XPS Surface Characterization of Disposable Laboratory Gloves and the Transfer of Glove Components to Other Surfaces

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Introduction

Disposable elastic gloves are ubiquitous in scientific laboratories and are also widely used in many industries during handling of critical surfaces. Disposable gloves are typically made from nitrile or latex rubber and offer their users protection from various aqueous acids and bases, biological and medical fluids, organic solvents, and other potentially harmful substances. A second major use of disposable gloves is to protect manufactured products and analytical samples from contamination caused by the transfer of skin cells, oils, salts, cosmetics, hand lotions, or other residues resulting from contact with bare hands. However, disposable gloves can also be an overlooked potential source of contamination on handled surfaces.

In addition to the primary polymer structure, many types of common laboratory gloves also contain a variety of inorganic salt additives in the glove formulation. Silicone-containing mold-release agents that allow powder-free gloves to be easily stripped from the glove formers during fabrication may be present on glove surfaces. Post-forming processes such as chlorination are often used to oxidize the outer glove surface to reduce surface tackiness. Furthermore, the inner surface on disposable gloves may have polymeric surface coatings for improved donning properties. These inner coatings or other bulk glove components may permeate the glove material and segregate to the outer glove surface after exposure to certain solvents. Contact with solvents during a rinsing of items may also transfer glove components to the surfaces of those items. Contamination resulting from surface residues on gloves can adversely affect materials used in industries where surface cleanliness is essential for optimum product performance and can also interfere with the analysis of samples depending on the specificity and sensitivity of the analytical technique. Therefore, it is important to know if the various components within a particular glove material are leached out by certain solvents or if manufacturing residues present on the surfaces of gloves are easily transferred to other materials.

X-ray photoelectron spectroscopy (XPS) is a qualitative and quantitative surface sensitive technique that can be used to evaluate the elemental and chemical surface composition of disposable gloves and to determine if contamination transfer occurs from gloves to other surfaces in a specific application. In this study, a Thermo Scientific K-Alpha XPS instrument was used to characterize the outer and inner surface compositions of a variety of common laboratory gloves. Changes in the surface composition of the gloves following exposure to several common laboratory solvents were also investigated. The transfer of surface components from the gloves to clean aluminum foil surfaces by light touching was also evaluated.

XPS, a qualitative and quantitative surface sensitive technique, is used to evaluate the elemental and chemical surface composition of disposable gloves and to determine if contamination transfer occurs from gloves to other surfaces.

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Experimental

In this study, 15 different product types of powder-free laboratory gloves were examined (seven nitrile, seven latex, and one neoprene). Fresh glove samples were obtained from unopened boxes of each type to avoid potential external sources of contamination on the glove surfaces. Sections (ca. 1 mm × 1 mm) were cut with a scissors from the finger region of each glove. No other sample preparation was necessary. The outer and inner surfaces of each glove were analyzed. In addition, the outer surfaces of each glove were re-analyzed following a 5 minute rinse (and subsequent air dry) in four different commonly used laboratory solvents: acetone, chloroform, hexane, and methyl alcohol. Potential transfer of glove components on the outer surface of the gloves to other surfaces was tested by analyzing the surface of the bright side (i.e., smoother side) of clean household aluminum foil (Reynolds Wrap®) after lightly touching the foil surface with a gloved finger.

The versatile K-Alpha sample stage (60 mm × 60 mm) can hold a large number of samples for high sample throughput and is height-adjustable to accommodate samples up to 20 mm thick. A K-Alpha sample stage loaded with several sections from various glove samples mounted on double-sided tape is shown in Figure 1. The simple to operate turn-key charge compensation system of the K-Alpha was used during the analyses to maintain stable analysis conditions on the insulating glove samples. The K-Alpha XPS system is equipped with a 128 multi-channel detector and a monochromated microfocusing Al Kα X-ray source with a variable spot size (i.e., 30–400 μm). All analyses of the glove and aluminum foil samples were conducted with a 400 μm X-ray spot size. Survey spectra (0–1350 eV) were acquired for qualitative and quantitative analysis and high resolution spectra were acquired for chemical state characterization. All data were processed using the advanced Thermo Scientific Avantage Data System. Binding energies were referenced to the main hydrocarbon C 1s peak = 285.0 eV. Depth profiling studies were conducted with an Ar+ ion gun operated at 1000 eV and rastered over a 2 mm × 4 mm area. Sputtered depths were calibrated with a 100 nm SiO_2/Si standard.

Figure 1: K-Alpha sample stage loaded with several sections of laboratory gloves mounted on double-sided tape

Results

XPS survey spectra allow easy and rapid qualitative and quantitative elemental characterization of glove surfaces. Examples of XPS survey spectra are shown in Figure 2 for the outer surfaces of a nitrile (Nitrile #4) and latex (Latex #2) glove. These results demonstrate that the surfaces of different laboratory gloves can vary to a large degree. In this case, the nitrile glove had only a small amount of oxygen present plus a few minor surface components (e.g., Si, S, and Ca). In comparison, the latex glove had much lower carbon and approximately ten times the oxygen present along with significant amounts of N, Mg, Si, S, Cl, and Ca, plus minor amounts of P and Zn. A select subset of the total data collected in this study is summarized in Table 1 to further demonstrate the variable surface compositions of different types of laboratory gloves as determined by XPS. Substantial differences in the qualitative and quantitative surface compositions were observed among the different brands and types of nitrile, latex, and neoprene gloves. Substantial differences in surface composition were also observed between the outer and inner surfaces for all of the gloves investigated in this study. Elements detected on the surfaces of one or more of the gloves included: C, N, O, Na, Mg, Al, Si, P, S, Cl, K, Ca, and Zn.

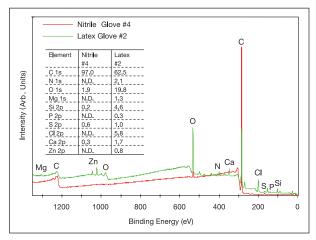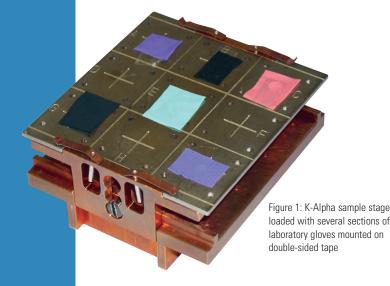| Element	Nitrile #4	Latex #2
C 1s	97.0	62.5
N 1s	N.D.	2.1
O 1s	1.9	19.8
Mg 1s	N.D.	1.3
Si 2p	0.2	4.6
P 2p	N.D.	0.3
S 2p	0.6	1.0
Cl 2p	N.D.	5.8
Ca 2p	0.3	1.7
Zn 2p	N.D.	0.8

Figure 2: XPS survey spectra of the outer surfaces of example nitrile and latex laboratory gloves and the qualitative and quantitative (atomic %) results (N.D. denotes "not detected")

Glove	C	N	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Zn
Nitrile #1 (O)	86.1	0.2	10.1	N.D.	N.D.	N.D.	0.2	N.D.	0.5	N.D.	N.D.	2.7	0.2
Nitrile #1 (I)	61.5	0.5	20.7	N.D.	N.D.	N.D.	13.9	N.D.	0.3	2.5	N.D.	0.5	0.1
Nitrile #2 (O)	67.7	1.6	20.2	N.D.	0.7	0.3	0.5	0.2	3.6	0.6	N.D.	4.1	0.5
Nitrile #2 (I)	72.1	2.0	12.7	0.1	2.0	N.D.	N.D.	N.D.	2.5	7.4	N.D.	1.0	0.2
Nitrile #3 (O)	60.1	0.4	21.7	0.1	N.D.	N.D.	15.2	0.1	0.7	N.D.	N.D.	1.4	0.3
Nitrile #3 (I)	67.4	2.3	15.4	0.5	1.5	N.D.	1.8	N.D.	1.8	8.1	N.D.	1.1	0.1
Latex #1 (O)	73.8	0.4	15.5	N.D.	N.D.	N.D.	7.4	N.D.	1.1	N.D.	N.D.	1.1	0.7
Latex #1 (I)	57.2	0.4	22.7	N.D.	N.D.	N.D.	18.7	N.D.	0.6	N.D.	N.D.	0.1	0.3
Latex #2 (O)	62.5	2.1	19.8	N.D.	1.3	N.D.	4.6	0.3	1.0	5.8	N.D.	1.8	0.8
Latex #2 (I)	63.6	3.4	15.5	N.D.	1.8	N.D.	4.1	N.D.	1.0	9.0	N.D.	0.9	0.7
Latex #3 (O)	82.4	0.7	11.6	N.D.	N.D.	N.D.	1.6	N.D.	0.3	1.4	N.D.	1.8	0.2
Latex #3 (I)	64.4	2.1	21.6	0.1	N.D.	N.D.	3.8	N.D.	1.4	3.8	0.2	1.9	0.7
Neoprene #1 (O)	84.0	0.2	10.6	N.D.	N.D.	N.D.	3.1	N.D.	0.4	0.2	N.D.	1.5	N.D.
Neoprene #1 (I)	51.3	N.D.	23.8	N.D.	N.D.	N.D.	24.9	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.

Table 1: Surface compositions (atomic %), as determined from the XPS survey spectra, for the outer (O) and inner (I) surfaces of various gloves examined in this study (N.D. denotes "not detected")

High resolution XPS can be used to determine the chemical states of carbon on glove surfaces as shown in Figure 3 for a nitrile glove (Nitrile #7). In addition to the main hydrocarbon peak (285.0 eV), a peak was observed corresponding to nitrile (C-N) and/or ether/alcohol (C-O) functional groups (286.6 eV), plus a peak characteristic of carbonate species (290.2 eV). (Note that trace amounts of potassium were also detected on this particular sample as determined from the presence of the K 2p peaks in the C 1s region.) A peak corresponding to carbonate species was observed in the C 1s spectra for several other gloves as well.

Knowledge of the functional groups present on glove surfaces can be useful for determining compatibility with other materials and when tracing sources of contamination on handled materials. High resolution XPS can also be used to investigate the chemical states of other elements present on glove surfaces. For example, Figure 4 shows the S 2p spectrum obtained for a nitrile glove (Nitrile #2). Sulfur was detected on this glove in two chemical states characteristic of sulfate (SO_3^{2-}) and/or sulfone (R_2SO_2) species (168.7 eV) plus sulfide (S^{2-}) and/or mercaptan (R-SH) species (163.2 eV). High resolution XPS results obtained for the various types of gloves studied indicated that in general, when detected, N was present as organically bound nitrogen species (~399–401 eV) and/or nitrates (~407 eV), Si was present as silicone and/or silicate species (~102–103 eV), P was present as phosphates (~132–133 eV), chlorine was present as organically bound chlorine (C-Cl) and/or chloride species (~199–200 eV), and all detected metals were present in their highest oxidation state.
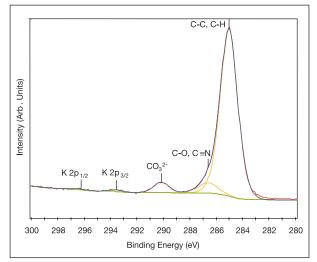

Figure 3: High resolution C 1s spectrum fitted with three peaks for the outer surface of Nitrile Glove #7. Note that trace amounts of potassium were also detected on this sample.
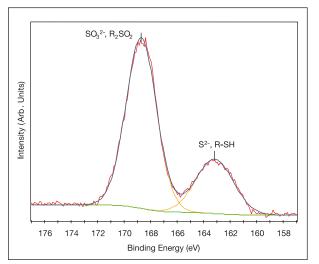

Figure 4: High resolution S 2p spectrum fitted with two peaks for the outer surface of Nitrile Glove #2

Use of laboratory gloves is the most common approach to protecting individuals from contact with hazardous chemicals. Some chemicals may remove components from the glove surface or they may cause bulk components to segregate to the glove surface. Therefore, the effects of various chemicals on the surface composition of laboratory gloves are of interest and XPS is an excellent technique for conducting such studies.

Figure 5 shows wide range (0–250 eV) high resolution XPS spectra obtained for an as-received latex glove (Latex Glove #3) and the same type of glove following a 5 minute rinse with acetone, chloroform, hexane, or methyl alcohol. The spectra indicate that the solvent rinses affect the surface composition of the glove. Table 2 shows examples of the qualitative and quantitative XPS results obtained for the solvent rinse studies on a nitrile (Nitrile #7) and latex glove (Latex #3). (All analyses were conducted on the outer glove surfaces.) The results shown in Table 2 indicate that the surface compositions of the rinsed gloves varied widely with the type of glove and the solvent. For example, all four solvents removed Cl from the surface of Latex Glove #3 below the detection limit. In contrast, only methyl alcohol removed Cl from the surface of Nitrile Glove #7. Rinsing Nitrile Glove #7 with either chloroform or hexane increased the Cl concentration several fold compared to the as-received glove, whereas rinsing with acetone had only a minor effect (see Table 2).

All four solvents also partially removed Si from the surface of Nitrile Glove #7. In contrast, all four solvents substantially increased the surface concentration of Si on Latex Glove #3. Similar variable composition results were obtained for the other gloves studied in this investigation. In any case, it is clear that common solvents can alter the surface composition and the contaminants present on laboratory glove surfaces.
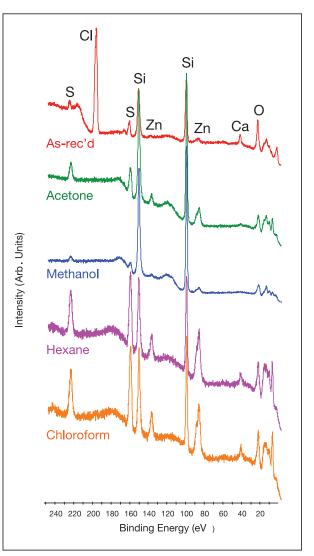

Figure 5: High resolution XPS spectra (~0–250 eV) for the as-received outer surface of Latex Glove #3 and following a 5 minute rinse in various solvents

Glove/Solvent	C	N	O	Na	Mg	Si	S	Cl	K	Ca	Zn
Nitrile #7, As-received	52.8	0.9	26.1	N.D.	N.D.	11.4	2.8	1.9	N.D.	3.7	0.4
Nitrile #7, Acetone	60.2	0.7	24.7	0.8	0.7	1.6	4.4	1.5	0.1	4.8	0.5
Nitrile #7, Chloroform	57.5	0.8	20.8	0.5	2.6	1.3	3.9	6.8	0.2	4.9	0.7
Nitrile #7, Hexane	56.5	0.7	24.3	0.4	1.0	2.0	4.2	4.7	0.1	5.3	0.8
Nitrile #7, Methyl Alcohol	56.6	1.5	27.7	N.D.	0.5	5.0	2.3	0.2	N.D.	5.7	0.5
Latex #3, As-received	82.4	0.7	11.6	N.D.	N.D.	1.6	0.3	1.4	N.D.	1.8	0.2
Latex #3, Acetone	65.8	0.5	17.7	N.D.	N.D.	14.9	0.4	N.D.	N.D.	0.4	0.3
Latex #3, Chloroform	79.1	0.2	13.0	N.D.	N.D.	5.5	0.5	N.D.	N.D.	1.2	0.5
Latex #3, Hexane	81.3	0.4	11.7	N.D.	N.D.	4.4	0.6	N.D.	N.D.	1.0	0.6
Latex #3, Methyl Alcohol	56.5	0.1	21.7	N.D.	N.D.	21.4	N.D.	N.D.	N.D.	0.2	0.1

Table 2: Surface compositions (atomic %), as determined from XPS survey spectra, for as-received and solvent rinsed (5 min) Nitrile Glove #7 and Latex Glove #3 (N.D. denotes "not detected")

Surface contamination on analytical samples or other handled materials resulting from the transfer of residues present on gloves is probably overlooked in most laboratories and industries, but it can be important and should be considered. For example, Figure 6 shows XPS survey spectra obtained for a clean, untouched sample of aluminum foil and the same foil after being lightly touched with a gloved finger (Latex #3). The main surface components detected on the clean aluminum foil were C, O, Mg, and Al, plus a trace amount of Ca. After the touch test, the surface concentration of C increased substantially compared to the clean surface (55.4 at.% vs. 6.1 at.%, respectively), and Si, which was undetected on the clean foil, was now a major surface component (20.9 at. %). After the touch test, the main surface components detected on the foil were C, O, and Si, plus only a small amount of Al and trace amount of Ca. The observed binding energy of the Si 2p peak (102.5 eV) on the glove touched sample would be consistent for silicone species, which suggests that a silicone oil surface contamination was present on this type of glove.

Table 3 summarizes the qualitative and quantitative XPS results obtained for the aluminum foil touch tests for all of the gloves studied in this investigation. After touching a foil sample with a bare finger (Bare Finger #1), XPS indicated that C, N, Na, Si, S, and Cl had been transferred to the foil surface. A second touch test with a bare finger after first lightly wiping the finger on the individual's forehead (Bare Finger #2) gave similar results (plus a trace amount of Ca); however, in the second test the surface concentration of C was much higher than that found for the bare finger test without the preceding forehead wipe. These results are consistent with the transfer of skin oils from the forehead to the bare finger in the second bare finger test.
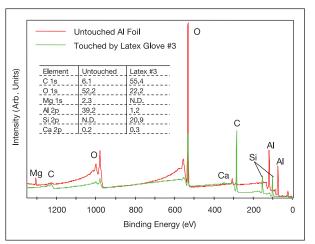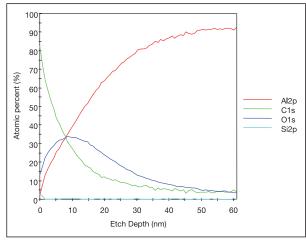

Figure 6: XPS survey spectra for clean, untouched aluminum foil and foil lightly touched by Latex Glove #3

The results shown in Table 3 indicate that C, N, Na, Si, S, Cl, K, Ca, and Zn may all potentially be transferred to other touched surfaces depending on the type of glove used. The amounts of these transferred elements detected on the foil surfaces varied greatly among the different glove types. Results indicated that carbon was the most frequently and presumably the most easily transferred element detected, regardless if the glove tested was nitrile, latex, or neoprene. In one case (Nitrile #4), the transfer of carbon species to the foil surface was such (91.2 at. % C) that the underlying aluminum foil was barely detectable (0.2 at. % Al). Only one of the 15 gloves tested (Nitrile #2) showed no detectable surface contamination transfer to aluminum foil, other than a small increase in the amount of surface carbon species.
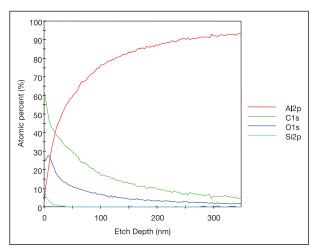
Sample/Glove	C	N	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Zn
Untouched Al Foil	6.1	N.D.	52.2	N.D.	2.3	39.2	N.D.	N.D.	N.D.	N.D.	N.D.	0.2	N.D.
Bare Finger #1	44.7	0.6	31.6	0.2	0.1	21.7	0.8	N.D.	0.1	0.2	N.D.	N.D.	N.D.
Bare Finger #2	74.8	0.3	16.2	0.3	N.D.	7.2	0.7	N.D.	0.3	0.1	N.D.	0.1	N.D.
Nitrile #1	59.2	N.D.	23.9	0.1	0.3	14.2	0.4	N.D.	0.2	N.D.	N.D.	1.7	N.D.
Nitrile #2	11.0	N.D.	50.9	N.D.	1.7	36.2	N.D.	N.D.	N.D.	N.D.	N.D.	0.3	N.D.
Nitrile #3	44.7	N.D.	30.5	N.D.	N.D.	15.9	7.6	N.D.	0.3	N.D.	N.D.	1.0	N.D.
Nitrile #4	91.2	0.4	5.6	0.1	N.D.	0.2	N.D.	N.D.	1.6	N.D.	N.D.	0.9	N.D.
Nitrile #5	11.7	0.3	50.5	0.2	2.1	33.8	N.D.	N.D.	0.3	0.2	N.D.	0.9	N.D.
Nitrile #6	37.3	1.0	37.4	0.5	0.5	20.5	N.D.	N.D.	0.7	N.D.	0.1	2.0	N.D.
Nitrile #7	15.6	N.D.	46.3	0.1	1.3	31.4	4.1	N.D.	N.D.	0.7	N.D.	0.4	0.2
Latex #1	81.0	N.D.	12.3	N.D.	N.D.	1.0	3.5	N.D.	N.D.	N.D.	N.D.	2.2	N.D.
Latex #2	17.9	0.3	44.6	N.D.	2.6	30.2	0.7	N.D.	N.D.	2.9	N.D.	0.5	0.3
Latex #3	55.4	N.D.	22.2	N.D.	N.D.	1.2	20.9	N.D.	N.D.	N.D.	N.D.	0.3	N.D.
Latex #4	13.4	N.D.	48.9	N.D.	2.4	33.8	N.D.	N.D.	N.D.	1.1	N.D.	0.2	0.2
Latex #5	35.7	N.D.	34.3	N.D.	1.3	24.4	N.D.	N.D.	1.2	2.6	N.D.	0.2	0.3
Latex #6	21.7	0.3	42.0	N.D.	1.9	32.3	N.D.	N.D.	N.D.	1.3	N.D.	0.3	0.4
Latex #7	21.5	3.0	43.0	0.2	0.1	28.6	N.D.	N.D.	0.2	1.9	N.D.	0.9	0.6
Neoprene #1	47.8	0.7	29.6	0.5	0.4	15.5	3.0	N.D.	0.3	0.5	N.D.	1.5	0.2

Table 3: Surface compositions (atomic %), as determined from XPS survey spectra, for as-received, untouched, aluminum foil and aluminum foil after light touching by bare fingers and fingers covered by various laboratory gloves (N.D. denotes "not detected")

Figure 7 shows an XPS depth profile for an aluminum foil sample that was touched by Latex Glove #1. The depth profile indicates that the silicon-containing species was concentrated in the topmost ~2-3 nm of the sample surface and a carbon/oxygen-containing material was detected to a sputtered depth of ~40 nm. In contrast, Figure 8 shows the XPS depth profile obtained for an aluminum foil sample that was lightly touched by Latex Glove #3. In this case, Si was concentrated in the topmost ~10 nm of the foil surface and a carbon/oxygen-containing material persisted to a sputtered depth of >100 nm on the foil surface. Note that the relative C and O profile shapes were different for the foil samples touched by Latex Glove #1 and Latex Glove #3 (see Figures 7 and 8, respectively), indicating different compositions for the transferred carbon/oxygen containing materials. These results also indicate that the thickness of surface contamination layers resulting from laboratory glove contact varies substantially with the type of glove.

Summary

K-Alpha was used to investigate the surface compositions of a wide variety of laboratory gloves. XPS results indicated that in addition to the expected rubber polymer components, silicones and numerous other compounds containing O, Na, Mg, Al, P, S, Cl, K, Ca, and/or Zn may also be present on the outer glove surfaces. Many of these additional surface components can be readily removed from the glove surfaces or may diffuse from the bulk glove material to the glove surface by contact with common laboratory solvents. In addition, many of the glove surface components may also easily transfer to other surfaces when only lightly touched. In this study, only one out of the 15 gloves studied did not transfer substantial amounts of contaminants to aluminum foil during a touch test. Therefore, when handling samples for XPS or other surface sensitive analyses or when handling materials where surface cleanliness is a priority, it is always best to make use of clean handling tools rather than gloved hands. If you use gloves in your laboratory or manufacturing process, XPS is the ideal analytical technique for investigating the surface composition of the gloves and for evaluating the potential for contamination transfer to handled surfaces.

Figure 7: XPS depth profile for an aluminum foil sample that was lightly touched by Latex Glove #1

Figure 8: XPS depth profile for an aluminum foil sample that was lightly touched by Latex Glove #3

When handling surface sensitive analyses or where surface cleanliness is a priority, clean handling tools should be used rather than gloved hands.

Acknowledgements

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