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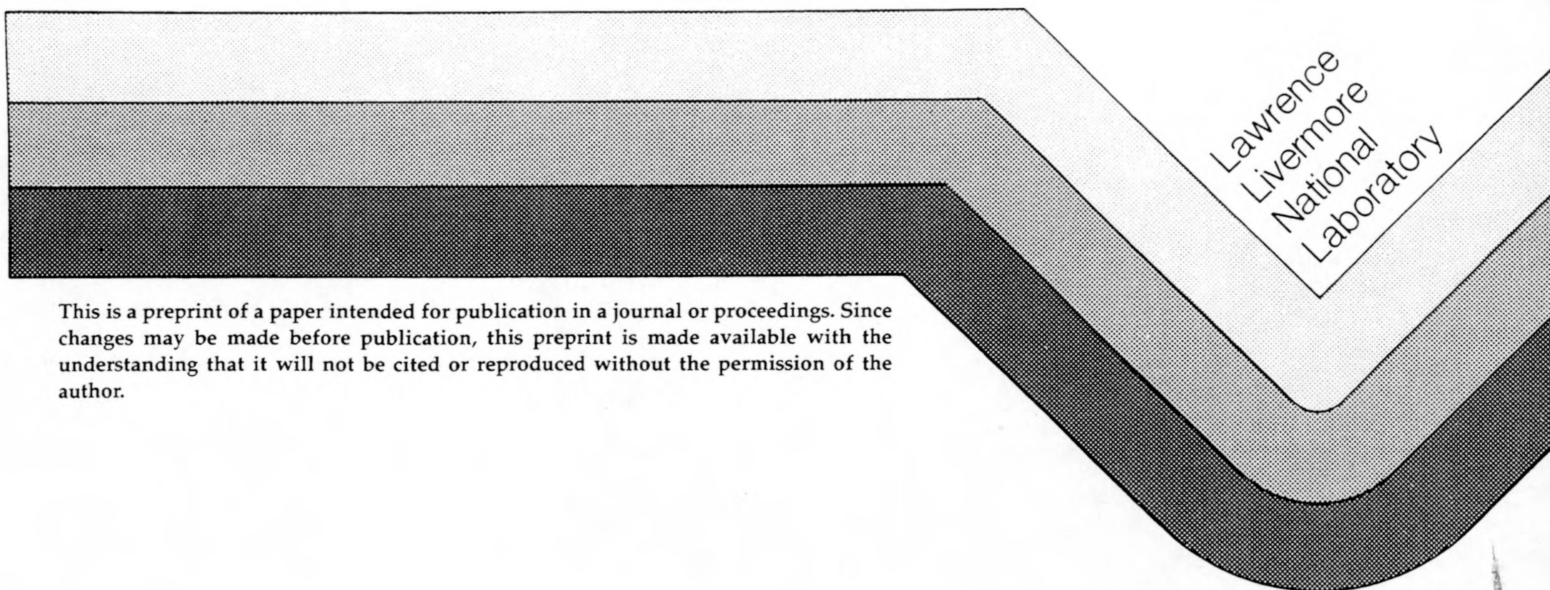

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Particle Emission Induced by the Interaction of Highly Charged Slow Xe-ions With a SiO_2 Surface

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Sputtering of surface atoms by low energy (a few keV) heavy ions is a commonly used technique in material science and applied physics. In general, sputtering occurs via nuclear energy transfer processes and is determined mainly by the atom-atom interaction potentials. In the energy range of interest these potentials depend only slightly on the charge state of one collision partner if the other is neutral. The development of new ion-sources, however, allows for the use of ions with charged states of $q > 50$. For these highly charged ions it is conceivable that electronic processes come into play as well. If, for example, the density of charged surface atoms exceeds a certain limit, then particle emission can occur via the electrostatic repulsion of target atoms, the so-called Coulomb explosion. Indications for such electronic effects have been found in a few investigations of ion-induced sputtering of Si ($q< 12$ in Ar^{q+}).[1,2] However, the order of magnitude of this effect is not clear until now.

In this work we present preliminary data on sputtering, ion backscattering, electron and photon emission from a SiO_2 surface induced by incident Xe ions of very high charge states (q=30-50). The experiment was performed at the electron beam ion trap (EBIT) of the Lawrence Livermore National Laboratory using a time-of-flight (TOF) ion analyzer-system from the Hahn-Meitner-Institute, Berlin. A 300 keV ^{132}Xe beam of about 10^3 ions/s was focussed onto the target at ~25° with respect to the surface and ejected recoil ions were accelerated perpendicular to the surface into a channel plate detector by voltages (V_{acc}) between

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15-2000 V. Electrons were deflected into a channel plate detector behind the target to produce fast start pulses for the TOF measurement.

Fig. 1 displays TOF spectra for two acceleration voltages and the assigned particle species. In this first experiment the pressure in the target region was about 2×10^{-7} torr. Thus, a surface contamination of hydrogen and adsorbed hydrocarbons could not be avoided. It is emphasized that no significant O-peak was observed, whereas the ejection of positively charged heavier molecules is clearly demonstrated. At $V_{acc} > 400$ V the measured total sputtering yield was constant. Therefore, the solid angle for detecting slow ions in this case is 2π and absolute sputtering yields could be deduced using previously determined detection efficiency. From the V_{acc} dependance of the total yield a mean energy of 20 ± 10 eV for the sputtered ions may be estimated. This is significantly lower than the value predicted by the TRIM Monte-Carlo code (50 eV for the charged plus the neutral fraction of sputtered particles).[3] From the figure it becomes clear that we are able to extract Xe backscattering yields and photon emission yields from the spectra with low acceleration voltages. It is noted, that the recoil-ion analyzer has a non-zero efficiency for detecting photons, especially at energies between 5 and 50 eV.

Fig. 2 displays the charge-state dependence of absolute sputtering yields (uncertainty 30%), backscattering yields (Xe^{q+}) and photon emission yields (both with an uncertainty of 40%) as well as the yield of ejected high energy ($\geq$10 eV) electrons (uncertainty 10%). Within the estimated uncertainties the sputtering of Si and all Si-compounds and the projectile backscattering is constant. Since both processes are related to a deep penetration of the solid, charge-state equilibration might influence these results. However, all other yields are increasing for higher charge states. The yield of high energy electrons is linearly proportional to q, and therefore less than linear to the total ionic potential energy W_q. The latter fact is known from previous investigations[4] for much lower incident charge states, where it was also shown that the yield is proportional to W_q for $q < 8$. The latter finding is related to the fact that

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electron emission at low incident energies is dominated by Auger cascades of nearly constant transition energies.

There are two reasons for an increasing photon yield: One is the q-dependence of target excitation and the other (probably dominant) is the increased number of photons from cascades. These photon cascades depend strongly on the projectile main quantum number n, into which target electrons are captured preferentially. According to simple estimates n is proportional to the incident charge state. If we do not consider Auger cascades, then the number of captured electrons is equal to q. Thus, the total number of photons emitted from the incident projectile should be nearly proportional to q^2. However, this does not completely explain our measured q-dependence of the photon yield. The absolute yields are estimated to be in the range of one to ten photons per incident ion for q=50. This large number of photons is inconsistent with emission processes of the incident projectile, since typical optical decay times exceed the ion-surface interaction time by orders of magnitude. Decay of excited states of sputtered atoms may come into play.[5] However, we expect that the measured photon yield is mainly due to backscattered ions or those which are stopped immediately behind the surface. It is noted that a minor fraction of the measured q-dependence of the photon emission might be influenced by the channel plate efficiency function.

The desorption of H increases by about a factor of two when the charge state is increased from 30 to 50. In this regime, the estimated kinetic sputtering due to elastic nuclear collision varies in the order of 10%. Thus, we conclude that the H-desorption is induced by electronic effects. It may be Coulomb repulsion of the hydrocarbons by the ion-induced charged in the substrate, but more probably the weak bonds between the adsorbates and the surface are broken due to the direct interaction with the highly charged incident ion. TRIM results for the absolute sputtering yield are much higher than the measured values for H^+ and $Si_nO_m^+$. This is due to the large fraction of neutral particles, which are not detected in our experiment. In conclusion, it is shown that the TOF analysis of ejected particles is a very efficient method to gain information on different processes in one experiment. Also it is

possible to perform these measurements with incident particles of only 1000 particles per second. Future experiments will be carried out in an ultra-high vacuum environment with well defined surface conditions.

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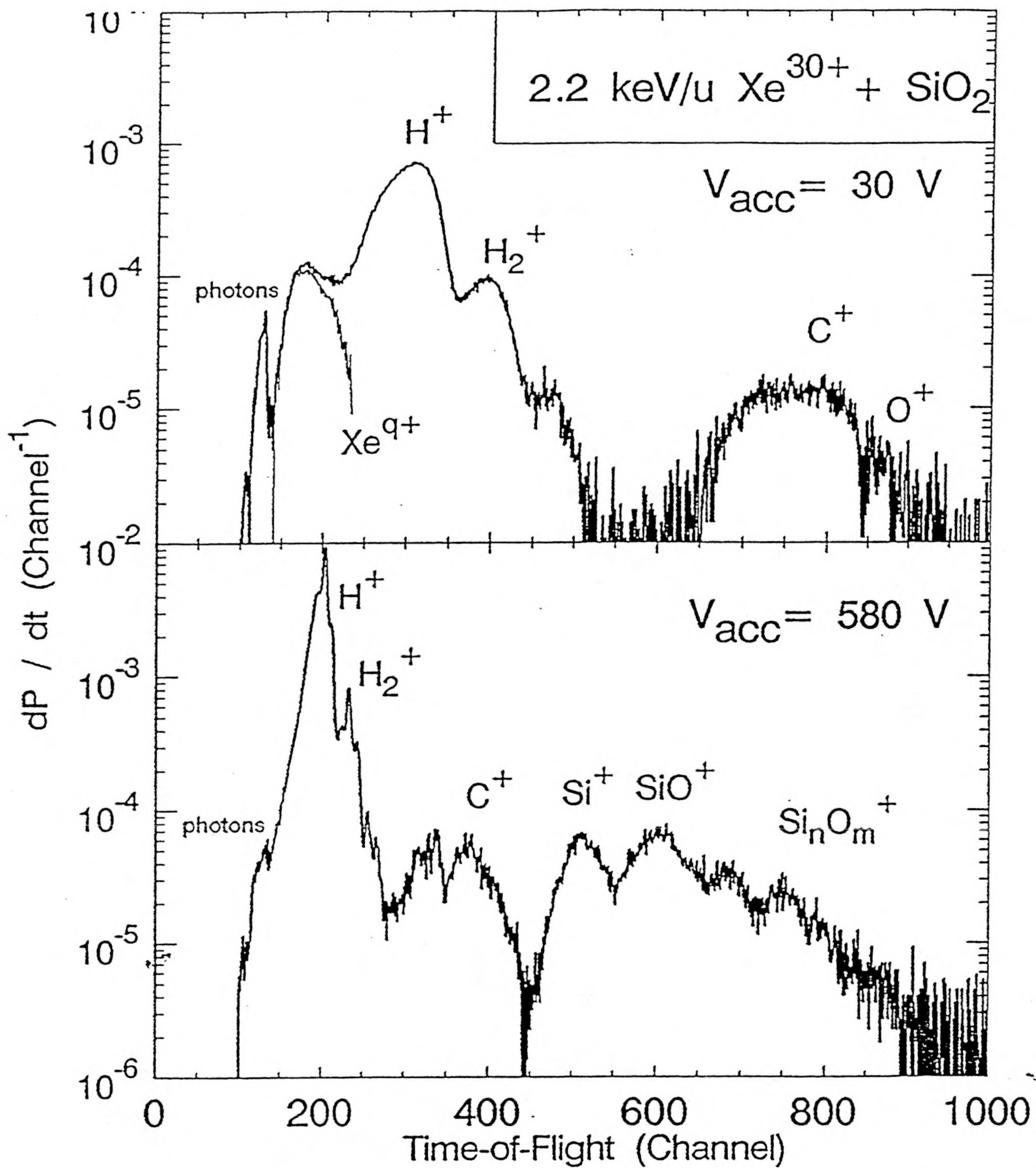
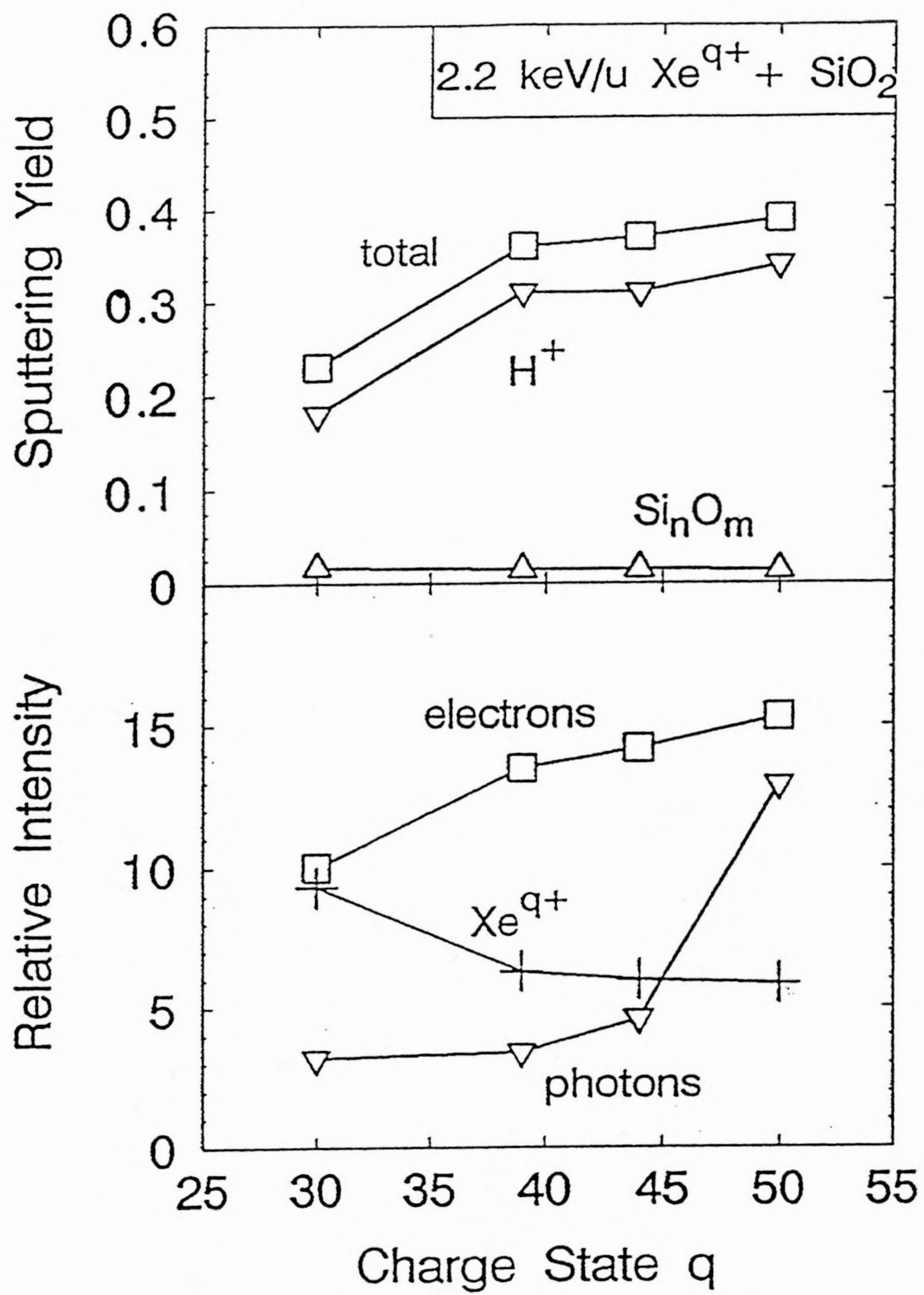
Figures

Fig. 1 TOF (Time-of-Flight) spectra of sputtered ions following 66 keV Xe^{30+} impact on SiO_2 for different sputter ion extraction voltages.

Fig. 2 Sputter ion yield and relative intensities for scattered Xe^{q+} ion, electrons and photons as function of incident ion charge states.



2.2 keV/u Xe^{30+} + SiO_2
V_{acc}= 30 V
V_{acc}= 580 V
H^+
H_2^+
photons
Xe^{q+}
C^+
O^+
Si^+
SiO^+
$Si_nO_m^+$
dP / dt (Channel^{-1})
Time-of-Flight (Channel)



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