

HAXPES of 6H-SiC wafer with Cr K α excitation

Pierre-Marie Deleuze^{1, a)}, Kateryna Artyushkova², Eugénie Martinez¹ and Olivier Renault¹

¹ Univ. Grenoble Alpes, CEA, Leti, F-38000 Grenoble, France

²Physical Electronics, 18725 Lake Drive East, Chanhassen, Minnesota 55317

(Received day Month year; accepted day Month year; published day Month year)

A C-terminated SiC wafer was analyzed by high-energy photoelectron spectroscopy (HAXPES) using monochromatic Cr K α (5414.8 eV) radiation. The data include a survey scan and high-resolution spectra of Si 1s, Si 2s, Si 2p, C 1s and O 1s core-levels.

Keywords: SiC, HAXPES, Cr K α

INTRODUCTION

Beyond conventional uses in abrasive tool and high-temperature mechanics, SiC has emerged as one of the most suitable material for wide bandgap semiconductor technologies thanks to the availability of low-defects 6H-SiC wafers. For example, thanks to a low lattice mismatch, such wafers allow the growth of GaN which is a prime candidate for power transistor applications. 6H-SiC has already been studied using Mg K α and Zr L α photons (Ref. 1) as well as Al K α radiation (Ref. 2) but never using higher energy lab sources.

In this work, we report HAXPES spectra recorded on a 6H-SiC wafer using monochromatic Cr K α excitation at 5414.8 eV. The data contain a survey scan as well as high-resolution spectra of Si 1s, Si 2s, Si 2p, C 1s and O 1s core-levels.

SPECIMEN DESCRIPTION (ACCESSION # 01713)

Host Material: SiC

CAS Registry #: 409-21-2

Host Material Characteristics: Homogeneous; solid; single crystal; semiconductor; semiconductor; Ceramic

Chemical Name: Silicon carbide

Source: Cree, Inc.

Host Composition: SiC

Form: SiC wafer

Structure: 6H hexagonal, C-terminated face

History & Significance: Air exposed SiC wafer

As Received Condition: SiC wafer

Analyzed Region: Same as host material

Ex Situ Preparation/Mounting: The sample was mounted on the sample holder using double sided conductive tape.

Accession#: 01713

Technique: XPS

Host Material: SiC

Instrument: ULVAC-PHI Quantes

Major Elements in Spectra: Si, C

Minor Elements in Spectra: O

Published Spectra: 6

Spectra in Electronic Record: 6

Spectral Category: comparison

In Situ Preparation: The sample was sputter cleaned by Ar⁺ ions (100 eV) for one hour prior to measurements to remove carbon and oxygen contamination.

Charge Control: Low-energy electrons (1 eV, filament 1.1 A) and low-energy Ar⁺ ions (10 eV)

Temp. During Analysis: 300 K

Pressure During Analysis: < 2.10⁻⁷ Pa

Pre-analysis Beam Exposure: 0 s

INSTRUMENT DESCRIPTION

Manufacturer and Model: ULVAC-PHI Quantes

Analyzer Type: spherical sector

Detector: multichannel resistive plate

Number of Detector Elements: 32

INSTRUMENT PARAMETERS COMMON TO ALL SPECTRA

■ Spectrometer

Analyzer Mode: constant pass energy

Throughput (T=E^N): The energy dependence can be modeled using the following equation: $\frac{A}{E_p} = \left(\frac{a^2}{a^2 + R^2}\right)^b$, where a and b are constants, E_p is the pass energy, A is the peak area and R is the retard ratio equal to E/E_p, where E is the kinetic energy. Three spectral regions are recorded on a sputter cleaned sample at different pass energies. The values of a and b are then determined by a linear least square fit of the data applying the equation described above.

Excitation Source Window: Al

Excitation Source: Cr K α monochromatic

Source Energy: 5414.8 eV

Source Strength: 50 W

Source Beam Size: 100 μ m x 100 μ m

^{a)}Electronic mail: pierre-marie.deleuze@cea.fr

Signal Mode: multichannel direct

■ **Geometry**

Incident Angle: 22 °

Source-to-Analyzer Angle: 46 °

Emission Angle: 45 °

Specimen Azimuthal Angle: 0 °

Acceptance Angle from Analyzer Axis: 0 °

Analyzer Angular Acceptance Width: 20 ° x 20 °

■ **Ion Gun**

Manufacturer and Model: ULVAC-PHI Quantes

Energy: 10 and 100 eV

Current: 1.4×10^{-5} mA

Current Measurement Method: Faraday cup

Sputtering Species: Ar

Spot Size (unrastered): 100 μ m

Raster Size: N/A

Incident Angle: 45 °

Polar Angle: 45 °

Azimuthal Angle: 45 °

Comment: Differentially pumped ion gun used for pre-sputtering of the sample and to prevent reoxidation during the XPS analysis.

DATA ANALYSIS METHOD

Energy Scale Correction: The decrease of photoelectron cross sections in HAXPES (Refs. 3 and 4) leads to a very low adventitious C 1s intensity. Therefore, the binding energy was referenced to the Si 2p binding energy position measured with Al K α radiation after shifting the adventitious C 1s peak to 284.8 eV. Doing so, the Si 2p binding energy was 101.3 eV. The spectra recorded with the Cr K α source were then rescaled by shifting the Si 2p to 101.3 eV. Note that, in general, the accuracy of the procedure may be limited in case of large band bending of highly-doped SiC surfaces, which is not the case here. It is estimated that the maximum error on peak position is around 0.3 eV.

Recommended Energy Scale Shift: 1.7 eV for binding energy

Peak Shape and Background Method: Shirley background was employed to treat the data. No curve fitting was conducted on the spectra.

Quantitation Method: PHI Multipak software Version 9.9.0.8 was used to perform quantification. Empirically determined sensitivity factors (RSFs) were provided by the software. The RSFs were derived from the pure-element relative sensitivity factor as defined in ISO 18118:2015 (Ref 5) which were measured on pure element samples using a Cr K α source. They therefore account for the decrease of cross-section and different escape depth of photoelectrons using higher energy photons. RSFs are reported proportional to the RSF of F 1s equal to 1. The reported concentrations were calculated using these RSFs corrected to include the transmission function and the asymmetry parameter.

ACKNOWLEDGMENTS

This work was performed at the Platform For NanoCharacterization (PFNC) of CEA-Leti with support from the Recherche Technologique de Base (RTB) program of the french ministry of research. The authors acknowledge the support of the PHI-Leti TANDEM collaboration program.

DATA AVAILABILITY STATEMENT

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

REFERENCES

1. A. R. Chourasia, *Surf. Sci. Spectra* **8**, 45 (2001).
2. M. J. Bozack, *Surf. Sci. Spectra* **3**, 82 (1994).
3. M.B. Trzhaskovskaya and V.G. Yarzhemsky, *At. Data Nucl. Data Tables* **119**, 99 (2018).
4. M.B. Trzhaskovskaya and V.G. Yarzhemsky, *At. Data Nucl. Data Tables* **129-130**, 101280 (2019).
5. International Organization for Standardization 2015, *Surface chemical analysis - Auger electron spectroscopy and X-ray photoelectron spectroscopy - Guide to the use of experimentally determined relative sensitivity factors for the quantitative analysis of homogeneous materials*, ISO 18118:2015.

This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512

SPECTRAL FEATURES TABLE							
Spectrum ID #	Element/ Transition	Peak Energy (eV)	Peak Width FWHM (eV)	Peak Area (eV x cts/s)	Sensitivity Factor	Concentration (at. %)	Peak Assignment
01713-02	Si 1s	1841.2	1.60	15149	4.653	48.3	SiC
01713-03	Si 2s	152.6	1.90	1236	0.436	...	SiC
01713-04	Si 2p	101.3	1.58	413	0.110	...	SiC
01713-05	C 1s	283.5	1.40	565	0.199	49.8	SiC
01713-06	O 1s	532.5	0.58	68	0.589	1.9	Contamination

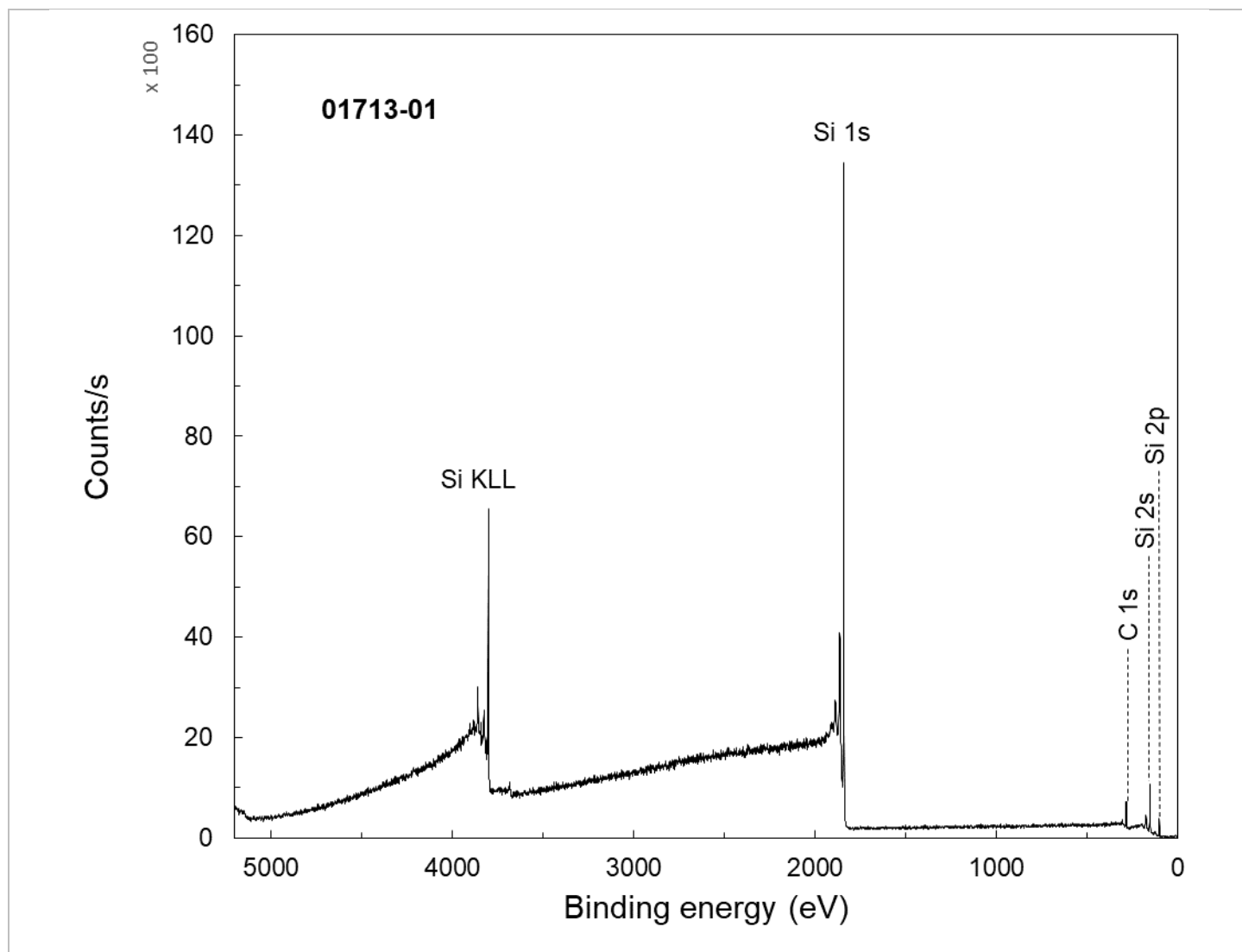
ANALYZER CALIBRATION TABLE							
Spectrum ID #	Element/ Transition	Peak Energy (eV)	Peak Width FWHM (eV)	Peak Area (eV x cts/s)	Sensitivity Factor	Concentration (at. %)	Peak Assignment
...	Ag3d _{5/2}	368.12	0.63	114999
...	Cu2p _{3/2}	932.61	0.96	40205
...	Au4f _{7/2}	83.89	0.78	100500

The spectra in the analyzer calibration table were recorded using Al K α photons.

GUIDE TO FIGURES					
Spectrum (Accession) #	Spectral Region	Voltage Shift*	Multiplier	Baseline	Comment #
01713-01	Survey	0	1	0	...
01713-02	Si 1s	-1.7	1	0	...
01713-03	Si 2s	-1.7	1	0	...
01713-04	Si 2p	-1.7	1	0	...
01713-05	C 1s	-1.7	1	0	...
01713-06	O 1s	-1.7	1	0	...

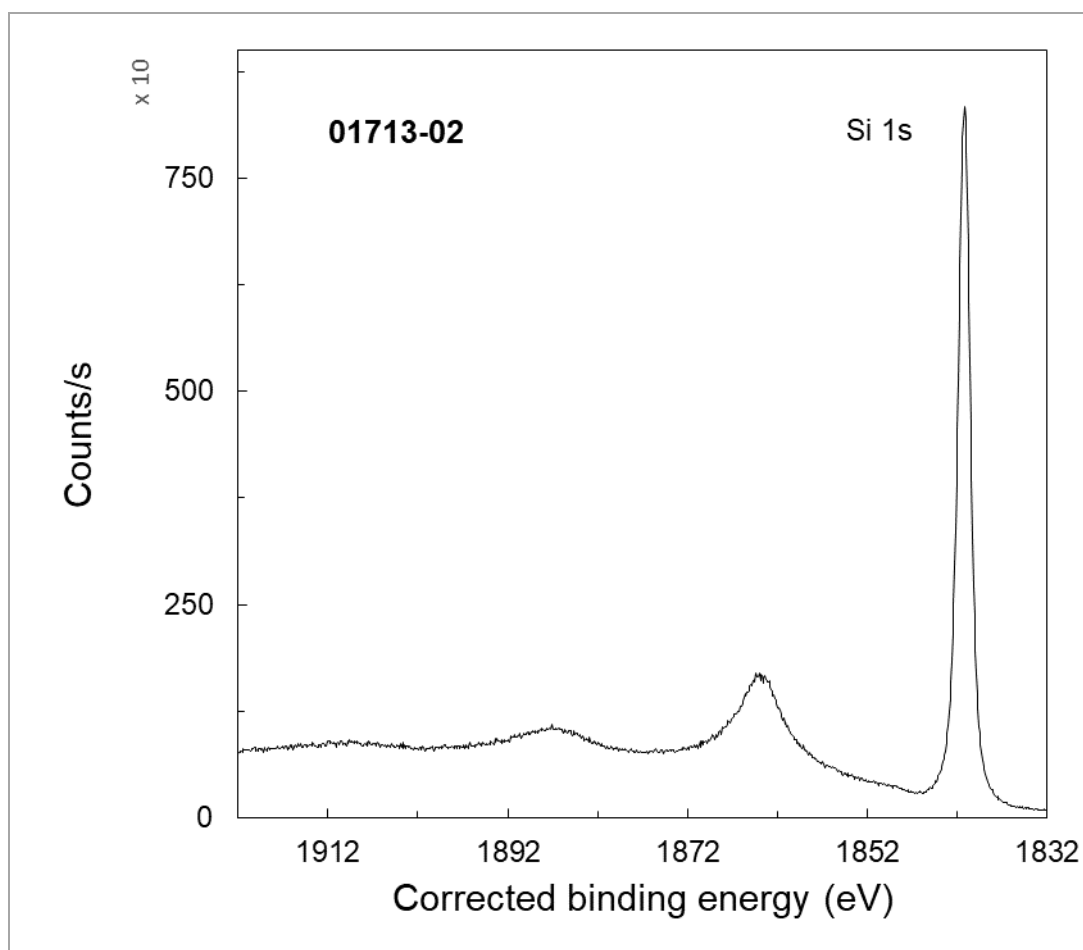
*Voltage shift of the archived (as-measured) spectrum relative to the printed figure. The figure reflects the recommended energy scale correction due to a calibration correction, sample charging, flood gun, or other phenomenon.

This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



Accession #	01713-01
Host Material	SiC
Technique	XPS
Spectral Region	survey
Instrument	ULVAC-PHI Quantes
Excitation Source	Cr K α monochromatic
Source Energy	5414.8 eV
Source Strength	50 W
Source Size	0.1 mm x 0.1 mm
Analyzer Type	spherical sector analyzer
Incident Angle	22°
Emission Angle	45°
Analyzer Pass Energy	280 eV
Analyzer Resolution	2.33 eV
Total Signal Accumulation Time	5240 s
Total Elapsed Time	5760 s
Number of Scans	10
Effective Detector Width	31 eV

This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



■ **Accession #:** 01713-02

■ **Host Material:** SiC

■ **Technique:** XPS

■ **Spectral Region:** Si 1s

Instrument: ULVAC-PHI

Quantes

Excitation Source:

Cr K_{α} monochromatic

Source Energy: 5414.8 eV

Source Strength: 50 W

Source Size: 0.1 mm x 0.1 mm

Analyzer Type: spherical sector

Incident Angle: 22 °

Emission Angle: 45 °

Analyzer Pass Energy 112 eV

Analyzer Resolution: 1.17 eV

Total Signal Accumulation

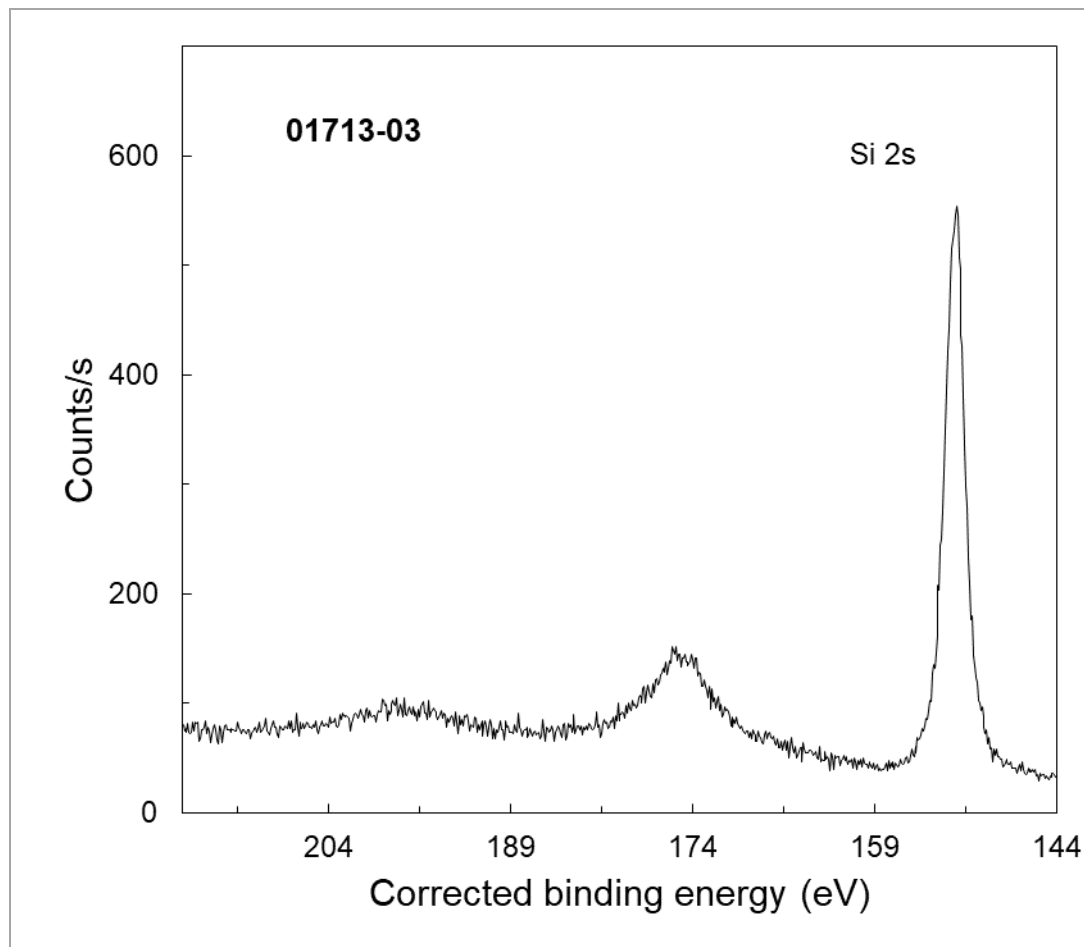
Time: 3684 s

Total Elapsed Time: 4056 s

Number of Scans: 9

Effective Detector Width: 12.4 eV

This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



■ Accession #: 01713-03

■ Host Material: SiC

■ Technique: XPS

■ Spectral Region: Si 2s

Instrument: ULVAC-PHI

Quantes

Excitation Source:

Cr K α monochromatic

Source Energy: 5414.8 eV

Source Strength: 50 W

Source Size: 0.1 mm x 0.1 mm

Analyzer Type: spherical sector

Incident Angle: 22 °

Emission Angle: 45 °

Analyzer Pass Energy 112 eV

Analyzer Resolution: 1.17 eV

Total Signal Accumulation

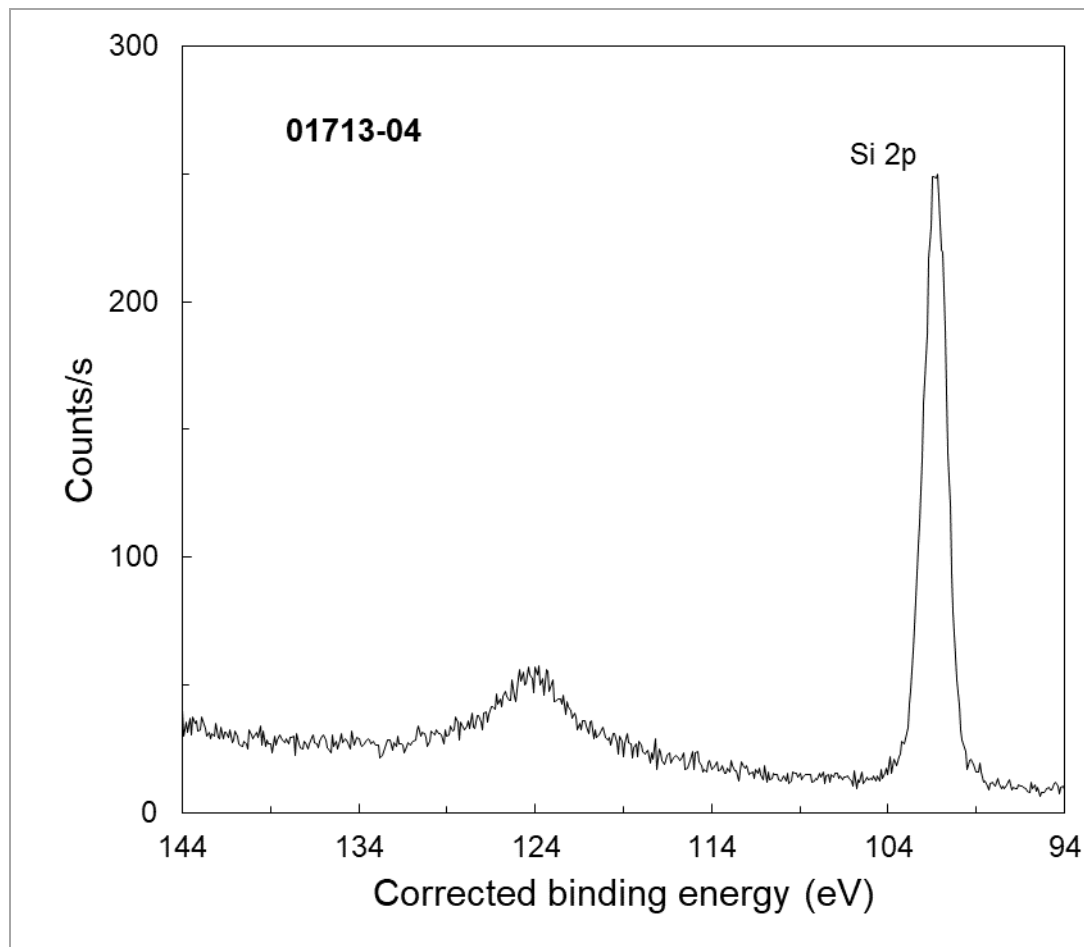
Time: 4050 s

Total Elapsed Time: 4458 s

Number of Scans: 12

Effective Detector Width: 12.4 eV

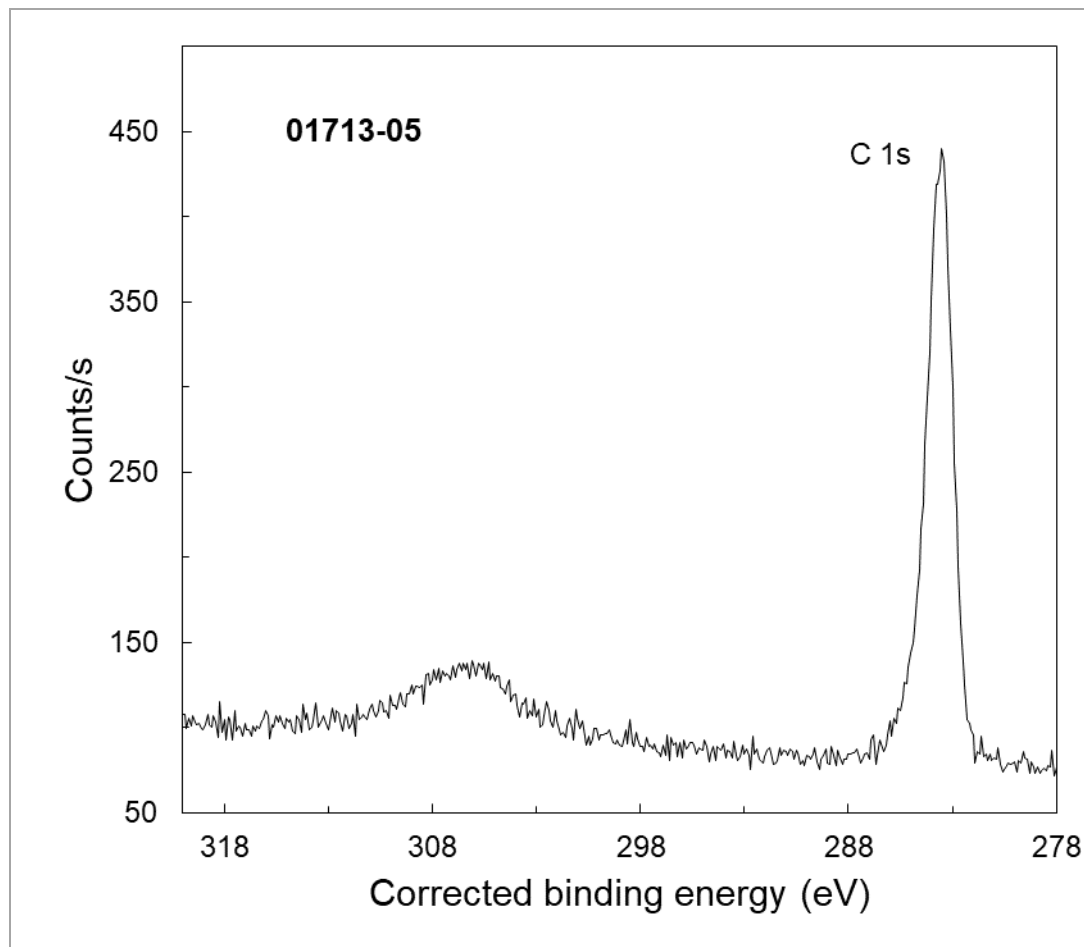
This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



- Accession #: 01713-04
- Host Material: SiC
- Technique: XPS
- Spectral Region: Si 2p

Instrument: ULVAC-PHI
Quantes
Excitation Source:
Cr K α monochromatic
Source Energy: 5414.8 eV
Source Strength: 50 W
Source Size: 0.1 mm x 0.1 mm
Analyzer Type: spherical sector
Incident Angle: 22 °
Emission Angle: 45 °
Analyzer Pass Energy 112 eV
Analyzer Resolution: 1.17 eV
Total Signal Accumulation
Time: 3744 s
Total Elapsed Time: 4122 s
Number of Scans: 17
Effective Detector Width: 12.4 eV

This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



■ **Accession #:** 01713-05

■ **Host Material:** SiC

■ **Technique:** XPS

■ **Spectral Region:** C 1s

Instrument: ULVAC-PHI

Quantes

Excitation Source:

Cr K α monochromatic

Source Energy: 5414.8 eV

Source Strength: 50 W

Source Size: 0.1 mm x 0.1 mm

Analyzer Type: spherical sector

Incident Angle: 22 °

Emission Angle: 45 °

Analyzer Pass Energy 112 eV

Analyzer Resolution: 1.17 eV

Total Signal Accumulation

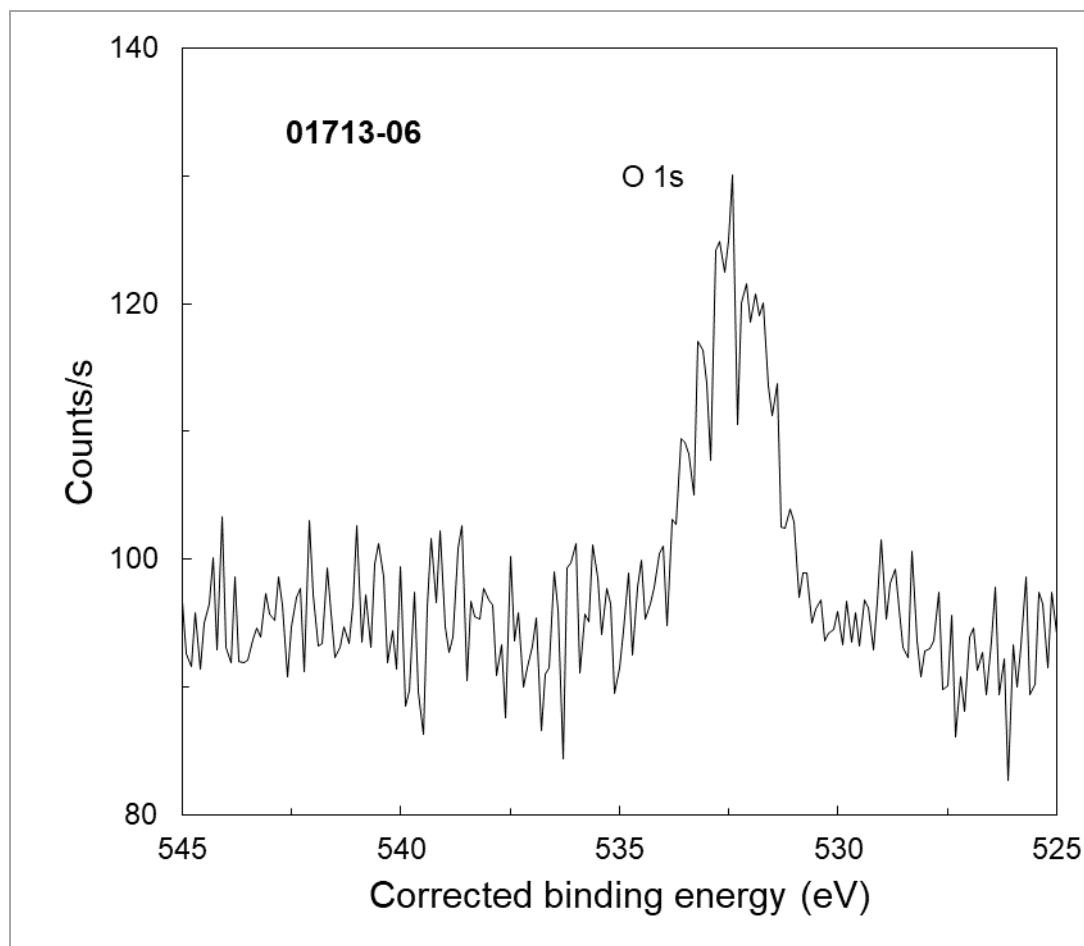
Time: 3918 s

Total Elapsed Time: 4314 s

Number of Scans: 20

Effective Detector Width: 12.4 eV

This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



■ Accession #: 01713-06

■ Host Material: SiC

■ Technique: XPS

■ Spectral Region: O 1s

Instrument: ULVAC-PHI

Quantes

Excitation Source:

Cr K α monochromatic

Source Energy: 5414.8 eV

Source Strength: 50 W

Source Size: 0.1 mm x 0.1 mm

Analyzer Type: spherical sector

Incident Angle: 22 °

Emission Angle: 45 °

Analyzer Pass Energy 112 eV

Analyzer Resolution: 1.17 eV

Total Signal Accumulation

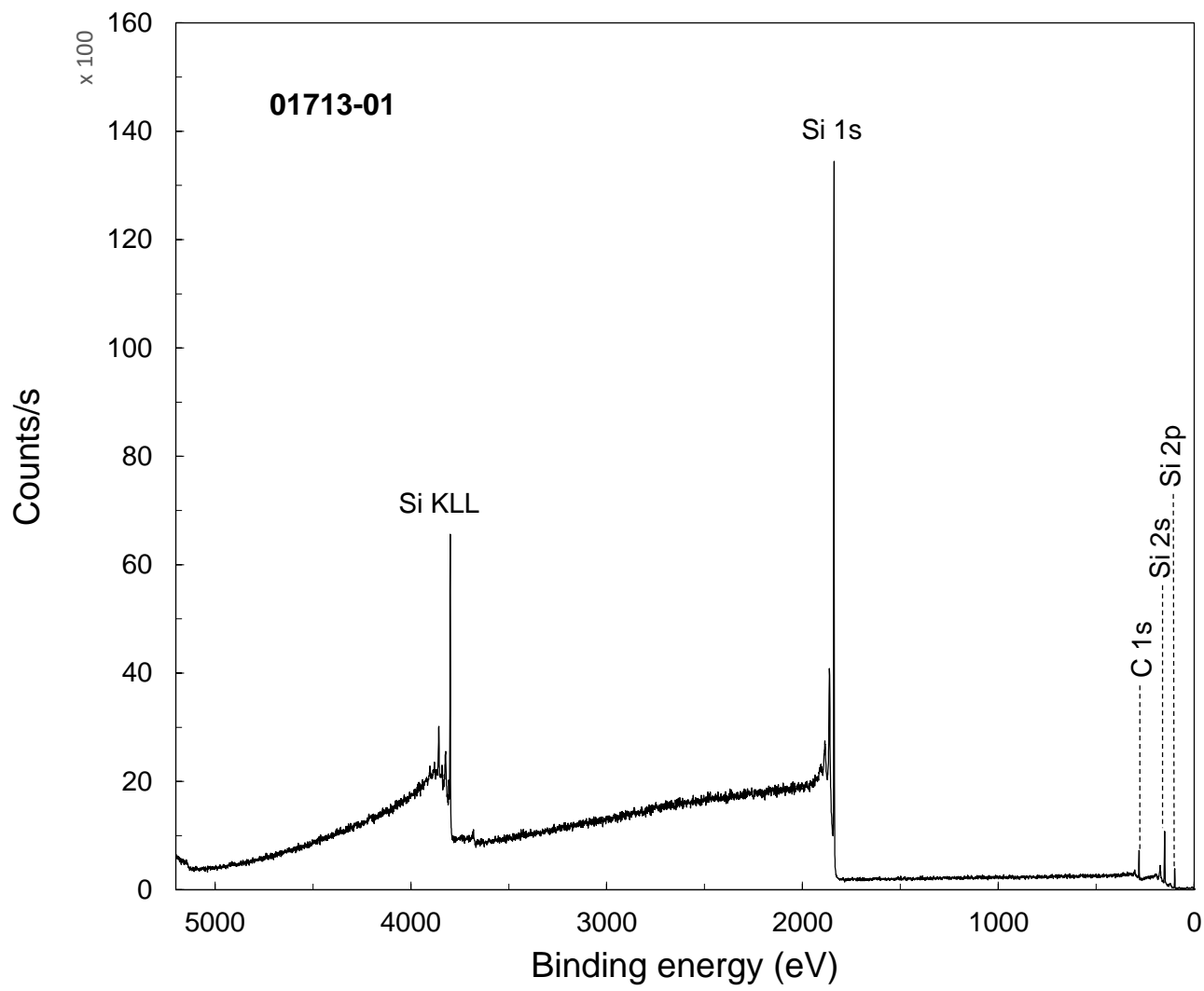
Time: 3108 s

Total Elapsed Time: 3426 s

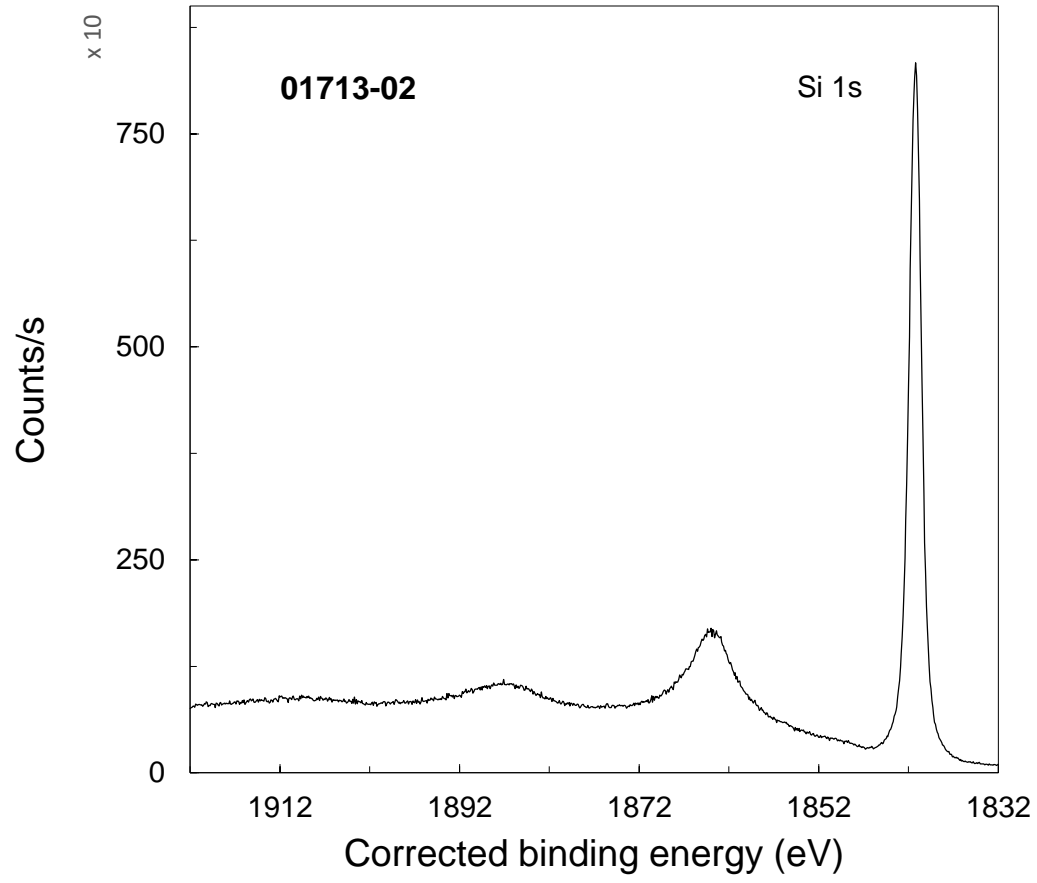
Number of Scans: 15

Effective Detector Width: 12.4 eV

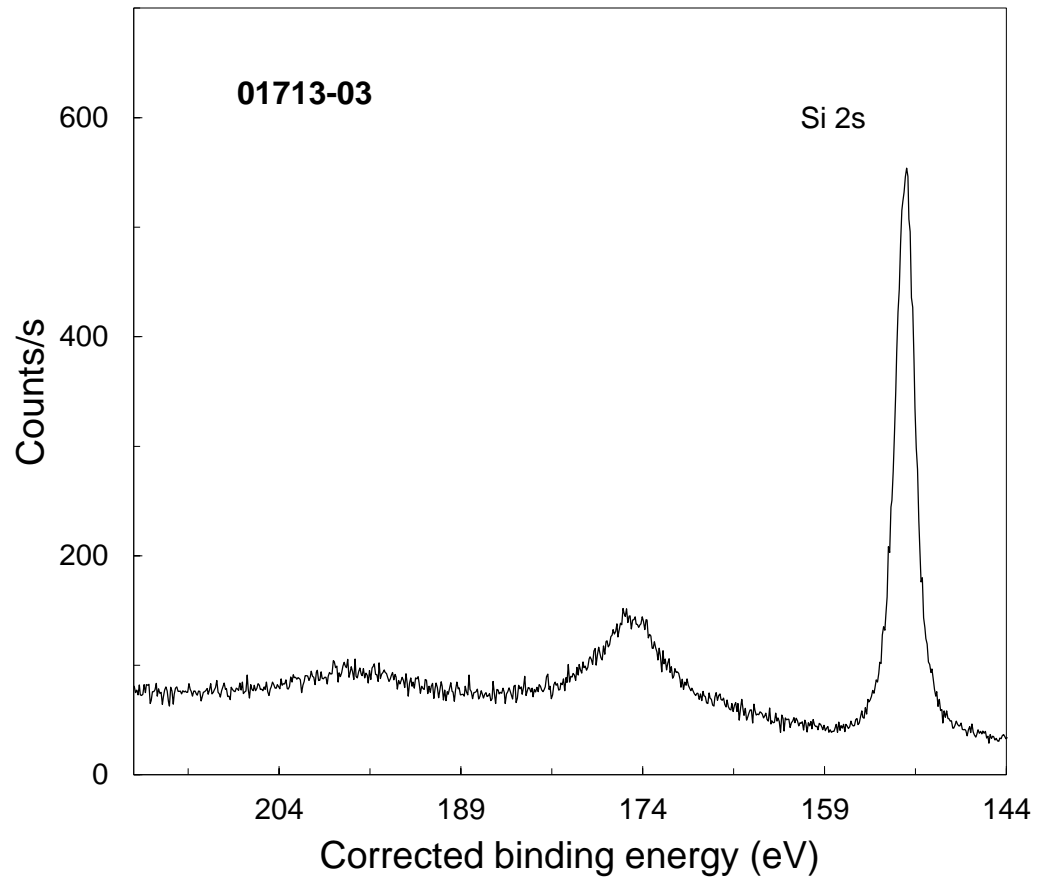
This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
 PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



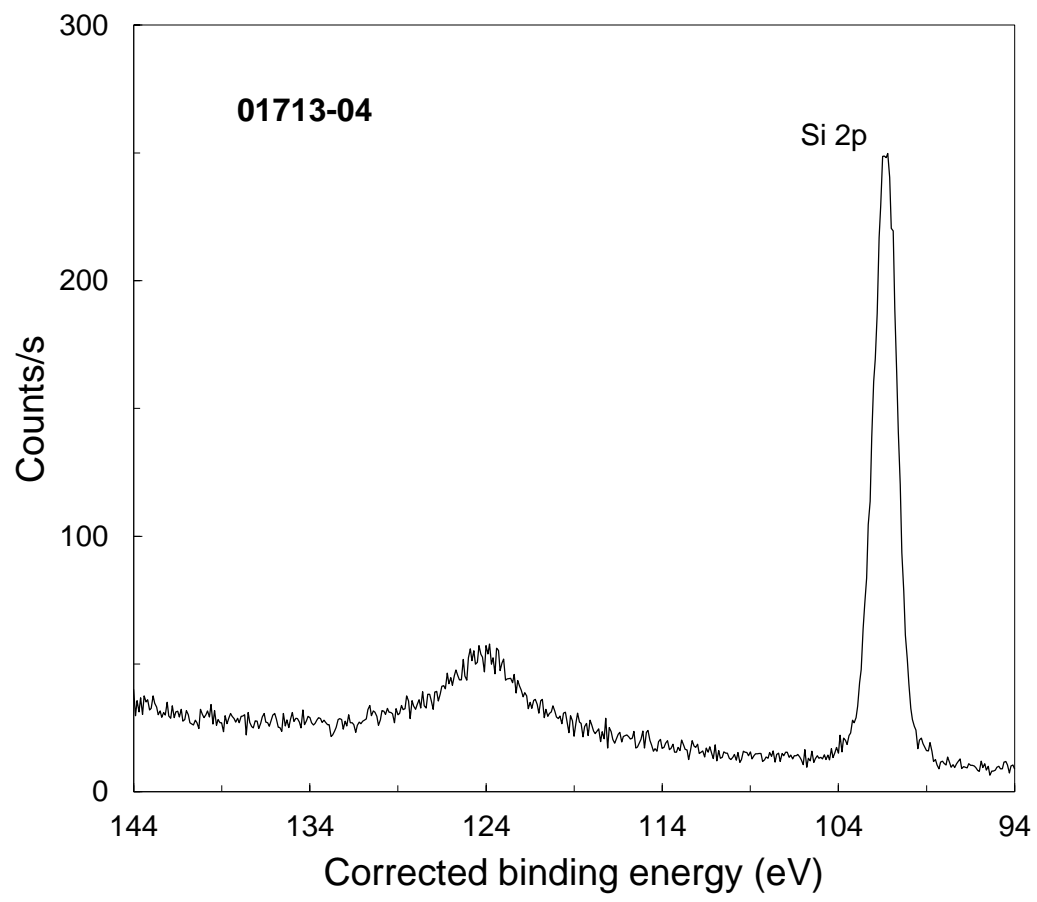
This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



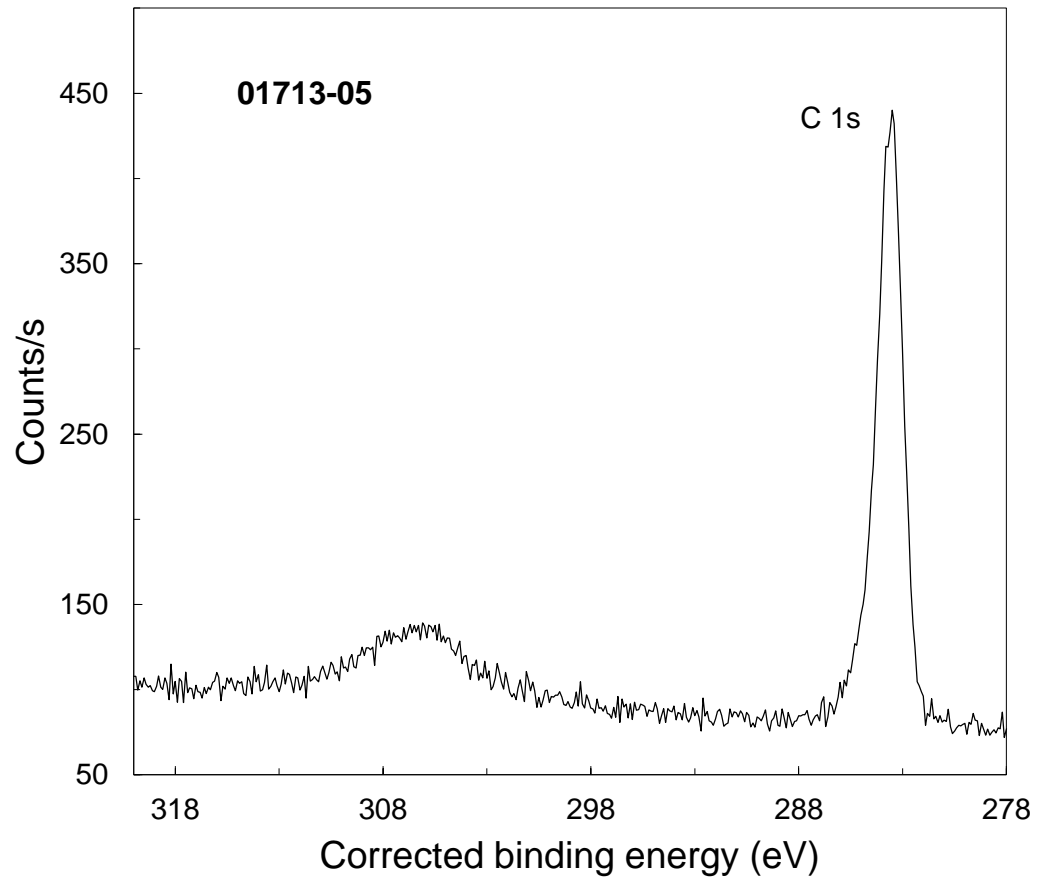
This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512



This is the author's peer reviewed, accepted manuscript. However, the online version of record will be different from this version once it has been copyedited and typeset.
PLEASE CITE THIS ARTICLE AS DOI: 10.1116/6.0001512

