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Development of polyatomic ion beam system using liquid organic materials

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Abstract

We have developed a new type of polyatomic ion beam system using liquid organic materials such as octane and ethanol, which consists of a capillary type of nozzle, an ionizer, a mass-separator and a substrate holder. Ion current extracted after ionization was 430 μA for octane and 200 μA for ethanol, respectively. The mass-analysis was realized using a compact $E \times B$ mass filter, and the mass-analyzed ion beams were transferred toward the substrate. The ion current density at the substrate was a few μA/cm^2 for the mass-separated ion species.

Interactions of polyatomic ion beams with silicon (Si) surfaces were investigated by utilizing the ellipsometry measurement. It was found that the damaged layer thickness irradiated by the polyatomic ions with a mass number of about 40 was smaller than that by Ar ion irradiation at the same incident energy and ion fluence. The result indicated that the rupture of polyatomic ions occurred upon its impact on the Si surface with an incident energy larger than a few keV. In addition, the chemical modification of Si surfaces such as wettability could be achieved by adjusting the incident energy for the ethanol ions, which included all the fragment ions.

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1. Introduction

Ion beam processes have been applied to surface treatment as a nanotechnology [1–3], in which surface and interface characteristics of materials can be controlled on an atomic scale. The predominant properties of the ion beam technology are based on the ability to control the ion kinetic energy by adjusting an acceleration voltage. In addition, atomic, molecular and polyatomic ions including cluster ions are available, and the interaction of these ions with solid surfaces is different

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depending on the ion species used [4–6]. Compared to atomic ions, polyatomic ions have several advantages, such as the ability to control the size and structure of polyatomic ions by adjusting the ionization conditions. However, ion beam processes using liquid source materials have not been widely investigated from the point of view of engineering applications, although increasing interest in liquid polyatomic ions has been shown in mass spectroscopic studies [7–9]. With regard to the liquid materials, which include organic materials, one of their excellent features is the presence of various kinds of structures. For example, there are many polyatomic fragments present in the organic materials such as octane and ethanol, which have different structures and chemical properties. The variety of these ions is very important for surface modification of materials such as hydrophilic or hydrophobic surface modification. In addition, the inherent fluid property of liquid materials is useful for providing a continuous supply of ions, which is advantageous in the engineering applications of ion beam processes.

In this article, a liquid polyatomic ion beam system is developed, and the configuration and characteristic of the system are described. By using the system, octane and ethanol ion beams are produced, and the interaction of the ion beams with silicon (Si) surfaces is investigated. Furthermore, the surface modification such as wettability using ethanol ion beams is discussed to be compared with argon ion beams.

2. Experimental apparatus

Fig. 1 shows a schematic illustration of the developed polyatomic ion beam system. The system consists of mainly a capillary type of nozzle, an ionizer, a mass-separator and a substrate holder. Vapors of liquid materials such as octane and ethanol are introduced into the system through a stainless steel pipe. The vapors are ejected through the nozzle into a vacuum chamber with a pressure of about 10^{-5} Torr, which is evacuated by a diffusion pump. They pass through a collimator and enter the ionizer. In the ionizer,

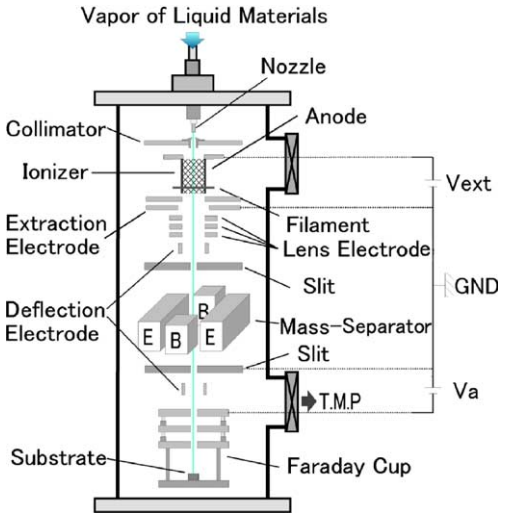

Fig. 1. Schematic illustration of the polyatomic ion beam system.

the neutral vapors are ionized by electron bombardment. The electron voltage for ionization (V_e) was adjusted between 0 V and 300 V, and the electron current for ionization (I_e) was adjusted between 0 mA and 100 mA. Several fragment ions can be produced by dissociative ionization. These ions are accelerated by applying a voltage to the extraction electrode. The extraction voltage (V_{ext}) was adjusted between 0 kV and 6 kV. The extracted ions are focused by an einzel lens, and deflected by applying an voltage to the deflection electrode. The deflected ions enter an $E \times B$ filter (Wien filter), in which ion beam axis, electric field (E) and magnetic field (B) are all mutually perpendicular. The mass-separated ion beams by adjusting the electric field in the $E \times B$ filter are accelerated toward a substrate, which is set on a substrate holder. The acceleration voltage (V_a) was adjusted between 0 kV and 10 kV. The substrates used were Si(1 0 0) substrates. The fluence of ions to the substrates is determined based on the collected ion current by a Faraday cup. When the desired ion fluence is attained, the shutter is closed to terminate ion irradiation. The background pressure around the substrate is 8×10^{-7} Torr, which is attained using a turbomolecular pump.