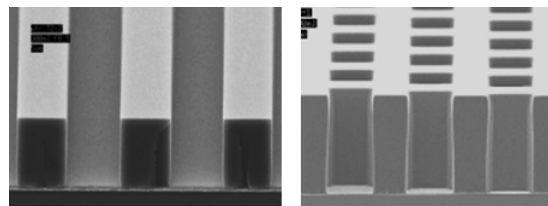




Lithography Process Overview

Line/Space and square hole images in AZ[®] 15nXT Photoresist

Following is a step by step overview of the basic lithography process from substrate preparation through developing of the photoresist image. It should be noted that the addition of anti-reflective coatings, lift-off layers, image reversal steps, etc. can add significant levels of complexity to the basic process outline shown below. Additional information on more complex processing schemes is available through your Integrated Micro Materials representative.



1. Substrate Preparation

To prevent complete or partial delamination of the photoresist film during pattern develop, wet etch or plating, substrate surfaces must be properly cleaned and dehydrated prior to coating. Trace residues, including surface moisture, will allow the developer, etchant, or plating solution to penetrate the photoresist/substrate interface and undercut the photoresist pattern.

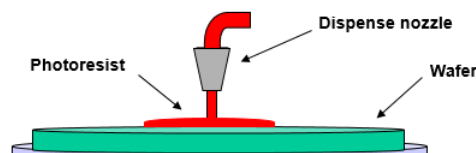
For non-oxide forming substrate surfaces, a robust residue removing wet clean (or plasma ash) followed by a dehydration bake at 140-160C often yields the surface hydrophobicity required to allow adequate photoresist adhesion. Note: some materials, including noble metals such as gold and silver, can be excessively hydrophobic to the point where de-wetting may occur. These substrates may require careful optimization of the photoresist coating program as well as elevated soft bake temperatures (and/or duration) to ensure adequate adhesion.

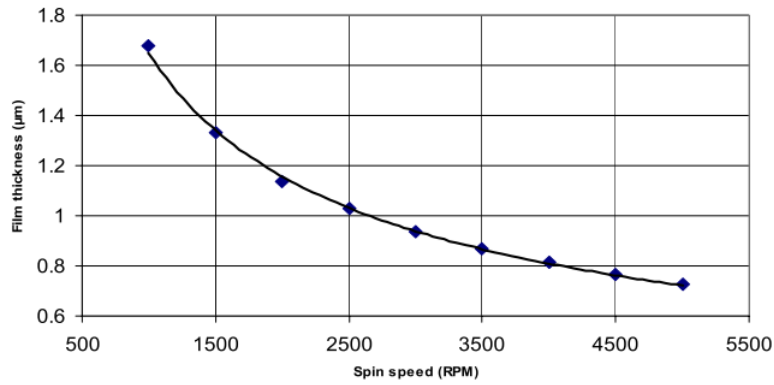
Oxidic surfaces such as SiO₂ and oxide forming Si or Al based substrates will exhibit surface OH bonds and may be too hydrophilic for resist adhesion even after the clean and dehydration bake. These surfaces typically require treatment with a chemical adhesion promoter such as HMDS (hexamethyldisilazane) to remove the surface OH bonds and increase hydrophobicity. For more information on HMDS substrate priming click [here](#).

2. Photoresist Coating

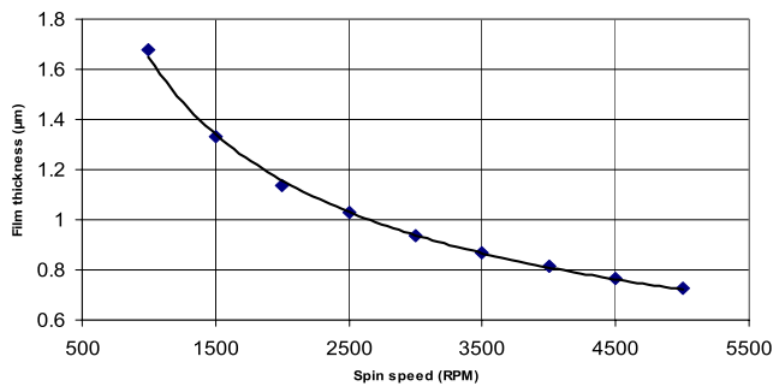
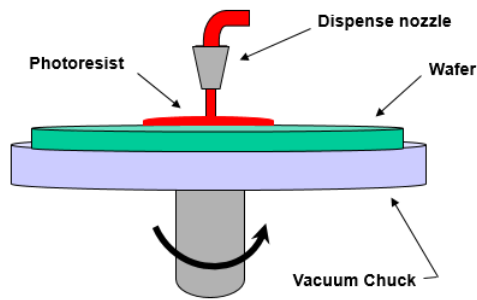
Spin coating is the most common method for applying photoresist to a substrate surface. Other less common methods include spraying, roller coating, dip coating and extrusion coating.

In a typical spin coating process, the photoresist is applied to the center of rotating wafer and the spin speed is then increased rapidly to spread the resist evenly from the center to the edges. This "spread step" is then followed by a fixed rpm spin step which sets the final coat thickness and allows solvent to evaporate, partially stabilizing the film. Higher spin speeds during this step will result in thinner resist films and lower RPM will yield thicker resist films.





Typical Photoresist Thickness vs. Spin Speed Curve



Typical Photoresist Thickness vs. Spin Speed Curve

Very high viscosity resists are often dispensed onto non-spinning or “static” wafers, followed by a ramp in speed. This results in a thicker film and potentially improved thickness uniformity. Spin coatings’ advantages include ease of processing and superior film thickness uniformity (for round substrates at least). One disadvantage of spin coating is partial planarization of substrate topography which results in localized film thickness variation over steps.

For rectangular or odd shaped substrates, alternative coating methods may provide improved nominal thickness uniformity, especially near corners, and a properly optimized spray coating process can provide superior conformal coatings over topography. See cross section SEM images of photoresist sprayed over large topography steps [here](#).

A 2-5mm wide band of very thick photoresist located along the very edge of the wafer will form when round substrates are spin coated. This ring of thick resist can cause bubbling problems during soft bake or "popping" during exposure (DNQ photoactive compounds evolve N_2 upon exposure which can agglomerate to form bubbles that may "pop"). The edge bead may also cause focus offset problems if exposure is performed via contact lithography (photomask in direct contact with the photoresist film). A solvent blend (i.e. AZ[®] EBR 70/30) sprayed along the very edge of a slow spinning wafer (~500-800rpm) is a common method for removing this edge bead. Edge bead removal is typically performed directly after the spin coat and before soft bake.

4. Soft Bake

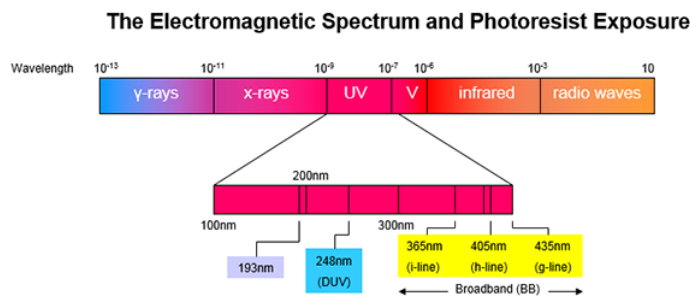
After spin coating, the photoresist is baked to drive off solvents and to solidify the film. Soft bakes are commonly performed on hot plates or in exhausted ovens and typical temperatures range from 90 to 110C. The soft bake process must be optimized to provide complete removal of solvents at the photoresist/substrate interface. The evaporation rate must be carefully controlled however, especially when processing thick photoresists (about 4-5 μ m and above). Solvents evolving too rapidly may cause bubbles which can be observed as round voids in the film post bake. Very thick photoresist films often require multiple bake steps at increasing temperatures in order to achieve an acceptable evaporation rate and prevent bubbling. In contrast, if the rate of evaporation too slow, the film may form a "skin" on the surface which can inhibit further evolution of the solvent.

Because retained solvent at the resist/substrate interface is a major cause of adhesion failure during wet etch or plating, the soft bake process must be carefully optimized to prevent photoresist delamination. Difficult substrates that do not respond well to HMDS treatment (noble metals gold and silver for example) require very precise optimization and control of the soft bake process if adequate adhesion is to be maintained during plating or wet etch. Often these substrates require elevated soft bake temperatures and/or extended soft bake times to allow for more complete removal of interfacial solvents.

In any case, it should be noted the manufacturer's recommended soft bake time and temperature for a particular photoresist should always be the starting point in developing a lithography process and it is important to remember excessively high soft bake temperatures (typically above 115C) can degrade or even destroy the DNQ photoactive compound (PAC) in a novolac/DNQ type photoresist system.

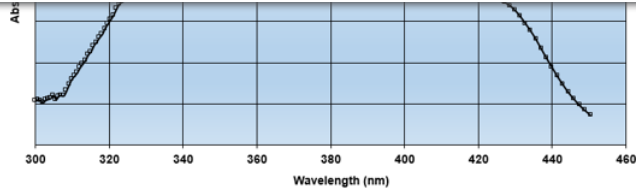
5. Exposure

Exposure wavelengths used in optical lithography are from the UV and near UV portions of the electromagnetic spectrum. Lithographers often refer to monochromatic exposure systems as "i-line", "g-line", DUV etc. as opposed to specifying the actual wavelength emitted. Systems with broad spectrum lamps or "broadband" systems typically emit wavelengths that span roughly the 350nm to 450nm wavelength range (or some subset of this range).



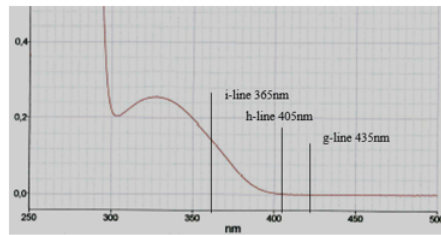
Determining the optimum exposure dose for a given lithography environment is often the most time consuming and frustrating step in developing a stable process. Given the huge array of exposure tool types and the number of environmental and process variables that affect the photo chemical reaction, zeroing in on the optimum exposure for a given printed feature (or set of features) is often a brute force, trial and error exercise. Adhering to a few general guidelines will ease the pain and simplify the process however.

First and foremost is to ensure that the exposure system to be used emits the correct wavelength radiation needed to activate the photoactive compound in the chosen photoresist. Novolac/DNQ systems typically are sensitive to radiation in the 350-450nm range (most DNQ PACs will activate below 350nm, however, the novolac resin becomes highly absorbing below 350nm hence resist performance is severely degraded).



Typical DNQ PAC sensitivity curve

The Photo Acid Generators (PAGs) used in chemically amplified resist systems generally do not exhibit such a wide sensitivity band. A chemically amplified resist designed for i-line exposure (365nm) for example, will typically exhibit zero or near zero sensitivity at h-line or g-line (i.e. above 400nm). Likewise, a DUV chemically amplified resist (designed for 248nm) will require radiation at wavelengths below 300nm.



Typical i-line PAG sensitivity curve

Second, the output intensity of the exposure system at the photoresist's activation wavelength must be understood in order to accurately compute the total dose as a function of exposure time. The output intensity at a given wavelength can be measured and controlled using commercially available meters with wavelength specific probes. However, reasonable estimates of the output intensity can often be determined simply by reviewing the tool's lamp (or laser) specification.

And finally, it is important to fix the develop process when running exposure test matrices. Varying exposure dose and develop time simultaneously will exponentially complicate the process of determining optimum dose. Again, the manufacturer's recommended develop process should be used as a starting point. For DNQ resists coated at less than 2.0µm thick for example, a puddle develop should generally be fixed at 60 seconds for the purpose of running initial exposure tests. Small adjustments to the develop process (to improve CD uniformity, clear residual resist, etc.) may be made after narrowing the dose window.

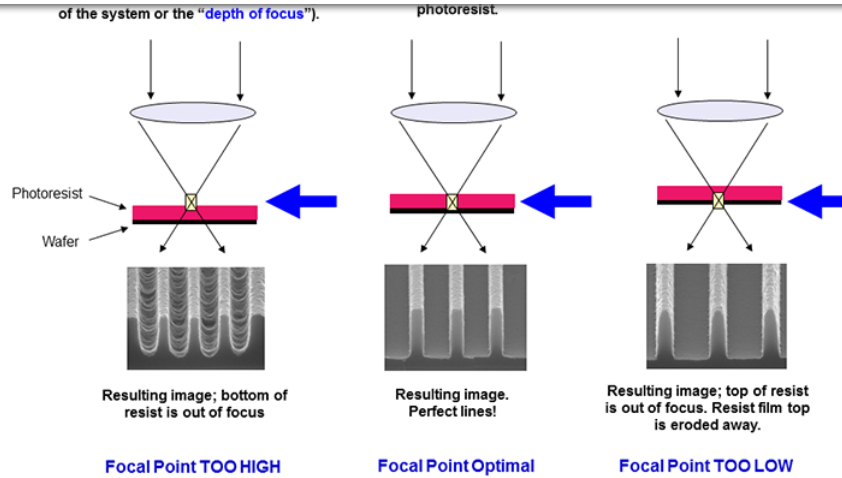
For optical projection type exposure equipment (i.e. projection aligners, steppers etc.) it is important to understand the relationship between the system's effective Numerical Aperture (NA) and the process window available for a given target feature size. High NA systems provide better resolution capability but at the direct expense of focus latitude or "depth of focus".

The NA, resolution capability and focus latitude of a given exposure process are related by the Rayleigh criteria (named for British physicist Lord Rayleigh and often referred to as "Rayleigh's Theorem" by optical lithographers).

$$\text{Resolution} \propto \frac{\lambda}{NA} \quad \text{and} \quad \text{DoF} \propto \frac{\lambda}{NA^2}$$

Since the focus window narrows with the square of the Numerical Aperture, it is important to note low NA systems are desirable when printed features are relatively large and/or the photoresist is very thick. High NA systems resolve much smaller features, however the photoresist film used must be quite thin in order to remain within the reduced focus window. Also note shorter wavelength incident energy provides better resolution but again, depth of focus is reduced.

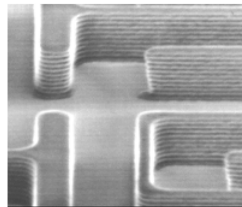
A graphical representation of focus window, focus offset and the resulting impact of varying defocus on the photoresist image is shown below:



As with exposure dose, the optimal focus offset for a given process must usually be determined experimentally. On stepping exposure systems where many exposures occur on each substrate, it is possible to vary the dose and the focus offset simultaneously on a single substrate. This procedure is known as a focus/exposure (or "FE") matrix. FE matrices greatly simplify the process of zeroing in on the optimum dose and focus offset in a new process.

6. Post Exposure Bake

An additional photoresist bake after exposure (or "PEB") can range from optional to critical depending upon the type of photoresist being used and how the photoresist will be processed after imaging. In DNQ type resists, a PEB will help smooth rough feature sidewalls caused by standing waves characteristic of thin film interference in a monochromatic exposure process. This smoothing effect in DNQ's is thought to be a result of short length diffusion of the PAC in response to the added thermal energy. An example of pronounced standing waves in a DNQ photoresist is shown below:



DNQ photoresist imaged with monochromatic radiation and no Post Expose Bake

In chemically amplified resist systems, the PEB typically plays a critical role in the imaging reaction however, and therefore it is not optional. Skipping the PEB for these resist will result in no (or a very faint) pattern after develop.

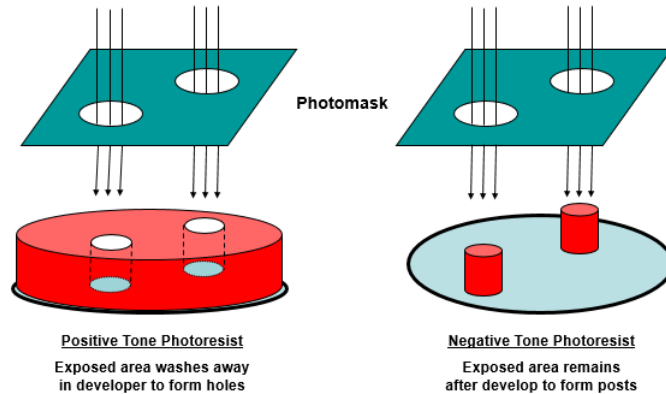
In both types of photoresist, the PEB may improve adhesion and dry etch resistance since more solvent is removed from the bulk film.

7. Developing the Image

The vast majority of photoresists in use today require aqueous base solutions for developing the exposed image. Early developer formulations were water/metal ion based solutions produced from dissociated Potassium or Sodium salts (NaOH, KOH, Potassium Borates, or Sodium Meta-silicates). Because metal ions can alter the electrical characteristics of a transistor gate structure, Metal Ion Free (MIF) developers based on the Tetra Methyl Ammonium Hydroxide (TMAH) compound were introduced.

which the developer solution and the substrate are temperature controlled. In all cases, an aqueous develop process is terminated by rinsing the developer from the substrate surface with water.

The photoresist areas that develop away after exposure (or after exposure and PEB) are determined by the photoresist's "tone". When the areas exposed to light energy develop away, the photoresist is said to be "positive tone" and if the exposed areas form the pattern after develop, the resist is "negative tone". This is shown schematically below:



8. Hard Bake

A post develop bake (or "hard bake") of the photoresist pattern is a common method for stabilizing the printed features to provide optimum performance at etch. This final bake step ensures complete removal of solvent, improving adhesion in wet etch (or plating) processes and resistance to plasma and/or RIE etches. To prevent thermal deformation of the patterns, the hard bake temperature should be equal to or no more than 5 degrees C higher than the PEB temperature. Delays between hard bake and etch (or plating) should be minimized to prevent re-hydration of the substrate and resist. The hard bake step may be repeated just prior to etch if the post bake delay exceeds about 1 hour. In manufacturing environments where it may not be practical for material to flow directly from hard bake to etch, storing the hard baked substrates in a dry box is good practice.

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