Measurement of Sticking Probability and Sputtering Yield of Au by Low-Energy Mass Selected Ion Beams with a Quartz Crystal Microbalance

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Abstract. A measurement system of sticking probability and sputtering yield in the energy range of 0-500 eV has been established with a low-energy mass selected ion beam system. The small change in mass of the substrate material by injected ions can be evaluated with the quartz crystal microbalance (QCM). In this study, sticking probabilities and self-sputtering yields of Au were measured as functions of the injection energy of Au ions.

1. Introduction
Noble metals such as Au and Pt are widely used in semiconductor devices as electrode materials. However, it is difficult to etch such materials selectively because of their chemical stability. Therefore physical sputtering by ions, rather than chemical or reactive ion sputtering, is used for etching processing in manufacturing. Thus information on sticking probabilities and sputtering yields of noble metals is often considered to be valuable in the light of such applications.

Sticking probabilities or sputtering yields of a material can be obtained from the total number of deposited or removed atoms. The total number of such atoms can be evaluated from a small change in mass of the substrate, which can be measured by a quartz crystal microbalance (QCM). The QCM utilizes the resonance frequency of quartz and the frequency can be monitored outside the process chamber. Therefore, the QCM can provide in situ information on sputtering yields and sticking probabilities.

In this study, sticking probability and self-sputtering yield of Au are measured with the use of the QCM in the energy range of 40-400 eV. Details of the measurement system and the experimental procedures are presented in this paper.

2. Experimental Apparatus
This experiment was performed in a low-energy mass selected ion beam system [1]. A schematic top view of the ion beam system is shown in Fig. 1. In the ion source, Au ions are produced by sputtering of a solid-state Au target with an Ar plasma. Ar and Au ions are extracted by the high voltage applied
to the extractor electrodes at -14 kV. Then Au ions are separated by the mass selector by removing Ar ions. Therefore, after the beam passing through the mass selector, only Au ions remain in the beam line. Finally, the incident ions are decelerated to the desired energy and injected into the substrate in the process chamber. Mass and energy distributions of the incident ions can be examined with a mass-energy analyzer (balzers, PPM421 plasma process monitor), which consists of a cylindrical mirror analyzer for energy analysis and a quadrupole mass spectrometer for mass analysis. The energy resolution of the mass-energy analyzer is 0.3 eV.

The sticking probability is the ratio of the number of deposited atoms to that of incident ions. The number of incident ions can be evaluated from the ion beam current measured by a Faraday cup with a picoammeter (KEYTHLEY-6485). The number of deposited atoms can be evaluated from the change in mass of the Au substrate formed on the QCM crystal (ULVAC-CRTS0). The QCM crystal is a gold-coated AT-cut crystal and it has a resonant frequency of 5 MHz. The mass change of Au deposited on the QCM crystal can be monitored by the QCM controller (ULVAC-CRTM9000). The mass resolution of the QCM system is $2.4 \times 10^{-11}$ g. The self-sputtering yield $Y$ of Au is related to the sticking probability of Au, $P$, as $Y = 1 - P$.

The Faraday cup and the QCM crystal are mounted on the manipulator. By moving the manipulator vertically, incident Au ions can be injected to either the Faraday cup or the QCM crystal, selectively. The ion beam can be also injected into the mass-energy analyzer by moving the manipulator to the uppermost position to prevent the Faraday cup and the QCM crystal from blocking the ion beam path.

The measurement procedures are as follows. Firstly, the ion beam is injected into the Faraday cup to measure ion beam current. Then, the ions are injected into the Au film on the QCM crystal and its change in mass is measured. Finally, the ion beam current is measured again to confirm that it has not changed during the measurement.

3. Results
Before the sticking probabilities or self-sputtering yields are measured, the quality of the ion beam was examined by the mass-energy analyzer. Figure 2 (a) shows the mass spectrum of Au ion beam. It was confirmed that the ion beam did not contain impurity ions and consisted only of Au ions. The energy spectrum of the incident Au ions is shown in Fig.2 (b). In this case, the peak energy was 304 eV and the full width at the half maximum of the distribution was about 3 eV.
Figure 3 shows the measured sticking probabilities of Au. The horizontal axis represents the peak energy of the ion beam determined by the mass-energy analyzer. Figure 3 shows that the sticking probabilities decrease monotonically with the increasing of ion energy and they became almost zero at the ion beam energy of 204 eV [2]. Figure 3 also shows that the sticking probability became negative in the energy range of 300-400 eV, showing that the Au substrate is sputtered by the ion beam in this energy range. The self-sputtering yields of Au are shown in Fig. 4. In Fig. 4, previous results in Ref. [3] and [4] are also presented. The sputtering yields obtained from the measurement with the use of QCM agreed with those in Ref. [3] approximately, however, are inconsistent with those in Ref. [4].

4. Summary
An ion beam system for the measurement of sticking probabilities and sputtering yields was established. The QCM was used in this system to evaluate the number of removed/deposited atoms. The quality of the ion beam was examined by the mass-energy analyzer. It was confirmed that the ion beams did not include the impurity ions and the energy distribution of the incident Au ions was determined in high accuracy. The sticking probabilities of Au were found to decrease monotonically as the ion energy increases. It has been also found that incident Au ions deposit on the substrate if the ion beam energy was 200 eV or less and the ions are sputtered from the substrate if the energy was higher.

References
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