Triode magnetron sputtering system의 제작 및 특성평가

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Characteristic evaluations and production of triode magnetron sputtering system

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Abstract

A rf triode magnetron sputtering system is designed and installed its construction in vacuum chamber. In order to calibrate the rf triode magnetron sputtering for thin films deposition processes, the effects of different glow discharge conditions were investigated in terms of the deposition rate measurements. The basic parameters for calibrating experiment in this sputtering system are rf power input, gas pressure, plasma current, and target-to-substrate distance. Because a knowledge of the deposition rate is necessary to control film thickness and to evaluate optimal conditions which are an important consideration in preparing better thin films, the deposition rates of copper as a testing material under the various sputtering conditions are investigated. Furthermore, a triode sputtering system designed in our team is simulated by the SIMION program. As a result, it is sure that the simulation of electron trajectories in the sputtering system is confined directly above the target surface by the force of E×B field. Finally, some teats with the above 4 different sputtering conditions demonstrate that the deposition rate of rf triode magnetron sputtering is relatively higher than that of the conventional sputtering system. This means that the higher deposition rate is probably caused by a high ion density in the triode and magnetron system. The erosion area of target surface bombarded by Ar ion is sputtered widely on the whole target except on both magnet sides. Therefore, the designed rf triode magnetron sputtering is a powerful deposition system.

Key Words : Triode, magnetron, sputtering system, deposition rate, sputtering conditions.

1. Introduction

Sputtering is an atom-by-atom process. Atoms are ejected from the surface of a target under ion bombardment and subsequently deposit to the substrate. Sputtering as a phenomenon was first observed to coat mirrors in the 1850s [1]. In the 1940s, sputtering was used to a significant extent as a commercial deposition process. To improve diode sputtering with very low deposition rate, in the mid-1970s a high-rate vacuum coating technique became known as magnetron sputtering. Magnetron sputtering exhibits several important advantages over other vacuum deposition techniques which are the low heating effect and minimal damage caused to delicate substrates[2-4]. Therefore, it has led to the development of a number of commercial applications.

As shown in figure 1, a typical magnetron sputtering has a shaped and closed path magnetic field to trap and concentrate the electrons produced in the discharge at the target

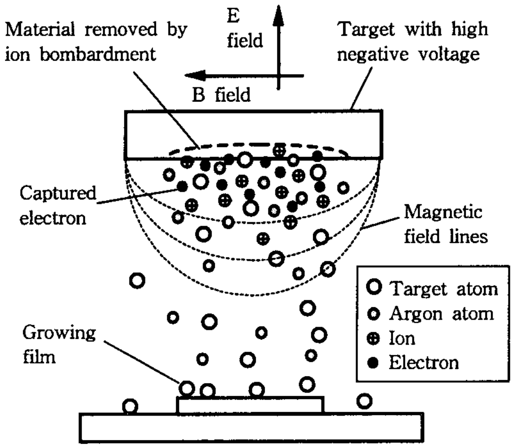

Fig. 1. Basic operation of magnetron sputtering system.

surface. The electrons are confined to above the target materials. The high density cloud of electrons promotes ionization of the sputtering gas in the region close to the target surface. The target is negatively biased to attract ions to the target. The high energy impact of these ions on the target dislodges atoms from the material which are collected on the substrate surface. Due to the high ionization efficiency of this process, low power levels may be used, and at the same time high deposition rates are achieved. Because electron leakage is restricted by the magnetic field, bombardment of the substrate is minimized and heating of the growing film and substrate is substantially reduced. A rf triode magnetron sputtering system is designed and installed in vacuum chamber. To calibrate the prepared rf triode magnetron sputtering, some basic tests with the various sputtering conditions is investigated for the successful application in rf magnetron sputtering system.

2. Experimentals

The magnetron sputtering process has many advantages[5,6]. The primary advantages are: (1) high deposition rate, (2) ease of sputtering any metal, alloy, or compound, (3) high-purity films, (4) extremely high adhesion of films, (5) excellent coverage of steps and small features, (6) ability to coat heat sensitive substrates, (7) ease of automation, and (8) excellent uniformity on large area substrates. As the above advantages, magnetron sputtering is a very powerful technique which can be used in a wide range of applications.

The vacuum system used for this RF triode magnetron sputtering system was previously an asymmetrical reaction ion etch system, model 640, built by Plasma-Therm, Inc. The vacuum system consists of a turbomolecular pump, rough and process mechanical pump. The ultimate pressure of our RF triode magnetron sputtering system is 2×10^{-6} torr. A residual gas analyzer (Leybold-Heraeus, Inficon, Quadrex 200) is attached to a flange between the base of the bell jar and the turbomolecular pump. It is used to monitor vacuum chamber performance such as various residual gases, and to detect leakage and contaminants. The target source assembly is a TRI-MAG, model 383, sputtering source by L. M. Simard, Inc. This sputtering source has an exceedingly high deposition rate for thin film research. The TRI-MAG stands for triode and magnetron sputtering system.

3. Results and discussion

In order to characterize RF triode magnetron sputtering system for thin film deposition processes, the effects of different glow discharge conditions are investigated in terms of the deposition rate measurements. The basic parameters of RF triode magnetron sputtering are RF power input, gas pressure, plasma current, and target to substrate distance.

The deposition rates dependent on the rf power are shown in figure 2. The sputtering conditions are: 70 mm distance between target and substrate, 20 mTorr argon gas pressure, 5 A plasma current, and 60 minutes deposition time. The deposition rates increase linearly with increasing rf power input. The temperatures of substrate holder caused by ion bombardments

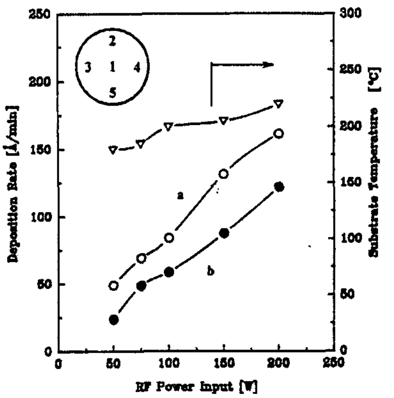

Fig. 2. Deposition rate dependent on rf power (a) at center "1" and (b) average of other 4 points.

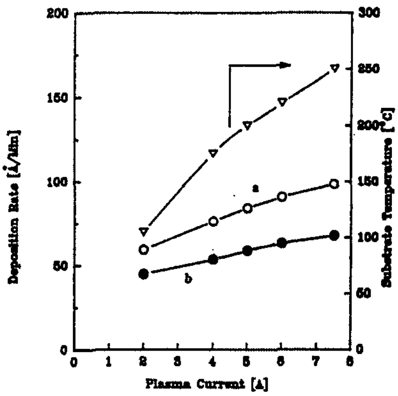

Fig. 4. Deposition rate dependent on plasma current.

and thermionic filament in triode system increase also with increasing rf power. The linear increasing curve of substrate temperatures is occurred largely by ion bombardment with increasing rf power because the plasma current for the thermionic filament is fixed during the growing processes.

Fig. 3 shows the effect of distance between target and substrate in the deposition rate curve. As shown in figure, the deposition rates decrease with increasing target to substrate distance. This means that the deposition rates are inversely proportional to the transit distance of copper atoms, and the probability of deposition on the substrate become low gradually with increasing transit distance. The measurements of substrate temperature is similar to the curve of deposition rates under the same sputtering conditions.

The advantages of triode system is that a high ion density is produced and the plasma current density for the deposition films can be controlled independently with the plasma voltage. Fig. 4 shows the deposition rates as a function of the plasma current. The sputtering conditions

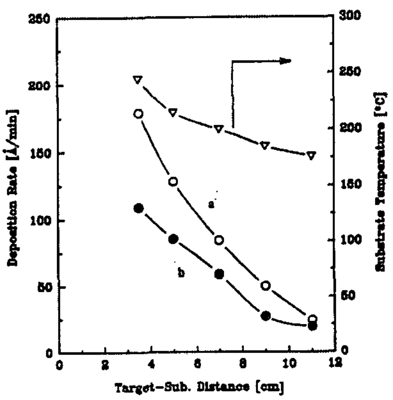

Fig. 3. Deposition rate dependent on target-to-substrate distance.

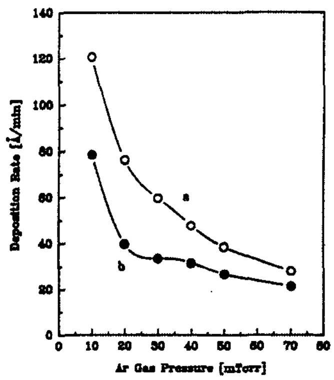

Fig. 5. Deposition rate dependent on Ar pressure.

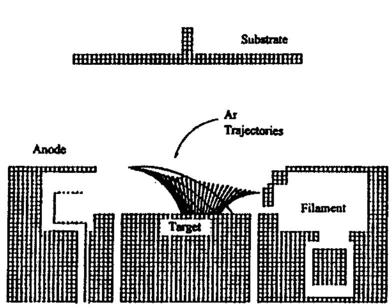

Fig. 6. SIMION simulation of Ar ions trajectories after bombardment with electron.

are: 70 mm distance between target and substrate, 20 mTorr argon gas pressure, 100 W rf power input, and 60 V plasma voltage. The deposition rates increase linearly with increasing plasma current. With increasing plasma current gradually, electrons by a thermionically heated filament are increased. These electrons accelerate toward the main anode where they then ionize a large portion of argon gas molecules. The process occurring in the triode system relies on the abundance of electron generated by the thermionic filament to ensure sufficient ionizing collisions. Thus, the ion population at the target surface is increased with increasing electrons, and the deposition rates increase. As shown in figure, the surface temperatures on the substrate holder depend on the plasma current in the triode method. The curve of the substrate temperature increases with increasing plasma current. It is caused by the sputtering deposition and by the thermionically heated filament.

Fig. 5 shows the deposition rates with the different sputtering pressure of argon gas at 70 mm distance between target and substrate, and 125 W rf power input. As the sputtering pressure of argon gas is increased, the deposition rates decrease due to the scattering between argon gas and the sputtering particles. The mean free path obviously decreases at higher sputtering pressures. Thus, the probability of collision between argon atoms and sputtering atoms increases with higher argon sputtering pressure, and the probability of a sputtering atom reaching the substrate without colliding with an argon atom reduces.

Fig. 6 shows the trajectories of Ar ions with the changes of their location after bombardment by electron.

4. Conclusions

The results of characteristic tests with four different sputtering conditions demonstrates that the deposition rate of rf triode magnetron sputtering is relatively higher than that of the conventional sputtering. This means that the higher deposition rate is probably caused by a high ion density in the triode and magnetron system. the surface temperatures, in the substrate holder, are particularly increased with increasing plasma current in a triode system. It is evident that the results of electron and Ar ion trajectories simulated by the SIMION program correspond well with the actual processes of triode magnetron sputtering and the erosion profile of the target surface. The erosion area bombarded by Ar ion is sputtered widely on the whole target except on both magnet-sides. Therefore, rf triode magnetron sputtering, which was prepared in this paper, is a powerful deposition system.

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