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TITLE A LOW EARTH ORBIT MOLECULAR BEAM SPACE SIMULATION FACILITY

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CHM-2

ABSTRACT

A brief synopsis of the low earth orbit (LEO) satellite environment is presented including neutral and ionic species. Two ground based atomic and molecular beam instruments are described which are capable of simulating the interaction of space craft surfaces with the LEO environment and detecting the results of these interactions. The first detects mass spectrometrically low level fluxes of reactively and nonreactively surface scattered species as a function of scattering angle and velocity while the second UHV molecular beam, laser induced fluorescence apparatus is capable of measuring chemiluminescence produced by either gas phase or gas-surface interactions. A number of proposed experiments will be described.

INTRODUCTION

The low earth orbit (LEO) environment has been extensively studied over the past ten years and we are now seeing an intensive investigation of the low earth orbit satellite (LEOS) environment (ref. 1) which is formed by the introduction of contaminant species into LEO by vehicle outgasing and the interaction of vehicle surfaces with the LEO environment at orbital velocities resulting in gas-surface collision energies of 5eV for oxygen atoms and 9.3eV for N_2 molecules. At an altitude of 300km the primary neutral constituents (ref. 2) are N_2 and O-atoms with number densities of approximately $10^8/cm^3$ and $5x10^8/cm^3$ respectively with a local temperature of 1000K while at 200km altitude the concentrations are roughly an order of magnitude higher with O_2 molecules having an equal concentration as C-atoms. Experiments on STS-3 (ref. 1) have shown a substantial perturbation of the natural LEO environment by the space shuttle creating a local low earth orbit satellite (LEOS) environment which interacts with shuttle surfaces. The following observations were made: plasma densities an order of magnitude higher than in the LEO environment, energetic (20-100eV) electron fluxes up to $10^{14}/cm^2$-s, ion fluxes with energies up to 30eV and densities of $10^4/cm^3$ for NO^+, $6x10^3/cm^3$ for $O_2{}^+$, and $5x10^5/cm^3$ for O^+-atoms at a altitude of 300km, a gas density up to $3x10^{11}/cm^3$ near surfaces facing the ram direction, and glow phenomena and plasma density increasing during thruster operations and daytime ram conditions. Extensive etching of surfaces exposed to LEOS environment has been observed (ref. 3, 4) and correlated with O-atom number density. The etching is most evident on those surfaces exposed in the ram direction (as high as 0.1 micron/orbit for kapton) but etching two to three times less has also been observed on shaded surfaces indicating that thermal reflected O-atoms are also quite reactive. In order to simulate and investigate the mechanism of space craft etching (ref. 3, 4) and glow (ref. 5) gas phase reactants and products need to be identified and characterized as to their angular and velocity distributions as well as their internal state distributions while products remaining on the surface need to be identified. It is evident from these observations that simulation of the low earth orbit satellite (LEOS) environment must entail not only investigations of gas-surface interactions but also ion, electron-surface (ref. 6) and gas-gas and gas-plasma interactions and simulation facilities which simultaneously incorporate sources of these reactants along with surface and gas phase detectors need to be developed.

ENVIRONMENT SIMULATION AND INTERACTION STUDIES

Figures 1 and 2 depict some of the apparatus available at Los Alamos which are capable of 1) simulating the LEOS environment, 2) characterizing surface reactants and products, and 3) detecting gas phase reaction products and chemiluminescence produced by gas phase or surface plasma excited species. The first apparatus, designated as the Los Alamos Molecular Beam Dynamics Apparatus (ref. 7) (LAMBDA, Fig. 1) and patterned from the design of Lee (ref. 8) and coworkers, can be configured either for gas phase crossed molecular beam studies or gas-surface beam investigations. Figure 1 depicts LAMBDA configured for gas-surface studies and shows the extensive differential pumping present on both the mass spectrometer detector (3 stages) and gas beam source

(4 stages). The advantages of this apparatus are: 1) high pumping speed, 2) excellent isolation of both the high intensity beam source (4 stages of differential pumping) and electron bombardment detector (3 stages of differential pumping) from the test specimen, 3) high detection efficiency of electron bombardment ionizer-quadrupole mass filter combination (10^{-4}), 4) angular scan capability of detector from -10 deg to 120 deg, 5) capability to perform time of flight analysis of scattered species over the angular range using high transmission cross correlation techniques (ref. 9), 6) capability of performing either crossed molecular beam scattering experiments or molecular beam-surface scattering experiments using a crystal manipulator which takes the place of one of the gas beams, 7) the capability of introducing photon or ion beams for simulation of plasma interactions, and 8) the capability of performing Auger analysis on the test specimen surfaces. The primary disadvantage for gas-surface experiments is the inability to obtain UHV operation in the low 10^{-10} torr range though the apparatus routinely obtains 2×10^{-8} torr when running gas phase experiments and when using the liquid nitrogen cryoliner the apparatus will operate in the high 10^{-9} torr range. A slotted disk velocity selector (ref. 10) can be added to the beam source in order to create a dark source though the beam intensity would be decreased roughly an order of magnitude.

The second apparatus designated the molecular beam-fluorescence detection apparatus shown in figure 2 was designed for molecular beam scattering experiments on well characterized surfaces held in a UHV environment (10^{-10} torr) and using laser induced fluorescence (LIF) for detection of the scattered species (ref. 11). The apparatus has three stages of differential pumping on the beam source; a cryoliner, ion-titanium sublimation and turbomolecular pumps on the bakeable UHV chamber along with Leed, Auger and LIF detection capability; and a bakeable differential pumping stage between the sample and nozzle beam source which can house a slotted disk velocity selector. The primary advantages of the system are 1) UHV capability and strict control of contaminant gases, 2) the capability of detecting fluorescence processes, and 3) the capability of performing insitu surface analytical procedures on the sample using Leed and Auger equipment. The primary disadvantages are relatively long path length from the beam source to the sample (50cm as opposed to 8cm on LAMBDA), fewer differential pumping stages on the beam source, and lack of a angular resolved mass spectrometer detector.

A number of low energy beam sources are on hand as well as a high temperature graphite source (ref. 12) for producing high velocity molecular and atomic beams. A thermal energy oxygen atom source employing discharge techniques (ref. 13) is being constructed for use in investigations of thermal O-atom etching of surfaces. The beam sources are interchangeable between the two apparatus and any source developed in the future would also be interchangeable thus increasing the number of options for experiments. In other words experiments involving particle identification and measurements of translational velocity distributions would be performed on LAMBDA and at a later time fluorescence experiments would be performed with the same beam source on the UHV apparatus. In many cases a dark beam source will be needed, i.e. a source which is not a source of photons itself and this would again be accomplished through the use of a slotted disk velocity analyser.

PROPOSED EXPERIMENTS

We will first study thermal O-atom etching to gain a basic insight into the mechanism of reflected O-atom interactions with space craft surfaces. Gas phase reaction products will be identified mass spectrometrically and their recoil velocity and angular distributions will be measured while reaction products remaining on the surface will be identified using Auger analysis. Though we do not at present have the hardware to introduce ions or electrons on to the surface, this capability would be added to study the effects of plasma interaction on etching rates and dynamics. The results of these experiments, i.e. product identify, angular and recoil velocity distributions, and surface reaction products, can be used in contamination modeling (ref. 14) of reflected O-atom etching of space craft surfaces operating in low earth orbit as well as for the development of a fundamental understanding of the etching mechanism. Further experiments investigating the glow phenomena (ref. 5) associated with space craft in low earth orbit as well as O-atom etching of ram exposed surfaces requires the use of a high translational energy (5eV) O-atom source. Our effort to develop such a source using cw CO_2 laser sustained discharge techniques will be discussed at the meeting.

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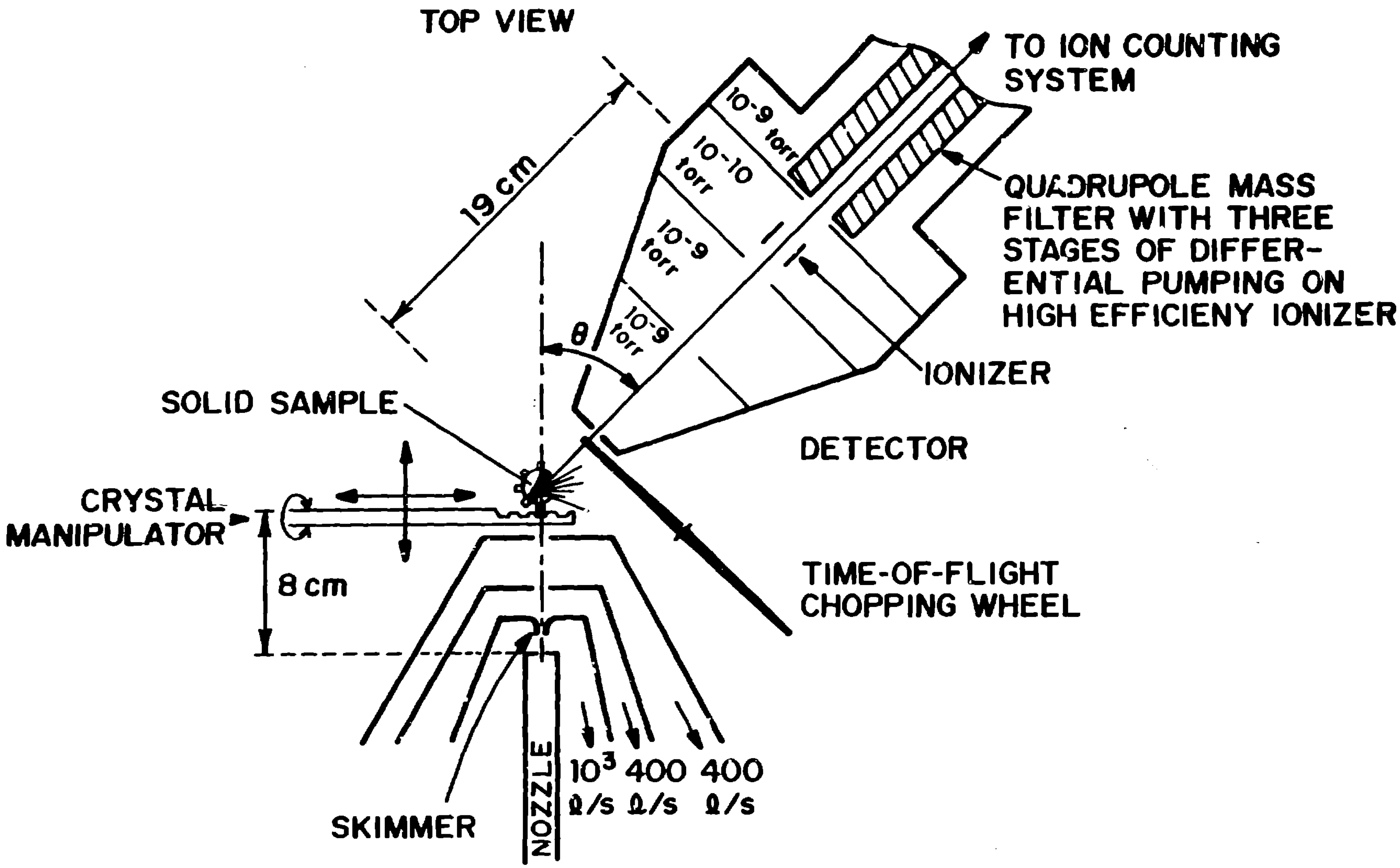
FIGURE CAPTIONS

1. Los Alamos Molecular Beam Apparatus (LAMBDA). This figure shows the central portion of the instrument including the molecular beam source, the crystal manipulator-molecular beam intersection zone and a portion of the moveable detector. The detector is a electron bombardment ionizer-quadrupole mass spectrometer suspended from the rotatable lid of the main vacuum chamber. Two different apertures can be used at the entrance to the detector. The smaller aperture is circular with a 0.15 mm diameter and is set in place when the detector is positioned to monitor the direct beam while the larger is rectangular, 3 mm wide by 2 mm high, and is used to detect reaction products scattered from the test surface. Also shown is a time of flight chopping wheel which contains a series of slots forming a pseudorandom sequence which allows for 50% transmission efficiency and time of flight measurements by cross correlating the data with the sequence. Pumping on the scattering chamber is accomplished with a liquid nitrogen cryoliner, turbomolecular pump and a closed cycle gaseous helium cryopump. Pressures of 10^{-8} to 10^{-9} torr are obtained in the scattering chamber. Not shown in the figure is Auger surface analysis equipment located in the crystal manipulator housing for identifying surface adsorbed species. This apparatus will be used for investigations of space craft surface etching by O-atoms.

2. **Molecular Beam Laser Induced Fluorescence Apparatus.** This figure shows a detailed view of the central components which consist of a nozzle chamber, a differential pumping chamber containing flags, choppers and a slotted disk velocity selector, and a UHV (10^{-10} torr) chamber containing a cryoshroud, crystal manipulator, surface analysis equipment consisting of Leed and Auger units, and provision for collecting fluorescence light and introducing laser or other photon sources of light. This apparatus would be used primarily for investigations of O-atom damage to optical surfaces and investigations of surface-plasma glow phenomena observed on space craft surfaces.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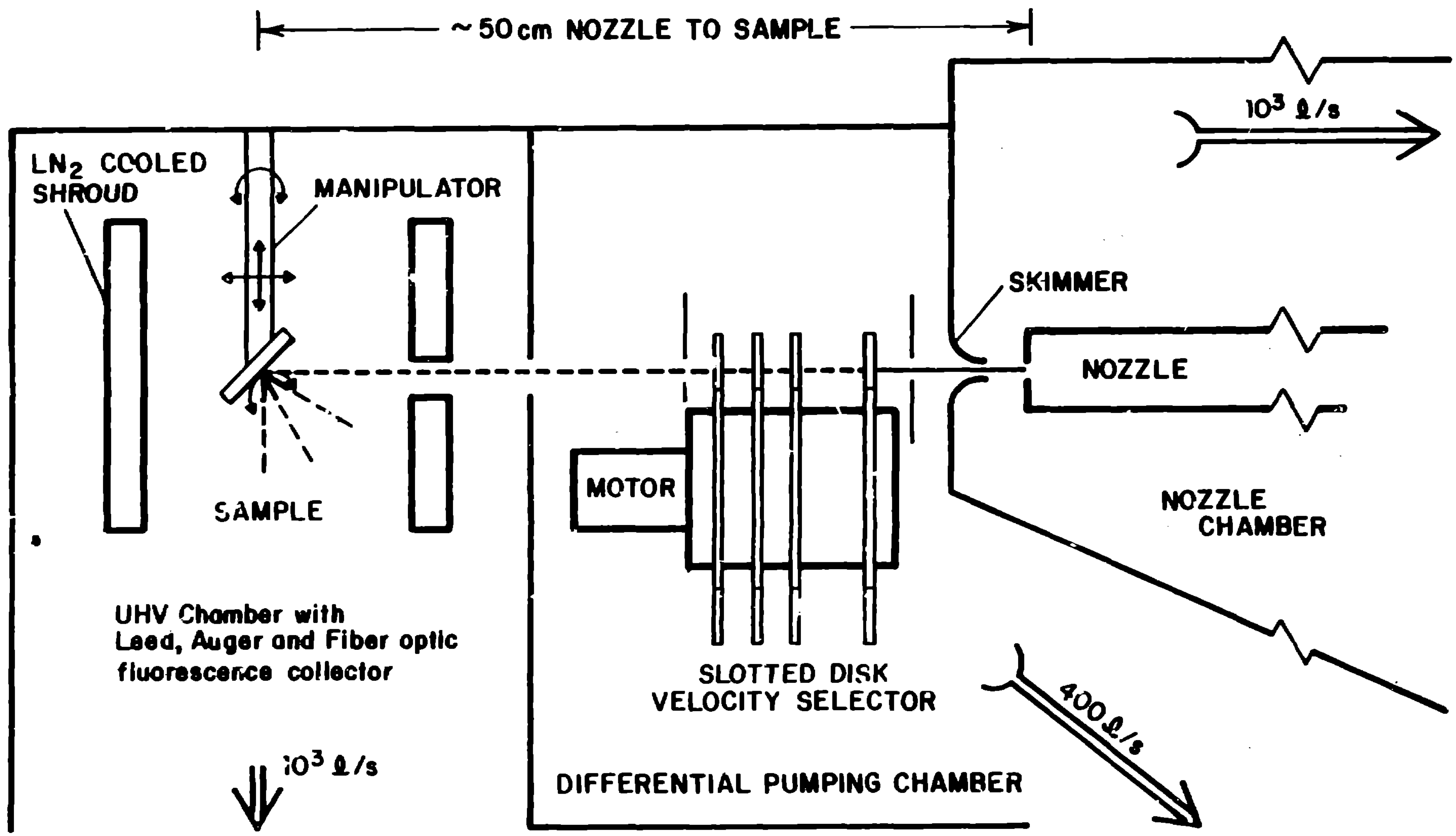
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SLOTTED DISK VELOCITY SELECTOR
400 ℓ/s
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