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23rd Summer School and International Symposium on the Physics of Ionized Gases

August 28th-September 1st 2006, Kopaonik, Serbia

CONTRIBUTED PAPERS

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ABSTRACTS of INVITED LECTURES,
TOPICAL INVITED LECTURES and PROGRESS REPORTS

Editors:

Nenad S. Simonović
Bratislav P. Marinković
Ljupčo Hadžievski

23rd SPIG CONTRIBUTED PAPERS



Institute of Physics
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**Institute of Physics
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Belgrade, 2006

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of the
23rd SUMMER SCHOOL AND INTERNATIONAL SYMPOSIUM
ON THE PHYSICS OF IONIZED GASES

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PREFACE

This book contains the Contributed papers and abstracts of the Invited lectures, Topical invited lectures and Progress reports to be presented at the 23rd Summer School and International Symposium on the Physics of Ionized Gases – SPIG 2006. The symposium will be held in National Park Kopaonik, Serbia, from August 28 to September 1, 2006. The meeting is organized under the auspices and with the support of the Ministry of Science and Environmental Protection, Republic of Serbia. The conference is at the list of European Physical Society (EPS) sponsored conferences.

The Invited lectures and Contributed papers are related to the following research fields: Atomic Collision Processes, Particle and Laser Beam Interaction with Solids, Low Temperature Plasmas and General Plasmas. The length of Contributed papers is limited and each is supposed to present an original work with sufficient amount of scientific information. The Scientific and Organizing Committees believe that this conference manages to maintain the high scientific level of contributed papers and invited speakers in accordance with SPIG's long tradition.

The Editors would like to thank the members of the Scientific and Advisory Committees of SPIG 2006 for their efforts in proposing the invited lectures and progress reports, review of the contributed papers and selection of 12 papers for the oral presentation. We acknowledge the EPS sponsorships granted through East West Task Force scheme. Also, we are grateful for the support of our sponsors Kryooprema d.o.o. and EUnet d.o.o. Especially we acknowledge the support of all members of the Organizing Committee who contributed a lot to the preparing and running of the conference.

The participants have been asked to send their papers camera ready, so no typing, spelling and grammatical errors have been corrected in the course of preparation of this book. The Editors apologize for all mistakes that emerged from the software problems in the process of printing.

Finally we would like to thank all the invited speakers and the participants for taking part in this year's SPIG, to wish them to have a pleasant stay in Kopaonik, and to gain additional momentum and ideas for the future work.

Belgrade, August, 2006

Editors

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SPIG 2006

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 - 1.2. Heavy Particle Collisions
 - 1.3. Swarms and Transport

- Section 2. PARTICLE AND LASER BEAM INTERACTION WITH SOLIDS**
 - 2.1. Atomic Collisions in Solids
 - 2.2. Sputtering and Deposition
 - 2.3. Laser and Plasma Interaction with Surfaces

- Section 3. LOW TEMPERATURE PLASMAS**
 - 3.1. Plasma Spectroscopy and Other Diagnostics Methods
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 - 3.3. Plasma Applications and Devices

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SPIG 2006

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Transmission of 50-200 eV Electrons through Highly Ordered Al₂O₃ Nanocapillaries

A. R. Milosavljević¹, Z. D. Pešić^{1a}, D. Šević¹, S. Mátéfi-Tempfli²,
M. Mátéfi-Tempfli², L. Piraux², Gy. Viktor³, and B. P. Marinković¹

¹ *Institute of Physics, Pregrevica 118, 11080 Belgrade, Serbia*

² *Unité de Physico-Chimie et de Physique des Matériaux, Université Catholique de Louvain, Place Croix du Sud, 1, B-1348 Louvain-la-Neuve, Belgium*

³ *Atomic Physics, Fysikum, AlbaNova, S-10691 Stockholm, Sweden*

Abstract. We report preliminary results on experimental investigation of transmission of low-energy (50-200 eV) electrons through highly ordered Al₂O₃ nanocapillaries of about 80 nm diameter and 15 μm length. The nanocapillaries were obtained as nanopores array in anodic alumina by two-step anodization. The intensity of the transmitted electrons was measured either as a function of tilt angle (the angle between the incident beam direction and the capillary axis) with a fixed observation angle (with respect to the capillary axis) or as a function of observation angle with a fixed tilt angle, for different incident electron energies. The preliminary results reveal interesting features when low energy electrons are passing through insulating nanotubes and still need to be explained.

Keywords: nanocapillaries, electrons.

PACS: 79.20.Rf, 34.50.Dy, 81.07.De

INTRODUCTION

In recent years considerable work has been devoted to investigate nanostructures produced at surfaces and solids. Particular attention has been paid to linear structures, such as ions tracks and capillaries, motivated by possible applications (e.g. single electron transistor and localized single ion implantation). These researches are linked with the quest for the new tools for surface characterization, for example possibility to obtain information characterizing inner walls of capillaries.

Recently, Stolterfoht and coauthors [1] reported the first results on transmission of Highly Charged Ions – HCI (3 keV Ne⁷⁺) through insulating capillaries which were produced by etching ion tracks in a polyethylene terephthalate (PET). Surprisingly, they have found that majority of Ne⁷⁺ ions transmitted through the capillaries preserved their initial charge state. Furthermore, the angular distributions of transmitted ions indicated propagation of Ne⁷⁺ along the capillary axis – *capillary guiding*. This was attributed to self-organized charge-up effects that suppressed ions from hitting the capillary walls. The obtained angular distributions with PET

* Present address: Physics Department, Western Michigan University, Kalamazoo, MI, 49008, USA and Advanced Light Source, LBNL, Berkeley, CA, 94720, USA

capillaries were much broader than defined by capillary aspect ratio. Nevertheless, the most recent results obtained in Stockholm [2] for highly ordered SiO_2 nanocapillaries show a very narrow angular distribution of the guided beam, close to the value defined by capillary aspect ratio. This disagreement with PET was partly explained by the capillaries in SiO_2 being parallel to a high degree, together with a much different bulk resistivities of SiO_2 and PET (see [2]). Schissl *et al.* [3] recently performed numerical simulations in order to explain the guiding effect. The obtained results were closer to Stockholm experiment [2] but a clear understanding of the difference between results for different insulating capillaries has not been achieved yet. Presently, new experiments investigating transmission of HCl through Al_2O_3 capillaries are going on [4].

To the best of our knowledge, an investigation of transmission of low(medium)-energy electrons (below 1 keV) through nanocapillaries has not been reported yet. Note that the low energy electrons are more sensitive to local variations of electric fields inside the capillaries than HCl's. On the other hand, Doll *et al.* [5] investigated, both experimentally and by use of simulations, the transmission of 1-20 keV electrons through micron-thick porous alumina membranes with closed pore endings. They reported high electron transparency above energy of 5 keV, which was attributed to the channeling of electrons along the negatively charged insulating capillaries after surmounting the entrance layer.

EXPERIMENTAL SET-UP

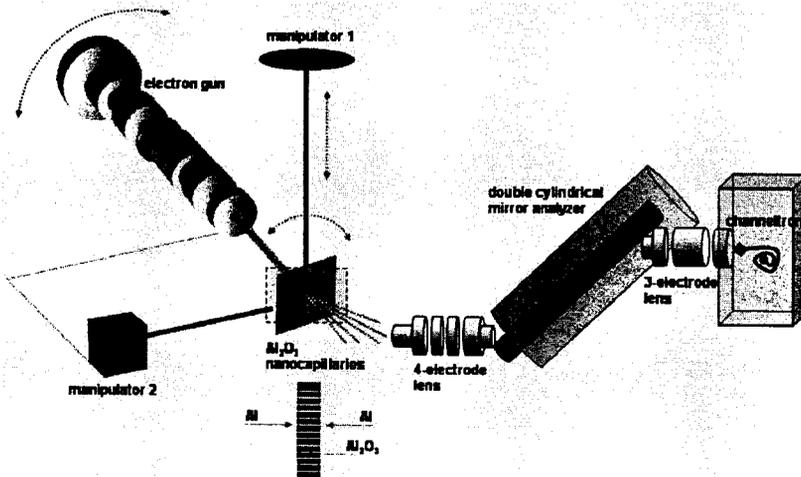


FIGURE 1. Schematic drawing of the experimental set-up. The Al lamella containing Al_2O_3 capillary array foil was mounted either at the manipulator 1 (allowing both independent rotation and up-down movement of the foil) or manipulator 2 (the foil rotates together with the electron gun).

For the purpose of present measurements, the cross-beam experimental set-up [6] has been modified as shown in Figure 1. Briefly, the incident electron beam was obtained using an electron gun, which is fixed on a turntable and can be rotated in the

angular range from about -45° to 110° with respect to the axis of the entrance analyzer lens. After being transmitted through the capillaries, the electrons were focused by a four-element cylindrical lens into a double cylindrical mirror analyzer, preceded by a three-element lens and detected by a single channel electron multiplier working in a single counting mode. For each experimental point, the intensity was measured at the maximum of the elastic peak obtained in the energy loss mode. The overall energy resolution (FWHM of the elastic peak) was about 0.5 eV. The radius and angular divergence of the incident electron beam were estimated to be 0.5-1 mm and 0.2-0.5 degrees, respectively (see [5]). The acceptance angle of the analyzing system (detector) was about 2° .

The Al_2O_3 capillaries (≈ 80 nm diameter, 15 μm length, 200 nm intercapillary distance) were obtained as nanopores array in anodic alumina prepared by two-step anodization [7]. To avoid charge up, the front and back of the capillary array are covered with metal. The circular Al_2O_3 foil (diameter of 0.9 cm) was attached to a small Al lamella, which was mounted either on the manipulator 1 or 2 (see Figure 1). In the former case, the lamella can be moved up-down (allowing direct measurements of angular distribution of the incident beam) or can be rotated independently of the rest of the system. When mounted on the manipulator 2, the lamella rotates together with the electron gun; hence the angular distribution as a function of the observation angle, for a fixed tilt angle, is measured. In following, these different experimental geometries will be named as Experimental Geometry (EG) 1 and 2, respectively.

RESULTS AND DISCUSSION

Firstly, we show some results for EG 1, where the observation angle θ_0 is fixed (angle between capillary axis and entrance lens axis) and intensity of transmitted current is measured as a function of tilt angle θ_T (angle between capillary axis and incident beam direction). In Figure 1 (left), θ_0 is fixed to 0° (giving a maximum signal) and several angular distributions are presented for different incident electron energies (E_0).

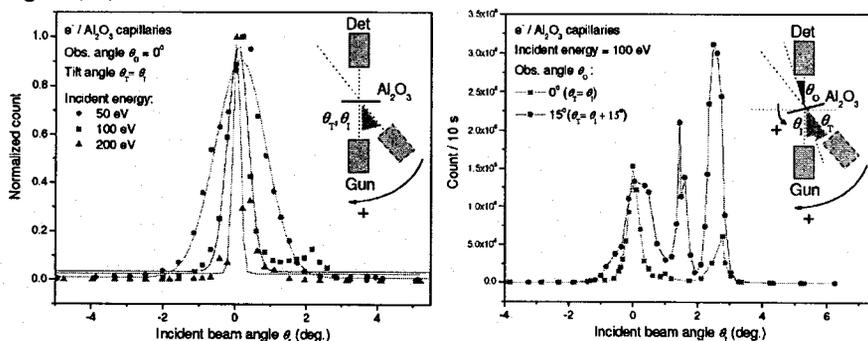


FIGURE 2. Left: Distributions of intensity of transmitted electron current as a function of tilt angle, for different incident electron energies. The observation angle is fixed to about 0° . Curves represent Gaussian fit of the experimental points. Right: Distributions of intensity of transmitted current as a function of tilt angle, for incident energy of 100 eV and two different observation angles (0° and 15°). Exp. points are connected by straight lines. Geometry of the measurements is shown in the insets.

As expected, with increasing E_0 the angular distribution is narrowing (FWHM: 1.6° , 0.7° and 0.2° for 50, 100 and 200 eV, respectively). However, the spectra are rather asymmetric, which is even more pronounced for higher E_0 where additional peaks can be seen. Figure 2 (right) shows two measured distributions for $E_0 = 100$ eV and two different θ_0 . It is interesting that the measured intensity at $\theta = 0^\circ$ was not changed significantly even the θ_0 is tilted for about 15° . Moreover, the additional structures become more intensive?!

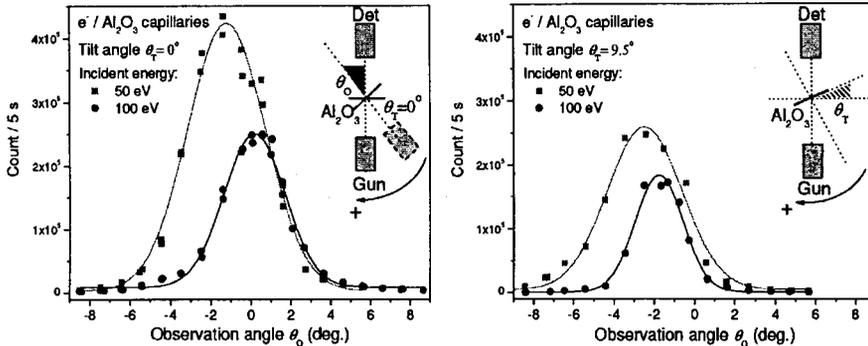


FIGURE 3. Distributions of intensity of transmitted electron current as a function of observation angle, for different incident electron energies. The tilt angle is fixed to about 0° (left) and 9.5° (right). Curves represent Gaussian fit of the experimental points. Geometry of the measurements is shown in the insets.

Results obtained in EG 2, where Al_2O_3 foil is fixed on the turntable allowing measurements of transmitted intensity as a function of θ_0 for a fixed θ_T , are presented in Figure 3. According to preliminary measurements, a significant angular shift of the intensity distributions (suggesting guiding effect) was not observed when foil was tilted for about 9.5° . However, the maxima of distributions are still positioned close to the $\theta_0=0^\circ$. Finally, investigation of transmitting of low energy electrons through insulating nanocapillaries has been started and for unambiguous understanding of their behavior a series of experiments is still needed.

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