Photolithography Basics

OVERVIEW:

Photolithography is one of many methods of defining patterned areas on a substrate in order to protect them from subsequent processing. A light-sensitive polymer film is coated onto the surface of the substrate and is then exposed by light directed through a patterned stencil (photomask). The substrate is then subjected to a development process where the exposed areas either are removed (positive tone) or remain in place while the unexposed areas are removed (negative tone). A copy of the photomask pattern formed by the remaining resist is left on the substrate.

SUBSTRATE:

Clean:

All substrate surfaces must be chemically CLEANED before coating. Failure to adequately clean the surface may result in defects and/or adhesion problems.

Cleaning methods vary widely depending on the history of the substrate. New silicon wafers will need cleaning and may require Standard Cleans 1&2 (aka RCA Cleans) for electronic device fabrication. Less aggressive methods may be adequate for less demanding uses. Materials other than silicon may require unusual cleaning methods. Wafers-in-process will require cleaning protocols designed to address the processing steps previously performed. Specific cleaning methods must be applied to remove the residues of specific processes. Research these methods carefully.

Prime:

Clean wafers should undergo a PRIMING process before applying photoresist. This often involves a separate dehydration step before applying a chemical primer if an appreciable oxide layer is present on the surface. Any water adhered to the surface will cause catastrophic adhesion loss.

The most commonly used priming chemical for silicon substrates is HMDS (Hexamethyldisilazane). HMDS displaces the silanol formed on the surface but cannot act as a dehydrating agent. Heat, vacuum, and solvents may be used for dehydration.

One common priming method is Liquid Priming, which is performed manually in the spin bowl. A solution of HMDS, typically 10%-20% HMDS in PGMEA, is applied to a static wafer. The solution is allowed to remain on the surface for 10 seconds, then spun off to dry the wafer. The PGMEA will displace the majority of any water on the surface

of a bare wafer but will not remove water from a layer of oxide; that will require a dehydration step first. The HMDS then displaces the silanol layer and binds to keep the surface dehydrated.

Many automated methods of priming are used which incorporate substrate heating and vapor phase HMDS application. These typically utilize a hot plate bake and are a part of a resist coating system. For best results, a Vacuum Vapor Prime process is desirable. In this vacuum oven process both the dehydration bake and chemical primer application are performed in-situ automatically. High temperature and vacuum together yield very effective dehydration, after which the chemical is applied in vapor phase for uniform deposition.

It should be noted that surfaces other than silicon may or may not benefit from HMDS priming. Known protocols for preparing different materials should be researched and examined before beginning any new process.

COATING:

Considerations:

Spin COATING of photoresist requires that the resist be dispensed quickly and uniformly, and that the wafer be accelerated immediately to final speed based on the resist viscosity, the wafer size, and the surface topology. Experimental optimization is needed for each situation.

Selections of photoresist type and viscosity are determined in part by the processing to be performed and by the wafer size. Resist should be selected based on the exposure source wavelength, the film thickness needed for processing, the chosen spin speed range, and the process application. Many photoresists are designed to yield better results in specific processes such as electroplating or wet etching, and these properties should also be considered in selection.

Resists are designed for maximum transparency at specific exposure wavelengths to yield vertical sidewalls. Mismatching resist and wavelength may result in poor sidewall slope or unexpected dose requirements. Data sheets provided by the manufacturers indicate intended use and usually include absorbance curve graphs.

These sheets also provide spin speed curves for the various available viscosities of the resists. Note that larger wafers must be spun at reduced speeds. Based on the spin speed range chosen, a viscosity is selected which provides the closest thickness match. Note also that actual measured results will not mirror the results shown in the data sheets; they serve only as a guide for viscosity selection. Final spin parameters must be determined by testing various accelerations and speeds to find the optimum conditions.

The amount of resist to be applied will again depend on the size and surface of the wafer, and finding the optimum dispense volume requires tests using varying amounts. Too little will leave areas of the wafer uncoated, while too much will cause non-uniform film formation. The balance between dispensed amount, acceleration, and final speed must be found empirically.

The best coating results are obtained using an Automated Dynamic Dispense, where the resist is applied to a rotating wafer. The rotation speed during resist application is important and depends yet again on the wafer size and surface. Additionally, the position of the resist dispensing nozzle can be varied during the process to minimize defects; radial arm dispense methods are common in this process. The wafer is then ramped up to the final speed and the spin continued for sufficient time to set thickness.

If automated equipment is not available a Manual Dispense method may be used. This usually dictates a Static dispense method, meaning that the wafer is not moving during resist application. The resist puddle must be well-centered on the wafer in the optimum amount, and then accelerated rapidly to the final speed. As the resist application is done by hand, results depend primarily on the skill of the operator. However, static dispensing often results in uncontrollable Defect levels which must be accepted as the cost of manual processing.

Other important considerations during spin coating are the placement of the dispense nozzle in both height and position relative to the wafer center, the rate of resist dispense, the volume of resist applied, and the exhaust flow through the spin bowl. Bubbles and drips must be avoided, and the dwell time of resist on the surface before spinning must be minimized.

Manual Coating Techniques:

Successful manual spin coating of wafers with photoresist requires experimentation and practice. In addition to the techniques the operator will need to develop, the best parameters for acceleration and speed as well as the optimum amount of resist to apply need to be found by trial and error. Ideally, operators would use a calibrated mechanism to dispense resist, but simple dropper bulbs are more typical. Experience can reduce the number of trials necessary, but some testing will always be required.

The techniques the operator needs to develop will combine their ability to consistently perform the dispense and spin procedure with the information previously mentioned. Repeatability is a key component of successful coating and takes practice. However, there are some important points to remember:

Keep the dispense nozzle close, 0.25" to 0.5" (6mm to 12mm) above the surface. Avoid dropping the resist from greater height (to avoid splattering) or touching the nozzle to the surface of the substrate.

Keep the nozzle centered, and the dispensed resist puddle ***well-centered***. This may require adjusting the nozzle position while dispensing to keep the puddle uniform and centered. Off-center dispensing will result in non-uniform film thickness.

Avoid bubbles throughout the process. Purge any bubbles before beginning the dispense and be careful not to create any, either at the beginning or at the end.

Dispense and spin as quickly as possible. Get the resist onto the surface rapidly and start the spin immediately. Any additional time on the surface can lead to drying defects.

Baking:

BAKE the resist as soon as possible, and carefully monitor the temperature and time of the bake. Repeatability in bake time and temperature is critical for repeatable results in exposed pattern dimensions. As hot plate bake times are typically only 60 seconds, a few seconds of variation become important. Use a chill plate to control the total substrate heating time by ending it predictably. If using a convection oven try to use the same cooling location each time.

Evaluate the results for uniformity, both from center-to-edge and across the surface. Center-to-edge variations usually indicate waiting too long to spin or airflow imbalance in the bowl. Across-surface variations can be caused by improper acceleration or a poorly centered dispense. Many other defect mechanisms are also possible.

Measurement

Monitoring the thickness of the resist can most easily be done using optical measurement. The **Filmetrics F50** in the spinner room allows quick and accurate measurement of most resist/film stacks. If your particular film stack is not available contact Photolith staff.

EXPOSURE:

Dose Characterization:

Every combination of substrate, resist, photomask, and exposure tool is unique. DOSE values may be approximated, but the optimum values must be determined empirically. Note also that any changes in the substrate surface, resist thickness or bake, or mask pattern will change the optimum dose and require additional characterization.

Based on available information, a range of test exposures should be designed for each process layer. Testing must be performed using the same substrate and resist processing as the final product. The range will ideally run from underexposure to overexposure so that the operator can positively identify the center of the range. A second narrowed test range using smaller steps should find the target doses. The operator should identify the highest and lowest doses that meet process criteria so as to have a usable range to account for process variations, and then select the center of those values for processing. Steps in dose testing should be small enough that several usable doses are found.

With projection tools a focus series will also need to be performed, but this can often be incorporated into the first test series by using a Focus-Exposure Matrix. Again, the focus test range should ideally show focus degradation in both positive and negative directions so that the center is clearly identified. Focus tests are best performed using a resolution mask, but dose testing must be performed using the actual mask to be used in the layer being characterized. Note that the developer chemistry and development process used can significantly affect the results. If a Post-Exposure Bake will be used in the process it must be incorporated into the testing. PEB can have a significant effect on the results.

Developing:

As mentioned, the development process has significant impact on the final result. Each resist has a recommended developer and process time. Many products contain the same chemicals in the same concentrations and may be substituted. However, using a different concentration or chemistry than recommended can drastically affect the results. Once a process has been characterized this chemistry should not be altered. Note also that some resists are even sensitive to surfactants and behave differently in developers with or without them.

Consistency is just as important in development as in other parts of the process, so automated tools are recommended. Defect levels scale with rinse time and often are as long as one minute or more. If a manual development process must be performed, it is suggested that the substrate be submersed and left undisturbed for the bulk of the process. Brief agitation before removing for rinsing should be acceptable, but repeatable manual agitation during the process is impossible, so agitation should be avoided. Substrates should be completely submersed in deionized water to end development. Thorough rinsing is required, but performing long rinses and blow drying by hand are difficult, sometimes resulting in breakage. Care must be taken to protect the patterned surface while still rinsing and drying completely. Using a Spin-Rinse Dryer (SRD) is strongly recommended if available.

Production:

After the optimum parameters for spin coat, bake, and development are established, the final devices can be made. If all characterization has been done correctly and all

processes performed consistently, the final results should be as expected. Any variations in final results are nearly always due to insufficient characterization or operator error. Exposure tools and photolithographic chemicals are almost never at fault. However, developer can degrade over time when exposed to atmosphere and should not be allowed to age beyond 20 minutes or so during manual development, even when covered.

In some processing it may be useful to perform a Post-Develop Bake in order to harden the resist for Reactive Ion Etching (RIE) or to increase adhesion to the surface for wet etching. This sometimes includes a DUV Curing step to retain the sidewall profile while hard baking. These steps may affect the final dimensions of the pattern and should be considered during testing. The times and temperatures used should also be compared to information in the manufacturer's data sheets, as well as evaluated for sidewall changes due to possible resist flow.

REMOVAL:

Removing resist from the surface of a processed substrate can be a frustrating task. Some processes, such as wet etching, usually allow for removal in solvents. Typical solvents used are Acetone and N-Methyl-2-pyrrolidone (NMP), often heated. (WARNING: FLAMABLE!) Even mildly aggressive RIE processes can cause additional steps to be needed, such as Oxygen Plasma Ashing. However, there are some processes, such as Ion Implantation, which cause cross-linking in the resist polymers and make removal extremely difficult. There are established protocols for resist removal associated with some process tools, and these protocols should be communicated to the operator during tool training. However, many situations will require unique strategies and careful investigation for successful outcomes.

Once the resist has been removed the surface will likely require additional cleaning, and this process must be designed to address the chemicals and methods used during resist removal. Consideration of whether or not additional processing will be performed on the substrate will also influence the cleaning methods used.

FINAL WORDS:

Successful processing of devices requires optimization of all these steps for each layer, substrate type, and exposure method. Be aware that every combination of pattern, substrate, and process is unique, and it will take time and effort to explore the available parameter space. Devoting the time and effort at the start can save much more time and effort later. The staff is always available to discuss processing and should be consulted with any questions.