New approach to the study of microchannel plate sensitive surface

Michael Gruntman

Space Sciences Center, University of Southern California
MC-1341, Los Angeles, CA 90089

ABSTRACT

A new approach to study the composition of microchannel plate sensitive surface by secondary ion mass spectrometry is described. The time-of-flight technique is implemented in an unconventional way which permits to use the continuous probing beam and concurrent multichannel mass identification. This makes the technique relatively simple and the low doses and low probing beam intensities give opportunity to perform non-destructive analysis of thin layers and fragile films.

1. INTRODUCTION

Microchannel plates (MCPs) are widely used in different types of image intensifiers, night vision devices, and various detectors (including position-sensitive) of individual particles and photons. Many characteristics of such instruments - noise, detection efficiency, life-time, etc - are determined to a large extent by the conditions of the MCP sensitive surface. During last decade, for example, a lot of effort has been devoted to improve MCP performance for EUV and soft x-ray astronomy, where there is a permanent struggle to register each incoming photon with utmost efficiency, by covering sensitive surfaces with different layers, mainly alkali halides.[1,2] It is very important to have an ability to study and monitor actual conditions of these sensitive layers as well as to know their depletion and degradation rates, the latter being espescially important for long duration space missions. Ion barrier film, sometimes attached to MCP, may affect substantially characteristics and life time of instrument, e.g. night vision device or fast photomultiplier, and knowledge of this film composition and its depletion rate is also very important.

One of the most powerful techniques to study surfaces is secondary ion mass spectrometry (SIMS). This technique is espescially sensitive to the composition of the few outermost atomic layers of the surface and therefore can be used efficiently to study the compositions (and contaminations) of deposited sensitive layers. In a typical SIMS analysis, the surface is bombarded by a collimated beam of ions (argon is commonly used) with an energy of 3-8 keV. The secondary ions are accelerated and directed into magnetic or electrostatic mass analyzer. The analyzing field is then changed in order to scan and to register a mass spectrum. Therefore, the conventional technique is essentially the consecutive single-channel SIMS, since only one mass is collected at a time and the others are lost, which results in a large consumption of the sample.

The high doses and the high-intensity (to study trace elements) probing beams are required, which is destructive and thus prohibitive to fragile and thin objects, e.g. thin sensitive layers and thin films. The aim of this work is to demonstrate a new relatively easy unconventional approach to the study of the MCP sensitive surfaces and thin films, which overcomes these difficulties.

2. TIME-OF-FLIGHT SIMS

It is obvious that if all masses of secondary ions are detected without loss, the dose and the sample consumption for complete mass analysis could be reduced significantly. The concurrent multichannel mass detection is implemented in **t**ime-**o**f-**f**light (TOF) mass spectrometers. The TOF analysis is based on the measurement of ion time of flight, i.e. time interval between the moment of secondary ion "birth" at the surface to be studied and its registration (after acceleration to a fixed energy and flying a known distance) by the detector. The time of flights of the ions with the fixed energy depend thus on the masses of secondary ions. In present-day surface analysis, the moment of the secondary ion "birth," i.e. the moment of the impact of the probing beam particle on the surface, is usually fixed by pulsing the probing beam. Commonly the pulses are produced by sweeping the beam across small diaphragm-orifice.[3] Because of the strong modulation(or electron "chopping") of the beam, the probing particles may hit the surface only during short (5-10 ns) well-defined time intervals. The moment, the beam is "switched on," the **START** pulse is generated, and the ion detection triggers the **STOP** pulse of TOF analyser.

There are several drawbacks inherent to TOF SIMS. Though enjoining such TOF technique advantages as multichannel detection with low dose and low sample consumption and insensitivity to probing beam intensity variations, the conventional TOF SIMS is rather inefficient since the beam is "switched on" only during a small part ($\leq 10^{-3}$) of the exposure time. Another drawback is connected with the significant difficulty in shortening ion pulse bunches down to 1 ns in order to match the typical accuracy of fixing the **STOP** pulses, which is required for high mass resolution. And finally, from the practical point of view, the TOF SIMS seems to be a rather complicated technique requiring a specially dedicated experimental facility and fine instrument adjustment which make it difficult to be used for routine analysis.

3. NEW APPROACH

The ability of a MCP to detect incoming particle/photon by multiplication of an emitted secondary electron allows precise independent determination of the time of probe particle impact on the MCP sensitive surface. This gives a unique opportunity to arrange TOF SIMS in an unconventional way with the use of a low intensity continious probing beam. A new acronim - MASTIF (**m**ass **a**nalysis of **s**econdaries by **t**ime-**o**f-**f**light technique) - was coined for this technique to distinguish it from the traditional TOF SIMS, which uses the pulsing of the probing beam. Incidentally, other types of secondary electron multipliers can be used in a similar way for the study of their sensitive surfaces.

The main idea of the technique, first proposed in 1985[4] and described in detail later,[5] is to use for the ion mass identification concurrently emitted (by the impact of the same particle) secondary electron and secondary ion. These secondary electron and secondary ion must be separated in space and/or time and detected independently. Then the measured time interval

between detections of the secondary electron and the secondary ion would be determined by the mass of the sputtered ion. The MCP (or another secodary electron multiplier) registers the secondary electron and thus produces the **START** pulse. So, what is needed is to extract and to detect secondary ion. The main advantageous features of such an approach are the following: i) Secondary ion detection is performed in coincidence with secondary electron detection. The coincidence mode makes possible the extraction of faint useful signals (coincidences) from the superior background count rate. It is important that simultaneously with secondary ion mass spectrum accumulation the valuable instrument housekeeping information on the detection efficiencies as well as the probing beam absolute intensity can be obtained without preliminary instrument calibration[6]. ii) The probing beam can be continuous, and as a result, the instrument can be relatively simple (there is no need for the rather complex "electronic chopper"), the beam is used with the highest possible efficiency, and the moment of the particle impact on the surface is fixed with the same accuracy as the secondary ion detection. iii) The probing beam intensity may be decreased (with a corresponding increase of exposure time) down to, in principle, arbitrarily low values. There is no rigorous requirement upon the probing beam intensity stability since the spectrum is accumulated in the parallel multichannel mode. iv) The use of the probing ions (atoms) of the same mass and energy as in conventional SIMS makes possible the application of the vast accumulated data on secondary ion yields under various conditions. It can be claimed, that the proposed MASTIF provides a quantitative analysis at least to the same extent as conventional SIMS.

Because of these features, trace elements and fragile and/or ultrathin objects sensitive to the damage by the probing beam may be studied. The choice of the possible objects to study by the technique is limited by the difficulty to separate in space and/or time secondary electrons and secondary ions.[5] However it can be rather easily realized for a MCP and an ion barrier film and the technique can be efficiently applied to them.

4. MICROCHANNEL PLATE SENSITIVE SURFACE

Figure 1 shows experimental setup for the study of a MCP sensitive surface.The sensitive area of the MCP is bombarded by probing beam atoms (argon, 3000 eV). Secondary electron, emitted at the impact of the probing beam particle, initiates an electron avalanche in the MCP stack and produce the **START** pulse. Sputtered positive secondary ion (ions) is accelerated (up to 2000 eV) by the voltage across the gap between the MCP sensitive surface and a nearby grid, and after turn in electrostatic mirror is directed towards another detector D_2 (also MCP stack). The **STOP** signal is triggered by the detection of this positive secondary ion. The **START** and **STOP** pulses are sent to a TOF analyzer built on the basis of commercially available CAMAC modules and microcomputer.

Secondary ions can be produced from semiconducting glass (the microchannel walls) and/or from a conducting metal layer. Since the triggering of D_1 is the necessary condition for registering a TOF event, then only secondary ions emitted from those parts of the MCP surface that contribute in the detection of particles will be studied by MASTIF. A portion of the secondary ion TOF spectrum, obtained from the sensitive area surface of the bare MCP is shown in Fig.2, which is rather complex and abundant in peaks. The calculated mass differences (in atomic mass units) are shown between adjacent mass peaks. Some peaks are widened due to to

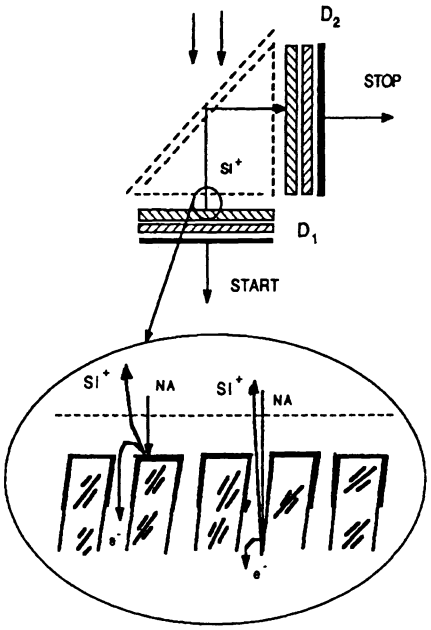

Fig.1. Setup to study microchannel plate sensitive surface area by the MASTIF technique. Secondary ions are emitted under bombardment of probing beam neutral atoms (NA) either from the semiconducting glass microchannel walls or from metal layer.

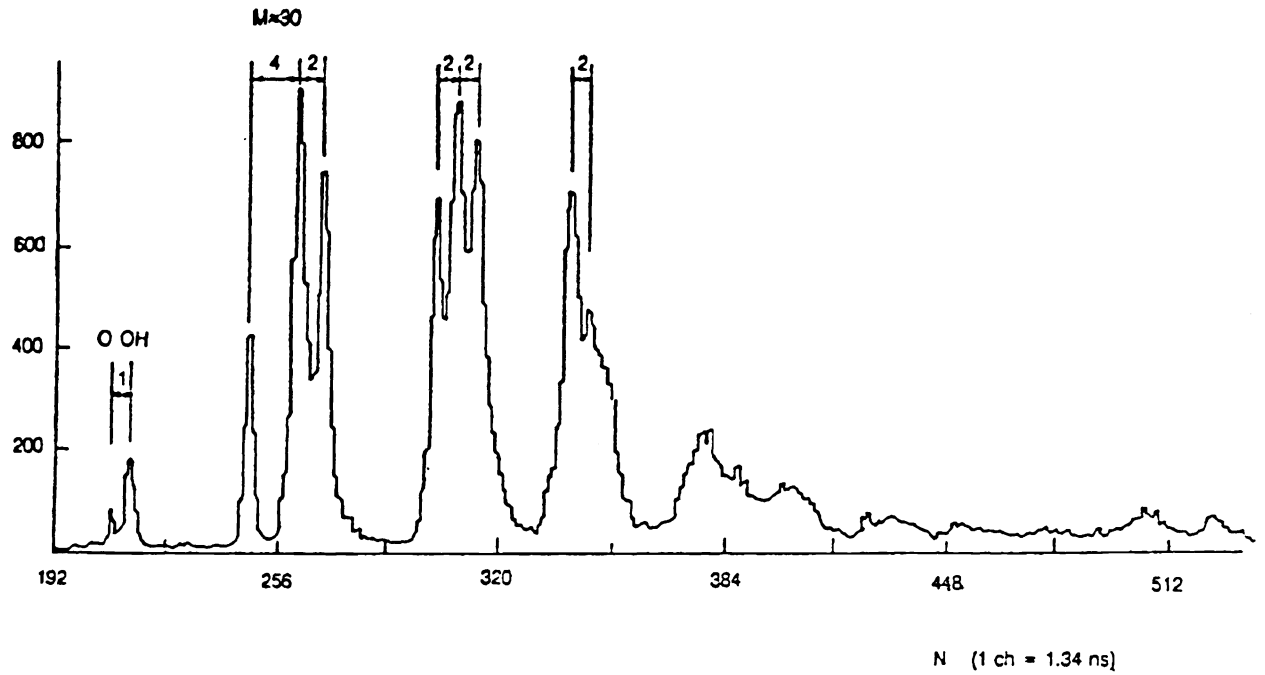

Fig.2. A portion of TOF spectrum (positive ions) obtained from MCP sensitive surface area. Calculated mass differences (in amu) between peeks are shown.

the dependence of the energy acquired by ions at the place of their "birth" in the microchannel. Mass resolution is rather poor ($\simeq$ 20), however it can be improved dramatically as it will be further discussed. The TOF spectrum clearly demonstrates the feasibility to study and to monitor the condition of the sensitive surface area of the MCP. Another obvious application of such a technique is to study the depletion of the sensitive layer when registering EUV and x-ray photons. Photosputtering has been rather poorly studied and the MASTIF spectra which can be obtained by registering such photons may give valuable information on the processes involved. The latter is espescially important for EUV and x-ray astronomical detectors, which are used for long duration space missions and where different layers (mainly alkali halides) have been tested to cover MCP surfaces to improve their characteristics in the desired wavelength range.

5. THIN FOIL

If an ion barrier film is attached to the MCP, this film will be the source of the secondary ions. Since a MCP with such a film was not availble for the experiment, it was simulated by the use of a separate thin (30 Å) self-supporting carbon foil, which was installed a few millimeters in front of the first MCP in the stack. The experimental setup is shown in fig.3. It should be noted here, that knowledge of the actual conditions of thin carbon foils is of great interest in itself for they are widely used now for a variety of laboratory and space applications. If the foil is "thin" enough, then electrons produced within the foil bulk material near the point of heavy particle impact on the input surface have a good chance of reaching and escaping the output surface of the foil. The electrons are registered by detector D_1 which provides **START** signal.

The secondary ions of any selected charge sign (depending on the extraction potential) may be accelerated and registered by detector D_2 . A portion of a typical TOF spectrum for negative secondary ions from the carbon foil is presented in Fig.4. The probing beam is 3 keV argon atoms. The emitted secondary ions were accelerated up to 2100 eV. A total number of about 3×10^4 events were accumulated in this spectrum. The calculated mass differences (in atomic mass units) are shown between adjacent mass peaks. The identification of the mass peaks clearly indicates that the carbon foil is covered by a "dirty" layer. The mass resolution for such a simple setup having a low acceleration voltage is better than 10. The same kind of TOF spectrum can also be obviously obtained for positive ions.[6] The presented spectrum clearly demonstrates the ability of the technique to measure the composition of an ion barrier film. It would be interesting also to try to register the mass spectrum of secondary ions under the illumination of a MCP by energetic electrons, which may provide information on the depletion of the ion barrier films in night vision devices and photomultipliers.

6. MASS RESOLUTION

The actual mass resolution of the MASTIF technique is determined by the geometrical characteristics of the electrostatic field of the analyzer as well as by the initial energy distribution of the secondary ions. If no special measures are implemented to focus in time ions with different initial energies, and if the ion acceleration distance is much smaller than the flight distance, then the mass resolution is given by $(M/\Delta M) \simeq E_A/(2\,E_i)$, where E_A is the energy acquired by an ion accelertion and E_i is the initial energy of the ion. Obviously, to achieve a high ($\geq$ 100) mass resolution is unrealistic by the straightforward increase of acceleration voltage, since the secondary

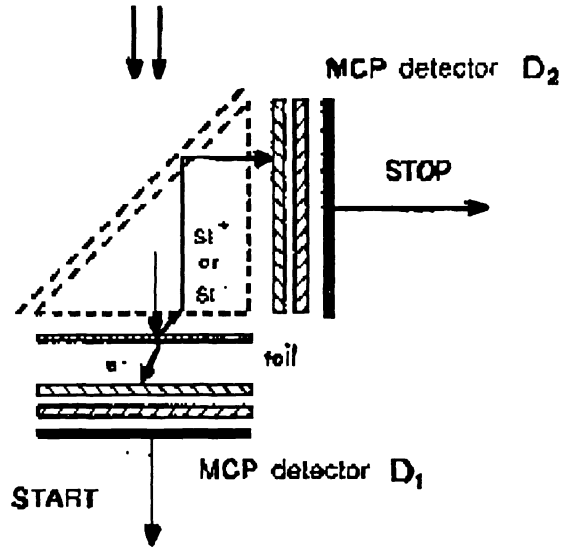

Fig.3. Setup to study thin carbon foil (simulating ion barrier film) by MASTIF technique. Ions of any selected charge sign may be analyzed. .

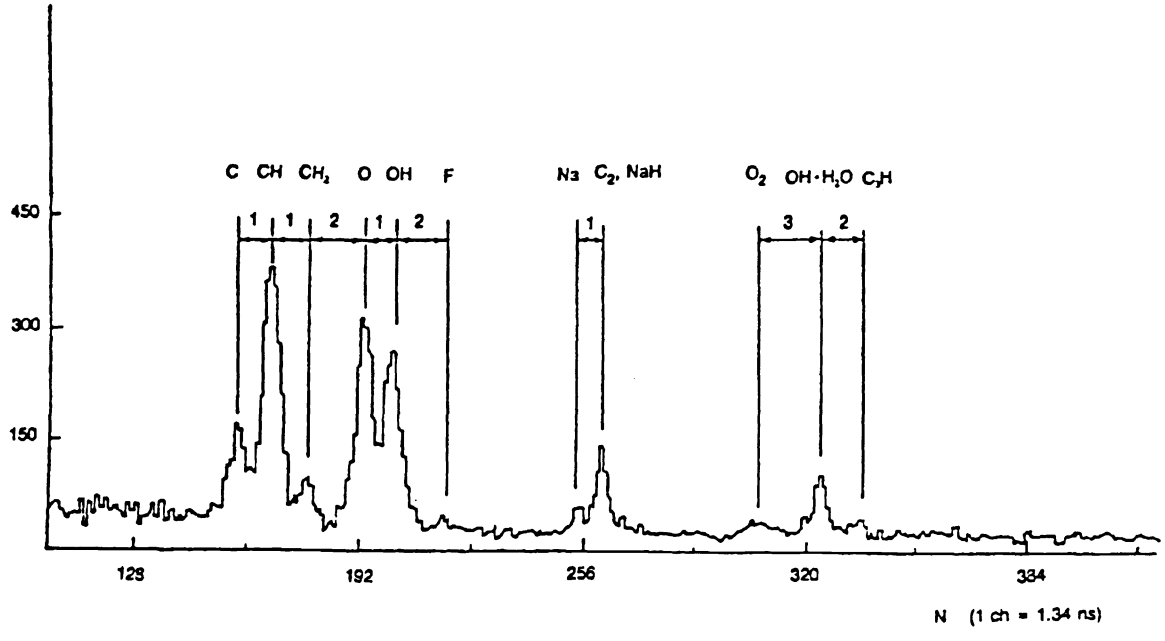

Fig.4 A portion of TOF spectrum (negative ions) obtained from carbon foil (30 Å thickness). Calculated mass differences (in amu) between peaks are shown.

ion energy distribution is characterized by a rather extended high energetic "tail" (up to 50 eV).

Drastic improvements in mass resolution may be achieved, however, if the trajectories of the ions are isochronous, i.e. the time of flight is independent of the initial energy of the secondary ions. Such time focussing was realized by Mamyrin *et al*[7] in a rather simple device called a "reflectron." The achievement of time focussing in more complex magnetic and electrostatic analyzers was considered extensively by Poschenrieder.[8,9] In this work, no special attemts for time focusing were made. The aim of the work is only to demonstrate that the MASTIF approach can be realized and the achieved mass resolution is modest at best (≈20).

The experimental realizations of the MASTIF principle, presented above, clearly show the feasibility of the approach to the study of the composition (and depletion rates) of MCP sensitive surfaces and ion barrier films. It is important that the technique does not require specially dedicated surface study experimental facilities, and may be relatively easy realized in existing experimental setups on the basis of commercially available electronics.

REFERENCES

1. O.H.W.Siegmund, E.Everman, J.V.Vallerga, J.Sokolowski, and M.Lampton, "Ultraviolet quantum detection efficiency of potassium bromide as an opaque photocathode applied to microchannel plates," *Appl. Optics*, v.26, , No.17, pp.3607-3614, September 1987.
2. D.G.Simons, G.W.Fraser, P.A.J. de Korte, J.F.Pearson, and L. de Jong, "UV and XUV quantum detection efficiencies of CsI-coated microchannel plates," *Nucl. Instrum. Methods Phys. Res. A*, v.261, N.3, pp.579-586, November 1987.
3. D.Rathmann, N.Exeler, and B.Willerding, "Ion beam pulsing for time of flight (TOF) experiments," *J. Phys. E: Sci. Instrum.*, v.18, N.1, pp.17-19, January 1985.
4. M.A.Gruntman, "Study of the surface by time-of-flight mass spectrometry of secondary ions," *Abstracts, All-Union Workshop of Young Scientists "Diagnostics of Surfaces by Ion Beams"*, pp.17-18, Uzhgorod, 1985 (in Russian).
5. M.A.Gruntman, "MASTIF: Mass analysis of secondaries by time-of-flight technique. A new approach to secondary ion mass spectrometry," *Rev. Sci. Instrum.*, v.60, pp.3188-3194, October 1989.
6. M.A.Gruntman, V.A.Morozov, "H atom detection and energy analysis by use of thin foils and TOF technique," *J. Phys. E: Sci. Instrum.*, v.15, pp.1356-1358, December 1982.
7. B.A.Mamyrin, V.I.Karataev, D.V.Shmikk, and V.A.Zagulin, "The mass reflectron, a new nonmagnetic time-of-flight mass spectrometer with high resolution," *Sov. Phys. JETP*, v.37(1), pp.45-48, July 1973.
8. W.P.Poschenrieder, "Multiple-focussing time-of-flight mass spectrometers. Part I. TOFMS with equal momentum acceleartion," *Int. J. Mass Spectrom. Ion Phys.*, v.6, N.5/6, pp.413-426, June 1971.
9. W.P.Poschenrieder, "Multiple-focussing time-of-flight mass spectrometers. Part II. TOFMS with equal energy acceleration," *Int. J. Mass Spectrom. Ion Phys.*, v.9, N.4, pp.357-373, September 1972.