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# Absolute sputtering yields from solid Ne by low energy $He^+$ and $Ar^{q+}$ $(1 \leq q \leq 6)$ impact

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**Abstract.** Absolute sputtering yields from the surface of solid Ne by low energy $He^+$ and $Ar^{q+}$ $(1 \leq q \leq 6)$ impact are measured. Very large sputtering yields (300 atoms/ion for 1 keV $He^+$ impact, and 3000 atoms/ion for 1keV $Ar^+$ impact) have been observed. A significant dependence of the sputtering yields on the chage state, i.e. the potential energy, of the incident ion for $Ar^{q+}$ has not been observed because it is estimated to be much smaller than that of the kinetic sputtering, which suggests that the mechanism of potential sputtering is similar to those known for the electron- and photon-stimulated desorption processes.

## 1. Introduction

Interaction of rare gas solids (RGS) with low energy photons and electrons were well studied in these two decades [1, 2]. In these studies, creation of excitons and ions is found to play an important role in the desorption processes. Sputtering from RGS by singly charged keV-energy ion impact has been investigated by some groups [3–8], and kinetically induced sputtering mechanism has been discussed in detail. However little report can be found for multiply charged ion impact. Here we report the results for the absolute sputtering yields from solid Ne by singly and multiply charged ion impact.

## 2. Experimental

Singly and multiply charged ions are produced in an electron cyclotron resonance ion source (ECRIS, NANOGAN). The ion beam extracted from the ion source is mass-analyzed and focused onto the sample surface at the center of a main chamber. The incident angle of the ion beam to the sample is 10 deg. from the normal direction of the sample surface. Schematic of the main chamber is shown in fig.1. The main chamber is evacuated by a series of turbo molecular pumps and a Ti-getter pump, and the ultimate pressure is about $8 \times 10^{-9}$ Pa.

The sample film was prepared on a polycrystaline-Cu disk of 8 mm diameter. This was fixed to a mechanical cryostat and cooled down to about 4.5 K. The sample film was condensed on the Cu disk by filling the chamber with a gaseous Ne to a pressure of $10^{-6} \sim 10^{-4}$ Pa. The film thickness was estimated from the exposure assuming the condensation coefficient to be unity.

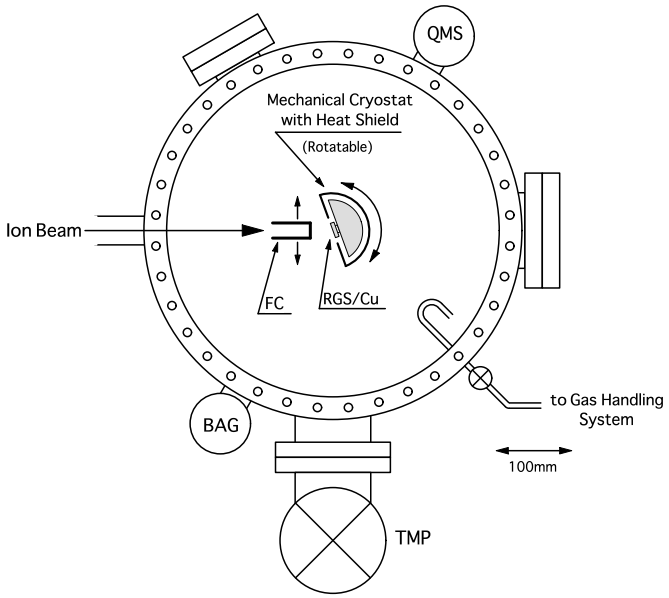


**Figure 1.** Schematic of the main chamber (top view). BAG: Bayard-Alpert ionization gauge, QMS: quadrupole mass spectrometer, TMP: tundem turbo molecular pump, FC: movable Faraday cup.

Absolute yield $Y_{\mathrm{Ne}}$ is estimated from the number of sputtered Ne atoms per second $N_{\mathrm{d}}$ and the number of incident ions per second $N_{\mathrm{ion}}$ by using the following equation, [9]

$$Y_{\mathrm{Ne}} = \frac{N_{\mathrm{d}}}{N_{\mathrm{ion}}} = \frac{S_{\mathrm{Ne}} \times \Delta P_{\mathrm{Ne}}}{kT} \cdot \frac{qe}{I_{\mathrm{ion}}} \tag{1}$$

where $S_{\mathrm{Ne}}, \Delta P_{\mathrm{Ne}}, k, T, q$ and $I_{\mathrm{ion}}$ are the pumping speed of the pumping system for Ne gas, the partial pressure change in the main chamber during the irradiation of the ion beam, Boltzmann constant, the ambient temperature, the charge state of the incident ion beam, and the ion beam current, respectively.

The sputtering rate was calculated from the pumping speed for Ne gas and the rise of the partial pressure in the vacuum chamber during irradiation of the sample. The total pumping speed of the turbo molecular pump and cold surfaces was measured to be 0.14 ± 0.01 $\mathrm{m}^3/\mathrm{s}$ for Ne, which was determined from the Ne pressure measured by an ionization gauge installed in the main chamber and from the flow rate calibrated volumetrically using a reference volume and a Baratron pressure gauge as reference. The small rise of the partial pressure during irradiation was detected by a quadrupole mass spectrometer which was calibrated against the ionization gauge for each run of the experiment. It should be noted that the uncertainty of the relative sensitivity of the ionization gauge was cancelled in the present method for determining the sputtering rate.

Incident ion beam current is monitored by a movable Faraday cup just in front of the sample surface. Typical ion beam current is 0.1 - 1 nA and the beam is 3 mm in diameter.

The over-all uncertainty is estimated to be ± 40%. The largest source of the uncertainty is the absolute pressure measured by the BA-gauge.

## 3. Results and Discussion

Experimental results for absolute sputtering yields for $\mathrm{He}^+$ and $\mathrm{Ar}^{q+}$ ($q$ = 1, 4 and 6) impact are shown in fig.2 and fig.3, respectively. The thickness of the sample is about 500 ML. The total (electronic + nuclear) stopping power $S_{\mathrm{Total}}$ at the surface calculated by SRIM2008 [10] are also shown in the figures. The ranges of the incident ions at an energy of 1.5 keV for $\mathrm{He}^+$

and 3 keV $Ar^+$ are estimated by SRIM2008 to be 31.6 nm and 9.0 nm, which correspond to about 110 ML and 30 ML of solid Ne, respectively.

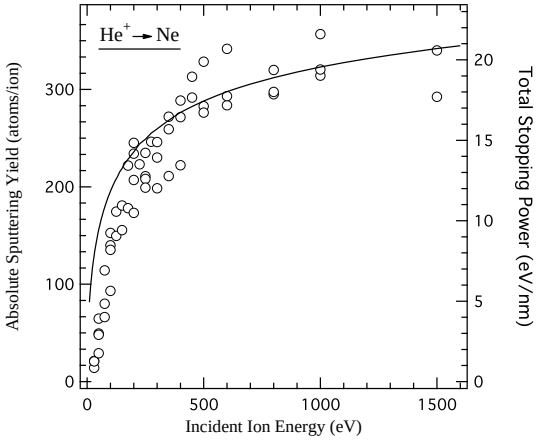


**Figure 2.** Absolute sputtering yields of solid Ne by $He^+$ impact as a function of the incident ion energy. The solid line is the total stopping power $S_{\mathrm{Total}}$ at the surface calculated by SRIM2008 [10]. Thickness of the sample film is about 500 atomic layers.

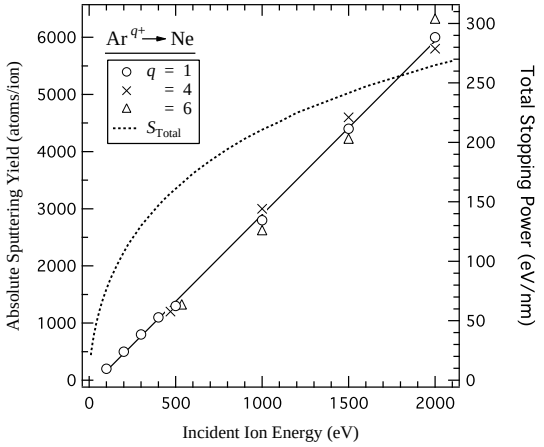


**Figure 3.** Absolute sputtering yields of solid Ne by $Ar^{q+}$ ($q = 1$ (○), 4 (×), 6 (△)) impact as a function of the incident ion energy. The dotted line shows the total stopping power $S_{\mathrm{Total}}$ at the surface calculated by SRIM2008 [10]. Thickness of the sample film is about 500 atomic layers. Some data points are slightly displaced horizontally for clarity of the presentation. The solid line is to guide the eye.

The sputtering yield for $He^+$ impact increases with the incident ion energy up to about 500 eV, and then saturates at about 300 (atoms/ion). This inicident energy dependence is similar to the total stopping power $S_{\mathrm{Total}}$ at the surface calculated by SRIM2008 [10] (solid line in fig.2), suggesting that the collision cascade mechanism is applicable to this system [5].

The results for $Ar^{q+}$ impact show surprisingly large sputtering yields even at relatively low incident energy, and that the yield is almost proportional to the incident ion energy. Charge state dependence of the sputtering yield is not observed within the experimental uncertainty. The fact that no dependence on the charge state, i.e. the potential energy of the incident ion, is observed in the present results can be explained as follows; an exciton or an ion created in solid Ne induces the desorption of 1 - 5 atoms [9]. If we assume that all of the potential energy of the incident ion can be used to create excitons ($E_{\mathrm{exciton}} = 17.2$ eV) or ions ($E_{\mathrm{g}} = 21.6$ eV for solid Ne), the "potential sputtering" [11, 12] (exciton- or ion-induced sputtering) yield will be at most 100 even by $Ar^{6+}$ (potential energy: 310 eV) impact, which is too small to be observed within the present experimental uncertainty. The present result suggests that the sputtering mechanism in the results of $Ar^{q+}$ impact is kinetic sputtering, and the mechanism of potential sputtering is similar to those known for the electron- and photon-stimulated desorption experiments [2].

All of the present results for the sputtering yields by singly-charged $He^+$ and $Ar^+$ impact are plotted in fig.4 together with the previously reported experimental data for $He^+$ [5, 13] and for $Ar^+$ [5]. Systematic differences with the data of Balaji et al. [5] by 50 to 100% were found, while the present results seem to be connected smoothly with the results by Ellegaard et al. [13].

In summary, we have measured the absolute sputtering yields from the surface of solid Ne by low energy $He^+$ and $Ar^{q+}$ ($q = 1 \sim 6$) ions. Surprisingly large sputtering yields for $Ar^{q+}$

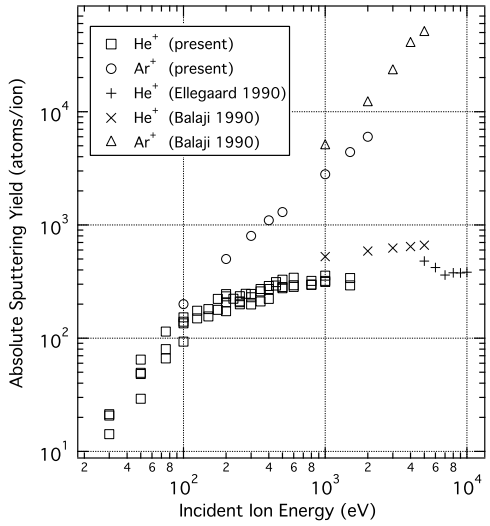


**Figure 4.** Absolute sputtering yields of solid Ne by $He^+$(□) and $Ar^+$(○) impact as a function of the incident ion energy. Also shown are experimental results for $He^+$ (+) [13] and (×) [5], and for $Ar^+$ (△) [5].

impact were found, where the kinetic sputtering process is dominant. Contributions from the potential sputtering have not been observed in the results of $Ar^{q+}$ impact because they are estimated to be much smaller than those of the kinetic sputtering. The presetn results suggest that the mechanism of potential sputtering is similar to those known for the electron- and photon-stimulated desorption processes.

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