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Production of liquid cluster ions and their application to surface etching

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Abstract

A new type of cluster ion beam system using organic liquid materials such as ethanol has been developed, and it has several advantages for surface etching and chemical modification based on the different properties of liquid cluster ions. Ethanol vapors were ejected through a nozzle into a high-vacuum region, and ethanol clusters were produced by an adiabatic expansion phenomenon at the vapor pressures larger than 1 atm. In another case of producing ethanol clusters at a lower vapor pressure, He gas was used to mix up with ethanol vapors, and the mixed gases were ejected into a high vacuum region. Even if a vapor pressure of ethanol was 0.1 atm, ethanol clusters were produced at the He gas pressure larger than 1 atm.

The ethanol clusters produced were ionized by an electron bombardment method, and the cluster ions were accelerated toward a substrate by applying an acceleration voltage. For the case of ethanol cluster ion irradiation at an acceleration voltage of 9 kV, the sputtering yields for Al, Cu, Ag and Au films, which were used as a substrate, were about ten times larger than that by Ar monomer ion irradiation. In addition, the surface flatness of the metal films was improved by irradiation of ethanol cluster ions.

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Keywords: Ethanol cluster; Cluster ion beam; Cluster size; Surface etching; Sputtering yield

1. Introduction

The ion beam process is one of the basic technologies in nanostructure fabrications such as etching and implantation [1–3]. However, the ion beam process using liquid source materials has not been investigated from the point of view of engineering applications, because the ion current available was extremely low [4,5]. With regard to liquid materials, which include organic materials, one of their excellent features is the presence of various kinds of structures and chemical properties [6]. This feature is useful for the chemical modification of solid surfaces using various kinds of liquid materials. In addition, the inherent fluid property of liquid materials might be effective for smooth surface formation, if liquid material ion beams are applied to the surface treatment.

A cluster is an aggregate of a few tens to several thousands of atoms, and equivalently low-energy and high-current ion beams can be realized using cluster ion beams [7]. The cluster ion beam technique has several advantages, one of which is that high-energy-density deposition and the collective motions of the cluster atoms during impact play important roles in the surface process kinetics [8–10]. The liquid cluster ion beam technique, which has the features of liquid materials as well as the advantages of cluster ion beams, has a high potential for the surface treatment as engineering applications such as surface etching and chemical modification. In this paper, the development of a new type of cluster ion beam system using organic liquid materials such as ethanol is described, and the size separation of the ethanol cluster ions by a retarding potential method is discussed. Furthermore, the surface etching for

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several kinds of metal films irradiated by the ethanol cluster ion beams is investigated in order to clarify the specific characteristics of the cluster ion beam process for surface treatment.

2. Experimental apparatus

Fig. 1 shows a schematic of the cluster ion beam system using organic liquid materials. Liquid material such as ethanol is introduced into a source, and it can be heated up to 150 °C by resistive heating of the source. The vapor pressure for ethanol is 44 Torr at room temperature, and it increases with the increase in source temperature. For example, the vapor pressures measured at the source temperatures of 105 °C, 118 °C and 125 °C were 2000 Torr, 3000 Torr and 4000 Torr, respectively. The vapors of ethanol are ejected through a nozzle into a high vacuum region, and the ethanol clusters are produced by an adiabatic expansion. In another case of producing the ethanol clusters at a lower vapor pressure, helium (He) gas is used to mix up with ethanol vapors, and the mixed gases are ejected through the nozzle into a high vacuum region. He gas has an important role of cooling down the ethanol vapors through the collisions, which result in effective production of ethanol clusters. The nozzle is made of glass, and it is a converging–diverging supersonic nozzle. The diameter of the nozzle at the throat was 0.1 mm.

The clusters produced pass through a skimmer and a collimator, and they enter an ionizer. In the ionizer, the neutral clusters are ionized by an electron bombardment method. 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 250 mA. The cluster ions are accelerated by applying an extraction voltage to the extraction electrode. The extraction voltage (V_{ext}) was adjusted between 0 kV and 2 kV. The extracted cluster ion beams are size-separated by a retarding potential method. The size-separated cluster ion beams 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 metal films such as Al, Cu, Ag and Au films. The film thickness was about 500 nm. The ion dose to the substrates is determined based on the ion current. When the desired ion dose is attained, the shutter is closed to terminate ion irradiation. The background pressure around the substrate was 6×10^{-7} Torr, which was attained using a diffusion pump.

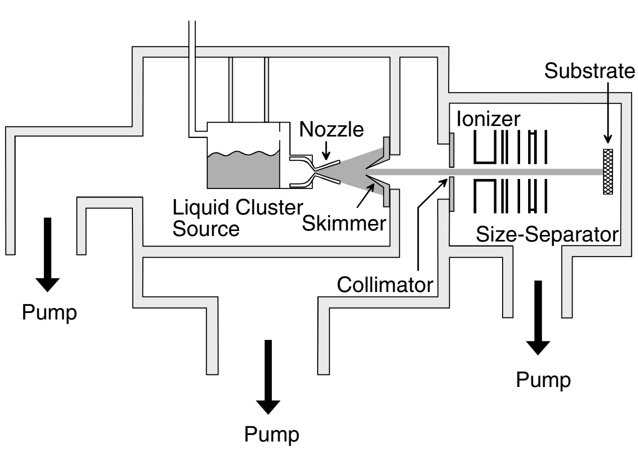

Fig. 1. Schematic of liquid cluster ion beam system.

3. Results and discussion

The cluster size was measured by a retarding potential method. The mass resolution in this method is low, but it is the most simple and the easiest way to measure the approximate cluster size distribution. Fig. 2 shows (a) a retarding spectrum for an ethanol ion beam and (b) a cluster size distribution as a parameter of vapor pressure without He gas. The electron voltage for ionization (V_e) was 200 V, and the electron current for ionization (I_e) was 200 mA. The extraction voltage (V_{ext}) was 1 kV, and the acceleration voltage (V_a) was 5 kV. As shown in Fig. 2(a), a cluster ion beam contains many monomer ions, and it decreases rapidly at a retarding voltage of 0 V. In addition, the cluster ion current measured at positive retarding

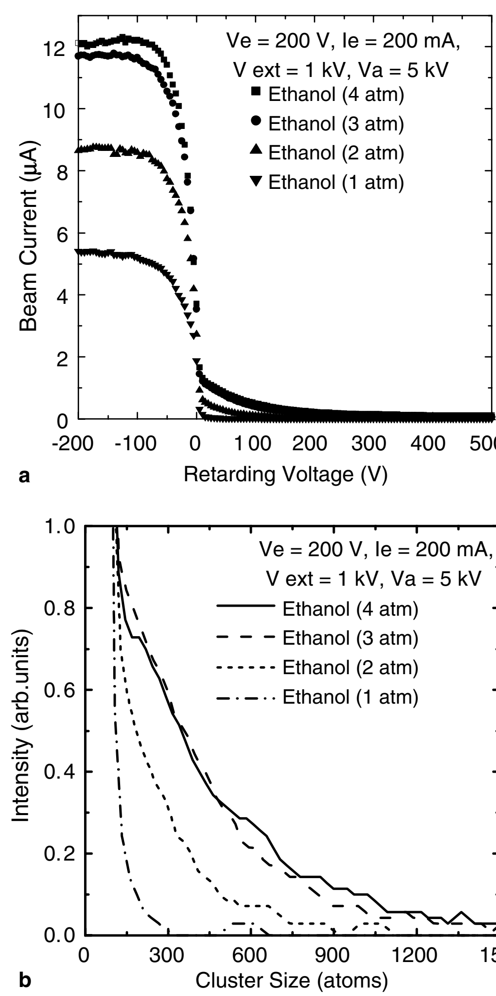

Fig. 2. (a) Retarding spectrum for an ethanol ion beam and (b) ethanol cluster size distribution measured at ionization conditions of $V_e = 200$ V and $I_e = 200$ mA as a parameter of ethanol vapor pressure.