

FRAGMENTATION OF ADENINE INDUCED BY He^{2+} AND F^{2+}

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The damages of the cellular DNA induced ionizing radiation are not produced by the mere direct impact of the primary high-energy particles, also are caused by secondary species generated by the primary ionizing radiation. Thus, it is important to understand the ionization mechanisms as well as the energy deposition at the molecular level. Several studies involving low energy electrons or protons colliding with DNA or RNA bases have shown that the dissociation of the molecule can occur well below the ionization energy threshold [1]. There are also few studies on fragmentation of biomolecular target or DNA bases induced by slow highly charged ions [2].

An experiment was performed using 30 keV He^{2+} impact on adenine at the new built beamline. Adenine ($\text{C}_5\text{H}_5\text{N}_5$) is one of the DNA bases, whose structure is shown in figure 1. In the experiment the biomolecular ions and its fragment ions produced in collisions were extracted by electric field and then detected by MCP detector in coincidence with scattered projectiles. The ion detecting system has the multi-hit function and records all the charged fragments produced in one collision. A total time-of-flight spectrum is shown in figure 2. The emission of light ions such as H^+ , CNH_2^+ can be identified, and the corresponding peaks are marked in the spectrum. The successive loss of neutral CNH from parent biomolecular ion can also be tracked from the TOF spectrum, namely, the decay chain: $(\text{C}_5\text{N}_5\text{H}_5)^+ \xrightarrow{\text{CNH}} (\text{C}_4\text{N}_4\text{H}_4)^+ \xrightarrow{\text{CNH}} (\text{C}_3\text{N}_3\text{H}_3)^+ \xrightarrow{\text{CNH}} (\text{C}_2\text{N}_2\text{H}_2)^+$. There are also other fragmentation patterns in the spectrum. Presently correlation analysis is being under performance.

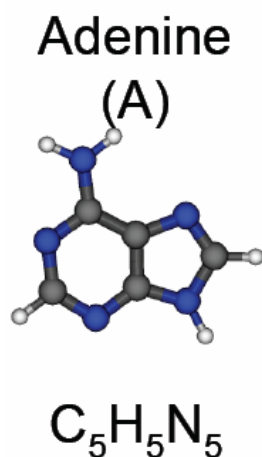


Fig.1 structure of Adenine molecule

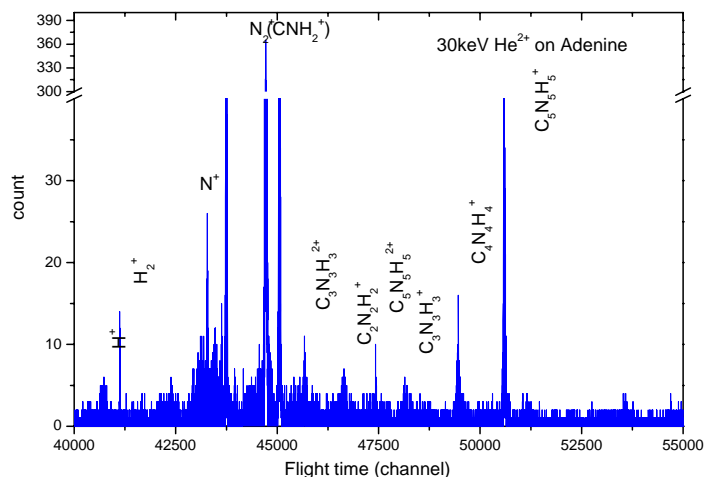


Fig 2. Total TOF spectrum recorded for 30 keV He^{2+} on Adenine

References

- [1] B. Boudaïffa, P. Cloutier, D. Hunting, M. A. Huels, L. Sanche. *Science* **287**(2000), 1658
[2] F Alvarado, S. Bari, R. Hoekstra, and Th Schlathölder. *J. Chem. Phys.* **127**(2007), 034301

Projectile q -dependence of Single, double and multiple ionization and fragmentation of C_{60} under first ion-impact and influence of GDPR

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Ionization and fragmentation studies of C_{60} fullerene provide useful insights about the energy transfer mechanisms in C_{60} -heavy ion collisions. The recoil ion spectra carries finger prints of various energy deposition, excitation and relaxation channels such as swift ionization, evaporation, multi-fragmentation etc. We shall present here our measurements of ionization and fragmentation cross sections of C_{60} in collisions with 3 MeV/u C, F and Si ions. The recoil ions were detected using time of flight technique. We have measured the absolute ionization cross sections of single, double and multiply charged ions of C_{60} . The ionization yields were found to increase linearly as a function of projectile charge state q (as shown earlier in ref [1-6]). The linearity was well reproduced by the GDPR model in case of single and double ionization up to $q \sim 9$ (i.e. for C and F ions). For these ions the triple ionization yields were found to be independent of q . This indicates the prominence of giant excitations in single and double ionization of C_{60} . Then higher charge state ions such as Si^{q+} ($q=6-14$) were used and it was found that single, double and even triple ionization cross sections show almost linear dependence on q (for $q > 9$) and the slopes were closely reproduced by the GDPR model. The behaviour of single ionization was also compared with CDW-EIS model for C-atom, which was modified to include the electron density (only approximately) effects of C_{60} . However, the CDW theory predicts a non-linear dependence of ionization yield on the projectile charge state q .

We have also studied the behaviour of multi-fragmentation ion yields as a function of q . The total multi-fragmentation yield increases linearly with projectile q , where as the fragmentation to total-recoil-ion yield ratio saturates at high- q of projectile. This can be understood in terms of equilibration of energy partitioning between nuclear and electronic degrees of freedom. The fragment ion mass distribution is usually modeled as power law of the type $\sim n^{-\lambda}$ (n =no. of atoms in a fragment) Different values of λ have been quoted in literature for different systems. We observe that the value of λ varies from 0.8 for low charge state projectiles to 2 for high q_p projectiles. The values of λ are often related to the amount of energy loss to the system. The odd-even oscillations in the fragmentation mass distribution are well known for C_{60} and have been observed earlier. We have also compared the over all mass distribution of C_{60} recoil ions with a parameterized bond percolation model. The model was found to fit well to data for different q by suitable adjustment of the bond breaking probability parameter. Details of the experiment and discussion of various results will be presented.

References

- [1] U. Kadhane et al. Phys. Rev. Lett. **90**, 093401 (2003)
- [2] U. Kadhane et al. Phys. Rev. A **75**, 041201 (R) (2007)
- [3] A. H. Kelkar et al. J. Phys. B **40**, 2481 (2007)
- [4] A. H. Kelkar et al. Nucl. Instrum. Meth. Phys. Res. B **256** 114 (1007)
- [5] A. H. Kelkar et al. J. Phys. Conf. Ser. **80**, 012009 (2007)
- [6] A. H. Kelkar et al. J. Phys. Conf. Ser. **80**, 012010 (2007)

MULTIPLY CHARGED IONS WITHIN A FULLERENE CAGE: PHOTOIONIZATION OF $\text{Ce}@C_{82}^+$

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The concept of an atom residing inside a ball shaped C_n molecule fascinates both chemists and physicists. Due to the high electron affinity of the carbon sphere, encapsulated metal atoms typically donate electrons to the fullerene cage to stabilize the endohedral complex. A Ce atom within a C_{82} sphere, for example, is expected to be triply charged, so that the whole endohedral fullerene can be described as $\text{Ce}^{3+}@C_{82}^{3-}$.

With the goal to investigate possible differences in the behaviour of free and of caged atomic ions exposed to ultraviolet radiation, photoionization of $\text{Ce}@C_{82}^+$, C_{82}^+ and of atomic Ce^{q+} ions ($q = 2, 3, 4$) were conducted using the merged-beams technique with monochromatized synchrotron radiation. Significant redistribution of oscillator strengths associated with excitation of the Ce 4d-shell could be observed when switching from free atomic Ce ions to their caged counterparts. The Ce 4d contribution to photo double ionization $\text{Ce}@C_{82}^+$ at around 125 eV is clearly seen in Fig.1.

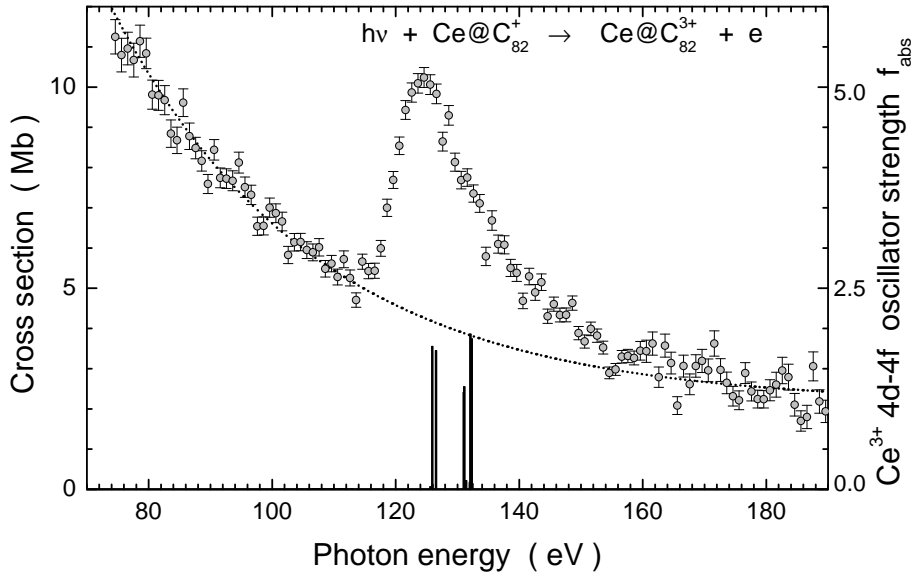


Figure 1: Experimental cross sections (circles with statistical error bars) for double ionization of $\text{Ce}@C_{82}^+$ ions by monochromatized VUV photons. The dotted line is a fit to the "background" below the Ce 4d contribution. The vertical bars correspond to the scale on the right and show the distribution of oscillator strengths for absorption by 4d-4f transitions in Ce^{3+} , calculated by using the Los Alamos Atomic Physics Codes Package.

ABSOLUTE CHARGE TRANSFER AND FRAGMENTATION CROSS SECTIONS IN He^{2+} - C_{60} COLLISIONS

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We consider the collision of $^4\text{He}^{2+}$ ions with C_{60} in the region of impact energies 0.1-250 keV, in which charge transfer is the dominant process and the resulting neutral, singly and doubly charged C_{60} preferentially decays by emission of neutral C_2 molecules [1-3]. At these impact energies, all electronic processes (electron capture, ionization, excitation) are much faster than fragmentation [4]. Thus, fragmentation can be considered as a postcollisional process in which the energy deposited by the collision in C_{60} is transferred to the nuclear (dissociative) degrees of freedom. Therefore, the mass spectrum associated with charge transfer in ion- C_{60} collisions is determined by two parameters: (i) the charge transfer cross sections σ_{CT} and (ii) the collision energy deposit E_{dep} . The former determines the proportion of the different C_{60}^{q+} ions produced in the collision and the latter the ensuing fragmentation. Both quantities are not easy to determine either theoretically or experimentally. This is due to the large number of active electrons and nuclear degrees of freedom involved, which implies the detection in coincidence of many particles and makes fully quantum dynamical theoretical approaches unfeasible.

In this work [5] we report on absolute measurements and theoretical calculations of charge transfer cross sections in $\text{He}^{2+} + \text{C}_{60}$ collisions at low impact energies. The experimental and theoretical cross sections are in reasonable agreement with each other, thus reinforcing the quantitative value of our predictions. The measurements cover a wide range of impact energy (3-250 keV) and make use of multicoincidence techniques to separate the different fragmentation channels. The theory explains the various charge transfer mechanisms and provides the energy deposit that eventually leads to fragmentation. We have found that the cross sections for the formation of He^+ and He^0 are comparable in magnitude, which cannot be explained by the sole contribution of pure single and double electron capture but also by contribution of transfer-ionization processes that are important even at low impact energies. The results show that multifragmentation is only important at impact energies larger than 40 keV; at lower energies, sequential C_2 evaporation is the dominant process.

- [1] S. Martin, L. Chen, A. Denis, R. Bredy, J. Bernard, and J. Desesquelles, *Phys. Rev. A* **62**, 022707 (2000)
- [2] S. Matt, R. Parajuli, A. Stamatovic, P. Scheier, T. D. Märk, J. Laskin, and C. Lifshitz, *Eur. Mass Spectrom.* **5**, 477 (1999)
- [3] L. Chen, S. Martin, J. Bernard, and R. Brédy, *Phys. Rev. Lett.* **98**, 193401 (2007)
- [4] C. Bréchnac, P. Cahuzac, B. Concina, J. Leygnier, L. F. Ruiz, B. Zarour, P.-A. Hervieux, J. Hanssen, M. F. Politis, and F. Martín, *Phys. Rev. Lett.* **89**, 183402 (2002)
- [5] A. Rentenier et al, *Phys. Rev. Lett.* **100**, 183401 (2008)

POTENTIAL AND KINETIC SPUTTERING OF MOLECULAR FRAGMENTS FROM ALKANETHIOLS-SAMs DUE TO HCI IMPACT

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Self-assembled monolayers (SAMs) are ordered molecular assemblies formed by the adsorption of an active surfactant on a solid surface. SAMs provide a convenient, flexible, and simple system with which to tailor the interfacial properties of metal, metal oxides and semiconductors [1]. The alkanethiols are one kind of molecules used to build SAMs. These molecules are constituted by the ligand group (sulfur), the alkane chain $(CH_2)_n$ and the terminal functional group (X), see figure 1.

In this work, we employ HCI to study the desorption of positive molecular fragments from two different alkanethiol SAMs on gold surfaces: MUA and DDT, $X = COOH$ and CH_3 respectively. The SAMs are bombarded with pulsed Ar^{q+} beam ($5 < q < 9$) with kinetic energies 5-20keV. The desorbed positive molecular ions were detected and analyzed from TOF spectra, from which the masses and yields of secondary ions were obtained [2]. A complementary scanning tunneling microscopy study has also been performed with HCI on identical SAM surfaces [3].

For both surfaces the mass spectra are proton peak dominated and the intensity is larger in MUA compared to DDT. In principle the protons come from the terminal groups due to their exposed positions which make them vulnerable to being ejected, but there is also possibly a contribution from the alkane chain. Molecular ions from the chain and terminal group plus chain fragments are also observed. Additionally, both spectra show a similar peak distribution due to the chain. The molecular peaks (e.g. $(CH_2)_n^+$) decrease monotonically with increasing cluster size from $n=3$. It is found that peak yields for heavier mass fragments are largely independent of the charge state of incident ions.

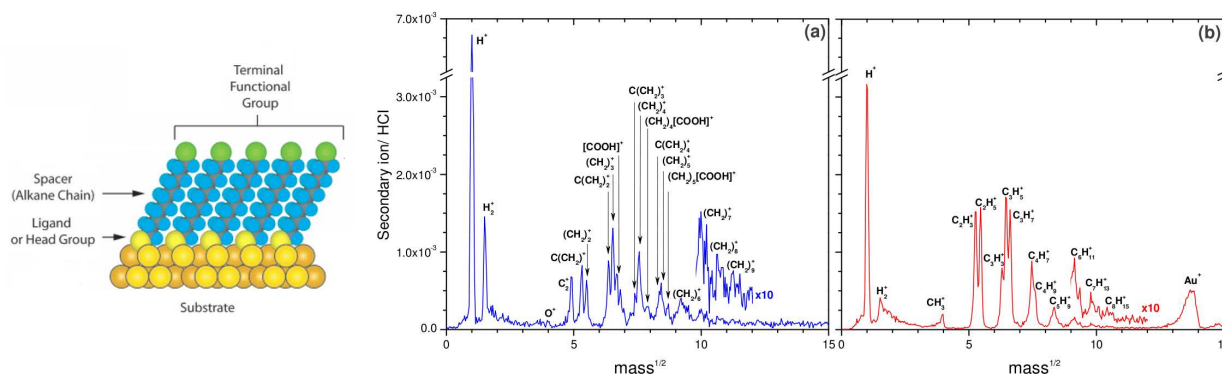


Figure 1: Left: Scheme of Alkanethiol-SAMs, from Love et al. [1]. Right: Mass spectra of secondary molecular ions emitted from SAMs surfaces (a) MUA and (b) DDT irradiated with Ar^{9+} at 18keV.

References

- [1] Ulman, Chem. Rev. **96** (1996) 1533; Love et al., Chem. Rev. **105** (2005) 1103.
- [2] Hamza et al., J. Vac. Sci. Technol. **A17** (1999) 303; Schenkel et al., Phys. Scrip. **T80** (1999) 73.
- [3] O'Rourke et al., these proceedings.

Guiding of Argon ions through PET nano capillary foils

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The transmission of charge state separated slow argon ions through nano capillaries with an aspect ratio of 1/100 in insulating polyethylene terephthalate (PET) polymers was investigated on argon ions with different charge states from Ar^{1+} up to Ar^{16+} . A beam of slow argon ions was extracted from an ion source of the Dresden EBIS-A type [1]. The experiments were performed with a beam line featuring an ion deceleration system [2]. With it the ion guiding of projectiles of different kinetic ranging from 600eV up to 9.6 keV has been studied.

For tilted capillaries, the ions are guided along the capillary axis, as shown for several ions in previous experiments [3]. In the following the guiding power as defined in [4] as well as the divergence angle of the transmitted ion beam have been studied in dependence on the initial ion charge state and the ion energy for Argon ions.

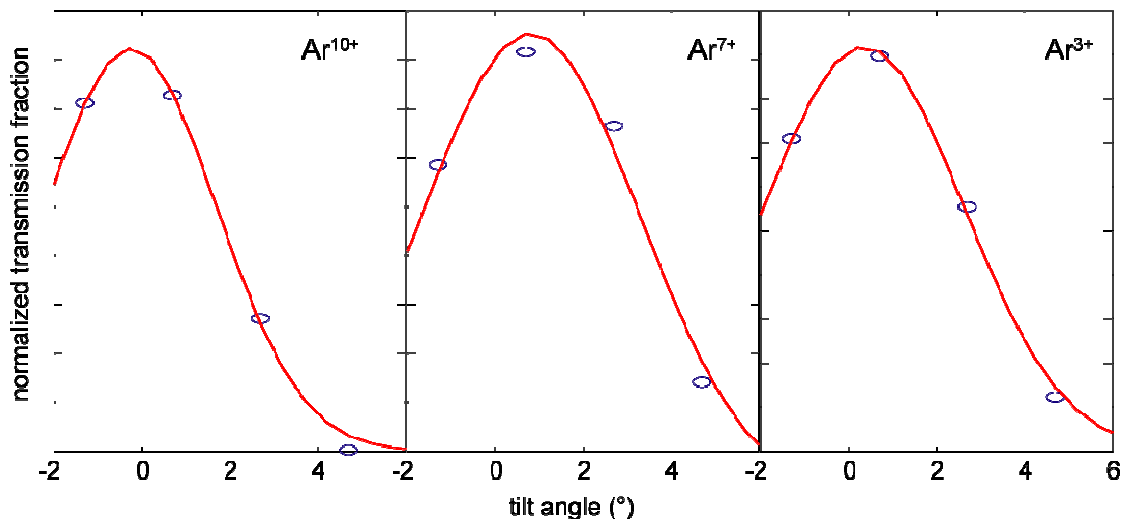


Figure 1: The measured (blue circle) and fitted (red line) transmission of Argon ions in dependence on the tilt angle of the capillary foil at a kinetic energy of q times 600 eV is shown. The guiding power is 2.7 ± 0.5 for Ar^{10+} , 3.5 ± 0.5 for Ar^{7+} and 3.2 ± 0.5 for Ar^{3+} .

The guiding power and the divergence angle of the transmitted ion beam were measured in dependence on the charge state at a constant deceleration voltage. Both values are independent on the charge state as shown in Figure 1. An increasing guiding power with increasing charge state at a constant ion energy is expected.

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References

[1] <http://www.dreebit.com>

[2] F. Grossmann, e.a.; Nuclear Instruments and Methods in Physics Research, **B256**, 565 (2007)

[3] Allen, F. I., e.a; Nucl. Instrum. Methods Phys. Res. B **244**, 323-326 (2006)

[4] R. Hellhammer, e.a.; Nucl. Instrum. Methods Phys. Res. B **258**, 159 (2007)

ION DESORPTION FROM SOLID RARE GASES BY SINGLY- AND MULTIPLY-CHARGED ION IMPACT

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Over the past few decades, a considerable number of studies has been conducted to the interaction of slow multiply charged ions (MCIs) with a solid target [1]. Because the MCI internal energy (sum of the ionization potential) can be consumed in the target surface, desorption mechanism for certain target shows strong dependence on the charge state of the projectile. However, little is known about the effect of MCI impact for condensed gas targets. In this work, we will discuss the internal energy contribution to ion desorption from the rare gas solids, on the basis of measurements of the mass spectrum and the kinetic energy distribution of the desorbed ions by singly- and highly-charged ion impact.

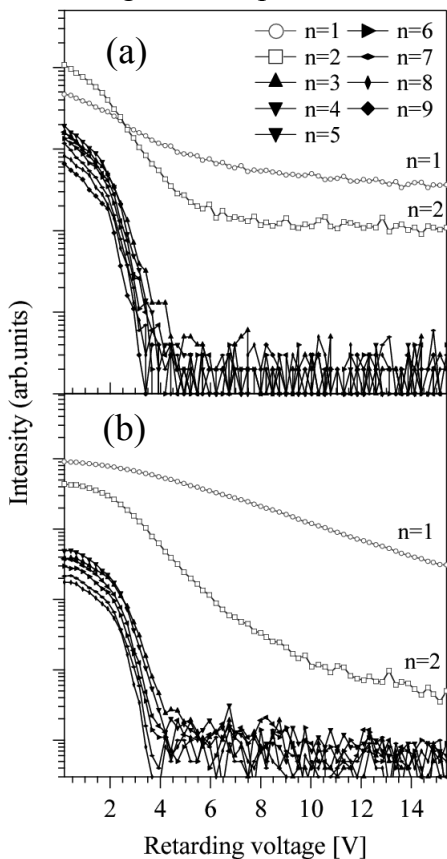


Figure 2. Retardation plots of desorbed Ne_n^+ ($n=1-10$) from solid Ne (500ML) by (a) Ar^+ impact and (b) Ar^{6+} impact.

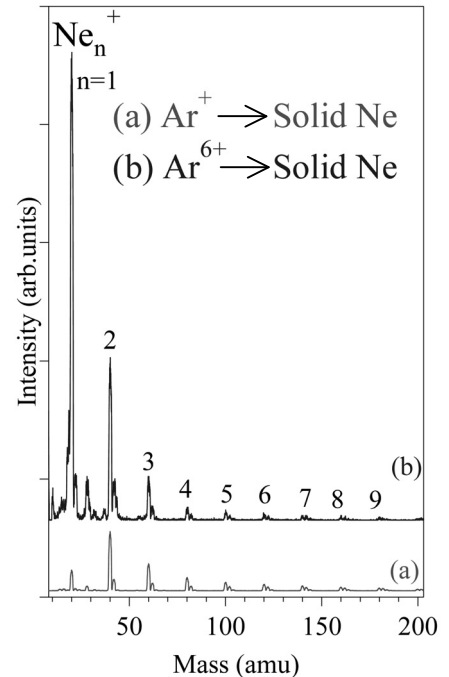


Figure 1. Mass spectra of desorbed ions from solid Ne (500ML) by (a) Ar^+ impact and (b) Ar^{6+} impact.

Mass spectrum of desorbed ions from solid Ne by 1.0 keV Ar^+ impact is shown in Fig. 1(a). The ions desorbed surface were detected by a quadrupole mass spectrometer (QMS). The peaks of Ne^+ and the cluster ions, Ne_n^+ , with a cluster size n from 2 to 19 were observed. The largest cluster size was limited by the range of QMS. We also measured the mass spectrum by 1.0 keV Ar^{6+} impact (Fig. 1(b)). Compared with singly charged ion impact, the desorbed Ne_n^+ ($n=1,2$) intensities were increased.

Kinetic energy distribution of the desorbed ions was analyzed by placing a retarding field analyzer of a 4-grid type in front of the entrance of QMS. Retardation plots of desorbed Ne_n^+ ($n=1-9$) from the surface of the solid Ne impacted by (a) Ar^+ and (b) Ar^{6+} are shown in fig. 2. The results indicated that the energy distributions of Ne_n^+ ($n=1,2$) strongly depend on the charge state of the projectile. We suggest that the effect of MCI impact contributes most to desorption of Ne^+ and small cluster ions.

References

[1] F. Aumayr, and HP. Winter, Phil. Trans. Roy. Soc. Lond. A **362**, 77 (2004), and references therein

Formation of Nano Pits on the KBr (001) Surface Induced by Single Impact of Slow Highly Charged Ions

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In recent years investigations of the potential energy dissipation of slow highly charged ions (HCI) on solid surfaces have brought out many new interesting phenomena, e.g. hollow atom formation, enhanced sputter yields, and potential electron emission [1].

The rapid release of the potential energy of a HCI produces a highly excited electronic system in the surface comparable to the excitation by high power ultra-short laser pulses or swift heavy ions [2]. This far from equilibrium state is known to induce various changes in the topography of insulating surfaces on a nanometer scale. Hence, HCIs are considered to be a promising tool for nano structuring and analysis [3]. However, the underlying detailed microscopic mechanisms, especially on atomically flat surfaces, are less investigated so far.

Therefore, we have studied the interaction of slow (300 eV/amu) highly charged Xe ions with the KBr (001) surface. The individual impact of such projectiles induces nanometer size pit-like structures on the surface. Thereby, the pit formation ability and the pit volume are found to depend strongly on the projectiles initial charge state and their kinetic energy. From complementary high fluence irradiations evidence is found that the pit formation is associated with the agglomeration of electronic defects induced by the potential energy dissipation into complex centers (X-centers).

References

- [1] F. Aumayr, P. Varga, and H. P. Winter, Int. J. Mass Spec. 192, 415 (1999)
- [2] E. Akcoltekin et al., Nature Nanotechnology 2, 290 (2007)
- [3] F. Aumayr, and H. P. Winter, e-J. Surf. Sci. Nanotech. 1, 171 (2003)

X-RAY EMISSION IN THE INTERACTION OF SLOW H-LIKE IONS WITH A METAL SURFACE

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We measured x-ray spectra to study the hollow atom below the surface in the interaction of H-like ions with the metal surface by the coincidence measurement with secondary electrons emitted. We will present the measurement of the x-ray spectra and the x-ray yields. It is found that the x-ray yields of the K shell for the hollow atom become larger than the atom. The x-ray yields represent the filling probability of a vacancy in the K shells being filled by x-ray transitions in competition with Auger processes for the K shell hole. Since the filling probability through Auger transition straightforwardly with the number of spectator electrons, x-ray yields would increase with decreasing the number of the spectator electrons in outer shell. By the measurement of K x-ray fluorescence yields we will discuss the deexcitation of the hollow atom below the surface. Figure 1 shows a typical x-ray spectrum from the hollow atom. The projectile is H-like I^{52+} ions and the target is cobalt.

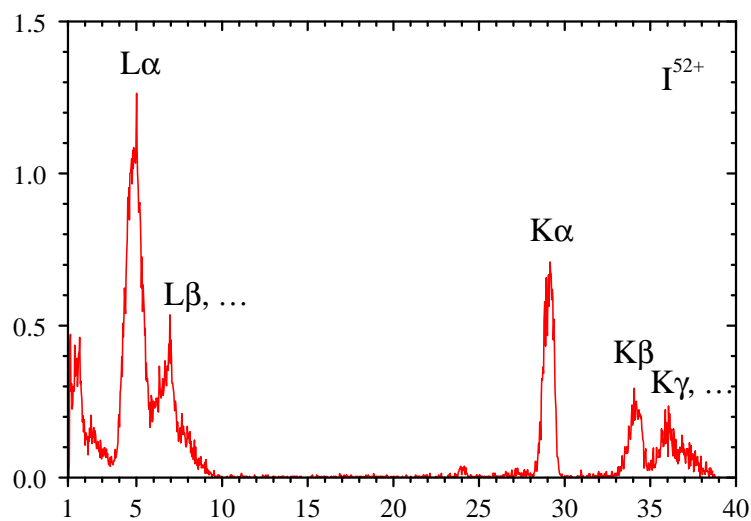


Figure 1: X-ray spectrum for collisions of H-like I^{52+} ions with a Co surface.

GUIDING OF SLOW HIGHLY CHARGED IONS THROUGH A THIN GAP BETWEEN A PAIR OF PARALLEL GLASS PLATES

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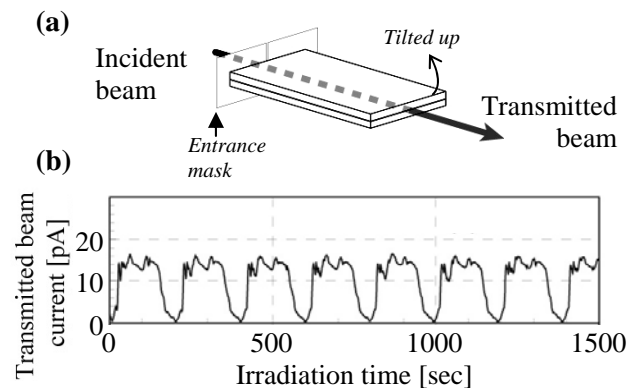
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Interaction of slow highly charged ions (HCI) with insulator multi-capillaries has recently been intensively studied experimentally as well as theoretically. One of the most prominent features is a so-called guiding effect, a transportation of slow HCIs along the capillary axis keeping their initial charge states even when the capillary axis was tilted against the beam direction. The fact that most of the guided ions keep their initial charge suggests that the ions do not touch the inner wall of the capillaries during transportation, i.e., an amazingly well-tuned electric field is automatically formed in each capillary. In other words, a self-organized charge-up of the inner wall plays an important role in realizing the guiding effect. We have developed a method to produce a micro-/nano-sized HCI beam with a tapered single glass capillary based on the guiding effect [1-3]. The glass capillary has a possibility to realize modification in a small area on the surface, micropatterning of nanodots and element-sensitive microscopy using HCI beams.

In order to provide a nanobeam as a tool using the glass capillary, stability of the transmission is required. The stability is expected to be sensitive to the balance between the charge-up and the discharge on the inner wall. We have employed a thin gap between a pair of parallel glass plates, which is easy to understand the irradiated position on the inner wall (Fig. (a)).

The transmitted beam currents through the gap (0.1 mm) were measured for several incident currents of 104 keV Ar⁸⁺ beams. Figure (b) shows the transmitted beam current as a function of the irradiation time and a repetition with precise structure. The incident beam was stable and monitored to be 5.9 nA at the entrance mask. When the incident current was varied, the frequency of the repetition changed. The frequency of the repetition was well-proportional to the incident currents ranging from 4 to 15 nA. It means that the reconstruction and the decay of the charge-up on insulator surface can be well-arranged. We will report the incident current dependence of the frequency and a model describing the glass surface conductivity based on the strength of the charge on the surface.



References

- [1] T. Ikeda, et al., Appl. Phys. Lett. **89**, 163502 (2006)
- [2] T. Ikeda, et al., J. Phys. Conf. Ser. **58**, 68 (2007)
- [3] T. Ikeda, et al., J. Phys. Conf. Ser. **88**, 012031 (2007)

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COLLISIONS OF IONS WITH INSULATING SURFACES: CHARGING AND DISCHARGING DYNAMICS.

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Guiding and focussing of keV to MeV ions by insulator micro-capillaries offers exciting perspectives for the production of low divergence micro-sized beams and a fine spatial control over the irradiated zone. Such high quality beams may find applications in surface nano- structuring. A spectacular demonstration of the effective use of a tapered capillary is the direct injection of ions inside a living cell [1]. The guiding effect results from the local charging of the capillary inner wall, so this effect depends only on the charging dynamics of the insulating material.

Finding the best material for these applications requires that the charge induced processes are well understood. For that purpose, we have studied the dynamical behaviour of charge deposition and beam deflection on well defined planar geometry where the exact number of charges left on the surface as well as the time dependant beam deflection can be monitored. Depending on surface composition, temperature and structure, discharging time constant vary by orders of magnitude giving rise to different characteristic behaviour.

We have also performed numerical simulations that, besides giving access to the field distribution above the surface plane, point to the importance of the intensity distribution within the incident beam.

[1] Y. Iwai, T. Ikeda, TM. Kojima, et al., App. Phys. Lett. **92** , 023509 (2008)

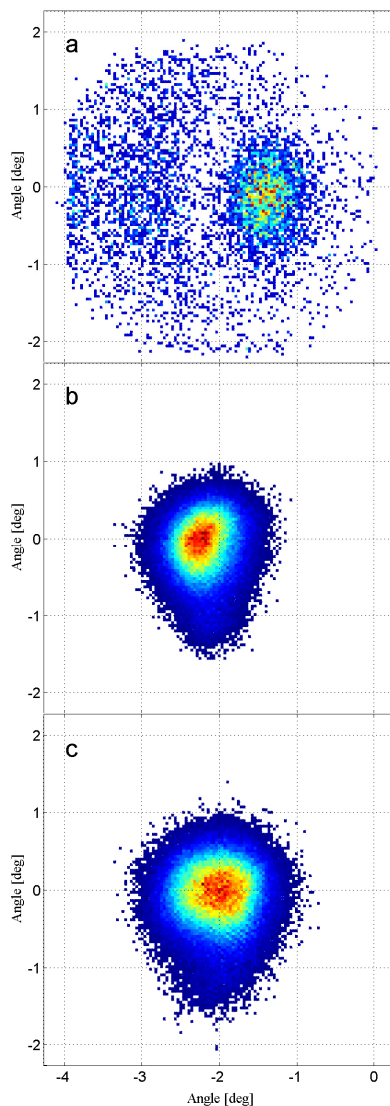
CHARGE-UP DYNAMICS IN GUIDING SLOW HIGHLY CHARGED IONS THROUGH NANO-CAPILLARIES

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Experiments have shown that Slow Highly-Charged Ions (HCI) are transmitted, without change of their charge, through insulating nano-capillaries even when the capillary membranes are tilted by angles much larger than the angle given by the aspect ratio, i.e. the ions are guided, when the capillary membrane is not geometrically open to the incident ion-beam [1-3]. This is explained by charge patches, deposited in a self-arranged pattern, on the inside of the capillary walls [1-5].



We have studied the time dependence of charge-up by two-dimensional distribution of 7 keV Ne^{7+} -ions guided through SiO_2 -capillaries. The transmitted ion angular distributions after different amounts of incident charge deposited on the membrane at tilt angle -2° during charging-up of the capillaries are shown in Fig. 1. The ions start to be seen at -1.4° (top) after 21 nC, the centroid moves to the left to -2.2° after 105 nC (middle), and the steady state is reached at -2° (bottom) after 356 nC. This is interpreted by successive build-up of three charge patches that guide the ions on zig-zag trajectories through the capillaries. The angular distributions are broadened with forming further charge patches and the amount of deposited charge in the charge patch at the capillary exit.

Fig. 1.

Two-dimensional images of the transmitted Ne^{7+} -ion distributions after different amounts of incident charge on the membrane during charging-up of the SiO_2 capillaries. top: after 21 nC, middle: after 105 nC, bottom: after 356 nC.

References

- [1] N. Stolterfoht *et al.* Phys. Rev. Lett., **88** 133201 (2002)
- [2] G. Vikor *et al.*, NIM B 233, 218 (2005)
- [3] M. B. Sahana *et al.* Phys. Rev. A **73**, 040901 (2006)
- [4] P. Skog *et al.*, NIM B 258 (1), 145-149, (2007)
- [5] K. Schiessl *et al.* Phys. Rev. A **72**, 062902 (2005).
- [6] R. T. R. Kumar *et al.* Nanotechnology **16** 1697–1700 (2005).

Investigation on a Nano-Structure on a Hydrogen-Terminated Si Surface Induced by Individual HCI impacts

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We have investigated properties of the interaction of slow highly charged ions (HCI) with a hydrogen terminated Si (Si-H) surface. Iodine HCIs (I^{q+}) having high q (up to naked ion, i.e., $q=53$) were produced in the Tokyo-EBIT and were incident onto a Si-H surface. During irradiation, emission yields for various kinds of secondary particles (e.g., secondary ions, photons, and so on) were measured with a coincidence technique. After irradiation, furthermore, a HCI-irradiated Si-H surface was observed by a scanning tunnelling microscope (STM). Figure 1 shows a typical STM image of a Si(100)-(2×1)-H surface induced by a I^{50+} impact. The sample was exposed to oxygen gas (partial pressure: $\sim 1 \times 10^6$ Pa, base pressure: 1×10^8 Pa) during irradiation (irradiation time: ~ 2 hours). We can note that a nano-structure indicated by a white arrow is at around the centre in addition to the atomic structure of the Si-H surface. We consider that the impact site includes Si-O bonds formed by a surface-chemical reaction that O atoms are attached to dangling bonds created after removing a large amount of hydrogen atoms by “potential sputtering”. We will discuss the physical and chemical properties of the structures.

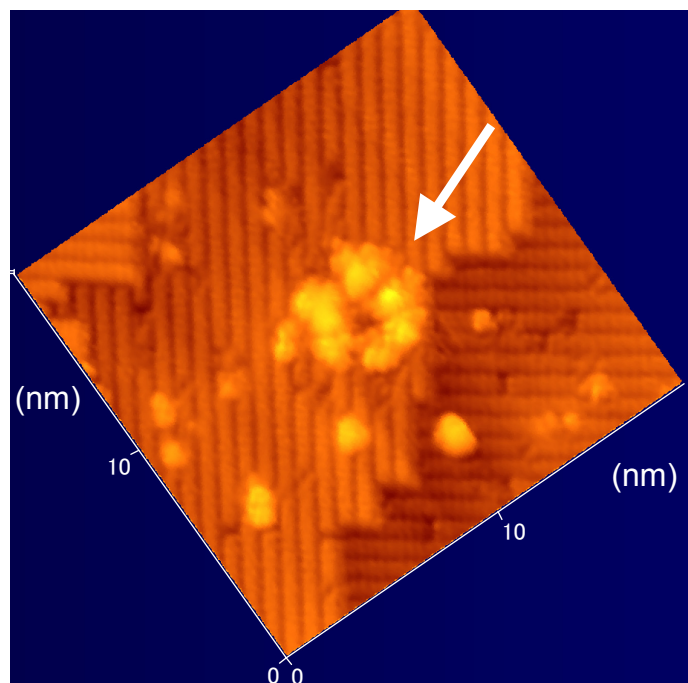


Figure 1. Nano-structure on Si-H surface induced by a I^{50+} HCI impact.

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GUIDING EFFECT OF MEDIATE AND LOW ENERGY ELECTRON-BEAM BY QUARTZ TUBE

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The study on interaction between charged particle and capillary has attracted lots of attention during these few years, especially after the guiding phenom of HCI through multi-channel PET capillary was reported by N. Stolterfoht *et. al.*[1] in 2002. After that, a serious of experimental and theoretical research had been done for investigating this guiding effect in more details. To the best of our knowledge, so far, all of the researches in or related to this area were focused on using weak beam current and micro-sized capillary. In this works, we investigated the guiding effect of low energy electron beam with strong beam current by a cylindrical bended macro-sized quart tube.

Electron beam was injected into a quart tube with 15° bended angle, its inner and outer diameter are 2.3mm and 4.5mm respectively. To overcome the limitation that PSD can not work under strong beam intensity, a position sensitive faraday cup was developed and used to detect the electron beam transmitted through the quartz tube, and the distribution of transmitted beam current on each channel of the Faraday cup was acquired. The faraday including sixteen channels, each one of them is 2.3mm width and 1.5mm high.

We found that, similar to those cases of micro-sized capillary, guiding effect also exist on the process of interaction between electron beam and macro-sized insulator tube which was also due to the self-organized charge-up effect above the inner wall of the insulator tube. The incident electrons can not pass through along the axis of the quart tube with 15° angle, while the self-organized charged-effect above the inner of the quart tube stop these electrons from hitting on the inner wall directly and “guided” them to transmit through the quart tube (see fig1). While compared to previous works, the result of our experiment indicated a fact that the guiding ability of the tube is proportion to the incident beam intensity, which, did not yet reported so far. We conclude that this was due to the impact generated by the big area of the inner wall of the insulator tube.

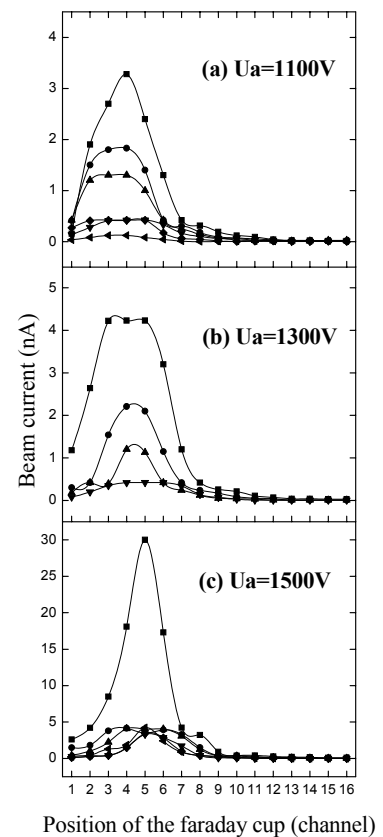


Fig 1. Distribution of beam current

References

- [1] N. Stolterfoht, J. H. Bremer, R. Hoffmann, et al. Phys. Rev. Lett. **88**, 133201 (2002).

DYNAMIC FEATURES OF BEAM GUIDING BY INSULATOR CAPILLARIES: INCIDENT ENERGY DEPENDENCE

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The electric property of insulator surfaces can be used to guide slow ions along the axis of an insulator capillary.[1, 2] Qualitatively, this guiding process can be explained as the deflection of ions by charge patches produced on the capillary surface by the preceding ion-surface collisions.[1, 3] Here, we present experimental results indicating the relationship between the growth of the charge patches and the dynamic behavior of the guided ions.

Experiments were carried out at RIKEN with 3.5 -7 keV Ne⁷⁺ ions from a 14.5 GHz ECR ion source. [4, 5] A polyethylene terephthalate (PET) foil was attached to the target holder and rotated. The PET foil included capillaries with a length of 10 μm and a diameter of 200 nm. The capillary density was 4 × 10⁶ capillaries/cm². A two-dimensional position-sensitive detector (PSD) was used to measure the transmitted ions.

Results for 3.5 - 7 keV Ne⁷⁺ are shown in Fig. 1. The PET capillary was tilted by 2.8° with respect to the beam direction. The transmitted intensities and deflection angles of the beams were plotted as functions of the charge deposited at the foil surface. The deflection angles changed along the tilt direction in accordance with the intensity evolution. Although this behavior seems to be a general feature for the beam guiding effect [4, 5, 6, 7], a detailed study has not been done.

The increase in deflection angle with the intensity evolution in Fig. 1 may be attributed to the growth of a charge patch at the entrance region of the capillary. Moreover, the decrease in deflection angle after the maximum in Figs. 1 (a) and (b) may be attributed to the growth of another charge patch in the capillary. It is noted that this oscillatory behaviour of the deflection angle along the tilt direction was clearly observed at low energies of 3.5 and 4.9 keV, and was not clear at 7 keV, as shown in Fig. 1.

References

- [1] N. Stolterfoht *et al.*, Phys. Rev. Lett. **88**, 133201 (2002).
- [2] T. Ikeda *et al.*, Appl. Phys. Lett. **89**, 163502 (2006).
- [3] K. Schiessl *et al.*, Phys. Rev. A **72**, 062902 (2005).
- [4] Y. Kanai *et al.*, NIM B **258**, 155 (2007).
- [5] N. Stolterfoht *et al.*, Phys. Rev. A **76**, 022712 (2007).
- [6] N. Stolterfoht *et al.*, NIM B **225**, 169 (2004).
- [7] M. Fürsätz *et al.*, J. Phys. Conf. Series **58**, 319 (2007).

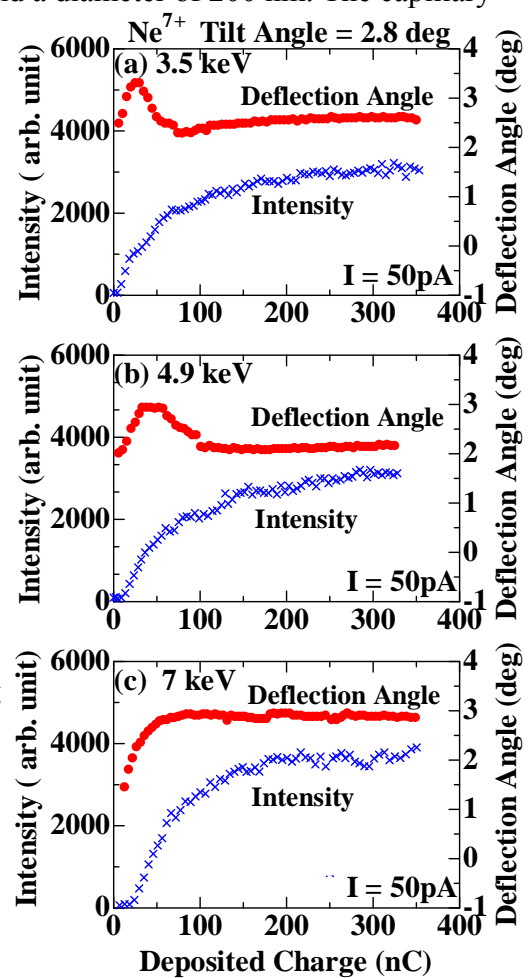


Fig. 1 Deflection angle and intensity evolution of transmitted, 3.5, 4.9, and 7 keV Ne⁷⁺ ions as functions of charge deposited at PET foil. The deflection angle was deduced from the peak position at the PSD

ION GUIDING THROUGH NANOCAPILLARIES IN PET POLYMERS WITH VARIABLE DIAMETER

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Recent studies [1] reported on guided ion transmission through capillaries in insulating polyethylene terephthalate (PET) polymers, i. e. the main fraction of ions is transmitted through the capillary in its incident charge state. The guiding phenomena can be understood by the charge deposition of the incident ions at the inner wall of the capillaries in a self-organizing manner. For a tilted foil the deposited charge in the entrance region increases until the electrostatic field is sufficiently high for a deflection of the ions towards the direction of the capillary exit. Due to the increasing interest in this subject, several laboratories have started investigations of capillary guiding [2-6].

In this work we performed measurements using the apparatus available at the ECR beam line of KVI in Groningen. We studied capillaries with diameters of 100, 200, 300, and 400 nm as shown in Figure 1.. The capillary density of $4 \times 10^6 \text{ cm}^{-2}$ and the projectile was 3 -keV Ne^{7+} . The tilt angle of the capillaries was varied from 0° to 11° . The tilt angle dependence of the total ion yield I can be fitted by a Gaussian function (Fig. 1).

The Gaussian fit allows for the determination of the *guiding angle* ψ_c , for which the intensity of the transmission profiles drops as $I(\psi_c)/I(0) = 1/e$. The guiding angle is a measure for the guiding power, which represents the capability of the capillaries to guide the ions. From the width of the Gaussian functions (Fig. 1) we determined the guiding angle for 100, 200, 300, and 400 nm capillaries. The guiding angle was found to vary within a relatively small range of $5^\circ - 6^\circ$ (in disagreement with previous preliminary studies [7]). From the new observation we conclude that the field in the entrance region is similar for all capillary diameters studied. This conclusion is unexpected, since the geometry of the capillaries changes considerably with varying diameter. The results are interpreted in terms of model calculations

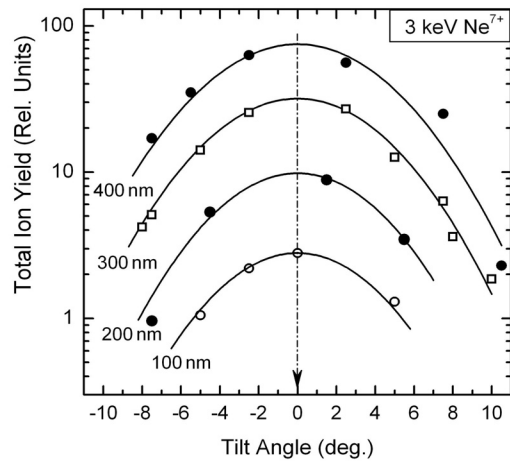


Figure 1: Total intensity of the emission profiles as a function of the tilt angle for different diameters of the capillaries. The solid lines are Gaussian fits.

REFERENCES

- [1] N. Stolterfoht *et al.*, Phys. Rev. Lett., **88**, 133201 (2002), Phys. Rev. A **76**, 022712 (2007), *ibid* **77**, 032905 (2008), and references therein
- [2] K. Schiessl *et al.*, Nucl. Instrum. Methods **232**, 228 (2005) and Phys. Rev. A, **72**, 062902 (2005).
- [3] M. B. Sahana, *et al.*, Phys. Rev. A **73**, 040901(R) (2006).
- [4] S. Mátéfi-Tempfli, *et al.*, Nanotechnology, **17**, 1 (2006).
- [5] A. R. Milosavljević *et al.*, Phys. Rev. A **75**, 030901(R) (2007)
- [6] S. Das *et al.*, Phys. Rev. A, **76**, 042716 (2007).
- [7] N. Stolterfoht *et al.*, Surface and Coating Technology **196**, 389 (2005)

COMPUTATION OF DOSE DISTRIBUTIONS FOR HEAVY CHARGED PARTICLES IN THERAPUTIC APPLICATIONS

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Proton and carbon ion tracks in muscle tissue were determined using the Monte Carlo method employed in Ref. [1]. The lateral dose distributions in the Bragg peak and the isodose curves were computed for a point-like beam as well as a pencil beam of protons and carbon ions in radiation therapy. Total dose deposited in the tissue were also obtained, and comparisons were made with the experimental values reported in the literature [2]. The computer program written for this purpose is able to analyze some problems in heavy charged particle therapy.

References

- [1] H. Noshad, N. Givechi, Rad. Meas. **39**, 521 (2005).
- [2] M. Goitein, R. Gentry, A. M. Koehler, J. Radiat. Oncol. Biol. Phys. **9**, 259 (1983).

SELECTIVE FORMATION OF MULTIPLY EXCITED STATES BY RESONANT COHERENT EXCITATION

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Multiply excited states attract great interests for the test of theories involving the strong electron correlations. Especially, investigation of triply excited Li or Li-like ions has progressed significantly in recent years. However, the triply excited Li-like system of heavier ions can be formed only by the atomic collisional processes such as electron capture to the outer shell since the synchrotron radiation is not applicable. Here we demonstrate a novel method for the formation of selective multiply-excited states of heavy ions.

We utilized three-dimensional resonant coherent excitation (3D-RCE) [1] of energetic heavy ions in a crystal, in which the traveling ions are resonantly excited through the interaction with the periodic crystal fields. With the use of ions at relativistic velocity, the available transition energy of RCE rises up to the x-ray region which enables us to excite the inner shell electron of highly-charged heavy ions. Since the oscillating field consists of numerous frequency components, the double resonance of RCE can be realized by adopting two of them simultaneously to the resonance.

We excited the two $1s$ -electrons of He-like Ar^{16+} and Li-like Ar^{15+} into the $n = 2$ orbitals by successive 3D-RCEs of different harmonics. The energy diagrams are shown in Fig. 1(a) and (b). The double resonance conditions are satisfied by independently adjusting two rotating angles of the thin Si crystal keeping the ion velocity constant, which is a significant advantage over the previous 2D-RCE method [2]. The experiment was performed at the heavy ion medical accelerator in Chiba (HIMAC) with the $\sim 400\text{MeV/u}$

ions. We observed the charge state distribution of the ions emerging from the crystal together with the emitted x-ray yields and their polarization. In both cases, our result provided clear evidence that the multiply excited states are formed in the crystal.

References

[1] C. Kondo *et al.* Phys. Rev. Lett. **97**, 135503 (2006)

[2] Y. Nakano *et al.* J. Phys. Conf. Ser. **58**, 359 (2007)

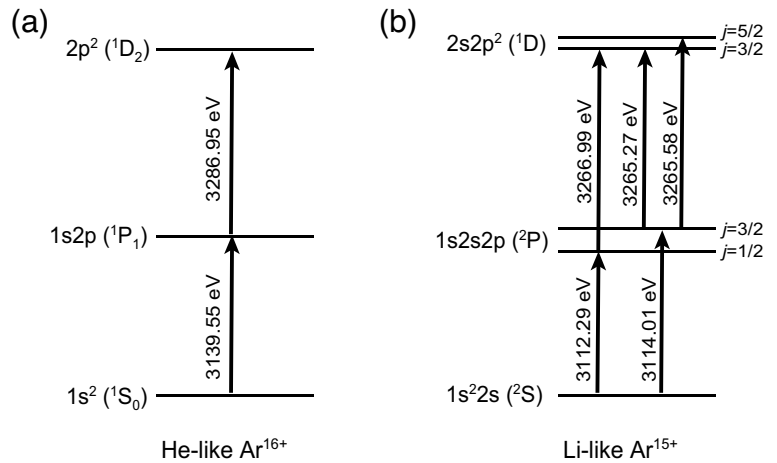


Figure 1: The level diagram of double electron excitation of (a) He-like Ar^{16+} and (b) Li-like Ar^{15+} .

SOLID-DENSITY PLASMA EXISTED AT INITIAL STAGE OF HEAVY ION TRACK FORMATION IN SOLIDS

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The processes undergo in solids immediately after excitation by single fast ions with energy of 0.1–1.0 GeV are considered. We analyze and discuss X-ray spectra of excited target atoms (Si and Al) were measured in [1,2]. It is shown the regularly used model of multiple collisional excitation of insulated target atom does not provide the correct simulation for relative intensities of K-shell dielectronic satellites spectral lines.

To describe the X-ray spectra we suggest to use specially developed model of time-dependend collision-radiative kinetics, which takes into account every relaxation process caused by target ion collisions with free electrons in dense matter. The time of raditation for registered spectra is about 10 fs, thus its represent the data for the matter parameters inside the track on so short timescale after initial excitation in collision with projectile ion. Further, the molecular dynamics modeling was applied to confirm the times of Maxwell distribution establishment and recombination processes are in the range of 1 and 100 fs, respectively. It is allow to consider the matter inside the heavy ion track as non-equilibrium solid density plasma on the timescale of X-ray spectra radiation (tens of fs).

Based on that, the plasma model was developed and used for experimental spectra simulation. The spectral measurements were done with spatial resolution along projectile ion stopping range, so the evolution of plasma parameters in depends on projectile energy was investigated. The temperature of free electrons in the central part of swift ion track was considered as free parameter during the simulation. According to the comparison with experimental data, the values of electron temperature in the range of 10-50 eV were obtained and the plasma model was verified successfully.

The results and using of plasma model approach are well-promising to be applied in considerations for the next stages of heavy ion track relaxation and latent track formation.

References

- [1] S.A. Pikuz Jr, V.P. Efremov, O. Rosmej et al., J. Phys. A **39**, 4765 (2006)
- [2] O.N. Rosmej, S.A. Pikuz Jr., A.D. Fertman et al., Phys.Rev. A **72**, 052901 (2005)