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Simple linear relationship between reactive gas flow rate and discharge power at mode transition on reactive sputter deposition of metal oxides

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Reactive sputter deposition process has become a very popular method to prepare oxide and other compound films in both academic and industrial fields. In the metal oxide deposition using this process, for example, a metal target is sputtered while oxygen gas is introduced into the deposition chamber to form the oxide on the substrate surface. In this process, two distinct operation modes appear corresponding to the target surface condition. In the "metallic mode", where the sputter etching of the target surface predominates the oxidation, a fast deposition rate is available while the deposited films tend to be off-stoichiometric or rather metallic. In the "oxide mode", where the relationship between the etching and oxidation rate is reversed, stoichiometric films are obtained at the cost of low deposition rate.
When applying a constant discharge power, mode transitions are observed by increasing or decreasing the O2 gas flow rate; metal to oxide (M2O) transition and oxide to metal (O2M) transition, respectively. In many cases, the transitions occur like state jumps and show a hysteresis. Namely, M2O transition occurs at a higher O2 gas flow rate than O2M one. This phenomenon has been well described by the Berg's model, in which the gettering of the reactive gases with the deposited metals on the chamber wall plays an important role [1]. Therefore, a cut-and-try approach has been necessary to find the best process parameters because each industrial deposition equipment has its own geometric configuration.
We have studied the mode transition behavior of Ti-Ar/O2 and V-Ar/O2 systems experimentally, and found a simple linear relationship between the O2 flow rate and discharge power. The discharge was generated by a DC power supply, and the discharge voltage was monitored to detect the mode transition [2]. Two kinds of experimental operations were carried out: one is the constant power operation with changing O2 flow rate, and the other is the constant flow rate operation with changing discharge power. Both were executed at several powers and flow rates, respectively, and the transition points were plotted in XY graph with flow rate and discharge power coordinates. The M2O and O2M transition points, irrespective of the kind of operation, lay on two corresponding straight lines which pass through the origin. It implies that the total mode transition can be predicted by a few pilot experiments.
As described, the mode transition is governed by the balance between the etching rate and the oxidation rate of the target surface. Therefore, our result strongly suggests that the target etching rate is proportional to the target power. This could be understood by considering the I-V relationship of the magnetron discharge (a kind of abnormal glow discharge) and the incident ion energy dependence of the sputtering yield. In the presentation, the effects of other experimental parameters, *e.g.* Ar gas pressure and the system pumping speed, will also be discussed.

1. Berg, *et al.*, JVSTA **5** (1987) 202.
2. Depla, *et al.*, JAP **101** (2007) 13301.

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