

# PHOTOMASK

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## Ruthenium Capping Layer Preservation for 100X Clean Through pH Driven Effects

**Davide Dattilo**, SUSS MicroTec Photomask Equipment, Ferdinand-von-Steinbeis-Ring 10, 75447 Sternenfels, Germany

**Uwe Dietze**, SUSS MicroTec Inc., 430 Indio Way, Sunnyvale, CA 94085, USA

**Jyh-Wei Hsu**, SUSS MicroTec (Taiwan) Co., 8F-11, No. 81, Shui-Lee Rd., HsinChu, 300, Taiwan

### ABSTRACT

In the absence of pellicle a EUVL reticle is expected to withstand up to 100x cleaning cycles. Surface damage upon wet and dry cleaning methods has been investigated and reported in recent years.<sup>1</sup> Thermal stress, direct photochemical oxidation and underlying Silicon layer oxidation are reported as the most relevant root-causes for metal damage and peeling off.<sup>2,3</sup> An investigation of final clean performance is here reported as a function of operating pH; the results show increased Ruthenium durability in moderately alkaline environment. The electrochemical rationale and the dependency of the reducing strength of the media with the pH will be presented as possible explanations for reduced damage.

### 1. Introduction

EUV technology uses light reflected from the photomask surface rather than light transmitted through the substrate, which changes the photomask nature for the imaging process onto the wafer level from transmissive to reflective. So far, the best EUV reflector design known for lithographic purposes at 13.5 nm is based on the stacking multilayer concept. Schematic representation of the EUV reflector scheme and the TEM image are shown in Figure 1.<sup>4</sup>

Silicon is easily oxidized into silicon dioxide; thus, the EUV reticle required a protective capping layer. This is currently accomplished by a 2-3nm layer of metallic Ruthenium; this is chosen because of its high transmission in the extreme ultra violet wavelength range and quite high resistance toward corrosive conditions.<sup>5,6</sup>

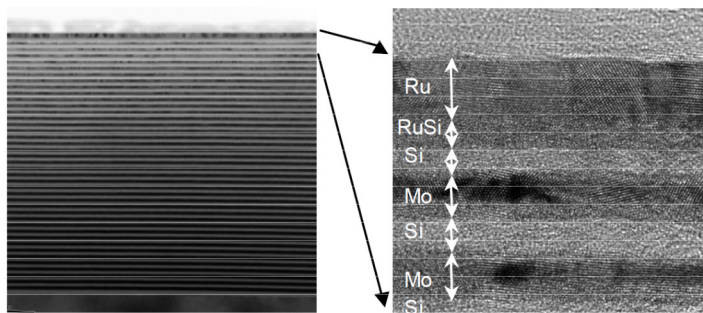


Figure 1. EUV reticle schematic: Molybdenum and Silicon layers alternate to form the reflector. Ideal reflectivity is found at 40 pairs of Mo/Si layers. 2-3 nm layer of Ruthenium is required to protect Silicon from oxidation and damage.

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**SPIE.**

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# EDITORIAL

## Reticle Cleaning: Don't Go Gently...

Zhenxing Han, Ph.D, Micron Technology, Inc.

Defects are considered a dirty word in a mask shop...pun intended. Troubleshooting reticle defects is a perplexing problem, because to be a successful mask shop the defect rate must be very low, and fighting an issue with a very low or intermittent rate of incidence leaves mask engineering teams very few clues to source the root cause. Even at these low incident rates, the pressure is high and continuous to reduce defects because a single defect can "kill" a reticle, or if it gets into the field undetected, result in millions of defective die. Due to this zero tolerance for defects, reticle cleaning has always been a critical part of the reticle manufacturing process.

One reticle cleaning challenge is achieving the right balance between being aggressive enough to remove defects while not being so aggressive as to cause unintended effects on the films such as thickness loss, CD change, film oxidation and dissolving, etc. Driven by the mask industry's demand for less film loss while remaining environmentally friendly, new cleaning methods have come into favor, including irradiation treatment in both dry and wet conditions, use of ozonated solutions, plasma surface treatments, and laser exposure. These methods have had limited success in achieving the zero defect goal.

One technology that appears to have promise for continued improvements is the application of acoustic waves. Over the last several years, the semiconductor industry has had decreasing interest and confidence in using acoustic wave-aided wet chemistries for surface cleaning, because although sonic irradiation in aqueous solutions can be a powerful and effective reticle clean, these cleans are also susceptible to cavitation events which can cause feature damage. Industry efforts have been directed towards suppressing cavitation events during acoustic propagation; however, observation has indicated reductions in cleaning efficiency. Substantial research has been focused on different variables to reduce feature damage while retaining cleaning efficiency. One of the approaches is to use narrow-band transducers to reduce high amplitude harmonics at lower frequencies, but cleaning efficiency is compromised and damage still intermittently occurs.

Ultimately, the higher the acoustic frequency used during cleaning, the higher the cavitation threshold will be. In an ideal case, this provides us with the possibility of applying much higher acoustic power without causing damage. In addition, thinner boundary layer thickness is achieved under higher acoustic frequencies, enhancing particle removal by providing more rolling momentum. As tool suppliers continue to improve the media control to eliminate the uncertainty of cavitation events, more powerful transducers operating at higher frequencies will be needed to supply enough physical force for particulate contamination removal.

We currently accept the necessity of using less aggressive wet chemistries due to the unwanted effects on metal films. This means development and implementation of more advanced acoustic cleaning at higher frequencies will be needed to maintain the cleaning power. Physically removing all possible contaminants from a reticle and applying new cleaning technologies can be a challenge...however don't go gently!

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Managing Editor/Graphics Linda DeLano

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P.O. Box 10, Bellingham, WA 98227-0010 USA

Tel: +1 360 676 3290

Fax: +1 360 647 1445

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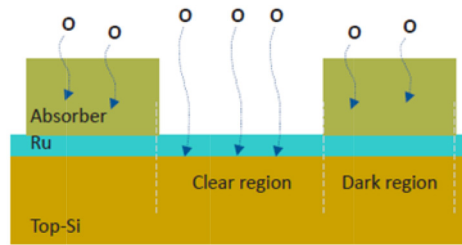


Figure 2. Oxygen inter-diffusion through Ruthenium layer into the under-laying Silicon layer.<sup>3</sup>



Figure 3. Silicon dioxide formation with resulting volume increase and Ruthenium peeling-off.

Presently, no pellicles are available for EUV masks to protect the pattern side from contamination during storage, use or transport. This implies that EUV masks are more exposed to contamination than optical masks and thus it is expected that EUVL masks need to undergo more cleaning cycles during their useful life in order to maintain high device production yields. With increasing cleaning cycles mask defectively remains one of the obstacles to commercial viability.<sup>7,8</sup> Key to overcome this is the development of a mask clean process that is effective for defect removal and preserves the integrity of the mask surface. Damage to the Ru capping surface degrades EUV reflectivity that can lead to critical dimension (CD) shift and non-uniformity.<sup>9</sup> Therefore, it is very crucial to understand the effect of cleaning and exposure processes on EUV mask quality and printing performance.

A full cleaning cycle includes a surface preparation step followed by photo-resist removal, particle and ion removal, and final clean. It has been shown that Ruthenium damage occurs mostly during the final clean step, where the metal layer is directly exposed to cleaning chemistry.<sup>10</sup>

In this paper we report a new chemical approach for final clean, which preserves the Ruthenium durability up to more than 100 cleaning cycles. Possible chemical explanations for metal preservation will be proposed

## 2. Background

Previously, HamaTech demonstrated techniques for organic removal; surface preparation, residual ion removal and final clean without surface damage on the 193i masks.<sup>11,12,13</sup> These new techniques are based on POU UV exposure of the wet cleaning chemistry and the mask surface simultaneously. Recently, the major root-causes for Ruthenium capping layer damage have been extensively reviewed and several mechanisms for metal damage have been proposed; two major root causes for capping layer degradation have been individuated:

1. Direct or in-direct metal oxidation;<sup>10</sup>

2. Silicon dioxide formation underneath the Ruthenium layer, leading to metal peeling off the surface.<sup>3</sup>  
Ruthenium oxidation can occur during exposure of the metal layer to UV-light and oxidizing agents:



Commonly used UV-light source are the two main mercury emissions at 185 and 254nm; oxidizing agents are formed *insitu* through the photolysis of absorbing media such as molecular Oxygen, Ozone or Hydrogen Peroxide.

Recently, an additional mechanism for Ruthenium peeling off has been proposed; Oxygen, in the form of molecule or atom (as radical) can inter-diffuse into the capping layer, as shown in Figure 2.

Under the absorber features Oxygen inter diffusion is quite difficult to occur; however, in clear regions, Oxygen can diffuse through the 2nm thick metal layer and get in contact with the first Silicon layer. This, in turn, leads to oxidation, as this is very favorable thermodynamic process for elemental silicon. Amorphous silicon dioxide has a higher volume than elemental Silicon, thus, the expansion of the underlying Silicon layer leads to Ruthenium peeling off (Figure 3).

Previous reports showed how EUV reticles can undergo capping layer damage after only a few cleaning cycles; Figure 4 shows a published result from 2011, where SEM surface image documents the Ruthenium damage in the form of massive peeling around the absorber features.

The damage becomes even more evident at the interface between absorber and Ruthenium capping layer. This suggested that thermal stress could also contribute to the damage. High-pressure Mercury lamps used during in-situ UV process have residual emission in the infrared spectrum, which could in turn heat the mask materials leading to stress and peeling off.<sup>2</sup>

Furthermore, it has been observed that the damage depends on mask vendor origin. This indicates a strong influence of the

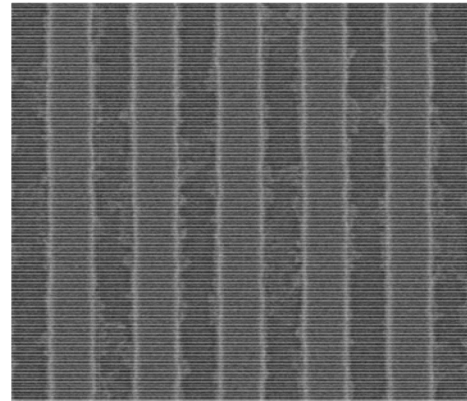
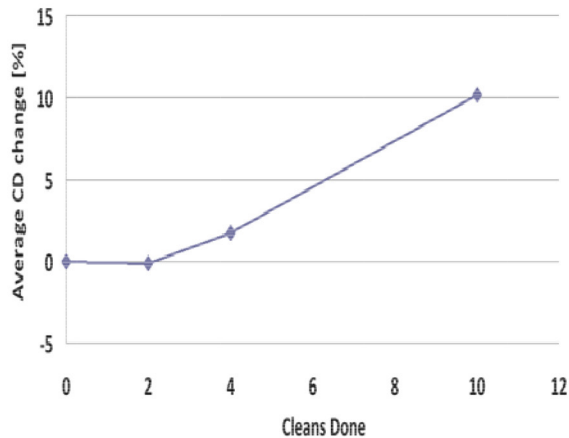


Figure 4. Average relative CD change in printed CD on wafer level after cleaning the mask in total for 10 times; a majority of these changes occurs between 4<sup>th</sup> and 10<sup>th</sup> cleaning process of the EUV mask (left); evidence of Ruthenium peeling at the interface between absorber and capping layer (right).<sup>15</sup>

mask manufacturing process on surface durability. Especially the absorber etch process has been reported to play a major role in the stability of the Ru layer during cleaning.<sup>14</sup>

### 3. Experimental

#### 3.1 Process parameters

All the tests were performed using the SUSS SMT PE MaskTrack-PRO (MTPro) mask-cleaning tool. The process parameters were automatically monitored and controlled with a standard recipe programmed on the MTPro tool. DI water used for the tests was de-gassed before it was supplied to the cleaning chemical distribution system. Chemicals and gases were added into the de-gassed water to prepare the respective cleaning media. The cleaning media tested are: Chemical A ( $4 \leq \text{pH} \leq 6$ ), Chemical B ( $6 \leq \text{pH} \leq 8$ ) and Chemical C ( $10 \leq \text{pH} \leq 12$ ).

#### 3.2 Characterization

To evaluate Ruthenium damage SEM pictures were taken at specific mask locations. TEM was used to assess Ruthenium integrity after 100 cleaning cycles.

### 4. Experiments Performed, Results and Discussion

Repeated final clean cycles, up to 100 times, have been performed by using in-situ UV technology. A water solution at pH comprised between 4 and 6 was used as baseline (Chemical A). The organic removal mechanism has been reported as direct Carbon activation through absorption of light followed by reaction with molecular Oxygen leading to consecutive oxidation steps; the final decomposition products of this photochemical reaction are  $\text{CO}_2$  and water.<sup>2</sup> Ozone formation through media absorption at 185nm, followed by photolysis into Hydroxyl radicals, also contributes to hydrocarbon decomposition. Figure 5 shows SEM image at different surface locations of Chemical A ( $4 \leq \text{pH} \leq 6$ ) treated EUV test reticle after 100 cleaning cycles.

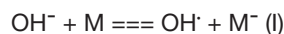
Massive peeling off was observed for Ruthenium at the top and bottom areas of the test EUV mask. Only the central area of the mask resulted in un-damaged capping layer; this observation demonstrates once more that the absorber etching parameters play a major role in the surface integrity upon repetitive cleaning cycles.<sup>15</sup>

#### 4.1 Electrochemical motivation

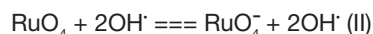
As explained, one major root-cause for Ruthenium damage is direct metal oxidation.<sup>10</sup> The 100 X clean experiment was conducted in water solution of Chemical A, which had a measured pH comprised between 4 and 6. A review of the electrochemical behavior of possible Ruthenium states (metallic ruthenium or ruthenium oxides) is required to individuate the best media environment for reduction or elimination of the damage. Figure 6 shows the Pourbaix diagram for Ruthenium.

Pourbaix diagrams are a schematic representation of the electrochemical potential (i.e., the amount of energy needed to get oxidation) respect to pH. These diagrams are strictly holding in solution phase, but can provide a fair estimation of the oxidation behavior of the possible involved ruthenium oxides (and metallic ruthenium). At higher electrochemical potentials, i.e., in highly oxidizing conditions,  $\text{RuO}_4$  is expected to be formed. This oxide is extremely volatile (boiling point  $40^\circ\text{C}$ ), thus leading to surface etching upon its formation. The Pourbaix diagram shows how at more alkaline pH values the system is in a reducing environment, with more stable lower oxidation state oxides or hydroxides such as  $\text{RuO}_2$  or  $\text{Ru}(\text{OH})_3$ .<sup>16</sup> Based on this scenario we decided to investigate the Ruthenium damage as a function of operating pH. A shift at more alkaline pH was then decided to check if direct metal oxidation has a major role in the damage mechanism.

To further motivate the choice of shifting the pH at more alkaline pH we reviewed the electrochemical behavior of different Ruthenium oxides at alkaline pH values along with electrochemical properties of aqueous alkaline media. Literature reports the ability of Hydroxide ion to be a good one-electron reducing agent:<sup>17</sup>



Equation (I) shows the one electron transfer to a generic metal center, with production of reduced  $\text{M}^-$  and  $\text{OH}^\cdot$ . As confirmation of the reducing power of Hydroxyl ions, the literature reports how  $\text{RuO}_4$  is reduced into more stable  $\text{RuO}_4^-$  and  $\text{RuO}_4^{2-}$  at alkaline pH:<sup>18</sup>



Equation (II) shows Ruthenium tetra oxide reduction by means of two mono-electron reducing events.

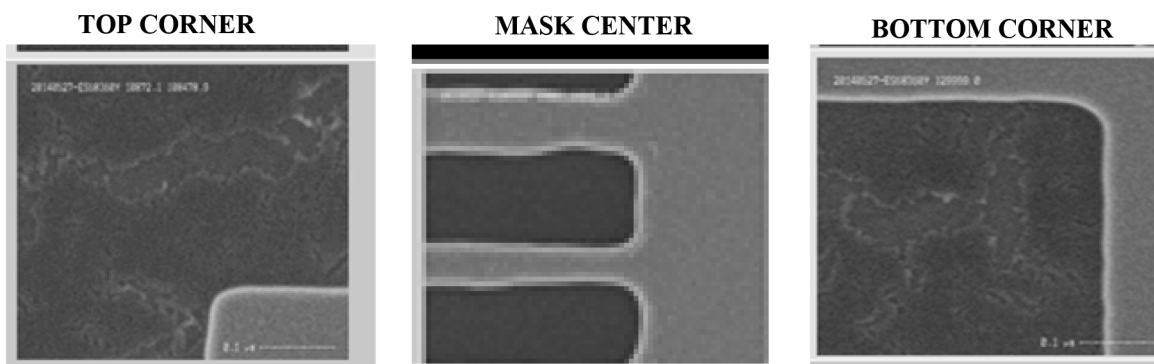
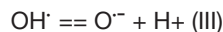
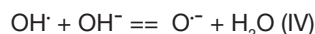


Figure 5. SEM image of Chemical A treated EUV test pattern: Ruthenium capping layer peeling-off was observed in the top and bottom mask corners (left and right images). No damage was observed for the central region of the EUV mask.

With emitting light sources at 185nm Hydroxyl radicals can be formed (by light absorption from water and Oxygen, leading to atomic oxygen which in turn reacts with water to lead to OH<sup>•</sup>); also, equations (I) and (II) show as the reaction byproduct of metal reduction in alkaline media is Hydroxyl radical; however, literature reports that Hydroxyl radical is partially converted into O<sup>•-</sup> radicals in alkaline media:

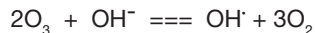


This can be written as a simple reaction between OH<sup>•</sup> and OH<sup>-</sup>:



This conversion is quantitative for pH>12 and partial at pH = 10÷12. O<sup>•-</sup> can be exposed to the same reactions as OH<sup>•</sup>, however its negative charge reduce its electrophilic character, i.e., in the presence of a metal center the one electron oxidation process is less favorable respect to OH<sup>•</sup>.<sup>19</sup> As for organic removal, where the mechanism is mostly by Hydrogen abstraction, their behavior is very similar.<sup>20</sup> This shows how conversion of OH radicals into O<sup>•-</sup> radicals prevents metal oxidation.

In presence of light source emitting below 200nm, Ozone is likely to be formed, due to UV-light absorption from dissolved molecular Oxygen; Ozone will be readily converted into Hydroxyl radicals, however, if the conversion is not quantitative, some undecomposed Ozone could still be in solution. Molecular Ozone is reported to be cause of surface oxidation for EUV mask cleaning.<sup>21</sup> In alkaline conditions, however, Ozone is readily converted to Hydroxyl radicals:<sup>22</sup>



This may further minimize the risk of direct surface oxidation.

Our literature overview of the electrochemical properties leads to the following conclusions:

- 1) Alkaline pH values represent a reducing condition (lower electrochemical potentials for Ru oxides; Figure 6);<sup>17</sup>
- 2) OH<sup>-</sup> as such, can act as reducing agent; RuO<sub>4</sub> that could arise from direct metal oxidation can be efficiently reduced back to RuO<sub>4</sub><sup>2-</sup> (equations I and II);<sup>18</sup>
- 3) Hydroxyl radicals (arising from 185nm exposure or by-product of reduction with OH<sup>-</sup> shown in equations I and II) are partially converted into less oxidizing O<sup>•-</sup> species. O<sup>•-</sup> is less aggressive toward metal centers, and equally efficient toward organic degradation.<sup>19,20</sup>
- 4) Any generated Ozone is readily converted into Hydroxyl

radicals and then into less oxidizing O<sup>•-</sup> ions, thus minimizing risk of surface damage.<sup>21</sup>

The above described four conclusions, in combination with experimental results from Chemical A treatment during final clean, which were conducted at acid pH (between 4 and 6), directed us to decide to run extensive (up to 100 cleaning cycles) at increased pH. We planned to run experiments at two different pH values, such as:

- a) Chemical B, 6 ≤ pH ≤ 8
- b) Dissolved strong base at high dilution, Chemical C, 10 ≤ pH ≤ 12

#### 4.2 Chemical B, pH comprised between 6 and 8. Results.

Given the results collected by using Chemical A as cleaning media, we thought to use Chemical B at pH comprised between 6 and 8 as intermediate experiment to check if a slight increase in pH would have led to any improvement in surface integrity. A test pattern EUV mask was cleaned multiple times in Chemical B and AFM inspection followed every 30 cleaning cycles. Figure 7 shows SEM images collected after 30 and 60 cleaning cycles.

After 30 cleaning cycles in Chemical B no Ruthenium damage was found, whereas at 60 cleaning cycles peeling off of the metal layer was observed. The experiment was not brought up to 100 cleaning cycles because a visible damage was already present after 60 cycles.

#### 4.3 Chemical C; molecular motivation.

In section 4.1 we have provided motivations for choosing alkaline chemistry during final clean of EUV mask. After having performed experiments at pH comprised between 6 and 7 we wanted to bring the pH to more alkaline values, such as between 10 and 12. Higher pH values (>12), although favorable in terms of oxidation chemistry, would have high risk of metal dissolution through the formation of soluble hydroxides. pH driven effects could not be the only ones playing a role in surface preservation. In section 2 we have reported the current root-causes for Ruthenium peeling, and mentioned a direct oxidation and Oxygen inter-diffusion as most relevant root-causes. The alkaline pH could cover the direct oxidation root-cause; however, Oxygen inter-diffusion has little to do with pH. To address this equally relevant root-cause for Ruthenium damage we have made molecular and reactivity considerations on choosing the appropriate base. As a matter of fact, the molecular structure of the used base could play an important role in surface integrity.

Literature reports a strong molecular size dependent effect happening during alkaline silicon and silicon dioxide etching; the

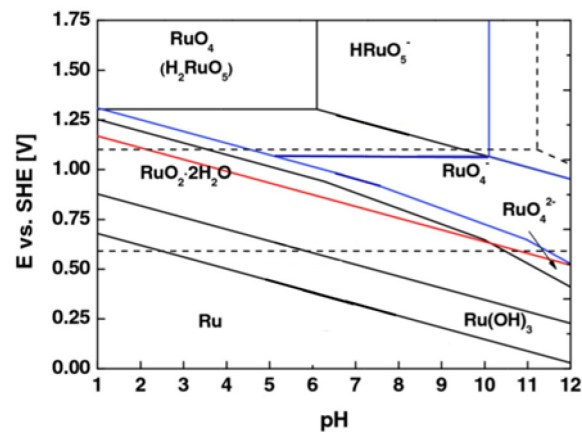


Figure 6. Pourbaix diagram for Ruthenium. Electrochemical potential for ruthenium and ruthenium oxides is decreasing with increasing pH.

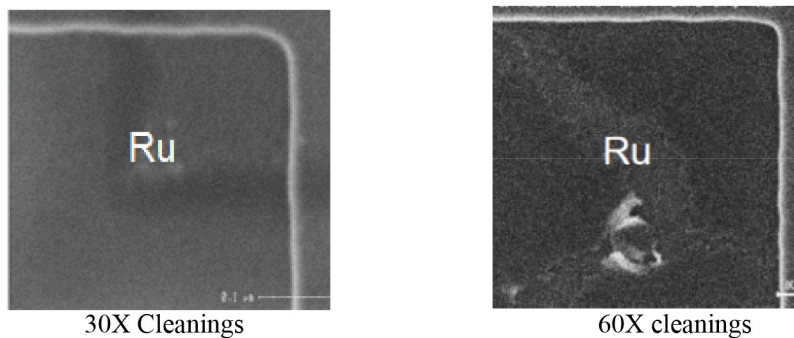


Figure 7. SEM images taken at different mask locations after cleaning of EUV test reticle at pH comprised between 6 and 7 (Chemical B) Left: after 30X cleaning cycles no Ruthenium damage is found. Right image: after 60X cleaning cycles, peeling off of metal layer was observed.

bigger is the positive counter-ion used, the slower is the etch rate into the silicon, because bigger positive ions electrostatically bond on the silicon surface and prevent further diffusion into the bulk silicon (*blocking effect*).<sup>23</sup>

Ammonia is very often used as a base during semiconductor cleaning; however the small size of the  $\text{NH}_4^+$  cation represents a high risk for oxygen inter-diffusion through the Ruthenium capping layer. For this reason, Chemical C was chosen to be:

- A strong base
- A base with molecular structure such that the positive counter ion is much bigger comparing to  $\text{NH}_4^+$  ion.

Both Ammonia and Chemical C bases give in solution Hydroxide ions, thus both bases could be used for pH adjustment.

However, the (positive) counter ion dimensions are quite different, with the  $\text{B}^+$  ion being substantially bigger than  $\text{NH}_4^+$  ion.

For these explained reasons we have chosen to conduct our experiment at pH comprised between 10 and 12 by using as a base such BOH. BOH was also chosen to be a non-coordinating agent. Coordinating agents (i.e., compounds capable to establish a direct bond with metal center through available external electrons) can in fact promote metal dissolution through the formation

of soluble complexes; Ammonia is a good coordinating agent, whereas BOH is not.

To avoid possible interaction with cleaning UV mechanism (i.e., direct absorption of Hydrocarbons at 254nm) we verified that absorption at 254nm of chemical A, Chemical B and chemical C was very low. Negligible absorption at 254nm is measured for the three used media, thus direct absorption of Hydrocarbons at 254nm is not influenced by media absorption. Residual absorption of BOH at 185nm could be expected, however massive photolysis can be excluded due to the very low BOH concentration in solution.

#### 4.4 Chemical C, pH comprised between 10 and 12. Results.

Extremely diluted BOH solutions ( $10 \leq \text{pH} \leq 12$ ) were used to run cleaning cycles and evaluate surface integrity afterward.

Figure 8 shows SEM images of EUV test pattern after 30, 60 and 100 cleaning cycles.

AFM images revealed that after 30, 60, and 100 cleaning cycles Ruthenium peeling off was not observed; only in a single spot, an increase in surface roughness was observed.

To assess Ruthenium integrity, TEM analysis was performed on Ruthenium capping layer; Figure 9 shows TEM results.

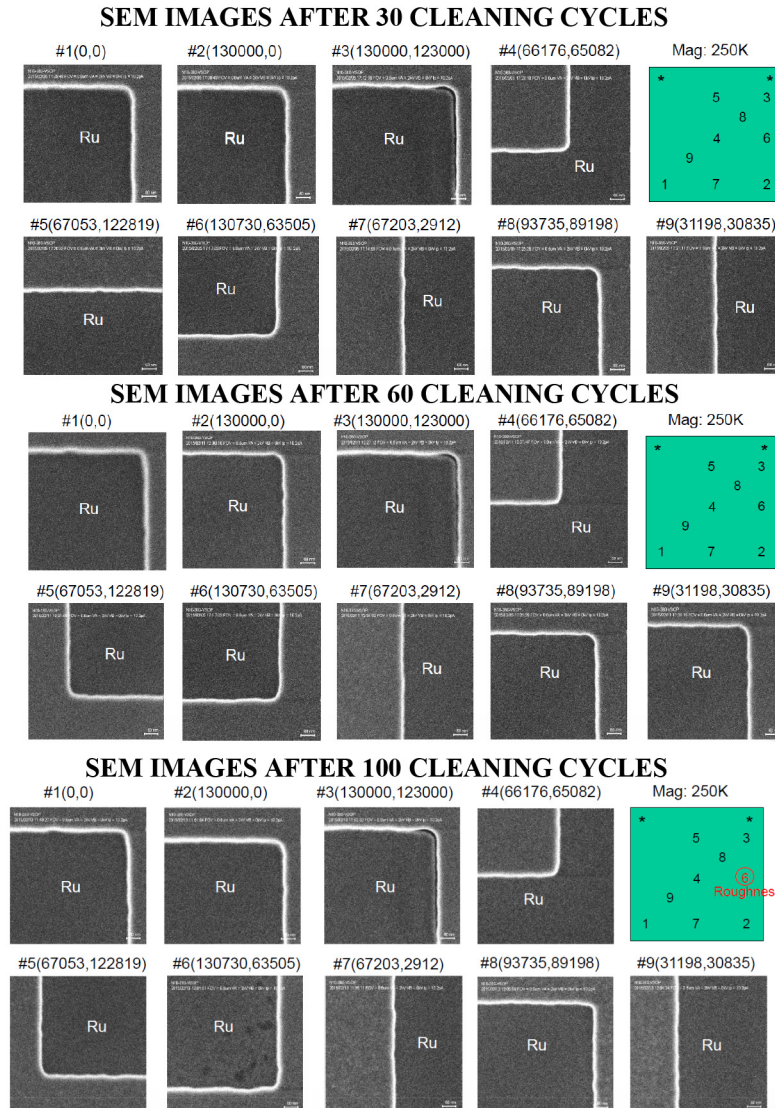


Figure 8. Top image: SEM pictures at different mask locations taken after 30 cleaning cycles in Chemical C; no Ruthenium damage was observed. Middle image: SEM pictures with same chemistry and in the same mask locations taken after 60 cleaning cycles; no Ruthenium damage was observed. Bottom image: SEM pictures with same chemistry and in the same mask locations taken after 100 cleaning cycles; no Ruthenium damage was observed; one single mask location showed increased roughness, without evident surface damage.

The SEM image shows preserved Ruthenium integrity; the metal layer looks uniform and without damage. A monolayer of Si/Mo has been used for this test EUV mask; the Silicon layer appears undamaged and uniform through the whole scanned area. Massive Silicon oxidation can be excluded because no increased volume has been observed.

## 5. Conclusions

EUV masks are more likely to be cleaned due to the lack of pellicle respect to traditional 193nm Mask. Particle deposition and carbon contamination can occur in several points in time of the mask lifetime, like during handling and exposure steps; along with these degrading effects Ruthenium damage is often observed in the

form of volatile  $\text{RuO}_4$  formation. In this paper, the latest proposed root-causes for Ruthenium damage have been recalled; direct metal layer oxidation, and underlying silicon dioxide formation are presented as major root-causes for capping layer peeling. A review of the electrochemical properties of Ruthenium oxides shows how alkaline pH place the metal layer into reducing conditions, thus optimal to decrease risk of direct Ruthenium oxidation. The ability of Hydroxyl ions to act as reducing agent is also recalled; furthermore, hydroxyl radicals convert into less oxidizing  $\text{O}^-$  species in alkaline media. Any dissociated molecular Ozone is also rapidly converted into Hydroxyl radicals. These theoretical considerations were tested by running sequential cleaning experiments at increasing pH (Chemical A,  $4 \leq \text{pH} \leq 6$ ; Chemical B,  $6 \leq \text{pH} \leq 8$ ; Chemical C,  $10 \leq \text{pH} \leq 12$ ). Results show decreasing damage

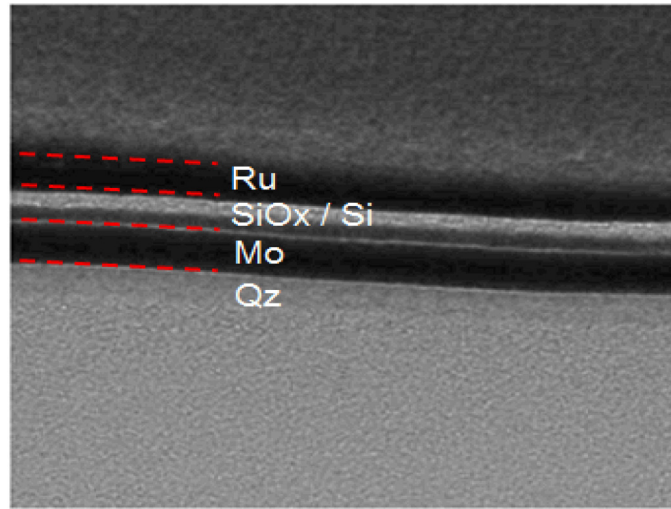


Figure 9. TEM image of Ruthenium capping layer of EUV test pattern reticle exposed to in-situ UV final clean for 100 cleaning cycles with alkaline ( $10 \leq \text{pH} \leq 12$ ) chemistry. The image shows uniform Ruthenium layer without damage; this is on top of a single Si/Mo layer; also the underlying silicon does not increase its volume, ruling out massive Silicon oxidation.

with increasing pH, and Ruthenium capping layer preservation after 100 cleaning cycles when operating at pH comprised between 10 and 12. Molecular effects (such as blocking effect) cannot be ruled out; thus, the choice of base for alkaline conditions may be of crucial importance. For an extensive understanding of surface integrity mechanism, further experiments are conducted by varying the base molecular structure, to separate pH from molecular symmetry driven effects. Weak vs. strong bases, coordinating vs. no coordinating bases as well as small vs. big molecular sized bases are being tested.

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# Industry Briefs

## ■ GPU-Based Computing In Photomask Manufacturing

**Aki Fujimura, Semiconductor Engineering, March 28, 2016**

Graphical-processing unit (GPU)-accelerated computing has reached maturity for professional, scientific computing applications. One example of this is the recent GPU-accelerated thermal application for semiconductor photomask manufacturing, which is used in 24/7 manufacturing environments.

Scientific computing applications, such as those used in semiconductor design and manufacturing, have an ever-increasing requirement for speed and reliability as the data sets upon which they must operate grow ever larger and more complex with each smaller process geometry.

GPU-acceleration is not a matter of replacing CPUs with GPUs. A simple port of an application written for CPU to a GPU-accelerated platform will only realize a 3 to 4X acceleration. To realize the >10X acceleration potential of GPU-accelerated computing, an application must be conceived and its algorithms designed for it.

So, instead of simply swapping out CPUs for GPUs, the task is to pair CPUs with GPUs (at some ratio). Clever engineering can optimize the combined resources for many computational problems, particularly scientific applications.

The biggest difference between CPUs and GPUs is the number of computing “threads” available. In the third generation of the D2S CDP, on each node, there are 12 running CPU threads and 6,000 running GPU threads. This factor of 500 makes a big difference for certain types of computational tasks. For any given computing sub-element, making it run well on GPUs is about finding an approach to the problem that fully utilizes the 500X difference in the number of threads available.

This is why GPU-acceleration really shines in applications where accuracy cannot be compromised, while the speed of execution remains critical. NuFlare’s thermal effect correction (TEC) capability and Advantest’s wafer plane analysis (WPA) capability (another collaboration with D2S) are two examples where GPU-acceleration enables complex simulations that were not previously practical in production use. Mask data processing (MDP) for multi-beam eBeam writers is another place where GPU-acceleration will become critical as the industry adopts multi-beam technology for advanced process nodes.

The semiconductor industry — and particularly the mask-manufacturing sector — is one of the areas where GPU-acceleration will shine brightest.

## ■ SEMI Reports 2015 Global Semiconductor Materials Sales of \$43.4B

**Solid State Technology, April 11, 2016**

The global semiconductor materials market decreased 1.5 percent in 2015 compared to 2014 while worldwide semiconductor revenues decreased 0.2 percent. The impact of exchange rate changes, coupled with lower overall semiconductor unit growth, contributed to the year-over-year revenue decline. According to the SEMI Material Market Data Subscription, Total wafer fabrication materials and packaging materials were \$24.1 billion and \$19.3 billion, respectively. Comparable revenues for these segments in 2014 were \$24.2 billion for wafer fabrication materials and \$19.8 billion for packaging materials. The wafer fabrication materials segment decreased 1 percent year-over-year, while the packaging materials segment decreased 2 percent. However, if bonding wire were excluded from the packaging materials segment, the segment would have remained flat relative to last year. The continuing transition to copper-based bonding wire from gold is negatively impacting overall packaging materials revenues. The depreciation of the Yen further impacted the total materials market due to the importance of materials suppliers based in Japan. For the sixth consecutive year, Taiwan was the largest consumer of semiconductor materials due to its large foundry and advanced packaging base, totaling \$9.4 billion. Korea rose in the rankings to claim the second spot during the same time. Annual revenue growth was the strongest in the Korean and Chinese markets. The materials market in North America and Europe experienced nominal growth of 1 percent, while the materials markets in Taiwan, Rest of World and Japan contracted.

# Join the premier professional organization for mask makers and mask users!

## About the BACUS Group

Founded in 1980 by a group of chrome blank users wanting a single voice to interact with suppliers, BACUS has grown to become the largest and most widely known forum for the exchange of technical information of interest to photomask and reticle makers. BACUS joined SPIE in January of 1991 to expand the exchange of information with mask makers around the world.

The group sponsors an informative monthly meeting and newsletter, BACUS News. The BACUS annual Photomask Technology Symposium covers photomask technology, photomask processes, lithography, materials and resists, phase shift masks, inspection and repair, metrology, and quality and manufacturing management.

### Individual Membership Benefits include:

- Subscription to BACUS News (monthly)
- Eligibility to hold office on BACUS Steering Committee

[www.spie.org/bacushome](http://www.spie.org/bacushome)

### Corporate Membership Benefits include:

- 3-10 Voting Members in the SPIE General Membership, depending on tier level
- Subscription to BACUS News (monthly)
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## Calendar

### 2016



#### SPIE Photomask Technology

12-14 September 2016  
San Jose Convention Center  
San Jose, California, USA  
[www.spie.org/pm](http://www.spie.org/pm)

*Abstract Due Date: 28 March 2016*

### 2017



#### SPIE Advanced Lithography

26 February-2 March 2017  
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San Jose, California, USA  
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P.O. Box 10, Bellingham, WA 98227-0010 USA  
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