Organotin photoresists for extreme ultraviolet lithography

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Chapter 4

Influence of thermal process on the chemical reaction and reaction yield in a model organotin EUV photoresist*

Tin oxo cages ([(RSn)$_{12}$O$_{14}$(OH)$_6$OH)$_2$) are considered as sensitive negative tone photoresists for extreme ultraviolet lithography. In addition to the photochemical process, subsequent processing steps (post exposure baking, developing, rinsing and hard baking) also play important roles in the final performance of the photoresist. Especially, the thermal effect in different bake processes can result in significant chemical changes in the photoresist. Here ultraviolet light (225 nm) was used as the irradiation source. Synchrotron radiation-based hard X-ray photoelectron spectroscopy (HAXPES) was used to monitor the chemical changes of the photoresist. The reaction yields in exposure, post-exposure bake and hard bake steps were calculated and compared. Higher reaction yield generated from the resist can be achieved by adding thermal processes.

4.1 Introduction

In the semiconductor industry, in order to achieve the smallest possible feature sizes, the wavelength of irradiation in photolithography has recently been decreased from 193 nm to 13.5 nm (extreme ultraviolet, EUV). In order to achieve high-resolution structures of the required quality, suitable photoresists are needed. While the traditional organic chemically amplified photoresists (CARs) can be adapted for EUV application, metal containing photoresist such as zirconium and hafnium nanoparticles and clusters, tin oxo cages, and platinum and palladium complexes have attracted attention in recent years because of the potential for stronger absorption of EUV photons and higher etch resistance.

When CARs are used, a post exposure baking step (PEB) is included in the process to allow spreading of the photogenerated acid and catalytic cleavage of dissolution inhibiting groups. In this way, the sensitivity of the photoresists is enhanced, albeit at the expense of resolution. When the organometallic photoresists are used, in some cases a post exposure bake (PEB) step is also added, and the performance of the pattern and the sensitivity of the photoresists can be improved. Although the PEB step has been used in the processing of organometallic photoresists, the reason why it can promote the reaction and improve the performance of the pattern generated from the photoresists thin film was not explained.

Figure 4.1. The chemical structure of the tin oxo cage with hydroxides as counterions (TinOH). The Sn atoms colored black (in the center of the structure) are 5-coordinated, the ones in blue (at the sides, bridged by OH groups) are 6-coordinated.

Tin containing molecular inorganic compounds have a potential advantage as photoresists for EUV lithography due to their high EUV absorption cross section. In this work, we choose a tin oxo cage, [(BuSn)\(_{12}\)O\(_{14}\)(OH)\(_6\)](OH)\(_2\), as a model photoresist, and used hard x-ray photoelectron spectroscopy (HAXPES) to analyse...
the changes in the photoresist thin film after exposing to deep UV light and processing with a post-exposure bake step at 100 °C for 2 min, and a final hard bake (HAB) step at 150 °C for 1 min. We found that the PEB process can promote the chemical conversion in the photoresist thin film, further oxidizing the exposed tin oxo cages. The HAB process (after development of the pattern) can even further improve the reaction yield. As shown in Chapter 6, thermal processes in the lithography procedure can increase the sensitivity in the pattern formation of tin oxo cages photoresist. This sensitivity increase is essentially promoted by the chemical reaction in the tin oxo cages photoresist thin films during baking.

4.2 Materials and methods

The tin oxo cage with hydroxide as counterion ([[(BuSn)$_{12}$O$_{14}$(OH)$_6$](OH)$_2$, TinOH, see Fig.1), was synthesized according to the literature.$^{21,22}$ Solutions in toluene (7.5 mg mL$^{-1}$) were filtered with a 0.2 µm PTFE filter and spin coated$^{23}$ on different substrates (20 nm Au coated glass and quartz) with an acceleration of 700 rpm/s, followed by 35 s at 2500 rpm. A post application bake (PAB; 90 °C, 60 s) was used to remove residual solvent. The thickness of the films was 20 ± 3 nm, as determined by Atomic Force Microscopy (AFM).

Thin films of tin oxo cages on different substrates (20 nm Au coated glass and quartz) were exposed under dry N$_2$ atmosphere to 225 nm ultraviolet light from an Ekspla NT342b laser running at 10 Hz (2.5 mJ/pulse) up to a total dose of 1.3 J cm$^{-2}$. Post exposure bake (PEB, 100 °C, 2 min) and hard bake (HAB, 150 °C, 1 min), were done on a hotplate in air atmosphere.

Hard X-ray photoelectron spectroscopy (HAXPES), was conducted on the HIKE end station at BESSY-II, Helmholtz-Zentrum-Berlin$^{24}$ with a photon energy of 2005 eV, as in our previous work.$^{25}$ All XPS spectra were calibrated using the Au 4f$^7/2$ line with a binding energy of 84.0 eV.$^{25}$ The resolution of the survey spectra is 0.25 eV, and the resolution of the high-resolution spectra is 0.1 eV. The band shapes were fitted with a sum of Voigt functions, i.e. a Gaussian convolved with a Lorentzian function (10%) that accounts for the finite lifetime of the core ionized state.

UV-Vis absorption spectra of the thin films of TinOH on quartz substrates were measured in transmission mode using a Shimadzu UV-2600 spectrometer.
4.3 Result and Discussion

4.3.1 Overview XPS spectra

Overview spectra XPS survey scans of unexposed, 1.3 J cm\(^{-2}\) DUV exposed, and further baked samples (PEB and HAB) are presented in Fig. 4.2. The atomic orbitals from which the electrons originate are marked in the spectra. All the relevant peaks of the elements (Sn M edge around 487 eV (3d\(_{5/2}\)) and 496 eV (3d\(_{3/2}\)), C K edge (1s) around 285 eV and O K-edge (1s) around 531 eV, Au 4f\(_{7/2}\) at 84.0 eV) are observed as expected.\(^{23,26}\) The Au 4f peaks are from the substrate underneath the photoresist thin film, indicating that the detection sensitivity of the measurement, due to the relatively high electron energies, is not limited to the sample surface. All the spectra are presented with the Sn 3d\(_{5/2}\) peaks normalized to the same intensity.

![HAXPES spectra of thin films of TinOH: unexposed sample, sample exposed to 1.3 J cm\(^{-2}\) DUV under dry N\(_2\), sample exposed to 1.3 J cm\(^{-2}\) DUV under dry N\(_2\) and further PEB (100 °C, 2 min) and sample exposed to 1.3 J cm\(^{-2}\) DUV under dry N\(_2\), PEB (100 °C, 2 min in air) and HAB (150 °C, 1 min in air). The spectra are scaled to equal intensities of the Sn 3d peaks.](image)

Figure 4.2. HAXPES spectra of thin films of TinOH: unexposed sample, sample exposed to 1.3 J cm\(^{-2}\) DUV under dry N\(_2\), sample exposed to 1.3 J cm\(^{-2}\) DUV under dry N\(_2\) and further PEB (100 °C, 2 min) and sample exposed to 1.3 J cm\(^{-2}\) DUV under dry N\(_2\), PEB (100 °C, 2 min in air) and HAB (150 °C, 1 min in air). The spectra are scaled to equal intensities of the Sn 3d peaks.

The relative number of atoms of each element in the sample can be derived from the peak area ratios of Sn 3d, O 1s and C 1s. The peak areas were calculated after subtracting the linear background at each peak position in the survey spectra, and the atom ratios (Table 4.1) were calculated using known sensitivity factors.\(^{27}\) We assumed that no Sn atoms are lost during the exposure and further processes. Thus,
the O 1s and C 1s peak areas are normalized to the Sn 3d peak areas which correspond to 12 tin atoms.

**Table 4.1.** Atomic ratio of unexposed TinOH sample, sample exposed to 1.3 J cm$^{-2}$ DUV under dry N$_2$, sample exposed to 1.3 J cm$^{-2}$ DUV under dry N$_2$ and PEB (100$^\circ$C, 2 min in air), and sample exposed to 1.3 J cm$^{-2}$ DUV under dry N$_2$, PEB, and HAB (150$^\circ$C, 1 min in air).

<table>
<thead>
<tr>
<th></th>
<th>Sn</th>
<th>O</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical</td>
<td>12</td>
<td>22</td>
<td>48</td>
</tr>
<tr>
<td>Unexposed</td>
<td>12</td>
<td>22 ± 1</td>
<td>48 ± 1</td>
</tr>
<tr>
<td>1.3 J cm$^{-2}$ (N$_2$)</td>
<td>12</td>
<td>22 ± 1</td>
<td>36 ± 1</td>
</tr>
<tr>
<td>PEB in air</td>
<td>12</td>
<td>29 ± 1</td>
<td>32 ± 1</td>
</tr>
<tr>
<td>HAB in air</td>
<td>12</td>
<td>25 ± 1</td>
<td>18 ± 1</td>
</tr>
</tbody>
</table>

As we can see from the data in Table 4.1, the atomic ratio in the unexposed sample corresponds well with the theoretical composition of the TinOH molecule free of solvents. After exposing the photoresist thin film in dry N$_2$ atmosphere to 1.3 J cm$^{-2}$ of 225 nm light, the carbon content decreased by about 25%. This indicates Sn-C or C-C bond cleavage with generation of carbon-containing volatile species, as we stated in our previous work.$^{23}$ With a further PEB step at 100 $^\circ$C for 2 min in air, another 8% more carbon was lost and about 32% extra oxygen was gained, likely due to oxidation reactions of photoproducts in the thin film. After a further HAB step at 150 $^\circ$C for 1 min, ~63% of the initial carbon atoms were lost, and ~14% of oxygen was lost comparing with the sample after the PEB step. In our previous study, we found the unexposed part to be stable in air at 100 $^\circ$C without mass loss. Upon baking at 150 $^\circ$C water was lost, probably due to deprotonation of the bridging OH groups by the hydroxide counter ions.$^{28}$ A further reason for oxygen loss could be the formation of unstable oxygen containing species that were detached from the thin film, or condensation reactions between cages that lead to elimination of water. In any case, it is clear that the PEB and HAB processes increase the chemical conversion of the photoresists significantly.

### 4.3.2 High-resolution XPS spectra

High-resolution XPS spectra were recorded around the Sn 3d, O 1s and C 1s peak positions of the four different samples. In Fig. 4.3, the high-resolution Sn 3d$_{5/2}$ spectra of unexposed, 1.3 J cm$^{-2}$ exposed and further PEB and HAB treated samples are shown with the respective fits of the band with a sum of two Voigt functions. The Sn 3d$_{5/2}$ peak from the unexposed sample is centered at 487.0 eV. After 1.3 J cm$^{-2}$, 225 nm DUV exposure in N$_2$, the peak shifts to 486.8 eV. With a further PEB
step in air, the Sn 3d\textsubscript{5/2} peak shifts to higher binding energy (487.2 eV). After a final HAB step, the peak maximum is found at 487.1 eV. Two kinds of Sn atoms are present in the tin oxo cage: 5-coordinated (in the central part of the cage) and 6-coordinated (at the sides of the cage), as shown in Fig. 4.1. The differences in the binding energies of these two types of Sn are small, but in order to fit the spectra from the unexposed sample (Fig. 4.3a) we use two Voigt line shapes centered at 486.7 and 487.3 eV, respectively. We previously assigned the peak with higher binding energy to the 6-coordinated Sn, but recent DFT calculations\textsuperscript{29} indicate that the assignment should be reversed. After DUV exposure and the following thermal processes, there are probably more than two kinds of environment of the Sn atoms, but to simplify the analysis, we only use the two types of Sn atoms to model the band of the Sn 3d electrons. We used the same peak position and bandwidths from the spectrum of the unexposed sample to fit the spectra of the exposed and baked samples, leaving only the intensity of the two components as the free parameter. Under these constraints, the spectra of the exposed and PEB, and HAB treated samples are fitted as shown in Fig. 4.3b-d. In Fig. 4.3a, the intensities of the two peaks were constrained to a 1:1 ratio, representing the equal numbers of the two types of Sn in the unexposed cages. After exposure and further thermal processes, the ratios between the two types of Sn atoms were changed. Since the areas of the spectra are proportional to the atomic concentration in the thin film, the ratio change between the low and high binding energy Sn atoms were calculated based on the fitting result and listed in Table 4.2.

**Figure 4.3:** High-resolution Sn 3d\textsubscript{5/2} HAXPES spectra of thin film of TinOH; (a) unexposed sample, (b) sample exposed to 1.3 J cm\textsuperscript{-2} DUV under dry N\textsubscript{2}, (c) sample exposed to DUV and PEB (100 °C, 2 min, in air), and (d) sample exposed to DUV, PEB and HAB (150 °C, 1 min in air).
As shown in Table 4.2, after DUV exposure under N$_2$, the fraction of Sn atoms with lower BE increased. After PEB in air, the higher-binding-energy component dominates. Finally, after a HAB step, the ratio of the two types of Sn is again closer to 1.

**Table 4.2.** Relative contributions of two types of Sn atoms derived from Sn 3d$_{5/2}$ spectra as well as extracted binding energies (BE) of the respective features (see Fig. 4.3).

<table>
<thead>
<tr>
<th></th>
<th>Sn$_{\text{low}}$</th>
<th>Sn$_{\text{high}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE / eV</td>
<td>486.7</td>
<td>487.3</td>
</tr>
<tr>
<td>Theoretical number</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Unexposed</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>1.3 J cm$^{-2}$ (N$_2$)</td>
<td>9.2</td>
<td>2.8</td>
</tr>
<tr>
<td>PEB in air</td>
<td>1.9</td>
<td>10.1</td>
</tr>
<tr>
<td>HAB in air</td>
<td>4.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

![Figure 4.4. High-resolution O 1s HAXPES spectra of thin film of TinOH](image)

*Figure 4.4. High-resolution O 1s HAXPES spectra of thin film of TinOH (a) unexposed sample, (b) sample exposed to 1.3 J cm$^{-2}$ DUV under dry N$_2$, (c) sample exposed to 1.3 J cm$^{-2}$ DUV under dry N$_2$ further PEB (100 °C, 2 min) and (d) sample exposed to 1.3 J cm$^{-2}$ DUV under dry N$_2$, PEB (100 °C, 2 min in air) and HAB (150 °C, 1 min in air).*

The high-resolution O 1s spectra of the four samples are shown in Fig. 4.4. We distinguish three kinds of oxygen atoms in the TinOH cages: 14 O atoms connected to 3 Sn atoms, 6 bridging OH groups, and two O atoms in the hydroxide...
counterions. Applying the same analysis method as for the Sn 3d peaks, three Voigt peaks representing the three kinds of oxygen atoms were fitted into each spectrum. Based on the stoichiometry, the lowest binding energy peak must represent the oxygen atoms shared by the three Sn atoms. The middle peak is assigned to the oxygen atoms at the side part of the cages in the OH groups shared by two Sn atoms, and the highest binding energy peak represents the oxygen atom in the OH\(^-\) counterions.

**Table 4.3.** Binding energies (BE, in eV) and relative numbers of three types of O atoms derived from O 1s spectra (see Fig. 4.4).

<table>
<thead>
<tr>
<th>BE / eV</th>
<th>Sn-O</th>
<th>SnOH</th>
<th>OH(^-)</th>
<th>Total number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical</td>
<td>530.9</td>
<td>532.1</td>
<td>533.1</td>
<td>22</td>
</tr>
<tr>
<td>Unexposed</td>
<td>14</td>
<td>6</td>
<td>2</td>
<td>22</td>
</tr>
<tr>
<td>1.3 J cm(^-2) (N(_2))</td>
<td>14</td>
<td>6.7</td>
<td>1.5</td>
<td>22</td>
</tr>
<tr>
<td>PEB in air</td>
<td>18</td>
<td>9.5</td>
<td>1.0</td>
<td>29</td>
</tr>
<tr>
<td>HAB in air</td>
<td>18</td>
<td>6.6</td>
<td>0.6</td>
<td>25</td>
</tr>
</tbody>
</table>

We use the same restrictions from the spectrum of unexposed sample to fit the exposed sample and PEB/HAB treated samples. After fitting, the ratios of the three peaks in different samples were calculated and listed in Table 4.3. After exposure, the ratio between the three kinds of oxygen atoms changed slightly. There is a small decrease in the intensity at the OH- peak position, which could be because of the detachment of the counterion and generation of water. With a further PEB in air, the ratio of the SnO and SnOH peaks was increased, indicating the oxygen from the air could oxidize the Sn atoms. After the HAB step, the ratio of SnOH and the highest OH\(^-\) peaks were decreased. This could be a result of loss of water due to the deprotonation by the OH\(^-\) groups or condensation reactions.

In Fig. 4.5 we show the high-resolution C1s spectra of the four samples with the fits with up to four components. The main C 1s peaks of the four spectra were almost at the same position. There are only two kinds of carbon atom distinguishable in the unexposed tin oxo cages, the C in the Sn-C and the C-C. The quantum-chemical calculations predict that the 6 C-atoms that are bound to the 6-coordinated Sn-atoms have a lower binding energy than the others.\(^{27}\) After exposure and further processes, a shoulder at \(\sim 286\) eV and a new peak at \(\sim 289\) eV are evident, which are likely carbon atoms in C-O and C=O bonds, respectively.\(^{30}\) The atomic ratios of the four kinds of carbon atoms are listed in Table 4.4. After exposure, the amount of Sn-C
and C-C decreased and the signal of C-O and C=O increased. After a PEB step, both the C-O and C=O shoulders were decreased slightly, indicating that C-O and C=O containing species are not stable under PEB conditions and detached from the thin film. After HAB, all kinds of carbon atoms decreased, indicating that the Sn-C bonds and C-O bonds in the film were not stable under HAB condition, and easily detached from the thin film further diffused into the atmosphere.

Figure 4.5. High-resolution C 1s HAXPES spectra of thin films of TinOH; (a) unexposed sample, (b) sample exposed to 1.3 J cm\(^{-2}\) DUV under dry N\(_2\), (c) sample exposed to 1.3 J cm\(^{-2}\) DUV under dry N\(_2\) further PEB (100°C, 2 min) and (d) sample exposed to 1.3 J cm\(^{-2}\) DUV under dry N\(_2\) further PEB (100°C, 2 min in air) and HAB (150°C, 1 min in air).

Table 4.4. Relative numbers of four types of C atoms derived from C 1s spectra as well as extracted binding energies of the respective features (see Fig. 4.5).

<table>
<thead>
<tr>
<th>Atom type</th>
<th>Sn-C</th>
<th>C-C</th>
<th>CO</th>
<th>C=O</th>
<th>Total number</th>
</tr>
</thead>
<tbody>
<tr>
<td>BE / eV</td>
<td>284.4</td>
<td>285.2</td>
<td>286.4</td>
<td>289.3</td>
<td>0</td>
</tr>
<tr>
<td>Theoretical</td>
<td>6</td>
<td>42</td>
<td>0</td>
<td>0</td>
<td>48</td>
</tr>
<tr>
<td>Unexposed</td>
<td>6</td>
<td>42</td>
<td>&lt;0.1</td>
<td>&lt;0.3</td>
<td>48</td>
</tr>
<tr>
<td>1.3 J cm(^{-2}) (N(_2))</td>
<td>5.1</td>
<td>26</td>
<td>3.3</td>
<td>1.7</td>
<td>36</td>
</tr>
<tr>
<td>PEB in air</td>
<td>5.3</td>
<td>25</td>
<td>0.7</td>
<td>1.5</td>
<td>32</td>
</tr>
<tr>
<td>HAB in air</td>
<td>1.6</td>
<td>16</td>
<td>1.7</td>
<td>0.8</td>
<td>18</td>
</tr>
</tbody>
</table>
4.3.3 UV-Vis spectroscopy

UV-Vis spectroscopy was also used to follow the chemical change in the TinOH thin film as shown in Fig. 4.6. Two samples were prepared with the same thickness on the quartz substrate for UV-Vis measurement. The first sample was exposed to DUV with doses of 60, 120 and 200 mJ cm\(^{-2}\) (Fig. 4.6a). The second sample was exposed to 60 mJ cm\(^{-2}\) DUV, and then treated with the thermal process (PEB, and HAB). The UV-vis spectra were recorded after each process step as shown in Fig. 4.6b.

![Figure 4.6](image)

**Figure 4.6.** (a) UV-vis spectra of TinOH thin film exposed to DUV with 60, 120 and 200 mJ cm\(^{-2}\). (b) UV-vis spectra of 200 mJ cm\(^{-2}\) DUV exposed TinOH thin film, followed by PEB and HAB processes.

As it can be observed in Fig. 4.6a, the absorption peak of the unexposed material is at around 225 nm. In this first sample, with increasing DUV exposure dose, the absorption decreases. Thermal processes were applied after exposure on the second sample. The decrease of the absorption peak after PEB in the second sample is comparable with the decrease when additional 60 mJ cm\(^{-2}\) DUV dose was applied on the first sample. The decrease of the absorption peak after HAB process applied on the second sample is comparable with the decrease when additional 80 mJ cm\(^{-2}\) DUV dose was applied in the first sample. A clear difference between the two sets of spectra appears on the absorption maxima position and the long-wavelength side of the band. As we have shown previously, the appearance of red-shifted absorption is consistent with conversion of Sn-C to Sn-O bonds.\(^{31}\)

4.3.4 Proposed mechanism

After analysing the HAXPES spectra, we can propose possible reaction mechanisms in the tin oxo cages as shown in Fig. 4.7. The chemical reactions that occurred during exposure under N\(_2\) are indicated with blue arrow. According to our previous work, we expect a Sn-C bond cleavage upon DUV exposure.\(^{23, 32}\) Since
there is no other reactive species present during the sample exposure in N₂, the two radicals may recombine again or the butyl radical could escape. It could form a stable molecule by donating or abstracting a hydrogen atom, forming butene or butane, respectively. These products have been independently detected as outgassing products in EUV irradiation (Chapter 7). The carbon chain could also re-attach to the oxygen atoms forming a structure with $\mu_2$-OBU bridging units. This would account for the C-O peaks in the C1s spectrum (Fig. 4.5b). Such bridging OR groups are known as a structural motif, e.g. resulting from methanolysis of TinOH,\textsuperscript{27} or as a building block of the recently discovered Na\textsuperscript{+} containing tin oxo cage.\textsuperscript{33,34} Moreover, in recent solution-phase DUV photolysis experiments, butanol was detected as a reaction product, in addition to butene and butyraldehyde.\textsuperscript{35} The latter could account for the C=O species detected by XPS.

When a butyl radical donates a hydrogen atom, a tin hydride can be formed. While trialkyl tin hydrides are well known, and fairly stable molecules, the type of hydride formed here may well be oxidation sensitive and give rise to products containing Sn-O bonds upon contact with air. Another oxidation sensitive product would arise from the direct elimination of butanol (Fig. 4.7).

**Figure 4.7.** Proposed photochemical reactions for TinOH exposed to DUV in N₂ and further PEB and HAB. For the purpose of illustration, reactions are depicted at the 6-coordinated tin sites in the “cap” on one side of the cage. The O-atoms drawn with only single bonds to the Sn atoms are part of the central “belt” of the cage.
The initially formed butyl radical can form butane by abstracting a hydrogen from the same molecule from which it originated, or from a neighboring molecule. One possibility is that a hydrogen atom is picked up from a bridging OH-group. Abstraction of hydrogen atoms from a butyl group could lead to radicals that can survive under nitrogen but react with oxygen as soon as the sample is exposed to air, if only briefly.

While we have no other direct evidence for the proposed intermediates, they do agree with the observed changes in the XPS spectra after photolysis. The loss of unsaturated or oxygen containing molecules leads to a net reduction of the tin cage, which explains the shift of the Sn 3d binding energy to slightly lower values.

During the PEB step in air at 100 °C, the active species left over from the exposure get the chance to react with oxygen or H₂O. The Sn atoms site were further oxidized as shown in Fig. 4.3c. The oxygen ratio increased significantly, as shown in Table 4.1. Further reactions occur in the HAB step at 150 °C. More carbon is lost, but also the oxygen content becomes smaller, indicating the loss of organic compounds containing oxygen and/or water resulting from condensation reactions. The intact tin oxo cage film, in contrast, is stable at this temperature (Chapter 6), apart from some loss of solvent and water. The chemical reactions during baking are indicated with red arrows in Fig. 4.7.

4.4 Conclusions

The thermal effects from PEB and HAB on the photoresist thin film after DUV exposure were investigated by means of HAXPES and UV-vis absorption measurements. Based on the analysis of the HAXPES spectra, chemical reactions in the tin oxo cages were proposed. Both the PEB and HAB can promote further chemical reaction after DUV exposure in the tin oxo cages. The PEB process leads to oxidation of intermediates produced in the exposed tin oxo cages, enhancing the chemical differences between the unexposed and exposed parts and further increasing the solubility differences in the development process. The HAB further reduces the amount of organic components in the pattern, and makes the pattern more robust.

4.5 References

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29. A. M. Brouwer, unpublished results.


