

ATMOSPHERIC ELECTRON-INDUCED X-RAY SPECTROMETER (AEXS) INSTRUMENT DEVELOPMENT. J.Z. Wilcox¹, E. Urgiles¹, R. Toda¹, T. George¹, and J. Crisp¹, ¹Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, 302-231, Pasadena, CA 91109 (Jaroslava.Z.Wilcox@jpl.nasa.gov).

Introduction: This paper describes the progress in the development of the AEXS instrument in our laboratory at JPL. The AEXS is a novel miniature instrument^[1-3] based on the excitation of characteristic X-Ray Fluorescence (XRF) and luminescence spectra using a focused electron beam, for non-destructive evaluation of surfaces of samples in planetary ambient atmosphere. *In situ* operation is obtained through the use of a thin electron transmissive membrane to isolate the vacuum within the AEXS electron source from the outside ambient atmosphere. The impinging electrons excite XRF spectra from the irradiated spots on samples in external atmosphere with high-to-medium (sub-mm to cm-scale) spatial resolution at Mars atmospheric pressure. The XRF spectra are analyzed using an energy-dispersive detector to determine surface elemental composition, or in the case of electron-induced luminescence to identify unusual formations on surface that cathodo-luminescence (CL). The AEXS system (Fig 1) consists of a high-energy (>10keV) electron gun encapsulated by the isolation membrane, an EDX detection and analyzer system to determine the elemental abundance, an optional CL detection system, and a high voltage power supply. The approach to demonstrating a proof of concept of the AEXS has been through 1) demonstrating the viability of micro-fabricated membranes, 2) assembling AEXS setups with increasingly integrated functional components, and 3) simulating the AEXS observational capabilities. This paper will focus on description of the development of the instrument.

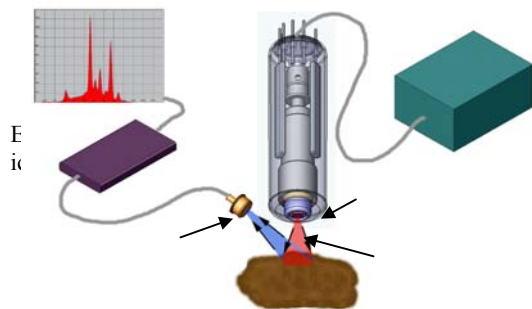


Fig. 1. The AEXS instrument concept. The AEXS consists of a miniature, vacuum-encapsulated electron source, HVPS, and XRF detector. The electron beam is transmitted through the electron-transmissive vacuum-isolation membrane into the ambient atmosphere, strikes the sample, exciting characteristic XRF spectra for elemental analysis of the irradiated spot. The spot area can be adjusted from sub-mm to several cm size by changing the membrane-sample working distance.

Instrument Development: The membrane properties were investigated in detail due to its critical role. A series of experiments determined that our designed membranes have high electron transmission, yet are capable of isolating high vacuum, are able to withstand differential pressure in excess of one atmosphere, survive vibrational shocks of a magnitude to be expected during a planetary mission. Our initial work has been with a 10 keV source and a 200 nm thick Silicon Nitride (SiN) encapsulation membrane microfabricated within a Si support frame (1.5 mm x 1.5 mm window openings). Fig 2 compares the spectra taken with the 10 keV source with spectra taken within SEM.

Following our initial work^[4] with the 10 keV source, we have selected as our “baseline” for the development of a portable, stand-alone instrument without the support of a vacuum pump, a Thomas Electronics electron gun rated for operation at up to 20keV. The use of more energetic electrons results in reduced beam divergence (smaller spot size on the target), increased beam transmission, and the ability to excite K-shell XRF from heavier elements. The membrane

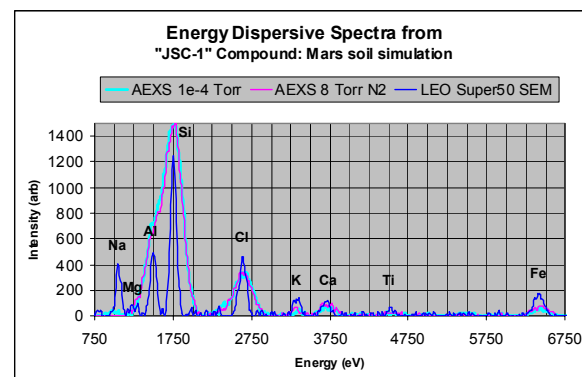
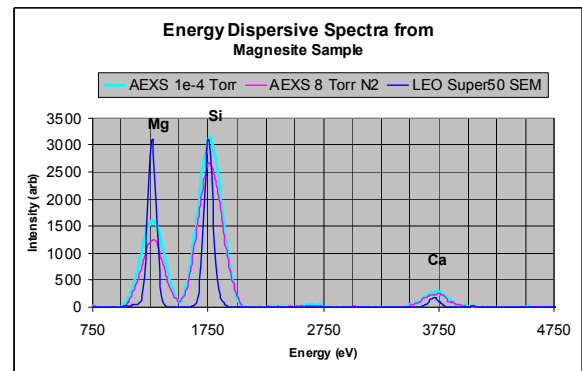


Figure 2. EDX spectra comparison taken for samples in SEM and in the AEXS environmental chamber using the encapsulated 10keV electron gun. (a) Magnetite, (b) JSC-1 sample.

thickness has been increased to 500 nm and the aperture made circular, to increase the window robustness. The window attachment process uses “double” anodic bonding. The encapsulated gun is now being used to acquire spectra both in the environmental chamber and Earth atmosphere.^[5] Figure 3 is a photo of the encapsulated gun.

Discussion. The most significant concern associated with using the encapsulation membrane is that it degrades the spatial resolution and energy coherence of the electron beam. Although the spatial resolution of the AEXS will never be as good as the nm-sized spots of laboratory scale SEMs, it is still significantly better than any of the state-of-the-art *in situ* XRF instruments. Whereas the spatial resolution for the Alpha-Particle X-ray Spectrometer (APXS) on MER mission is on the order of several cm, the surface area irradiated by the AEXS beam can be varied from several cm to less than 1 mm by varying the “working” distance between the instrument membrane and target. In fact, the spatial dispersion for the electron beam enables two different modes, a large spot-size (cm-scale) “survey”, and a high-resolution (sub-mm scale) observation. The focusing properties of the electron beam are controlled by electron optics within the electron source. This occurs because the interaction of the transmitted electrons with the membrane and outside atmosphere leads to beam divergence (that depends on membrane composition and thickness, atmosphere pressure, and electron energy). The beam spreading can in turn be used to vary the size of the irradiated spot on the sample by varying the distance between the membrane and the sample. By positioning the instrument head between several millimeters to several centimeters away from the target, the spot size can be var-

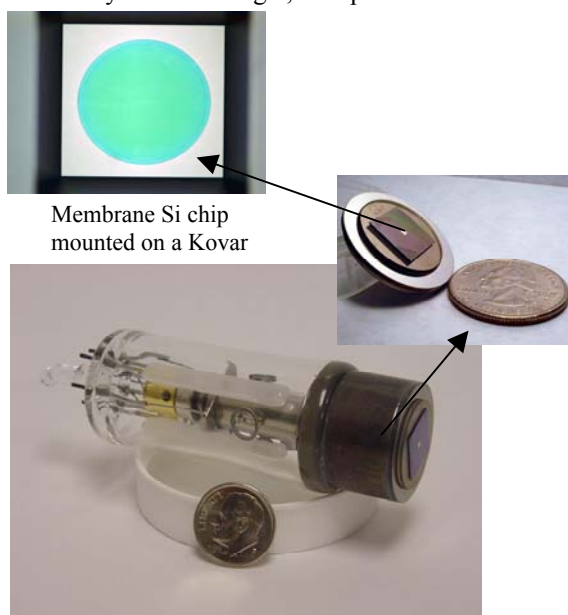


Figure 3. Vacuum-Isolated 20keV Electron source

ied from sub-mm to several cm in the Mars atmosphere.^[6] Using a relatively large working distance (10 cm-scale on Mars) the size of the irradiated spot can be cm-scale, making it possible to use the AEXS instrument for surface reconnaissance. When an area appears interesting, the instrument head could be brought close to the surface for a more detailed inspection. Rapid acquisition of XRF data is enabled due to the combination of a large flux and high excitation efficiency using an electron beam. Electron-induced excitation is a one-step process, leading to spectra acquisition times less than 1 minute for a 10 μ A beam (as compared to about 1 hour for APXS). Such short times will also result in low energy consumption per spectrum and thus enable multiple readings assessing sample heterogeneity.

We are also planning to replace the thermionic emitter with a Carbon-nanotube-based field-emitter,^[7] thus greatly simplifying the power supply architecture, leading to additional savings in mass as well in a significantly lower power consumption. The predicted mass and size for the completed instrument are on the order of 1 kg and 10cm-scale dimensions, respectively.

References: [1] J.E. Feldman, J.Z. Wilcox, T. George, N. Bridges, “*Atmospheric Electron X-ray Spectrometer Development*”, paper presented at IEEE’01 conference; [2] J.E. Feldman, J.Z. Wilcox, T. George, D. Barsic, and A. Scherer, “*Elemental Surface Analysis at Ambient Pressure by Electron-Induced X-ray Fluorescence*”, Rev. Sci. Instr., March 2003; [3] J.Z. Wilcox, E. Urgiles, T. George, J. Crisp, E. Baumgartner, “*Atmospheric Electron Induced X-ray Spectrometer (ELXS) for exploration of samples on Martian surface in-situ*”, NASA’s ‘04 MIDP program; [4] J.Z. Wilcox, E. Urgiles, S. Douglas, and T. George, “*Electron Induced Luminescence and X-ray Spectrometer (ELXS) Development*”, presented at the LPSC’04 conference; [5] E. Urgiles, J.Z. Wilcox, R. Toda, J. Crisp, and T. George, “*Characterization of the XRF performance of the Atmospheric Electron Induced X-ray Spectrometer (AEXS)*”, paper presented in the oral session at this conference; [6] J.Z. Wilcox, “*Simulation of Transmissivity of Electron Beam in Mars Atmosphere*”, JPL Internal Document, 1997; [7] H.M. Manohara, P.H. Siegel, M.J. Bronikowski, B.K. Vancil, K. Hawken, “*Development of a micro-machined THz nanoklystron- A status report*,” 31st IEEE International Conference on Plasma Science, Baltimore, MD, June 28-July 1, 2004; Full paper to appear in *IEEE Transactions on Plasma Science* (Feb. 2005).