Single Crystal Perovskites Analyzed Using X-ray Photoelectron Spectroscopy: 2. YAlO3(110)

Richard T. Haasch, Eric Breckenfeld, and Lane W. Martin

Citation: Surface Science Spectra 21, 95 (2014); doi: 10.1116/11.20140902
View online: http://dx.doi.org/10.1116/11.20140902
View Table of Contents: http://scitation.aip.org/content/avs/journal/sss/21/1?ver=pdfcov
Published by the AVS: Science & Technology of Materials, Interfaces, and Processing

Articles you may be interested in
Single Crystal Rare-earth Scandate Perovskites Analyzed Using X-ray Photoelectron Spectroscopy: 4. TbScO3(110)

Single Crystal Rare-earth Scandate Perovskites Analyzed Using X-ray Photoelectron Spectroscopy: 3. GdScO3(110)

Single Crystal Rare-earth Scandate Perovskites Analyzed Using X-ray Photoelectron Spectroscopy: 2. NdScO3(110)

Single Crystal Rare-earth Scandate Perovskites Analyzed Using X-ray Photoelectron Spectroscopy: 1. PrScO3(110)

Single Crystal Perovskites Analyzed Using X-ray Photoelectron Spectroscopy: 2. YAlO₃(110)

Richard T. Haasch
Department of Materials Science and Engineering and Materials Research Laboratory, University of Illinois, Urbana-Champaign

Eric Breckenfeld
Department of Materials Science and Engineering and Materials Research Laboratory, University of Illinois, Urbana-Champaign; and Naval Research Laboratory, Washington, DC

Lane W. Martin
Department of Materials Science and Engineering and Materials Research Laboratory, University of Illinois, Urbana-Champaign; Department of Materials Science and Engineering, University of California, Berkeley; and Materials Science Division, Lawrence Berkeley National Laboratory

(Received 3 October 2014; accepted 4 December 2014; published 29 December 2014)

X-ray photoelectron spectroscopy (XPS) was used to analyze a commercially available YAlO₃(110) bulk single crystal. XP spectra were obtained using incident monochromatic Al Kα radiation at 0.83401 nm. A survey spectrum together with O 1s, Y 2p, C 1s, Y 3d, Al 2p, Y 4p, and O 2s core level spectra and the valence band are presented. The spectra indicate the principle core level photoelectron and Auger electron signals and show only minor carbon contamination. Making use of the O 1s, Y 3d, Al 2p lines and neglecting the components related to surface contaminants, XPS quantitative analysis reveals an altered stoichiometry of the air-exposed crystal surface of YAl₁₀₆O₂₄₈. © 2014 American Vacuum Society. [http://dx.doi.org/10.1116/11.20140902]

Keywords: yttrium aluminum oxide; perovskite

INTRODUCTION

Transition metal oxides present an impressive variety of functionality which is not available in more traditional systems such as group IV and III-V semiconductors or elemental metals. Among the many possible functionalities are, for instance, ferroelectricity (Ref. 1) and magnetism (Ref. 2), colossal magnetoresistance (Ref. 3), and high temperature superconductivity (Ref. 4), with transport character ranging from insulating to semiconducting to metallic. Furthermore, these properties are extremely sensitive to perturbations from chemistry, structural defects, strain and many other effects and this, in turn, provides the materials engineer a number of routes by which to engineer new functionalities in this class of materials (Ref. 5). While even simple oxide systems, such as binary oxides, exhibit a broad diversity of properties, it is the ternary systems which have received the most attention in recent years. In particular, materials possessing the perovskite structure (with chemical formula ABO₃) have been observed to exhibit an incredible variety of functionality and phenomena. Advances in thin film epitaxy, particularly pulsed laser deposition, RF magnetron sputtering, and molecular beam epitaxy, have enabled researchers to carefully tune material properties using epitaxial strain. Such approaches have provided an opportunity to apply large biaxial strains (as much as several percent in some cases) to nanoscale films of various materials which would lead to cracks in bulk materials under similar values of hydrostatic strain (Ref. 6).

SPECIMEN DESCRIPTION (ACCESSION #01311)

Host Material: Single crystal YAlO₃
CAS Registry #: 12005-21-9
Host Material Characteristics: homogeneous; solid; single crystal; dielectric; inorganic compound
Chemical Name: yttrium aluminum oxide
Source: Crystec, GmbH. Grown by the Czochralski method.
Host Composition: YAlO₃
Form: single crystal
Structure: orthorhombic, perovskite-like structure, a = 0.5330 nm, b = 0.7375 nm, c = 0.5180 nm (Ref. 7)
History & Significance: YAlO₃ has been primarily studied as a substrate material for high TC oxide superconductors (Ref. 8). It has been found that for common oxide superconductors such as YBa₂Cu₃O₇₋ₓ, YAlO₃ serves as an ideal high-quality single-crystal substrate. It has several advantages over other materials due to its lack of twins and low dielectric constant when compared to LaAlO₃ and SrTiO₃, respectively. Furthermore, rare-earth-doped YAlO₃ has been considered a very promising material for optical applications and has been used in solid-state lasers (Ref. 9), scintillators (Ref. 10), phosphors (Ref. 11), power resonators (Ref. 12), and ceramic pigments (Ref. 13). In order to gain an increased understanding of the surfaces and hetero-interfaces of perovskite-based materials, a YAlO₃(110) bulk single crystal was analyzed using X-ray photoelectron spectroscopy.

As Received Condition: as grown
Analyzed Region: same as host material

**Ex Situ Preparation/Mounting:** Samples were cleaned ultrasonically for 5 min each in Formula 409\textsuperscript{V}, methyl alcohol, and deionized water. Samples were mounted onto the sample holder using double-sided carbon tape (Pella product number 16074).

**In Situ Preparation:** None

**Pre-Analysis Beam Exposure:** less than 2 min; no x-ray degradation effects observed

**Charge Control:** low energy flood gun/magnetic immersion lens combination, filament current = 1.8 A, charge balance = 3 V, filament bias = 1 V

**Temp. During Analysis:** 300 K

**Pressure During Analysis:** <3 × 10^{-7}

**INSTRUMENT DESCRIPTION**

- **Manufacturer and Model:** Kratos Axis Ultra
- **Analyzer Type:** spherical sector
- **Detector:** channeltron electron multiplier
- **Number of Detector Elements:** 8

**INSTRUMENT PARAMETERS COMMON TO ALL SPECTRA —**

- **Spectrometer**
  - **Analyzer Mode:** constant pass energy
  - **Throughput \((T = E^2)\):** N = 0
  - **Excitation Source Window:** not specified
  - **Excitation Source:** Al K\textsubscript{α}, monochromatic
  - **Source Energy:** 1486.6 eV
  - **Source Strength:** 180 W
  - **Source Beam Size:** 2000 \(\mu\)m × 2000 \(\mu\)m
  - **Signal Mode:** multichannel direct

- **Geometry**
  - **Incident Angle:** 54\degree
  - **Source to Analyzer Angle:** 54\degree
  - **Emission Angle:** 0\degree
  - **Specimen Azimuthal Angle:** 45\degree
  - **Acceptance Angle from Analyzer Axis:** 0\degree
  - **Analyzer Angular Acceptance Width:** 40\degree × 40\degree

**DATA ANALYSIS METHOD**

- **Energy Scale Correction:** The binding energy scale was referenced to C 1s = 285.0 eV.
- **Recommended Energy Scale Shift:** +2.103 eV for high resolution spectra

**Peak Shape and Background Method:** Background: Custom three parameter Tougaard background (Ref. 14), U 4 Tougaard (B, C, D, T0 = 0) (Ref. 15), was used. O 1s, C 1s, Y 3d, Al 2p: B = 299 eV\textsuperscript{2}, C = 542 eV\textsuperscript{2}, D = 275 eV\textsuperscript{2}.

**Quantitation Method:** Quantification was done using region and component definitions with CasaXPS version 2.3.15. Sensitivity factors supplied by Kratos Analytical. Errors are given as ±1 standard deviation. Standard deviations are calculated by CasaXPS using a Monte Carlo method for determining the error distribution for the computed areas.

**ACKNOWLEDGMENTS**

This work was carried out in the Frederick Seitz Materials Research Laboratory Central Research Facilities, University of Illinois. E.B. and L.W.M. acknowledge support from the National Science Foundation under grants DMR - 1124696 and DMR - 1451219.

**REFERENCES**

### SPECTRAL FEATURES TABLE

<table>
<thead>
<tr>
<th>Spectrum ID #</th>
<th>Element/Transition</th>
<th>Peak Energy (eV)</th>
<th>Peak Width FWHM (eV)</th>
<th>Peak Area (eV × cts/s)</th>
<th>Sensitivity Factor</th>
<th>Concentration (at. %)</th>
<th>Peak Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>01311-02</td>
<td>O 1s</td>
<td>529.9</td>
<td>1.05</td>
<td>43815.5</td>
<td>0.780</td>
<td>40.82</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-02ᵃ</td>
<td>O 1s</td>
<td>531.9</td>
<td>2.14</td>
<td>10573.2</td>
<td>0.780</td>
<td>9.85</td>
<td>hydroxide, carbonate</td>
</tr>
<tr>
<td>01311-03</td>
<td>Y 3p3/2</td>
<td>300.4</td>
<td>2.22</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-03</td>
<td>Y 3p1/2</td>
<td>312.3</td>
<td>2.22</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-03ᵃ</td>
<td>C 1s</td>
<td>285.0</td>
<td>1.18</td>
<td>4628.4</td>
<td>0.278</td>
<td>12.09</td>
<td>hydrocarbon</td>
</tr>
<tr>
<td>01311-03ᵃ</td>
<td>C 1s</td>
<td>286.3</td>
<td>1.70</td>
<td>776.2</td>
<td>0.278</td>
<td>2.03</td>
<td>C-hydroxide</td>
</tr>
<tr>
<td>01311-03ᵃ</td>
<td>C 1s</td>
<td>289.0</td>
<td>1.35</td>
<td>462.8</td>
<td>0.278</td>
<td>1.21</td>
<td>carbonate</td>
</tr>
<tr>
<td>01311-04</td>
<td>Y 3d</td>
<td>...</td>
<td>...</td>
<td>49345.0</td>
<td>2.175</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>01311-04</td>
<td>Y 3d5/2</td>
<td>157.2</td>
<td>0.98</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-04</td>
<td>Y 3d3/2</td>
<td>159.3</td>
<td>0.98</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-05</td>
<td>Al 2p3/2</td>
<td>73.5</td>
<td>0.98</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-05</td>
<td>Al 2p1/2</td>
<td>74.0</td>
<td>0.98</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-06</td>
<td>Y 4p3/2</td>
<td>24.9</td>
<td>1.69</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-06</td>
<td>Y 4p1/2</td>
<td>26.4</td>
<td>1.69</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-06</td>
<td>O 2s</td>
<td>21.4</td>
<td>2.55</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-06ᵇ</td>
<td>valence band</td>
<td>9.4</td>
<td>1.80</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-06ᶜ</td>
<td>valence band</td>
<td>7.6</td>
<td>1.35</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-06ᵈ</td>
<td>valence band</td>
<td>6.2</td>
<td>2.00</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
<tr>
<td>01311-06ᵉ</td>
<td>valence band maximum</td>
<td>3.4</td>
<td>1.20</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>YAlO₃</td>
</tr>
</tbody>
</table>

ᵃ Result of exposure to air
ᵇ O 2p and Al 3s (Ref. 16)
ᶜ O 2p and Al 3p (Ref. 16)
ᵈ O 2p, Al 3p and Y 4d (Ref. 16)
ᵉ The position of VBM was estimated by subtracting 1/2 of the full width at half maximum (FWHM) from the position of the maximum intensity at the VBM.

### ANALYZER CALIBRATION TABLE

<table>
<thead>
<tr>
<th>Spectrum ID #</th>
<th>Element/Transition</th>
<th>Peak Energy (eV)</th>
<th>Peak Width FWHM (eV)</th>
<th>Peak Area (eV × cts/s)</th>
<th>Sensitivity Factor</th>
<th>Concentration (at. %)</th>
<th>Peak Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au 4f7/2</td>
<td>84.0</td>
<td>0.72</td>
<td>151917.9</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Ag 3d5/2</td>
<td>368.2</td>
<td>0.58</td>
<td>230506.2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Cu 2p3/2</td>
<td>932.6</td>
<td>0.88</td>
<td>410979.8</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Surface Science Spectra, Vol. 21, 2014
<table>
<thead>
<tr>
<th>Spectrum (Accession) #</th>
<th>Spectral Region</th>
<th>Voltage Shift</th>
<th>Multiplier</th>
<th>Baseline</th>
<th>Comment #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1311-01</td>
<td>survey</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1311-02</td>
<td>O 1s</td>
<td>-2.103</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1311-03</td>
<td>Y 3p, C 1s</td>
<td>-2.103</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1311-04</td>
<td>Y 3d</td>
<td>-2.103</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1311-05</td>
<td>Al 2p</td>
<td>-2.103</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>1311-06</td>
<td>Y 4p, O 2s, valence band</td>
<td>-2.103</td>
<td>1</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

* 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.
<table>
<thead>
<tr>
<th>Accession #</th>
<th>01311–01</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Host Material</strong></td>
<td>Single crystal YAlO₃</td>
</tr>
<tr>
<td><strong>Technique</strong></td>
<td>XPS</td>
</tr>
<tr>
<td><strong>Spectral Region</strong></td>
<td>survey</td>
</tr>
<tr>
<td><strong>Instrument</strong></td>
<td>Kratos Axis Ultra</td>
</tr>
<tr>
<td><strong>Excitation Source</strong></td>
<td>Al $K_a$ monochromatic</td>
</tr>
<tr>
<td><strong>Source Energy</strong></td>
<td>1486.6 eV</td>
</tr>
<tr>
<td><strong>Source Strength</strong></td>
<td>180 W</td>
</tr>
<tr>
<td><strong>Source Size</strong></td>
<td>2 mm x 2 mm</td>
</tr>
<tr>
<td><strong>Analyzer Type</strong></td>
<td>spherical sector</td>
</tr>
<tr>
<td><strong>Incident Angle</strong></td>
<td>54°</td>
</tr>
<tr>
<td><strong>Emission Angle</strong></td>
<td>0°</td>
</tr>
<tr>
<td><strong>Analyzer Pass Energy:</strong></td>
<td>160 eV</td>
</tr>
<tr>
<td><strong>Analyzer Resolution</strong></td>
<td>2.4 eV</td>
</tr>
<tr>
<td><strong>Total Signal Accumulation Time</strong></td>
<td>560 s</td>
</tr>
<tr>
<td><strong>Total Elapsed Time</strong></td>
<td>1120 s</td>
</tr>
<tr>
<td><strong>Number of Scans</strong></td>
<td>4</td>
</tr>
<tr>
<td><strong>Effective Detector Width</strong></td>
<td>33.6 eV</td>
</tr>
</tbody>
</table>
Accession #: 01311–02
Host Material: Single crystal YAlO$_3$
Technique: XPS
Spectral Region: O 1s

Instrument: Kratos Axis Ultra
Excitation Source: Al K$_x$
monochromatic
Source Energy: 1486.6 eV
Source Strength: 180 W
Source Size: 2 mm x 2 mm
Analyzer Type: spherical sector
Incident Angle: 54°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.3 eV
Total Signal Accumulation Time: 1206 s
Total Elapsed Time: 3316.5 s
Number of Scans: 20
Effective Detector Width: 4.2 eV

Accession #: 01311–03
Host Material: Single crystal YAlO$_3$
Technique: XPS
Spectral Region: Y 3p; C 1s

Instrument: Kratos Axis Ultra
Excitation Source: Al K$_x$
monochromatic
Source Energy: 1486.6 eV
Source Strength: 180 W
Source Size: 2 mm x 2 mm
Analyzer Type: spherical sector
Incident Angle: 54°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.3 eV
Total Signal Accumulation Time: 3606 s
Total Elapsed Time: 9916.5 s
Number of Scans: 20
Effective Detector Width: 4.2 eV
**Accession #:** 01311-04  
**Host Material:** Single crystal YAlO$_3$  
**Technique:** XPS  
**Spectral Region:** Y 3d

Instrument: Kratos Axis Ultra  
Excitation Source: Al K$_\alpha$ monochromatic  
Source Energy: 1486.6 eV  
Source Strength: 180 W  
Source Size: 2 mm × 2 mm  
Analyzer Type: spherical sector  
Incident Angle: 54°  
Emission Angle: 0°  
Analyzer Pass Energy: 20 eV  
Analyzer Resolution: 0.3 eV  
Total Signal Accumulation Time: 1206 s  
Total Elapsed Time: 3316.5 s  
Number of Scans: 20  
Effective Detector Width: 4.2 eV

---

**Accession #:** 01311-05  
**Host Material:** Single crystal YAlO$_3$  
**Technique:** XPS  
**Spectral Region:** Al 2p

Instrument: Kratos Axis Ultra  
Excitation Source: Al K$_\alpha$ monochromatic  
Source Energy: 1486.6 eV  
Source Strength: 180 W  
Source Size: 2 mm × 2 mm  
Analyzer Type: spherical sector  
Incident Angle: 54°  
Emission Angle: 0°  
Analyzer Pass Energy: 20 eV  
Analyzer Resolution: 0.3 eV  
Total Signal Accumulation Time: 1608 s  
Total Elapsed Time: 4422 s  
Number of Scans: 20  
Effective Detector Width: 4.2 eV
Accession #: 01311–06
Host Material: Single crystal YAlO3
Technique: XPS
Spectral Region: Y 4p; O 2s; Valence band

Instrument: Kratos Axis Ultra
Excitation Source: Al Kα monochromatic
Source Energy: 1486.6 eV
Source Strength: 180 W
Source Size: 2 mm × 2 mm
Analyzer Type: spherical sector
Incident Angle: 54°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.3 eV
Total Signal Accumulation Time: 6734 s
Total Elapsed Time: 18518.5 s
Number of Scans: 20
Effective Detector Width: 4.2 eV