Multilayers ZnS/SnS2/Cu2S Synthesized by alloy CZTS. XPS analyses indicate significant mixing between SnS2 and Cu2S, which favors CZTS.

Survey and detailed spectral analysis of the multilayer ZnS/SnS2/Cu2S are presented step-wise, as XPS data for CZTS as well as a step-by-step analysis of each of preceding layers: thin film Cu2S, a bilayer SnS2/Cu2S and a trilayer ZnS/SnS2/Cu2S. An extensive interdiffusion between SnS2 and Cu2S was observed by XPS at a synthesis temperature as low as 135°C upon the bilayer growth. To achieve a target stoichiometry in CZTS, precursor stacks were carefully designed and quantified by x-ray fluorescence (XRF). Thus, XPS quantification is strongly supported by accurate composition XRF analyses.

Spectral Category: technical
Accession #: 01346, 01347, 01348, 01349

INTRODUCTION

Metal-sulfide binaries and multinaries are being considered or used for a broad range of applications, including 2D channels in field effect transistors (Ref. 1), solid-state electrolytes in nanoscale memory elements (Ref. 2) and Li-ion batteries (Ref. 3), and catalysts (Ref. 4). Another class of applications is photovoltaics, where metal-sulfides are used as absorber layers (Refs. 5 and 6) or building blocks in organic-inorganic blends for bulk-heterojunction devices (Ref. 7). Because many applications shifted toward ultra-thin layers, metal-sulfides just recently gained significant attention from the ALD community. At present, however, there exists a significant gap in the number of publications involving the ALD synthesis of metal oxides compared to that of ALD synthesis of metal sulfides. To illustrate the situation, an apples-to-apples comparison of successfully synthesized metal-oxides versus metal-sulfides was presented elsewhere (Ref. 8). Since metal-sulfides are attractive and relatively new to ALD, systematic compositional studies using surface sensitive techniques are of particular technological interest.

The focus of the present study is on a multicomponent metal-sulfide material Cu2ZnSnS4 crucial for thin film photovoltaics. The current ALD route to thin film CZTS involves the deposition of layers of binary metal sulfides, which are subsequently annealed in an inert atmosphere (Ref. 9). In this report we present XPS data for CZTS as well as a step-by-step analysis of each of preceding layers: thin film Cu2S, a bilayer SnS2/Cu2S and a trilayer ZnS/SnS2/Cu2S. An extensive interdiffusion between SnS2 and Cu2S was observed by XPS at a synthesis temperature as low as 135°C upon the bilayer growth. To achieve a target stoichiometry in CZTS, precursor stacks were carefully designed and quantified by x-ray fluorescence (XRF). Thus, XPS quantification is strongly supported by accurate composition XRF analyses.

SPECIMEN DESCRIPTION (ACCESSION #01346, 1 OF 4) —

Host Material: Cu2S thin film
CAS Registry #: 22205-45-4
Host Material Characteristics: homogeneous; solid; polycrystalline; semiconductor; inorganic compound; thin film
Chemical Name: copper sulfide
Source: thin film prepared by atomic layer deposition (ALD) on Si(100)
Host Composition: Cu, S
Form: thin film
Structure: polycrystalline

History & Significance: Atomic layer deposition was performed in a Savannah S200 (Cambridge Nanotech, Cambridge, MA) customized for compatibility with H2S. For all depositions, the hot-wall chamber temperature was 135°C. The high-purity nitrogen flow rate was 10 sccm, and deposition was carried out in pulse mode (continuous flow). Under nitrogen flow with no precursor pulsing, the chamber pressure was approximately 0.5 Torr. The sulfide source was 1% H2S balance N2. The H2S was delivered to the precursor manifold through a 0.3 mm orifice (Lennox Laser) that was placed just upstream of the pneumatic valve. The delivery pressure from the corrosive gas...
regulator was –18 in of mercury gauge pressure. Cu₂S was deposited using a following procedure. The precursor for Cu⁺ was his(N,N’-disec-butylacetamidino)dicopper(I) (DOW Chemicals), abbreviated as Cu₂DBA. The Cu₂DBA precursor reservoir was kept at 160 °C. The vapor was fed into the chamber using a nitrogen-assisted vapor delivery system. The procedure to dose the Cu₂DBA was to repeat the following steps five times: pressurize Cu₂DBA cylinder for 0.015 s using nitrogen at 25 psia, wait 1.0 s for the nitrogen to equilibrate and the precursor to mix, pulse the nitrogen/Cu₂DBA mixture into the chamber. One cycle of Cu₂S was completed by first dosing Cu₂DBA, followed by a 10 s purge, 1.0 s H₂S dose, finishing with a 10 s purge. In total 190 cycles were accomplished which corresponded to 24 nm. The films were polycrystalline (Ref. 9).

As Received Condition: as grown
Analyzed Region: same as host material
Ex Situ Preparation/Mounting: as received
In Situ Preparation: none
Pre-Analysis Beam Exposure: none
Charge Control: not specified
Temp. During Analysis: 293 K
Pressure During Analysis: <1.3 × 10⁻⁷ Pa

SPECIMEN DESCRIPTION (ACCESSION #01347, 2 OF 4)

Host Material: SnS₂/Cu₂S bilayer thin film
CAS Registry #: 1315-01-1
Host Material Characteristics: homogeneous; solid; polycrystalline; semiconductor; inorganic compound; thin film
Chemical Name: tin disulfide
Source: thin film bilayer SnS₂/Cu₂S prepared by atomic layer deposition (ALD) on Si(100)
Host Composition: Sn, S
Form: thin film
Structure: polycrystalline

History & Significance: Atomic layer deposition was performed in a Savannah S200 (Cambridge Nanotech, Cambridge, MA) customized for compatibility with H₂S. For all depositions, the hot-wall chamber temperature was 135 °C. The high-purity nitrogen flow rate was 10 sccm, and deposition was carried out in pulse mode (continuous flow). Under nitrogen flow with no precursor pulsing, the chamber pressure was approximately 0.5 Torr. The sulfide source was 1% H₂S balance N₂. The H₂S was delivered to the precursor manifold through a 0.3 mm orifice (Lennox Laser) that was placed just upstream of the pneumatic valve. The delivery pressure from the corrosive gas regulator was –18 in of mercury gauge pressure. For ZnS, a process employing diethyl zinc (DEZ, Sigma-Aldrich) and H₂S was used. The diethyl zinc was kept at room temperature. One cycle of ZnS consisted of a 0.015 s pulse of DEZ, followed by a 20.0 s purge, followed by a 1.0 s H₂S pulse, finishing with a 20.0 s purge. In total 290 cycles were accomplished which corresponded to 31 nm. The films were polycrystalline (Ref. 9).

As Received Condition: as grown
Analyzed Region: same as host material
Ex Situ Preparation/Mounting: as received
In Situ Preparation: none
Pre-Analysis Beam Exposure: none
Charge Control: not specified
Temp. During Analysis: 293 K
Pressure During Analysis: <1.3 × 10⁻⁷ Pa

SPECIMEN DESCRIPTION (ACCESSION #01348, 3 OF 4)

Host Material: ZnS/SnS₂/Cu₂S trilayer thin film
CAS Registry #: 1314-98-3
Host Material Characteristics: homogeneous; solid; polycrystalline; semiconductor; inorganic compound; thin film
Chemical Name: zinc sulfide
Source: thin film trilayer ZnS/SnS₂/Cu₂S prepared by atomic layer deposition (ALD) on Si(100)
Host Composition: Zn, S
Form: thin film
Structure: polycrystalline

History & Significance: Atomic layer deposition was performed in a Savannah S200 (Cambridge Nanotech, Cambridge, MA) customized for compatibility with H₂S. For all depositions, the hot-wall chamber temperature was 135 °C. The high-purity nitrogen flow rate was 10 sccm, and deposition was carried out in pulse mode (continuous flow). Under nitrogen flow with no precursor pulsing, the chamber pressure was approximately 0.5 Torr. The sulfide source was 1% H₂S balance N₂. The H₂S was delivered to the precursor manifold through a 0.3 mm orifice (Lennox Laser) that was placed just upstream of the pneumatic valve. The delivery pressure from the corrosive gas regulator was –18 in of mercury gauge pressure. For ZnS, a process employing diethyl zinc (DEZ, Sigma-Aldrich) and H₂S was used. The diethyl zinc was kept at room temperature. One cycle of ZnS consisted of a 0.015 s pulse of DEZ, following by a 20.0 s purge, followed by a 1.0 s H₂S pulse, finishing with a 20.0 s purge. In total 290 cycles were accomplished which corresponded to 31 nm. The films were polycrystalline (Ref. 9).

As Received Condition: as grown
Analyzed Region: same as host material
Ex Situ Preparation/Mounting: as received
In Situ Preparation: none
Pre-Analysis Beam Exposure: none
Charge Control: not specified
Temp. During Analysis: 293 K
Pressure During Analysis: <1.3 × 10⁻⁷ Pa

SPECIMEN DESCRIPTION (ACCESSION #01349, 4 OF 4)

Host Material: Cu₂ZnSnS₄ thin film
CAS Registry #: 12158-89-3
Host Material Characteristics: homogeneous; solid; polycrystalline; semiconductor; inorganic compound; thin film

Cu₂ZnSnS₄ and Its Parent Multilayers Analyzed by XPS
Recommended Energy Scale Shift:

Energy Scale Correction: The spectrometer calibration was performed using the gold XPS emission line (Au 4f7/2 with binding energy 84.0 eV).

Recommended Energy Scale Shift:

Peak Shape and Background Method: When processed by CasaXPS (Copyright 2009 Casa Software Ltd.), all measured peaks used for quantification were corrected for inelastic scattering by first subtracting the Shirley background from the raw spectra, followed by fitting of the peaks using asymmetric pseudo-Voigt peaks with different relative content of Gaussian and Lorenzian components that were optimized for the best fit.

Quantitation Method: (1) All samples were quantified by CasaXPS using default sensitivity factors taken from the Handbook of X-ray Photoelectron Spectroscopy (Ref. 10) for x-ray source at 54.7°.

(2) Compositions of all samples were also quantified by XRF using an Oxford ED2000, equipped with an Ag anode white x-ray source operated at 15 keV. Calculations were performed using the Berkeley Lab X-ray Interactions with Matter tool. It was verified that XRF measurements were performed in the thin film limit using a fixed angle of 45° in the energy range from 2 to 10 keV. All samples had a thickness <10% of the attenuation length and an x-ray transmission >90% in the energy range of interest. Samples for XRF were deposited on fused silica (quartz) to minimize interference from substrate impurities. The XRF standards were a 41 nm Cu metal film for [Cu] cation, 41 nm Sn metal film for [Sn] cation, and 22 nm ZnS film for [Zn] cation and [S] anion. XRF and XPS were performed in parallel on samples from the same synthesis run. Thus, no x-ray induced transformation/damage is expected. See Ref. 9 for more details.

(3) XPS analysis suggested significant mixing of the Cu$_2$S and the SnS$_2$ layers in the bilayer SnS$_2$/Cu$_2$S, i.e. strong 2p peaks of Cu were observed. To quantify Cu content on the SnS$_2$ layer surface, a special method was applied - using the Cu 3p line at 75 eV and the Sn 4d line at 25 eV (Ref. 11) - as specified herein. Because it is assumed that these lines are less affected by electron scattering - as these are photoelectrons with the highest kinetic energies - the measured intensities of these lines were corrected to known photo-ionization cross-sections (Ref. 12). Doing so allows an atomic percentage of Cu in the SnS$_2$ layer to be estimated; this analysis resulted in 8 at.% of Cu in the SnS$_2$ layer. Indeed, further analysis, using secondary ion mass spectrometry (SIMS), demonstrated inter-diffusion between both layers (Ref. 13).

Note, that sulfur peaks corresponding to 2p$_{1/2}$ and 2p$_{3/2}$ were not resolved. When calculating stoichiometry, fitting to separate these peaks was not performed, and the whole as-measured sulfur signals were integrated for all samples.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy, Office of Science, Basic Energy Sciences, Materials Sciences and Engineering Division.

SCR was supported in part by the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Postdoctoral Research Awards under the EERE Solar Program administered by the Oak Ridge Institute for Science and Education (ORISE) for the DOE. ORISE is managed by Oak Ridge Associated Universities (ORAU) under DOE contract number DE-AC05-06OR23100.
## SPECTRAL FEATURES TABLE

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<th>Peak Energy (eV)</th>
<th>Peak Width FWHM (eV)</th>
<th>Peak Area (eV x cts/s)</th>
<th>Sensitivity Factor</th>
<th>Concentration (at. %)</th>
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### NOTES

a. Quantified by CasaXPS using sensitivity factors from Ref. 10. By XRF, the ratio between Cu and S was close to 2:1. Presence and shape of the shake-up peak between Cu 2p₁/₂ and Cu 2p₃/₂ confirms that some of surface Cu was oxidized in the form of CuO (Ref. 14). The measured Auger parameter for Cu was 1850.6 eV (Cu 2p₁/₂ binding energy 933 eV and Cu LMM kinetic energy 917.6 eV); this value lies between values for Cu₂S (1849.9 eV [Ref. 10]) and CuO (1851.8 eV [Ref. 10] or 1851.3 eV [Ref. 15]). Ratio of the Cu 2p₃/₂ peak area to shake-up peak area was 5.3. XPS quantification results show that Cu₂S surface composition was Cu-deficient by about 4 at.% which is consistent with our previous finding on djurleite and digenite phases formation (Refs. 6 and 16) upon Cu₂S oxidation in ambient that leads the semiconductor become degenerate.

b. Quantified by CasaXPS using sensitivity factors from Ref. 10. The special procedure (Ref. 11) that makes use of high kinetic energy Cu 3p and Sn 4d lines also estimated Cu content as high as 8 at.% on the surface. The stoichiometric ratios, between Sn and S, and Cu and S, determined by XRF were 1:2 and 2:1, respectively. Presence of the shake-up peak between Cu 2p₁/₂ and Cu 2p₃/₂ confirms that segregated Cu on the surface was oxidized in the form of CuO. Ratio of Cu 2p₃/₂ peak area to shake-up peak area was 2.0.

c. Quantified by CasaXPS using sensitivity factors from Ref. 10. By XRF, ratio between Zn and S was 1:1.

d. Quantified by CasaXPS using sensitivity factors from Ref. 10. Final formula unit stoichiometry of CZTS was measured by XRF as Cu₁.₉Zn₁.₅Sn₁S₃.₆. XPS results suggest that CZTS surface composition (about 5 nm under the surface) was Sn-rich and S- and Zn-deficient - this is consistent with our previous high resolution SIMS depth profiles (Ref. 13).

---

## ANALYZER CALIBRATION TABLE

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<th>Spectrum ID #</th>
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<th>Peak Area (eV x cts/s)</th>
<th>Sensitivity Factor</th>
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<th>Baseline</th>
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* Voltage shift of the archived (as-measured) spectrum relative to the printed figure. The figure reflects the recommended energy scale correction due to a calibration correction, sample charging, flood gun, or other phenomenon.

[NP] signifies not published; digital spectra are archived in SSS database but not reproduced in the printed journal.

1. Cu$_2$S thin film
2. SnS$_2$/Cu$_2$S bilayer thin film
3. ZnS/SnS$_2$/Cu$_2$S trilayer thin film
4. Cu$_2$ZnSnS$_4$ thin film

**GUIDE TO FIGURES**

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86 Surface Science Spectra, Vol. 22, 2015 Cu$_2$ZnSnS$_4$ and Its Parent Multilayers Analyzed by XPS

Redistribution subject to AVS license or copyright; see http://scitation.aip.org/termsconditions. Download to IP: 99.32.226.96 On: Thu, 02 Jul 2015 12:03:21
**Accession #** 01346–01

**Host Material**

Cu$_2$S thin film

**Technique**

XPS

**Spectral Region**

Survey

**Instrument**

Custom designed instrument

**Excitation Source**

Mg $K_a$

**Source Energy**

1253.6 eV

**Source Strength**

300 W

**Source Size**

not specified

**Analyzer Type**

180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system

**Incident Angle**

45°

**Emission Angle**

0°

**Analyzer Pass Energy:**

44 eV

**Analyzer Resolution**

0.45 eV

**Total Signal Accumulation Time**

not specified

**Total Elapsed Time**

not specified

**Number of Scans**

1

**Effective Detector Width**

0.5 eV/step
**Accession #: 01346–02**
**Host Material:** Cu\(_2\)S thin film
**Technique:** XPS
**Spectral Region:** Cu 2\(p_{1/2}\), Cu 2\(p_{3/2}\)

Instrument: Custom designed instrument
Excitation Source: Mg K\(_x\)
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180\(^\circ\) hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45\(^\circ\)
Emission Angle: 0\(^\circ\)
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step

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**Accession #: 01346–03**
**Host Material:** Cu\(_2\)S thin film
**Technique:** XPS
**Spectral Region:** S 2\(p_{1/2, 3/2}\)

Instrument: Custom designed instrument
Excitation Source: Mg K\(_x\)
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180\(^\circ\) hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45\(^\circ\)
Emission Angle: 0\(^\circ\)
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step
<table>
<thead>
<tr>
<th>Accession #</th>
<th>01347–01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Host Material</td>
<td>SnS₂/Cu₂S bilayer thin film</td>
</tr>
<tr>
<td>Technique</td>
<td>XPS</td>
</tr>
<tr>
<td>Spectral Region</td>
<td>survey</td>
</tr>
<tr>
<td>Instrument</td>
<td>Custom designed instrument</td>
</tr>
<tr>
<td>Excitation Source</td>
<td>Mg K₂</td>
</tr>
<tr>
<td>Source Energy</td>
<td>1253.6 eV</td>
</tr>
<tr>
<td>Source Strength</td>
<td>300 W</td>
</tr>
<tr>
<td>Source Size</td>
<td>not specified</td>
</tr>
<tr>
<td>Analyzer Type</td>
<td>180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system</td>
</tr>
<tr>
<td>Incident Angle</td>
<td>45°</td>
</tr>
<tr>
<td>Emission Angle</td>
<td>0°</td>
</tr>
<tr>
<td>Analyzer Pass Energy</td>
<td>44 eV</td>
</tr>
<tr>
<td>Analyzer Resolution</td>
<td>0.45 eV</td>
</tr>
<tr>
<td>Total Signal Accumulation Time</td>
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<td>Total Elapsed Time</td>
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<td>Number of Scans</td>
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<tr>
<td>Effective Detector Width</td>
<td>0.5 eV/step</td>
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</table>
Accession #: 01347–02
Host Material: SnS₂/Cu₂S bilayer thin film
Technique: XPS
Spectral Region: Sn 3d₃/₂, Sn 3d₅/₂

Instrument: Custom designed instrument
Excitation Source: Mg Kα
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45°
Emission Angle: 0°
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step

Accession #: 01347–03
Host Material: SnS₂/Cu₂S bilayer thin film
Technique: XPS
Spectral Region: S 2p₁/₂, 2p₃/₂

Instrument: Custom designed instrument
Excitation Source: Mg Kα
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45°
Emission Angle: 0°
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step

Cu₂ZnSnS₄ and Its Parent Multilayers Analyzed by XPS
**Host Material**
ZnS/SnS$_2$/Cu$_2$S trilayer thin film

**Technique**
XPS

**Spectral Region**
survey

**Instrument**
Custom designed instrument

**Excitation Source**
Mg $K_\alpha$

**Source Energy**
1253.6 eV

**Source Strength**
300 W

**Source Size**
not specified

**Analyzer Type**
180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system

**Incident Angle**
45°

**Emission Angle**
0°

**Analyzer Pass Energy:**
44 eV

**Analyzer Resolution**
0.45 eV

**Total Signal Accumulation Time**
not specified

**Total Elapsed Time**
not specified

**Number of Scans**
1

**Effective Detector Width**
0.5 eV/step
**Accession #: 01348–02**
**Host Material:** ZnS/SnS$_2$/Cu$_2$S trilayer thin film
**Technique:** XPS
**Spectral Region:** Zn $2p_{1/2}$, Zn $2p_{3/2}$

Instrument: Custom designed instrument
Excitation Source: Mg $K_x$
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45°
Emission Angle: 0°
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step

**Accession #: 01348–03**
**Host Material:** ZnS/SnS$_2$/Cu$_2$S trilayer thin film
**Technique:** XPS
**Spectral Region:** S $2p_{1/2,3/2}$

Instrument: Custom designed instrument
Excitation Source: Mg $K_x$
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45°
Emission Angle: 0°
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step
Accession #: 01348-04
Host Material: ZnS/SnS$_2$/Cu$_2$S trilayer thin film
Technique: XPS
Spectral Region: O 1s

Instrument: Custom designed instrument
Excitation Source: Mg $K_\alpha$
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45°
Emission Angle: 0°
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step
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<thead>
<tr>
<th>Accession #</th>
<th>01349–01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Host Material</td>
<td>Cu₂ZnSnS₄ thin film</td>
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<tr>
<td>Technique</td>
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<td>Spectral Region</td>
<td>survey</td>
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<tr>
<td>Instrument</td>
<td>Custom designed instrument</td>
</tr>
<tr>
<td>Excitation Source</td>
<td>Mg Kα</td>
</tr>
<tr>
<td>Source Energy</td>
<td>1253.6 eV</td>
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<tr>
<td>Source Strength</td>
<td>300 W</td>
</tr>
<tr>
<td>Source Size</td>
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<tr>
<td>Analyzer Type</td>
<td>180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system</td>
</tr>
<tr>
<td>Incident Angle</td>
<td>45°</td>
</tr>
<tr>
<td>Emission Angle</td>
<td>0°</td>
</tr>
<tr>
<td>Analyzer Pass Energy:</td>
<td>44 eV</td>
</tr>
<tr>
<td>Analyzer Resolution</td>
<td>0.45 eV</td>
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<tr>
<td>Total Signal Accumulation Time</td>
<td>not specified</td>
</tr>
<tr>
<td>Total Elapsed Time</td>
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</tr>
<tr>
<td>Number of Scans</td>
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</tr>
<tr>
<td>Effective Detector Width</td>
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</tbody>
</table>
Accession #: 01349–02
Host Material: Cu₂ZnSnS₄ thin film
Technique: XPS
Spectral Region: Cu 2p₁/₂, Cu 2p₃/₂

Instrument: Custom designed instrument
Excitation Source: Mg Kα
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45°
Emission Angle: 0°
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step

Accession #: 01349–03
Host Material: Cu₂ZnSnS₄ thin film
Technique: XPS
Spectral Region: Zn 2p₁/₂, Zn 2p₃/₂

Instrument: Custom designed instrument
Excitation Source: Mg Kα
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45°
Emission Angle: 0°
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step
Accession #: 01349–06
Host Material: Cu₂ZnSnS₄ thin film
Technique: XPS
Spectral Region: O 1s

Instrument: Custom designed instrument
Excitation Source: Mg Kα
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45°
Emission Angle: 0°
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step

Accession #: 01349–07
Host Material: Cu₂ZnSnS₄ thin film
Technique: XPS
Spectral Region: C 1s

Instrument: Custom designed instrument
Excitation Source: Mg Kα
Source Energy: 1253.6 eV
Source Strength: 300 W
Source Size: not specified
Analyzer Type: 180° hemispherical analyzer (HA100) with 100 mm mean radius and input lens system
Incident Angle: 45°
Emission Angle: 0°
Analyzer Pass Energy: 44 eV
Analyzer Resolution: 0.45 eV
Total Signal Accumulation Time: not specified
Total Elapsed Time: not specified
Number of Scans: 3
Effective Detector Width: 0.1 eV/step