Formation of Metal Cluster Ion Beams Investigated by Mass Spectrometry and Optical Emission Spectroscopy

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Introduction

About “Cluster”

Definition ... aggregates of several to several hundreds of atoms.

Number of atoms (size)

Magnetron Sputtering Method ... one of the methods for cluster generation.

Experimental Setup

Light emission

ion guide

optical fiber

Spectrometer measurement of emission spectra

Cluster Ion Source

Generation of an ion beam of silver cluster cations (Agₙ⁺)

(1) An Ar gas ionized by discharge sputters the plate

(2) Metal atoms aggregate by collision with a cold helium gas

Discharge power (1 – 12 W)

Results

Mass Spectra

Mass distribution shifted to larger sizes as discharge power increased. Here the average cluster size, N_avg, was evaluated by the following equation:

N_avg = \sum_{i=1}^{N} n_i \times \frac{1}{i}

\text{Measurable size range was limited up to 115 due to the setup.}

Emission Spectra

The intensity of Ag lines increased as discharge power increased, indicating an increase in the amount of Ag atoms.

Assignment of Emission Lines... referring to the NIST Atomic Spectra Database

Discussion

Evaluation of the Amount of Ag atoms, n

Emission intensity, I, should be proportional to the number of atoms, n, assuming that population of excited states follows the Boltzmann distribution:

I = I_0 \exp \left( - \frac{E}{kT} \right) \propto n

Relative values of n can be evaluated.

Analysis of Mass Spectra

We tried to find out the size-distribution function that explains the experimental data.

Spectra were reproduced by linear combination of Poisson distributions with several different average sizes.

Lattice Model for Cluster Formation

To explain the result of mass spectroscopic measurements, we propose a lattice model:

Analysis of the Cluster Source based on the Model

Size-distribution of clusters produced

The size distribution f(N) follows a Poisson distribution.

f(N) = \frac{\lambda^N}{N!} \exp(-\lambda)

\lambda: average cluster size

\rho: density of sputtered atoms

The combination of multiple distributions rather than a single distribution implies inhomogeneity in the density of Ag atoms.

Relationship between the Density and the Amount of Ag Atoms

We compared the density of Ag atoms, \rho (\propto N_avg) with the amount of sputtered Ag atoms, n.

Volume of cluster-growth region enlarges as the discharge power is raised

\rho is NOT proportional to n, but rather to \sqrt{n}

Summary

We investigated formation of metal-cluster ion beams by optical emission spectroscopy as well as by mass spectrometry.

We propose a lattice model for cluster formation, which can reproduce size-distribution of clusters by assuming inhomogeneous density distribution of silver atoms.

We found that the cluster-growth region enlarges at high discharge power, which resulted in suppression of cluster growth.

References