The use of energetic heavy ions to produce nanometre resolution molecular images in ambient conditions

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Introduction

Ambient mass spectrometry techniques relying on differentially-pumped mass spectrometers and various ionisation methods that can be applied in air (e.g. lasers, charged droplets, plasmas, etc.) have been put to routine analytical use over the past decade. All ambient ionisation methods have poorer imaging capabilities than secondary ion mass spectrometry (SIMS), which uses keV/u atomic and cluster ions in a vacuum to sputter material from a sample's surface. MeV/u primary ions induce electronic sputtering and can be extracted from a vacuum system to offer a comparable imaging performance to traditional SIMS. Our group has developed ambient MeV-SIMS to provide simultaneous X-ray and molecular analysis [1-4] (see Fig. 2) with submicron lateral resolution, thus providing a completely new working regime for SIMS. It has become evident that significant improvements can still be made to MeV-SIMS by increasing the mass of the primary ion to achieve nanometre lateral resolution of massive (>45 kDa) intact molecular species with ambient MeV-SIMS. The proposed method is outlined below.

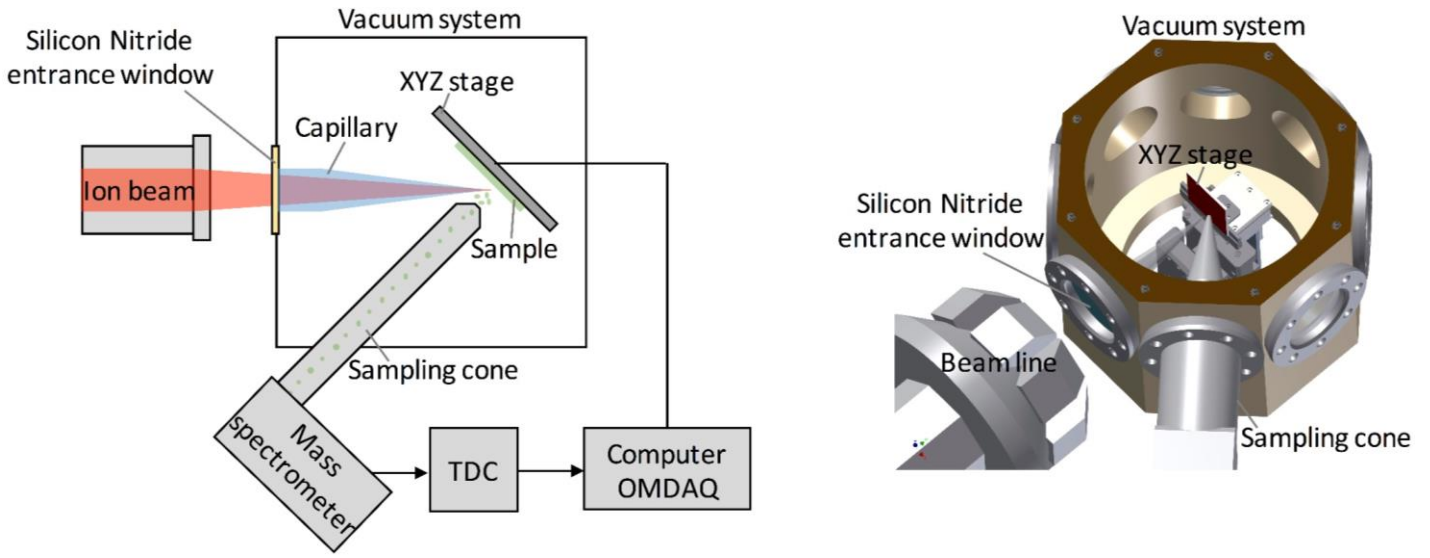

Figure 1. The proposed system

The Idea/Concept

The ideal heavy ion beam for ambient MeV-SIMS analysis can be provided by a linear accelerator or a superconducting cyclotron, such as the one found at KVI-CART of the University of Groningen, Netherlands; specifically, the use of Pb ions or heavier at 1 to 3 MeV/u gives the best possible useful lateral resolution for desorbing intact molecular species as massive as proteins. To achieve the required spot size, a tapered glass capillary forms a nanoprobe to bombard the target with a low current of the heavy ions. A vacuum compatible XYZ positioning system providing nanometre precision will be used to scan the samples to produce an image. A differentially-pumped orthogonally-pulsed mass spectrometer will collect and analyse the molecular signal generated. The entire system will be transportable for use at different facilities. Various ionisation sources can be attached when accelerator beam time is not available. To make vacuum analysis possible with this system, a thin silicon nitride entrance window (see Fig. 1), which maintains a vacuum for the sample and the mass spectrometer while allowing the primary ion beam to pass, can be attached.

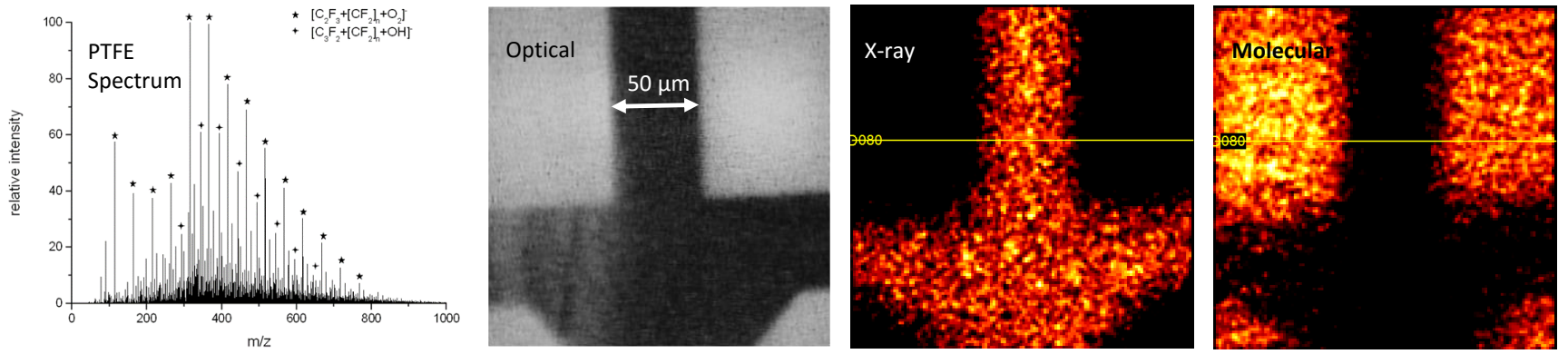

Figure 2. Preliminary data of Cu grid on PTFE polymer acquired using a focussed beam of 0.2 MeV/u oxygen in air

Potential Impact

The major impact of ambient MeV-SIMS is that it provides analysts with the only nanometre lateral resolution ambient imaging mass spectrometry technique that also allows for simultaneous X-ray analysis. This offers a completely unique approach for chemical and elemental analysis of samples in biology, materials science, art, archaeometry, forensics and cultural heritage.

References

[1] Wakamatsu Y, Yamada H, Ninomiya S, Jones BN, Seki T, Aoki T, Webb R, Matsuo J. Highly sensitive molecular detection with swift heavy ions. Nucl Instr Meth Phys Res B 2011;269(20):2251-253.

[2] Jones BN, Matsuo J, Nakata Y, Yamada H, Watts J, Hinder S, Palitsin V, Webb R. Comparison of MeV monomer ion and keV cluster ToF-SIMS. Surf Interface Anal 2011; 43(1-2):249-52.

[3] Wakamatsu Y, Yamada H, Ninomiya S, Jones BN, Seki T, Aoki T, Webb R, Matsuo J. Biomolecular emission by swift heavy ion bombardment. AIP Conf Proc 2010; 1321(1):233-36.

[4] Jones BN, Palitsin V, Webb R. Surface analysis with high energy time-of-flight secondary ion mass spectrometry measured in parallel with PIXE and RBS. Nucl Instr Meth Phys Res B 2010;268(11-12):1714.

Acknowledgements

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