RESEARCH ARTICLE | SEPTEMBER 08 2023

Zinc sulfide chemical vapor deposition optical ceramic analyzed by XPS

Brian Butkus ; Alexandros Kostogiannes ; Andrew Howe ; Myungkoo Kang ; Romain Gaume ; Kathleen A. Richardson ; Parag Banerjee

Surf. Sci. Spectra 30, 024019 (2023)
https://doi.org/10.1116/6.0002777

SSS SURFACE SCIENCE SPECTRA | ARTICLE | pubs.aip.org/avs/sss

Zinc sulfide chemical vapor deposition optical ceramic analyzed by XPS

Cite as: Surf. Sci. Spectra **30**, 024019 (2023); doi: 10.1116/6.0002777
Submitted: 20 April 2023 · Accepted: 4 August 2023 ·
Published Online: 8 September 2023

View Online | Export Citation | CrossMark

Brian Butkus,[1] Alexandros Kostogiannes,[1,2] Andrew Howe,[2] Myungkoo Kang,[2] Romain Gaume,[2,3] Kathleen A. Richardson,[1,2] and Parag Banerjee[1,3,4,5,a)]

AFFILIATIONS

[1]Department of Materials Science and Engineering, University of Central Florida, Orlando, Florida 32816
[2]College of Optics & Photonics, University of Central Florida, Orlando, Florida 32816
[3]NanoScience Technology Center, University of Central Florida, Orlando, Florida 32816
[4]Florida Solar Energy Center, University of Central Florida, Orlando, Florida 32816
[5]REACT Faculty Cluster, University of Central Florida, Orlando, Florida 32816

[a)]**Electronic mail:** Parage.Banerjee@UCF.edu

ABSTRACT

Commercially available zinc sulfide (ZnS) ceramics, synthesized using chemical vapor deposition and subsequently hot isostatically pressed, are optically transparent as compared to other zinc sulfide chemical vapor deposited films and ceramics. The unique optical transparency along with the hardness and chemical resistance of ZnS makes it an important material for infrared transmission applications. X-ray photoelectron spectroscopy and x-ray induced Auger electron spectroscopy were performed on an optically transparent ZnS ceramic. This report includes charge corrected scans for the survey along with S *2s*, S *2p*, S *LMM*, Zn *2p*, Zn *2s*, Zn *3d*, Zn *3p*, Zn *3s*, Zn *LMM*, O *1s*, and C *1s* surface photoelectron signals. The scans provide photoelectron spectroscopy investigation data to help with the identification of metal sulfide compounds.

Key words: ZnS, sulfides, chemical vapor deposition, CVD, ceramics, x-ray photoelectron spectroscopy, XPS

Accession #: 01862	**Major Elements in Spectra:** Zn, S
Technique: XPS, XAES	**Minor Elements in Spectra:** O, C
Host Material: Zinc Sulfide CVD Optical Ceramic	**Published Spectra:** 12
Instrument: XPS ESCALAB 250Xi Fisher Scientific	**Spectral Category:** Comparison

INTRODUCTION

Zinc sulfide (ZnS) ceramics transmit in the infrared wavelength range between 1 and 12 μm (Ref. 1). This material is also semiconducting with a bandgap of 3.67 eV and exhibits unique optical and electrical properties, making it a popular choice for various applications, such as thermal imaging cameras, night vision devices, and lasers (Refs. 2–4).

Chemical vapor deposition (CVD) allows for the deposition of bulk ZnS ceramics with precise control over thickness, uniformity, and crystalline structure. This makes it possible to produce high-quality ZnS with low defects and excellent optical properties, including high optical transparency, low absorption, and high refractive index (2.35 ± 0.01) (Ref. 5). The resulting ZnS are also durable and resistant to environmental degradation. While the ceramics made by CVD are of high quality, the visual clarity of the material is not clear. Upon hot isostatic pressing, the ceramics transform into optically transparent substrates.

There are little to no reports of the x-ray photoelectron spectroscopy (XPS) of ZnS transparent ceramics. The reports available are either incomplete or the available XPS spectral characterization is for ZnS with other form factors such as thin films, powders, and nanoparticles (Refs. 2 and 6–8).

In this study, we analyze ZnS CVD transparent ceramic by XPS to study and quantify the bonding states of observable electron shells for Zn and S, along with minor species C and O. The use of XPS also provides quantification of atomic percentages (i.e., stoichiometry) along with the bonding states of trace level impurities, if present. From the oxygen (O *1s*) fine spectra, we see that the material has surface level oxidation. The sulfur fine spectrum (S *2p*) does not show evidence of oxidized sulfur, indicating that O is associated primarily with zinc.

SPECIMEN DESCRIPTION (ACCESSION # 01862)

Host Material: Zinc Sulfide Bulk Ceramic
CAS Registry #: 1314-98-3
Host Material Characteristics: Homogeneous; solid; polycrystalline; semiconductor; inorganic compound; Ceramic
Chemical Name: Zinc Sulfide
Source: APC American Photonics, 6621 19th Street East Sarasota, FL 34243, USA
Host Composition: ZnS
Form: CVD Zinc Sulfide Ceramic
Structure: Microcrystalline cubic zinc blend
History & Significance: The specimen was received from APC American Photonics in an optics case with lens tissue and lining and stored in normal atmosphere at room temperature. ZnS is commonly used in infrared windows, domes, and optical elements. While the ZnS nanocrystalline CVD thin film has been cataloged in the past, this work is done on a commercially available ZnS CVD ceramic sample that is optically transparent. The samples were used as received.
As Received Condition: Optically clear ceramic window
Analyzed Region: Same as the host material
***Ex Situ* Preparation/Mounting:** Ceramic was sonicated for 5 min in hexane, then transferred to isopropanol and sonicated for 5 min, and finally transferred to de-ionized water for a final 5 min of sonication. The sample was then dried by compressed air. The sample was mounted on the XPS stage using double-sided carbon tape.
***In Situ* Preparation:** 600 s argon ion sputtering at 500 eV was used to clean the surface before analysis.
Charge Control: Charge compensation is delivered by both an in-lens electrostatic electron flood source (1 eV, 100 μA) and a dual-beam low-energy electron and ion coaxial flood source (2 eV, 100 μA).
Temp. During Analysis: 300 K
Pressure During Analysis: 5×10^{-8} Pa
Pre-analysis Beam Exposure: 0 s

INSTRUMENT DESCRIPTION

Manufacturer and Model: Thermo Fisher Scientific ESCALAB 250Xi
Analyzer Type: Spherical sector
Detector: Channeltron
Number of Detector Elements: 6

INSTRUMENT PARAMETERS COMMON TO ALL SPECTRA

Spectrometer

Analyzer Mode: Constant pass energy
Throughput ($T = E^N$): Calculated from a polynomial fit to a plot of log [peak area/(PE × XSF)] versus log[KE/PE], where PE is the pass energy, KE is the kinetic energy, and XSF is the relative sensitivity factor.
Excitation Source Window: None
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Beam Size: $650 \times 650\,\mu m^2$
Signal Mode: Single channel direct

Geometry

Incident Angle: 58°
Source-to-Analyzer Angle: 58°
Emission Angle: 0°
Specimen Azimuthal Angle: 90°
Acceptance Angle from Analyzer Axis: 45°
Analyzer Angular Acceptance Width: 22.5° × 22.5°

Ion Gun

Manufacturer and Model: Thermo Fisher Scientific EX03 Ion Gun System
Energy: 500 eV
Current: 0.02 mA
Current Measurement Method: biased stage
Sputtering Species: Ar^+
Spot Size (unrastered): 500 μm
Raster Size: $4500 \times 4500\,\mu m^2$
Incident Angle: 40°
Polar Angle: 40°
Azimuthal Angle: 270°
Comment: These parameters correspond to ion-cleaning methods used in optical materials requiring surface cleaning.

DATA ANALYSIS METHOD

Energy Scale Correction: Binding energy scale was referenced to C 1s = 284.8 eV fine spectra pre and post sputter
Recommended Energy Scale Shift: Shift +0.15 eV
Peak Shape and Background Method: THERMO SCIENTIFIC AVANTAGE software version 5.9902 was used for peak shape and background subtraction. The smart (Shirley function) was used to subtract the background for Zn *2p*, S *2p*, O *1s*, and C *1s* peaks. Using the smart feature utilizes revised constraints that limit the background from having greater intensity than data from points in the collection region.
Quantitation Method: Atomic percentages were calculated using the THERMO SCIENTIFIC AVANTAGE software version 5.9902. Sensitivity factors were obtained from the THERMO SCIENTIFIC AVANTAGE software database and were used in the calculation of elemental atomic percentages. The peak library is ALWAG (Ref. 9).

ACKNOWLEDGMENTS

The authors thank the Lockheed Martin University Engagement and Applied Research organizations, the US Naval Surface Warfare Center, the US Army Research Laboratory, and the US Air Force Research Laboratory for their integral and collaborative support of this research. The authors acknowledge the NSF MRI: ECCS: 1726636 and the MCF-AMPAC facility, MSE and CECS along with Kirk Scammon MCF Research Engineer. This research was supported, in part, by the Florida High Tech Corridor's Matching Grant Research Program at the University of Central Florida.

AUTHOR DECLARATIONS

Conflict of Interest

The authors have no conflicts to disclose.

Author Contributions

Brian Butkus: Conceptualization (lead); Data curation (lead); Formal analysis (lead); Investigation (lead); Methodology (lead); Software (lead); Visualization (lead); Writing – original draft (lead); Writing – review & editing (equal). **Alexandros Kostogiannes:** Investigation (supporting); Validation (supporting); Writing – review & editing (supporting). **Andrew Howe:** Investigation (supporting); Visualization (supporting); Writing – review & editing (supporting). **Myungkoo Kang:** Validation (supporting); Visualization (supporting); Writing – review & editing (supporting). **Romain Gaume:** Conceptualization (supporting); Formal analysis (supporting); Funding acquisition (equal); Project administration (equal); Resources (equal); Supervision (supporting); Validation (supporting); Writing – review & editing (supporting). **Kathleen A. Richardson:** Conceptualization (supporting); Formal analysis (supporting); Funding acquisition (lead); Project administration (equal); Resources (equal); Supervision (supporting); Validation (supporting); Visualization (supporting); Writing – review & editing (equal). **Parag Banerjee:** Conceptualization (equal); Formal analysis (supporting); Funding acquisition (equal); Investigation (supporting); Project administration (equal); Resources (equal); Supervision (lead); Validation (equal); Visualization (supporting); Writing – review & editing (equal).

DATA AVAILABILITY

The data that support the findings of this study are available within the article and its supplementary material.

REFERENCES

[1] J. S. McCloy, R. Korenstein, and B. Zelinski, J. Am. Ceram. Soc. **92**, 1725 (2009).
[2] K. R. Murali, J. Abirami, and T. Balasubramanian, J. Mater. Sci. Mater. Electron. **19**, 217 (2008).
[3] D. Harris *et al.*, Proc. SPIE **6545**, 654502 (2007).
[4] J. McCloy, Proc. SPIE 6545, 654503 (2007).
[5] H. H. Li, J. Phys. Chem. Ref. Data **13**, 103 (1984).
[6] D. Barreca, E. Tondello, D. Lydon, T. R. Spalding, and M. Fabrizio, Chem. Vap. Deposition **9**, 93 (2003).
[7] D. Barreca, A. Gasparotto, C. Maragno, and E. Tondello, J. Electrochem. Soc. **151**, G428 (2004).
[8] D. Barreca, A. Gasparotto, C. Maragno, E. Tondello, and T. R. Spalding, Surf. Sci. Spectra **9**, 54 (2002).
[9] C. D. Wagner, L. E. Davis, M. V. Zeller, J. A. Taylor, R. H. Raymond, and L. H. Gale, Surf. Interface Anal. **3**, 211 (1981).
[10] D. W. Langer and C. J. Vesely, Phys. Rev. B **2**, 4885 (1970).
[11] C. Battistoni, J. L. Dormann, D. Fiorani, E. Paparazzo, and S. Viticoli, Solid State Commun. **39**, 581 (1981).
[12] D. Briggs and M. P. Singh, *Practical Surface Analysis–Auger and X-Ray Photoelectron Spectroscopy*, 2nd ed. (Wiley, Chichester, 1990), Vol. 1, p. 151.
[13] L. S. Dake, D. R. Baer, and J. M. Zachara, Surf. Interface Anal. **14**, 71 (1989).
[14] S. W. Gaarenstroom and N. Winograd, J. Chem. Phys. **67**, 3500 (1977).
[15] J. F. Moulder, in *Handbook of X-ray Photoelectron Spectroscopy; A Reference Book of Standard Spectra for Identification and Interpretation of XPS Data*, 1995 version ed. (Physical Electronics, Eden Prairie, MN, 1995).
[16] J. Cheon, D. S. Talaga, and J. I. Zink, J. Am. Chem. Soc. **119**, 163 (1997).

SPECTRAL FEATURES TABLE

Spectrum ID #	Element/ Transition	Peak Energy (eV)	Peak Width FWHM (eV)	Peak Area (eV counts/s)	Sensitivity Factor	Concentration (at. %)	Peak Assignment
01862-02	S *2s*	226.29	2.10	21 373.08	1.294	…	Zinc sulfide
01862-03	S $2p_{3/2}$	162.17	1.97	34 340.82	1.881	45.22	Zinc sulfide
01862-03	S $2p_{1/2}$	163.35	…	…	…	…	Zinc sulfide
01862-04[a]	S *LMM*	151.32	7.09	78 819.67	0.460	…	Zinc sulfide
01862-05	Zn $2p_{3/2}$	1021.74	1.45	326 328.37	21.391	…	Zinc sulfide
01862-05	Zn $2p_{1/2}$	1044.81	1.52	157 131.76	10.471	…	Zinc sulfide
01862-06	Zn *2s*	1195.70	5.15	48 691.46	4.200	…	Zinc sulfide
01862-07	Zn *3d*	10.75	1.28	21 996.46	0.716	…	Zinc sulfide
01862-08	Zn $3p_{3/2}$	89.24	2.63	50 018.35	2.600	46.19	Zinc sulfide
01862-08	Zn $3p_{1/2}$	92.00	…	…	…	…	Zinc sulfide
01862-09	Zn *3s*	140.24	2.37	17 085.14	0.800	…	Zinc sulfide
01862-10[a]	Zn *LMM*	989.58	2.14	66 530.64	4.916	…	Zinc sulfide
01862-10[a]	Zn *LMM*	992.59	3.37	43 942.32	4.916	…	Zinc sulfide
01862-11[b,c]	O *1s*	531.24	…	4 177.20	2.881	3.90	Metal carbonate, metal oxide
01862-12	C *1s*	284.75	1.63	1 861.12	1.000	4.69	Carbon

[a]Peak energy in kinetic energy (KE).

[b]Quantification of oxygen is not included due to interaction with Auger electron peaks.

[c]Overlap between *Zn LMM* Auger electron signal and O *1s* peak [see comment to (01862-01)]; due to this overlap, we have avoided the evaluation of the O *1s* FWHM and estimated only the BE (footnote to 01862-11).

Footnote to 01862-03: The measured S *2p* is used for atomic percentage calculation for more accurate representation when compared to Zn *3d* and can be more representative of the actual atomic personage. The S *2p* position was centered at BEs typical for sulfide species BE (S $2p_{3/2}$)=162.17 eV; FWHM=1.97 eV, and the peak for a sulfite or sulfate are shifted to the higher BEs with the sulfates at BEs≈7.0 eV higher (Refs. 6 and 10).

Footnote to 01862-05: The measured Zn $2p_{3/2}$ position binding energy (BE)=1021.74 eV, and a full width at half maximum (FWHM)=1.45 eV was not consistent with handbook data on zinc sulfide but was consistent with D. Barreca *et al.*, since reported values for the Zn $2p_{3/2}$ BEs for both zinc sulfide and zinc oxide are similar ZnS (1021.6 eV) and ZnO (1022.1 eV) (Refs. 8, 11, and 12). As with previous articles on ZnS, we evaluated the Auger electron α parameter, α=BE(Zn $2p_{3/2}$) + KE(Zn *LMM*) (Ref. 13) was used to confirm our evaluations to identify ZnS presence. The obtained value (2011.32 eV) agreed with those previously reported in the literature for zinc sulfide (Refs. 8, 10, 14, and 15).

Footnote to 01862-08: The Zn *3p* photoelectron peak was used to obtain a more accurate evaluation of atomic percentages, the S/Zn ratio. If the Zn $2p_{3/2}$ peak is used, the intensity of the Zn signal peak is non-congruent. This intensity difference would be represented as different escape depths and would result in off stoichiometry for the Zn:S ratio (Refs. 8 and 13).

Footnote to 01862-10: The KE of the Zn *LMM* peak (989.62 eV) was evaluated by the most intense Auger electron peak component.

Footnote to 01862-11: The O *1s* signal was fitted by a single component (BE=531.24) (Refs. 8 and 16). The O 1s peak signal intensity was reduced to just above noise level after a sputtering Ar+ erosion. Due to the overlap between Zn *LMM* Auger electron signal and O 1s peak (see footnote to 01862-10), the relative percentages could not be determined by direct measurement of the O *1s* peak area. And for this reason, at.% will be left out of these calculations.

Footnote to 01862-12: Carbon presence was limited to surface contamination since the post-sputtering Ar^+, C *1s* peak reduced in intensity to just above the noise in the fine spectra and noise level in the survey.

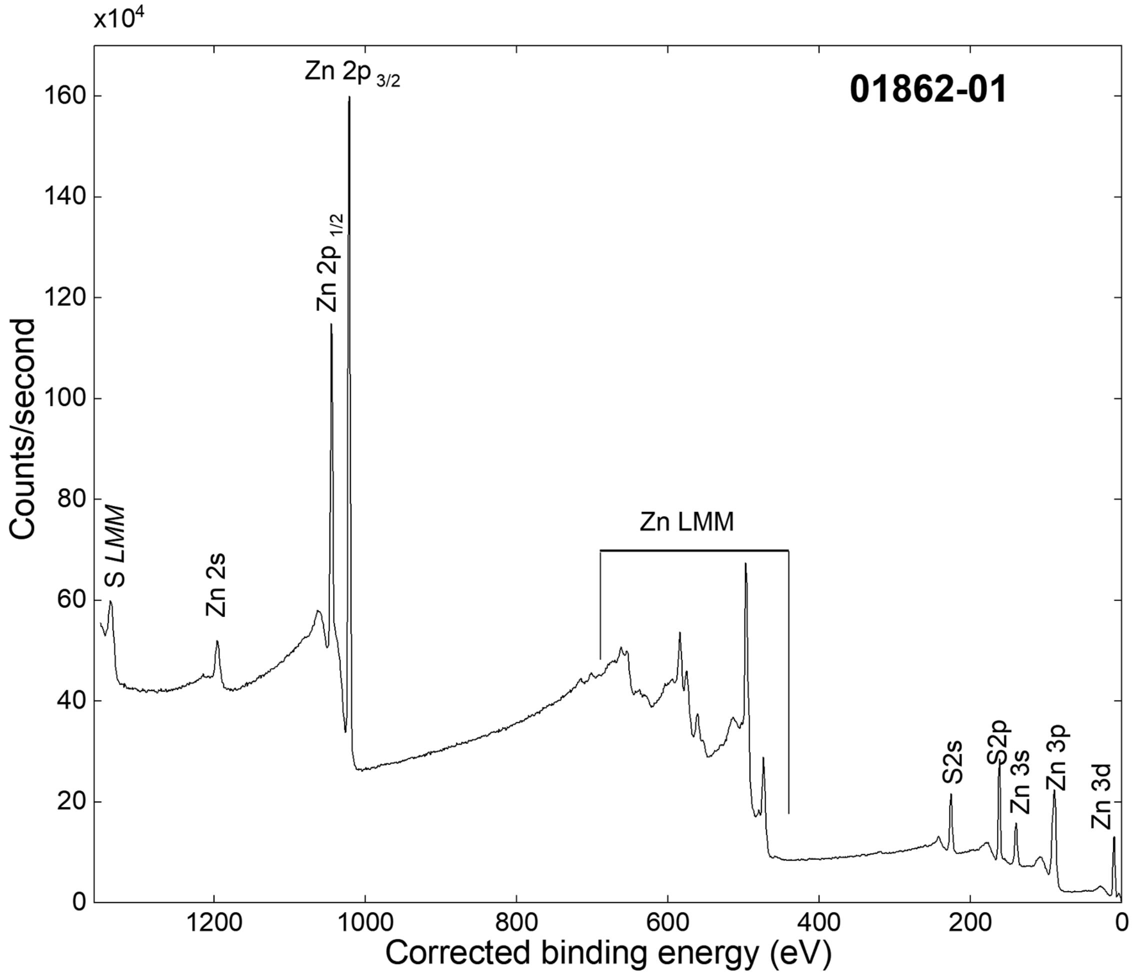
ANALYZER CALIBRATION TABLE

Spectrum ID #	Element/ Transition	Peak Energy (eV)	Peak Width FWHM (eV)	Peak Area (eV counts/s)	Sensitivity Factor	Concentration (at. %)	Peak Assignment
…	Au *4f*	84.05	0.57	262 830.05	20.735	…	Au
…	Ag *3d*	368.36	0.48	386 600.57	22.131	…	Ag
…	Cu *2p*	932.8	0.77	655 133.11	26.513	…	Cu

GUIDE TO FIGURES

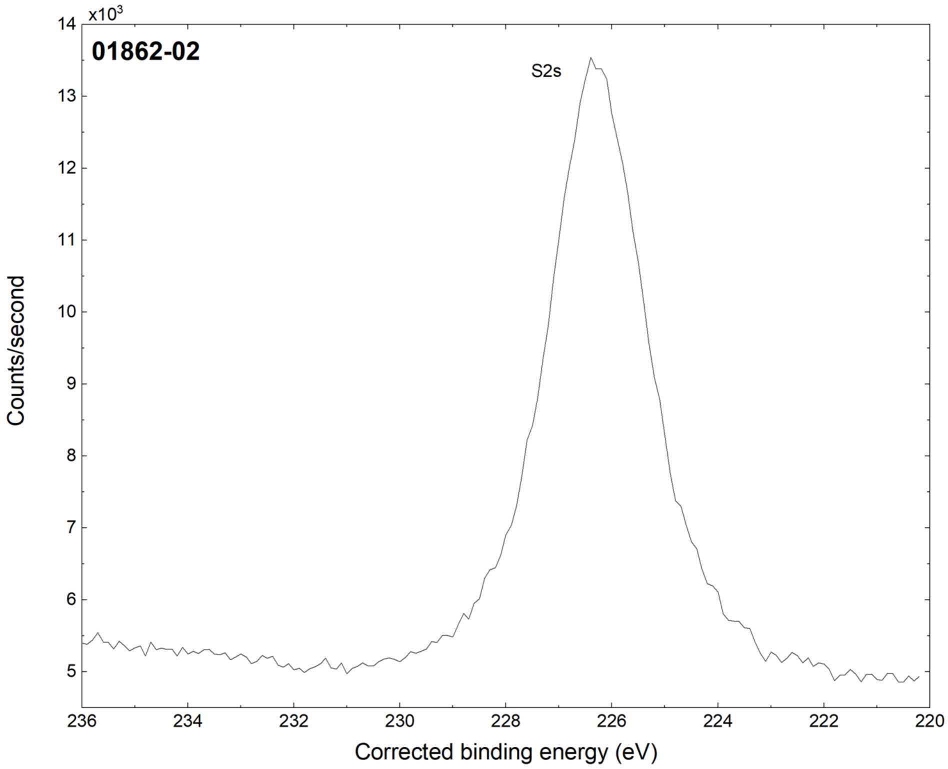
Spectrum (Accession) #	Spectral Region	Voltage Shift[a]	Multiplier	Baseline	Comment #
01862-01	Survey	−0.15	1	0	1
01862-02	S *2s*	−0.15	1	0	1
01862-03	S *2p*	−0.15	1	0	1
01862-04	S *LMM*	+0.15	1	0	1
01862-05	Zn *2p*	−0.15	1	0	1
01862-06	Zn *2s*	−0.15	1	0	1
01862-07	Zn *3d*	−0.15	1	0	1
01862-08	Zn *3p*	−0.15	1	0	1
01862-09	Zn *3s*	−0.15	1	0	1
01862-10	Zn *LMM*	+0.15	1	0	1
01862-11	O *1s*	−0.15	1	0	1
01862-12	C *1s*	−0.15	1	0	1

[a]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.
1. ZnS Ceramic.



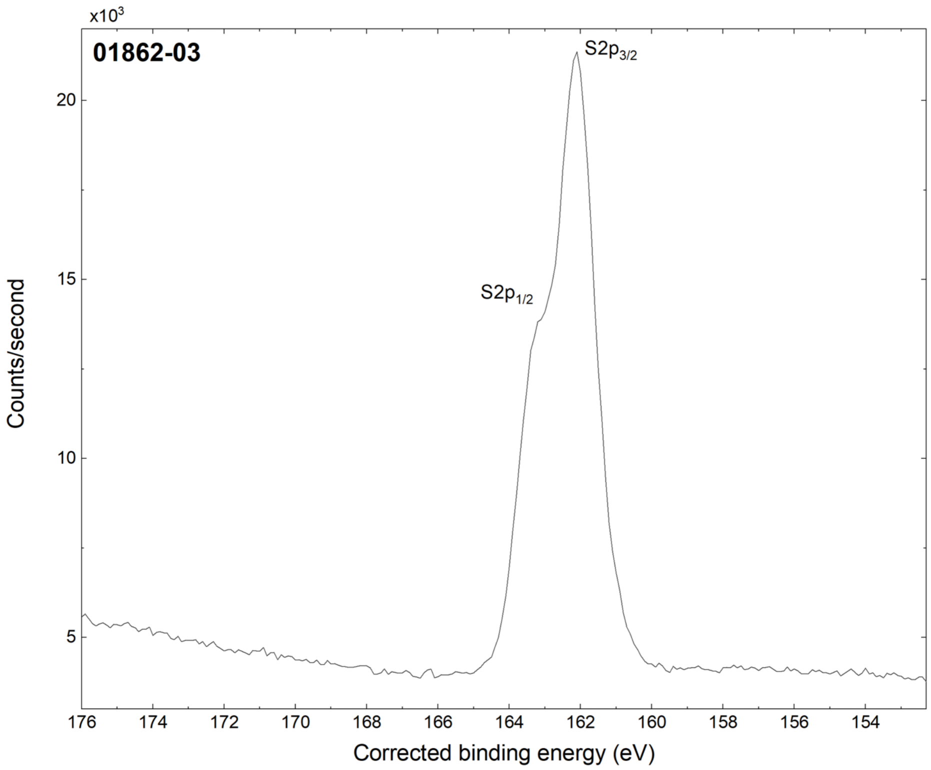
09 May 2024 16:28:04

Accession #	01862-01
■ Host Material:	ZnS
■ Technique:	XPS
■ Spectral Region:	Survey
Instrument:	Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source:	Al K_α monochromatic
Source Energy:	1486.6 eV
Source Strength:	200 W
Source Size:	0.9 × 0.9 mm^2
Analyzer Type:	Spherical sector analyzer
Incident Angle:	58°
Emission Angle:	0°
Analyzer Pass Energy:	150 eV
Analyzer Resolution:	1.000 eV
Total Signal Accumulation Time:	136 s
Total Elapsed Time:	229 s
Number of Scans:	5
Effective Detector Width:	25.441 eV
Comments:	Number of Energy Steps 1361



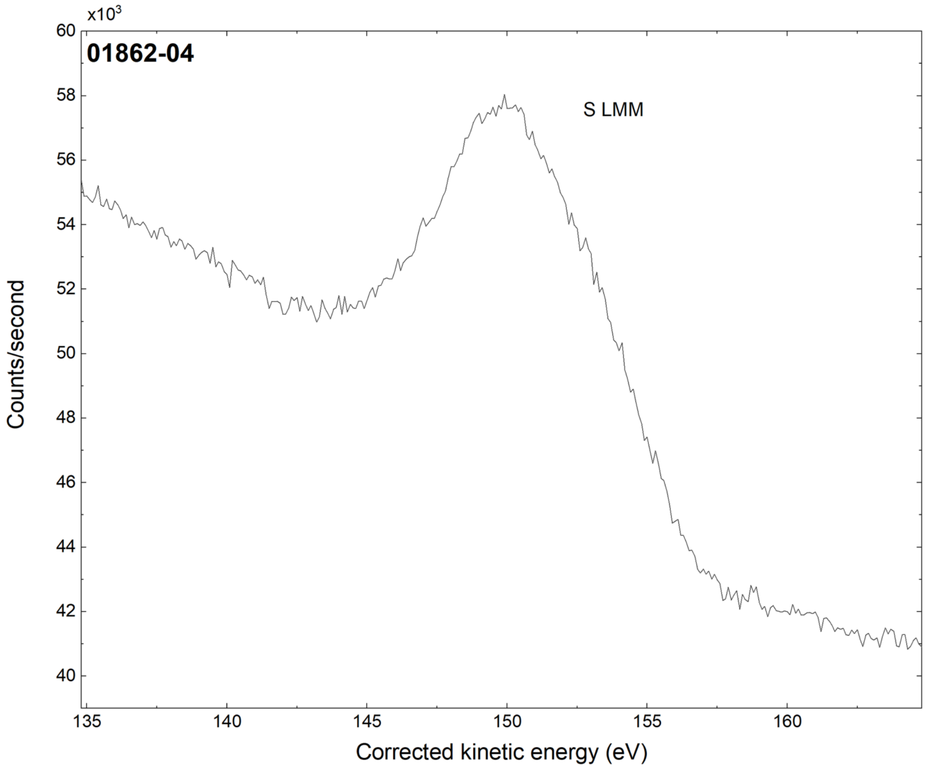
- **Accession #:** 01862-02
- **Host Material:** ZnS
- **Technique:** XPS
- **Spectral Region:** S *2s*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 135.7 s
Total Elapsed Time: 172 s
Number of Scans: 15
Effective Detector Width: 3.392 eV



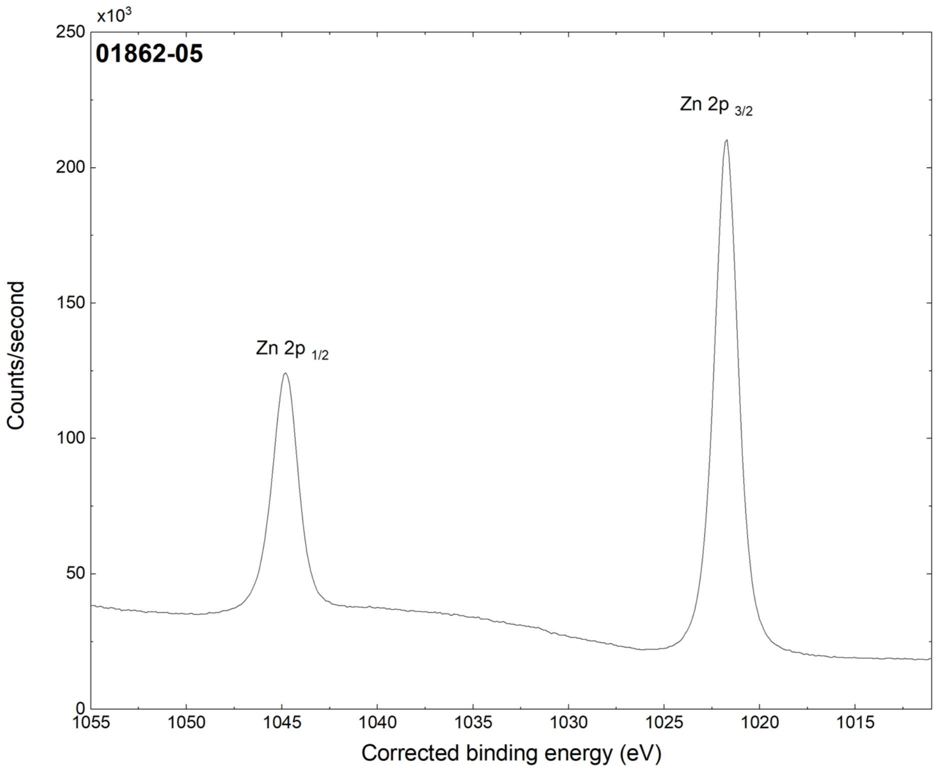
- **Accession #:** 01862-03
- **Host Material:** ZnS
- **Technique:** XPS
- **Spectral Region:** S *2p*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 210.7 s
Total Elapsed Time: 252 s
Number of Scans: 15
Effective Detector Width: 3.392 eV
Comments: See footnotes SPECTRAL FEATURES TABLE.



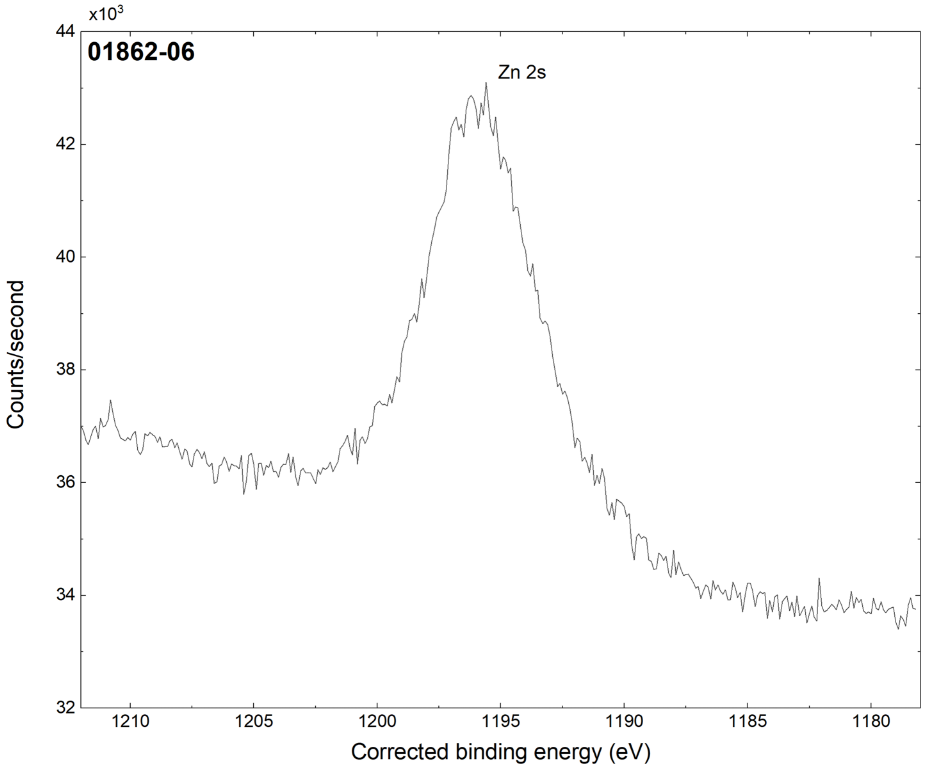
- **Accession #:** 01862-04
- **Host Material:** ZnS
- **Technique:** XAES
- **Spectral Region:** S *LMM*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 225.7 s
Total Elapsed Time: 268 s
Number of Scans: 15
Effective Detector Width: 3.392 eV



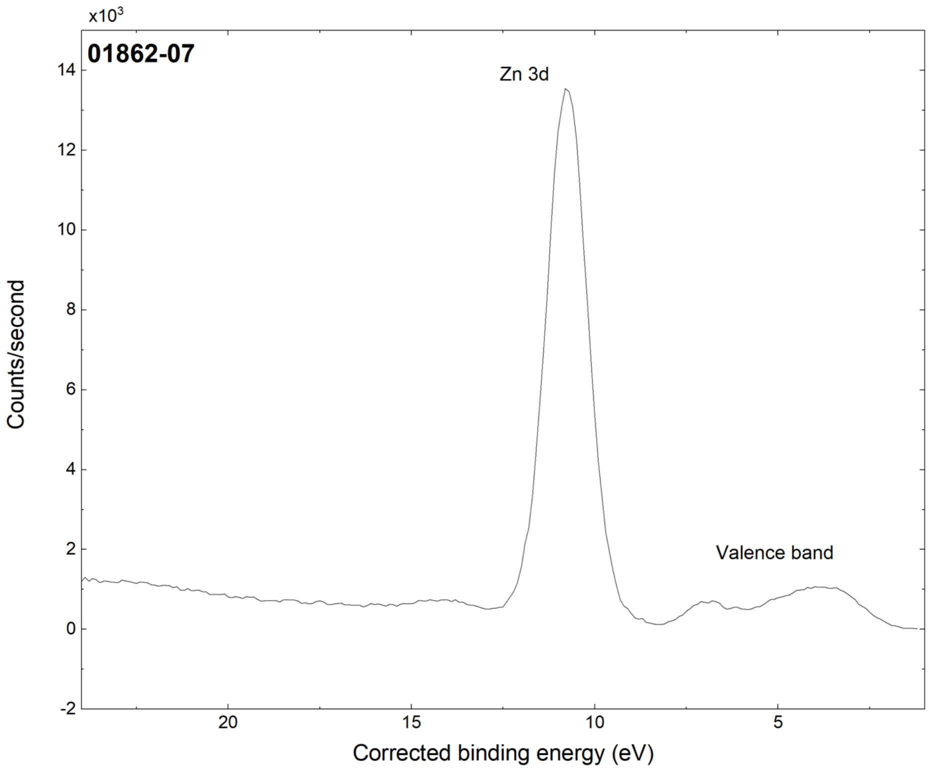
- **Accession #:** 01862-05
- **Host Material:** ZnS
- **Technique:** XPS
- **Spectral Region:** Zn *2p*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 353.1 s
Total Elapsed Time: 406 s
Number of Scans: 15
Effective Detector Width: 3.392 eV
Comments: See footnotes SPECTRAL FEATURES TABLE



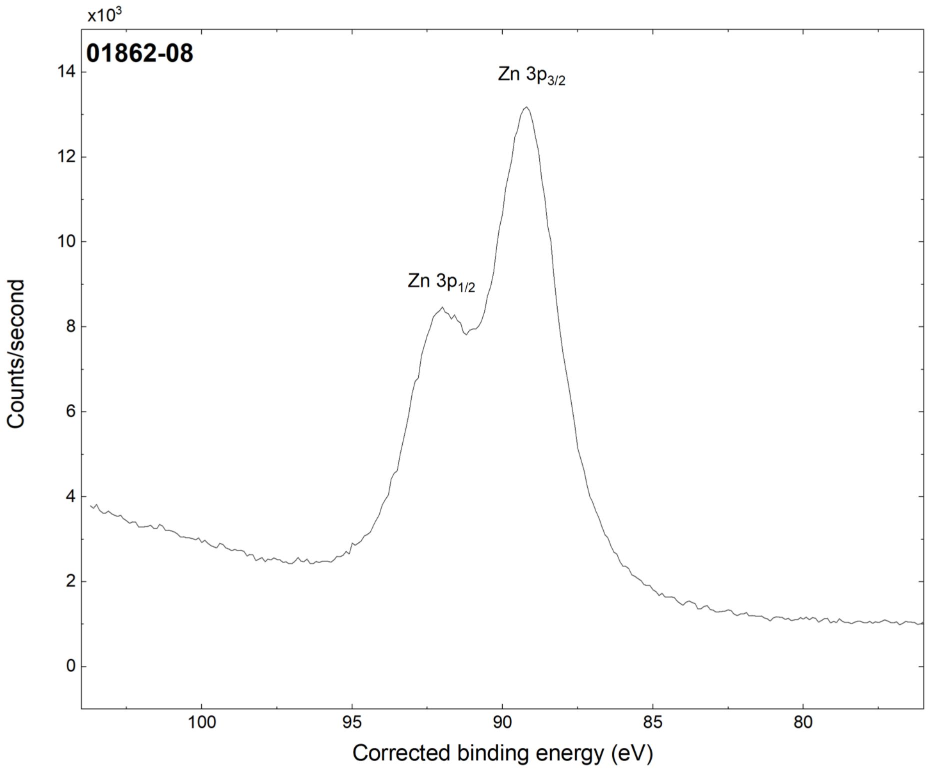
- **Accession #:** 01862-06
- **Host Material:** ZnS
- **Technique:** XPS
- **Spectral Region:** Zn *2s*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 255.6 s
Total Elapsed Time: 300 s
Number of Scans: 15
Effective Detector Width: 3.392 eV



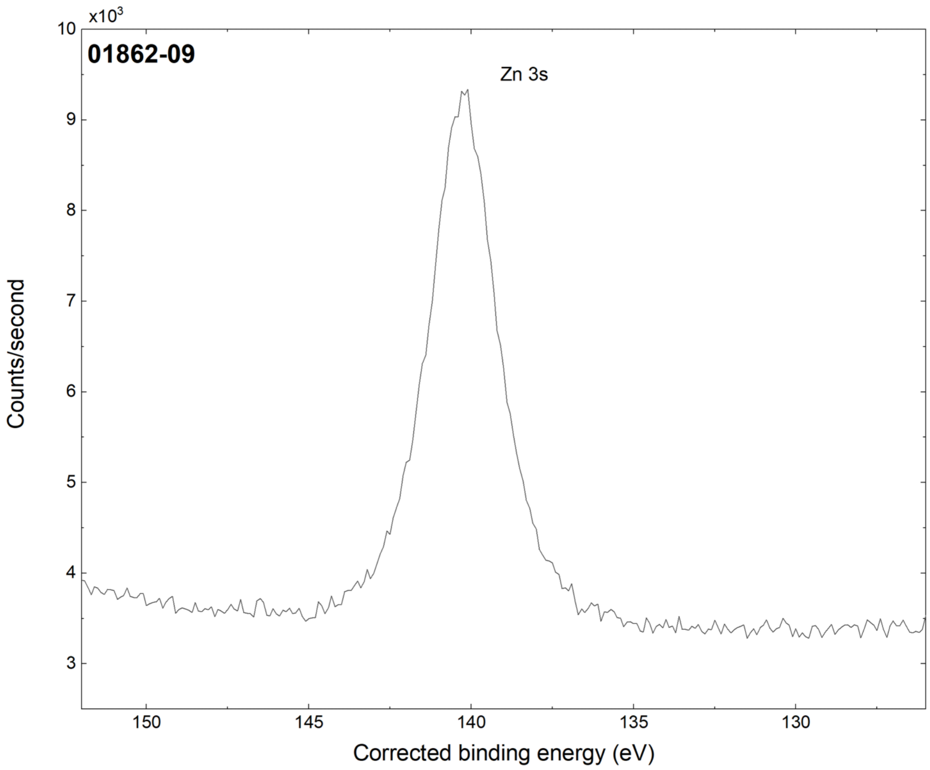
- **Accession #:** 01862-07
- **Host Material:** ZnS
- **Technique:** XPS
- **Spectral Region:** Zn *3d*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 173.2 s
Total Elapsed Time: 221 s
Number of Scans: 15
Effective Detector Width: 3.392 eV



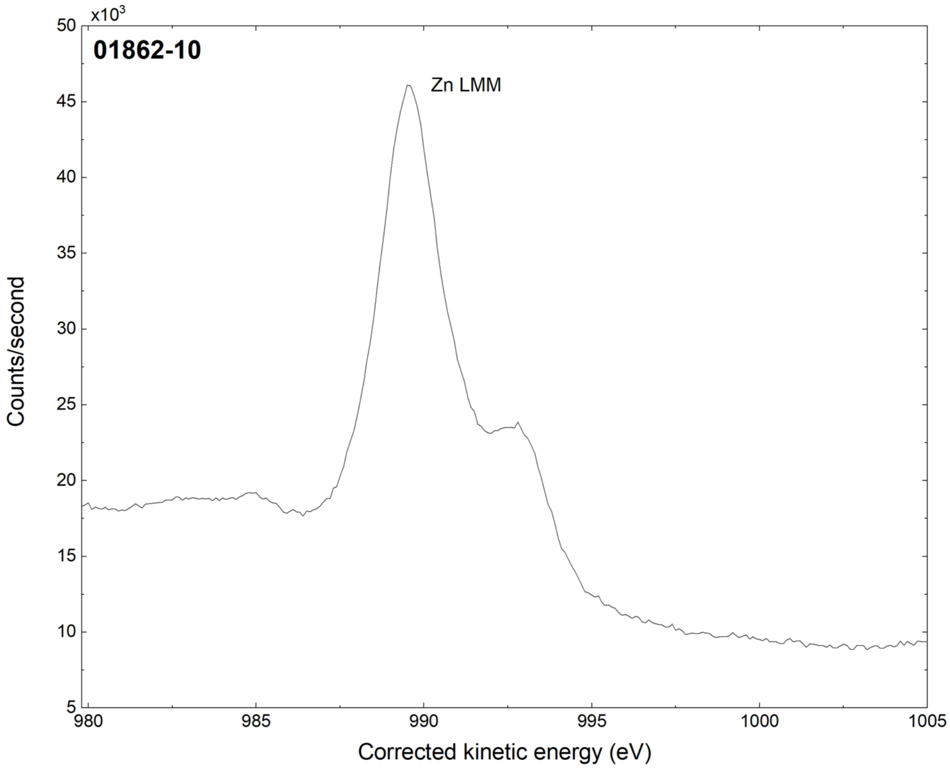
- **Accession #:** 01862-08
- **Host Material:** ZnS
- **Technique:** XPS
- **Spectral Region:** Zn *3p*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 214.4 s
Total Elapsed Time: 256 s
Number of Scans: 15
Effective Detector Width: 3.392 eV
Comments: See footnotes SPECTRAL FEATURES TABLE.



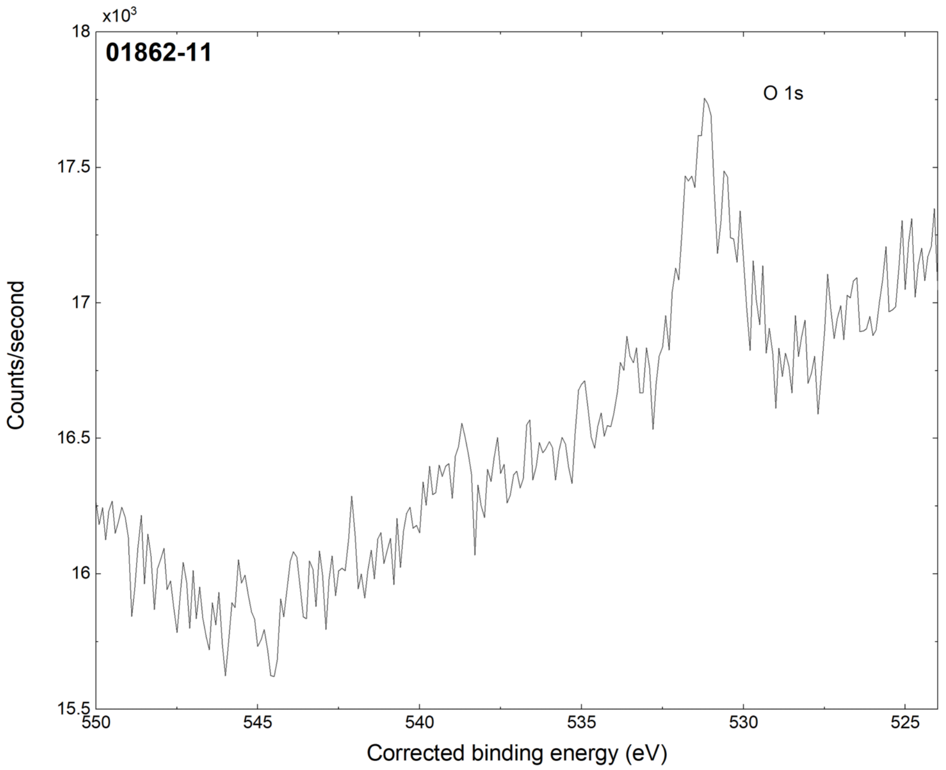
- **Accession #:** 01862-09
- **Host Material:** ZnS
- **Technique:** XPS
- **Spectral Region:** Zn *3s*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 203.2 s
Total Elapsed Time: 244 s
Number of Scans: 15
Effective Detector Width: 3.392 eV



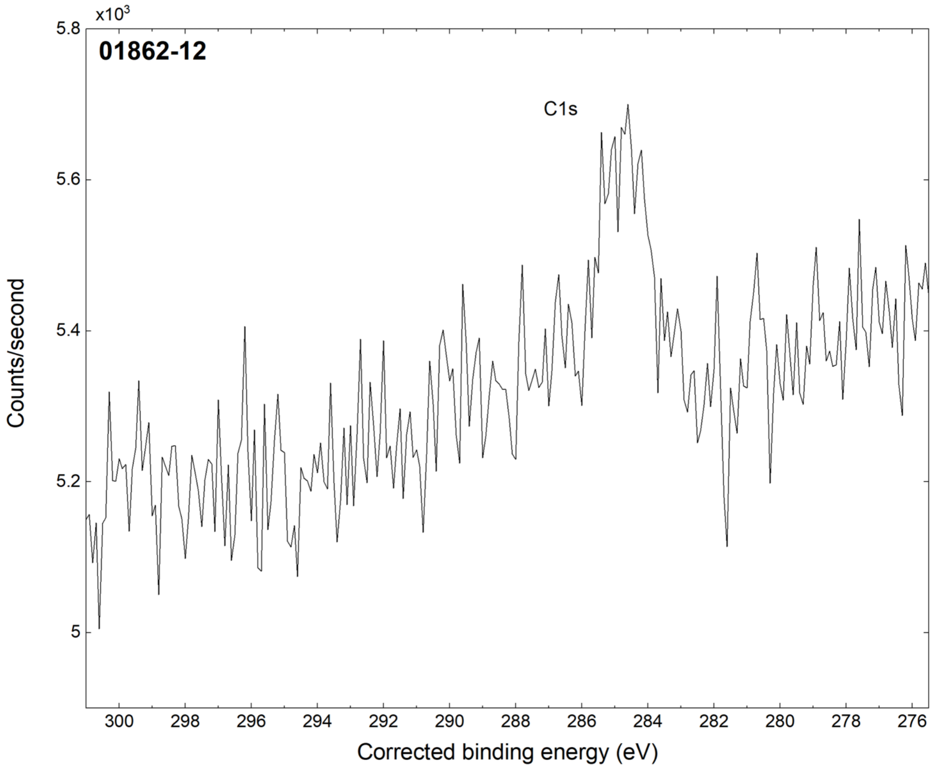
- **Accession #:** 01862-10
- **Host Material:** ZnS
- **Technique:** XAES
- **Spectral Region:** Zn *LMM*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 203.2 s
Total Elapsed Time: 245 s
Number of Scans: 15
Effective Detector Width: 3.392 eV
Comments: See footnotes SPECTRAL FEATURES TABLE



- **Accession #:** 01862-11
- **Host Material:** ZnS
- **Technique:** XPS
- **Spectral Region:** O *1s*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 225.7 s
Total Elapsed Time: 268 s
Number of Scans: 15
Effective Detector Width: 3.392 eV
Comments: See footnotes SPECTRAL FEATURES TABLE



- **Accession #:** 01862-12
- **Host Material:** ZnS
- **Technique:** XPS
- **Spectral Region:** C *1s*

Instrument: Thermo Fisher Scientific ESCALAB 250Xi
Excitation Source: Al K_α monochromatic
Source Energy: 1486.6 eV
Source Strength: 200 W
Source Size: 0.9 × 0.9 mm^2
Analyzer Type: Spherical sector
Incident Angle: 58°
Emission Angle: 0°
Analyzer Pass Energy: 20 eV
Analyzer Resolution: 0.100 eV
Total Signal Accumulation Time: 218.2 s
Total Elapsed Time: 259 s
Number of Scans: 15
Effective Detector Width: 3.392 eV
Comments: See footnotes SPECTRAL FEATURES TABLE