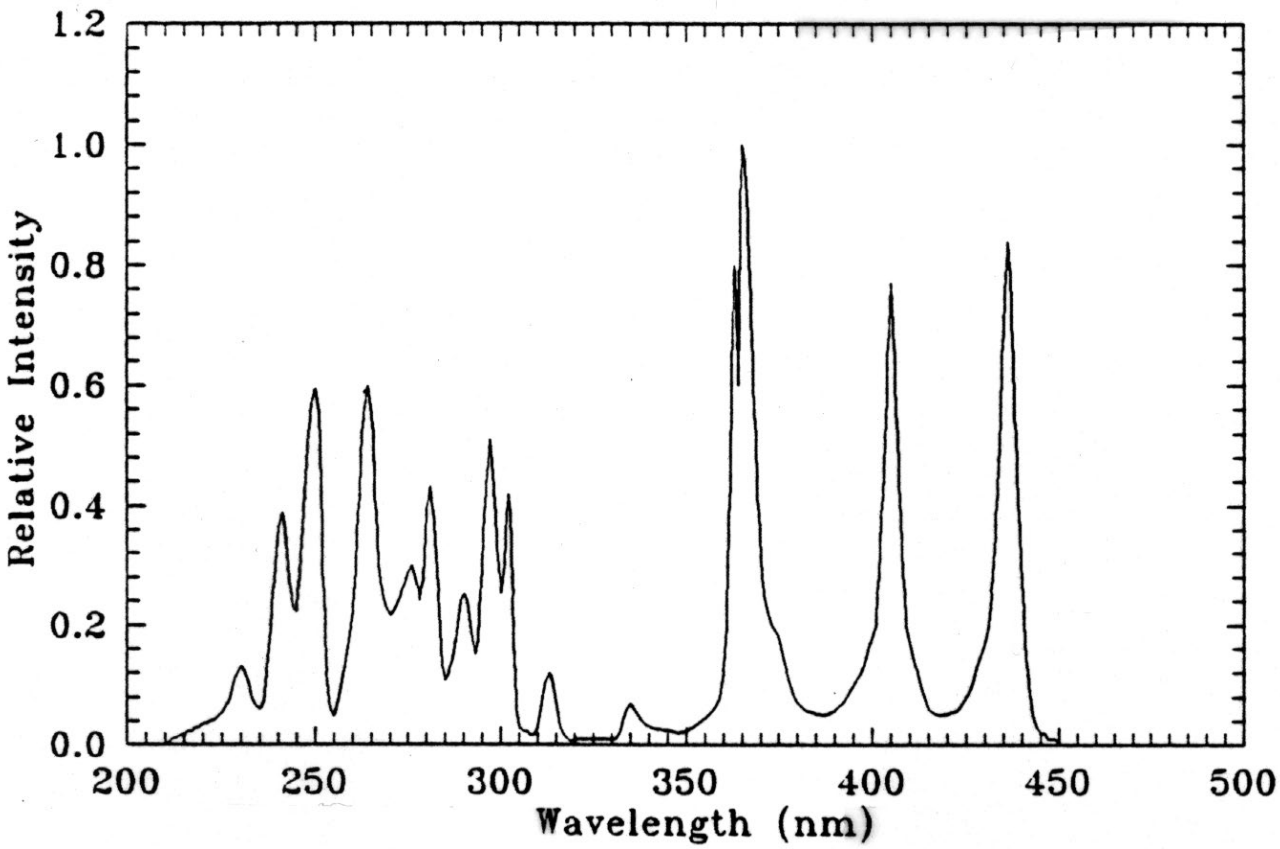
Figure ORTC4 *2011 ITRS—MPU/high-performance ASIC Half Pitch and Gate Length Trends*

SIA Roadmap

LIGHT SOURCES

Most optical exposure tools use **high-pressure mercury** (Hg) arc lamps. They are used because the spectrum of the light output has large, fixed peaks in the UV. The dominant emission lines are at wavelengths of 436nm (g-line), 405nm (h-line), and 365nm (i-line).

Mercury Arc Lamp Emission Spectrum
(DUV output not to scale)



C. A. Mack, **Theory and Techniques in Optical Lithography**,
pre-published short course notes, 1990, p. 1-5

Since resolution scales directly with wavelength, efforts have been made to find higher intensity sources in the **Mid-** and **Deep-UV** ranges. Some contact aligners use a **Hg-Xe** arc lamp to provide greater output in this wavelength range, though the intensity is still relatively low.

Below is a diagram of what these lamps look like. Keep in mind that these are expensive and delicate: the lamps used in the steppers and mask aligners run at 30 atmospheres internal pressure and have a surface temperature of 700˚C. They are, however, very robust and reliable in operation.

Fig. 1 Lamp Structure (USH-350DP)

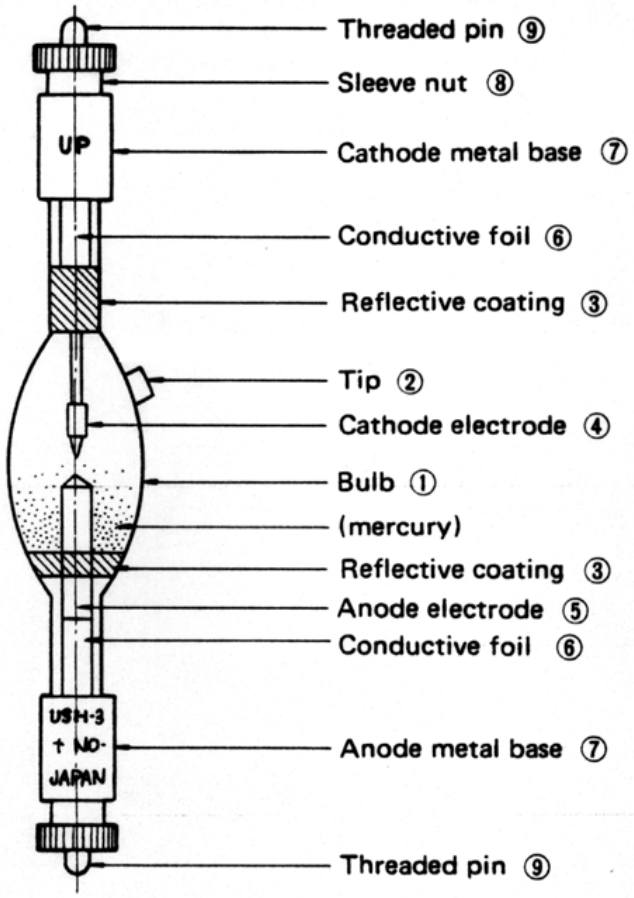
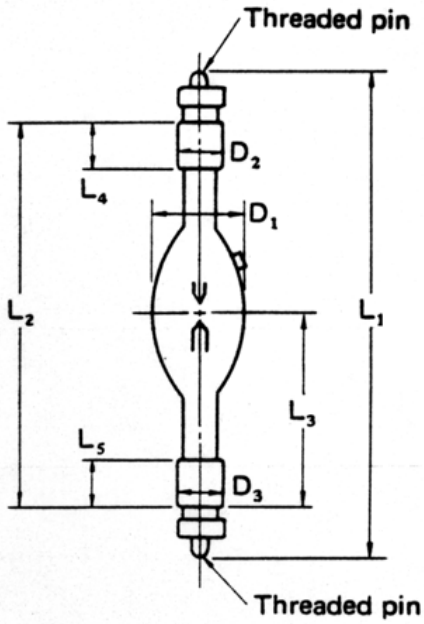


Fig. 2 Lamp Dimensions (USH-350DP)



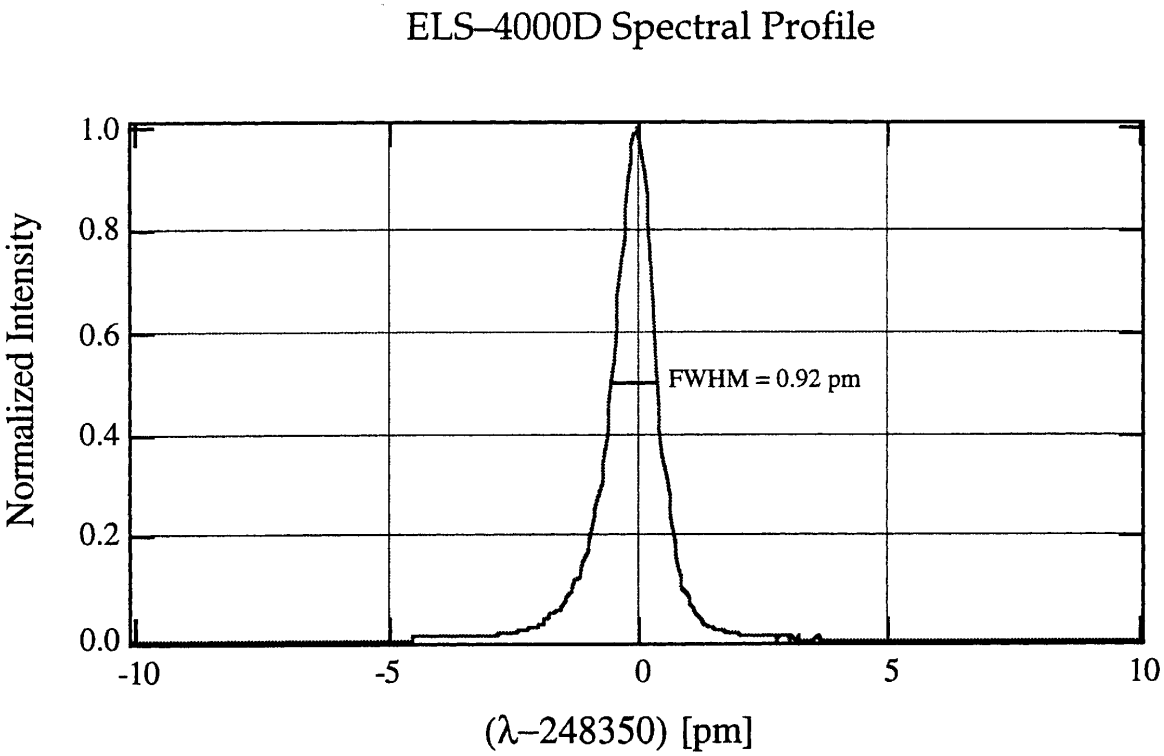
Standard dimensions

L_1	-------	124mm
L_2	-------	101mm
L_3	-------	48mm
D_1	-------	20mm
D_2, D_3	-------	10mm
L_4, L_5	-------	15mm
Threaded pin	-------	No.8 — 32UNC

Ushio Technical Data Sheet

Some newer optical tools use KrF and ArF **Excimer Lasers** as light sources. ArF excimer lasers can produce 193nm light at up to 120W @ 6KHz. This is enough power to expose as many as **275** 300mm wafers per hour on a stepper. The output bandwidth is also very narrow, which is important for focusing and dose control.

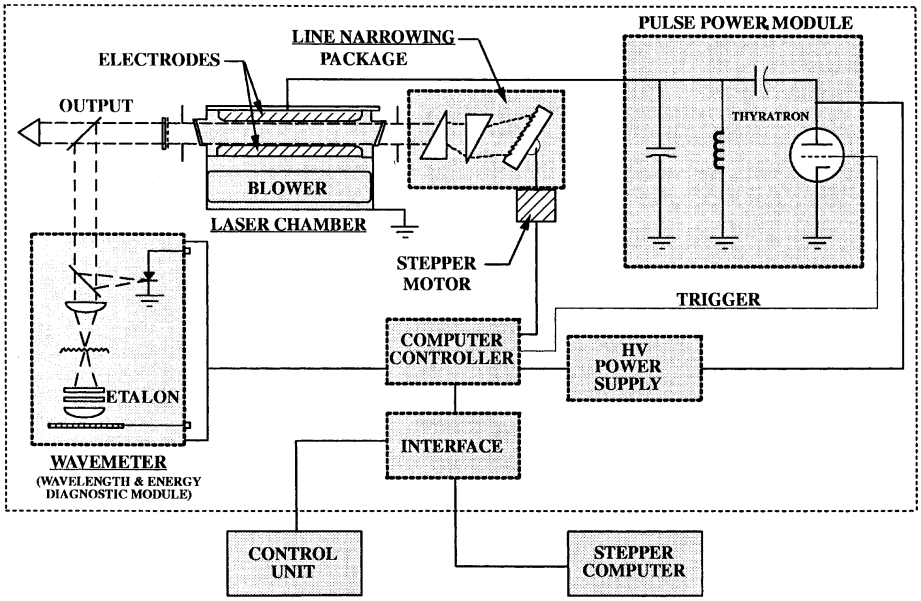
ELS–4000D Typical Laser Spectrum[1]:



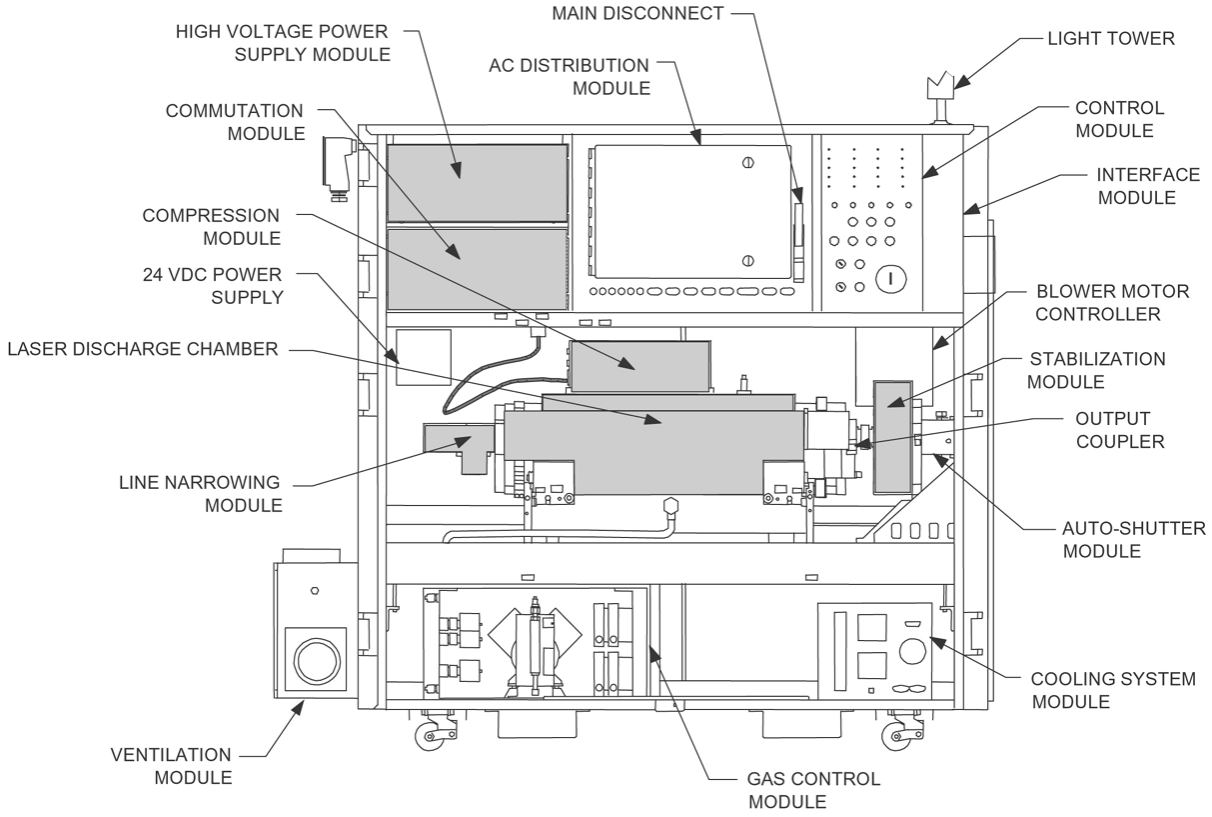
Cymer promotional material

Excimer lasers are also relatively simple, as lasers go, and relatively easy to maintain. This makes them ideal for production facilities where uptime is extremely important. They are expensive, however, and drive up the cost of leading-edge manufacturing.

Lithography Laser System Schematic



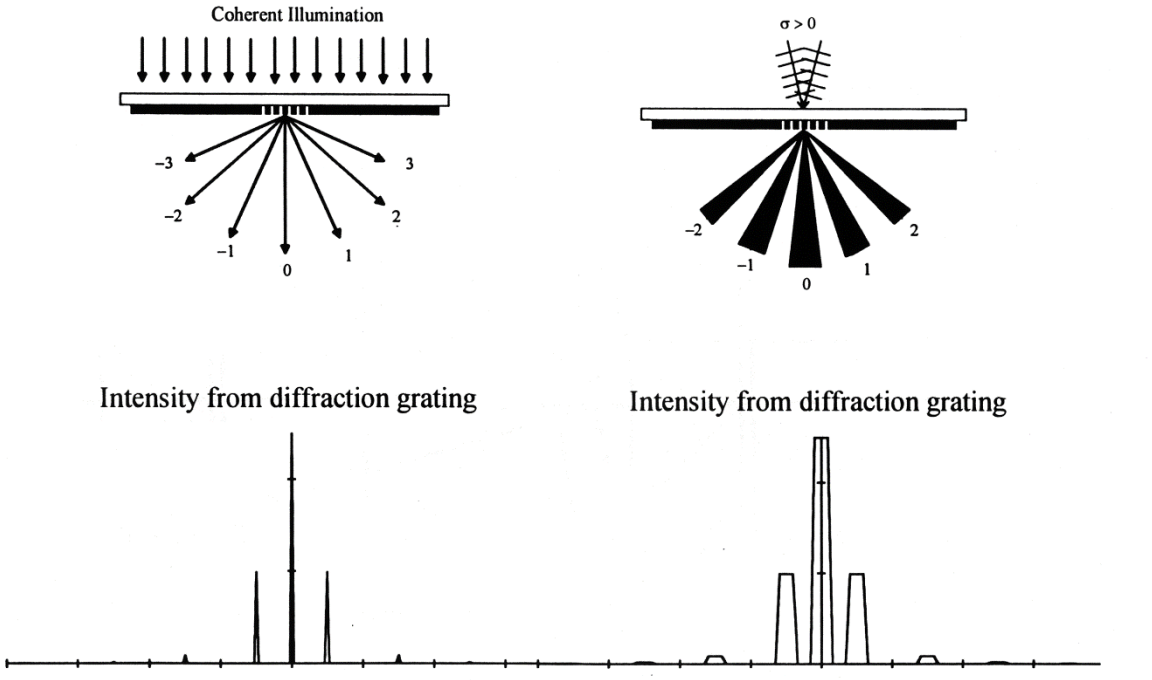
Standard DUV Excimer Laser Module Layout



Courtesy of Cymer, Inc. (ELS-5000 Series)
www.cymer.com

Cymer promotional material

It should be noted that no optical tools use **coherent** illumination. While it may seem that coherent light would offer better resolution and control, usually the opposite is true. A range of limited illumination angles, called **Partial Coherence,** enhances resolution and depth of focus of fine features. This is illustrated below:



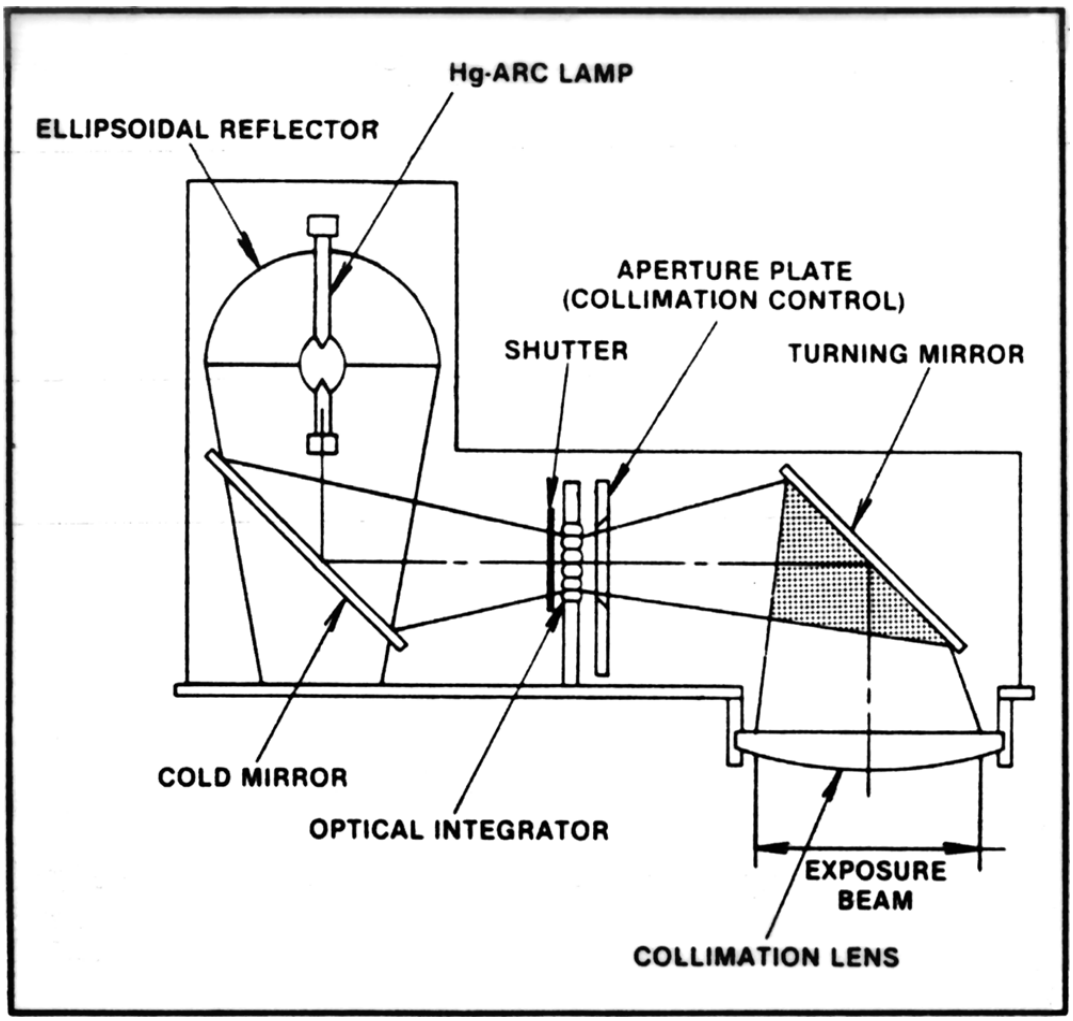
B. W. Smith, PhD; RIT; **The Fundimental Limits of Optical Lithography**; SPIE 1999

The additional spread of angles of the diffracted orders of light allow acceptable resolution of features that would otherwise not be successfully printed. Steppers use Köhler illumination, which allows good control and uniformity of angular output.

CONTACT AND PROXIMITY PRINTING

This is the most straightforward method for exposing a substrate using a photomask. Light is directed through the mask and onto the resist-coated substrate, which is held in direct **contact** or close **proximity** to the mask.

The light from the arc lamp must be collimated (made into partially-coherent plane waves) and filtered to pass the desired wavelength(s). Contact aligners have a relatively simple design, shown schematically below:

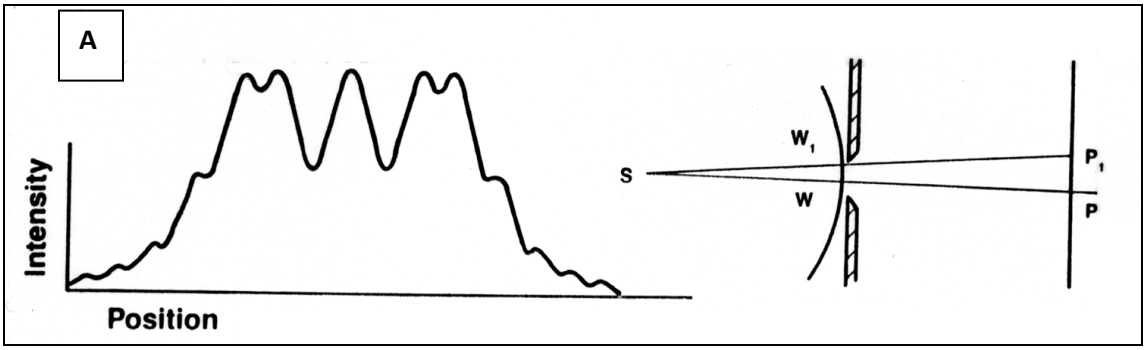


Moreau, p. 379

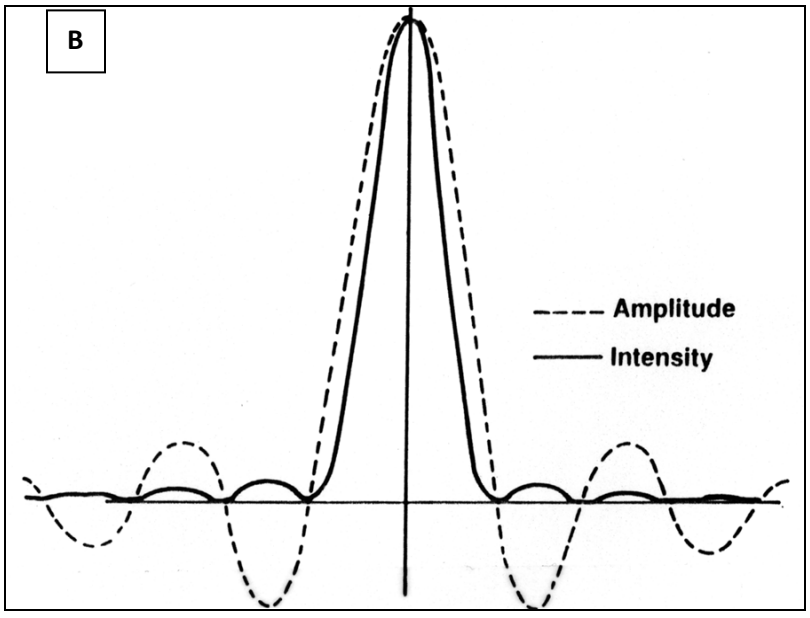
DIFFRACTION IN CONTACT LITHOGRAPHY

In contact lithography, the mask pattern is transferred directly into the resist in a 1:1 process. Unfortunately, the transfer is never perfect because of the fundamental limitation of all optical lithography: ***diffraction***.

The type of diffraction you likely studied in Physics class is ***Fraunhofer*** diffraction (**large** separation between object and image). We see this in <u>projection</u> lithography. However, for contact lithography, there is a **small** separation between the image and the object. This is the ***Fresnel*** diffraction regime. To illustrate the difference between the two regimes, consider the classic single slit diffraction pattern:



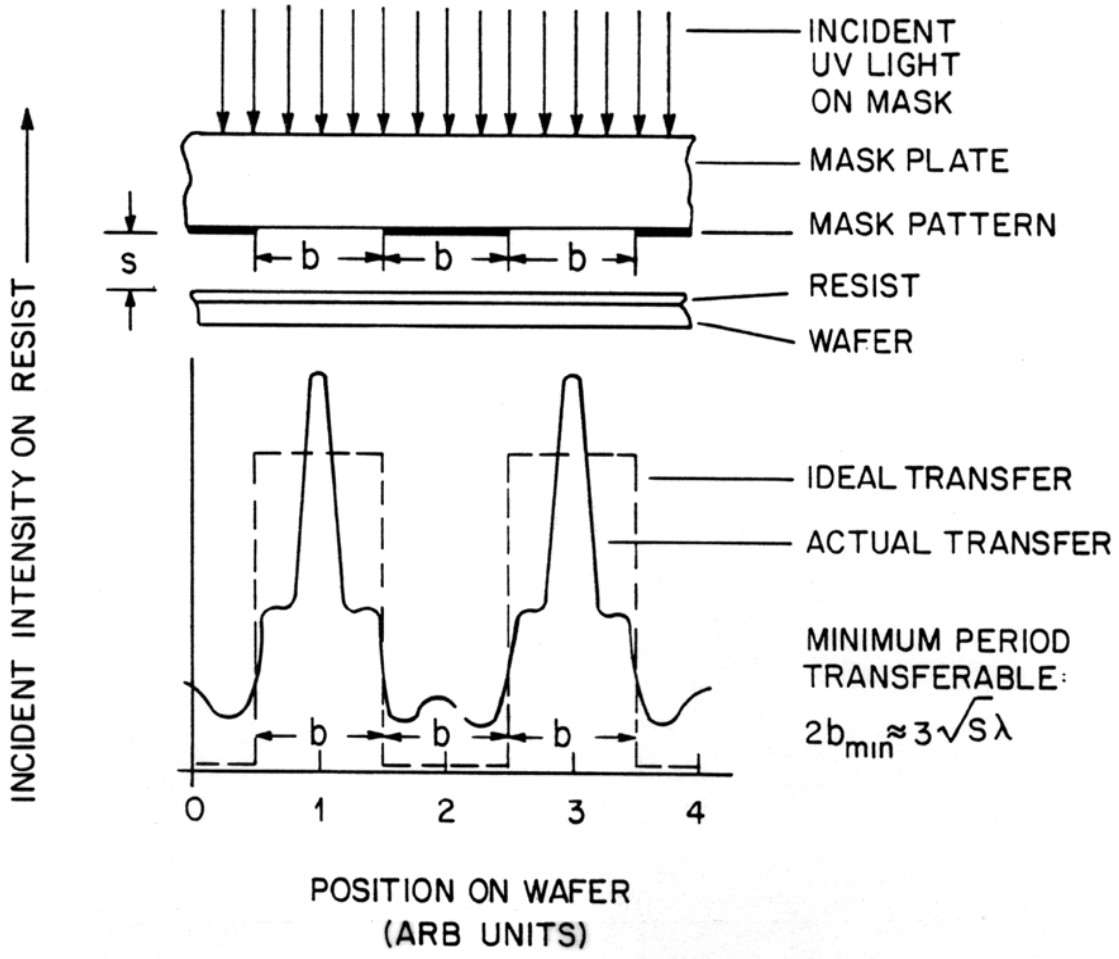
A. Intensity pattern for single-slit Fresnel diffraction



B. Intensity pattern for single-slit Fraunhofer diffraction.

Moreau, p. 376

Consider imaging a pattern of equal lines and spaces of width ***b*** onto a substrate. The separation between mask and substrate is ***s***.



L. F. Thompson, C. G. Wilson and M. J. Bowden, **Introduction to Microlithography**, Amer. Chem. Soc., Washington, 1983, p. 18.

As the figure illustrates, the pattern transfer is not perfect, and success will depend largely on the threshold sensitivity and contrast of the resist.

The theoretical resolution for a pattern of equal lines and spaces in contact/proximity lithography is given by:

$$2\,b_{min} = 3\,[\,\lambda\,(\,s + 0.5\,d\,)\,]^{1/2}$$

where, $2\,b_{min}$ = grating period,

s = width of gap between mask and resist surface,

d = resist thickness, and

λ = exposure wavelength

Assuming perfect contact, $s = 0$, one obtains:

$$2\,b_{min} = 3\,[\,\lambda\,d\,/\,2\,]^{1/2}$$

Using these equations, we obtain the theoretical limiting resolution for contact lithography tools, b_{min} :

	λ = 405 nm	λ = 220 nm
d = 1.0 μm	0.68 μm	0.50 μm
d = 0.5 μm	0.48 μm	0.35 μm

It should be clear from the equations that the best resolution can be obtained using ***short wavelengths***, ***thin resist*** and ***perfect contact*** . Not surprisingly, there are problems that arise when attempting to achieve ***any*** of these conditions.

Wavelength – Most contact aligners use dichroic surface mirrors, which allow the reflection of a desired range of wavelengths from the Hg arc lamp. The output wavelength range of typical contact tool mirrors is 405 - 365 nm, also described as **near-UV**. Some 436 nm light may also be produced, as well as some shorter wavelengths, but in reduced intensity.

The mirror coatings and optical trains of different tool manufacturers vary, resulting in somewhat differing spectral outputs between their tools. Because of the sensitivities of commonly used resists, they all use the typical output wavelengths mentioned (405 - 365nm). However, some tools can be configured to produce 365nm light only, or even 248nm light for specific applications and resists.

Resist Thickness -- As the wafer must come into contact with the mask for planarization of the wafer to the mask, and to maximize resolution, any particulates which adhere to the mask or substrate can be forced into the resist. These can result in "pinhole" defects. The thinner the resist is, the greater the likelihood of such defects. This suggests that thicker films should yield fewer defects.

Soft Contact, Hard Contact, and Proximity -- Achieving good contact depends on having flat masks and highly polished substrates. These criteria *may* be met, but contact is never perfect. This can be caused by resist edge-bead, particulates, contamination, or non-flatness in the tooling itself. It is also possible for the mask to "bow" and make uneven contact if the pressure used is excessive.

The mode in which the substrate is brought just into contact with the mask is called ***soft contact***. Since soft contact suffers from some of the effects mentioned above, the aligners have another mode called ***hard contact***, which uses significant pressure between the mask and wafer. The highest resolution is achieved using ***vacuum contact***, in which a gasket seals the substrate to the mask, then vacuum is used to force them into contact. This mode has the disadvantage of resulting in greater defects in the resist, and greater wear on the mask.

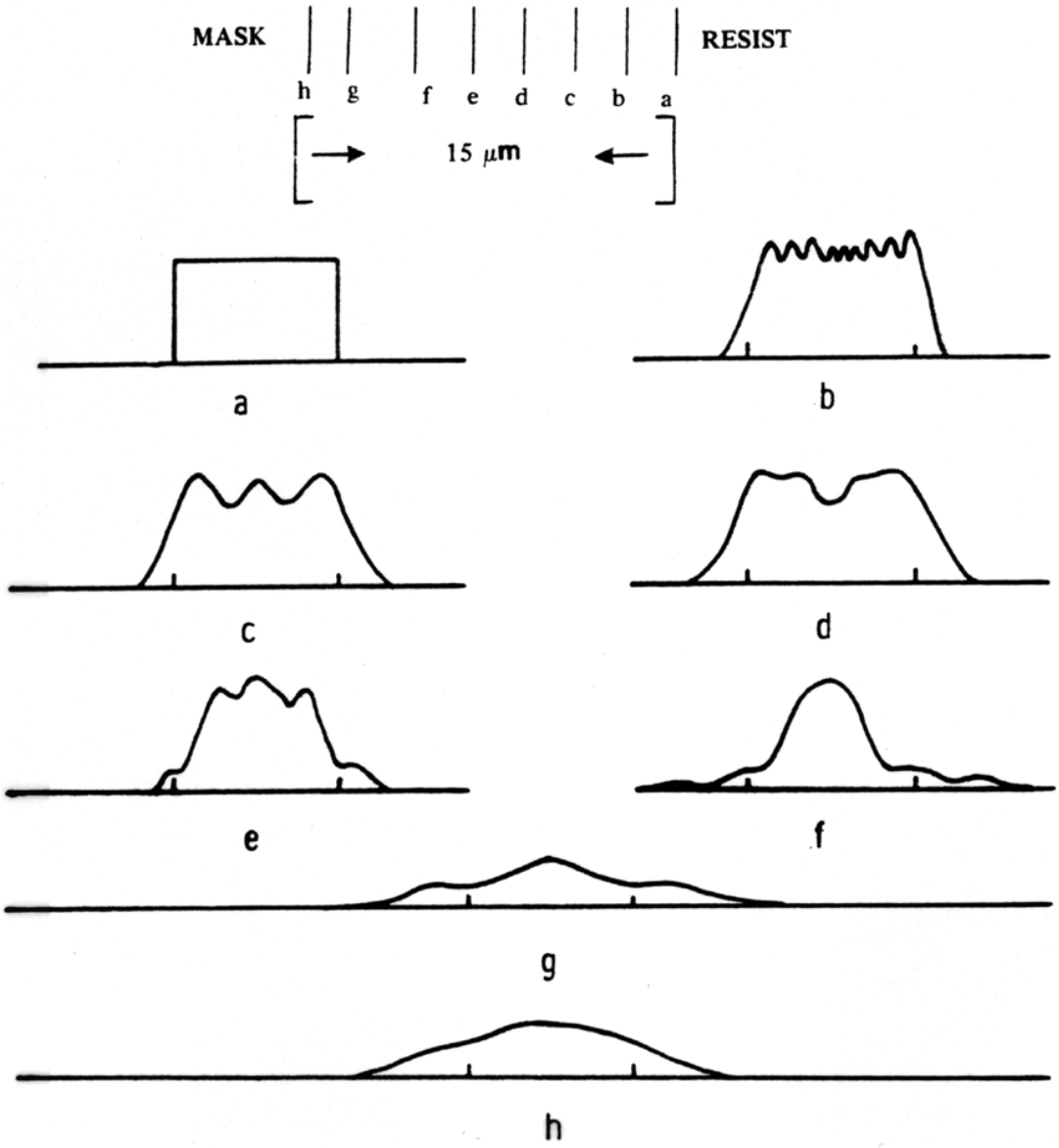
One method for overcoming the disadvantages of mask wear and resist defects is to use ***proximity printing***. Here the substrate is brought very close to the mask (about 5 - 10 μm) but does not touch it. However, one can see from the resolution equation that any gain in mask life and defect reduction comes at the price of lost resolution. This can be partially compensated for by biasing the features on the mask.

If the resist thickness is negligible compared to the substrate-mask separation, the equation becomes:

$$2\, b_{min} \sim 3\, [\, \lambda\, s\,]^{1/2}$$

If the gap s = 10 μm, and λ = 405nm, b_{min} = 3.0 μm. For λ = 220nm, b_{min} only improves to 2.2 μm.

The effect of increased separation is clearly a large degradation in resolution. This is shown in the next figure, where the image intensity is shown as a function of substrate-mask separation, *s,* from s = 0 to s = 15 μm.



Moreau, p. 377

The decrease in image quality noted here affects not just proximity exposure but any contact lithography in which particulates or other problems have caused there to be distance between the mask and substrate.

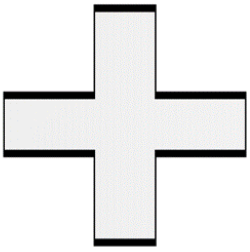
ALIGNMENT USING CONTACT LITHOGRAPHY

Usually the fabrication of functioning devices requires several levels (mask layers) of lithography. In order to achieve good ***registration*** between all the levels, an alignment scheme must be worked out in the planning stages, before the masks are made. There are a few important points to keep in mind:

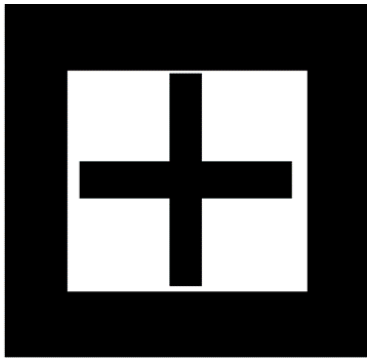
The pattern placed on the first level mask must be ***clearly visible*** on the substrate after the initial pattern transfer step. It is this pattern to which other levels of lithography will be aligned by looking ***through*** the next level mask.

The marks on higher-level masks must consist of mostly ***clear*** areas, so that the marks on the substrate below can be seen ***through*** the mask once a gap is introduced to facilitate alignment. This requires careful consideration of the mask tone and design of the marks.

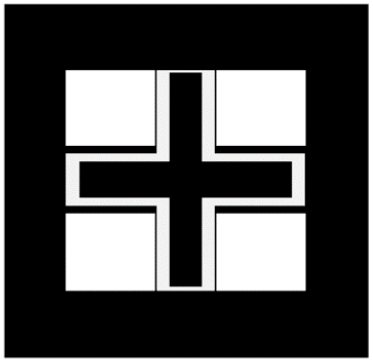
Since those clear areas you look through to see the mark will also allow that area to be ***exposed***, a ***series*** of marks is usually required, one for each alignment step. Mark alignment is shown simplistically below:



Mark on Substrate



Mark on Second Level Mask



Marks in Perfect Alignment

Because of the difficulty in achieving and maintaining alignment after moving back into contact, **contact processes should be limited to ± 1 μm overlay accuracy**. Higher accuracy is **very** difficult to achieve and requires sophisticated marks and schemes.

A single alignment mark allows only for ***translational*** alignment at one point, so for all parts of the pattern to align properly, pairs of marks must be used for ***rotational*** alignment. Mask aligners are usually equipped for split-field viewing of two marks simultaneously. The requirement for simultaneous viewing is that the marks have a separation as wide as possible, but within the range of the alignment system motion.

ADVANTAGES OF CONTACT LITHOGRAPHY

1:1 pattern transfer means field size can be large, even wafer sized. Tools can expose wafers up to 200mm in diameter using 9-inch masks.

Substrates of various sizes and thicknesses can be used because there are no focus problems to consider.

Substrates that have non-parallel front and backsides (wedge error) can be used because chucks on the aligners can tilt to planarize the sample.

By using DUV illumination, high resolution can be obtained, or mix and match lithography using e-beam resists can be performed.

Contact lithography is much easier to learn than projection.

DISADVANTAGES OF CONTACT LITHOGRAPHY

Good contact is difficult to achieve because of particulates between mask and substrate, and flatness variations.

As a result of particulates and resist adhesion issues, defects are more numerous than in projection lithography.

Small geometries (< 2 μm) can require expensive photomasks.

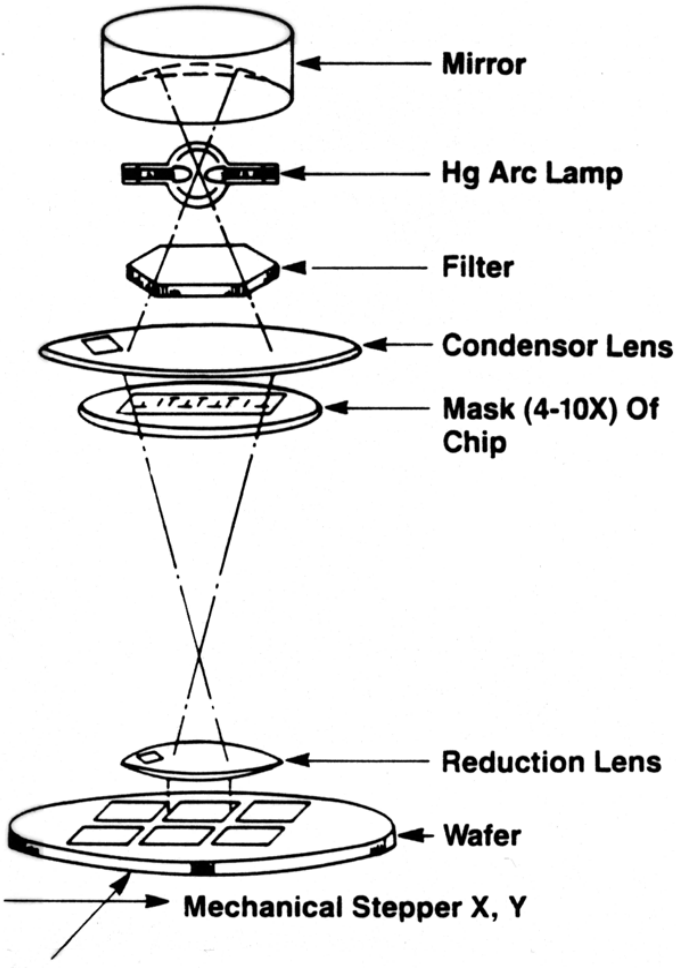
DUV exposures require a quartz mask.

Alignment can be time consuming and is not highly accurate (especially if the scheme for marks has not been well planned).

PROJECTION PRINTING

In contrast to contact lithography, projection lithography involves the introduction of extremely complicated lens elements into the optical system. It also involves a sophisticated mechanical step-and-repeat wafer stage utilizing laser interferometry, along with computer control of the stage motion and the exposures. Despite the introduction of such complexity, there are considerable benefits derived from the use of projection lithography. They are what have made it the dominant form of lithography in industry for decades.

Using a wafer stepper, multiple images or "die" are repeated over the wafer with the programmed spacing and exposure.



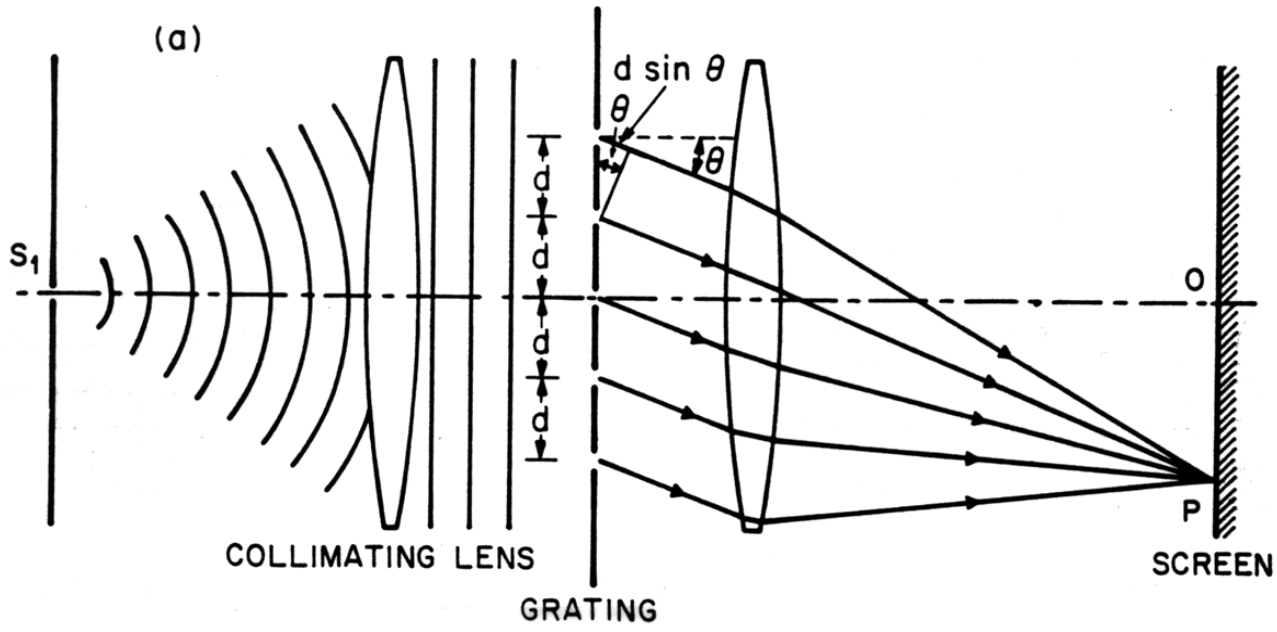
Moreau, p. 363

DIFFRACTION IN PROJECTION LITHOGRAPHY

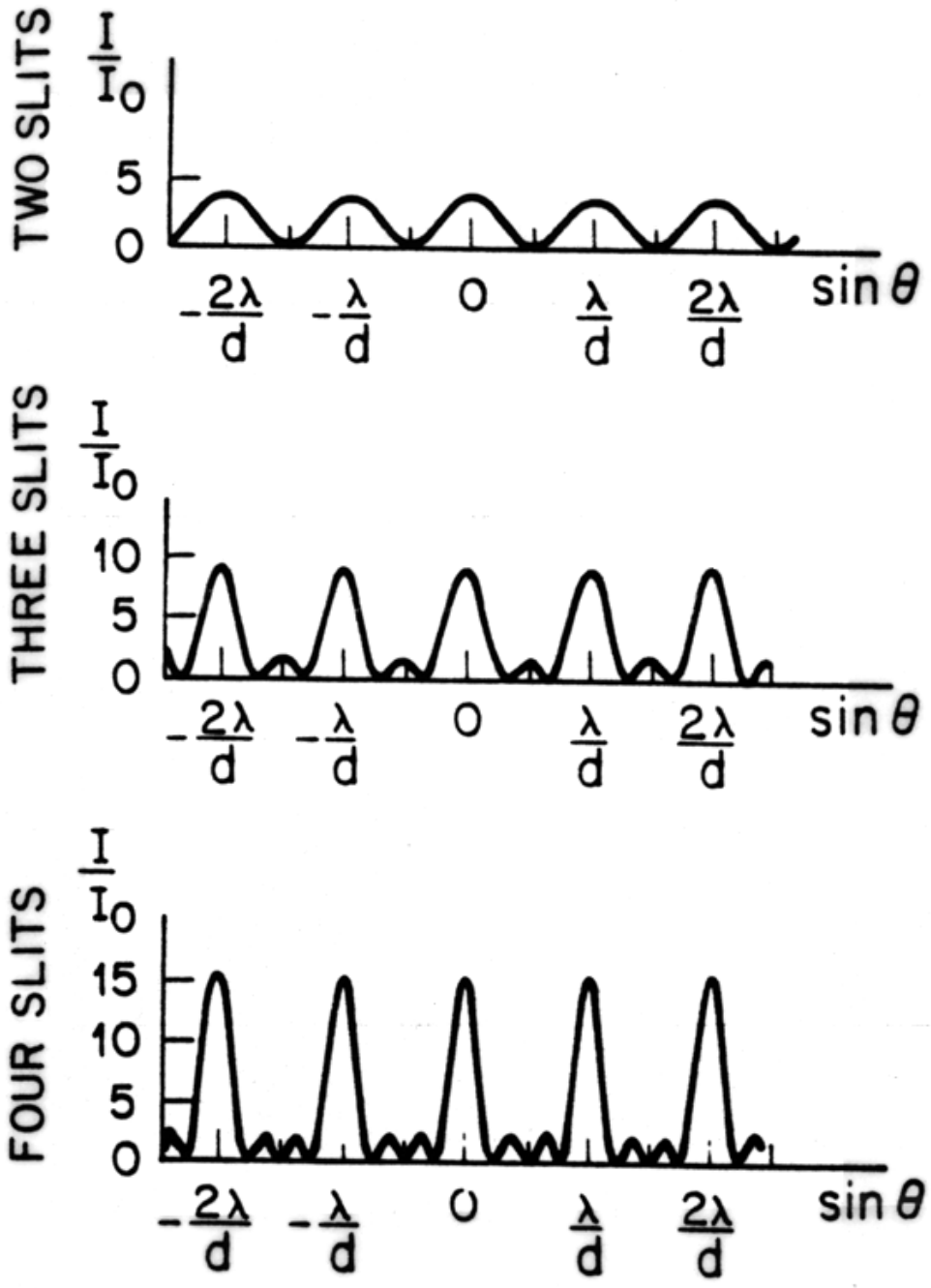
As mentioned earlier, Fraunhofer diffraction governs the behavior of the image formed in projection lithography. For a plane wave incident on a grating of period *d*, the angles θ at which the intensity maxima in the image occur are given by:

$$\sin\theta = N\lambda/d, \quad \text{where } N = 0, 1, 2, \ldots$$

This is shown in the figure below, and in the following plots of intensity versus **sin** θ for different numbers of slits.

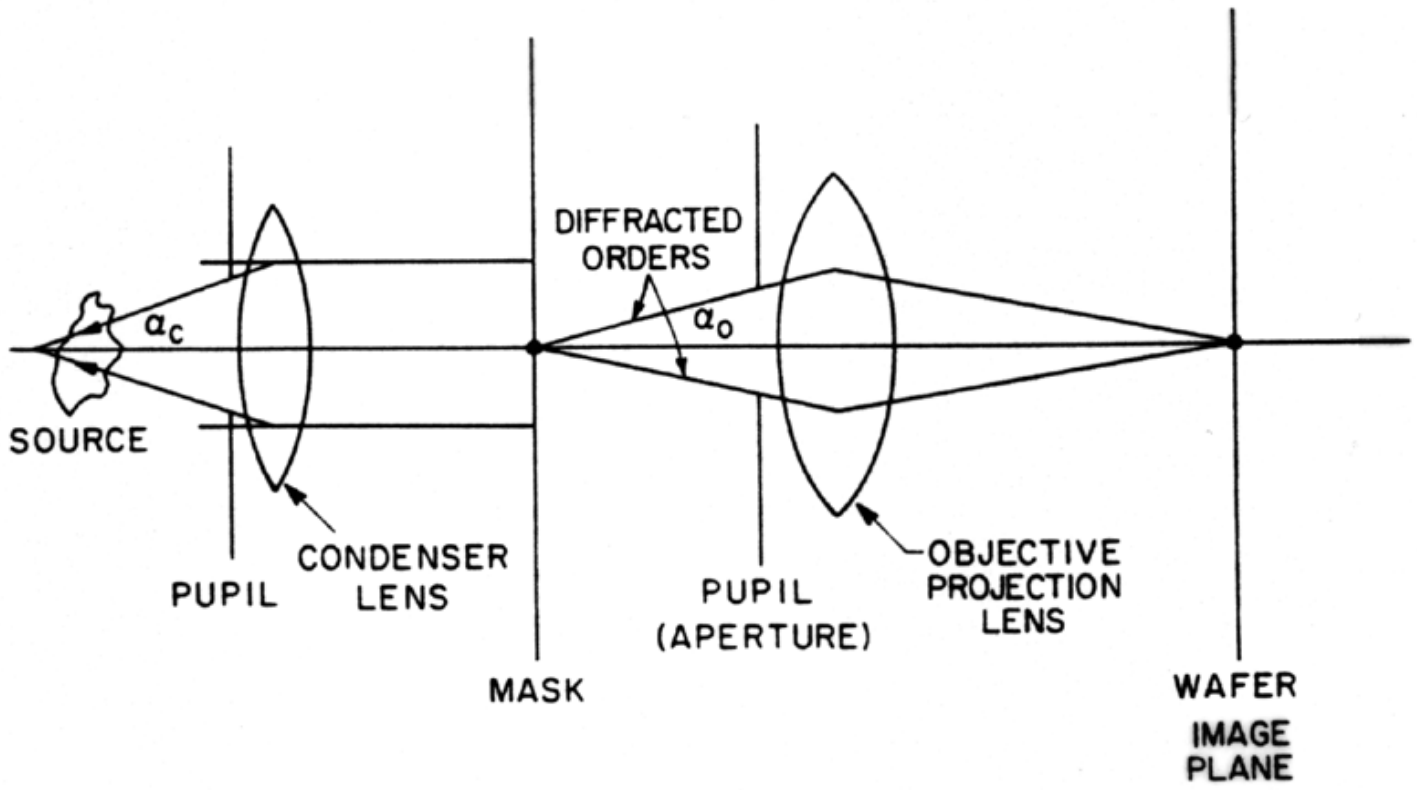


Thompson, Willson, and Bowden, p.33



Thompson, Willson, and Bowden, p.33

Now consider the case of a grating in a projection lithography system, as shown below:

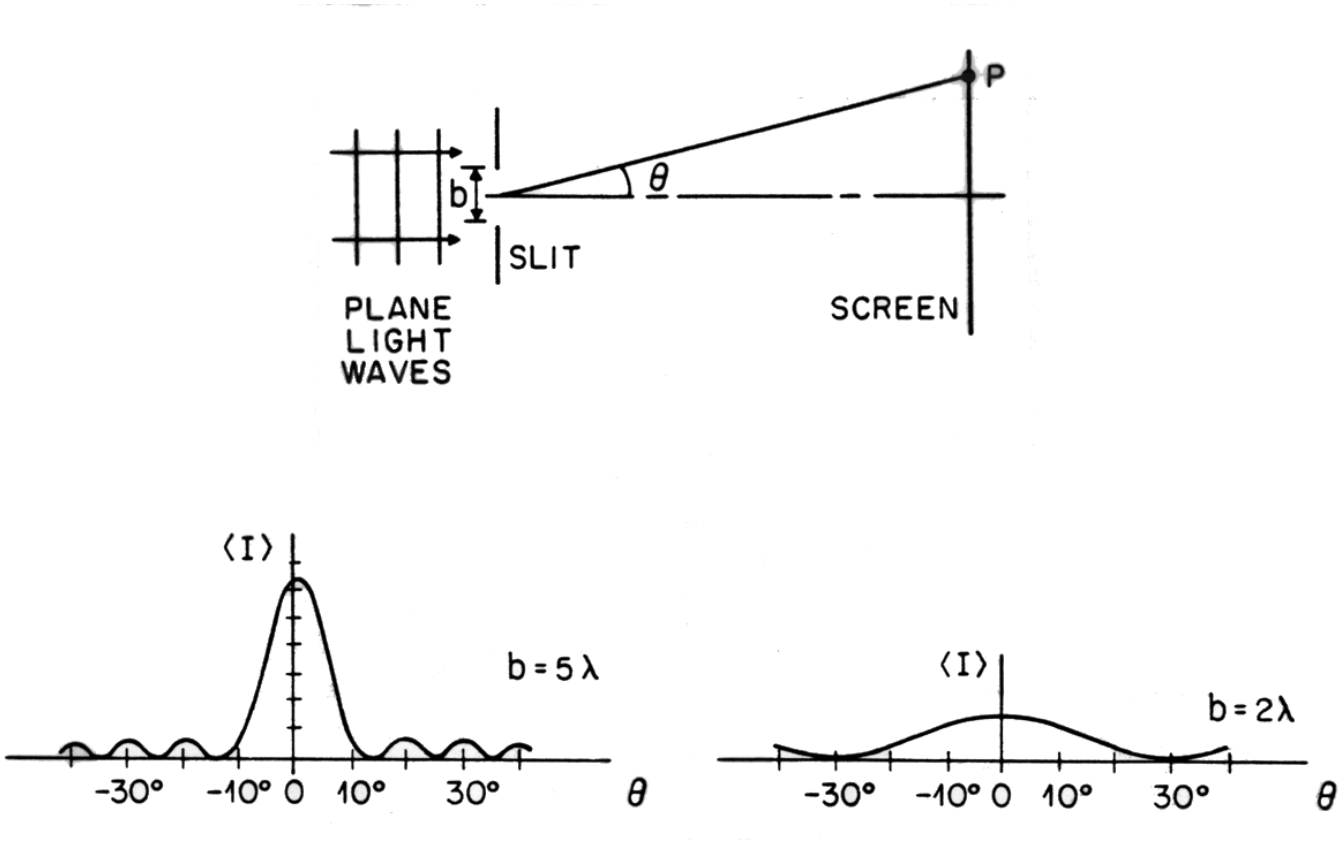


Thompson, Willson, and Bowden, p.34

The angle θ (as in the first figure) is the maximum angle for which diffracted light from the mask will be collected for imaging by the lens. With this restriction, we can see that the equation above becomes:

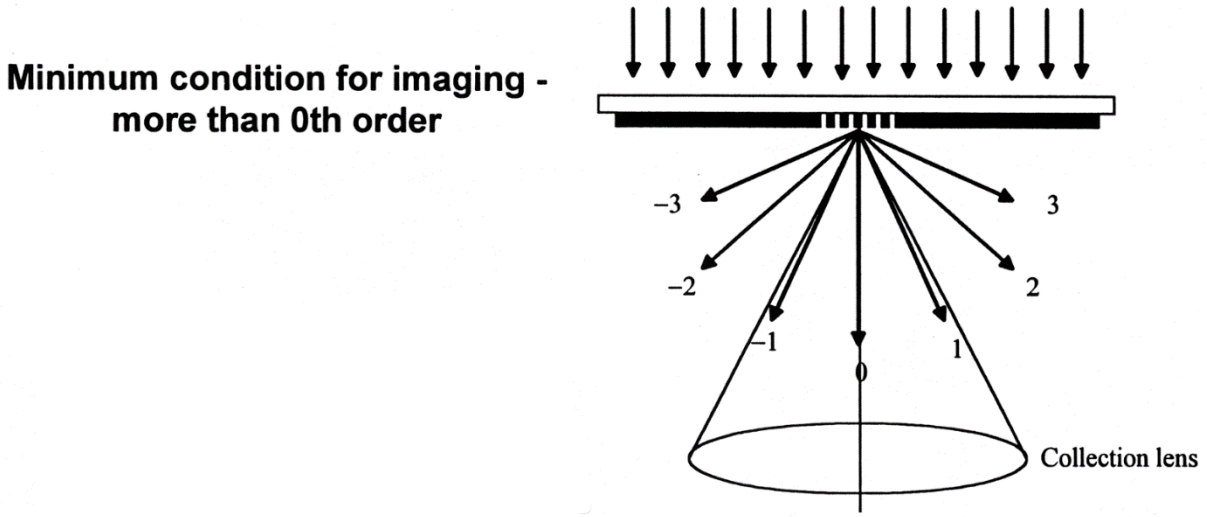
$$\sin \theta = N \lambda / d$$

Only those values of N for which the term on the right is less than sin θ are allowed. Thus, as the period *d* gets smaller (λ/d gets larger), N gets smaller (i.e. lower diffracted orders). The figure below shows the spread of the diffracted orders caused by a decrease in relative slit width.



Thompson, Willson, and Bowden, p.30

The reason for the loss of the diffracted orders becomes apparent in the diagram below:

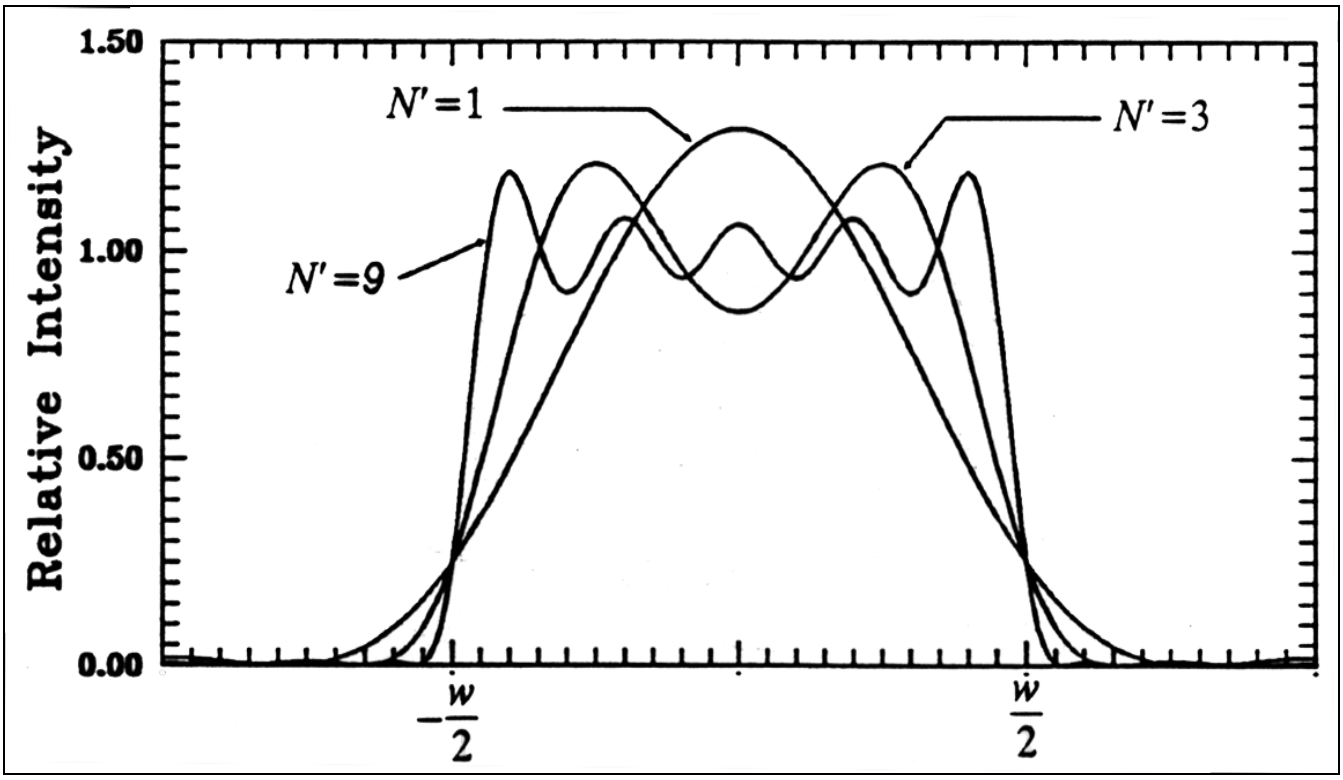


Minimum conditioning for imaging - more than 0th order.

Dr. B. Smith, RIT; **The Fundamental Limits of Optical Lithography**; SPIE 1999

The angles of diffraction increase as the grating openings become smaller. As the angles of the diffracted orders continue to increase, their light can no longer be collected by the lens and are lost. If at least two diffracted orders are not present in the lens, no image is formed. This defines the diffraction limit of the system.

The figure below shows the effect of including increasing numbers of diffracted orders on the image of a slit of width *w*. You can think of the aperture as truncating these diffracted orders at some small number, effectively acting as a *low-pass filter*.



Mack, p. 10-8

The sin of the widest angle of successful collection (sin θ) is called the ***numerical aperture***, usually written as **NA**. If the value of the NA is small for a system, fewer orders will be imaged, and smaller features cannot be resolved.

Applying this to features on a mask, we can say that the minimum feature size, d_{min}, which can be resolved by an optical system, is:

$$d_{min} = k\,\lambda/\mathrm{NA}$$

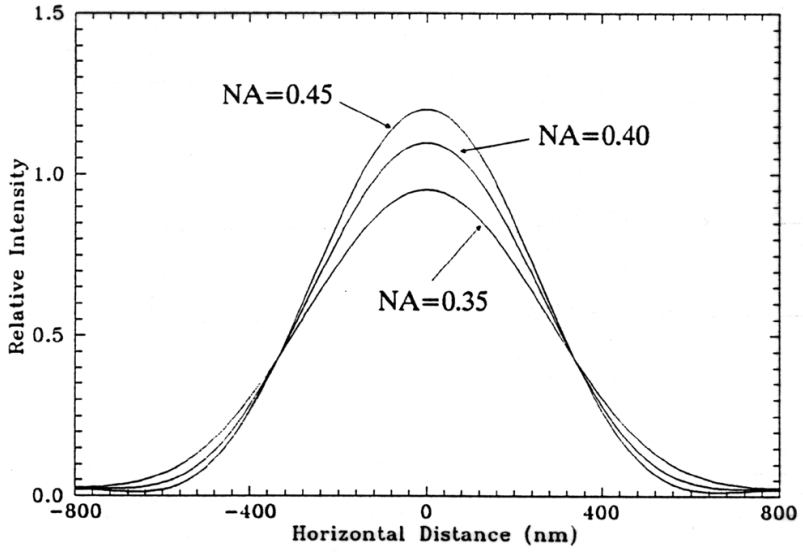
where k is a process variable with a typical value between 0.6 and 1.0. Engineers usually consider k values of 0.8 achievable in production, while lower values may be possible for machines in research. In DUV lithography, ***chemically amplified*** resists can allow k values in production below 0.4!

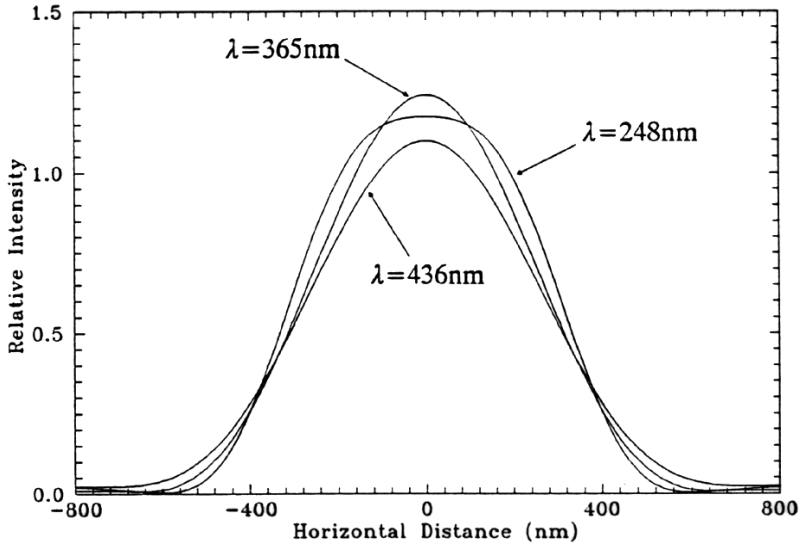
An important way in which projection lithography differs from contact is that the focus of the imaging lens must be considered. It has been shown that the ***depth of focus***, D, or the range of focus within which a feature can be resolved, is given by:

$$D = k\,\lambda/2\,(\mathrm{NA})^2$$

It should be clear that increasing NA will exponentially decrease the focus latitude of the system. These two equations describe all the problems and promise of optical lithography using projection tools: the way to increase resolution is to **decrease the wavelength** at which the system operates, and to **increase the numerical aperture** of the lens. However, both actions have the effect of **decreasing the depth of focus**.

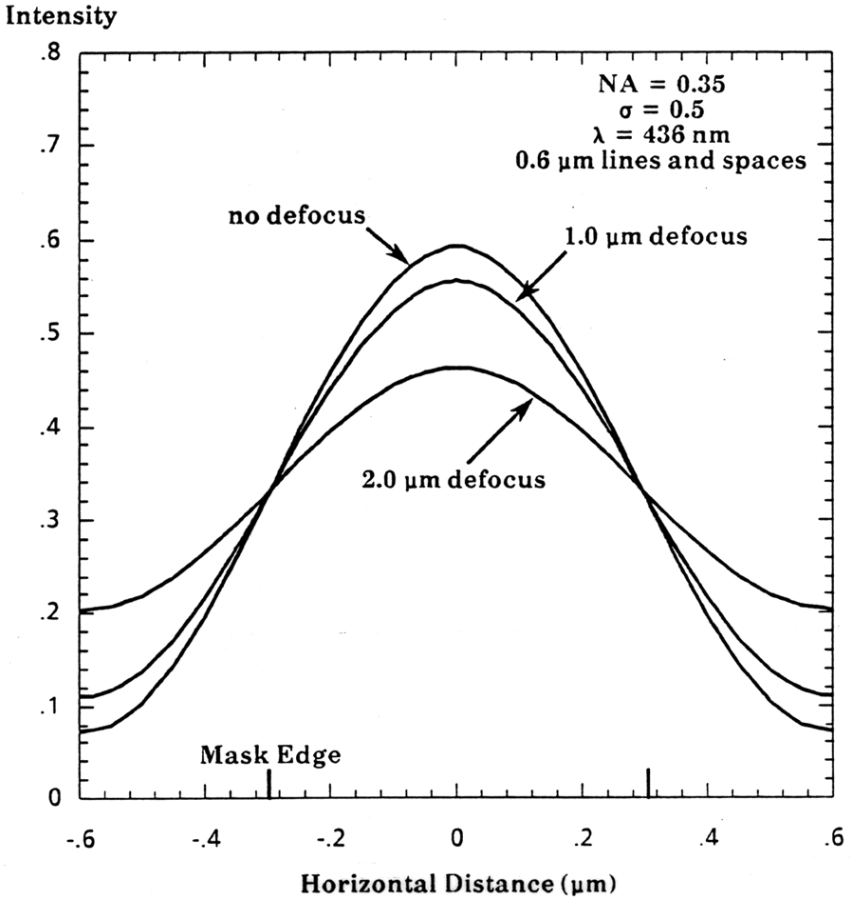
The figures below show the effect of wavelength and numerical aperture on the aerial image for a 0.8 μm slit.





Mack, p. 9-6

The figure below shows the effect of defocus on a slit of width 0.6 µm.



Mack, p. 20-13

The depth of focus becomes a significant limiter in successful printing of device layers. Once the substrate has been affected by deposition, etching, or any thermal processing, the surface is no longer flat. Any feature topology or non-flatness from stress reduces the usable depth of focus. In the case of DUV lithography, the total available focus can often be less than the thickness of typical resist. For this reason, in manufacturing ***chemical-mechanical polishing,*** or **CMP,** is used on nearly every process layer to afford surfaces flat enough for lithography.

CNF STEPPER PERFORMANCE CHARACTERISTICS

At CNF we have three steppers (two GCA, g- and i-line, and one ASML 248nm) for projection lithography. The following is a table of their performance characteristics:

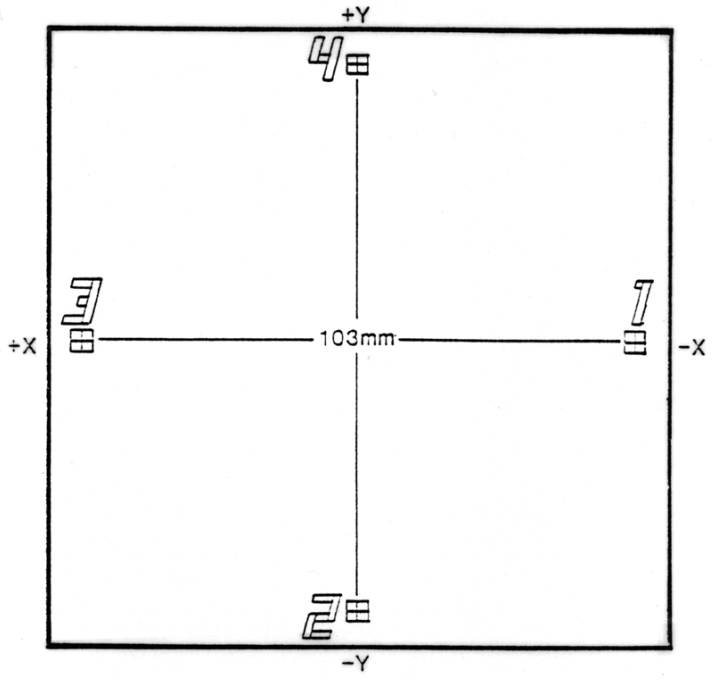
Reduction	**GCA 5:1**	**GCA 5:1**	**ASML 4:1**
Field Size	15 mm	15 mm	22 mm
Wavelength	436 nm (g-line)	365 nm (i-line)	248 nm (DUV)
N.A.	0.30	0.45	0.63-0.40
Resolution k=0.8 k=0.6	 1.2 µm 0.9 µm	 0.65 µm 0.45 µm	 0.25 µm* 0.15 µm*
Depth of Focus	± 2.42 µm	± 0.87 µm	± 0.25 µm

Resolution -- This is not a fixed number, but depends on the pattern, resist thickness, and wafer topography. For example, it can be easier to print an isolated feature than a grating (or sometimes harder). It is also easier to print small features in a 0.5 µm thick resist layer than in one 3 µm thick (depth of focus). Exposing a feature over a step normally results in a linewidth change, so topology is important.

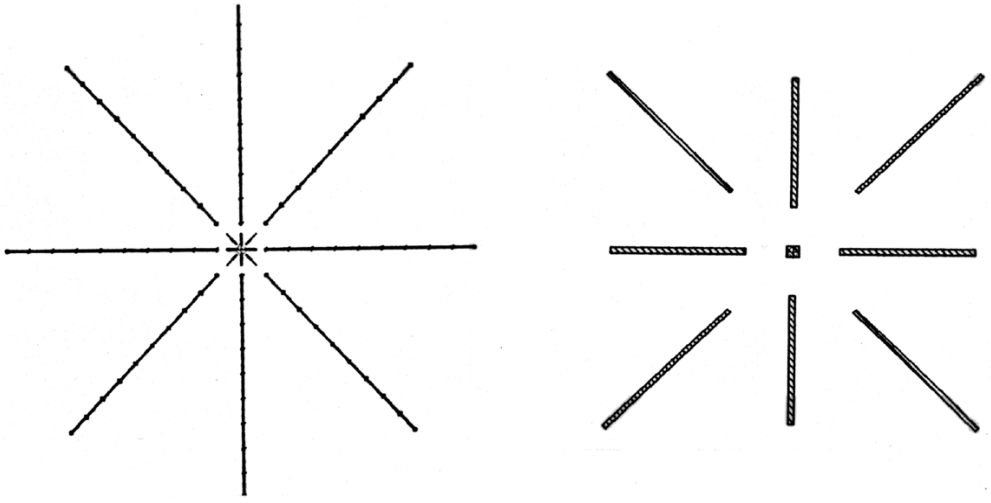
Focus -- Because focus is so critical, steppers must use an auto-focus mechanism. A stepper uses the reflection of a beam of light from the substrate to determine the wafer surface location. It then adjusts the lens-to-wafer distance to achieve the proper focus value. However, there is a limited range over which the system can move, so there is a requirement that substrates be within the range of the hardware limitations. These vary with each tool, so verify that the tool can accommodate your substrate early in planning.

Alignment -- The alignment scheme on a stepper is very different than the one discussed for contact lithography. Effectively, it is **not** a through the lens system - the user cannot look through the mask and lens at the pattern on the substrate. It is a system in which all masks are aligned to the optical column, and all substrates are aligned to the optical column, but masks and substrates are **not** aligned directly to each other.

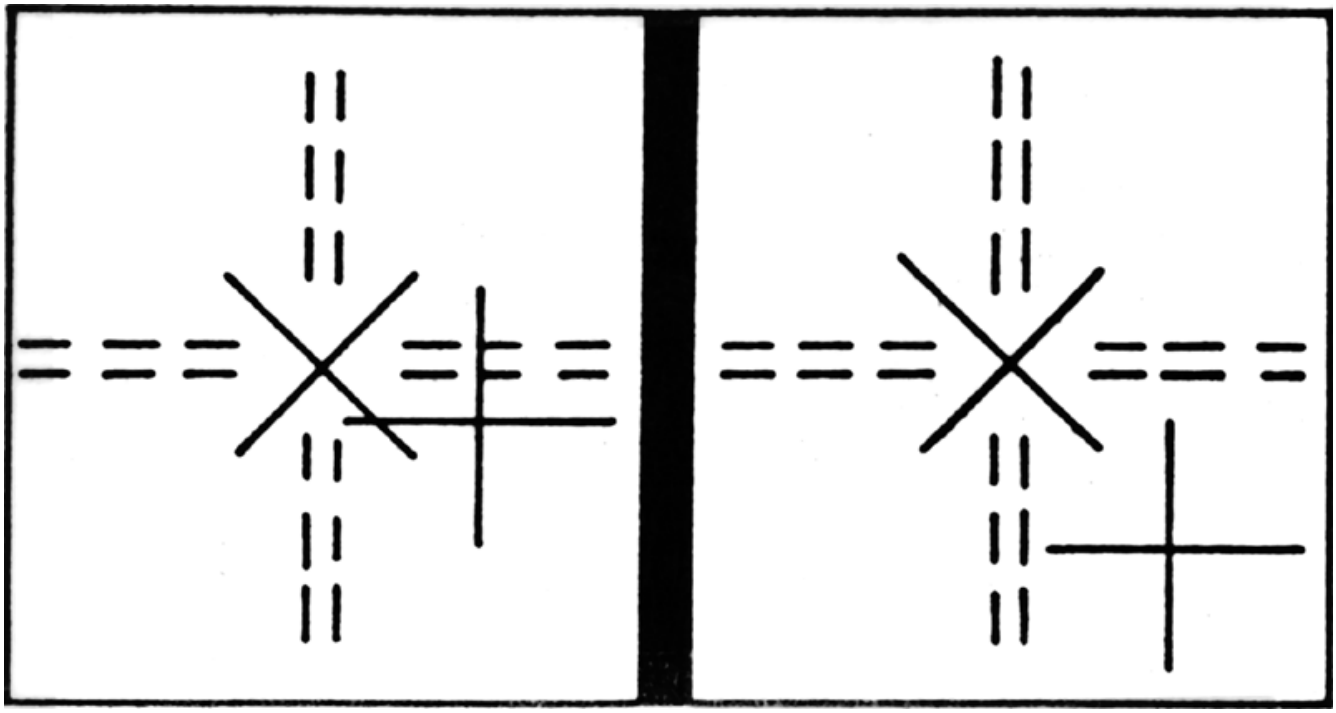
Masks made for the steppers **must** be made with special mask alignment marks, called ***fiducials***. These are needed to align the mask (and your pattern) to the column. The first level exposure **must** include special wafer alignment ***keys***, which match marks built into the stepper alignment system. Subsequent levels often **do not** need to print new alignment marks, unlike the case for contact lithography. This produces very good alignment, typically ± 0.25 μm aligning manually, ± 0.12 μm on older tools using automated alignment, and <0.05 μm on newer ones. Each tool uses different schemes for marks, so research the requirements before finalizing mask design.



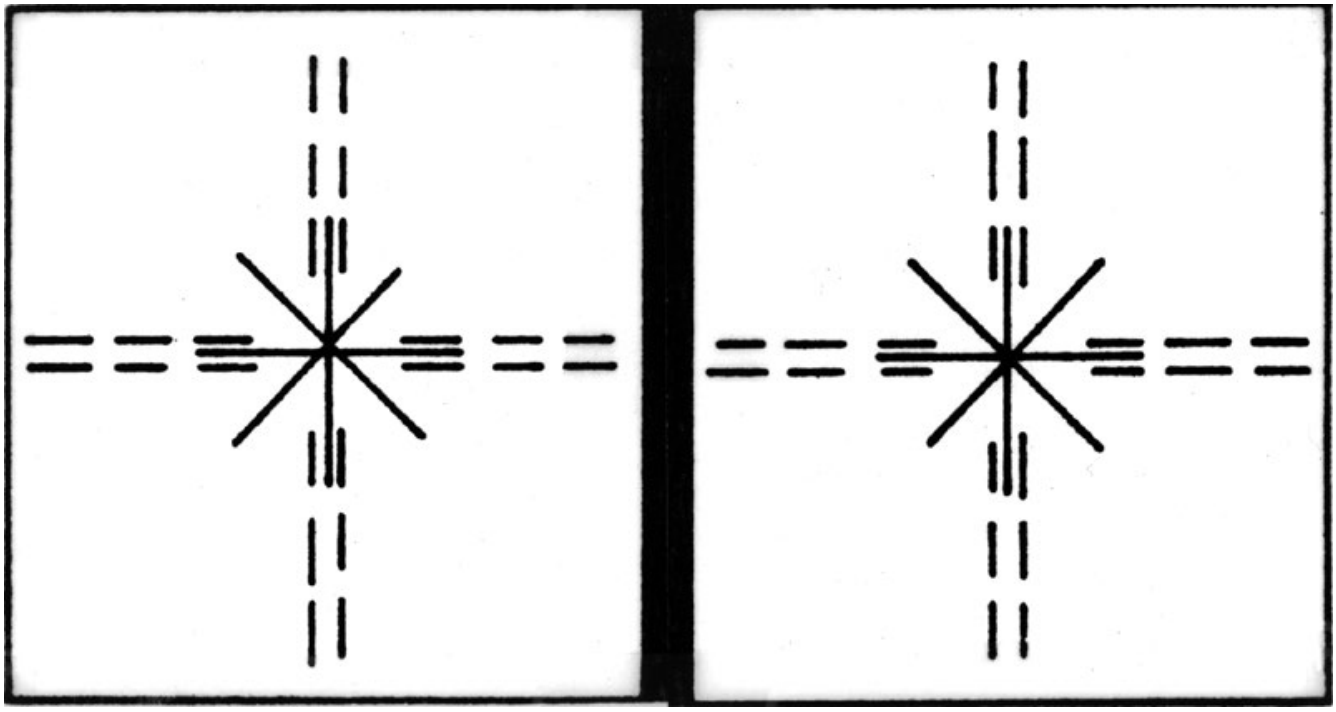
Fiducial marks placed on 5X GCA stepper masks.



Alignment marks for the GCA steppers placed on the first wafer level.



GCA stepper alignment marks offset relative to the microscope reference marks.



GCA stepper alignment marks in perfect registration with the microscope reference marks.

ADVANTAGES OF PROJECTION LITHOGRAPHY

Resolution is superior to contact lithography with no degradation of mask or resist.

More tolerant of mask errors since mask image is 4-5x larger than substrate image. Almost all local use masks can be made in CNF.

Step and repeat allows many exposures per wafer, with the flexibility of computer control.

Better alignment accuracy, typically ± 0.25 μm for the older GCA stepper, ± 0.12 μm for the AS200, and ± 0.045 μm for the ASML. Current state-of-the-art tool spec is <0.006 μm.

DISADVANTAGES

Focus requirements mean that substrate thickness is limited, as well as allowable wedge error (newer steppers have leveling).

Field size is limited.

Masks can be expensive for DUV.

More complicated to learn than contact lithography.

Much more expensive tools.

OPTICAL LITHOGRAPHY

MASK MAKING

INTRODUCTION

Before considering mask making, take a look at the requirements listed in the introduction as they apply to optical lithography specifically.

Your pattern requirements:

pattern size, feature sizes, alignment accuracy

The requirements of the lithography tool:

field size, mask size, mask type, alignment marks

The requirements of the technique you will use for the pattern transfer:

mask tone, resist type, resist thickness

Most of the items listed here must be considered during the CAD process, and again during the process which follows that: making the mask.

Optical lithography requires the fabrication of a ***photomask***.

Chrome-on-glass is the standard photomask material universally used. A layer of sputtered Cr about 100 nm thick is deposited on a very flat glass plate. Photoresist is then spin-coated onto the plate, and a pattern is exposed. The exposures can be made with either optical or e-beam writers. After development, the Cr is removed from the unprotected areas, usually with an acid etch, and then the photoresist is removed. This results in an image of the pattern etched into the Cr.

Mask Making circa 1972 using Xacto blades

THE MASK WRITERS

The lithographic capabilities of the exposure tools at CNF usually allow you to make a mask using a laser writer on-site. There are specific exceptions to this, typically related to resolution. Our mask writing tools are described below:

Heidelberg DWL 66fs Specifications

- Data input: 0.10 μm; this is the least count for object placement
- Spot size: 1.0 μm in Mode II; 2.5 μm in Mode III
- Stage motion range: 150 mm
- Image positioning accuracy: < 0.10 μm over 100 mm of stage motion -- this is 1.0 ppm
- Alignment error: +/- 250 nm in Mode II; +/- 500 nm in Mode III

Heidelberg DWL 2000 Specifications

- Data input: 0.01 μm; this is the least count for object placement
- Spot size: 0.6 μm in Mode I; 0.7 μm in Mode II
- Stage motion range: 200 mm
- Image positioning accuracy: < 0.05 μm over 100 mm of stage motion -- this is 0.5 ppm
- Alignment error: +/- 70 nm in Mode I; +/- 80 nm in Mode II

There are two things to remember here:

For steppers, the potential errors decrease as the reduction ratio increases. This means that masks made for 5:1 stepper lithography are much more tolerant of errors than masks made for contact at 1:1.

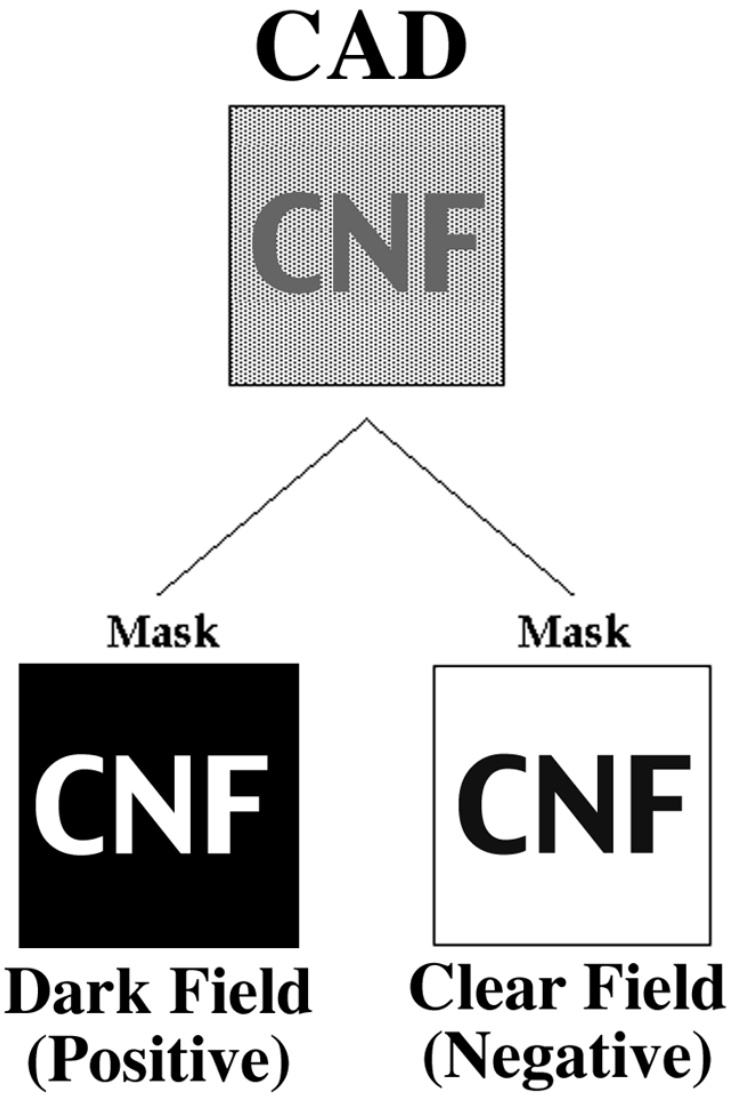
The actual errors are not usually as bad as the worst-case specifications. However, some patterns are more unpredictable than others.

PHOTOMASKS: MASK TONE

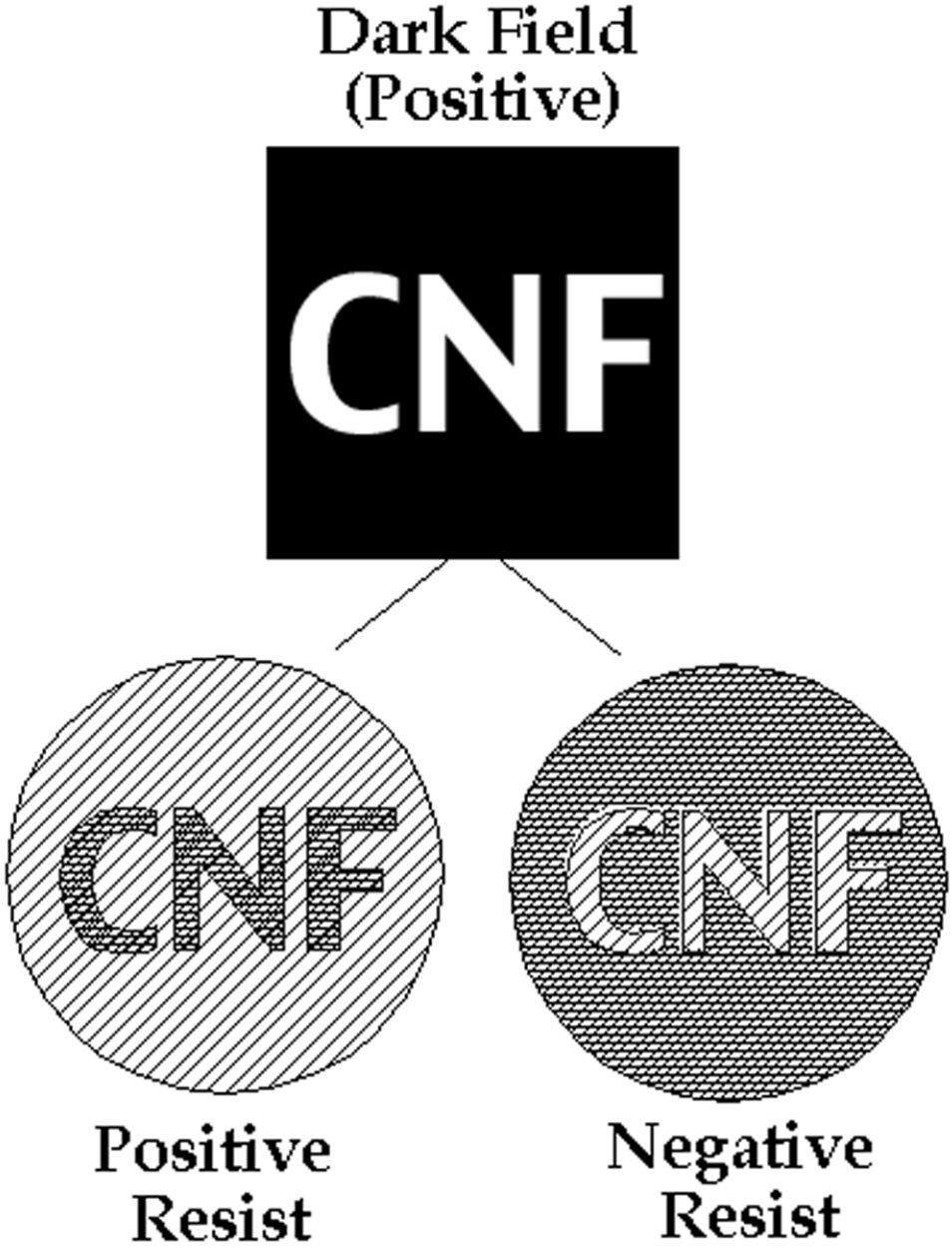
Masks can be made to be in positive or negative tone with respect to the desired pattern. When you draw an object in CAD, the pattern you have defined is exposed and will become an opening in the mask. The unexposed, or background area is typically called the ***field***.

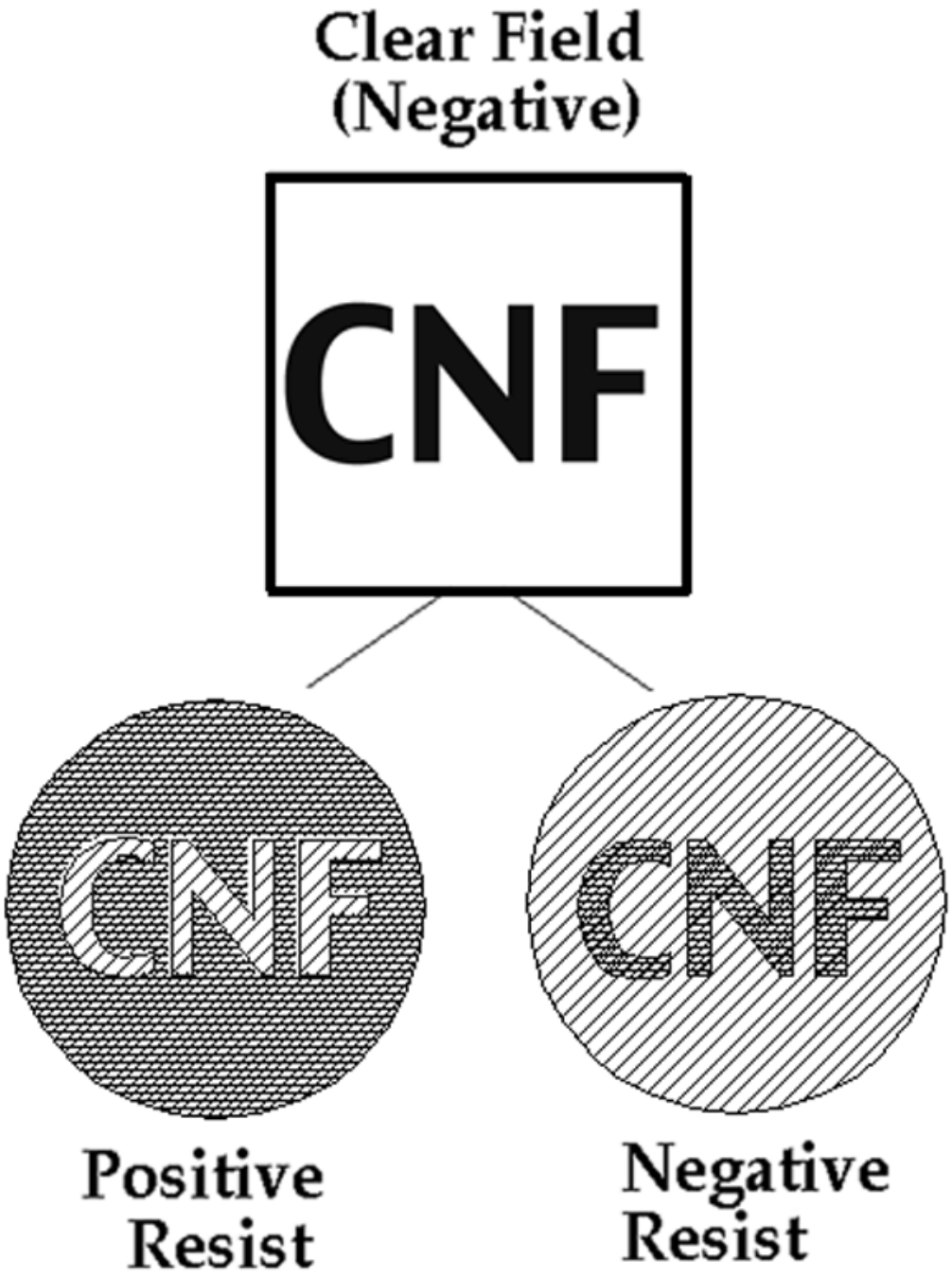
A ***positive tone*** or ***dark field*** mask is one on which the pattern is clear with the background dark.

A ***negative tone*** or ***clear field*** mask is one on which the pattern is dark with the background clear.



The combination of mask tone and resist tone affects the tone of the final product; a positive (dark field) mask, used with positive resist, is equivalent to a negative (clear field) mask used with a negative resist, in terms of the final pattern. However, there is an important difference between these two alternatives. The difference has to do with the effect on the ***sidewall slope*** of the resist. This was shown to be of critical importance when attempting to perform lift-off after metallization.




Clear Field
(Negative)
CNF
CNF
CNF
Positive
Resist
Negative
Resist

TYPES OF GLASS

One final consideration that is important is the type of glass from which the mask is made. There are a few considerations here: the ***thermal expansion*** of the glass and its ***transmission*** at the exposure wavelength, as well as the ***flatness*** specification of the plate.

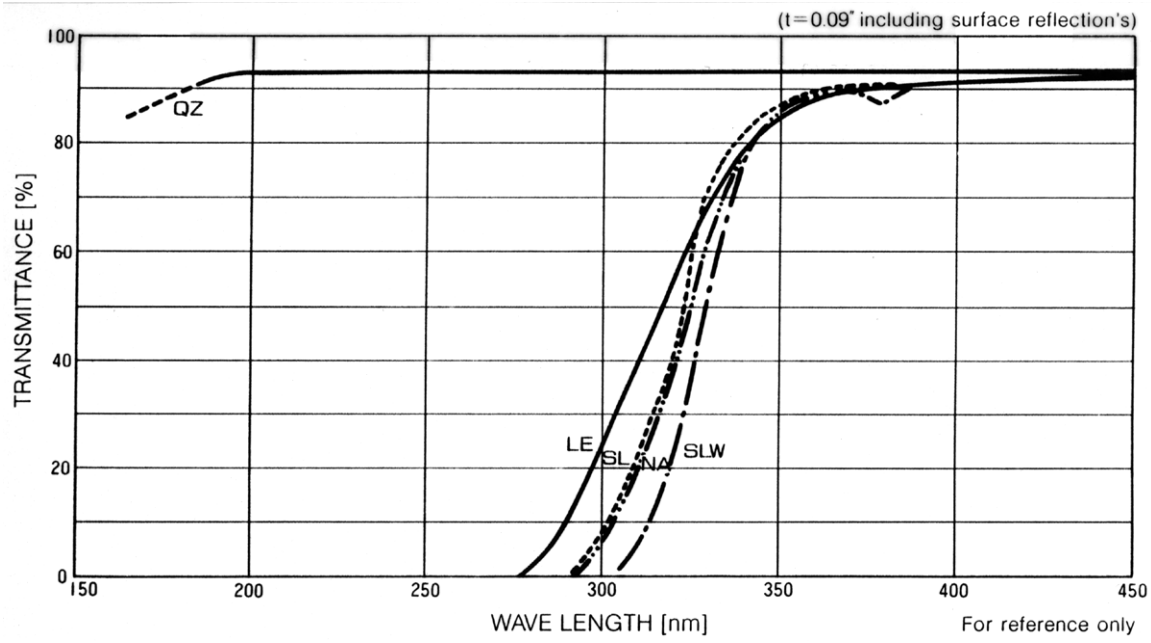
Thermal coefficients for different types of glass are:

Soda-lime:	9.3 ppm/˚C
Borosilicate:	3.7 ppm/˚C
Quartz:	0.5 ppm/˚C

Soda-lime glass has a 1.2 µm change in size across a 5-inch mask for every 1˚C variation in temperature.

Borosilicate glass has better properties and is more expensive.

Fused Silica (Quartz) has the best properties, particularly in transmission, and is the most expensive, but is usually what we use at CNF.



Hoya Product Literature

Flatness grades of plates are typically specified as **Standard** - 15 µm**, Tightened** - 5 µm**,** and **Master** - 2 µm. We typically use Master at CNF.

OTHER MASK-MAKING TECHNIQUES

GCA Stepper in Photorepeater Mode - Both GCA steppers have a mode in which resist-coated chrome masks can be exposed using a 5:1 "master." This is useful for masks on which an individual pattern is repeated many times across a mask. Good examples are arrays of dots and large field gratings, which are expensive and time-consuming to make full size on a mask writer, or contact masks with many copies of the same image. Making a subset of the array on one mask and then repeating it in this mode on another mask using the stepper can be much less expensive.

Outside Vendors - Complex data files can be sent to mask making shops for fabrication if necessary. Typical requirements for this would be high resolution, inspection and repair capabilities, or cost for Industrial users.

***

Now you can begin thinking about that list of requirements shown earlier:

Your pattern requirements:

pattern size, feature size, alignment accuracy

The requirements of the lithography tool:

field size, mask size, mask type, alignment marks

The requirements of the technique you will use for the pattern transfer:

mask tone, resist type, resist thickness

With these in mind, you can begin to plan your process. Seek input from CNF Staff members and other experienced users. Notes on resist processes used at CNF follow.

Fujifilm OiR 897-12i Photoresist

i-line (365 nm) specific photoresist, used with the AS200 Stepper and mask aligners.

Available as OiR 897-12i, 1.2 μm thick @ 4000 rpm.

1.a. (Optional) Dehydration bake at 150°C for 5 minutes (hotplate).

1.b. Liquid prime with P-20 (20% HMDS) primer. Apply primer over entire wafer, allow to remain for 10 seconds, then spin dry (3000-5000 rpm, 30 sec.)

-or-

1. Vapor prime wafer with YES Oven HMDS process.

2. Dispense photoresist in middle of wafer. Spin immediately at desired speed, 20 - 30 seconds (thicker films may take a longer time to reach uniformity). You must adjust ramp rate to the desired speed for best coverage over topography.

3. Solvent removal bake at 90°C for 1 minute on vacuum hot plate or 30 minutes in the 90°C oven. Thicker films benefit from longer baking.

4. Expose. Time will vary depending on resist thickness, bake time, substrate reflectivity, intermediate film thickness, etc. See Sample Processes sheet for approximate exposure times.

5. Post-exposure bake, 115°C for 1 minute on vacuum hotplate. Post-exposure baking for this resist is **recommended** for optimum resolution.

6. Develop for 1 minute in AZ 726 MIF.

7. (Optional) Hard bake at 115°C - 125°C for 1 to 2 minutes on vacuum hot plate, or 30 minutes in the oven. The hard bake serves to promote adhesion during wet etching or increase selectivity during dry etching.

Dow Ultra-i 123 1.0 Photoresist

i-line (365 nm) specific photoresist, used with the AS200 Stepper and mask aligners.

Available as Ultra-i 123 1.0, 1.0 μm @ 4000 rpm.

1.a. (Optional) Dehydration bake at 150°C for 5 minutes (hotplate).

1.b. Liquid prime with P-20 (20% HMDS) primer. Apply primer over entire wafer, allow to remain for 10 seconds, then spin dry (3000-5000 rpm, 30 sec.)

-or-

1. Vapor prime wafer with YES Oven HMDS process.

2. Dispense photoresist in middle of wafer. Spin immediately at desired speed, 20 - 30 seconds (thicker films may take a longer time to reach uniformity). You must adjust ramp rate to the desired speed for best coverage over topography.

3. Solvent removal bake at 90°C for 1 minute on vacuum hot plate or 30 minutes in the 90°C oven. Thicker films benefit from longer baking.

4. Expose. Time will vary depending on resist thickness, bake time, substrate reflectivity, intermediate film thickness, etc. See Sample Processes sheet for approximate exposure times.

5. Post-exposure bake, 115°C for 1 minute on vacuum hotplate. Post-exposure baking for this resist is **required** for optimum resolution.

6. Develop for 1 minute in AZ 726 MIF.

7. (Optional) Hard bake at 115°C - 125°C for 1 to 2 minutes on vacuum hot plate, or 30 minutes in the oven. The hard bake serves to promote adhesion during wet etching or increase selectivity during dry etching.

Dow 1800 Series Photoresist

General purpose **broadband (365 nm - 436 nm)** resist, best suited for use on the 5X Stepper and ABM or MA6 Contact Aligner. Not recommended for the i-line Stepper.

Available as S1805, S1813, S1818, S1827 (0.5, 1.3, 1.8, 2.7 μm @ 4000 rpm).

1.a. (Optional) Dehydration bake at 150°C for 30 minutes.

1.b. Liquid prime with P-20 (20% HMDS) primer. Apply primer over entire wafer, allow to remain for 10 seconds, then spin dry (3000-5000 rpm, 30 sec.)

-or-

1. Vapor prime wafer with YES Oven HMDS process.

2. Dispense photoresist in middle of wafer. Spin immediately at desired speed, 20 - 30 seconds (thicker films take a longer time to reach uniformity). You must adjust ramp rate to the desired speed for best coverage over topography.

3. Solvent removal bake at 90°C - 115°C for 1 to 2 minutes on vacuum hot plate or 30 minutes in the 90°C oven. Thicker films benefit from longer baking.

4. Expose. Time will vary depending on resist thickness, bake time, substrate reflectivity, intermediate film thickness, etc. See Sample Processes sheet for approximate exposure times.

5. Develop for 1 minute in AZ 726 MIF. Can also use MF-321 (higher dose required), or Micro Dev Concentrate (MDC) diluted 1:2 (MDC minimizes Al etch rate but is not metal-ion free). USE AGITATION AT END OF DEVELOPMENT TO REMOVE RESIDUES.

6. (Optional) Hard bake at 115°C for 1-3 minutes on vacuum hot plate, or 30 minutes in the oven. The hard bake serves to promote adhesion during wet etching or increase selectivity during dry etching.

Dow SPR220 Series Photoresist

General purpose **broadband (365 nm - 436 nm)** resist, suited for use on the 5X Stepper and ABM or MA6 Contact Aligners, as well as the AS200 i-line Stepper.

Available as SPR220-3.0, SPR220-4.5, and SPR220-7.0 (3 – 7 µm @ 4000 rpm).

1.a. (Optional) Dehydration bake at 150°C for 30 minutes.

1.b. Liquid prime with P-20 (20% HMDS) primer. Apply primer over entire wafer, allow to remain for 10 seconds, then spin dry (3000-5000 rpm, 30 sec.)

-or-

1. Vapor prime wafer with YES Oven HMDS process.

2. Dispense photoresist in middle of wafer. Spin immediately at desired speed, 20 - 30 seconds (thicker films take a longer time to reach uniformity). You must adjust ramp rate to the desired speed for best coverage over topography.

3. Solvent removal bake at 115°C for 1-1/2 - 3 minutes or longer on vacuum hot plate or 30 - 45 minutes in the 90°C oven. Thicker films benefit from longer baking (see product data sheets).

4. Expose. Time will vary depending on resist thickness, bake time, substrate reflectivity, intermediate film thickness, etc. See Sample Processes page for approximate exposure times.

5. Develop for 1 to 6 minutes in AZ 726 MIF. Can also use Micro Dev Concentrate (MDC) diluted 1:2 (MDC minimizes Al etch rate but is not metal-ion free).

6. (Optional) Hard bake at 115°C for 1-1/2 minutes or longer on vacuum hot plate, or 30 minutes or more in the oven. The hard bake serves to promote adhesion during wet etching or increase selectivity during dry etching.

AZ 5200 Series Photoresist

Image-reversable photoresist, used with all optical lithography instruments. Process is usually optimized for a lift-off profile. The profile is controlled through the combination of exposure time and post exposure bake.

Available as AZ 5206 and 5214 (0.6 or 1.4 μm @ 4000 rpm).

1.a. (Optional) Dehydration bake at 150°C for 30 minutes.

1.b. Liquid prime with P-20 (20% HMDS) primer. Apply primer over entire wafer, allow to remain for 10 seconds, then spin dry (3000-5000 rpm, 30 sec.)

-or-

1. Vapor prime wafer with YES Oven HMDS process.

2. Dispense photoresist in middle of wafer. Spin immediately at desired speed, 20 - 30 seconds (thicker films take a longer time to reach uniformity). You may wish to ramp up to the desired speed for better coverage over topography.

3. Solvent removal bake at 90°C for 1 to 2 minutes on vacuum hot plate or 20 - 30 minutes in the 90°C oven. Thicker films benefit from longer baking.

4. Expose. Time will vary depending on resist thickness, bake time, substrate reflectivity, intermediate film thickness, etc. See Sample Processes page for approximate exposure times.

5. Post-exposure bake, 115°C for 3 minutes (or more) on vacuum hotplate, or 20 minutes in oven. This bake is necessary for image reversal. The hotplate gives more consistent results than the oven.

6. Flood expose using the HTG for 30 seconds.

7. Develop for 1 minute in MF-321 (no dilution).

YES Oven Image Reversal

The YES Oven uses an ammonia diffusion process to reverse the tone of positive photoresists. This process has been developed specifically to generate an undercut profile for lift-off. Good results have been obtained for virtually all positive resists at CNF.

1.a. (Optional) Dehydration bake at 150°C for 5 minutes (hotplate).

1.b. Liquid prime with P-20 (20% HMDS) primer. Apply primer over entire wafer, allow to remain for 10 seconds, then spin dry (3000-5000 rpm, 30 sec.)

-or-

1. Vapor prime wafer with YES Oven HMDS process.

2. Dispense photoresist in middle of wafer. Spin immediately at desired speed, 20 - 30 seconds (thicker films take a longer time to reach uniformity). You must adjust ramp rate to the desired speed for best coverage over topography.

3. Solvent removal bake time and temperature dependent upon the type and thickness of resist used. Follow normal processing steps.

4. Expose. Time will vary depending on resist thickness, bake time, substrate reflectivity, intermediate film thickness, etc. See Sample Processes sheet for approximate exposure times.

5. Run YES Oven ammonia diffusion process. See YES Oven operating instructions for details.

6. Flood expose for 60 seconds (more for very thick films) using a mask aligner.

7. Develop for 1 minute in **MF-321**. See staff regarding thick resists.

Cr Plate Processing

Development

Develop mask resist side up in Hamatech Mask Processing tool using Recipe #2, 120 sec. Mask Develop. Inspect mask.

Cr Etch

Process plate with resist side up in Hamatech Mask Processing tool using Recipe #1, Mask Chrome Etch. Inspect mask.

Resist Strip

Process plate in Hot Strip Bath in Photolith Spinner room using supplied holders. Soak for 10-30 minutes in each bath beginning with right side bath. Rinse in Dump Rinse tank, then spin dry on Hamatech Mask Processing tool using Recipe #10, Rinse and Dry. Multiple masks can be rinsed and dried using the Verteq SRD next to the Hot Strip Bath.

Fujifilm OiR 620-7i Photoresist

i-line (365 nm) specific photoresist, used with the AS200 Stepper and mask aligners.

Available as OiR 620-7i (0.62 μm @ 3000 rpm).

1.a. (Optional) Dehydration bake at 150°C for 5 minutes (hotplate).

1.b. Liquid prime with P-20 (20% HMDS) primer. Apply primer over entire wafer, allow to remain for 10 seconds, then spin dry (3000-5000 rpm, 30 sec.)

-or-

1. Vapor prime wafer with YES Oven HMDS process.

2. Dispense photoresist in middle of wafer. Spin immediately at desired speed, 20 - 30 seconds. You must adjust ramp rate to the desired speed for best coverage over topography.

3. Solvent removal bake at 90°C for 1 minute on vacuum hot plate or 30 minutes in the 90°C oven.

4. Expose. Time will vary depending on resist thickness, bake time, substrate reflectivity, intermediate film thickness, etc. See Sample Processes sheet for approximate exposure times.

5. Post-exposure bake 115°C for 90 seconds on vacuum hotplate. Post-exposure baking for this resist is **required** for optimum resolution.

6. Develop for 1 minute in AZ 726 MIF.

7. (Optional) Hard bake at 115°C - 125°C for 1 - 2 minutes on vacuum hot plate, or 30 minutes in the oven. The hard bake serves to promote adhesion during wet etching or increase selectivity during dry etching.

Dow SPR700-1.2 Photoresist

i-line (365 nm) specific photoresist, used with the AS200 Stepper and mask aligners.

Available as SPR700-1.2 (1.2 μm @ 3000 rpm).

1.a. (Optional) Dehydration bake at 150°C for 5 minutes (hotplate).

1.b. Liquid prime with P-20 (20% HMDS) primer. Apply primer over entire wafer, allow to remain for 10 seconds, then spin dry (3000-5000 rpm, 30 sec.)

-or-

1. Vapor prime wafer with YES Oven HMDS process.

2. Dispense photoresist in middle of wafer. Spin immediately at desired speed, 20 - 30 seconds. You must adjust ramp rate to the desired speed for best coverage over topography.

3. Solvent removal bake at 95°C for 1 minute on vacuum hot plate or 30 minutes in the 90°C oven.

4. Expose. Time will vary depending on resist thickness, bake time, substrate reflectivity, intermediate film thickness, etc. See Sample Processes sheet for approximate exposure times.

5. Post-exposure bake 115°C for 90 seconds on vacuum hotplate. Post-exposure baking for this resist is **recommended** for optimum resolution.

6. Develop for 1 minute in AZ 726 MIF.

7. (Optional) Hard bake at 115°C - 125°C for 1 - 2 minutes on vacuum hot plate, or 30 minutes in the oven. The hard bake serves to promote adhesion during wet etching or increase selectivity during dry etching.

Dow SPR955-CM Photoresist

i-line (365 nm) specific photoresist, used with the AS200 Stepper and mask aligners.

Available as SPR955-CM-0.9 and SPR955-CM-2.1 (0.9 or 2.1 µm @ 3000 rpm).

1.a. (Optional) Dehydration bake at 150°C for 5 minutes (hotplate).

1.b. Liquid prime with P-20 (20% HMDS) primer. Apply primer over entire wafer, allow to remain for 10 seconds, then spin dry (3000-5000 rpm, 30 sec.)

-or-

1. Vapor prime wafer with YES Oven HMDS process.

2. Dispense photoresist in middle of wafer. Spin immediately at desired speed, 20 - 30 seconds (thicker films take a longer time to reach uniformity). You must adjust ramp rate to the desired speed for best coverage over topography.

3. Solvent removal bake at 90°C for 1 to 1-1/2 minutes on vacuum hot plate or 30 minutes in the 90°C oven.

4. Expose. Time will vary depending on resist thickness, bake time, substrate reflectivity, intermediate film thickness, etc. See Sample Processes sheet for approximate exposure times.

5. Post-exposure bake 115°C for 90 seconds on vacuum hotplate. Post-exposure baking for this resist is **required** for optimum resolution.

6. Develop for 1 minute in AZ 726 MIF.

7. (Optional) Hard bake at 115°C - 125°C for 1 - 2 minutes on vacuum hot plate, or 30 minutes in the oven. The hard bake serves to promote adhesion during wet etching or increase selectivity during dry etching.