Formation of metal nanoparticles by short-distance sputter deposition in a reactive ion etching chamber

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A new method is reported to form metal nanoparticles by sputter deposition inside a reactive ion etching chamber with a very short target-substrate distance. The distribution and morphology of nanoparticles are found to be affected by the distance, the ion concentration, and the sputtering time. Densely distributed nanoparticles of various compositions were fabricated on the substrates that were kept at a distance of 130 μm or smaller from the target. When the distance was increased to 510 μm, island structures were formed, indicating the tendency to form continuous thin film with longer distance. The observed trend for nanoparticle formation is opposite to the previously reported mechanism for the formation of nanoparticles by sputtering. A new mechanism based on the seeding effect of the substrate is proposed to interpret the experimental results. © 2009 American Institute of Physics. [doi:10.1063/1.3211326]

I. INTRODUCTION

In the past years, metal nanoparticles were intensively investigated due to their unique magnetic,1-2 catalytic,3-6 and optical7-9 properties. Both chemical and physical methods have been developed to prepare nanoparticles with various compositions. Typically, in chemical approaches,1,6,9 metal nanoparticles were obtained by reducing the metal compounds to form well-dispersed colloidal solutions with the nanoparticles. One problem with the chemical methods is the inevitable presence of stabilizers to prevent aggregation of the nanoparticles. Components to form continuous films on the substrate. On the other hand, if the pressure is increased to 0.1 Torr (13.3 Pa), the mean free path of the sputtered species is 5 cm. If the distance between the target and the substrate is 7 cm, the sputtered atoms arrive at the substrate without experiencing many collisions, resulting in the formation of continuous films on the substrate. The sputtering equipment is less expensive than electron-beam lithography systems. Because the atom vapor is typically generated from targets of pure materials, nanoparticles created by sputtering usually contain fewer impurities in the composition than those created by chemical methods. And since the different target materials can be sputtered simultaneously, it is able to produce alloy nanoparticles with easier control on composition than the corresponding chemical reduction methods, in which metal ions are reduced in multiple steps for their different reduction potentials. Therefore, sputtering has been widely studied and applied as a primary physical method for the production of metal nanoparticles.

Based on the same principle as sputtering of metal thin films, several parameters can be modified to generate metal nanoparticles, including the gas species, the target-substrate distance, the chamber pressure, the substrate temperature, and the sputtering time.10-14 Kaatz et al.10 reported the formation of Mo nanoparticles using a sputtering process with a target-substrate distance of about 9 cm. Chow and co-workers11,12 synthesized Mo nanocrystals in an Al layer by sputtering. In the study, they created a temperature gradient by cooling the substrate with liquid nitrogen and thus obtained an enhanced deposition rate. It is found that the formation of nanoparticles instead of a continuous film on the substrate was attributed to the high pressure of the chamber. According to their explanation, at a pressure of several millitorrs (<0.1 Pa), the estimated mean free path of the sputtered species is 5 cm. If the distance between the target and the substrate is 7 cm, the sputtered atoms arrive at the substrate without experiencing many collisions, resulting in the formation of continuous films on the substrate. On the other hand, if the pressure is increased to 0.1 Torr (13.3 Pa), the mean free path for the sputtered species is reduced to approximately 500 μm, which substantially increases the collisions between atoms. The sputtered atoms will then rapidly condense and subsequently grow into nanoparticles in the vapor before they reach the substrate. A similar nanoparticle formation mechanism was also proposed by Hahn and Averback.26 They suggested that the typical pressure to form nanoparticles is 102–103 Pa, which is several orders higher than the operating pressures used in normal sputter processes (10−1–10−2 Pa). They found that a dc/rf magnetron sputter coater operated at the millibar (∼102 Pa) range can produce nanoparticles of 5–20 nm. It was also demonstrated that a shorter deposition time is an effective factor to promote the formation of GaAs nanoparticles27 instead of a continuous film.

In the present study, metallic nanoparticles were deposited on different substrates in a reactive ion etching (RIE) chamber by keeping the target and the substrate at a very...