Advanced Depth Profiling Characterization of Mixed Organic/Inorganic Layers Using X-ray Photoelectron Spectroscopy (XPS) and a Combined Monatomic and Gas Cluster Ion Source (MAGCIS)

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Organic electronic devices are becoming increasingly important in a wide variety of applications. These nano-structured devices are typically composed of complex thin/ultrathin multilayers of novel organic or organometallic compounds, along with inorganic materials. The overall electronic behavior of these devices is strongly influenced by the electronic properties and chemical compositions of the individual layers, as well as interactions at the various layer interfaces. Detailed knowledge of surface and interface chemistry is a crucial factor for the successful production and optimization of such devices.

X-ray photoelectron spectroscopy (XPS), with its high surface sensitivity and chemical state specificity, is the ideal analytical technique for evaluating the qualitative and quantitative surface composition of materials. XPS depth profiling, where XPS is combined with argon ion sputtering, allows the identification of chemical variations from the topmost surface of solid materials (i.e., ≤ ~10 nm) to hundreds of nanometers or more into the bulk, which facilitates characterization of complex layered structures. However, XPS depth profiling of most organic materials can be problematic when using traditional monatomic argon ion sources because of structural and chemical damage caused by the ion beam sputtering process, particularly when using high primary beam energies. Energetic ion impacts can break chemical bonds, thus disrupting polymeric and other organic structures. Hence, the surface composition during and after ion sputtering often does not closely resemble the intact starting material and important chemical state information may be missing from the XPS spectra.

Recent advances in ion source design have resulted in the introduction of argon gas cluster ion beams (typical cluster size: Ar₁₀₀₀₋₂₀₀₀⁺) for enhanced “soft” depth profiling and/or sputter-cleaning applications for organic materials. Argon cluster ion beams offer exceptionally gentle sputtering compared to monatomic sources, which allows materials that are unstable under monatomic argon ion bombardment to be successfully depth profiled. In addition, noble gas cluster ion sources do not deposit surface carbon contamination, as is often found with organic-based cluster ion beam sources.

While cluster ion beams have proven useful for depth profiling organic and polymeric materials, it still remains necessary to use monatomic argon ion beams for depth profiling inorganic layers because inorganic materials, unlike organic materials, are not effectively sputtered by cluster ions. This poster describes applications of a unique combined monatomic and gas cluster argon ion source (MAGCIS) that allows full depth profiling of complex electronic devices based on mixed organic/inorganic thin film stacks. Results will be presented for the analysis of an organic solar cell device and an organic field effect transistor (FET) device. XPS depth profiling results obtained using MAGCIS were consistent with minimal ion beam induced sample damage and preservation of important XPS chemical state information throughout the depth profiles.

For example, Fig. 1 shows an XPS depth profile obtained using MAGCIS for an FET device. The device consisted of an outer semiconductor thin film (~12 nm) of copper phthalocyanine (CuPc) on a
thicker layer (~120 nm) of silicon oxide on a silicon substrate. Argon cluster ions were used to depth profile through the thin organometallic layer followed by monatomic argon ion depth profiling through the silicon dioxide film into the silicon substrate. Quantitative XPS results for the CuPc film and high resolution Cu 2p XPS spectra indicated that the CuPc film was not degraded during the cluster ion depth profiling. These results, along with those obtained for an organometallic solar cell device, demonstrate that the unique MAGCIS source, which can operate with either monatomic or cluster argon ions, can be used to successfully depth profile mixed organic/inorganic multilayer devices.

Fig. 1. XPS depth profile of an organometallic/inorganic FET device using a combined monatomic and gas cluster ion source (MAGCIS).