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Collection of Abstracts

TEMPERATURE CONTROL OF ION GUIDING THROUGH STRAIGHT INSULATING MACRO - CAPILLARIES

G. Kowarik[1], R. J. Bereczky[2], E. Gruber[1], F. Ladinig[1], D. Schrempf[1], P. Gunacker[3], C. Lemell[3], J. Burgdörfer[3], K. Tőkési[2], and F. Aumayr[1,*]

[1] Institute of Applied Physics, TU Wien - Vienna University of Technology, 1040 Vienna, Austria, EU
[2] Institute of Nuclear Research of the Hungarian Academy of Sciences, (ATOMKI), 4001 Debrecen, Hungary, EU
[3] Institute of Theoretical Physics, TU Wien - Vienna University of Technology, 1040 Vienna, Austria, EU

1. INTRODUCTION

First experiments on guiding of highly charged ions (HCI) through straight insulator nano-capillaries showed a remarkable effect: after an initial charge up phase, the ion beam could be steered by tilting the capillary axis while remaining in the initial charge state indicating that the transmitted ions never touched the inner walls [1]. Subsequent experiments confirmed this guiding effect also for macroscopic glass capillaries, both straight [2,3] and tapered ones [4]. The microscopic simulations revealed that a self-organized charge up of the capillary walls due to preceding HCI impacts leads to an electric guiding field, which steers the incoming projectile ions along the capillary axes [5]. Ion guiding ensues as soon as a dynamical equilibrium of charge-up by the ion beam and charge relaxation by bulk or surface conductivity is established. The simulations showed that a stable transmission regime required a delicate balance between incident ion flux and charge relaxation via surface and bulk conduction, conditions, which were obviously met in almost all cases studied experimentally so far. In this contribution we show that a key control parameter for guiding is the small residual electric conductivity of the highly insulating capillary material whose dependence of temperature σ(T) is nearly exponential.

2. EXPERIMENTS

We use a single straight macroscopic glass capillary (inner diameter: 160 µm; length: 11.4 mm) made of Borosilicate (Duran) for which the guiding effect has been previously established [2]. The current experimental set-up allows for a controlled and uniform temperature variation of the glass capillary between -30°C and +90°C [6]. Within such a moderate variation of the temperature the conductivity changes by almost five orders of magnitude. Beams of Ar^{7+} and Ar^{9+} ions with a kinetic energy of 4.5 keV are collimated to a divergence angle of less than 0.5° and eventually hit a metallic entrance aperture directly in front of the capillary (120 µm diameter). Transmitted ions are registered by a position sensitive micro-channel-plate detector with wedge-and-strip anode, located about 18 cm behind the sample. Transmission rates are recorded for each capillary tilt angle after steady-state conditions (i.e. a dynamical equilibrium) are reached.

3. RESULTS

Experimental transmission curves are normalized with respect to the transmission in forward direction (Fig.1).

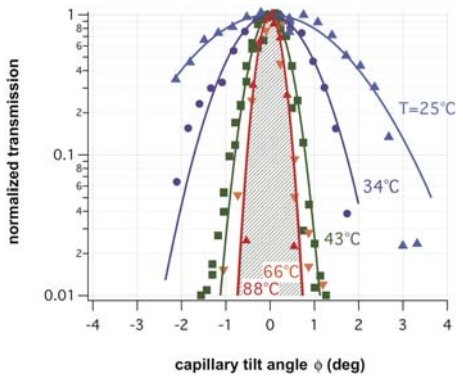

Figure 1: Normalized transmission curves for 4.5 keV Ar^{9+} ions guided through a glass capillary for different temperatures ranging from 24°C to 88°C. The flux of the incident 4.5 keV Ar^{9+} ions was kept constant at about 5000 ions entering the capillary per second. The shaded area indicates the geometric limit of transmission in the absence of guiding.

Our experiments [7] show that increasing the temperature of a glass capillary and therefore its conductivity leads to a reduction of guiding and, eventually, to a complete disappearance of the guiding effect. This strong temperature dependence can be employed to stabilize guiding against Coulomb blocking due to a high incident ion flux [8].

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* Corresponding author e-mail address: aumayr@iap.tuwien.ac.at

Tuesday

A MICROSCOPIC MODEL FOR TRACK FORMATION BY SWIFT HEAVY IONS

G. Wachter[1,*], *K. Tőkési*[2], *G. Betz*[3], *C. Lemell*[1] *and J. Burgdörfer*[1]

[1] Institute for Theoretical Physics, Vienna University of Technology, Wiedner Hauptstraße 8-10, A-1040 Vienna, Austria, EU
[2] Institute of Nuclear Research of the Hungarian Academy of Science (ATOMKI), H-4001 Debrecen, P.O. Box 51, Hungary, EU
[3] Institute for Applied Physics, Vienna University of Technology, Wiedner Hauptstraße 8-10, A-1040 Vienna, Austria, EU

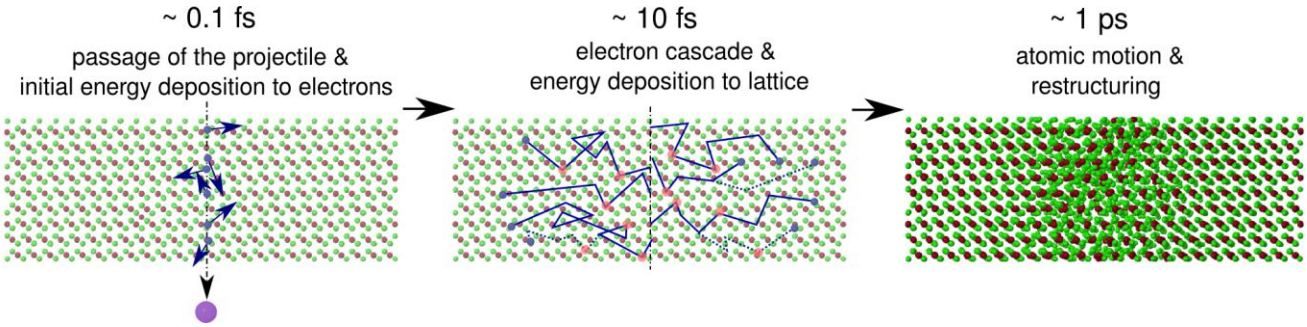

Figure 1: Sketch of the step sequence of processes leading to track formation, time scales as indicated.

1. SYNOPSIS

Collisions of swift heavy ions with insulator targets lead to a damage zone around the path of projectiles, the so-called tracks. We theoretically investigate track formation and propose a fully microscopic three-step model that incorporates processes on multiple time scales (see Fig. 1). The appearance of tracks is linked to melting of the target on a nanometric length scale.

2. MODEL FOR TRACK FORMATION

Experiments show that tracks in insulator targets appear only if above a threshold energy transfer per path length to the medium, i.e. above a critical stopping power. Earlier interpretation has associated this threshold with the melting temperature of the material. Theoretical work was largely based on a macroscopic description, the thermal spike model [1]. In this work, we focus on the microscopic processes that lead to track formation. We find that for a class of target materials the sequence of events leading to track formation can be well described by a three-step model due to the disparate time scales involved (see Fig. 1):

Excitation of the electronic subsystem of the target. The primary energy deposition from the swift projectile is modeled within time-dependent perturbation theory for binary ion-atom collisions (continuum distorted wave - eikonal initial state, CDW-EIS [2]).

Energy diffusion in the electronic system and energy transfer to the target lattice. The resulting electron cascade is modeled by a classical trajectory Monte Carlo simulation [3,4] incorporating lattice heating via electron-phonon-interaction. The energy transferred to the target lattice leads to an elevated temperature, allowing melting of the lattice around the ion path.

Nano-melting. In the third step we follow the temporal evolution of a heated region in a crystal at ambient temperature using a proof-of-principle classical molecular dynamics simulation.

Our simulation allows to link experimentally observed threshold behavior to melting on the nano scale. Results presented for the test system Xe → CaF_2 are found in good agreement with experiment.

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* Corresponding author e-mail address: georg.wachter@tuwien.ac.at

NANO-HOLES MILLED IN 1 NM THICK CARBON NANOMEMBRANES WITH SLOW HIGHLY CHARGED IONS

R. Ritter[1], R. A. Wilhelm[2], M. Stöger-Pollach[3], A. Mücklich[2], U. Werner[4], A. Beyer[4], S. Facsko[2], A. Gölzhäuser[4], and F. Aumayr[1,*]

[1] Institute of Applied Physics, TU Wien - Vienna University of Technology, 1040 Vienna, Austria, EU
[2] Helmholtz-Zentrum Dresden Rossendorf, 01314 Dresden, Germany, EU
[3] USTEM, TU Wien - Vienna University of Technology, 1040 Vienna, Austria, EU
[4] Fakultät für Physik, Universität Bielefeld, 33615 Bielefeld, Germany, EU

1. INTRODUCTION

We have recently discovered that the impact of individual slow highly charged ions (HCI) is able to cause permanent nano-sized hillocks on the surface of a CaF_2 single crystal [1]. The experimentally observed threshold of the projectiles potential energy necessary for hillock formation could be successfully linked to a solid-liquid phase transition (nano-melting) [1 - 3]. Meanwhile a variety of materials has been found, which are susceptible to nano-structuring by the impact of slow HCI [3]. The nature, appearance and stability of the created structures, however, depend heavily on the properties of the target material and the involved interaction processes (determined by the potential and kinetic energy of the projectiles) [3]. Not in all cases nano-hillocks but nano-craters or -holes are formed on a surface, like for KBr [4] or PMMA [5].
In this contribution we present the first investigations on the effect of individual slow highly charged ion bombardment of freestanding carbon nano-membranes [6].

2. EXPERIMENT

The carbon nanomembranes (CNMs) are produced by cross-linking of an aromatic self-assembled monolayer of biphenyl units with low-energy electrons. The substrate is then subsequently removed and the resulting nanosheet (1 nm thickness) transferred onto a holey carbon TEM grid.
CNMs produced in such a way are irradiated by slow highly charged Xe^{q+} ions of various charge states ($20 \leq q \leq 40$) and kinetic energies ($4\ keV \leq E \leq 180\ keV$). After irradiation the CNMs are inspected by high resolution imaging techniques, e.g. transmission electron microscopy (TEM), secondary electron microscopy (SEM), atomic force microscopy (AFM) and He-ion microscopy (HIM).

3. RESULTS

After irradiation by slow HCI we find nanoscopic holes (3 - 30 nm in diameter) at positions, where the sheet extends over holes in the carbon film (fig. 1). The number density of these nanopores corresponds well with the incident ion fluence, indicating that about every HCI produces a nano-hole in the CNM. These holes have so far been imaged in TEM, SEM as well as in AFM.

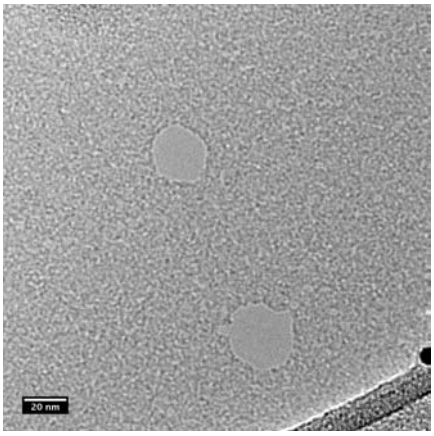

Figure 1: TEM image of 2 holes in a carbon nanomembrane induced by impact of two Xe^{40+} ions (E_{kin} = 40 keV, E_{pot} = 38.5 keV).

First evaluations of the size distribution of the created holes indicate that the average diameter of a pore induced by a given ion depends strongly on the potential energy of the projectile ion, but is also influenced by the kinetic energy.

4. ACKNOWLEDGEMENTS

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* Corresponding author e-mail address: aumayr@iap.tuwien.ac.at

Electron emission due to impact of highly charged ions on C_{60} covered gold surfaces and HOPG

K. Dobes[1,*], *E. Bodewits*[2], *G. Kowarik*[1], *R. Hoekstra*[2] *and F. Aumayr*[1]

[1] Institute of Applied Physics, TU Wien, Vienna Austria, EU
[2] KVI-Atomic and Molecular Physics, University of Groningen, Groningen, The Netherlands

1. INTRODUCTION

Electron emission as a result of the interaction of highly charged ions (HCI) with solid surfaces is of substantial interest both with regard to fundamental research as well as technical applications such as controlled nanostructuring of surfaces or plasma surface interaction in e.g. thermonuclear fusion devices. The emission of electrons during the impact of a HCI on a solid surface is generally divided into two different regimes, i.e. kinetic emission (KE) and potential emission (PE). The former process is driven by the kinetic energy of the impinging projectile, while the latter is induced by the potential energy stored in a highly charged ion Z^{q+} due the removal of q electrons. A widely accepted model that describes the dissipation of the large amounts of potential energy, which are carried by a HCI, at the surface is the so-called hollow atom scenario [1,2]. It describes the neutralization and relaxation of the HCI upon surface impact. This process is not only governed by the potential energy of the projectile, i.e. its charge state q, but also depends on the electronic structure of the surface, the work function and electron transport properties of the target material [1].
To understand the influence of these properties on the electron emission yield and the hollow atom decay in greater detail, we studied and compared ion-induced electron yields from different target materials with different work functions. We investigated clean Au(111), a gold surface covered with 1 – 5 monolayer thin films of C_{60} and highly ordered pyrolytic graphite (HOPG) under the impact of highly charged Ar and Xe ions at different impact angles and energies.

2. EXPERIMENTAL SETUP

Experiments were performed at the setup IISIS at KVI Groningen [3]. The Au and HOPG target respectively were mounted within an UHV chamber at a base pressure of the order of 10^{-10} mbar. The Au surface was cleaned by cycles of sputtering and annealing. The HOPG sample was cleaved with a scotch tape before it was transferred to the vacuum chamber. Thin films of C_{60} were deposited onto the Au sample by means of an Omicron EFM3 evaporator. Single monolayers of C_{60} were deposited by first determining the deposition rate with a quartz crystal microbalance and then exposing the sample to the C_{60} beam for a corresponding time interval.
Ar^{q+} ions (q = 4, 6 - 13) and Xe^{q+} ions (q = 10, 12, 14, 16, 18, 20, 22, 24, 26, 28) were extracted from a 14 GHz ECR ion source. The Ar ion energies ranged from 3.9 keV up to 91 keV. The impinging Xe ions were in an energy range from 7.2 keV to 328 keV.
The electron statistics detector [4] is mounted under 90° with respect to the incoming ion beam. It is an energy sensitive, passivated implanted planar silicon (PIPS) detector. Secondary electrons, which are emitted in an ion-surface collision event, are collected by a set of six different electrodes surrounding the target and are then accelerated towards the detector, which is biased to +30 keV. The number of electrons produced in a single ion impact event is determined by pulse height analysis. From this the electron number statistics is obtained in addition to the mean number of emitted electrons per incident projectile ion.

3. RESULTS

When comparing secondary electron yields from Au and Au covered with 1 – 5 ML of C_{60}, an increase in electron yield is found. This increase in electron yield is well described by an exponential gain function and is virtually independent of the potential energy of the projectiles between 0.5 and 10 keV. It saturates at 35%, when five monolayers of C_{60} are evaporated on the surface [5]. Also for a clean HOPG surface a higher yield is found as compared to a clean Au surface. A detailed comparison of the results obtained on the different targets will be presented and possible scenarios will be discussed that are able to explain this increase in electron yield.

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* Corresponding author e-mail address: dobes@iap.tuwien.ac.at

CONTROLLING ION GUIDING THROUGH TAPERED GLASS - CAPILLARIES WITH TEMPERATURE

E. Gruber[1], P. Hischenhuber[1], S. Wampl[1], M.J. Simon[2], and F. Aumayr[1,*]

[1]Institute of Applied Physics, TU Wien, 1040 Vienna, Austria, EU
[2]Labor für Ionenstrahlphysik, ETH Zürich, 8093 Zürich, Switzerland

1. INTRODUCTION

Guiding of highly charged ions (HCI) through tilted insulating capillaries, both straight and tapered ones [1-5], has developed from an area of basic research to a tool to efficiently collimate and focus ion beams. Applications range from nanoscale modifications of surfaces to irradiation of single living cells. Consequently, parameters are searched for to control and, possibly, optimize designer ion beams. One such parameter is the electrical conductivity of the insulating material [6]. Its strong temperature dependence is the key to transmission control and can be used to balance transmission instabilities arising from too high incident ion fluxes which otherwise would lead to Coulomb blocking of the capillary.

2. EXPERIMENTS

For our experiments we use a single tapered glass capillary made of Borosilicate. The entrance diameter of the conical shaped capillary is 0.86 mm, while the exit diameter is 82 µm. After a 5 mm long straight section the conical part of the capillary is about 5 cm long. The capillary is placed in a specially designed copper cylinder surrounded by stainless steel coaxial heaters and thermo shields. The temperature of the copper parts is monitored by a K-Type thermocouple and the heating power regulated by a PID controller. The current experimental set-up allows for a controlled and uniform temperature variation of the glass capillary between room temperature and +90°C. Within such a moderate variation of the temperature the conductivity changes by three to four orders of magnitude [6].

A beam of Ar^{7+} ions with a kinetic energy of typically 4.5 keV is collimated to a divergence angle of less than 0.7° and eventually hits a metallic entrance aperture directly in front of the capillary. Transmitted ions are registered by a position sensitive micro-channel-plate detector with wedge-and-strip anode, located about 14 cm behind the sample. Transmission rates are recorded for each capillary tilt angle after steady-state conditions (i.e. a dynamical equilibrium) are reached.

3. RESULTS

For our tapered capillary at room temperature we observe "guiding" of the incident ions up to several degrees tilt angle of the capillary with respect to the incoming ion beam. At very small tilt angles (close to the straight direction), however, we find a considerable suppression of the transmission of ions. Such a "blocking" effect has been reported previously by Nakayama et al. [7] and Kreller et al. [8] for ions transmitted through tapered glass capillaries at small angles, low beam energy and high beam intensity. It can be attributed to repulsive Coulomb forces of a uniformly charged ring-shaped region in the tapered part of the capillary. In our experiments we demonstrate, that by heating the tapered capillary (and thus increasing the conductivity of the glass capillary) the excess charge can be removed, and the blocking of the capillary can be terminated.

4. CONCLUSION

The strong temperature dependence of the conductivity of glass can be employed to successfully stabilize ion-guiding against Coulomb blocking due to a high incident ion flux.

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* Corresponding author e-mail address: aumayr@iap.tuwien.ac.at

Tuesday Poster

AN ULTRA-COMPACT SETUP FOR MEASURING ION-INDUCED ELECTRON EMISSION STATISTICS

D. Schrempf, W. Meissl, and F. Aumayr*

Institute of Applied Physics, TU Wien, 1040 Vienna, Austria, EU

1. INTRODUCTION

Impact of heavy particles as atoms, molecules, positive or negative ions on solid surfaces gives rise to electron emission, which is of great importance for many applications, e.g. surface and space science, sensitive particle detection/counting, plasma wall interaction, electrical discharges, etc. Particle-induced electron emission is of special relevance for the registration of extremely small particle currents, for which the statistics of the electron emission plays a crucial role. The emission statistics (ES), i.e. the probabilities W_n for emission of a given number n of electrons due to a single impact event immediately permits evaluation of the related total electron yield γ as the mean number of emitted electrons

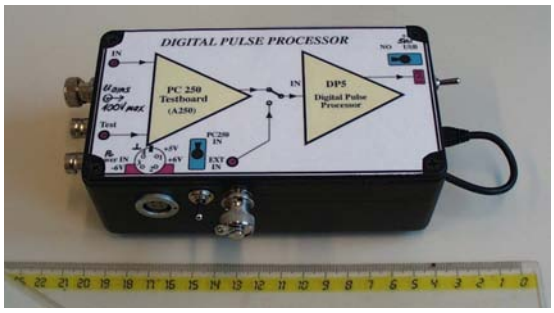
$$\gamma \equiv \bar{n} = \sum_{n=1}^{\infty} n \cdot W_n \; ; \qquad \sum_{n=0}^{\infty} W_n = 1$$

as well as the fraction of projectiles, which do not emit at least one electron and which are therefore not registered by electron emission.

2. EXPERIMENTAL SETUP

To measure the ES distribution during ion-surface interaction usually the electrons emitted from the interaction region are extracted by a weak electric field through a highly transparent grid and accelerated onto a surface barrier type detector biased at +30 kV [1 - 6]. The n electrons emitted due to a particular ion impact will be registered like one electron of n times 30 keV rather than n individual 30 keV electrons. The number of electrons emitted in a particular ion-impact event can therefore be deduced from the detector's pulse height distribution. More details on this ES detection method and its appropriate evaluation can be found in [1 - 3] and refs. therein.

The usual setup for ES measurements involves a NIM crate with detector bias, spectroscopy amplifier and power supply operated at HV potential and a suitable data transfer from HV to ground potential. We have now designed and constructed a novel light and ultra-compact electronics replacing this heavy and bulky equipment by small and light components, which can be operated using a battery pack only. Even the pulse height analysis is now performed at high voltage and just the resulting pulse height spectrum is communicated by optical fibers to the measurement PC at ground potential. A photo and the schematics of the new electronics is shown in fig. 1.



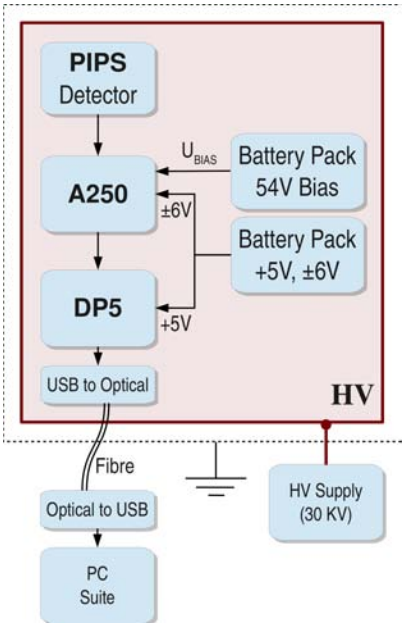


Figure 1: New ultra-compact ES detection electronics

Not only the compact design but also the low cost of the new electronics presented in this contribution, will allow other groups to easily employ the ES technique at their beam lines and use it e.g. to determine the composition of their HCI or cluster ion beams as described in [4, 6] or for basic ion-surface collision studies.

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* Corresponding author e-mail address: aumayr@iap.tuwien.ac.at

Sputtering of fusion relevant surfaces by seeding impurities

K. Dobes[1,*], *J. Pyszkowski*[1], *T. Schäfer*[1] *and F. Aumayr*[1]

[1] Institute of Applied Physics, TU Wien, Association EURATOM-ÖAW, Vienna Austria, EU

1. INTRODUCTION

The interaction of a fusion plasma with the walls of its containing vessel will constitute one of the key challenges in the successful realization of a future fusion power plant. A profound knowledge about sputtering yields of plasma facing components under the impact of fusion relevant ion species is hence desired. Besides the evolution of plasma facing materials like tungsten, beryllium and possibly also carbon in the environment of a burning fusion plasma and especially the mixing of materials is of considerable interest. In addition also the retention of hydrogen isotopes in plasma facing components is of major concern. Particularly the build-up of a tritium inventory within the plasma vessel imposes operational limits due to safety considerations.

ASDEX Upgrade was the first fusion machine to operate with a full tungsten wall [1]. Also in future fusion devices like ITER tungsten is foreseen as a divertor target [2]. In order to reduce the power load to the divertor target plates to acceptable values, radiation cooling is essential [3]. Especially in all-metal fusion machines, where no carbon is present in the vessel, radiation due to intrinsic impurities is no longer sufficient and has to be replaced by seeding of additional impurities [3]. At ASDEX Upgrade nitrogen seeding with feedback control has meanwhile matured into a standard operational scenario [1]. Using nitrogen, the divertor target power flux could be mitigated by high radiation to a technically acceptable level, and the performance of the plasma was even increased compared to discharges without impurity seeding [1]. At ITER heavier seeding impurities like Ne and Ar will be necessary and used for radiative cooling. It is hence of considerable interest to study the interaction of different seed impurity ions (N^+, N_2^+, Ne^+, Ar^+) with tungsten and other fusion relevant surfaces.

2. EXPERIMENT & RESULTS

In our studies we are using a quartz crystal microbalance (QCM) technique [4 - 7] that has been designed at Vienna University of Technology. The experimental technique has been optimized for extreme high sensitivity and accuracy. It is capable of determining mass changes of as small as 2 amu/ion·nA/mm^2 or accordingly $3 \cdot 10^{-4}$ tungsten monolayers per second. Total sputtering yields for N^+, N_2^+, Ne^+ and Ar^{q+} ions on tungsten have been investigated under controlled laboratory conditions. The high sensitivity of our QCM [7] allows us to study the change in surface composition during seed impurity impact and its influence on the sputtering yield in-situ and in real-time. The code TRIDYN [8], which takes into account a change of the surface under ion impact due to implantation and erosion, is used to model and better understand the investigated sputtering phenomena.

We will present the flux dependence of tungsten erosion by different seed impurity ions at fusion relevant impact energies. In addition sputtering of tungsten-nitride surfaces, which are formed as a result of high flux nitrogen bombardment of tungsten [9], were investigated. Furthermore a comparison of sputtering yields under the impact of singly and multiply charged ions at the same impact velocities will be presented and discussed.

3. ACKNOWLEDGEMENT

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* Corresponding author e-mail address: dobes@iap.tuwien.ac.at

Wednesday

SECONDARY ELECTRON YIELD FROM HCI ON AU AND THIN FILMS OF C_{60}

E. Bodewits[1,*], *K Dobes*[2], *F. Aumayr*[2], *and R. Hoekstra*[1]

[1] KVI - Atomic and Molecular Physics, University of Groningen, Zernikelaan 25, 9747 AA Groningen, The Netherlands
[2] Institute of Applied Physics, TU Wien - Vienna University of Technology, A - 1040 Vienna, Austria

Recently we investigated the influence of C_{60} thin films evaporated on Au(111) on the secondary electron yield of highly charged ions (HCI) [1]. It was found that the relative secondary electron yield from C_{60} follows an exponential growth curve as function of the number of monolayers (ML) and saturates at an increase of 35% for 5 ML of C_{60} on Au as shown in figure 1.

Recently the original over-the-barrier model was extended by Lake et al. [2] by the inclusion of a thin dielectric film on top of a metal surface. They showed that a highly charged ion approaching an Al_2O_3 film may perturb the thin film such that throughout the film the bottom of its conduction band drops below the workfunction of the substrate while the barrier between the HCI and the thin film is still that high that over-the-barrier transitions between the film and the HCI are not yet possible. In this way the insulating aluminium oxide film effectively lowers the substrate workfunction by a few eV. The earlier onset of the neutralization and creation of hollow atoms will give more time in front of the surface for the relaxation processes of the hollow atoms. This would lead to an increase in the secondary electron yields.

There might be another cause for the increase in the secondary electron yield too, namely an increase in the escape length of electrons produced below the surface. The thin films of C_{60} have a very open structure, therefore electrons produced in the C_{60} film may have a higher probability of escaping and being detected as compared to electrons produced below a closer packed Au surface.

Here we discuss further experiments concerning the increase in secondary electron yield. In the new series of experiments we investigated how changing the incidence angle and the kinetic energy of the HCI affects the secondary electron yield. Also, experiments with highly ordered pyrolytic graphite (HOPG) have been done for comparison with the C_{60} layers [3].

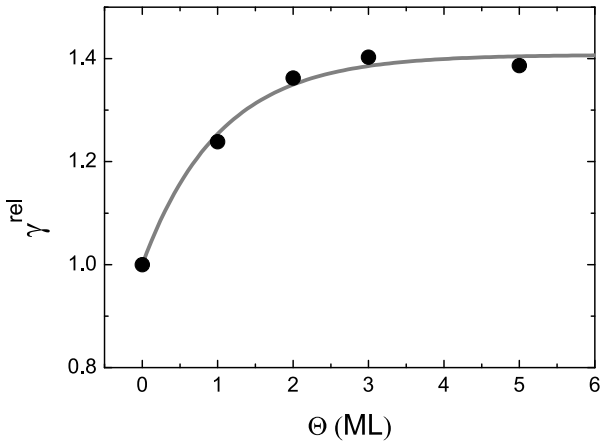

Figure 1: Relative secondary electron yield obtained with 70 keV Xe^{24+} impinging under 40 degree incidence angle as function of C_{60} monolayers compared to clean Au. Also shown is an exponential growth curve.

1. REFERENCES

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*Corresponding author e-mail address: ebodewits@kvi.nl