ION-SURFACE REACTIONS RELEVANT TO FUSION EDGE PLASMAS

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Ion surface (reactive) collisions is a research area which is rapidly growing in an effort to identify and explore new methods for both characterizing gaseous ions and the nature of the surface [1,2]. Besides physical and chemical sputtering the following processes have been identified and investigated in the past years for collisions in the range of tens of eV laboratory energy: (1) reflection, (2) surface induced dissociation (SID), (3) charge exchange reactions (CER) and (4) surface induced reactions (SIR). In addition of being of fundamental importance, polyatomic ion-surface reactions are also relevant to technological applications [2] encompassing such diverse fields as (i) secondary ion mass spectrometry, (ii) reactive scattering for surface analysis, (iii) surface-induced dissociation for structural analysis, (iv) surface modifications for the preparation of new electronic materials (including the large area of plasma processing) and, quite importantly, (v) plasma-wall interactions in electrical discharges and fusion plasmas [3].

For example, dielectric etching using fluorocarbon plasmas [4] is a major tool in the integrated circuit (IC) manufacturing industry. Models of low-temperature, nonequilibrium plasmas, in particular for the description of the physical phenomena, have developed rapidly [5]. However, lack of fundamental data for the most important species is the single largest factor limiting the successful application of such models to emerging problems of industrial interest [5]. Besides volume processes, heterogeneous (surface) reactions are at the heart of plasma materials processing techniques, but unfortunately in many instances these plasma/wall processes are less well understood than are gas phase processes. Even for some of the key species, such as SiH_4 and CF_4, the knowledge on surface reactions is sketchy at best. A similar situation exists for data concerning plasma wall interactions of relevance to the plasma edge of fusion tokamaks [3,6].

Recent studies in the field of thermonuclear fusion based on the magnetic confinement of high temperature plasmas have demonstrated that the conditions at the plasma periphery (plasma edge) play an important role for achieving, sustaining and controlling thermonuclear fusion plasmas [6]. Because of the relatively low temperature in the plasma edge the plasma contains - besides electrons and atomic ions - also a significant number of neutral hydrogen atoms, low-charged atomic and molecular impurities produced and introduced via plasma/wall interactions [3]. The impurities present will depend on the materials used for the plasma facing components such as the first wall, the protective tiles and the divertor plates. Most of today's tokamaks operate with plasma facing surfaces covered with graphite tiles or carbon and boron containing films and, moreover, graphite tiles are part of the reference design of ITER. According to [3] the issue of plasma/surface interaction has been mainly focused - besides on the hydrogen fuel recycling - on the neutral impurity flux from the plasma facing components. The present study supplements these studies by generating information about the ionic part in these fluxes produced by ion/surface collisions. One reason for the present studies is that the larger interaction cross sections of these ions with neutrals in the plasma edge (as compared to the reactions between neutrals) makes up for their smaller abundance in the reflected particle flux and thus enhances their importance for the gross behavior in this region.

Finally, a particular interesting and exciting sub-field in the area of ion surface collisions is the interaction of clusters with surfaces [7]. Whereas cluster science has developed in the past two decades to a well established field in physics and chemistry [8,9], recently a novel and potentially very useful area has emerged, i.e., the interaction of neutral or ionized clusters with surfaces [7]. Depending on the initial kinetic energy of the impinging cluster projectile the interaction with a surface leads either to cluster deposition, to cluster fragmentation or even to cluster ionization or the emission of electrons (see [7] and references given in [10]). Experimental studies concerning cluster ion-surface „reactions“ have been mainly restricted to SID reactions (see references in [11,12]), nevertheless including also the observation of surface pick-up reactions [13,14]. Recently, the possible existence of intracluster reactions was suggested [15,16].

In a recent effort to improve this situation we have constructed the tandem mass spectrometer set-up BESTOF (consisting of a B-sector field combined with an E-sector field, a Surface and a Time Of Flight mass spectrometer) [17-22] which allows the investigation of ion/surface reactions with high primary mass and energy resolution (energy spreads of as low as 80 meV have been achieved). Using BESTOF we have extended previous investigations in three respects [17-22]. Firstly, we have revisited previously investigated surface induced reactions of various polyatomic ions including the acetone ion, the benzene ion and CF3+ interacting with hydrocarbon covered stainless steel surfaces. In addition we have started to investigate the reactions of polyatomic hydrocarbon ions such as $C_nH_m^+$ with carbon tiles from the Tore Supra tokamak in Cadarache. Finally, we have investigated surface induced reactions (using stainless steel and gold surfaces) of cluster ions as a function of cluster size n and cluster charge state z including for the first time intracluster reactions [22].

The experimental apparatus BESTOF constructed recently in Innsbruck consists of a double focusing two sector field mass spectrometer in combination with a time-of flight mass spectrometer. Beams of neutral atoms, molecules or clusters produced by different techniques are passing through a skimmer before entering transversely into a Nier-type electron impact ion source. A direct gas inlet may be substituted for the beam sources for the study of conventional SID experiments. Neutral molecules are ionized by impacting them with electrons whose energy can be varied from below the ionization energy up to about 500 eV.

The ions produced are extracted from the source region and accelerated to 2930 V for mass- and energy-analysis by a double-focusing two-sector-field mass spectrometer. After passing the exit slit of the mass spectrometer ions are refocused by an Einzel lens and deceleration optics positioned in front of the surface. The collision energy of ions impacting on the surface is defined by the potential difference between the ion source and the surface. The potential difference (hence, the collision energy) can be varied from zero to about 2 keV. We have determined the energy and energy spread of the primary beam by using the surface as a retarding potential and measuring the total ion signal as a function of the surface potential. The energy spread (as low as 80 meV) is given by the fwhm of the first derivative of the total ion signal. Field penetration effects are minimized by shielding the surface by conical shield plates. A fraction of the secondary ions formed at the surface exits the shielded chamber through a 1 mm diameter orifice and is extracted and accelerated into the analyzer mass spectrometer, which is a linear time-of-flight mass selector with a flight tube of about 80 cm in length. The mass selected ions are detected by a channelplate which is connected to a pulse counting unit and a laboratory computer. Background gas pressure in the target region is in the 10^{-9} Torr range, consequently the stainless steel target is covered by several monolayers of hydrocarbons originating primarily from pump oils.

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