LOW ENERGY INELASTIC COLLISION PROCESSES: SURFACE REACTIONS IN SPACE

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ABSTRACT

The electonic transition rates in low-energy ion-surface interaction were studied by emplaying tilted-foil and grazing incidence geometries, and the linear and circular polarizations of light emitted were observed, respectively. The theoretical understanding of the dynamics is still expected.

Key words: Desorption Electronic transition (DIET) Grazing incidence Tilted-foil nentralization

I . INTRODUCTION

Erosion and glow greatly impede the useful operation and shorten the lifetime of spacecraft in low earth orbit[1,2]. Attempts to understand, and to eventually control, these macroscopic phenomena require a detailed understanding of the microscopic processes that underlie them; and this detailed understanding must in part rely on laboratory data taken under carefully-controlled ultra high vacuum conditions. Because the environment of the low earth orbit is rich in neutrals and ions[3], laboratory observations of the effects of low-energy atom, molecular and ion beams on surfaces comprise an important subset of the required data. Sufficiently detailed studies can provide information regarding the transfer, storage and redistribution of energy which is brought to the surface and ultimately manifests itself as glow or as the kinetic energy of eroding particles[4].

II .LOW ENERGY O AND N BEAM COLLISIONS WITH SURFACES

These studies involve the detection and characterization of species that are eroded from surfaces by atom, molecule, ion, electron or photon irradiation by optical and mass spectrographic techniques[6]. Thus our primary data relate to individual atomic and molecular processes; and we intend to build a general model of how these processes give rise to damage, erosion and glow.

The desorption of particles from surfaces may occur via sputtering processes,which

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involve a significant transfer of momentum from the bombarding particle to the surface; and via electronic interactions,which involve the breaking of electronic bonds and the creation of solid-state defects. At the low energies (~5 eV) of importance to the space environment, desorption induced by electronic transitions (DIET) should be the predominant mode of erosion; and we have seen definite indications of DIET processes in the desorption of excited neutral atoms caused by low-energy ion bombardment.[6]

During the past two and a half years we have constructed a new dedicated low-energy ion source and have used it to study desorption from an Al(Li) alloy. The source delivers ion beams over the energy range from 4 to 5000 eV with significant current and will be used as the basis of our already developed neutral beam source,[7] Typical beam currents for various species are: 50nA for O and O_2, 1 μ A for N_2, Ar, Kr, Xe and Ne; and 150 nA for N. These currents are independent of beam energy in the range of 4 to 2000 eV.

We have used the ion source to systematically study fluorescence due to beam-induced erosion from the oxide layer of an Al(Li) alloy under bombardment by different ionic species. (Because of their low densities, Al(Li) alloys have potential use in structural components of low-orbit spacecraft.). Using ion beams of O, N, N_2, He, Ne, Ar, Kr and Xe we have carefully studied the energy depedences of the strongest line emissions of excited Al* and Li* desorbing from the oxide layer of the alloy surface. In all cases studied the emission spectrum consists of a low, broad and diffuse spectrum on which is superimposed intense emission lines from the desorbing excited Li* and Al* (Fig.1*a*,*b*)

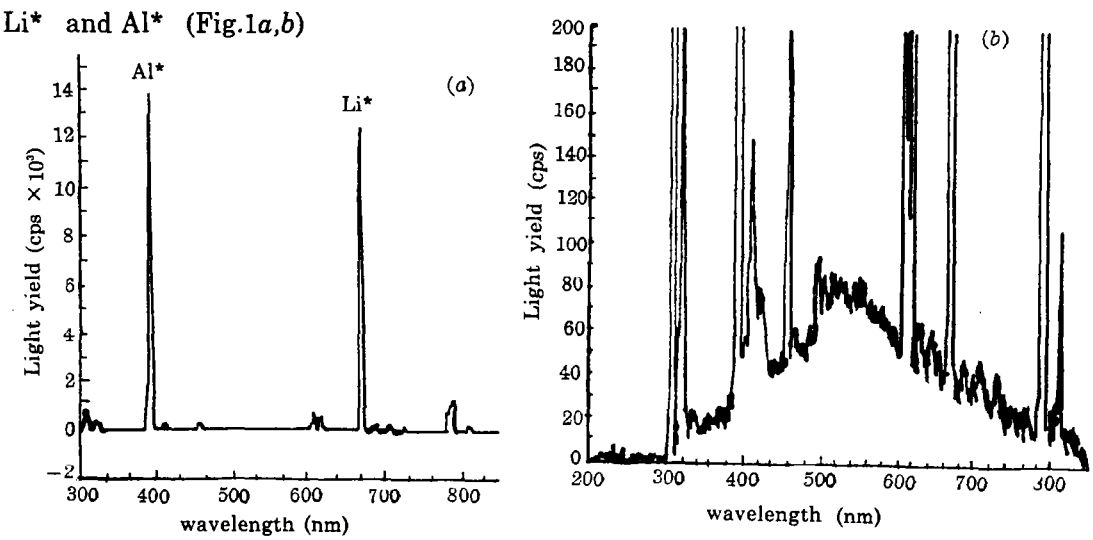

Fig.1 2keV N_2+on Al(Li) spectra

The typical spectrum The low diffuse spectrum

The energy-dependent data for Al* are shown in Fig.2*a*. An interesting and meaningful contrast to this figure is shown in Fig.2*b* in which the beam energies are

referred to the center of mass of the beam－aluminum system. Here a much simpler picture emerges. There is a threshold at an energy of ～75 eV for all but the heaviest of the bombarding species. This energy is the binding energy of the 2p core level in the aluminum atom. Obviously this level plays a central role in the production of the desorbing excited aluminum atoms. The center of mass scaling of this feature allows us to associated it directly with the energy absorption step. Varying the bombarding ion species allows us to unambiguously recognize the process responsible for the initial energy deposition.

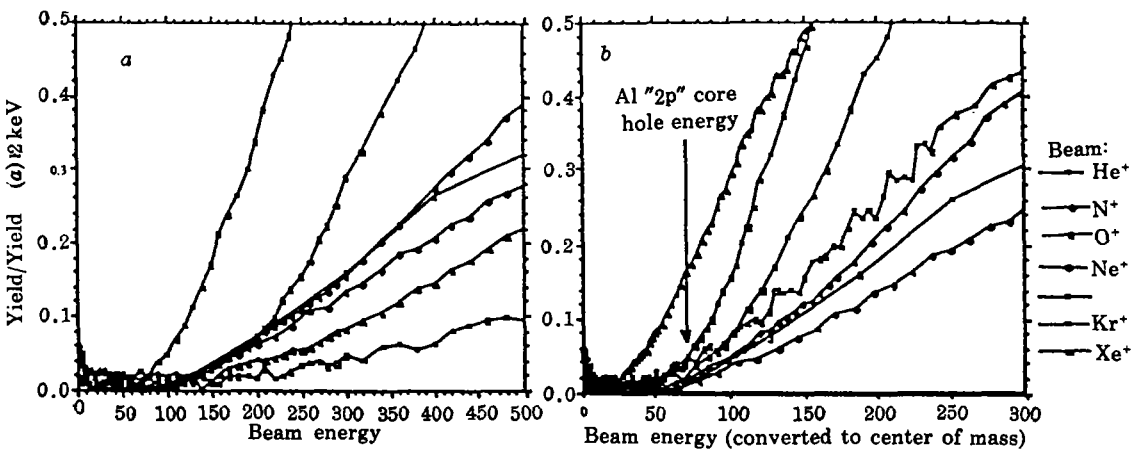

Fig.2 Yield of Al* from Al(Li) vs. energy *(a)* and yield of Al* vs. energy (C.M.) *(b)*

The data for the Li* desorption are shown in Fig.3*a* and once again a meaningful contrast is obtained when the beam energy is determined in the center of mass system (the beam－lithium C of M), as shown in Fig.3*b*. There is distinct threshold at ～5.5 eV, which is close to the lithium ionization energy.

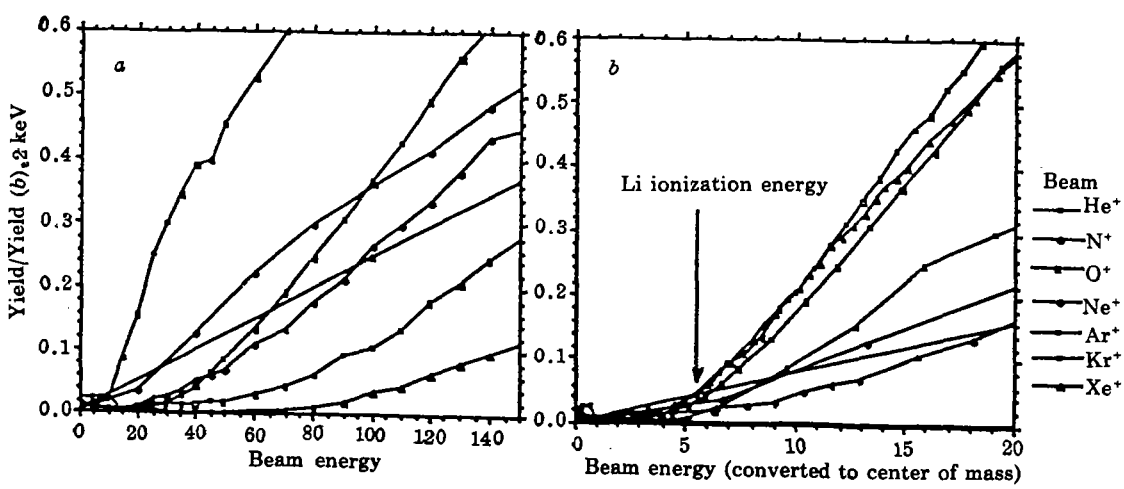

Fig.3 Yield of Li* from Al(Li) vs. energy *(a)* and yield of Li* vs. energy(C.M.)*(o)*

These energy－dependent data clearly indicate that the desorption processes are

mediated by electronic transitions, and that the processes producing line emission are probably related to the processes producing desorption. This work illustrates how the optical spectra of particles ejected from surfaces as a result of particle bombardment can provide detailed information regarding the atomic-scale processes that mediate particle desorption (erosion) and light emission(glow).

III. GRAZING INCIDENCE AND TILTED- FOIL NEUTRALIZATION

Detailed understanding of particle-surface electron exchange processes is essential in determining the final states of particles desorbed, sputtered or scattered from surfaces in space. The final state (following ionization, neutralization or excitation) of an emitted atom or molecule may have significant influence *(a)* on the reactivity of the atom or molecule in the near surface plasma, and *(b)* on the capability of the atom or molecule to cause erosion and glow due to multiple particle-surface collisions. Our experimental and theoretical investigations of ion-surface interactions are among the most fundamental possible in elucidating electron transition rates at surfaces.

Experimentally we measure the polarization of light emitted by excited neutral atoms and employ quantum phase interference (quantum beat) techniques to better characterize the states of the excited atoms which have been neutralized by interactions with a surface. The data obtained are sensitive to the electronic state of the surface at the time of charge transfer. This technique provides an effective experimental arena in which to test postulates regarding neutralization processes at surfaces.[8]

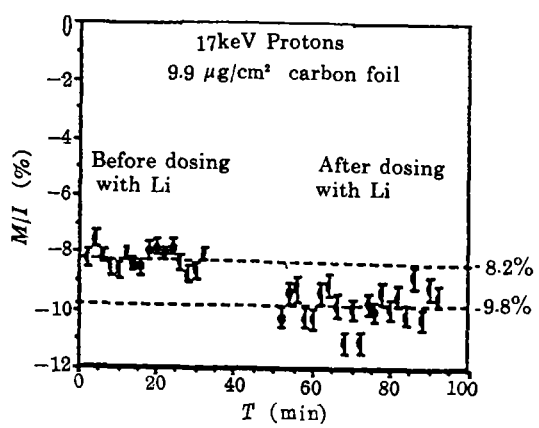

Fig.4 Change in M/I due to dosing with lithium in beam- foil experiment

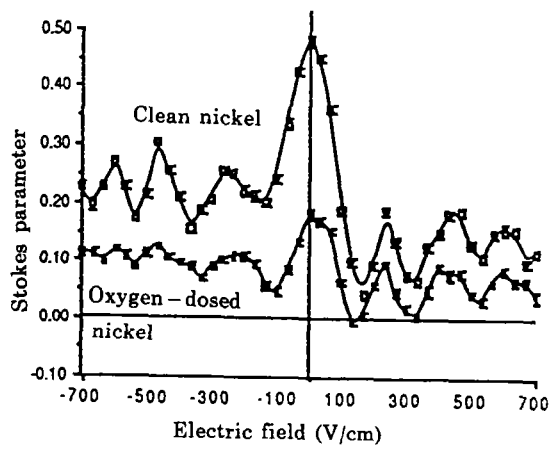

Fig.5 Quantum beats form 9 keV H+on Ni(100)

In our experiments we have employed two geometries; beam passage through thin tilted-foils and beam reflection from smooth surfaces at grazing-incidence angles. The tilted-foil experiments involve carbon foils (<50 nm thick) which permit the

passage of hydrogen ions with energies >5 keV. Light emitted by an atom neutralized during passage through the foil is slightly linearly polarized. When we modify the electronic structure of the exit surface of the foil by the introduction of adsorbates (e.g.lithium metal) we observe a shift in the polarization of the light (Fig.4).

Optical polarization effects in thin-foil neutralization have been known since the early seventies[9, 10]. This is the first application of thin foil techniques to study neutralization at a well characterized exit surface. These data clearly indicate that the neutralization process is influenced by the electronic nature of the exit surface; however at present no model of thin-foil neutralization can explain the shift in polarization.

In the grazing-incidence geometry, a hydrogen beam is scattered from a nickel metal surface at the grazing angle of four degrees or less. Light emitted from scattered excited atoms is characteristically circularly polarized (>50% for a clean nickel surface); quantum beats are measured for clean surfaces and for surfaces with adsorbed oxygen. Fig.5 shows the quantum-beat pattern of the circular polarization as indicated by the Stokes parameter *S/I*. Differences between the data taken with and without adsorbed oxygen are obvious. Especially prominent is the sharp reduction in the central peak when oxygen is present. A similar reduction in circular polarization has been seen in argon scattering off oxygen covered surfaces.[11].

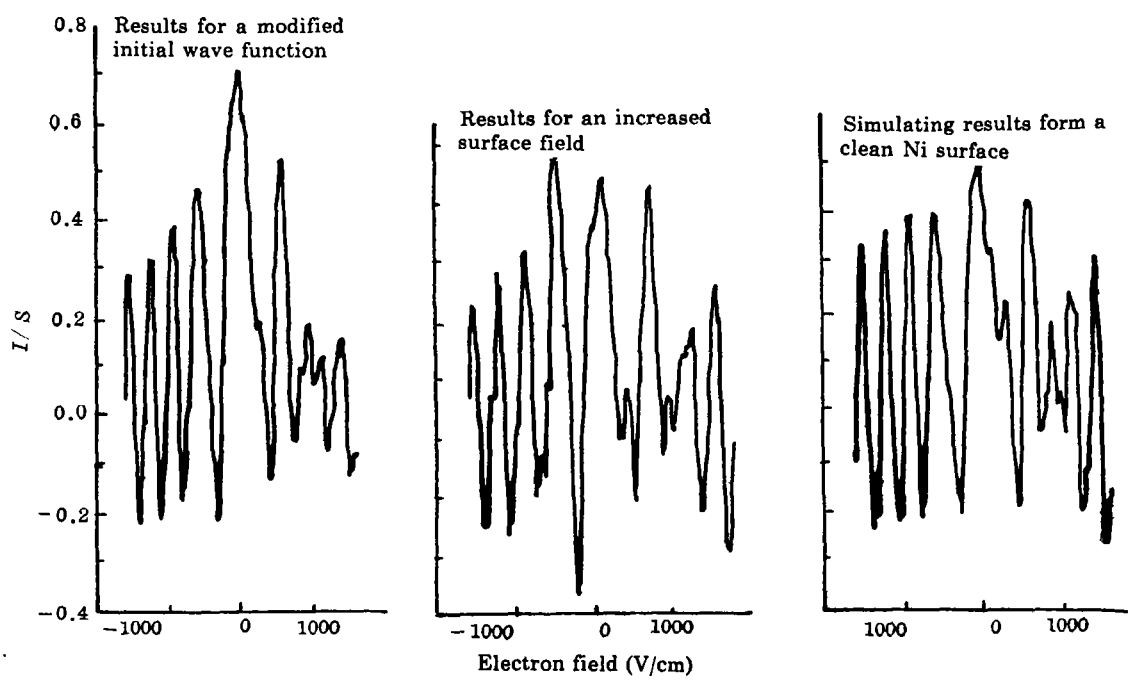

Fig.6

Theoretical studies suggest that this reduction may result from either an actual change in the neutralization process or a modification of the atomic state through

interactions between the atom and surface fields generated by the oxygen coverage. Density matrix model calculations of the time evolution of the hydrogen atom after neutralization show that a significant reduction in the central peak in Fig.5 can be obtained by either a change in the initial wave function of the electron (which implies a change in the capture process) or by an increase in the near surface field[9-12]. The results of these calculations are shown in Fig.6.

Recent theoretical studies performed at Vanderbilt of the behavior of hydrogen near surfaces has yielded unexpected results in the form of inordinately long lifetimes for hydrogen states near the surface[13]. This is in marked contrast to calculations based on the Anderson model[14]. Early attempts by Burgdorfer et al to improve on the Anderson model calculations are very promising but have so far been unsuccessful in reproducing experimental results[15]. Much improvement in the near future is expected in the theoretical understanding of the dynamics of grazing incidence scattering.

ACNOWLEDGEMENT

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