TECHNOLOGY

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LITHOGRAPHY: RETICLE MAINTENANCE

Extending Reticle Life Through Better Cleaning Budgets

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INTRODUCTION

Production fabs are constantly balancing the cost of manufacturing against yield. As device sizes shrink, there is an additional factor with which lithography engineers and fab managers must now contend: the relationship between reticle cleaning and printed image quality.

It is well known that reticles require maintenance in order to provide high-quality images necessary for device yield. Historically, reticles made of chrome (Cr) and quartz protected with a pellicle were relatively simple to clean and maintain. Unless there was handling damage, reticles had a long service life. When cleaning was required, traditional chemical cleaning processes, complimented by soft brush scrubbing, were quite effective. Even though the cleaning changed the reticle characteristics, the allowance was large enough to enable a few cleaning cycles prior to reticle "retirement."

Due to reduced feature sizes and changing lithography technology, this allowance is no longer as forgiving. Advanced product designs, tighter process tolerances and yield goals require today's advanced reticles to print a near-perfect image quality onto the wafer. Furthermore, with the increasing cost of reticle purchases, extending the usable life is a key element of every fab manager's objectives.

These trends and requirements are driving the leading edge of production reticle management. Like the industry facing the challenges of new materials, larger wafer sizes and smaller linewidths, lithography faces a similar challenge of smaller linewidths with optical proximity correction (OPC) features, new reticle materials such as MoSi, and new image projection techniques using EPSM and EUV. With all of these changes taking place while managers take aim on the goal of printing a perfect image on each wafer produced, managing the reticles in production is becoming more complex with each technological advancement.

IMAGE DEGRADATION AND RETICLE LIFE

When a reticle is used in production, handling, exposures and particles all contribute to degeneration in the printed image quality. The lithography engineers then have the responsibility of cleaning the mask to bring its image quality back to acceptable production standards. The main difficulty with reticle cleaning is that with each clean cycle, critical reticle characteristics are changed ever so slightly. With the strict reticle specifications, the change, or amount of "budget," determines when a reticle is to be retired. These factors affect the critical balance between printed image quality, reticle cleanliness and reticle lifetime.

When device geometries were relatively large, on the order of 0.25 μm and greater, the reticle budget was quite large. It was safe and desirable to utilize standard chemical and physical techniques to clean the particles and organics. Despite the aggressive nature of these traditional cleanings, the larger geometry reticle specifications were more generous and allowed more particle and organic contamination before a cleaning was required. This large allowance enabled the reticles to be utilized in production for extended exposures between cleanings, resulting in an overall acceptable reticle production life.

Today, with the change to smaller linewidths and the introduction of phase shift masks with MoSi, ARC and other layers, the tighter specification tolerances or "budgets" drive the need to actively manage the cleaning process. Management of cleaning cycles, cleaning technology and the reticles' total available budget adds to the challenges of reticle management.

RETICLE BUDGETS

The basic goal of cleaning a reticle is to remove organics, ionics and particles. Organics, which attenuate the exposure, and particle adders, which affect the image, both decrease the resulting image quality and directly affect the device yield.

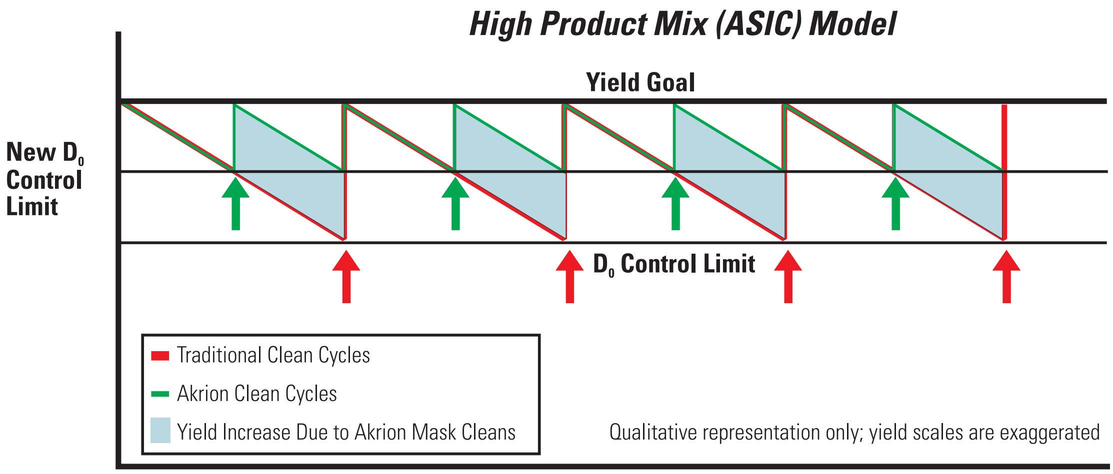
Adding to this complexity is ionic contamination, a consequence of the traditional SPM/SC1 cleaning practice. Under the intense light of exposure, mobile ions tend to migrate and form salt particles. These light-induced particles are a substantial problem in meeting today's technology node and must be considered in the reticle maintenance cycle.

The lithography engineer is faced with a dilemma: clean more often and pay a penalty in reducing the reticle lifetime, or take a yield hit. This is the problem a reticle maintenance strategy can manage. The strategy begins with looking at the expectations of a reticle maintenance program. This starts with definitions of the budgeted reticle parameters.

- **Phase Angle:** The difference in the phase of the waves that light rays have as they pass through the clear and the

FIGURE 1

Cleaning more often enhances yield



Qualitative representation only; yield scales are exaggerated

phase shift regions of a PSM. It is measured with an interferometer (like a LaserTec MPM193) that can detect and report this difference.

- **Transmittance:** The ability of the mask to pass light without attenuation or reflection. It is also measured with an instrument like a LaserTec MPM193. The level of transmittance is determined by comparing the ratio of incident light intensity passed through the reticle (i.e., light out as a percentage of light in).
- **Critical Dimension Control:** The ability to maintain the intended feature size control on the reticle.
- **Particles:** These are measured with an instrument that responds to the particle-induced light scattering as a laser beam passes over the reticle. The KLA-Tencor Starlight is an example of this instrument. Particles are measured by the smallest "pixel" size that the tool is set to detect. On occasion, the metrology picks up particle sizes smaller than the system is programmed to detect due to an optimum scattering profile. This results in erroneous readings, so this aspect should be thoroughly reviewed when evaluating results for specification verification.

The next factor in a reticle maintenance program is to set the goals based on the usage type. High-product-mix manufacturers, such as ASIC houses, tend to handle masks frequently due to constant device code changes. Typically, reticles are retired based on product changes that render the reticle obsolete. Since the mask lifetime is not as critical, image quality takes precedence. Figure 1 depicts the opportunity a high-mix fab has to increase yields by cleaning more often without reducing the overall reticle lifetime.

In high-volume manufacturers, such as DRAM and microprocessor houses where reticle handling is significantly reduced and products have longer manufacturing runs, reticles are primarily retired based on wear. In these cases, reticle lifetime takes precedence and maintaining historical cleaning criteria, lower budget consumption lengthens the reticle lifetime.

Why not clean a reticle on a regular basis? It would be ideal to have a fast-turn system capable of cleaning reticles without changing performance characteristics. Traditional cleaning processes are quite aggressive. These processes have a degrading effect on the key reticle features of transmittance, phase angle and CD control. Successful reticle management is focused on the management of the available reticle budget and the budget cost of cleaning styles.

With traditional cleaning technologies and concentrations, reticle budgets were consumed rather quickly, leading to a very short lifetime. Sulfuric peroxide chemistry is effective at removing organics, but it attacks MoSi. Standard Clean 1 (SC1) removes particles, but affects phase angle by attacking quartz substrates. Frequent cleaning also means that reticle life is extremely limited. Sometimes the reticle budget allows for only two or three cleaning cycles. With reticle sets now exceeding $1 million, the expense of traditional cleaning over the device product life cycle is very high.

FUTURE TRENDS

The International Technology Roadmap for Semiconductors (ITRS) has an aggressive schedule continuing through the 45 nm node that identifies defect reduction technology as one of the top 10 goals to be met. One major IC

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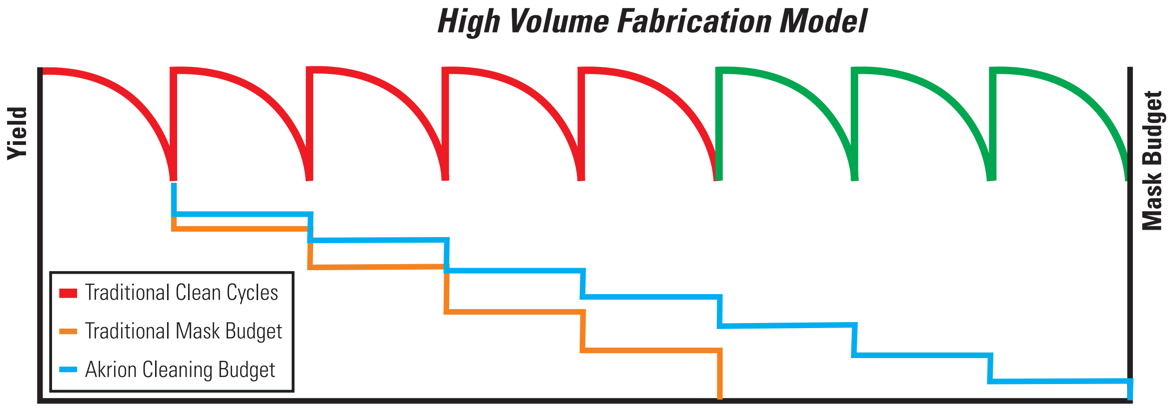
FIGURE 2

Extend mask life to lower budget demand



Qualitative representation only; yield scales are exaggerated

manufacturer announced that the 45 nm node would be in production in 2007, and it also expects to use EUV reticles at the 32 nm node and beyond. With both the ITRS roadmap and actual commercial investments confirming the ongoing geometry reduction and the resulting changes to photolithography requirements, it is necessary to not only develop the new reticle technology but also to develop production cleaning technologies that address both cleaning efficiencies and reticle lifetime.

> **The lithography engineer is faced with a dilemma: clean more often and pay a penalty in reducing the reticle lifetime, or take a yield hit.**

The reticle manufacturing industry is also becoming more aware of the total cost of ownership. Reticle blank suppliers now look not only at the support of the reticle manufacturing process but also at the production maintenance requirements of metrology, cleaning, pellicles and repair. Some reticle shops are introducing new cleaning technologies to improve their manufacturing processes and to offer maintenance cleaning services that reduce the consumed reticle budget and extend usable reticle life.

ORGANIC CONTAMINANT REMOVAL

Reticle maintenance technology is also changing. Contact cleaning with brushes is now unacceptable. It is both inefficient for small geometries, and its contact causes damage to the delicate structures. Traditional spray and immersion chemistries are falling by the wayside. Cleaning requires lower-concentration chemistries, alternative chemistries, tighter temperature control, and non-contact particle removal. In addition, automation is becoming more critical to maintaining extreme control on how the reticle is cleaned. Future technologies will likely include production-worthy 172 nm wavelength cleaning for organic removal, super critical CO_2 for particle removal and drying, and alternative chemistries for the reticle materials currently under development. Also, as particle control requirements tighten up, higher levels of cleaning integration can be expected with systems having integrated pellicle management, inspection systems and stockers. Luckily for the current 90 nm node requirements, existing technology is available which meets the needs for successful cleaning with smaller budget consumption.

As identified earlier, the primary elements of a reticle budget include the transmittance, phase angle, CD and particles. Controlling the budget while removing organics and particles is the measure of success. The traditional method for cleaning organic defects, as earlier described, utilizes a heated sulfuric peroxide mix to oxidize and remove the organics. While this step is fully capable, it also attacks the MoSi and potentially leaves sulfuric residues that ultimately become exposure-induced particles. Options for reducing budget consumption include use of lower temperatures and ultra-dilute chemistries to optimize the cleaning process.

As an alternative to this budget-consuming sulfuric process, recent development work has evaluated ozonated DI water immersion cleaning. Ozonated DI runs at ambient temperatures (avoiding the pitfalls of a high-temperature sulfuric peroxide bath) and is generated *in situ*. That eliminates sulfuric acid and hydrogen peroxide distribution and consumption. Besides saving chemical costs, ozone is benign to the MoSi and other reticle films enabling extended reticle lifetime. This process has found it to be a very effective, low budget-consuming alternative for organic removal. An additional benefit of ozonated water is its inherent safety which also compliments the industry's drive toward environmentally friendly processes.

PARTICLE REMOVAL

For maximum flexibility to address the cleans and the available budget, a reticle manager may choose to utilize a mix of sulfuric peroxide and ozonated DI for a process best suited to the individual needs of the production fab.

Traditional particle removal has been accomplished with Standard Clean 1 (SC1), a mix of NH_4OH and H_2O_2 in DI water. However, in the case of reticle cleaning, SC1 affects the quartz and thus changes phase shift characteristics. Temperature controlled ultra-dilute SC1, coupled with high efficiency megasonic power dispersal, allows a system with laminar fluid flow to effectively eliminate particles from the reticle with low budget costs.

One word of caution: Lithography is always in a dynamic state. Frequent re-evaluation of the processes used is necessary. New materials, new budget constraints and new processes require planners and managers to require maximum flexibility to tune processes to reticle needs. With proper reticle evaluation, knowing acceptable contamination levels allows the reticle manager to select processes that accomplish the cleaning requirements without consuming more budget than necessary.

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SUMMARY

The reticle manager now has enormous cleaning flexibility and a set of guidelines in which to match reticle maintenance programs to image quality objectives. Manufacturers with different production models can now tailor reticle maintenance programs based on their specific needs. High-product-mix producers can clean more often, stay within budget and reap better yields. High-volume producers can keep the same cleaning tolerances and, with less budget expended per clean, significantly extend the reticles' useful production life. Regardless of the manufacturing model, users will benefit either their yields or manufacturing costs with a reticle management program and the newer cleaning technologies.

> **As particle control requirements tighten up, higher levels of cleaning integration can be expected with systems having integrated pellicle management, inspection systems and stockers.**

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