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ABSTRACTS of INVITED LECTURES, TOPICAL INVITED LECTURES and PROGRESS REPORTS

Editors:
Nenad S. Simonović
Bratislav P. Marinković
Ljupčo Hadžievski

Institute of Physics
Belgrade, Serbia

Transmission of 50-200 eV Electrons through Highly Ordered Al_2O_3 Nanocapillaries

A. R. Milosavljević[1], Z. D. Pešić[1a], D. Šević[1], S. Mátéfi-Tempfli[2], M. Mátéfi-Tempfli[2], L Piraux[2], Gy. Vikor[3], and B. P. Marinković[1]

[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 Al_2O_3 nanocapillaries of about 80 nm diameter and 15 μm length. The nanocapillaries were obtained as nanopores array in anodic alumina by two-step anodiziation. 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 Ne^{7+}) through insulating capillaries which were produced by etching ion tracks in a polyethylene teraphthalate (PET). Surprisingly, they have found that majority of Ne^{7+} ions transmitted through the capillaries preserved their initial charge state. Furthermore, the angular distributions of transmitted ions indicated propagation of Ne^{7+} 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

[a] 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 Stockolm 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 HCI 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 HCIs. 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

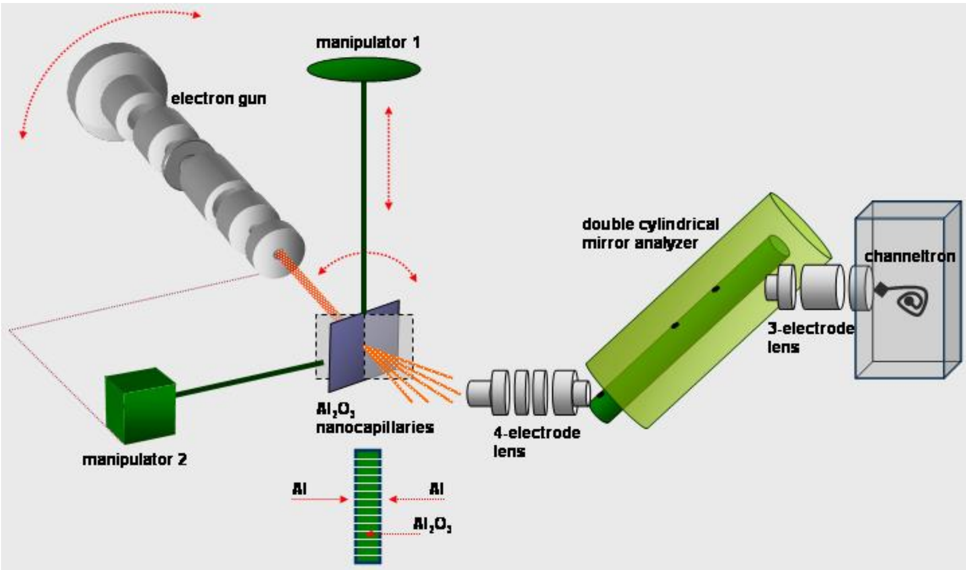

FIGURE 1. Schematic drawing of the experimental set-up. The Al lamella containing Al_2O_3 capillary array foil was mounted either at the manipulator 1 (allowing both independent rotation and up-down movement of the foil) or manipulator 2 (the foil rotates together with the electron gun).

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 a 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_O 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_O is fixed to 0° (giving a maximum signal) and several angular distributions are presented for different incident electron energies (E_0).

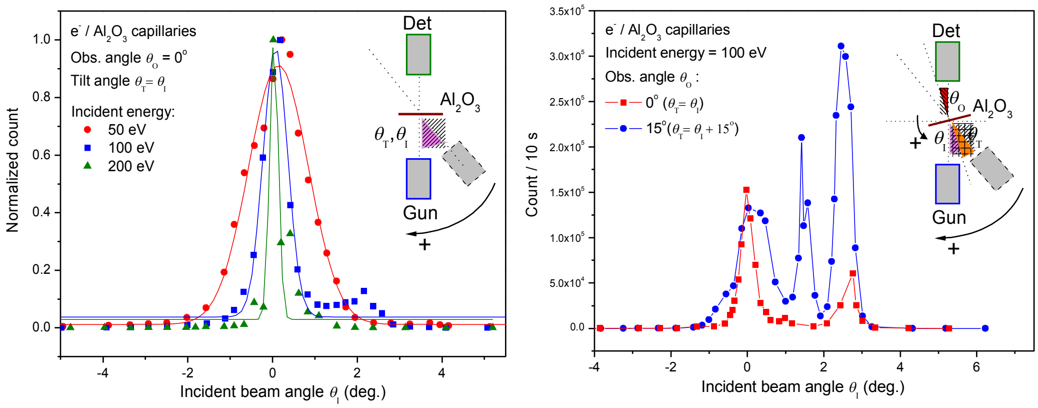

FIGURE 2. Left: Distributions of intensity of transmitted electron current as a function of tilt angle, for different incident electron energies. The observation angle is fixed to about 0°. Curves represent Gaussian fit of the experimental points. Right: Distributions of intensity of transmitted current 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_O. It is interesting that the measured intensity at θ_I = 0° was not changed significantly even the θ_O is tilted for about 15°. Moreover, the additional structures become more intensive?!

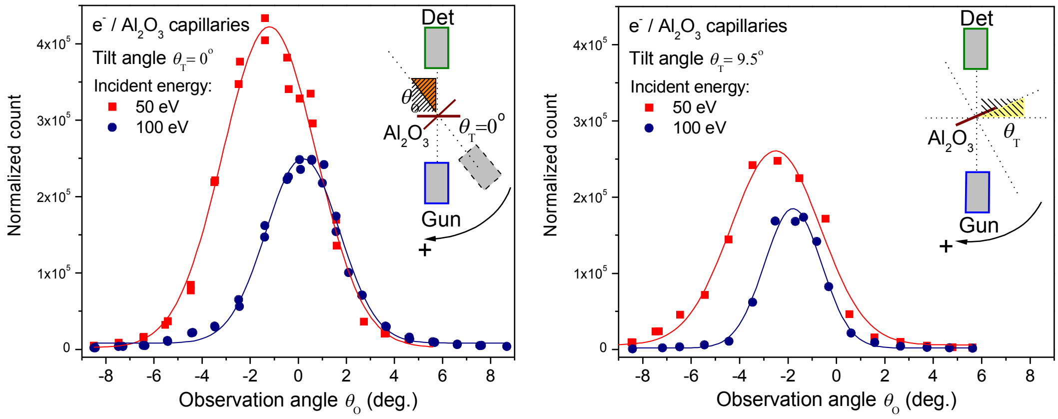

FIGURE 3. Distributions of intensity of transmitted electron current as a function of observation angle, for different incident electron energies. The tilt angle is fixed to about 0° (left) and 9.5° (right). Curves represent Gaussian fit of the experimental points. Geometry of the measurements is shown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

ACKNOWLEDGMENTS

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