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Observation of surface modification and secondary particle emission in HCI–surface interaction

Satoshi Takahashi [a,*], Masahide Tona [b], Kazuo Nagata [a], Nobuo Yoshiyasu [c], Nobuyuki Nakamura [a], Makoto Sakurai [d], Chikashi Yamada [c], Shunsuke Ohtani [a]

[a] *Institute for Laser Science, University of Electro-communications, Chofu, Tokyo 182-8585, Japan*
[b] *Japan Science and Technology Agency, Chofu, Tokyo 182-8585, Japan*
[c] *Department of Applied Physics and Chemistry, University of Electro-communications, Chofu, Tokyo 182-8585, Japan*
[d] *Department of Physics, Kobe University, Kobe, Hyogo 657-8501, Japan*

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Abstract

We have observed secondary particle emission in collision of HCI with Si and HOPG surfaces. For HOPG, we have measured the number of secondary electrons and the number of dot structures on the surface as the imprint of the incidence by STM. The single ion impact is surely observable with almost 100% efficiency by detecting an event of the secondary electron emission. For hydrogen terminated Si(111), H^+, H_2^+, H_3^+, C^+ and Si^+ ions have been detected. The proton sputtering yield, which depends on the charge of HCI, has been examined.

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Keywords: Highly charged ions; Single ion implantation; H-terminated Si surface; Secondary electron; Secondary ion

1. Introduction

Collisions of slow highly charged ions (HCIs) with surfaces have received great attention in recent years [1–3]. The potential energy of a HCI is so large that single HCI impact can induce nanoscale surface modification with a quantum efficiency of 1 by depositing the huge potential energy on a nanometer area in femotosecond time scale.

In this article, we report two experiments which demonstrate the usability of HCIs for nano-fabrication; one is a demonstrative experiment for

* Corresponding author. Tel.: +81 424 43 5709; fax: +81 424 85 8960.
E-mail address: satoshi@ils.uec.ac.jp (S. Takahashi).

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single ion implantation [4] and another is the sputtering yield measurements for proton from hydrogen-terminated silicon. In the first experiment, it has been shown that single ion impact is detectable by detecting a large number of secondary electrons. Single ion implantation is one of the most important technologies necessary for down-sizing integrated semiconductor devices, and several groups have been trying to achieve it by detecting secondary electrons for singly or low charged ion impact [5]. However, since the secondary electron yield is usually less than 1, the reliable detection of single ion impact becomes quite difficult. On the other hand, single ion implantation using HCIs takes advantage of a large secondary electron yield, which reaches as large as 100 electrons per one incident HCI for charge state of about 50+ [6].

Kuroki et al. [7] measured the sputtering yield of protons from hydrogen terminated Si(1 0 0) for the impact of HCIs with $q < 10$ and found that the yield reveals strong q dependence which is as strong as (q^5). However the absolute value of the sputtering yield is still in the order of 10^{-3} even for $q = 10$.

In the second experiment the sputtering yield of proton from H-terminated Si(1 1 1) was measured for several charge states of Xe–HCIs. According to this charge state dependence, the sputtering yield of proton may well exceed unity for very highly charged Xe ions. In the sputtering yield measurements, the flux of primary ions was counted by detecting secondary electron emissions from the surface, as confirmed in the first experiment.

2. Experimental

HCIs extracted from the Tokyo-EBIT [8] were introduced to the beamline [9] with several einzel lenses and deflectors. After charge selection with an analyzing magnet, the HCIs were transported to two collision chambers; the first chamber was connected with a scanning tunneling microscope (STM), and the second one was equipped with a time of flight secondary ion mass spectrometer (TOF-SIMS) and low energy electron diffraction (LEED) apparatus.

In the present study, two types of measurements were performed. One is demonstrative experiment for single ion implantation technique [4] done with the first chamber. Another one is secondary ion observation with the second chamber. Experimental setup in the first collision chamber is shown in Fig. 1. The highly oriented pyrolytic graphite (HOPG) was used as a sample. The sample was electrically floated from the ground potential to define the incident energy of HCIs. Secondary electrons emitted from the sample surface were detected by a channel electron multiplier (CEM). The entrance cone of the CEM was positively biased with respect to the sample and the casing surrounding the sample was negatively biased to optimize the collection efficiency for secondary electrons. Another CEM was located behind the sample to monitor the incident ions by removing the sample before irradiation. After HCI irradiation, the sample was transported to a STM chamber under UHV condition, where modified microscopic structures and their density on the surface were observed by the STM.

Experimental setup in the second collision chamber is shown in Fig. 2. A position sensitive detector (PSD) was placed at the right angle to the HCI beam. A hydrogen terminated Si(1 1 1) sample was set at 45° against PSD and HCI beam. The sample preparation was done by adsorbing

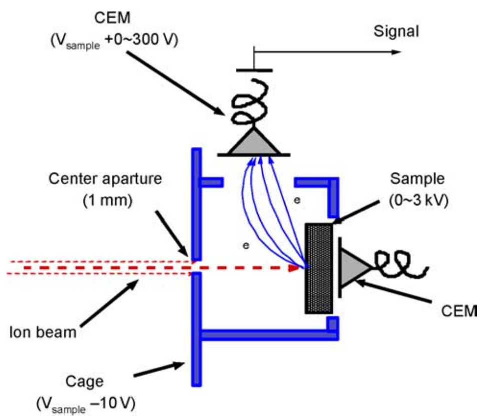

Fig. 1. Experimental setup for irradiation of HCIs and monitoring secondary electrons.