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TRANSMISSION OF ELECTRONS THROUGH Al_2O_3 NANOCAPILLARIES IN THE ENERGY RANGE 2-120 eV

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Abstract. Electron transmission through insulating Al_2O_3 nanocapillaries (diameter 140 nm and aspect ratio 110) has been investigated, for low incident energies from 2 to 120 eV. An energy dependence of the transmission function has been investigated both with and without an energy analysis of the electrons and differences are discussed. Significant intensities of transmitted electrons (without the energy analysis) were observed even at the lowest electron energies.

1. INTRODUCTION

The transmission of charged particles through insulating nanocapillaries has been attracting a great deal of attention in recent years, since Stolterfoht et al. in 2002 reported an experiment showing a guiding of slow positive ions (3 keV Ne^{7+}) through highly insulating nanocapillary foils of polyethylene teraphthalate (PET). The observed phenomenon offered new possibilities for fundamental investigations, characterization of the inner walls of the insulating nanotubes and different applications. Thereafter, an intensive experimental investigation has been reported on the guiding of positive ions, mainly slow HCIs, by insulating nanocapillaries: PET (see Stolterfoht et al. 2008 and references therein), SiO_2 (Sahana et al. 2006) and Al_2O_3 (Mátéfi-Tempfli et al. 2006, Skog et al. 2007, Krause et al. 2007). The experimental work was accompanied by classical trajectory Monte Carlo simulations by Schiessl et al. 2005, 2007, which related the microscopic charge-up with macroscopic material properties.

Using the electrons as projectiles gives new possibilities both for a fundamental understanding of the guiding phenomenon and applications. However, only recently the first results on guided transmission of electrons through insulating nanocapillaries have been reported by Milosavljević et al. 2006 (200-350 eV for Al_2O_3) and Das et al. 2007 (500 and 1000 eV for PET). Both these experiments confirmed an existence of electron guiding, as found for HCIs. Still, they also showed a very small transmissivity of electrons through insulating nanocapillaries in comparison with ions. Furthermore,

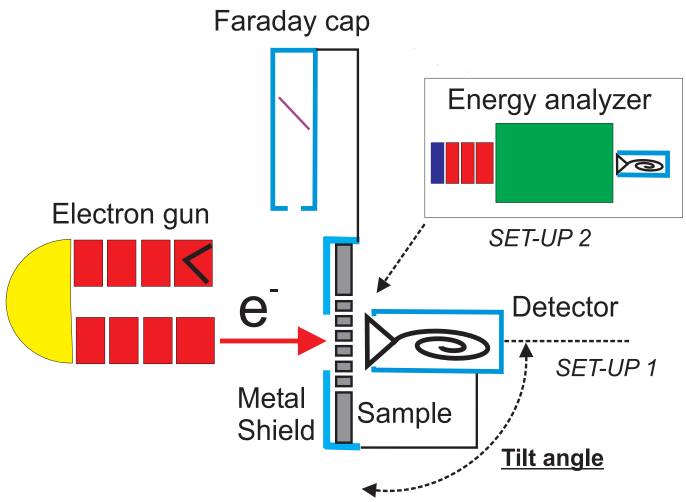

Figure 1: A schematic view of the experimental set-up.

it appears that the transmission rate (even for electrons transmitted along the capillary axis) decreases strongly with decreasing the electron energy. Therefore, the characteristics of electron guiding at very low energies down to a few eVs remained unknown. It is an open question even if it is possible to transmit very slow electrons through the insulating nanocapillaries, considering a significant charge-up of the inner walls. Therefore, we arranged an experimental set-up to investigate transmission of electrons through Al_2O_3 nanocapillary foils for low energies down to almost 0 eV. The next step then would be to investigate guiding phenomenon in this region.

2. EXPERIMENT

A highly ordered hexagonally close-packed Al_2O_3 nanochannels array was prepared using the self-ordering phenomenon during a two-step anodization process of a high purity (99.999%) 0.5 mm tick aluminium foil. To prevent a macroscopic charge-up of the target surface, the niobium layers of 20 nm thickness were deposited by dc-sputtering on both sides of the final well-ordered honeycomb membrane. A more detailed description of the fabrication process has been given by Mátéfi-Tempfli et al. 2006. The diameter of the used Al_2O_3 capillaries is about 140 nm, the intercapillary distance about 320 nm, while the length is 15 μm. The calculated geometrical transparency is about 8.4%.

The measurements were performed on a modified threshold electron impact spectrometer, which was described elsewhere (Cvejanović et al. 1992, Jureta et al. 2004). A schematic view of the present experimental set-up is given in figure 1. Electrons are produced in a Pierce type electron gun and focused by a system of three-element aperture lenses into a hemispherical monochromator. Between the monochromator and the interaction region, the electron beam passes two sets of lenses in order to satisfy the constant focusing in a large incident energy range. Measurements of the incident beam current in the Faraday cup as a function of the electron energy con-

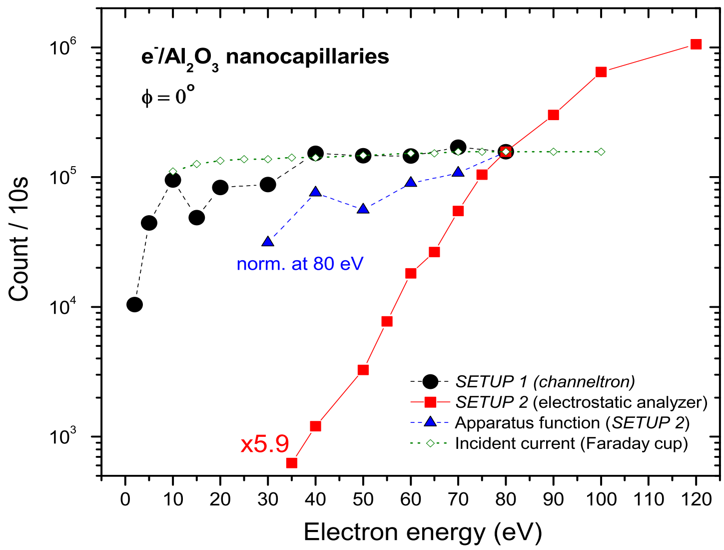

Figure 2: The intensity of the signal of electrons transmitted through Al_2O_3 nanocapillaries in the straightforward direction as a function of the incident energy.

firmed a constant geometry of the incident beam down to about 20 eV. In this energy range, the radius of the incident beam is estimated to be about 1 mm at the position of the sample. The present measurements were usually performed with an incident electron current of 8 nA, thus resulting in about 10 nA/mm^2 of the current density at the nanocapillary foil. The electron energy scale has been previously calibrated according to the positions of the 2^3S and 2^1S resonance structures in the metastable excitation spectrum of helium (19.820 eV and 20.616 eV, respectively). The energy spread in the incident electron beam has been determined to be about 50 meV.

3. RESULTS AND DISCUSSION

Figure 2 shows the transmitted electron current intensity in the straightforward direction as a function of the incident electron energy, for both used experimental configurations - without (*SETUP 1*) and with (*SETUP 2*) the energy analyzer. The *SETUP 1* configuration insures that practically all transmitted electrons are detected, regarding both the angular and the energy spread. For *SETUP 2*, however, detection was limited to the incident energy and a few degrees angular spread around the axis. Even for the *SETUP-UP 2*, the range of the energy of detected electrons transmitted through the insulating nanocapillaries has been significantly extended regarding Milosavljević et al. 2006 down to about 35 eV (red squares in fig. 2). Still, the transmission appears to decrease very quickly with decreasing the electron energy, as it was previously reported. As a consequence, it was impossible to obtain a statistically accurate signal below about 30 eV. Note that the apparatus function (blue triangles in fig. 2) shows significantly different behavior, itself decreasing much slower. Hence, this difference must be ascribed to an influence of the insulating nanocapillaries. However, placing the detector directly behind the nanocapillary foil (*SETUP-UP 1*) did allow us to measure a significant signal of transmitted electrons even at the lowest used incident energy of 2 eV. Furthermore, the curve representing the energy dependence appears to be rather flat in this case, with a behavior that is similar to the apparatus function (note that the later also includes the transmission of the analyzer, resulting in a steeper slope). At very low energies below about 20 eV, an inevitable geometrical divergence of the incident beam resulted in a lower electron flux at the nanocapillary foil and, hence, a decrees of the signal.

One of the possible explanations for the strong difference of transmission functions with and without an analyzer is, of course, a significant influence of the insulating nanocapillaries to the transmission of the analyzer-detector system, due to an angular divergence of the transmitted electrons. However, an increase of the portion of inelastically scattered electrons from the nanocapillary walls could be a possible contribution to the decrease of the signal in *SETUP-UP 2* configuration, since only the electrons with the incident energies are selected in this case. Note that electrons deflected by the charge deposited on the walls cannot be distinguished from the elastically scattered ones.

To conclude, transmission of electrons through Al_2O_3 nanocapillaries has been measured for the first time at low energies (2-120 eV). The transmission in the straight forward direction strongly depends on a setup of the detector system.

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