Self-assembled monolayers: surface engineering and characterization

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Self-assembled monolayers
monomolecular organic film

Self-assembly
spontaneous chemisorption of active surfactant on a solid from gas/liquid phase

Terminal functional group
exposed SAM-gas/liquid interface
methyl, phenyl, amine, carboxylic acid, alcohol, …

Hydrocarbon segments
lateral interactions and tilt to minimise free volume
generally alkyl chains with VdWs interactions

Head group
bonding to specific substrate sites
thiol/metals, silane/SiO$_2$, acid/metal oxide

Organic surfaces ‘made-to-order’

Composition controls structure and chemistry
Manipulate atomic scale properties
Engineer surfaces and interfaces

‘pseudo-(100)’ octanethiolate on Cu(111)$^1$

Application of SAMs in Nanoelectronics: surface engineering

- ALD of WCₓNᵧ/various-SAMs
  - Atomic layer deposition
  - SAM compatibility with ALD
  - Effect of SAM termination
  - Influence of alkyl chain length

- SAMs as Cu diffusion barrier
  - Previous work
  - Adhesion & Cu silicide formation

- Characterization of Cu/CO₂H-SAM
  - LEIS: SAM outer most surface
  - XPS: SAM-metal bonding

- Conclusions
Atomic Layer Deposition (ALD) for interconnect metallization in IC technology

Shrinking dimensions $\rightarrow$ Al/SiO$_2$ $\rightarrow$ Cu/low-$k$ $\rightarrow$ conformal Cu diffusion barrier $\rightarrow$ ALD

- ALD depends on surface chemistry$^1$ - combination of precursors and their sequence and the type and density of reactive substrate surface sites
- For interconnect metallization - ALD of WC$_x$N$_y$ as Cu diffusion barrier form on low-$k$ substrates$^2$

$$WF_6 + NH_3 + B(C_2H_5)_3 + \text{surface groups} \rightarrow WC_xN_y$$

- Selective (enhance/inhibit) WC$_x$N$_y$ ALD - identify favourable/unfavourable surface groups using monofunctionalised surfaces

Use self-assembled monolayers as model substrates for studying ALD processes

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Experimental

SAM precursor \( X(CH_2)_nY \)
- terminal group \( X = CH_3, Br, CN \)
- \( CH_2 \) chain length \( n = 7-17 \)
- head group \( Y = SiCl_3 \)

- alkyltrichlorosilanes \( CH_3-C_n-SAM \)
  - CH(\( CH_2)_nSiCl_3 \)
  - \( n=7,9,10,11,15,17,21 \)

- bromoundecyltrichlorosilane Br-C(\( CH_2)_{11})-SAM \)
  - Br(\( CH_2)_{11}SiCl_3 \)

- cyanoundecyltrichlorosilane CN-C(\( CH_2)_{11})-SAM \)
  - CN(\( CH_2)_{11}SiCl_3 \)

**ALD WC\(_x\)N\(_y\):**

ALCVD\(^T^M\) Pulsar\(^R\) 2000 reactor integrated with an automated wafer handling platform (ASM Polygon\(^T^M\) 8200). A precursor (mixed with a nitrogen carrier gas flow) pulse sequence of \((C_2H_5)_3B, WF_6, \) and \( NH_3 \) represents one deposition cycle. Excess precursor gas was removed by flowing nitrogen after each precursor pulse. The deposition temperature was 300\(^\circ\)C.

**Analysis:**

- \( H_2O \) contact angle, XPS, TDS, \( R_s \), XRF, ellipsometry, AFM, SEM, EF-TEM, TOF-SIMS, XRR, AES
Experimental

SiO₂/Si(100) immersed in 10⁻³ M in toluene 1 hr.
Rinsed with toluene, acetone, ethanol.
Dried under nitrogen flow.

**ALD WCₓNᵧ:**

ALCVD™ Pulsar® 2000 reactor integrated with an automated wafer handling platform (ASM Polygon™ 8200). A precursor (mixed with a nitrogen carrier gas flow) pulse sequence of (C₂H₅)₃B, WF₆, and NH₃ represents one deposition cycle. Excess precursor gas was removed by flowing nitrogen after each precursor pulse. The deposition temperature was 300°C.

**Analysis:**

H₂O contact angle, XPS, TDS, Rₛ, XRF, ellipsometry, AFM, SEM, EF-TEM, TOF-SIMS, XRR, AES
SAM compatibility with ALD: Me-C$_n$-SAM thermal stability

TDS masses 11-100

<table>
<thead>
<tr>
<th>Mass Range</th>
<th>n=7</th>
<th>9</th>
<th>11</th>
<th>15</th>
<th>17</th>
</tr>
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<tbody>
<tr>
<td>26-29</td>
<td>Yes</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>39-43</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>47</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>53-58</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>66-71</td>
<td>Y</td>
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<td>Y</td>
<td>Y</td>
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</tr>
<tr>
<td>79-85</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td>96-98</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

All CH$_3$-C$_n$-SAMs (n = 7-17) show:
- No water desorption
- Leading edge ~ 500°C
- Maximum 600°C

Decomposition 470-690°C

For fixed n, substitution of CH$_3$ with Br or CN reduces thermal stability

Previous EELS study in vacuum of decomposition mechanism for n=3,7,17
- Stable to 470°C
  - C-C bond cleavage $\rightarrow$ HC desorption
- Creates surface CH$_3$-Si groups to 620°C
- Siloxane head groups to 830°C

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SAM compatibility with ALD: WC\textsubscript{x}N\textsubscript{y}/Br-C\textsubscript{11}-SAM

Contact angle, XPS, TDS

### Water contact angle for as-prepared Br-C\textsubscript{11}-SAM

- Literature: 86.2 ± 1.2°
- Experimental: 86.6 ± 1.5°

### XPS composition analysis of Br-C\textsubscript{11}-SAM before and after WC\textsubscript{x}N\textsubscript{y} ALD

<table>
<thead>
<tr>
<th>ALD cycles</th>
<th>O %</th>
<th>C %</th>
<th>Si\textsubscript{ox} %</th>
<th>Si\textsubscript{substrate} %</th>
<th>Br %</th>
<th>W %</th>
<th>N %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>26.77</td>
<td>40.35</td>
<td>11.9</td>
<td>18.8</td>
<td>2.0</td>
<td>0.46</td>
<td>0.79</td>
</tr>
<tr>
<td>50</td>
<td>33.15</td>
<td>42.2</td>
<td>9.8</td>
<td>13.5</td>
<td>0.46</td>
<td>6.23</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>41.95</td>
<td>44.08</td>
<td>3.5</td>
<td>4.2</td>
<td>6.23</td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>41.75</td>
<td>41.29</td>
<td>11.13</td>
<td>5.80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>43.17</td>
<td>36.15</td>
<td>13.21</td>
<td>7.37</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### All SAMs show:
- Well-ordered surfaces with expected termination
- No chlorine present
- Desorption maximum 550-600°C
- Survive multiple ALD cycles

### Suitable model substrates for studying ALD of WC\textsubscript{x}N\textsubscript{y}
Effect of SAM termination on WC$_x$N$_y$ growth: W content

- Initial non-linear growth on all SAMs
- Linear growth regime from 100-200 cycles for C$_{10}$ & C$_{11}$ SAMs
- Growth on CN-terminated SAM favoured

Initial non-linear growth

Transient regime

WC$_x$N$_y$/substrate

Linear regime

WC$_x$N$_y$/WC$_x$N$_y$

1 CPS = 2.70E+15 atoms
1.11E+15 atoms = 1 MLE

Off-set from linearity

Effect of terminal group but also influence of alkyl chain length?
Influence of SAM alkyl chain length on $\text{WC}_x\text{N}_y$ growth: selectivity

- Selectivity for $\text{WC}_x\text{N}_y$ growth varies with $n$
- Offset from linearity increases with increasing chain length
- $\text{C}_{17}$ most crystalline with few defects available for metal nucleation – retarding film growth
- $\text{C}_7$ least ordered SAM with higher population of defects available for metal nucleation

But defects unlikely to be linear over $n = 7$ to $17$
Influence of SAM alkyl chain length on \( \text{WC}_{x}\text{N}_{y} \) growth: mechanism AFM

- **As-prepared**: \( \text{CH}_3\text{-C}_{15}\text{-SAM} \)
  - 100 X 100 nm²

- **After cycles of ALD \( \text{WC}_{x}\text{N}_{y} \)**
  - + 100
  - + 200
  - + 500

- **RMS (nm)**

- **Graph**
  - CH3-C7-SAM
  - CH3-C11-SAM
  - CH3-C15-SAM

- **Islanding growth mechanism**
- **Constant island density**
- **Lateral and vertical growth before coalescence**

**Same for all \( \text{CH}_3\text{-C}_n\text{-SAM} \) with chain length dependent offset**
Influence of SAM alkyl chain length vs. terminal group on $WC_xN_y$ growth: selectivity

Selectivity for $WC_xN_y$ growth varies with $n$ BUT influence of $n$ not exclusive

CN-C$_{11}$-SAM vs.

CH$_3$-C$_{11}$-SAM

CN-C$_{11}$-SAM similar to CH$_3$-C$_7$-SAM shows terminal group enhancement of growth

Both terminal group and alkyl chain length determine $WC_xN_y$ growth behaviour

![Graph showing W (atom nm$^{-2}$) vs. No. $WC_xN_y$ ALD cycles for CH$_3$-C$_{11}$-SAM, CH$_3$-C$_7$-SAM, and CN-C$_{11}$-SAM]
Silane SAMs investigated as model substrates for WC$_x$N$_y$ ALD for:

- SiCl$_3$ head group, chain lengths ($n = 7-17$) and terminal groups (CH$_3$, CN, Br)

- SAMs stable to $>470^\circ$C and present after multiple 300$^\circ$C ALD cycles

- SAM termination effects WC$_x$N$_y$ growth:
  - CN-termination favoured
  - CN-, Br- & CH$_3$-terminated C$_{10}$ & C$_{11}$-SAM vs. CH$_3$-C$_{17}$ SAM

- Selectivity for WC$_x$N$_y$ growth varies with $n$ due to thickness rather than structural defects within the SAMs

**Both terminal group and alkyl chain length determine WC$_x$N$_y$ growth behaviour**

- SAMs provide suitable model substrates for studying metal deposition

  **Vary substrate structure (alkyl chain) & chemistry (terminal group) to selectively control growth**
Application of SAMs in Nanoelectronics: surface engineering

- ALD of WC$_x$N$_y$/various-SAMs
  - Atomic layer deposition
  - SAM compatibility with ALD
  - Effect of SAM termination
  - Influence of alkyl chain length

- SAMs as Cu diffusion barrier
  - Previous work
  - Adhesion & Cu silicide formation

- Characterization of Cu/CO$_2$H-SAM
  - LEIS: SAM outer most surface
  - XPS: SAM-metal bonding

- Conclusions
Previous work SAMs as Cu diffusion barrier


Cu diffusion barrier properties chain length & terminal group dependent

Most promising candidate, SAM-SH, enhances Cu-SiO₂ adhesion & acts as Cu diffusion barrier

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Chemical formula</th>
<th>IUPAC Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAM1</td>
<td>CH₂(CH₂-Si-(OCH₃)₃</td>
<td>3-[2-(trimethoxysilyl) ethyl] pyridine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chain and bulky head group with reactive heteroatom</td>
</tr>
<tr>
<td>SAM2</td>
<td>CH₂(CH₂-Si-(OCH₃)₂</td>
<td>2-(trimethoxysilyl) ethyl benzene</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chain and bulky head group</td>
</tr>
<tr>
<td>SAM3</td>
<td>CH₃-CH₂-CH₂-Si-(OCH₃)</td>
<td>n-propyl trimethoxysilane</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Chain, no bulky head group</td>
</tr>
<tr>
<td>SAM4</td>
<td>Si-(OCH₃)₂</td>
<td>phenyl trimethoxysilane</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No chain, bulky head group</td>
</tr>
</tbody>
</table>

Graphical representation of Cu diffusion barrier properties showing time to failure for different SAMs.
Concept: selective process for DD integration


SAM-S\text{\textsubscript{sacrificial}}: \text{CH}_3(\text{CH}_2)_9\text{SH}

SAM-B\text{\textsubscript{barrier}}: \text{HS}(\text{CH}_2)_3\text{Si(OCH}_3)_3

Pre SAM DD Structure

Uniform SAM Deposition

Selective SAM Deposition

1. Poor Adhesion: Cu seed to SAM
   Questionable electrical conductivity
   Good SAM-diel adhesion

2. No flux divergence
   Good Cu-Cu adhesion
   Good SAM-diel adhesion
   Good SAM-Cu adhesion
Concept: selective process for DD integration


SAM-S\textsubscript{sacrificial}: CH\textsubscript{3}(CH\textsubscript{2})\textsubscript{9}SH

SAM-B\textsubscript{barrier}: HS(CH\textsubscript{2})\textsubscript{3}Si(OCH\textsubscript{3})\textsubscript{3}

SAM-S

SAM-B

SAM-S, CH\textsubscript{3}HS-Cu

SAM-B, Si(OCH\textsubscript{3})\textsubscript{3}-SiO\textsubscript{2}
Assessment of SAMs with systematic variation of molecular structure

Longer chain length \((\text{CH}_2)_n\) for improved film order & Cu blocking efficiency

New head group \(-\text{SiCl}_3\) for improved adhesion, coverage-packing density & thermal stability

\[\text{SH}(\text{CH}_2)_n>6\text{SiCl}_3\] not commercially available

Same terminal & head groups but different chain lengths

\[\text{CH}_3(\text{CH}_2)_n\text{SiCl}_3\] where \(n = 7,9,10,11,15,17,21\)

Same terminal & chain length but different head group

\[\text{CH}_3(\text{CH}_2)_{17}\text{Si}X_3\] where \(X = \text{Cl}_3, \text{Cl}_2(\text{OCH}_3), (\text{OCH}_3)_3\)

Same head group & chain length but different terminal group

\[\text{CH}_3(\text{CH}_2)_{11}\text{SiCl}_3\] vs. \(\text{CN}(\text{CH}_2)_{11}\text{SiCl}_3\) vs. \(\text{Br}(\text{CH}_2)_{11}\text{SiCl}_3\)

\[\text{SH}(\text{CH}_2)_3\text{Si}(\text{OCH}_3)_3\] vs. \(\text{NH}_2(\text{CH}_2)_3\text{Si}(\text{OCH}_3)_3\) vs. \(\text{C}_5\text{H}_4\text{N}(\text{CH}_2)_2\text{Si}(\text{OCH}_3)_3\)
SiO$_2$/CN-SAM/Cu
N 1s peaks $\rightarrow$ Cu and the SiO$_2$ side
Strong head group-SiO$_2$ & CN-Cu bonding

SiO$_2$/Br-SAM/Cu
Br 3d peaks $\rightarrow$ Cu side
Weak head group-SiO$_2$ & strong Br-Cu bonding

SiO$_2$/SH-SAM/Cu
S 2p peaks $\rightarrow$ Cu side
Weak head group-SiO$_2$ & strong S-Cu bonding

Cu-SH = Br > CN
SH-SAM failure at oxide in agreement with literature
A crude look at Cu/SAM/SiO$_2$ barrier properties: visual inspection

Annealing Temp. (°C)

- HS(CH$_2$)$_3$Si(OCH$_3$)$_3$
- H$_2$N(CH$_2$)$_3$Si(OCH$_3$)$_3$
- HNC$_5$H$_4$CH$_2$Si(OCH$_3$)$_3$

Pyridine
NH$_2$
SH
blank
A crude look at $\text{Cu/SAM-B/SiO}_2$ barrier properties: $R_s$ vs. temperature

![Graph showing the sheet resistance of different samples versus temperature.]

- **Cu/SiO$_2$**: Shows a decrease in sheet resistance with increasing temperature.
- **Cu/SAM-SH/SiO$_2$**: Displays a complex behavior with notable points indicating Cu silicide formation.
- **Si/SiO$_2$/Cu Recipe I UV-O3 cleaning**: A straightforward increase in sheet resistance.
- **Si/SiO$_2$/Cu Recipe I UV-O3 cleaning**: Similar to the first but with a slight variation.

**Cu silicide formation** is indicated by red circles on the graph.
### SAMs compared: adhesion & Cu silicide formation

<table>
<thead>
<tr>
<th>Sample</th>
<th>Tape test</th>
<th>Sheet resistance ($\Omega/\square$)</th>
<th>Visual inspection upon anneal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same CH$_3$ terminal and SiCl$_3$ head groups but different chain lengths, n= 7-21</td>
<td>Fail</td>
<td>No Cu silicide formation &lt; 400$^\circ$C</td>
<td>No change</td>
</tr>
<tr>
<td>Same CH$_3$ terminal &amp; chain length, n=17, different head group, SiCl$_3$, Si(OCH$_3$)$_2$ &amp; Si(OCH$_3$)$_3$</td>
<td>Fail except Si(OCH$_3$)$_3$</td>
<td>No Cu silicide formation &lt;400$^\circ$C but Si(OCH$_3$)$_3$ &gt;300$^\circ$C slight inc.</td>
<td>No change</td>
</tr>
<tr>
<td>Same SiCl$_3$ head group &amp; chain length, n=11, but different terminal groups, Br, CN, &amp; CH$_3$</td>
<td>Fail</td>
<td>No Cu silicide formation &lt;400$^\circ$C</td>
<td>No change</td>
</tr>
<tr>
<td>Same Si(OCH$_3$)$_3$ head group &amp; similar chain length, n=1 or 3, but different terminal groups, NH$_2$, SH &amp; HNC$_5$H$_4$</td>
<td>Pass</td>
<td>Cu silicide formation &gt;300$^\circ$C* for SH &amp; HNC$_5$H$_4$ slight inc.</td>
<td>Darkened except for NH$_2$</td>
</tr>
</tbody>
</table>
(2) SAMs as Cu diffusion barrier - conclusions

- Molecules with SiCl₃ head group show enhanced inhibition of silicide formation (> 400°C) - related to the relatively high thermal stability of the SAM (550-600°C) and dense SAM packing

- No obvious effect of chain length n = 7-21 or terminal group CH₃, Br & CN

- Significant effect from head group, all molecules (including CH₃ terminated) with Si(OCH₃)₃ head group pass tape tests - less densely packed SAMs may allow Cu penetration promoting adhesion

- In general, molecules with Si(OCH₃)₃ head group, even with reactive terminal groups, show lower inhibition of silicide formation (250-300°C) compared with molecules with SiCl₃ head group (>400°C). But adhesion on Si(OCH₃)₃ >> SiCl₃.
Application of SAMs in Nanoelectronics: surface engineering

- ALD of WC$_x$N$_y$/various-SAMs
  - Atomic layer deposition
  - SAM compatibility with ALD
  - Effect of SAM termination
  - Influence of alkyl chain length

- SAMs as Cu diffusion barrier
  - Previous work
  - Adhesion & Cu silicide formation

- Characterization of Cu/CO$_2$H-SAM
  - LEIS: SAM outer most surface
  - XPS: SAM-metal bonding

- Conclusions
LEIS: preparation of the Au(111) substrate

LEIS spectra measured with 3 keV $^4$He$^+$ ions from a (111)-textured Au surface as-received, following oxidation treatment with an atomic oxygen source, and after cleaning by $^{20}$Ne$^+$ sputtering cycles and annealing to $\sim$500 K for 30 min.

M. de Ridder and H.H. Brongersma

*Calipso B.V., Eindhoven, The Netherlands.*
LEIS spectra measured with 3 keV $^4$He$^+$ ions showing (a) the entire spectrum, (b) the oxygen peak, and (c) the high-energy onset of the background for a 3-MPA SAM adsorbed from the gas phase on Au(111). The spectra are normalised to the maximum background intensity of the first spectrum measured.
LEIS: gas vs. liquid phase adsorption

Surface oxygen content

Change in the oxygen peak area with increasing ion dose for 3-MPA and 11-MUA SAMs adsorbed from the gas or liquid phase on Au(111). Measurements were done with 3 keV $^4$He$^+$ ions. Peak areas were determined by fitting with a Gaussian after linear background subtraction.

Film thickness

LEIS spectra measured with 3 keV $^4$He$^+$ ions showing the high-energy onset of the background for 3-MPA and 11-MUA SAMs adsorbed from the gas or liquid phase on Au(111). A spectrum from clean Au(111) is shown for comparison with the Au peak normalised to the same height as the SAM/Au spectra at 2200 eV.
LEIS: gas vs. liquid phase adsorption

Surface oxygen content

Change in the oxygen peak area with increasing ion dose for 3-MPA and 11-MUA SAMs adsorbed from the gas or liquid phase on Au(111). Measurements were done with 3 keV $^4$He$^+$ ions. Peak areas were determined by fitting with a Gaussian after linear background subtraction.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Thickness (Å)</th>
<th>Theoretical thickness (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-MPA(g)</td>
<td>4 ± 1</td>
<td>4.5</td>
</tr>
<tr>
<td>3-MPA(l)</td>
<td>6.5 ± 2</td>
<td>4.5</td>
</tr>
<tr>
<td>11-MUA(l)</td>
<td>11 ± 2</td>
<td>13.9</td>
</tr>
</tbody>
</table>
XPS: gas phase adsorption of 3MPA

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LISE, FUNDP, Namur, Belgium.
Cu/CO$_2$H-SAMs: possible bonding interactions
XPS: evaporation of Cu on 3MPA

**CO$_2$H-Cu bonding**

<table>
<thead>
<tr>
<th>Cu [ML]</th>
<th>5.0</th>
<th>3.6</th>
<th>2.2</th>
<th>1.4</th>
<th>0.72</th>
<th>0.35</th>
<th>0</th>
</tr>
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<tbody>
<tr>
<td>Intensity [Arb. Units]</td>
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<td></td>
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</table>

**Cu-O bonding**

<table>
<thead>
<tr>
<th>Cu [ML]</th>
<th>5.0</th>
<th>3.6</th>
<th>2.2</th>
<th>1.4</th>
<th>0.72</th>
<th>0.35</th>
<th>0</th>
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<tbody>
<tr>
<td>Intensity [Arb. Units]</td>
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</tr>
</tbody>
</table>
XPS: evaporation of Cu on 3MPA

Cu interacts with CO$_2$H group
Selective deposition at OH site
XPS: evaporation of Cu on 3MPA

- Cu-O interaction weak and/or Cu clusters
- Cu oxidation state Cu(0)-Cu(I)
- no Cu penetration to Au surface
(3) Cu/CO₂H-SAM characterization - conclusions

- **LEIS**
  Different CO₂H-SAMs for gas vs. liquid phase formation:
  - Thickness 4 vs. 6.5 Å
  - Surface oxygen content x 5 difference

- **XPS**
  Thiolate surface intermediate with an intact carboxylic acid function

  Cu adsorption:
  - induces changes in carboxylic acid C 1s
  - preferential modification of the hydroxyl group
  - indicating unidentate complexation
  - Cu 2p comparable with bulk suggests cluster growth and weak Cu-CO₂H-SAM interactions
  - No penetration to the Au surface
Final remarks

- **ALD of WC\textsubscript{x}N\textsubscript{y}/various-SAMs**
  
  Terminal group and alkyl chain length determine growth behavior

  *Vary substrate structure & chemistry to selectively control growth*

- **SAMs as Cu diffusion barrier**

  Cu silicide formation: SAM-SiCl\textsubscript{3} show enhanced inhibition attributed to high thermal stability and dense packing of SAM but no obvious effect of chain length or terminal group

  Adhesion: significant effect from head group, SAM-Si(OCH\textsubscript{3})\textsubscript{3} less densely packed may allow Cu penetration, XPS fracture analysis shows failure at SAM/SiO\textsubscript{2} interface (vs. Cu/SAM for SiCl\textsubscript{3})

  *SAM composition impacts adhesion & barrier properties*

- **Characterization of Cu/CO\textsubscript{2}H-SAM**

  LEIS reveals SAM outer most surface

  XPS identifies exact SAM-metal bonding
Acknowledgements

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THANK YOU!

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