

---

## Enhancement of Structural Strength of Octadecylphosphonic Acid Film on Aluminum by Ion Bombardment

Ripon Kumar Dey<sup>1\*</sup>

<sup>1</sup>Department of Electrical and Computer Engineering (Nanotechnology), University of Waterloo, Waterloo, Ontario, N2L 3G1, Canada.

### Author's contribution

The sole author performed the experiment and analyzed the experimental data, wrote the protocol, and wrote the manuscript and managed the literature search. Here Dr. Heng-yong Nie and Dr. Leo Lau guided me and gave me the research fund.

Research Article

Received 20<sup>th</sup> March 2013  
Accepted 17<sup>th</sup> August 2013  
Published 7<sup>th</sup> October 2013

---

### ABSTRACT

Surface modification with kinematics-driven reaction on uniform and well-ordered Octadecylphosphonic acid (OPA) Langmuir-Blodgett (LB) on aluminium (Al) oxide surface is reported and few of its mechanical properties using different surface analysis techniques are characterized. The hyper thermal hydrogen induced collision (HHIC) approach with low proton energy can induce the hydrocarbon long chain chemical bonding and the actual ordered lattice into an array of clusters of the Octadecylphosphonic acid virgin film. By controlling the kinematics-driven reaction fluence at constant bombardment energy, the nanocluster growth of OPA coated surface has been modified on aluminum oxide substrate. In a specified reaction condition with a controllable degree of cross-linking, this hyper thermal hydrogen-driven reaction can change the cluster shape. The LB film on oxidized Al was the only system stable enough to retain a cohesive and smooth molecular layer after the cross-linking process in compared with Muscovite mica and silicon oxide substrates. The better mechanical strength of the OPA film on aluminum was reported, indeed.

**Keywords:** Langmuir-blodgett film; atomic force microscopy; self-assembled monolayers; octadecylphosphonic acid; contact angle; hydrogen bombardment.

---

\*Corresponding author: Email: [ripon4t@gmail.com](mailto:ripon4t@gmail.com);

## ABBREVIATIONS

**OPA:** Octadecyl phosphonic acid; **HHIC:** Hyperthermal hydrogen induced cross-link; **LB:** Langmuir-blodgett.

## 1. INTRODUCTION

For many-polymer system, it has been observed that the polymeric long hydrocarbon chain is a crucial factor in forming the monolayer using self-assembly monolayer technique; rather it has been examined and proved in this study that this is not a factor in using Langmuir-Blodgett technique [1]. The main difficulty is to deposit well-ordered Octadecylphosphonic acid film on roughed aluminum oxide surface to form the Aluminium oxide-functional group system. Nowadays, the experiment of Langmuir-Blodgett film on variety of surfaces gives rise to nanomaterial scientists with a significant importance. Langmuir-Blodgett monolayers are well-ordered and homogeneous molecular assemblies which are continuously formed by the transformation of molecules lied on the DI water with functional head groups that enables well-ordering on the different substrates [2].

According to Woodward [3] the interaction occurred between the OPA functional headgroup and variety of surfaces serves as a model system to understand molecule-substrate interaction [4,5]. In addition, organic phosphonic acid dissolved in a polar [6,7] or non-polar [8] solvent is expected to have strong adsorption with Al oxide surface in self-assembly-monolayer technique. For short-length organic phosphonic acids, the functional phosphonic headgroup adsorbed with chemical bonding onto oxidized Aluminium surface extracting the water molecules [9] where the bonding between organic phosphonic acid an Al oxide surface is formed via P-O-Al through condensation reaction of overlayer group with surface hydroxyl groups [10]. In this study, the aluminium-oxide functional acid system has been examined. Aluminium holds a potential in expanded demand of technological applications. And phosphonic acid functional group plays a significant role on Al substrate with a condensation reaction where hydroxyl groups on the surface interact with those from the headgroup of the phosphonic acid [11]. The chemical bonding of the functional acid group,  $\text{PO}(\text{OH})_2$ , with the oxide is much more stronger than carboxylic acid group [12] which is one of the reasons to imply this in this study. In this study, modification of OPA on interacting the functional phosphonic headgroup with hydrophilic surface of oxidized Al is described.

The alumina surface has received significant attention as this can be applied as a substrate for preparing thin film devices used in the biomedical industry [13]. It is one of the important aspects to characterize and pre-treat of the Al surface prior to deposit OPA molecules in order to create highly reactive substrates [14]. To control the OPA deposition rate, it is very important to explore the chemistry and structure of the uncoated Al substrate. The hydroxyl group on Al oxide is considered to contribute to chemical bonding for a number of organic molecules [15]. For example, the higher the hydroxyl group attached with the bare Aluminium surface, the higher the absorption of functional phosphonic acid group [16]. The root-mean-square roughness of the Al surface used in this study was below 3 nm (estimated from a scan area of  $5\mu\text{m} \times 5\mu\text{m}$ ), where the hydroxyl fraction has been determined by X-ray photoemission spectroscopy (XPS). The height of thin OPA film was observed by XPS Effective attenuation length (EAL) [17] method with using XPS and Atomic force microscopy (AFM) together.

Modification of Octadecylphosphonic acid on interacting the functional phosphonic headgroup with hydrophilic surface of oxidized Al has been described. The approach to use the Langmuir-Blodgett technique with non-polar solvent to transfer the full coverage OPA molecules on oxidized Al surface in room temperature. It is proposed and proved that this ion bombardment dry-reaction could enhance the mechanical strength and chemisorption of organic molecules with Al oxide substrate via ultrasonic bath and ex-situ XPS and in situ AFM and few others instrument. Moreover, the existence of well-packed Langmuir-Blodgett OPA film was confirmed with contact angle goniometer experiment for OPA coated on evaporated aluminium onto silicon wafer [18]. The molecular orientation and height/thickness of Octadecylphosphonic acid molecule were investigated with high resolution AFM and XPS analysis. The highest surface sensitivity and controlling power measured by different optical technique depends on the surface root-mean-square roughness as well. To optimize the root mean square roughness below 3nm, UV/ozone pre-treatment and ethanol wash has been used which also enhanced the hydroxyl fraction and thickness of monolayer. The height of thin film on pre-treated and optimized aluminium surface was observed by XPS EAL method with using XPS and AFM together.

## 2. METHODOLOGY

A layer of 50-nm-thick Al film was deposited with the HOSER E-beam metal evaporator onto cleaned n-type Si (100) wafer. 99.9995% pure Al target was used at ~10 kV in this evaporation process. Later on, the Al sample was blown with N<sub>2</sub> gas and was pre-treated with UV/ozone (Ultra-violet) experiment with a discharge ozone generator from dry air flow for around 60 min. UV/ozone experiment was served to remove organic contamination from the Al surface and render it more hydrophilic. In addition, it exposed in air in lesser period of time.

The solution of OPA (n-Octadecylphosphonic Acid, CH<sub>3</sub>(CH<sub>2</sub>)<sub>17</sub>P(O)(OH)<sub>2</sub>; purchased from Alfa Aesar, Ward Hill, MA) with concentration 1mM (3.34 mg/10ml, Molecular weight of OPA: 334.47 g/mole) dissolved in chloroform (99.9%; Alfa Aesar, Ward Hill, MA) was made in room temperature. The solution was heated with hotplate to 650 0C for 20 min prior to use. Notably, keeping the solution in room temperature for about 15 minutes, crystalline flakes have been observed in the solution. Those can be found as aggregates on the film performed by AFM technique. Using either new solution or re-heat the solution the solution can be completely re-dissolved. To deposit the OPA monolayer film, a KSV LB trough is employed (Company: Model: 5000) systems which is coated with Teflon. Distilled water (DI) (A Milli Q, Boston, MA) purification system was employed to produce the DI water with a resistivity of 17.5-18 MΩ-cm for all experiments as subphase and put on the LB trough until it brimmed over the top (about 2mm over the rim of the LB trough). Then 30 μL of OPA dilute solution was poured at the air-water interface on a Langmuir trough using a micro-litre syringe over the water subphase and waited around 20 min to allow the solvent to be volatilized at around 23.4 ± 0.2°C. The solvent then evaporated leaving a homogeneous and uniform OPA monolayer of the compound at the air-water interface. Following this, the amphiphilic organic molecules layer was compressed at a speed of 2.3-2.5 cm min<sup>-1</sup> by the double barrier of LB system. The Aluminium substrate was then dipped through the water subphase maintaining the Y-type method to transfer the OPA phosphor-organic molecules onto the hydrophilic substrate. During the LB experiment real time surface pressure was continuing to measure with a paper Wilhelmy plate which was suspended from a KSV microbalance at around 23.4 ± 0.2°C.

To characterize the Langmuir-Blodgett film surface and measure the height of the film of OPA, non-contact mode dynamic Force Atomic force Microscopy (Park System; Model: XE-100) was used. It also investigated phase transition coverage of organic molecules of the surface. Rectangular shape silicon cantilevers with spring constant of  $\sim 40$  N/m were attached in this microscopy tool. The volume of the cantilever was  $125 \times 35 \times 4 \mu\text{m}$ . This NC dynamic force mode AFM characterizes the surface morphology maintaining constant oscillation amplitude while the scanning tip running on the contour of the surface. All images were captured at a scan rate of  $5 \mu\text{m/s}$ . The images had been gathered in scan area of  $5 \mu\text{m} \times 5 \mu\text{m}$ .

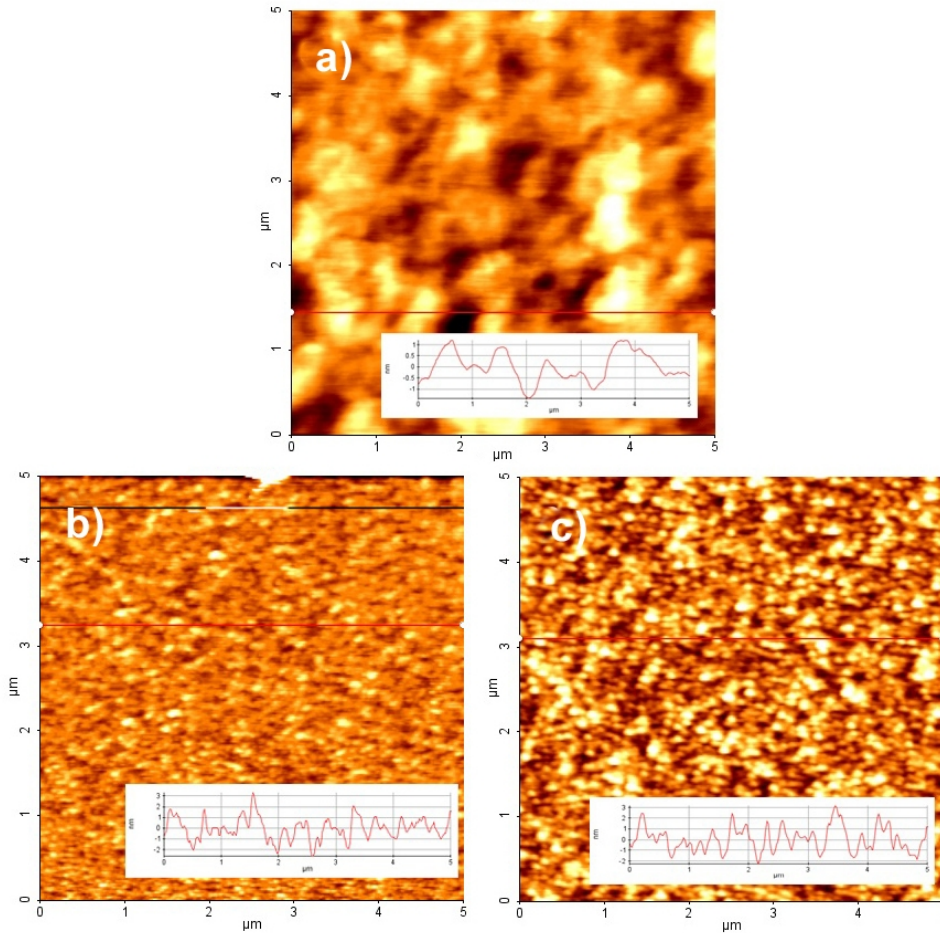
Kratos AXIS Ultra spectrometer was employed in this work for both the chemical composition analysis of sample calibrated with a monochromatic Al K ( $\alpha$ ) source (15mA, 14kV) and film thickness measurement. The latter was examined by comparing the XPS intensity of the Al (2p) peak of OPA coated to that of Al (2p) peak of uncoated aluminium surface. In the calibration, this X-ray photoemission spectroscopy can detect all atoms in a depth of 5-7 nm except H and He detection and it has limits from 0.1 to 0.5 at% which depends on surface chemical compound. This equipment was calibrated so as to the work function gives a binding energy of 83.96 eV for the Au 4f<sub>7/2</sub> line for metallic gold and in addition, the spectrometer dispersion was maintained to give a BE of 932.62 eV for the Cu 2p<sub>3/2</sub> line of metallic Cu. In all samples the Kratos charge neutralizer system was implemented. The area  $300 \times 700 \mu\text{m}$  was used for wide scan analysis keeping the take-off angle 90° and pass energy 160 eV. Also, for high resolution spectrum results, area  $300 \times 700 \mu\text{m}$  was maintained with pass energy 20 eV. Spectra have been charge modified to the adventitious C (1s) spectrum set to 284.8 eV. In order to analyze the spectra, CasaXPS software (vrs 2.3.14) was used.

To modify the coated aluminum surface, the bombardment with hydrogen projectile (around 5-8eV) had been carried out at a pressure of around  $8.0 \times 10^{-4}$  torr for about 10 and 40 seconds in room temperature. The system had been employed in ultrahigh vacuum to hit an adsorbed organic hydrocarbon precursor to transfer the kinetic energy to a hydrogen target atom to break the C-H bond where the energy is in sufficient to further bond breakage in this system. This left carbon radicals which could react with each other to form X-linked modified surface.

### **3. RESULTS AND DISCUSSION**

#### **3.1 Morphology of OPA Film after Bombardment**

The topography image of OPA on Al wafer was shown in Figure 1(a). And, in Figure 1(b) it demonstrated that the domain structure of the OPA monolayer is likely to be broken into smaller shapes after 10 s hydrogen bombardment and the size of domain seems like higher on higher bombardment time, such as 40 s as shown in Figure 1(c). The root-mean square deviation of the 10 s bombarded sample was 2.4 nm and that of the 40 s is  $\sim 4.0$  nm. Figure 1(b) and (c) show topography images where the a bit changes has been observed with the function of bombarded time in this kinematics-driven reaction effect indicating that the molecules were becoming a little bit aggregated and mosaic-shaped.



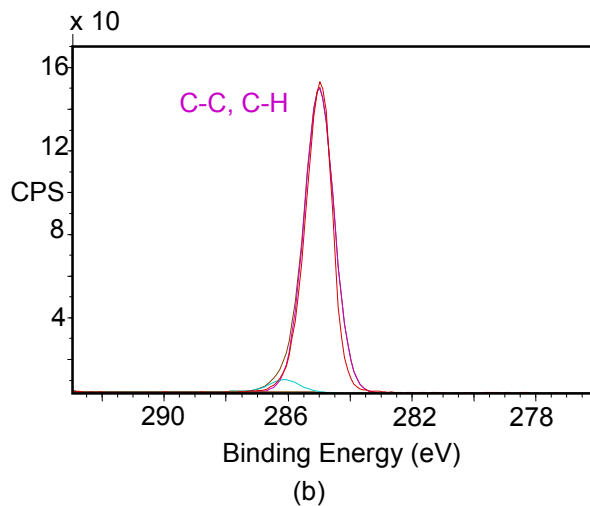
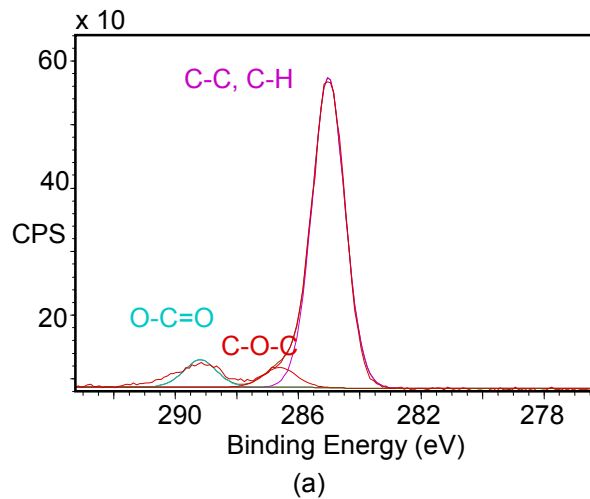
**Figure 1. Schematic illustrations of non-contact dynamic force mode AFM images of OPA LB film morphology: (a) topography image; modified surface with hyperthermal hydrogen induced collision which was bombarded for (b) 10 s (c) 40 s onto 50 nm thick evaporated Al film. Inset demonstrated the roughness of those films. All are in same scaled**

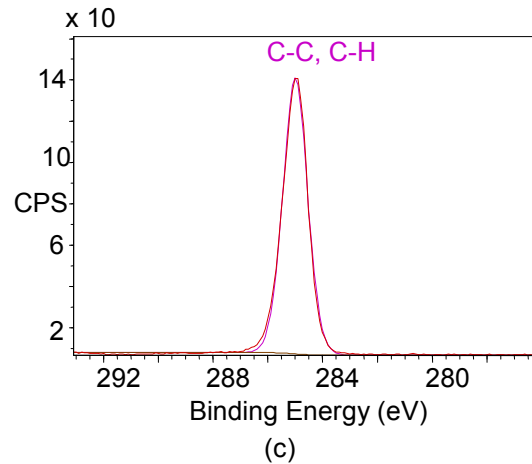
The degree of residual defects was enhanced with increasing the degree of cross-linking on higher efficiency of H bombardment. Root mean square roughness was increased significantly after bombardment and cluster size became larger with increasing bombardment time such as for 40 s.

Hyperthermal hydrogen collision leads to C-H cleavage preferentially with no cleavage of phosphonic acid group of adsorbed hydrocarbon according to Zheng et al. [19]. When adjacent molecules form cross-linked C-C bond to replace van der Waals interaction forces, this change may overcome the substrate-molecule adsorption. Therefore, increasing the degree of cross-linking as a function of time (40 s) at constant hydrogen energy (around 5 eV) leads to higher roughness than 0 s bombardment. In addition, it turns uniform and ordered OPA coated surface to the larger island clusters. Thus, Figure 1(c) shows larger clusters growth of hydrocarbon molecules in increased degree of reaction via fluence.

### 3.2 XPS Study for Modified Surface

Under the dry reaction process the weak intermolecular van der Waals interaction is expected to be replaced by covalent intermolecular C-C cross-bonds. If the molecules of thin film weakly adsorb on the substrate, the intermolecular C-C cross-links bond strains are stronger enough to perturb the adsorbant-adsorbate bonding configuration. However, for adsorbant-adsorbate molecular configuration along with stronger adsorption strength, intermolecular C-C cross-bond strains are not strong enough to destroy the multilayers monolayer configuration which is formed due to cross-linking. A novel kinematic collision-driven hyperthermal hydrogen collided covalently cross-linked monolayer is thus formed. 5 eV proton energy is employed to bombard OPA samples deposited onto evaporated aluminium surface. Carbon concentration in the bare aluminum has been observed which was form with adventitious carbon.





**Figure 2. XPS high resolution C (1s) core-level spectra of (a) bare aluminum, (b) OPA coated aluminum surface (c) bombarded for 10 s OPA on aluminum by hydrogen projectiles having kinetic energy of 5 eV**

Figure 2 illustrated for an uncoated aluminum surface. The difference of the binding energy between C-C, C-H peak and C-O-C peak was  $1.58 \pm 0.01$  eV. For the 95% coverage OPA sample before cross-linking, the difference became  $1.13 \pm 0.01$  eV. For 10 s bombarded cross-linked OPA, no C-O-C bonds were observed, indicating the homogeneous and uniform overlayer in OPA coated sample and significant cross-linking C-C bonding are existed after 10 s bombardment. A difference of  $0.45 \pm 0.01$  eV in between C-O-C and C-C, C-H on bare aluminum, which is characteristic for adventitious carbon, was verified. A 7.6% area of O-C-O bonds was detected on bare aluminum surface.

The continuous line shortening of core shape-peak centroid from uncoated aluminum surface towards coated substrate suggests inhomogeneous and un-uniform surface structure on the evaporated aluminum substrate. The area% of C-C, C-H was gradually increasing and C-O-C bonds were gradually decreasing as a function of coverage and also as a function of bombardment time. Consequently, cross-linking by kinematics driven effect had enhanced the uniformity of OPA overlayer on roughed aluminum surface. Thus, it may be concluded that the weak intermolecular van der Waals bonds has been replaced by chemically covalent C-C bonds of polymer on surface.

According to Table 1, high resolution binding energy area of carbon (1s) line position for evaporated aluminum surface, OPA covered aluminum with nearly full coverage and 10 s bombarded OPA samples. As shown in Figure 2(a), the full width at half maximum (FWHM) of C-C, C-H bond of C (1s) for the bare aluminum is nearly 1.23 eV and %area is 86.8. The FWHM of the OPA sample decreases to 1.10 eV with %area 96.3. After 10 s hydrogen projectile bombardment for 10 s, it decreases to 1.04 eV. This suggests that the C-C, C-H bonding in the OPA specimen results further homogeneous and uniform C (1s) spectra than the adventitious C (1s). It is also interesting to observe that for a bare aluminum, the area of C-O-C and O-C-O bonds is significant, e.g., 5.6% and 7.6%, respectively. The C-O-C bond decreases gradually for OPA coated surface and 10 s bombarded specimen.

**Table 1. FWHM and %area of C-C, C-H, C-O-C and O-C-O bonds of bare Al, 0 s bombarded OPA and 10 s bombarded OPA**

Materials	C-C, C-H		C-O-C	
	FWHM (eV)	%Area	FWHM (eV)	%Area
Bare Al (0% coverage)	1.23	86.8	1.23	5.6
0s bombarded OPA (~95% coverage)	1.10	96.3	1.10	3.7
10 s bombarded OPA	1.04	100	--	0

**Table 2. The area (%) of P (2p) OPA/aluminum, 10 s and 40 s bombarded OPA are given below respectively**

Materials	P 2p, Area (%)
OPA on aluminum	86.0
bombarded for 10 s	55.7
bombarded for 40 s	52.1

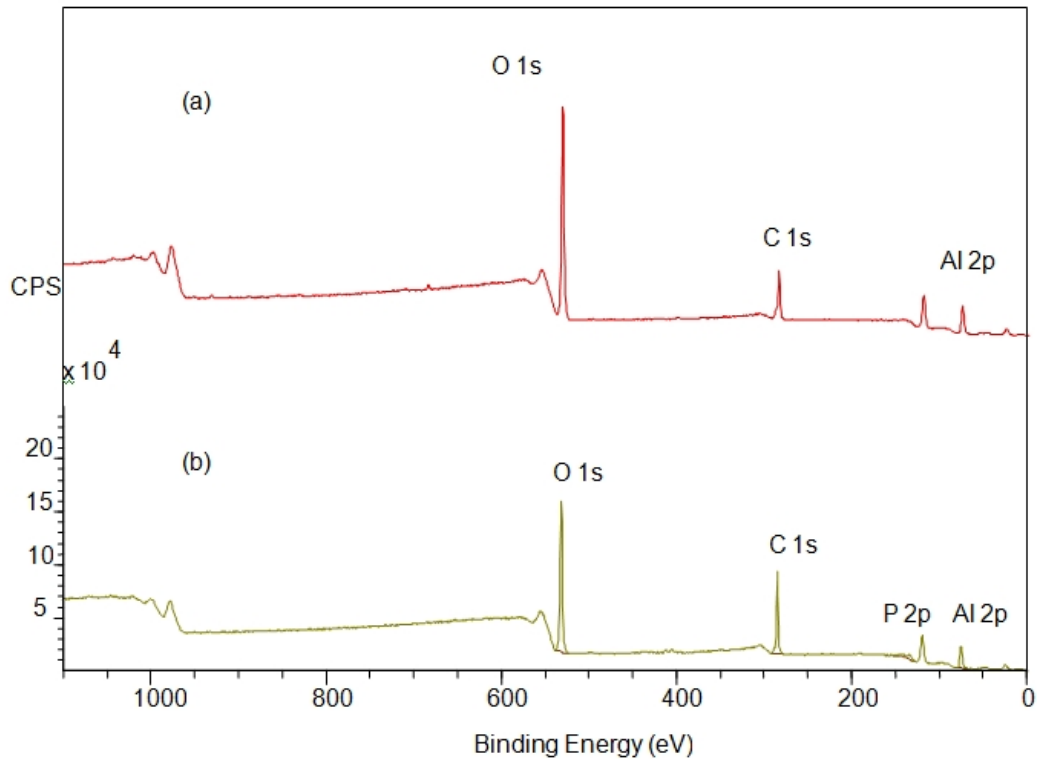
From the Table 2, it can be summarized that the significant amount of P 2p existed on overlayer of OPA. The observed P (2p) of precursor molecules with 86% which decreased after bombardment towards 55.7% for 10 s and 52.1% for 40 s.

### 3.3 Washing Experiment with Hexane and Ethanol

To enhance the mechanical strength of OPA molecule with surface is a crucial matter in surface science. The dry-reaction cross-linking bonds can optimize the molecular strength replacing the van der Waals interaction force with C-C chemical bonds where functional organo-phosphonic acid group's activity is kept intact. The hyperthermal hydrogen induced cross-linking-treated film can survive the ultrasonic dissolution test along with functional group retention (Characterized by XPS and AFM techniques).

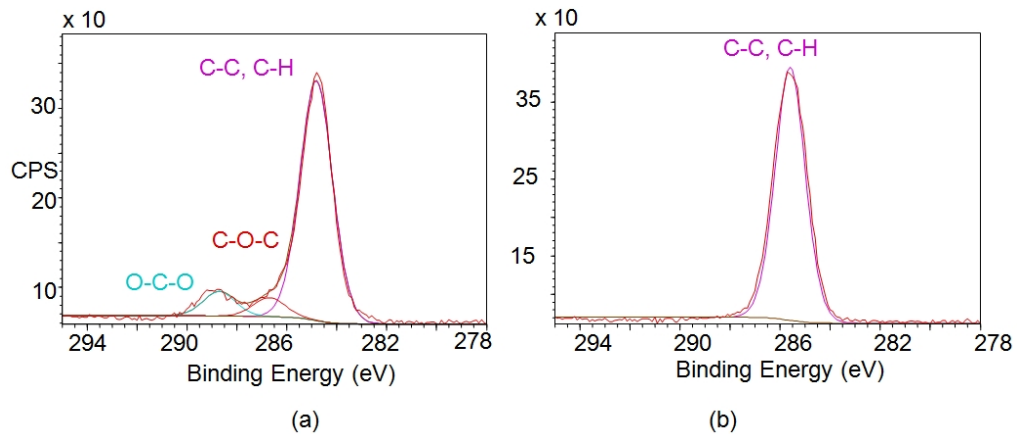
The HHIC-treated film survived the hexane washing test with an existed thickness along with detectable phosphorus spectrum. It said that virgin OPA LB film was not mechanically strong enough to withstand a 3 min ultrasonic bathing with hexane. Moreover, the cross-linked OPA molecules survived even stronger chemical attack demonstrated in the ethanol washing tests. This gave the significant experimental results and evidence that chemical stability can be enhanced by the degree of cross-linking.

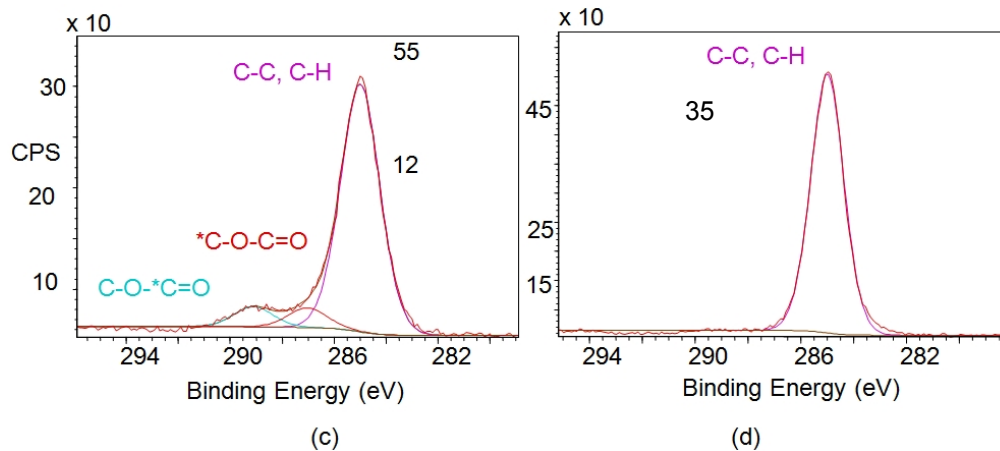




**Figure 3. XPS wide scan results of (a) virgin OPA LB film and (b) cross-linked OPA LB films with 10 s HHIC bombardment and after ultrasonic bath with Ethanol.**

Figure 3 shows the XPS survey spectrum of the virgin and cross-linked OPA molecular films after ultrasonic bath with polar ethanol for around 3 minutes. According to those wide scan spectra, the P 2p signal was not observed in the virgin films while found in the cross-linked OPA LB film on aluminum surface. The area% of P 2p of dry cross-linked OAP films after washing with ethanol is 4.3 whereas that of virgin films is absent after wash. However, the amount of P 2p of bombarded films for 10 s after wash with ethanol is less than that of the same films without washing.





**Figure 4. X-ray photoemission spectroscopy C (1s) core-level spectra for (a) virgin OPA LB film and (b) cross-linked OPA LB film (bombarded for 40 s) washed with hexane, (c) virgin OPA LB film and (d) cross-linked OPA LB film (bombarded for 40 s) washed with ethanol**

According to Figure 4, the FWHM of C-C, C-H bond of C (1s) for the virgin specimen washed with hexane is nearly 1.52 eV and %area is 84.6. After cross-linking of the OPA overlayer, the ultrasonic bath experiment shows the full width at half maximum of C-C becomes narrower (1.40 eV) with a greater %area ~100. Washing with ethanol results in the half width of those bonds for the virgin film to be 1.77 eV with %area 86.1. For cross-linked OPA LB film, the half width is 1.46 eV and %area ~100, which indicates that virgin specimen C 1s core-line spectra is similar to the that of bare aluminum surface with adventitious C 1s as shown Figure 2(a). The cross-linked samples confirmed the existence of enhanced C 1s spectrum, i.e., with stronger chemical strength. For virgin film, the binding energy of C-O-C and O-C-O peaks has been observed with area% 6.7 and 8.7, respectively. For this OPA sample, the BE of C-O-C=O is also observed with area% 13.9 after ethanol washing, suggesting that ethanol modified the C bonding of the OPA molecules deliberately.

#### 4. CONCLUSION

The uniform and well-ordered Octadecylphosphonic acid Langmuir-Blodgett film on evaporated aluminum oxide surface was formed and characterized. In this study, it demonstrated that long hydrocarbon chain chemical bonding was modified with hyperthermal hydrogen induced collision effect which induced cross-linking keeping its functional group of Octadecylphosphonic acid intact. Inherently, OPA functional group bonds chemically with aluminum oxide following the condensation reaction which makes the bonding stronger by default. Nevertheless, taking advantage of the fact that phosphonic functional headgroup (-P(O)(OH)<sub>2</sub>) bonds are stronger than C(1s)-H bonds, the mechanical strength of the OPA film on aluminum without modifying the chemical functionalities of the molecules is enhanced which were analyzed by few surface analysis methods. In this study, kinematics-driven approach with hyperthermal proton energy can induce cross-linking of the adsorbed OPA onto surface and can modify the actual ordered LB lattice into an array of clusters of the OPA film on aluminum oxide. The nanocluster growth is to be narrowed by increasing the dry-reaction time at fixed bombardment energy and at a modified fluence which indicates the degree of cross-linking can be controlled with a function of bombardment

time. Thus with a controllable bombardment condition with function of fluence can modify the cluster shape and enhance the mechanical strength.

## **ACKNOWLEDGEMENTS**

I greatly acknowledged to Dr. Heng-yong Nie, Dr. Leo Lau for providing financial support on this thesis and guideline. I would like to thank Dr. Tim Goldhawk and Dr. Rick Glew to cooperate to use Langmuir-Blodgett technique at Nanofab lab, the University of Western Ontario, London Ontario, Canada in the clean room environment. I also wish to thank you Mark, SSW, London, ON, Canada for helping me out to use the XPS.

## **COMPETING INTERESTS**

Author has declared that no competing interests exist.

## **REFERENCES**

1. Wink T, Van-Zuilen S, Bult A, Van-Bennekom W. (Self-assembled monolayers for biosensors) *Analyst*. 1997;122:43-50.
2. Schreiber F. (Organic molecular beam deposition: Growth studies beyond the first monolayer) *Prog. Surf. Sci.* 2000;65:151-256.
3. Woodward JT, Schwartz DK. (In Situ observation of self-assembled monolayer growth) *J. Am. Chem. Soc.* 1996;118:7861-7862.
4. Bastani B, Fernandez D. (Intellectual property rights in nanotechnology). *Inform. Technol. J.* 2005;4:69-74.
5. Bawa R, Bawa SR, Maebius SB, Flynn T, Wei C. (Protecting new ideas and inventions in nanomedicine with patents). *Nanomedicine*. 2005;1:150-158.
6. Benn J, Clarke J. (Future applications of nanotechnology within veterinary medicine. Research Paper Based on Pathology). *Lectures at Medlink*; 2007.
7. Bianco A, Kostarelos K, Partidos CD, Prato M. (Biomedical applications of functionalised carbon nanotubes). *Chem. Commun.* 2005;5:571-577.
8. Bollo E. (Nanotechnologies applied to veterinary diagnostics). *Vet. Res. Commun.* 2007;31:145-147.
9. Ramsier RD, Henriksen PN, Gent AN. (Adsorption of phosphorus acids on alumina) *Surf. Sci.* 1988;203:72.
10. Pellerite MJ, Dunbar TD, Boardman LD, Wood EJ. (Effects of fluorination on self-assembled monolayer formation from alkanephosphonic acids on aluminum: kinetics and structure) *J. Phys. Chem. B.* 2003;107:11726.
11. Haque E, deRose J, Kulik G, Hoffman P, Mathieu H, Bhusban B. *J. Phys. Chem. B.* 2006;110:10855-10861.
12. Adolphi, B, Jahne E, Busch G, Cai X. Characterization of the adsorption of omega-(thiophene-3-yl alkyl) phosphonic acid on metal oxides with AR-XPS). *Anal. Bioanal. Chem.* 2004;379(4):646-652.
13. Yoshimoto M, Maeda T, Ohnishi T, Koinuma H, Ishiyama O, Shinohara M, Kubo M, Miura R, Miyamoto A. (Orientation-defined molecular layer epitaxy of  $\alpha$ -Al<sub>2</sub>O<sub>3</sub> thin films) *Appl. Phys. Lett.* 1995;67(18):2615-2617.
14. Van-den JB, Blajiev O, Beentjes PC, Terryn H and de-Wit JHW. (Interaction of anhydride and carboxylic acid compounds with aluminum oxide surfaces studied using infrared reflection absorption spectroscopy). *Langmuir*. 2004;20:6308-6317.

15. Liakos, IL, Newman RC, McAlpine E, Alexander MR. (Study of the resistance of SAMs on aluminium to acidic and basic solutions using dynamic contact angle measurement). *Langmuir*. 2007;23:995-999.
16. Blajiev OL, Lthurbide A, Hubin A, Van-Haesendonck C and Terryn H. (XPS study of the assembling morphology of 3-hydroxy-3-phosphono-butiric acid tert-butyl ester on variously pretreated Al surfaces). *Progress Organic Coatings*. 2008;63:272–281.
17. Petrovykh DY, kimura-Suda H, Tarlov MJ, Whitman L. (Quantitative characterization of DNA films by X-ray photoelectron spectroscopy) *Langmuir*. 2004;20:429-440.
18. Liakos IL, Newman RC, McAlpine E, Alexander MR. (Study of the resistance of SAMs on aluminium to acidic and basic solutions using dynamic contact angle measurement). *Langmuir*. 2007;23:995-999.
19. Zheng Z, Kwok WM, Lau WM. (A new cross-linking route via the unusual collision kinematics of hyperthermal protons in unsaturated hydrocarbons: the case of poly (trans-isoprene)) *Chem. Commun*. 2006;3122-3124.

© 2014 Dey; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/3.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*

*The peer review history for this paper can be accessed here:*

<http://www.sciencedomain.org/review-history.php?iid=283&id=4&aid=2211>