Potassium Ion Transport through Poly-para-Xylylene Films

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ABSTRACT
Bombardment of poly-para-xylylene films by a beam of potassium ions induces ion transport through the polymer material, which originally is an electrical insulator. The ion transport can easily be detected as neutralization current on an electrode at the back side of the film. The transport is accompanied by the formation of an electro-diffusion profile of potassium in the film as shown by time-of-flight secondary ion mass spectrometry. The potassium depth profiles can be rationalized by theoretical calculations based on numerical solving the Nernst-Planck-Poisson equations. The results may shed new light on the formation and dynamics of space charge zones in polymers and is thus potentially relevant for electret research.

Index Terms — Ionic conductivity, diffusion profiles, polymer membranes.

1 INTRODUCTION

According to the accepted definition an electret is a material exhibiting a macroscopic electric field at its surface. This field can be due to e.g. ions incorporated into the material of interest (space charge electrets) or to dipolar orientation (dipolar electrets). The formation, the properties and applications of electrets have been described in a seminal book and several review articles [1-4]. Among the space charge electrets those based on polymeric materials receive particular attention [5, 6]. Often these polymeric electrets are formed via corona discharge [7]. Characterization of the electrets in general involves measuring the surface potential and the electric field at the surface as a function of time [4, 8, 9]. In contrast to the technical function the mechanism of electret formation is often more difficult to understand, e.g. in the context of gas filled voids [7].

The aim of the current work is to present an alternative experimental approach for incorporating charged particles into a thin polymer film. The techniques is an extension of the recently developed bombardment induced ion transport (BIIT) method [10, 11]. Here, a continuous ion beam with well defined kinetic energy is aimed at the sample surface. Ions are attached to this surface, thus generating a surface potential. Ultimately a potential gradient and a concentration gradient across the sample is caused, which induces ion transport through the sample according to the laws of electro-diffusion [12]. As a result of the ion transport a current is measured on the backside electrode, from which characteristic sample properties, e.g. the conductivity and the diffusion coefficient, can be determined. Here we present evidence that potassium ions can be easily transported through a poly-p-xylylene film, which is an electronic insulator, the electric breakdown strength being on the order of 1.4 GV/m [13]. Combining such an ion transport experiment with a subsequent chemical analysis by time-of-flight secondary-ion-mass-spectrometry (TOF-SIMS) ultimately allows determining depth profiles of the charge carrier in the polymer film.

2 EXPERIMENTAL SETUP

The experimental setup for the bombardment induced ion transport experiments is comprised of three parts: the ion source, the ion optics and the sample holder with the collector electrode. The setup is placed in a high vacuum chamber and all measurements are carried out at a pressure of 10^-5 Pa (10^-7 mbar). The setup is shown schematically in Figure 1.

The ion source is a home-made thermionic synthetic leucite K[AlSi2O6] emitter. The properties of the thermionic ion source have been described elsewhere [14]. To produce

Figure 1. Sketch of the experimental setup.
the leucite, $K_2CO_3$, $Al_2O_3$ and SiO$_2$ in a molar ration of 1:1:4 are grinded in a ball mill, placed in a corundum tube and heated at 1000 °C for three days. In a second tempering step, the ball milled material is heated to 1200 °C and annealed for 12 h. After cooling, the mixture is ball milled once again and molybdenum (Mo) powder is added in a ration of 1:4 to optimize the heat flow through the emitter and guarantee a homogenous temperature of the material. The so obtained powder is compressed into a steel pot and tempered in vacuum at a pressure of 10$^4$ Pa (10$^6$ mbar) and a temperature of 1200 °C for 12 h. This pot is welded onto an assembly that heats the leucite. During the experiment, the emitter is heated such that potassium ions are thermally emitted [14-17] through an emission opening of a diameter of 3 mm at the top of the pot. The emissivity of these ion sources may be modified by altering the temperature via the heating current (typically between 800 K and 900 K), changing the electric field in front of the emitter (typically on the order of 1000 V/cm) or altering the opening of the steel pot (typically several mm) [14, 18-20].

The potassium ions leaving the emitter are repelled by a positive voltage applied to the repeller lens, LR, and accelerated towards the abstraction lens, AL. The voltage applied to the repeller ($U_{R}$) ultimately defines the initial kinetic energy of the ions. For the experiments discussed in this manuscript, the repeller voltage is either set to 15 V or 150 V. The voltage applied to the abstraction lens is chosen in such a way that the field between AL and LR is limited by the maximum allowed surface potential (given by the repeller potential) and the actual resistance of the sample or by the blind current if the latter is too small. Note also that the maximum surface potential of 150 V combined with the film thickness of 1.26 µm corresponds to a maximum field strength of 0.12 GV/m, less than 10% of the breakdown value [13]. The repeller voltages applied in the current work are below the saturation regime (c.f. Figure 6a in [10]), i.e. the current detected is limited by the conductivity of the sample rather than the blind current.

In the experiment described in this manuscript, the blind current has been 11 nA during the entire experiment. The input current is initially 11 nA, as well. Upon deposition of ions on the sample the potential at the surface rises such that the impinging ions start to feel a repulsive force when they approach the sample. Ultimately, this force may lead to a reduction of the input current as parts of the ions are reflected (due to trajectories non-perpendicular to the surface or due to the thermal energy distribution of the ions). Eventually, the surface potential equals the repeller potential. In this situation the charge distribution inside the sample still varies until a steady state is yet reached, where \( I_{\text{input}} = I_{\text{back}} \) and the charge distribution does not change anymore. Now, only as many ions can enter the sample from the front side as are discharged at the back side. The rest of the ions are reflected. Depending on the applied repeller voltage and the thickness of the sample, it may take some days until the steady state is reached.

The current at the rear electrode is measured via an electrometer amplifier (QME 311, Balzers) that is connected to the electrode via a high voltage electrical feed through. The current is A/D converted and processed in a personal computer.

The investigated sample is a film made out of the thermoplastic polymer poly-para-xylene (PPX). PPX is a transparent, hydrophobic, insulating and chemically-inert material that is obtained by chemical-vapor-disposition via the Gorham-process [21]. The polymerization is a quantitative two step process (Figure 2).

The first step is a vacuum pyrolysis of paracyclophane (I) at 650 °C. The formed reactive intermediates are two para-xylene (II) diradicals. At room temperature these diradicals polymerize to linear, high molecular poly-para-xylene (III) via condensation onto the sample holder surface [21;22]. The obtained PPX is highly surface conform and the produced thin films are pinhole free [23-25]. The PPX is coated onto one side of a highly polished copper plate which also acts as the detection electrode. The coating thickness is 1.26 µm.

The steady-state ion distribution measurements carried out in this paper have been investigated by a time of flight secondary ion mass spectrometer (TOF.SIMS 5, IONTOF)

![Figure 2. PPX synthesis via the Gorham process.](image-url)
GmbH, Münster, Germany). In this work we used Bi⁺ in high current bunched mode (pulsed target current: 0.5 pA) as a primary ion source and a dual source column (DSC-S) sputter gun, operating with O₂ as the sputter species (target current: 175 nA). The sputter crater dimension was 300 x 300 µm² and the Bi⁺ ions scanned over an area of 100 x 100 µm² for analysis. All depth profiles were acquired in non-interlaced mode (1.5 s sputter time, 0.5 s pause) and a low energy electron gun (20 eV) was used for charge compensation.

The investigation of the ion concentration profiles via TOF-SIMS requires stopping the bombardment and transfer of the sample to the TOF-SIMS machine. Upon removal of the sample from the vacuum chamber of the BIIT experiment the surface of the sample is electrically neutralized. In this situation only the concentration gradient of the potassium in the sample persists and can in principle lead to a further redistribution of the concentration profiles. Since the diffusion coefficient of potassium in the PPX is extremely small and the time between the end of the BIIT experiment and the TOF-SIMS measurement is kept below 1 h, we expect that the potassium concentration profiles measured by TOF-SIMS can be identified with the profiles generated in the BIIT experiment.

3 THEORY

Accompanying to the experiment, numerical simulations are performed to gain a full understanding of the transport process. Therefore, we apply the theory introduced in [10] and use the self-consistently coupled set of Nernst-Planck and Poisson equations [26-28] to numerically describe the ion transport through the PPX film. The theory is adjusted to exactly map the experimental conditions.

The ion optics introduced above generally lead to the bombardment of a circular area of the film surface. The ion beam is homogenous in a good approximation. Additionally, the radial extension of the sample is much larger than the thickness of the sample. As a consequence of these conditions, transport in radial and angular direction is negligible. Only transport perpendicular to the film surface (z-direction) needs to be taken into account. Consequently, the one dimensional Nernst-Planck and Poisson equations are sufficient to describe the main aspects of the ion transport.

Initially, the film is free of mobile charges. During the experiment potassium ions are deposited at the sample surface and transported through the sample, which may lead to a change of the sample structure. These modifications may generally lead to a spatial variation of the diffusion coefficient and the dielectric function. In this manuscript, we aim to demonstrate the influence of a spatial variation of the diffusion coefficient solely and neglect aspects from a variation of the dielectric function. The latter one will be the subject of future investigations.

Hence, the Nernst-Planck equation consequently reads

\[ J = -D \left( \frac{\partial n}{\partial z} + n \frac{\partial \phi}{\partial z} \frac{Ze}{kT} \right) \]  \hspace{1cm} (1)

where \( J \) is the ion flux density, \( D \) is the z-dependent diffusion coefficient, \( \phi \) is the electrostatic potential, \( Ze \) is the charge of the bombarding ion species and \( k_BT \) is Boltzmann’s constant times the temperature. Correspondingly, the Poisson equation is

\[ \varepsilon \varepsilon_0 \frac{\partial \phi}{\partial z} = -Ze n \] \hspace{1cm} (2)

with the vacuum dielectric permittivity \( \varepsilon_0 \) and \( \varepsilon \) the dielectric constant. The Nernst-Planck equation describes the diffusion and migration of the ions through the film while the coupling to the Poisson equation leads to a self-consistent description of the charge and potential distribution. The time evolution of the ion transport may be investigated applying Fick’s second law

\[ \frac{\partial}{\partial t} n = -\frac{\partial J}{\partial z} \] \hspace{1cm} (3)

In order to solve the coupled set of Nernst-Planck and Poisson equations, we discretize the z-axis into space elements which generally may have different sizes. Therefore, Equations (1)-(3) become

\[ J_{i+1}^{n+1} = -D \left( \frac{n_{i+1}^n - n_i^n}{\Delta z} + n_i^n \frac{\phi_{i+1} - \phi_i}{\Delta z} \frac{Ze}{kT} \right) \] \hspace{1cm} (4)

\[ \phi_i = \left\{ \begin{array}{ll}
\frac{en_i \Delta z \phi_{i+1} \phi_{i-1} + \phi_{i+1} \Delta z_i + \phi_{i-1} \Delta z_i}{(\Delta z_{i+1} + \Delta z_{i-1})} \\
(\Delta z_{i+1} + \Delta z_{i-1})
\end{array} \right\} \] \hspace{1cm} (5)

\[ \frac{\partial}{\partial \Delta t} n_i^n = -\frac{J_{i+1}^{n+1} - J_{i}^{n+1}}{\Delta z_i} \] \hspace{1cm} (6)

where \( \Delta z_i \) is the size of the respective space element and \( \Delta z_{i+1}=1/2(\Delta z_i+\Delta z_{i+1}) \). The ion flux density between the adjacent space elements \( i \) and \( i+1 \) is given by \( J_{i+1}^{n+1} \) while \( \phi_{i+1}^- \) and \( n_{i+1}^- = (n_i \Delta z_{i+1} + n_{i+1} \Delta z_i) / (\Delta z_{i+1} + \Delta z_i) \) are the diffusion coefficient and the ion density at the boundary of these two space elements. The time increment is given by \( \Delta t \). For the calculations used in this manuscript \( \Delta t=10^{-3} \)s and \( 1.05 \times 10^5 \) time steps have been used. The space grid has been chosen piece wise equidistant with \( \Delta z=1 \)nm in the first 260 nm below the front surface and \( \Delta z=10 \)nm in the rest of the sample.

3.1 BOUNDARY CONDITIONS

The Poisson equation is a second order equation. That is why two boundary conditions for the potential are necessary to solve equations (4) - (6). The needed information is provided by the experimental conditions at the front side and the back side of the sample.

More precisely, the backsie of the sample is in contact with a grounded metal electrode surface is given by \( \phi_{\text{back}} = \phi_{\text{surf}} (d e) \). Hence, we end up with a boundary condition of the 3rd kind \( \phi_{\text{surf}} \phi_{\text{surf}} / \partial z = \phi_{\text{surf}} / (d e) \) and \( \phi_{\text{back}} = 0 \) \([10]\). Please, note that the overall such that the electric potential of the electrode \( \phi_{\text{back}} \) may be taken as zero.
neglecting contact potentials. The same applies to the potential at lens L3 which is grounded as well. The electric field in vacuum between the front surface of the sample and L3, $E_{\text{vac}}$, is uniform such that the potential at the front surface $\phi_{\text{surf}}$ (which is prior unknown and found in the course of the numerical calculation) is equal to $E_{\text{vac}}d$, with $d$ the distance between L3 and the surface. At the same time, the field inside the film and near the charge in the film is compensated by two negatively charged layers at the surface of the backside electrode and L3.

Additionally, we assume that the ions are neutralized once they arrive at the position of the backside electrode. Hence the ion density becomes zero behind the electrode surface. The vanishing potential at the backside interface and the condition there for the ion density together with equation (4) yields the ion flux at the backside boundary. The ion flux density through the front surface is defined by the input current. Assuming a homogeneous ion beam with perfectly parallel trajectories, we have shown in [10] that the full blind current reaches the sample surface as long as the surface is not fully charged and the entire ion current is reflected otherwise. Hence, we may define

$$ j_0' = \frac{I_{\text{blind}}}{ZeA} \quad \phi_{\text{surf}} < U_a $$

$$ j_0' = 0 \quad \phi_{\text{surf}} \leq U_a $$

(7)

Based on these boundary conditions, equations (4)-(6) have been solved using a fourth order Runge-Kutta routine. Before every time step, the potential distribution has been calculated self-consistently to the carrier distribution. As initial conditions, we assume that no ions have been present in the sample prior to the bombardment and that the input current is identical to the blind current.

4 RESULTS

A 1.26 µm thick film has been bombarded with a potassium ion beam. The kinetic energy of the ions has been set to 15 eV and 150 eV, respectively. The blind current has been fixed to 11 nA in both cases by applying appropriate voltages at the focusing lens L1. The voltages have been established in a reference experiment where the sample has been replaced by a plain copper electrode.

In the experiment, where the potassium ions have a kinetic energy of 15 eV, a steady-state ion current of 0.19 nA ± 0.06 nA is obtained after bombarding the film for 70 h. At a kinetic energy of 150 eV, a steady-state ion current of 2.18 nA ± 0.04 nA is obtained after bombarding the film for 90 h. Subsequent to the bombardment, the ion profiles in the PPX film have been analyzed by TOF-SIMS. The profiles have been detected at different positions at the sample showing that potassium ions could be found in a circular region of 1.4 cm diameter.

Figure 3 shows the depth profile of the sample bombarded with the 15 eV ion beam in the center of the bombarded region. The black stars shows the carbon ion signal and the profiles of the two potassium isotopes with 39 atomic mass units and 41 atomic mass units are shown as dark red squares and light green diamonds respectively. The carbon profile remains constant over the entire sample, which is due to the fact that the Gorham process [21] produces a linear and uniform coating of the PPX guaranteeing a homogeneous film. The depth of the carbon profile defines the thickness of the PPX sample. The obtained potassium ion distributions show a very pronounced diffusion profile for both isomers. The shape of both potassium distributions is identical with an ion signal that peaks directly under the sample surface and exhibits a constant level at 1/100 of the peak signal deep inside the film. Over the entire sample, the ratio of $^{39}\text{K}/^{41}\text{K}$ is found to be the one in natural potassium. Please note that the potassium profiles reach through almost the entire film. The intensity of $^K$ levels off just 60 nm before the end of the film is reached. The ion profiles in the film bombarded with the 150 eV ion beam qualitatively show a very similar behavior to the 15 eV case except the potassium profiles indicate a four times higher potassium density. Especially, the ratio between the potassium concentration below the surface and the concentration in bulk is similar. The decay of the 15 eV profile is a bit steeper than the decay of the 150 eV profile.

A detailed comparison between the potassium profiles gained by the two different kinetic energies is shown in Figure 4 where the two potassium profiles are shown as a dark red squares (15 eV) and a light blue diamonds (150 eV). Please note that the first 10 nm of the depth profiles below the surface could potentially be modified by transient matrix effects, an intrinsic error of the TOF-SIMS measurements.

As a first numerical analysis, the depth profiles of the potassium distribution have been calculated using a spatially constant diffusion coefficient. Therefore, we have solved equations (4)-(5) including the time evolution (6). The time evolution has been calculated until a steady state was reached.

Experimentally, the surface potential (given by the repeller potential) and the ion current at the backside electrode are known. Using the known sample thickness and the extension of the bombarded area, this allows to calculate the specific conductivity of the sample and hence

![Figure 3. TOF-SIMS of the PPX film bombarded with a K⁺-ion beam of a kinetic energy of 15 eV.](image-url)
the average diffusion coefficient \(D = 1.18 \times 10^{-13} \text{ cm}^2\text{s}^{-1}\) which has been used in the numerical simulations.

The results of this calculation are shown in Figure 5, where the potassium profiles are shown as a dark dashed (15 eV) and a light blue solid (150 eV) lines. One obtains a good qualitative agreement between experiment and theory.

However, there are also aspects of the diffusion profiles that are not well reproduced by the theory that has been applied so far. Firstly, the ratio between the ion distribution directly below the surface and the bulk potassium concentration is about 10 in the theory while it is 100 in the experiment. Secondly, the ratio of the ion densities is about three throughout the sample not four as in the experiment. Hence, applying a constant diffusion coefficient, we find a qualitative agreement between experiment and theory but not a quantitative agreement.

From the ion transport through ion conducting glasses it is well known that the presence of a foreign ion species may strongly modify the mobility of the original ion species in the material. This effect, often called mixed alkali effect, may originate from slight modifications of the glass structure as the foreign ion species often differ in size and charge density from the original ion species. In the film, there is no original ion species. Nevertheless, the presence of the potassium ions may influence the material, for example induce polarizations in the material or block and create ion paths through the material.

In the framework of the Nernst-Planck-Poisson theory, polarization effects may be simulated via the variation of the dielectric function whereas the modification of the ion paths results in a different diffusion coefficient. Generally, both effects are expected to be dependent on the concentration.

In order to get an idea about the influence of the material modification on the transport processes, we first concentrate on a spatial variation of the diffusion coefficient and neglect polarization effects. Comparing experiment and theory, we will then conclude a concentration dependent diffusion coefficient for the PPX.

Therefore, we chose a functional form of \(D\) that is consistent with the concentration variation in the material. Hence, the variation of \(D\) should be largest in the vicinity of the front surface of the sample and vanishing in the bulk of the film where the ion concentration is small. As an ansatz,
In order to compare experiment and theory, the arbitrary units in the experimental ion distributions need to be transformed into a physically meaningful ion density. The transformation factor must be the same for both kinetic energies. For the following comparison, a factor of 5 ions / μm² per unit signal intensity has been determined.

The exponential function maps the functional form of the diffusion coefficient reduction with the parameter b that yields the width of the decline. D₂ has been chosen such that the simulated ion current at the backside electrode matches the experimentally measured ion currents. We choose

\[ D = D_0 \left( 1 - k \cdot e^{-\frac{s}{b}} \right) \]

with adjustable parameters \( D_0 \) and \( k \) that represent the bulk diffusion coefficient and the reduction of the diffusion coefficient in the vicinity of the sample surface. The inverse of the equation this implies that the measurement accuracy the diffusion coefficient is anti-proportional to the ion density. For the Nernst-Planck equation this implies that the simulated ion current at the backside electrode as well as the ion distribution agree properly; compare green solid line in Figure 6. As a comparison ion distributions using a different k-factor are shown as black short dashed and blue long dashed lines. The corresponding z-dependent diffusion coefficients are shown in Figure 8a. Note, \( D_0 \) is different from the diffusion coefficient having been used in the case with a constant diffusion coefficient. In the constant case the diffusion coefficient averages over the full sample whereas \( D_0 \) is the coefficient in the case of a very low potassium concentration.

In order to compare experiment and theory in the high kinetic energy case, too, we use \( D_0=4.45 \times 10^{-13} \text{cm}^2\text{s}^{-1} \), \( k=0.9988 \) and \( b=5 \). For these parameters, we find a very good agreement between experiment and theory; compare solid green line in Figure 7. Again, two ion distributions using a different k-factor are shown as blue long dashed and black short dashed lines. The exact shapes of the diffusion coefficients are given in Figure 8b. A comparison between the space dependent ion distribution and the space dependent diffusion coefficient allows concluding a density dependence of the diffusion coefficient for both kinetic energies. Therefore, in Figure 9 the diffusion coefficients are presented as a function of the ion density for 15 eV (dark red dashed line) and 150 eV (light blue solid line) in a double logarithmic plot. In both cases, one mainly observes a power law like dependence of the diffusion coefficient on the ion density with powers -0.91 (15 eV) and -0.96 (150 eV). Over a wide range of ion densities, both curves lay almost on top of each other indicating a unique dependence between diffusion coefficient and ion density. However, both curves exhibit a different behavior with less expressed density dependence, when they approach their highest ion densities. These points correspond to positions directly below the front surface where the ion density is largest and the diffusion coefficient is smallest but levels off. This concerns the first 20 to 30 nm below the sample surface, for which we cannot categorically rule out the presence of matrix effects in TOF-SIMS. Hence, the non-power-law like behavior could be interpreted as influence of the surface on the diffusion of the ions.

Interestingly, the observed powers suggest that within the measurement accuracy the diffusion coefficient is anti-proportional to the ion density. For the Nernst-Planck equation this implies that
$J = -D \left( \frac{1}{n} \frac{\partial n}{\partial z} + \frac{\partial \phi}{\partial z} \right)$ \hspace{1cm} (9)

where $D$ is density independent. The migration contribution then does not explicitly depend on the ion density deposited. Further implications of this result for the current-voltage relation are subject of ongoing work in our laboratory.

5 CONCLUSION AND OUTLOOK

We have investigated the electro-diffusion of potassium ions through a 1.26 µm thick poly-para-xylene film via the bombardment induced ion transport technique. The kinetic energy of the ions has been set to either 15 eV or 150 eV. In the case of 15 eV (150 eV), a steady state current of 0.19 nA (2.18 nA) has been observed after a bombardment time of 70 h (90 h). After the bombardment, the films have been analyzed with a time-of-flight secondary-ion-mass spectrometry method. The obtained ion concentrations showed a pronounced diffusion profile of the potassium ions that penetrates through the entire sample. The profiles for both kinetic ion energies qualitatively showed a similar behaviour except for the higher kinetic energy the ion density was about four times larger. Accompanying to the experiment, numerical simulations have been performed on the basis of the Nernst-Planck-Poisson equations. In a first sequence of numerical simulations, a spatially constant diffusion coefficient has been applied. The numerical results showed a good qualitative agreement with the experimental findings, reproducing the steep profile and low potassium level at high kinetic energies. However, the ratio between the maximum ion concentration close to the front surface and the spatially constant level of potassium concentration in the bulk did not agree with the experiment. Therefore, a second sequence of numerical simulations has been performed where the diffusion coefficient was allowed to be space dependent taking into account the possibility of blocking transport pathways within the poly-para-xylene by the presence of the potassium ions. The spatial variation of the diffusion coefficient has been chosen such that it mirrors the ion distribution found in the experiment. The simulations with the spatially dependent diffusion coefficient are in very good agreement with the experiment, when the diffusion coefficient close to the surface was reduced. For a kinetic ion energy of 15 eV the reduction factor was 40 and for 150 eV it was 1000. For these values not only calculated and measured diffusion profiles were matching but also the calculated and measured steady-state ion currents at the backside of the film excellently agreed. Ultimately, the space dependence of diffusion coefficient has been translated into a concentration dependence. The diffusion coefficient clearly decreases with increasing ion concentration most likely due to a blocking of the ion transport pathways.

A similar concentration dependence of a diffusion coefficient has been reported for supported bilayer membranes, where it was ascribed to the effect of exclusion volume [29].

The current work clearly demonstrates the formation of a unipolar space charge zone in a polymer film. This constitutes – at least temporarily – the properties similar to an electret. These properties exist as long as the conditions of the sample are unchanged. For the current experiment we assumed that the sample is neutralized upon removal from the vacuum chamber.

For the future we plan to investigate in more detail the temporal evolution of concentration profiles. The theoretical investigation of this is possible within the framework used for the current study. However, the experimental realization is laborious. It not only requires significant modification of the current experimental setup but also a considerable investment of time, simply because the TOF-SIMS approach is an ex-situ technique.

ACKNOWLEDGMENT

We thank Prof. Roling and Prof. Greiner for support.

REFERENCES


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Martin Schäfer was born in Marburg, Germany in 1979. From 2005 to 2009 he was a member of the physics department of the Philipps-Universität Marburg where he received the Diplom degree in 2005 and the Ph.D. degree in 2008. In 2009 he moved to the department of chemistry, were he currently works as a Post Doctoral Fellow. His field of interest is the ion transport through glasses and through films.

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