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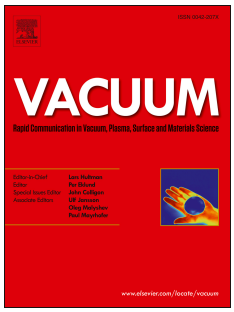

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Mass spectrometry investigation of magnetron sputtering discharges

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Abstract

This paper deals with the mass spectrometric characterization of atoms, radicals and ions generated in the RF magnetron discharges sputtering metal targets in Ne, Ar, Kr and Xe gases. In magnetron discharges different kinds of species such as atoms, radicals and positive and negative ions according to the target material and sputtering gas pressure can be generated. The mass spectrometry of the magnetron discharge, which gives the detailed information on these species, is of key importance for the development of new advanced thin films. The amount of individual atoms, radicals and ions and the ion energy distribution as a function of flow and pressure of the sputtering gas, and the magnetron power is discussed in detail. This article shows (1) the ion distribution functions of gas and sputtered target material ions as a function of sputtering gas pressure, (2) the evolution of the amount of single-ionized and double-ionized atoms of gases and metals generated in the RF discharge during sputtering of Ag films in various inert gases as a function of gas pressure, and (3) the contamination of the sputtered metallic films by the oxygen from a residual gas atmosphere in the deposition chamber at low film deposition rates.

1. Introduction

At present, the sputtering process is a widely used method for the formation of thin films and coatings. DC, RF, pulsed and high-power pulsed magnetron (HPPM) sputtering of thin films and coatings is well mastered. Properties of sputtered films are controlled by different deposition parameters, in particular by the magnetron power P_d, magnetron voltage U_d, magnetron current I_d, target power density $W_t = U_d I_d/A$, substrate temperature T_s, substrate bias U_s, substrate ion current density i_s, substrate-to-target distance d_{s-t}, deposition rate of the film a_D and the total pressure $p_T = p_{IG} + p_{RG}$ of the sputtering gas mixture; here A is the area of sputtered target, p_{IG} and p_{RG} is the partial pressure of inert and reactive sputtering gas, respectively. Every deposition parameter strongly influences the mechanism of the film growth and thereby its properties. Therefore, the formation of the film with the prescribed properties needs a careful optimization of all deposition parameters used in sputtering.

The properties of the sputtered film are, however, strongly influenced also by atoms, radicals and positive and negative ions of the sputtering gas and the sputtered material, which are generated in the magnetron discharge, and by their amount. These species in the discharge also play important role in formation of the sputtered film. They interact with the surface of the growing film and in the case of reactive sputtering gas even chemically react with the sputtered atoms, thus influencing the film mechanism of growth, its phase composition, structure and microstructure. The existence of individual species and their amounts in the discharge strongly depend on the sputtering gas pressure p and the power P_d delivered to the discharge [1]. This is illustrated in Fig.1 where the species generated in a microwave discharge are shown. From this figure it is clearly seen that different species are generated in the microwave oxygen discharge at different oxygen pressures p_{O2}. In low pressure discharge (p_{O2}= 4 Pa, Fig. 1a) the molecular oxygen O_2^+ ions, the atomic oxygen O^+ ions and the oxygen O atoms are generated. The generation of the atomic oxygen O^+ ions strongly decreases with increasing pressure p. In medium pressure discharge (p_{O2} = 10 Pa, Fig.1b) the amount of generated oxygen O atoms and that of the molecular oxygen O_2^+ ions is approximately the same. In high pressure discharge (p_{O2} = 100 Pa, Fig. 1c) the oxygen O atoms dominate over the molecular oxygen O_2^+ ions and the atomic oxygen O^+ ions disappear. This experiment clearly shows that not only the ion bombardment of the growing film but also the chemical reaction of the reactive gas with sputtered atoms and the surface of sputtered magnetron target is important [2], because it strongly changes with the total sputtering gas pressure p_T. This is why the knowledge of the amount and the kind of molecular and atomic ions and radicals in the discharge is so important for optimization of the sputtering process. These data can be obtained by mass spectrometric measurements [3-21].