Fundamentals
Room Great Lakes B - Session FM-WeM3

Fundamentals - Secondary Ion Formation II
Moderator: Andrew Giordani, Procter & Gamble Company

10:20am **FM-WeM3-11 Ion Suppression Effect of Atrazine in SIMS and MALDI Imaging in Earthworm Samples and its Correlation to Gas Phase Basicity**, *T. Weintraut, S. Heiles, A. Henss,* ***Marcus Rohnke****,* Justus Liebig University Giessen, Germany

Rationale: In mass spectrometry imaging (MSI), ion suppression can lead to misinterpretation of results. Especially phospholipids, most of which exhibit high gas-phase basicities, are known to suppress the ionization rates of metabolite and drug molecules out of tissues. Thus, for a distinct MSI anaylsis of a selected tissue type, it is essential to reveal and cope with these ion suppression effects. Motivated by unexpected analyte distributions within environmentally relevant tissue sections, we systemtatically investigated the apparent suppression of an herbicide signal in earthworm samples with ToF-SIMS and MALDI-MSI. We hypothise that the gas-phase basicity correlates with ion suppression effects.

Methods: The accumulation of the herbicide atrazine in earthworms was investigated with ToF-SIMS and MALDI-MSI and subsequently compared with untreated samples spiked with the herbicide. Furthermore, the relationship of signal intensity and gas-phase basicity in binary mixtures of lipids and herbicide was evaluated and applied for measurements with atrazine. Finally, atrazine standards with varying concentrations of a homogenized earthworm suspension were analysed in ToF-SIMS and MALDI-MSI.

Results: ToF-SIMS measurements of the earthworm sections revealed pronounced ion suppression of protonated atrazine in most sample areas. MALDI-MSI showed similar ion suppression, but in comparison more areas with atrazine could be detected. For binary lipid-atrazine mixtures, the logarithmic intensity ratios of the two protonated components followed a linear relationship when plotted as a function of the corresponding gas phase basicity. A possible range for the gas-phase basicity of atrazine (GB_{ATR}=930-985 kJ/mol) was determined. Measurements of the atrazine standards with varying earthworm content showed no clear dependence on concentration.

Conclusions: The presence and elevated concentration of phospholipids in ToF-SIMS and MALDI-MSI analysis of earthworm samples leads to ion suppression of the protonated atrazine signal. The determined possible range for the gas-phase basicity of atrazine (GB_{ATR}=930-985 kJ/mol) lies significantly lower than the known gas-phase basicity of one of the major lipid components, phosphatidylcholine (GB_{PC}=1044.7 kJ/mol).[1] Therefore, competition for protons in the desorption process of both MSI techniques is most likely the cause for the observed ion suppression of atrazine.

[1] Miller ZM, Zhang JD, Donald WA, Prell JS. Gas-Phase Protonation Thermodynamics of Biological Lipids: Experiment, Theory, and Implications. Anal Chem. 2020;92(15):10365-10374. doi:10.1021/acs.analchem.0c00613.

10:40am **FM-WeM3-13 Ion Emission of Molecules from Graphene and Carbon Nanotube Substrates via Large Cluster Impacts: Mechanisms of Ionization**, ***Stanislav Verkhoturov****, D. Verkhoturov,* Department of Chemistry, Texas A&M University*; M. Gołuński, S. Hrabar, Z. Postawa,* Department of Physics, Jagiellonian University, Kraków, Poland*; A. Kolmakov,* National Institute of Standards and Technology, Gaithersburg*; E. Schweikert,* Department of Chemistry, Texas A&M University

We study here the ion emission of molecules stimulated by impacts of cluster ions of C_{60} and Au_{400} (~1 keV/projectile atom) from Graphene and Carbon Nanotube substrates. Figure 1 (supplemental document) shows the sketch of bombardment/emission directions. The analytes are: a) sub-single molecular layer of Phe molecules deposited on 2L graphene; b) sub-single layer of Phe molecules on multi-wall carbon nanotubes; c) a polymer layer of PMMA (~1 mm) covered by a single-layer ^{13}C graphene.

Two custom-built Cluster ToF SIMS devices with similar parameters were used. The experiments were run in the event-by-event bombardment/detection mode; thus, the regime of bombardment is super-static [1]. The primary cluster ions used were 50 keV C_{60}^{2+}, and 520 keV Au_{400}^{4+}.

For the cases a) and b) (C_{60} impacts), the mechanism of ejection is described with the "trampoline" model [2]. The proposed mechanisms of molecule ionization are electron tunneling and direct proton transfer exchange. For both mechanisms, the presence of graphene support plays an important role as an electron donor.

The configuration c) is different. The emission of molecular ions is suppressed by a single layer of graphene (C_{60} impacts). MD simulations show that this is not a case of low ionization probability for this sample configuration but in fact graphene suppresses the ejection of molecules. The compression of matter in the excitation volume around the impact is not sufficient to destroy the graphene.

However, impacts of 520 keV Au_{400}^{4+} stimulate abundant emission of molecular ions (configuration c). We will discuss new mechanisms of ejection/ionization for the case of 520 keV Au_{400}^{4+} impacts. We posit that these mechanisms involve an electromagnetic interaction of Au_{400} projectile with graphene (case c).

[1] M. Eller et al. Anal. Chem. 88 (2016)

[2] S.V. Verkhoturov et al. J. Chem. Phys. 150 (2019)

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11:00am **FM-WeM3-15 Oxygen Enhancement of Sputtered Ion Yields: Anomalous Behavior of Electropositive Impurities (Al and B) in Cu(O) Matrices**, ***Peter Williams****, K. Franzreb,* Arizona State University

Oxygen enhancement of sputtered ion yields continues to be one of the most useful, yet least understood, phenomena in SIMS.In an earlier study [] we noted that the yield of an Al implant in silicon was almost unaffected by the oxygen content of the sample, whether delivered by an oxygen primary ion beam or by oxygen gas flooding or both.Here we extend this study to single crystal copper and aluminum substrates.With the oxygen content of the targets calibrated using an implanted 18O internal standard, we observed that the yields of both Al+ and B+ from implants in Cu were minimally -- or not at all -- enhanced by changing O levels.As a check, oxygen enhancement of Al+ ion yields from an Al metal target behaved "normally", i.e. could be enhanced by almost 3 orders of magnitude by increasing oxygen content.Cu+ sputtered from a Cu target started to be enhanced at O/Cu levels ~ 0.1.In contrast, Cu+ from a Cu implant in Al responded to added O at levels of a few % and in fact paralleled the behavior of Al+/Al at a factor of ~5 lower yield.Currently we rationalize these behaviors in terms of:

a) enhanced ion yields of both Al and impurities in the maximally ionic Al(O) lattice;

b) gettering of trace amounts of O in Cu by B and Al to form nanoprecipitates of Al2O3 and B2O3 (and similarly of O in Si by trace Al) that result in ion yields of B+ and Al+ similar to the bulk oxides, and

c) incorporation of trace Cu in Al(O) into cation sites in the aluminum oxide lattice and/or in Al2O3 precipitates that give yield enhancement similar to that of Al+ (although lower in absolute magnitude due to the higher ionization potential of Cu).

11:20am **FM-WeM3-17 Strategy for the Construction of Accurate 3D NanoSIMS Depth Profiling Images of Cells Despite Lateral Variations in Sputter Rate**, *M. Brunet, B. Gorman,* ***Mary Kraft****,* University of Illinois Urbana-Champaign

We present a new strategy that enables the construction of accurate three-dimensional (3D) NanoSIMS depth profiling images of cells in the presence of lateral variations in sputter rate and the absence of correlated topography data. We use the secondary electrons that were collected in parallel with the negatively charged secondary ions during NanoSIMS depth profiling to reconstruct the cell's morphology at the time each depth profiling image was acquired. Next, we adjust each of these morphology reconstructions so that the height at every x, y location decreases with increasing image plane. Finally, we shift each voxel in the component-specific 3D NanoSIMS images to the z-position of the corresponding pixel in the morphology reconstruction for the same image plane. We validated this strategy by comparing the morphology reconstruction created using the first secondary electron depth profiling image acquired from a cell with focused ion beam - secondary electron microscopy (FIB-SEM) to AFMmeasurements of the cell taken before depth profiling. The shape, curvature, and relative height of the reconstructed morphology agreed well with the AFM data. Use of this approach to depth correct 3D NanoSIMS depth profiling images of ^{18}O-cholesterol and ^{15}N-sphingolipids that were metabolically incorporated into a mammalian cell yielded more accurate representations of the cholesterol and sphingolipid distributions within the cell. Depth correction also improved the clarity of the component-specific

3D images, allowing transport vesicles and organellar membranes containing ^{18}O-cholesterol and ^{15}N-sphingolipids to be more clearly visualized. This strategy opens the door to constructing relatively accurate 3D NanoSIMS images that show the distributions of molecules of interest within cells without requiring a constant sputter rate or correlated topography measurements.

11:40am **FM-WeM3-19 Cs^+ SIMS using a Low Temperature Ion Source (LoTIS)**, ***Brenton Knuffman****, A. Schwarzkopf, A. Steele,* zeroK NanoTech

We present SIMS instruments featuring the Cs^+ Low Temperature Ion Source (LoTIS). When compared with other cesium ion sources LoTIS can deliver much smaller spot sizes (1 pA into ~2.5 nm), or substantially more current into moderate spot sizes (~100 pA into 50 nm). LoTIS offers high sputter rates, high yields of secondary ions, and a wide range of beam currents from pA to many nA.

The talk will center on our new Secondary Ion Mass Spectrometry (SIMS) system called SIMS:ZERO. It is currently the highest-resolution SIMS instrument in the world and was built in collaboration with the Luxembourg Institute of Science and Technology (LIST). SIMS:ZERO is capable of high-resolution focused ion beam operations while also providing SIMS data. Its spectrometer has a mass-resolving power of ~400 at full transmission, making it suitable for general materials analysis or as a replacement for EDX. We will also show how the capabilities of a FIB allow for in-situ preparation of extremely smooth sample surfaces for SIMS analysis, and how these contribute to data quality. A soon-to-be-added continuous focal plane detector will further enhance the utility of SIMS:ZERO in the analysis of complex, multi-element samples.

Data from several demonstration targets will be presented. These include a Rb-doped CIGS solar cell, localization of tiny TnO nanoparticles, and deconstruction of silica-encased diatoms.

12:00pm **FM-WeM3-21 Development and Characterization of a Drug Dosed Biomimetic Reference Material for a Sims Vamas Inter-Laboratory Study to Study Sensitivity and Linearity***, **Jean-Luc Vorng**, A. Eyres,* National Physical Laboratory, U.K.*; C. Newman, A. West,* GlaxoSmithKline, UK*; I. Gilmore,* National Physical Laboratory, UK

The application of SIMS to biological materials has expanded substantially in the last decade [(1)]. There have been important advances in technology including the use of a wide range of gas cluster ion beams for analysis using argon [(2)], water / CO_2 mixtures [(3)] and water [(4)]. In addition, new analysers have been developed for improved biological analysis including the J105 [(5)] (Ionoptika, UK) and the OrbiSIMS [(6,7)] (Hybrid-SIMS, IONTOF GmbH, Germany) amongst others. SIMS now allows molecular imaging of complex biological samples ranging from cells to tissues. To improve repeatability and determine reproducibility between laboratories with varying instrument configurations there is a need to define and establish a biologically relevant biomimetic sample for pharmaceutical and small molecule analysis.

In this study, we present a step-by-step approach for sample preparation of a biomimetic reference material composed of doped tissue homogenate from rat liver using a protocol developed by GlaxoSmithKline for MALDI MS [(8)]. The resulting material was characterised using ToF-SIMS (Bi_3^+ analysis beam) and OrbiSIMS (Ar_{2500}^+) depth profiling. The spiking of different drugs in the resulting material is used to study the influence of matrix effects on detection sensitivity [(9)], limit of detection and calibration for quantification. This study evaluates the possibility of using this reference material for a future VAMAS interlaboratory comparison suitable for dual beam and single beam analysis instruments.

Reference:

(1): D. Schaumlöffel J. Anal. At. Spectrom. ***2020****,35, 1045-1046*

(2): M. Fuji et *al*. Rapid Commun Mass Spectrom. **2014**, 30;28(8):917-20

(3): M. Lagator et *al*. Surf Interface Anal. **2022**,54:349–355

(4): S.Sheraz et *al*. Anal. Chem. **2019,** 91, 14, 9058–9068

(5): S. Rabbani et *al*. Surf. Interface Anal. **2011**,43, 380–384

(6): M.K. Passarelli et al. Anal. Chem. ***2015****, 87, 6696-6702*

(7): M.K. Passarelli et *al*. Nature Methods. **2017**, 14, 1175–1183

(8): J. A. Barry et *al*, Bioanalysis. **2019**,11(11):1099-1116

(9): J-L. Vorng et al Anal. Chem.**2016**, 88, 22, 11028–11036

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