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ScienceDirect
Nuclear Instruments and Methods in Physics Research B 258 (2007) 68–71
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Grazing scattering of fast C_{60}^{+} ions from an Al(0 0 1) surface under axial surface channeling

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Available online 13 January 2007

Abstract

10 keV C_{60}^{+} clusters are scattered from a clean and flat Al(0 0 1) surface under a grazing angle of incidence. The angular distributions of clusters are observed as function of the azimuthal angle of rotation of the target close to the ⟨1 1 0⟩ direction in the surface plane. For sufficiently small impact energies with respect to the motion along the surface normal, fractions of fragmented clusters are small, and projectiles are specularly reflected from the topmost layer of surface atoms. For a slight detuning of the azimuthal angle of incidence with respect to the ⟨1 1 0⟩ direction, scattered C_{60} clusters show a characteristic azimuthal deflection in the opposite direction to the sense of rotation of the target surface. The data are analyzed in terms of computer simulations based on classical trajectories calculated from an effective interaction potential for C_{60}^{+} clusters in front of the surface.

PACS: 79.20.Rf; 78.30.Na; 79.20.Ap; 79.60.Bm; 61.85.+p

Keywords: Ion-surface scattering; Metal surface; Aluminium; Fullerenes; C_{60}; Channeling; Angular distributions; Simulation; Molecular dynamics

1. Introduction

Collisions of fullerenes imply important features concerning the interactions of large molecules with atomic, molecular, and solid targets [1]. In particular, studies on the scattering of charged and neutral C_{60} clusters from surfaces of metals and insulators have revealed interesting processes for large molecules interacting with solid matter. From experiments performed with clusters at hyperthermal energies, i.e. projectile energies of typically some 10 eV to some keV, and large angle to near-grazing impact details on fragmentation, charge transfer, or kinetic energy loss have been revealed [2–10]. Kolodney and coworkers have studied the formation of negative C_{60}^{-} ions during impact on graphitized metal surfaces and derived electron tunneling rates from image charge effects on projectile trajectories [2–4]. In the same collision regime this group has also performed studies on fragmentation of fullerenes [5]. In glancing angle collisions of fullerenes with a graphite surface the electron transfer dynamics and the energy transfer to the crystal lattice of the target surface has been investigated [6,7]. Subspecular scattering of projectiles was interpreted in terms of a substantial transfer of energy from projectiles to lattice atoms. From studies on delayed fragmentation and ionization the activation energy for the fragmentation of C_{60}^{+} was derived [8]. Deposition of carbon, partly in terms of an ordered superstructure, was observed for impact of C_{60}^{+} ions with energies up to some 100 eV on Ni(1 0 0) and Cu(1 0 0) [9]. Recently, Kimura and coworkers observed elastic scattering of C_{60}^{+} projectiles with energies of 3 keV and studied charge states of specularly reflected projectiles for impact on a KCl(1 0 0) surface under a grazing angle of typically 1° [10].

Recently, we have scattered C_{60}^{+} ions with energies up to 100 keV under grazing angles of incidence < 2° from an Al(0 0 1) surface and observed for sufficiently small angles of incidence specularly reflected and intact clusters [11]. Compared to former studies of C_{60}–surface collisions

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0168-583X/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.nimb.2006.12.179

[2–9] where a large fraction of incident kinetic energy of the cluster was transferred to the surface which complicated the interpretation of the data, scattering under a grazing angle of incidence of $\sim 1°$ proceeds in a series of small angle scattering events (surface channeling) with the advantage of negligible nuclear energy losses [16]. The work presented here was motivated from studies performed with atomic beams where for grazing impact along low index axial channels in the surface plane ("axial surface channeling") effects owing to "rainbow scattering" [12] were observed [13]. The signatures for this scattering regime are pronounced peaks at defined azimuthal angles out of the scattering plane and it turns out that the angular position of such "rainbow peaks" is directly related to the corrugation of the scattering potential [13,14]. Studies on this phenomenon allow one to derive information on the effective scattering potential with good accuracy [13]. In the present study we explore the effect of spatially extended projectiles (compared to an atomic projectile) on the scattering process under axial channeling conditions, i.e. to what extent scattering is affected by the size of projectiles (diameter of $C_{60} \sim 13$ a.u., atomic units are used throughout unless otherwise stated) which exceeds the typical length scales of interatomic distances in the crystal lattice ($\sim$5 a.u.). A key issue in such investigations is the feasibility to derive effective interaction potentials for cluster ions in front of metal surfaces.

2. Experiment and results

In our experiments we have scattered 10 keV C_{60}^+ clusters and Ar^0 atoms from a clean and flat Al(001) surface under a grazing angle angle of incidence $0.5° \leqslant \Phi_{in} \leqslant 2°$. C_{60}^+ ions were produced in an ECR ion source (Nanogan, Pantechnique) operated at 10 GHz from evaporation of C_{60} powder in 10^{-4} mbar Ar atmosphere. Neutral Ar atoms were produced via resonant charge transfer in a target operated with Ar gas in the beam line of the accelerator. For the neutralization of C_{60} clusters in the gas target operated with Cs vapor no defined angular distributions were found and the remaining charged clusters showed substantial fragmentation. It was not possible to check for the fragmentation of the neutralized projectiles, so that we postponed experiments on neutral cluster impact. The beams were collimated by sets of vertical and horizontal slits of 0.2 mm width to a divergence of about 0.1 mrad. These slits are part of differential pumping stages in order to maintain a pressure of some 10^{-11} mbar in the UHV chamber. Defined energies E_z for the motion of projectiles normal with respect to the surface plane were achieved by adjustment of the angle of incidence Φ_{in} according to $E_z = E_o \sin^2\Phi_{in}$ for a given projectile energy E_o. The target surfaces were prepared by cycles of sputtering with 25 keV Ar^+ ions under a grazing angle of incidence of typically 2° and subsequent annealing to temperatures of about 500 °C. The scattered projectiles are recorded by a commercially available position-sensitive channelplate detector located 66 cm behind the target. The detection efficiency was inspected in separate studies with the direct beam being wobbled over the active area of the channelplate.

In Fig. 1 we show angular distributions for scattering of 10 keV C_{60}^+ clusters (left panels) and 10 keV Ar^0 atoms (right panels) at different azimuthal settings of the target surface with respect to the incident beam. In the upper panels we show data for impact of projectiles along a $\langle 110 \rangle$ direction of the Al(001) surface. The middle and lower panels show angular distributions obtained for a detuning of the azimuthal angle of incidence by $-5°$ (middle) and $+5°$ (bottom) from the $\langle 110 \rangle$ direction. Striking feature of the results presented in the figure is a clearly different behaviour for clusters and atoms. The angular distributions for clusters are slightly broader than those for the atoms which is partly attributed to the charge of the cluster and the resulting image charge attraction [16]. Using the deflection by electric field plates between target and channelplate detector we found that scattered clusters did only show minor fragmentation for projectile energies up to some 10 keV, if E_z is smaller than about 10 eV.

The upper panels of Fig. 1 reveal a clearly different behaviour for scattering under axial surface channeling. Whereas the data for Ar atoms shows well resolved rainbow peaks resulting from a pronounced azimuthal deflection, the angular distributions for clusters do not differ from those obtained for "random" scattering, i.e. scattering under high index directions with a sufficiently large detuning of the azimuthal angle of incidence with respect to $\langle 110 \rangle$. For small angular offsets from a $\langle 110 \rangle$ low index direction, however, the clusters are scattered out of the plane of surface normal and incident beam in opposite direction to the azimuthal rotation. In the middle and

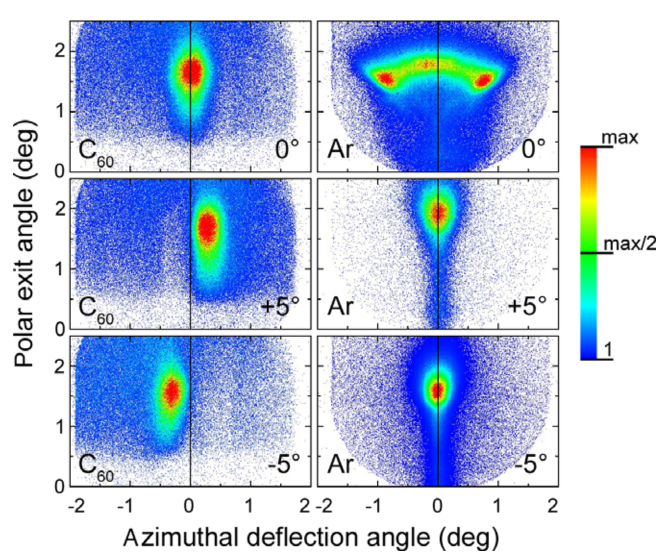

Fig. 1. Angular distributions for scattered projectiles for impact of 10 keV C_{60}^+ clusters (left panels) and 10 keV Ar^0 atoms (right panels) under a grazing polar angle of $\Phi_{in} = 1.8°$. Azimuthal orientation of beam with respect to $\langle 110 \rangle$ direction of Al(001) surface 0° (upper panel), +5° (middle panel), $-5°$ (lower panel).