

# Alkyl Monolayers on Silica Surfaces Prepared from Neat, Heated ClSi(CH<sub>3</sub>)<sub>2</sub>(CH<sub>2</sub>)<sub>6</sub>CH=CH<sub>2</sub> Analyzed by XPS

Ghaleb A. Husseini, Amarchand Sathyapalan, Eric T. Sevy, Matthew R. Linford, and Matthew C. Asplund

Dept. of Chemistry and Biochemistry, Brigham Young University, Provo, UT

Silane monolayers on silica, prepared from mono-, di-, and trichlorosilanes, are widely used in industry for surface functionalization and modification. However, unlike di- and trichlorosilanes, monochlorosilanes are particularly easy to work with because they can dimerize, but not polymerize, upon reaction with water. Typically, an organic solvent is used when depositing a silane monolayer. Here we show XPS spectra of monolayers of ClSi(CH<sub>3</sub>)<sub>2</sub>(CH<sub>2</sub>)<sub>6</sub>CH=CH<sub>2</sub> (octenyldimethylchlorosilane, CAS# 17196-12-2) on silicon oxide (silicon wafer) prepared using a rapid, solvent-free approach. Reaction conditions are 120 °C for 10 min using the neat (pure) compound, and no inert atmosphere or special treatment of the compound is required. © 2003 American Vacuum Society. [DOI: 10.1116/11.20020503]

**Keywords:** *x-ray photoelectron spectroscopy; silane; alkylation; monochlorosilanes*

**PACS:** 82.80.Pv, 81.05.Lg

## INTRODUCTION

Silanes (Ref. 1) attach to silica surfaces by reacting with surface silanols (Si–OH). While monolayers prepared from monochlorosilanes are more subject to hydrolysis than those derived from di- and trichlorosilanes, surface functionalization with the mono-functionalized compounds is generally more straightforward because they cannot polymerize. Numerous preparations of silane monolayers on surfaces have been reported in the literature. For example, Maoz and Sagiv first showed that alkyl-terminated monolayers can be prepared on planar silicon using trichlorosilanes (Ref. 2). Recognizing the advantages of mono- over di- and trichlorosilanes, Rabolt and co-workers described a gas phase procedure for depositing perfluorinated alkyldimethylchlorosilanes on SiO<sub>2</sub> (Ref. 3). Both Linton and co-workers (Ref. 4) and Watts and co-workers (Ref. 5) deposited monolayers of alkyldimethylchlorosilanes, onto silica particles using an organic solvent. Typical surface modification conditions call for exposing a surface to a heated, dilute solution of a silane under inert atmosphere. In contrast, here we take clean, dry, native-oxide-terminated silicon (1.5–2.0 nm), place ClSi(CH<sub>3</sub>)<sub>2</sub>(CH<sub>2</sub>)<sub>6</sub>CH=CH<sub>2</sub> on its surface, and heat it at 120 °C for 10 min (relative humidity = 70%). After reacting, the surface is cleaned, dried, loaded into an XPS UHV chamber, and analyzed by XPS, which showed carbon levels consistent with monolayer quantities of surface alkyl chains [ellipsometric thickness = 0.72 ± 0.14 nm, advancing contact angle ( $\theta_a$ ) = 90.5° ± 0.5°, receding contact angle ( $\theta_r$ ) = 76.0° ± 2.2°].

Three replicate samples were subjected to identical treatment and analysis, to show the reproducibility of our technique. Only one sample, with its spectra, is published here, except that the Table of Spectral Features lists comparable features from all three samples. In addition, complete data and spectra for all three samples are archived in the Surface Science Spectra database.

## SPECIMEN DESCRIPTION

**Host Material:** Alkyl monolayer on clean, native oxide terminated silicon derived from ClSi(CH<sub>3</sub>)<sub>2</sub>(CH<sub>2</sub>)<sub>6</sub>CH=CH<sub>2</sub>

**CAS Registry #:** 7440-2-13

**Accession #** 00737

**Technique:** XPS

**Host Material:** Alkyl monolayer/Si – ClSi(CH<sub>3</sub>)<sub>2</sub>(CH<sub>2</sub>)<sub>6</sub>CH=CH<sub>2</sub>

**Instrument:** Surface Science SSX-100

**Major Elements in Spectrum:** C, Si, O

**Minor Elements in Spectrum:** none

**Printed Spectra:** 7

**Spectra in Electronic Record:** 21

**Spectral Category:** technical

**Original Submission:** 5/23/2002

**Accepted for Publication:** 9/30/2002

**Host Material Characteristics:** homogeneous; solid; single crystal; semiconductor; glass; thin film; coating

**Chemical Name:** silicon/silicon oxide

**Source:** Montco Silicon Technologies, Inc.

**Host Composition:** Si/SiO<sub>2</sub>

**Form:** single crystal wafer, *p*-type

**Lot #:** W9969 sample 4

**Structure:** Si(100)

**As Received Condition:** silicon wafer, 125 mm diameter

**Analyzed Region:** host material plus prepared monolayer

**Ex Situ Preparation/Mounting:** The silicon surfaces were first cleaned with a solution of NH<sub>4</sub>OH (conc.): H<sub>2</sub>O<sub>2</sub> (conc.) (50:50) (v/v) for 30 min at room temperature. They were then rinsed with water and finally washed with 5% vol. HCl (conc.) for 1 h. After reaction in the oven (for 10 min), the wafers were rinsed with acetone, cleaned with a soft artists brush using a 2% sodium dodecyl sulfate solution in water, and placed in a Soxhlet apparatus overnight using *m*-xylene (b.p. ~139 °C) as the extraction solvent. The samples were then removed from the Soxhlet, rinsed with water, dried, and mounted into the XPS machine. (Note: source beam size on the instrument was not well characterized and may be up to twice as large as the manufacturer's values given here [See entry for Source Beam Size at Specimen Surface].) Warning: this procedure should not be attempted with volatile silanes. Fumes from a volatile organic compound are potentially explosive. In addition, the NH<sub>4</sub>OH/H<sub>2</sub>O<sub>2</sub> cleaning solution is extremely caustic and should be used with great care.

**In Situ Preparation:** not specified

**Charge Control:** none

**Temp. During Analysis:** 298 K

**Pressure During Analysis:** <1.79×10<sup>-7</sup> Pa

## INSTRUMENT DESCRIPTION

**Manufacturer and Model:** Surface Science Laboratories, Inc., SSX-100

**Analyzer Type:** spherical sector

**Detector:** resistive anode position detector

**Number of Detector Elements:** 128

## INSTRUMENT PARAMETERS COMMON TO ALL SPECTRA

### ■ Spectrometer

**Analyzer Mode:** constant pass energy

**Throughput ( $T=E^N$ ):**  $N=0$

**Excitation Source Window:** 10  $\mu\text{m}$  Mylar

**Excitation Source:** Al  $K_{\alpha}$  monochromatic

**Source Energy:** 1486.6 eV

**Source Strength:** 200 W

**Source Beam Size:** 0.8 mm  $\times$  0.8 mm

**Signal Mode:** multichannel direct

### ■ Geometry

**Incident Angle:** 55°

**Source to Analyzer Angle:** 70.8°

**Emission Angle:** 55°

**Specimen Azimuthal Angle:** 0°

**Acceptance Angle from Analyzer Axis:** 30°

**Analyzer Angular Acceptance Width:** 30°  $\times$  30°

## DATA ANALYSIS METHOD

**Peak Shape and Background Method:** background Shirley function

## ACKNOWLEDGMENTS

The authors acknowledge the help of Yit-Yian Lua at Brigham Young University in using the XPS.

## REFERENCES

1. E. P. Plueddemann, *Silane Coupling Agents* (Plenum, New York, 1991).
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3. P. W. Hoffman, M. Stelzle, and J. F. Rabolt, *Langmuir* **13**, 1877 (1997).
4. S. J. Simko, M. L. Miller, and R. W. Linton, *Anal. Chem.* **57**, 2448 (1985).
5. V. A. Brown, D. A. Barrett, P. N. Shaw, M. C. Davies, H. J. Ritchie, P. Ross, A. J. Paul, and J. F. Watts, *Surf. Interface Anal.* **21**, 263 (1994).

### SPECTRAL FEATURES TABLE

Spectrum ID #	Element/Transition	Peak Energy (eV)	Peak Width FWHM (eV)	Peak Area (counts)	Sensitivity Factor	Concentration (at. %)	Peak Assignment
00737-02	Si 2p	100.00	1.744	49165	0.9	42.12	...
00737-03	C 1s	285.70	3.127	26524	1.0	20.533	...
00737-04	O 1s	533.13	1.998	120269	2.49	37.344	...
00737-05	Si 2p	99.94	1.257	10839	0.9	...	...
00737-06	C 1s	285.97	1.671	1886	1.0	...	...
00737-07	O 1s	533.12	2.951	28488	2.49	...	...
00737-09	Si 2p	99.98	1.423	52907	0.9	41.796	...
00737-10	C 1s	285.64	2.741	27256	1.0	19.454	...
00737-11	O 1s	533.17	2.489	135341	2.49	38.750	...
00737-12	Si 2p	99.99	1.196	10467	0.9	...	...
00737-13	C 1s	285.6	1.80	5591	1.0	...	...
00737-14	O 1s	533.06	3.018	30507	2.49	...	...
00737-16	Si 2p	101.43	4.83	28571	0.9	43.642	...
00737-17	C 1s	286.07	3.546	13648	1.0	18.826	...
00737-18	O 1s	533.08	2.205	67850	2.49	37.532	...

**SPECTRAL FEATURES TABLE (CONT.)**

Spectrum ID #	Element/Transition	Peak Energy (eV)	Peak Width FWHM (eV)	Peak Area (counts)	Sensitivity Factor	Concentration (at. %)	Peak Assignment
00737-19	Si 2 <i>p</i>	101.5	4.65	5164	0.9	...	...
00737-20	C 1 <i>s</i>	285.97	2.438	2168	1.0	...	...
00737-21	O 1 <i>s</i>	533.31	2.295	13327	2.49	...	...

**ANALYZER CALIBRATION TABLE**

Spectrum ID #	Element/Transition	Peak Energy (eV)	Peak Width FWHM (eV)	Peak Area (counts)	Sensitivity Factor	Concentration (at. %)	Peak Assignment
... <sup>a</sup>	Au 4 <i>f</i> <sub>7/2</sub>	83.92	0.98	2200	10.67	...	...
... <sup>b</sup>	Au 4 <i>f</i> <sub>7/2</sub>	83.92	1.6	6000	10.67	...	...
... <sup>c</sup>	Cu 3 <i>s</i>	122.36	3.0	1600	1.05	...	...
... <sup>b</sup>	Cu 2 <i>p</i> <sub>3/2</sub>	932.45	1.78	4000	9.73	...	...

<sup>a</sup> Spot size 300 μm, pass energy 50 eV, 2 scans.

<sup>b</sup> Spot size 800 μm, pass energy 150 eV, 1 scan.

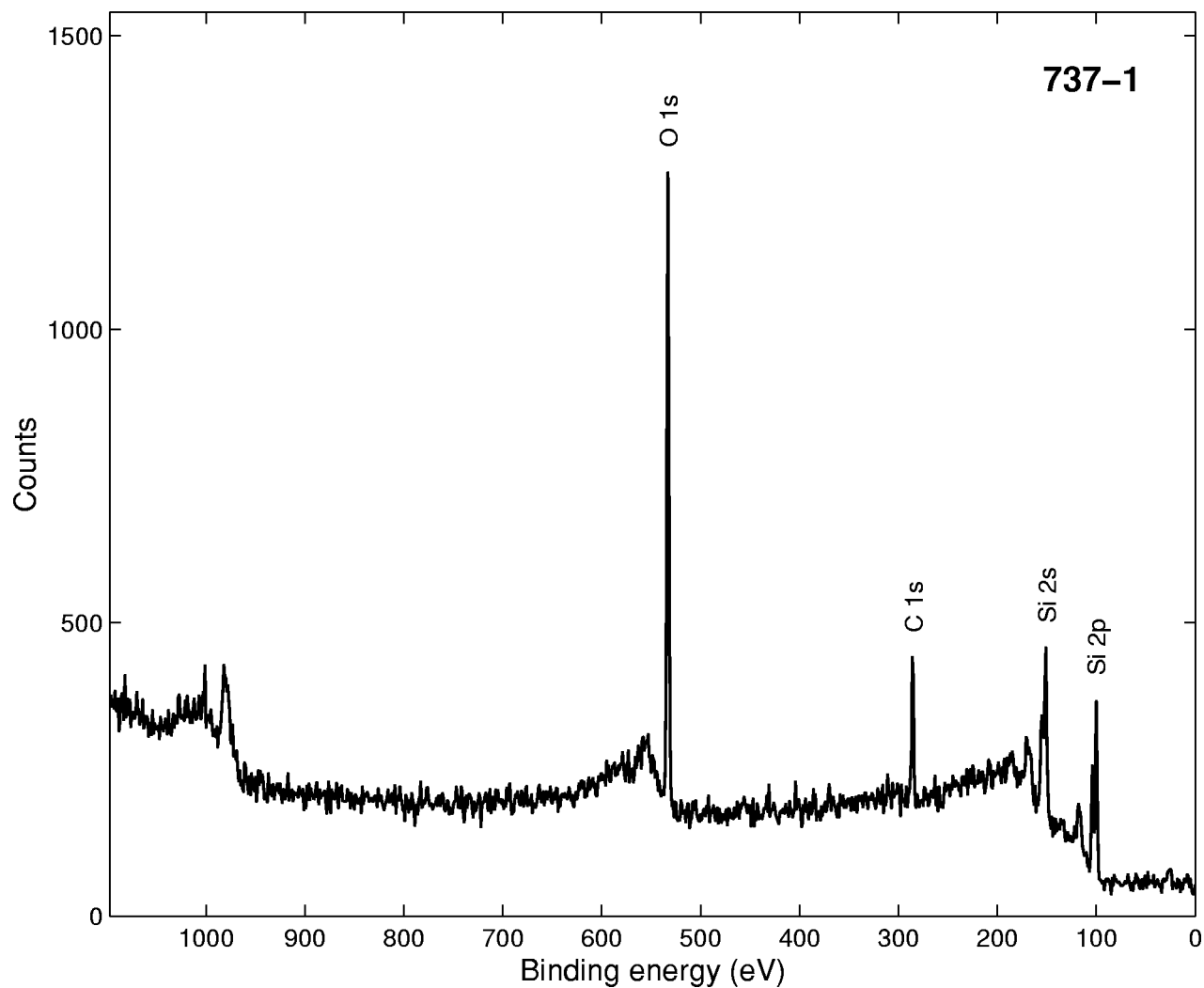
<sup>c</sup> Spot size 800 μm, pass energy 150 eV, 3 scans.

**GUIDE TO FIGURES**

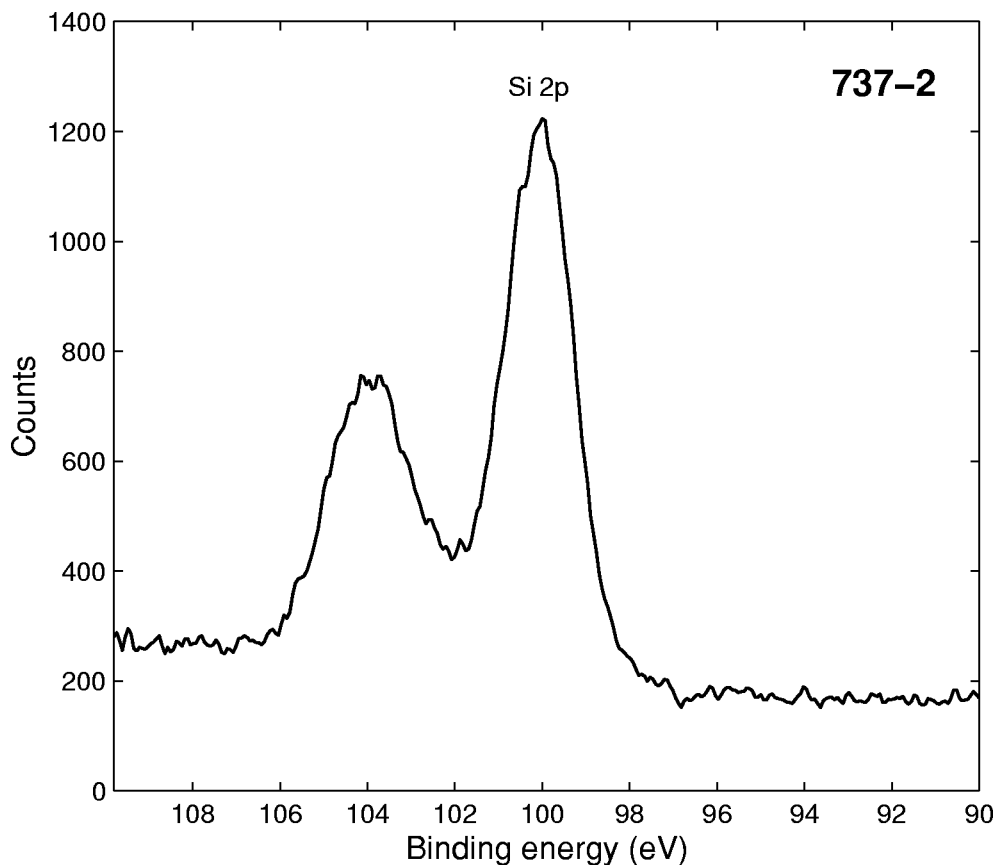
Spectrum (Accession) #	Spectral Region	Voltage Shift*	Multiplier	Baseline	Comment #
737-1	Survey	0	1	0	
737-2	Si 2 <i>p</i>	0	1	0	
737-3	C 1 <i>s</i>	0	1	0	
737-4	O 1 <i>s</i>	0	1	0	
737-5	Si 2 <i>p</i>	0	1	0	
737-6	C 1 <i>s</i>	0	1	0	
737-7	O 1 <i>s</i>	0	1	0	
738-1 [NP]**	Survey	0	1	0	
738-2 [NP]	Si 2 <i>p</i>	0	1	0	
738-3 [NP]	C 1 <i>s</i>	0	1	0	
738-4 [NP]	O 1 <i>s</i>	0	1	0	
738-5 [NP]	Si 2 <i>p</i>	0	1	0	
738-6 [NP]	C 1 <i>s</i>	0	1	0	
738-7 [NP]	O 1 <i>s</i>	0	1	0	
739-1 [NP]	Survey	0	1	0	
739-2 [NP]	Si 2 <i>p</i>	0	1	0	
739-3 [NP]	C 1 <i>s</i>	0	1	0	
739-4 [NP]	O 1 <i>s</i>	0	1	0	
739-5 [NP]	Si 2 <i>p</i>	0	1	0	
739-6 [NP]	C 1 <i>s</i>	0	1	0	
739-7 [NP]	O 1 <i>s</i>	0	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.

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

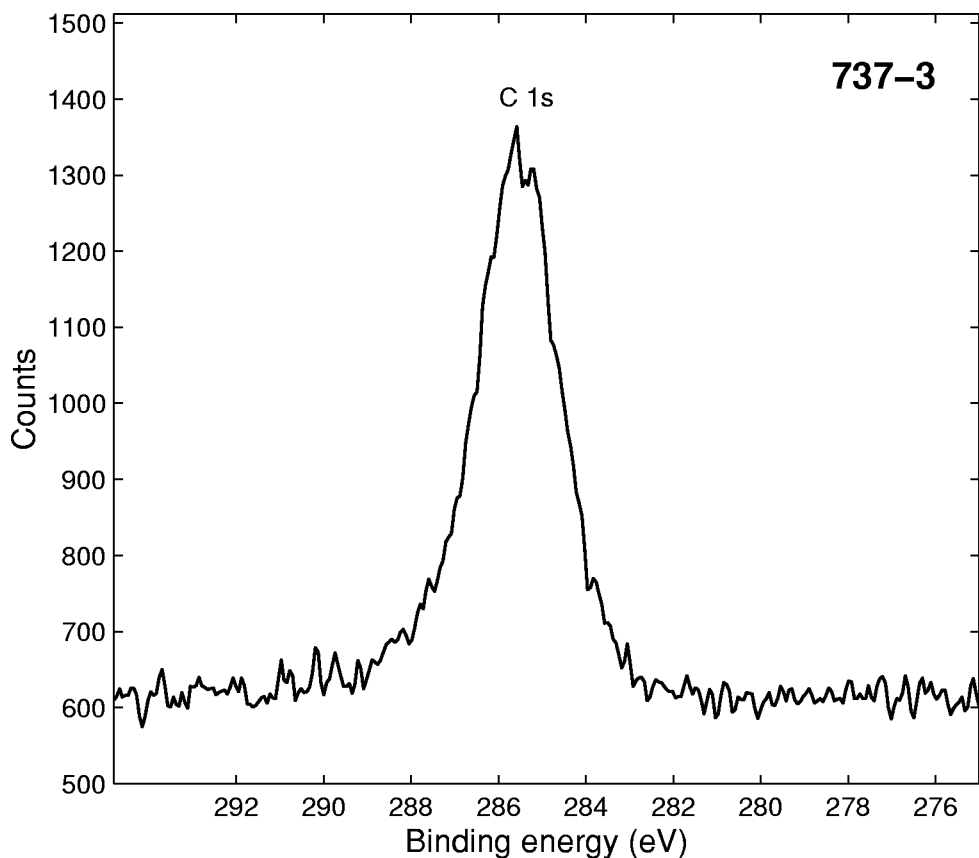


<b>Accession #</b>	<b>00737-01</b>
<b>Host Material</b>	Alkyl monolayer on native oxide terminated silicon derived from $\text{ClSi}(\text{CH}_3)_2(\text{CH}_2)_6\text{CH}=\text{CH}_2$
<b>Technique</b>	XPS
<b>Spectral Region</b>	survey
<b>Instrument</b>	Surface Science SSX-100
<b>Excitation Source</b>	Al $K_\alpha$ monochromatic
<b>Source Energy</b>	1486.6 eV
<b>Source Strength</b>	200 W
<b>Source Size</b>	0.8 mm × 0.8 mm
<b>Analyzer Type</b>	spherical sector
<b>Incident Angle</b>	55°
<b>Emission Angle</b>	55°
<b>Analyzer Pass Energy</b>	150 eV
<b>Analyzer Resolution</b>	1.5 eV
<b>Total Signal Accumulation Time</b>	220 s
<b>Total Elapsed Time</b>	420 s
<b>Number of Scans</b>	1
<b>Effective Detector Width</b>	13.0906 eV
<b>Analyzer Width</b>	1500 $\mu\text{m}$ × 12000 $\mu\text{m}$



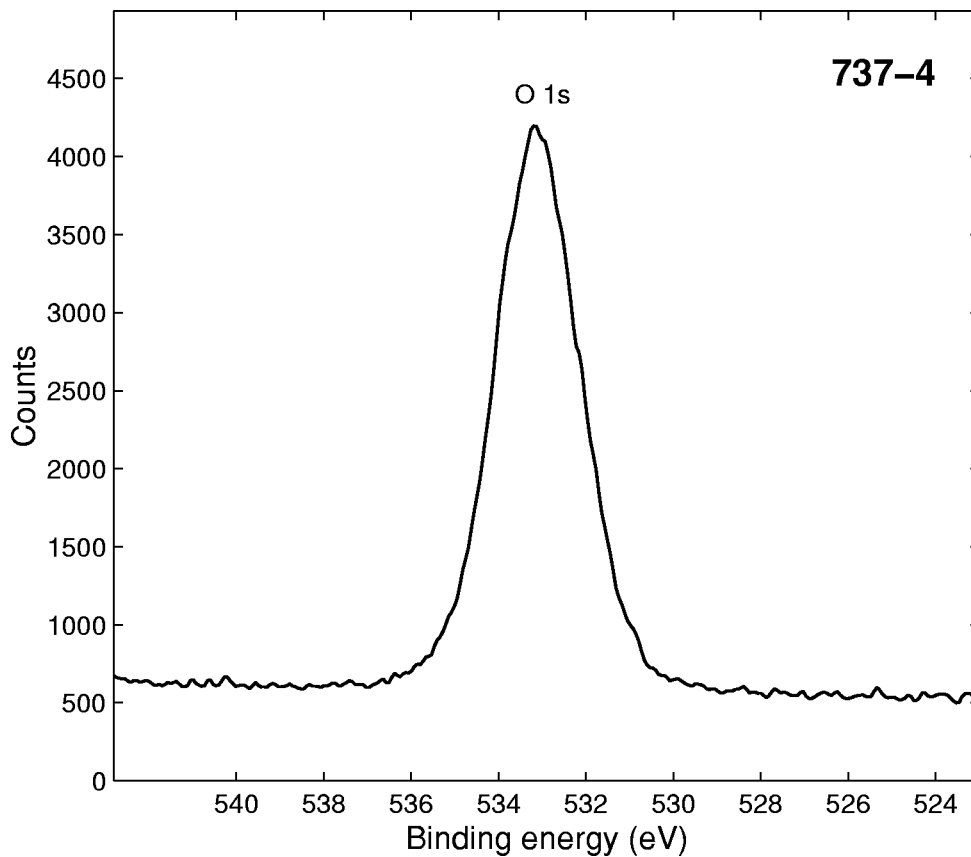
■ **Accession #:** 00737-02  
 ■ **Host Material:** Alkyl monolayer on native oxide terminated silicon derived from  $\text{ClSi}(\text{CH}_3)_2(\text{CH}_2)_6\text{CH}=\text{CH}_2$   
 ■ **Technique:** XPS  
 ■ **Spectral Region:** Si 2p

Instrument: Surface Science SSX-100  
 Excitation Source: Al  $K_{\alpha}$  monochromatic  
 Source Energy: 1486.6 eV  
 Source Strength: 200 W  
 Source Size: 0.8 mm  $\times$  0.8 mm  
 Incident Angle: 55°  
 Analyzer Type: spherical sector  
 Analyzer Pass Energy: 150 eV  
 Analyzer Resolution: 1.5 eV  
 Emission Angle: 55°  
 Total Signal Accumulation Time: 184 s  
 Total Elapsed Time: 353 s  
 Number of Scans: 3  
 Effective Detector Width: 13.0906 eV  
 Analyzer Width: 1500  $\mu\text{m}$   $\times$  12000  $\mu\text{m}$



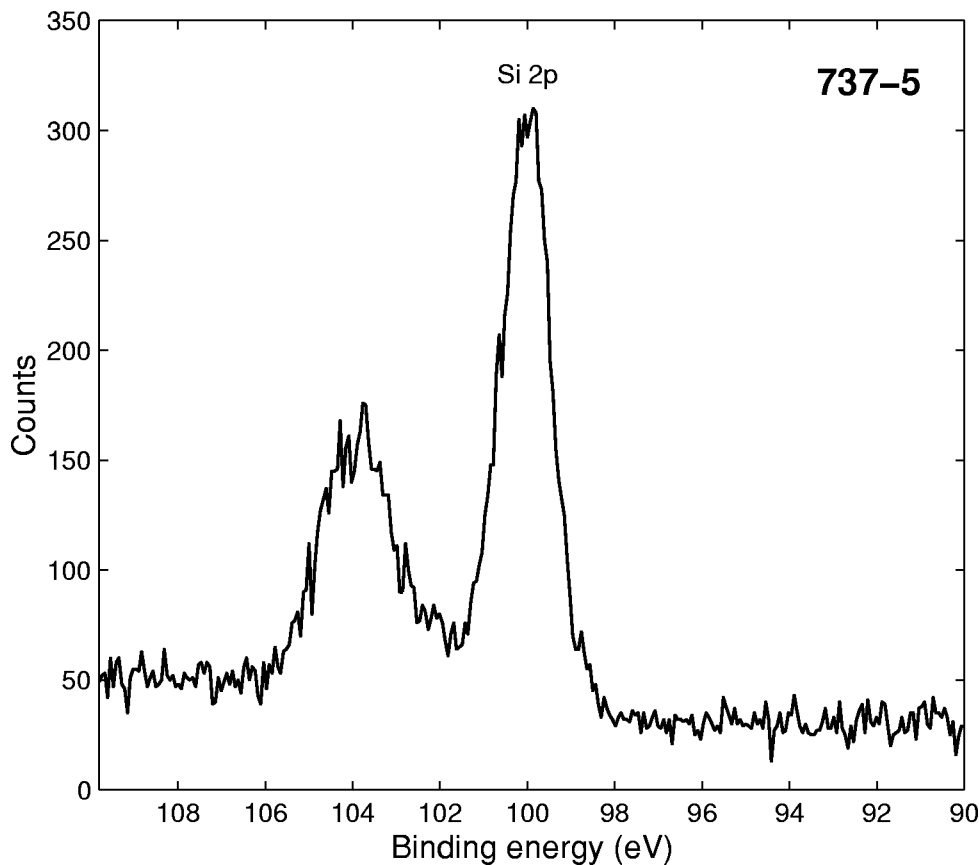
■ **Accession #:** 00737-03  
 ■ **Host Material:** Alkyl monolayer on native oxide terminated silicon derived from  $\text{ClSi}(\text{CH}_3)_2(\text{CH}_2)_6\text{CH}=\text{CH}_2$   
 ■ **Technique:** XPS  
 ■ **Spectral Region:** C 1s

Instrument: Surface Science SSX-100  
 Excitation Source: Al  $K_{\alpha}$  monochromatic  
 Source Energy: 1486.6 eV  
 Source Strength: 200 W  
 Source Size: 0.8 mm  $\times$  0.8 mm  
 Incident Angle: 55°  
 Analyzer Type: spherical sector  
 Analyzer Pass Energy: 150 eV  
 Analyzer Resolution: 1.5 eV  
 Emission Angle: 55°  
 Total Signal Accumulation Time: 184 s  
 Total Elapsed Time: 353 s  
 Number of Scans: 3  
 Effective Detector Width: 13.0906 eV  
 Analyzer Width: 1500  $\mu\text{m}$   $\times$  12000  $\mu\text{m}$



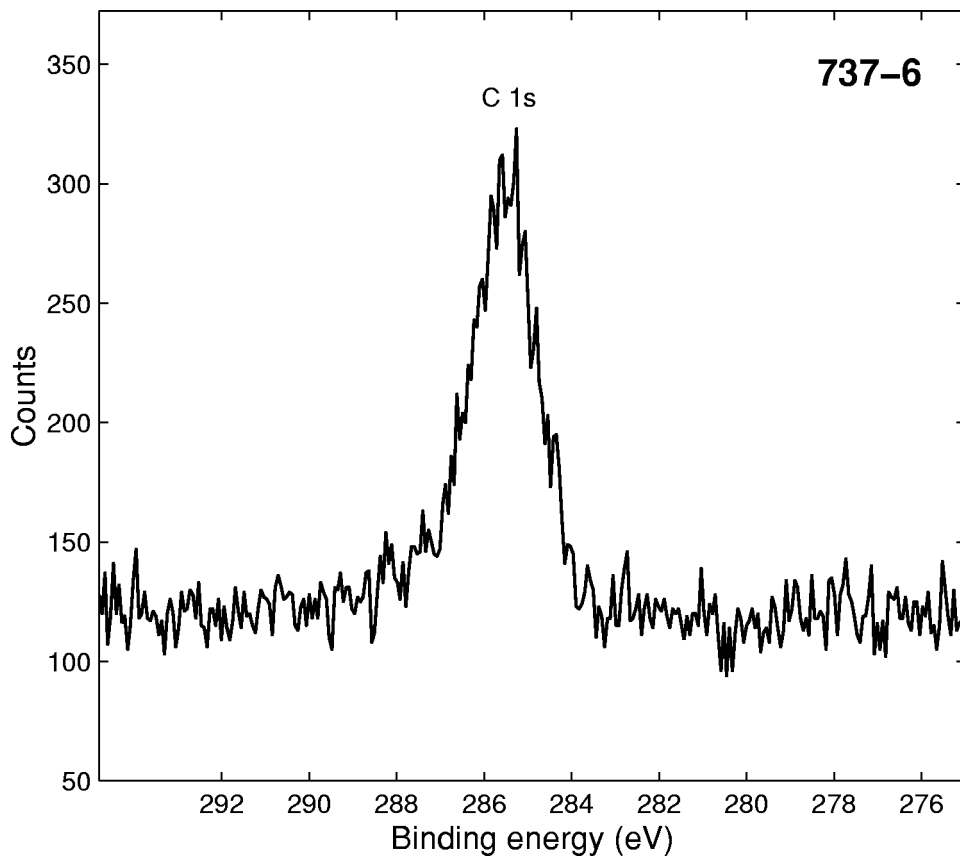
■ **Accession #:** 00737-04  
 ■ **Host Material:** Alkyl monolayer on native oxide terminated silicon derived from  $\text{ClSi}(\text{CH}_3)_2(\text{CH}_2)_6\text{CH}=\text{CH}_2$   
 ■ **Technique:** XPS  
 ■ **Spectral Region:** O 1s

Instrument: Surface Science SSX-100  
 Excitation Source: Al  $K_{\alpha}$  monochromatic  
 Source Energy: 1486.6 eV  
 Source Strength: 200 W  
 Source Size: 0.8 mm  $\times$  0.8 mm  
 Incident Angle: 55°  
 Analyzer Type: spherical sector  
 Analyzer Pass Energy: 150 eV  
 Analyzer Resolution: 1.5 eV  
 Emission Angle: 55°  
 Total Signal Accumulation Time: 184 s  
 Total Elapsed Time: 353 s  
 Number of Scans: 3  
 Effective Detector Width: 13.0906 eV  
 Analyzer Width: 1500  $\mu\text{m}$   $\times$  12000  $\mu\text{m}$



■ **Accession #:** 00737-05  
 ■ **Host Material:** Alkyl monolayer on native oxide terminated silicon derived from  $\text{ClSi}(\text{CH}_3)_2(\text{CH}_2)_6\text{CH}=\text{CH}_2$   
 ■ **Technique:** XPS  
 ■ **Spectral Region:** Si 2p

Instrument: Surface Science SSX-100  
 Excitation Source: Al  $K_{\alpha}$  monochromatic  
 Source Energy: 1486.6 eV  
 Source Strength: 200 W  
 Source Size: 0.8 mm  $\times$  0.8 mm  
 Incident Angle: 55°  
 Analyzer Type: spherical sector  
 Analyzer Pass Energy: 50 eV  
 Analyzer Resolution: 0.5 eV  
 Emission Angle: 55°  
 Total Signal Accumulation Time: 184 s  
 Total Elapsed Time: 353 s  
 Number of Scans: 3  
 Effective Detector Width: 5.442 eV  
 Analyzer Width: 750  $\mu\text{m}$   $\times$  6000  $\mu\text{m}$



- **Accession #:** 00737-06
- **Host Material:** Alkyl monolayer/Si –  $\text{CISi}(\text{CH}_3)_2(\text{CH}_2)_6\text{CH}=\text{CH}_2$
- **Technique:** XPS
- **Spectral Region:** C 1s

Instrument: Surface Science SSX-100

Excitation Source: Al  $K_{\alpha}$   
monochromatic

Source Energy: 1486.6 eV

Source Strength: 200 W

Source Size: 0.8 mm × 0.8 mm

Incident Angle: 55°

Analyzer Type: spherical sector

Analyzer Pass Energy: 50 eV

Analyzer Resolution: 0.5 eV

Emission Angle: 55°

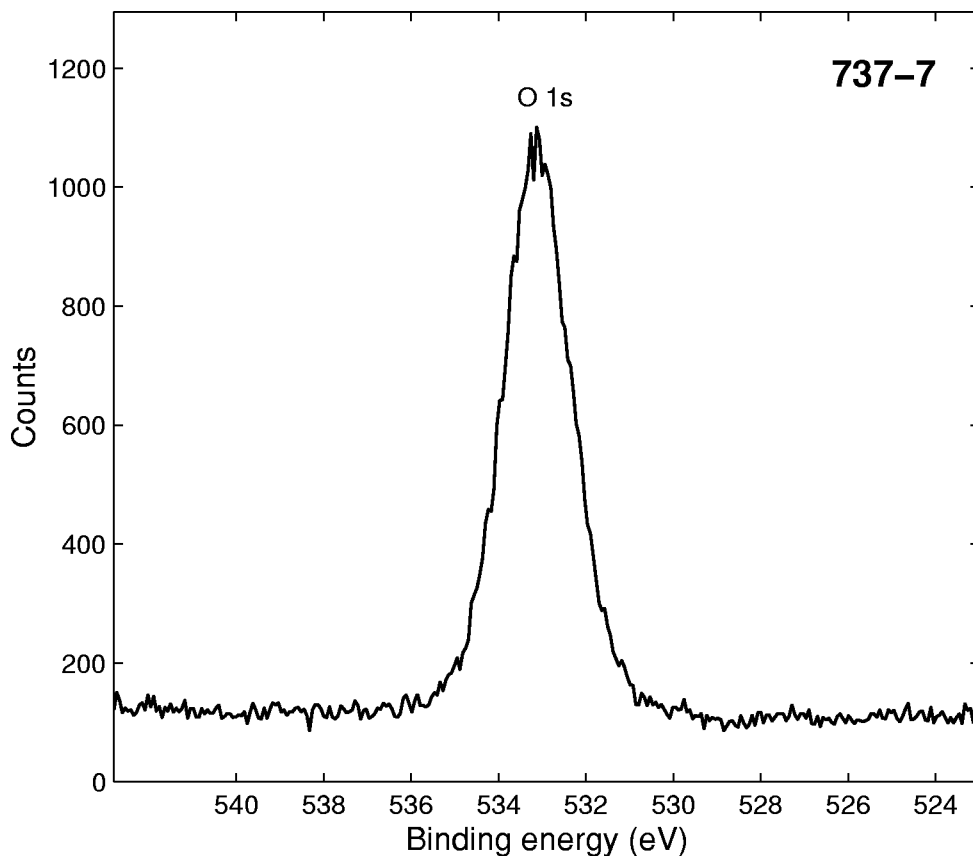
Total Signal Accumulation Time: 184 s

Total Elapsed Time: 353 s

Number of Scans: 3

Effective Detector Width: 5.442 eV

Analyzer Width: 750  $\mu\text{m}$  × 6000  $\mu\text{m}$



- **Accession #:** 00737-07
- **Host Material:** Alkyl monolayer/Si –  $\text{CISi}(\text{CH}_3)_2(\text{CH}_2)_6\text{CH}=\text{CH}_2$
- **Technique:** XPS
- **Spectral Region:** O 1s

Instrument: Surface Science SSX-100

Excitation Source: Al  $K_{\alpha}$   
monochromatic

Source Energy: 1486.6 eV

Source Strength: 200 W

Source Size: 0.8 mm × 0.8 mm

Incident Angle: 55°

Analyzer Type: spherical sector

Analyzer Pass Energy: 50 eV

Analyzer Resolution: 0.5 eV

Emission Angle: 55°

Total Signal Accumulation Time: 184 s

Total Elapsed Time: 353 s

Number of Scans: 3

Effective Detector Width: 5.442 eV

Analyzer Width: 750  $\mu\text{m}$  × 6000  $\mu\text{m}$