DNA Topical Conference
Room 311 - Session DN+BI-TuM

DNA Surface Characterization

Moderator: D.W. Grainger, Colorado State University

8:20am **DN+BI-TuM1 First-principles Calculations of DNA Core Level Energies**, ***J.M. Sullivan,*** Northwestern University and Naval Research Laboratory; *D.Y. Petrovykh,* University of Maryland and Naval Research Laboratory; *G.C. Schatz,* Northwestern University; *L.J. Whitman,* Naval Research Laboratory

X-ray photoelectron spectroscopy (XPS) is emerging as a powerful method for characterizing DNA on surfaces.@footnote 1@ The relative positions of core electron binding energies (CBEs) suggest likely binding geometries and strength of chemical bonds, and the peak areas provide a quantitative measure of the coverage. Although CBEs for simple molecules can often be readily assigned to specific adsorption sites and bonding configurations based on historical data, such interpretation for CBEs of DNA is not possible. As a start to developing a comprehensive ab initio understanding of DNA-surface interactions, we are using density functional theory to determine the geometric and electronic configuration of DNA nucleobases, nucleosides, and nucleotides in the generalized gradient approximation. We have initially focused on the nitrogen spectra because these are the easiest to interpret experimentally, arising solely from the nucleobases. Binding energies of core-electrons are evaluated in a variety of standard methodologies including spin-restricted and spin-unrestricted versions of Slater's and generalized transition state methodologies, and a @Delta@KS-type approach in which the CBE is determined directly by the difference between the total energy of the molecule with and without the core hole. We find the theoretical XPS spectra for isolated nucleic components are surprisingly similar to experimental spectra measured on DNA films, suggesting that-although the films are adsorbed on the surface-the underlying electronic structure of the nucleobases is "free-like". @FootnoteText@ @footnote 1@D. Y. Petrovykh, et al., J. Am. Chem. Soc. 125, 5219 (2003); D. Y. Petrovykh, et al., Langmuir 20, 429 (2004).

8:40am **DN+BI-TuM2 Entropic Recoil of Single DNA Molecules from Nanochannels**, ***J.T. Mannion,*** *C.H. Reccius, J.D. Cross, H.G. Craighead,* Cornell University

Entropic recoil of DNA molecules from pillar arrays has previously been reported.@footnote 1@ It has been shown that this effect has the potential to separate molecules according to length.@footnote 2@ A molecule straddling the interface between two microfabricated regions with vastly different volumes of configuration space experiences a force causing it to retract from the region which has less accessible volume. We have tested a device in which DNA molecules recoil from an array of channels as opposed to pillars. Nanochannels (100nm by 100nm) connected to the end of a microchannel (40 microns by 100nm) have been fabricated in a fused silica wafer. This change in geometry eliminates the possibility of herniation, which had previously been observed for molecules recoiling from pillar arrays. Using channels instead of pillars also makes it possible to track a molecule undergoing the recoil process more precisely and to carefully observe the dynamics of this process. As a consequence, we have been able to study the recoil and drag forces in greater detail. In addition we have clearly identified molecules that enter channels in a folded manner, and can observe unfolding events during recoil. @FootnoteText@ @footnote 1@ Turner, S. W. P.; Cabodi, M.; Craighead, H. G. Phys. Rev. Lett. 2002, 88, 128103-1-128103-4.@footnote 2@ Cabodi, M.; Turner, S. W. P.; Craighead, H. G. Anal. Chem. 2002, 74, 5169-5174. .

9:00am **DN+BI-TuM3 Surface Analysis Characterization of DNA-Microarray Chemistry**, ***L.J. Gamble,*** University of Washington **INVITED**

DNA microarrays have received considerable attention in the fields of bio- and nanotechnology due to their importance in the development of biosensing and diagnostic devices. The construction of these surfaces often entails the attachment of presynthesized oligonucleotides onto a derivatized surface. The hybridization efficiency of DNA microarrays and biosensors is determined in part by variables such as the density and orientation of the single stranded DNA oligomers used to build the devices. Surface analysis techniques such as X-ray photoelectron spectroscopy (XPS), near edge X-ray adsorption fine structure, time-of-flight secondary ion mass spectrometry (ToF-SIMS), and surface plasmon resonance (SPR) can aid in producing reliable, quantitative, and reproducible microarray chemistry. Our initial studies have used model surfaces of self assembled monolayers of thiolated DNA on gold to compare surface characterization (XPS and NEXAFS) of the DNA with hybridization efficiency (SPR and radio-labeling). Factors such as the DNA purity, DNA-surface interaction, and the non-fouling capabilities of the background are discussed. Commercial surfaces and surfaces modeled to simulate the commercial substrates are analyzed with surface analysis techniques as well.

9:40am **DN+BI-TuM5 Surface Science of DNA: The Time Has Come**, ***D.Y. Petrovykh,*** University of Maryland and Naval Research Laboratory **INVITED**

The development of practical DNA-based applications in bio- and nanotechnology has uncovered a menagerie of complications, many related to interactions of molecules with surfaces. Fortunately, the tools and methods developed or adapted for analyzing DNA and other biointerfaces are now significantly advanced to make an impact in both basic and applied surface science of DNA. I will focus on the progress in understanding DNA-surface and DNA-DNA interactions resulting from our ex-situ spectroscopic studies by XPS, FTIR, and NEXAFS. Homo-oligonucleotides have emerged as a useful model system for the study of such interactions. A few examples from the surprisingly wide range of phenomena that we have uncovered include polyelectrolyte behavior of weakly-interacting oligo(dT) strands, buffer-induced cross-linking in oligo(dC) films, and singularly high affinity of oligo(dA) for gold. The most practical impact of our analysis of DNA-functionalized surfaces has been quantifying the effects of experimental conditions (concentration, temperature, buffer salt, etc.) on DNA immobilization and hybridization. Improved understanding of nucleobase-dependent interactions should also facilitate the rational design of immobilization chemistries and DNA probe sequences. Ultimately, the challenge is to apply surface science methods to more complex biomolecular systems and processes, such as label-free characterization of DNA hybridization. @FootnoteText@ This work was done in close collaboration with A. Opdahl, H. Kimura-Suda, V. Perez-Dieste, J. M. Sullivan, F. J. Himpsel, M. J. Tarlov, and L. J. Whitman.

10:20am **DN+BI-TuM7 Kinetics and Thermodynamics of DNA Binding at Surfaces and in Solution**, ***R.M. Georgiadis,*** Boston University **INVITED**

This talk will review recent results on DNA oligonucleotide binding at surfaces and in solution. Using surface plasmon resonance spectroscopy for unlabeled oligonucleotide probes and solution oligonucleotide target species, we examine how the kinetics and thermodynamics of apparent binding for DNA/DNA hybridization depends on strand secondary structure, mismatches, and probe attachment chemistry. We show how SPR imaging can be used for quantitative monitoring of the kinetics of drug/DNA binding for an intercalating drug (actinomycin-D) interacting with array surfaces presenting multiple DNA target sequences containing different drug binding sites. SPR imaging is also used for optimization of attachment chemistry and for development of convenient surface coatings that resist non-specific binding of the pentapeptide containing drug. The array results are compared with solution phase measurements and other non-array SPR measurements and discussed in the context of chemical reaction mechanisms.

11:00am **DN+BI-TuM9 Measurement of RNA Density of States, Ionization Energy, Work Function and Charge Injection Barriers to Inorganic Materials**, *M.M. Beerbom,* ***J.P. Magulick,*** *B. Lagel, A.J. Cascio, R. Schlaf,* University of South Florida

In light of recent conductivity measurements on single DNA stands, which yielded a wide range of results from insulating to metallic, it is interesting to investigate the electronic structure of oligonucleotides. In our experiments we directly measured the highest occupied molecular orbital (HOMO) density of states, the ionization energy, the work function and the charge injection barriers to graphite and Au of RNA homopolymers. This was achieved using photoemission spectroscopy (PES) in combination with clean multi-step in-vacuum deposition of RNA thin films using a homebuilt electrospray deposition system. This system allows the deposition of macro-molecular materials with a level of control similar to Knudsen cells directly from solution allowing essentially contamination free fabrication of thin films suitable for PES measurements. Furthermore, multi-step depositions without breaking the vacuum are enabled by this technique. Our presentation will give an introduction to the measurement technique, and introduce the experimental set-up. Data from several experiments on RNA homopolymer interfaces to graphite and Au will be discussed, and conclusions with regard to conductivity measurements made.

11:20am **DN+BI-TuM10 Compression and Free Expansion of Single DNA Molecules in Nanochannels**, ***C.H. Reccius***, *J.T. Mannion, J.D. Cross, H.G. Craighead,* Cornell University

A variety of micromanipulation techniques have been used in the past to study the mechanical properties of DNA.@footnote 1@ Characterization of these properties is important for an understanding of DNA packing into chromatin or bacteriophage heads and also for the verification of theoretical biopolymer models. Extensive experiments have been conducted on stretching DNA in order to study its elasticity.@footnote 2@ In contrast to stretching by an external force, we are investigating the compression and subsequent free expansion of DNA molecules in artificial nanoscale devices. In this work, single lambda DNA multimers were driven through fluidic channels with a diameter of 100 nm by an electric field. Since the radius of gyration of the biomolecules was bigger than the channel diameter, their equilibrium state was no longer a sphere but instead an elongated cylinder.@footnote 3@ Forcing the stretched DNA into a channel constriction led to a compression of the molecule into a tight conformation. When the electric field was turned off, the DNA molecule slowly expanded back to the energetically favorable stretched out conformation. This expansion can be interpreted with the help of a simple polymer model based on self-avoidance effects. @FootnoteText@ @footnote 1@ Strick T. R., Dessinges M-N., Charvin G., Dekker N. H., Allemand J-F., Bensimon D., and Croquette V., Rep. Prog. Phys., 66, 1-45 (2003).@footnote 2@ Smith S. B., Finzi L., and Bustamente C., Science, 258, 1122-1126 (1992).@footnote 3@ Tegenfeldt J. O., Prinz C., Cao H., Chou S., Reisner W. W., Riehn R., Wang Y. M., Cox E. C., Sturm J. C., Silberzan P., and Austin R. H., PNAS, 101, 10979-10983 (2004).

11:40am **DN+BI-TuM11 In-situ Infrared Spectroscopic Study of Protonation of DNA Aggregated at Electrode Surfaces in Aqueous Solution**, ***K. Miyamoto***, *K. Ishibashi, R. Yamaguchi, Y. Kimura, H. Ishii, M. Niwano,* Tohoku University, Japan

Recently we have proposed a method of monitoring hybridization of nucleic acids using infrared absorption spectroscopy (IRAS) in the multiple internal reflection geometry (MIR). The advantages of our method are follows: (1) Fluorescence labeling is not necessary for detection of DNA hybridization (label-free), (2) IRAS provide us with valuable information about conformations of biomolecules, and (3) MIR-IRAS enable us to in-situ monitor biomolecules in aqueous solution. We confirmed that hybridization of DNA can be detected through infrared spectral profiles: Formation of hydrogen bonding between complementary single-stranded (ss-) DNAs induced specific spectral changes in the frequency region of 1600-1750 cm@super -1@.@footnote 1@ Additionally, we demonstrated that when a positive potential is applied to the Si MIR-prism, negatively-charged ss-DNA molecules are aggregated on the prism surface, and that those aggregated ss-DNA molecules show infrared spectral profiles that are quite different from those of isolated DNA molecules floating in the solution. In this study, we have investigated the infrared spectral changes caused by DNA aggregation at an electrode (anode) surface in aqueous solution. By comparing previous IRAS data obtained for the base protonation under acidic condition, we determine that the observe spectral changes are due to protonation of the bases of DNA in the vicinity of the anode (Si MIR-prism) surface where electrochemical reactions generate a large number of protons. Results of ab-initio calculations support our interpretation. @FootnoteText@ @footnote 1@K. Miyamoto, K. Ishibashi, K. Hiroi, Y. Kimura, H. Ishii, M. Niwano, Appl. Phys. Lett. 86, 053902 (2005).

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