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Effects of low temperature on the characteristics of tantalum thin films

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ABSTRACT

In this paper the effects of substrate temperature (room temperature – 350 °C) on the phase composition and crystallization orientation of the tantalum thin film deposited by direct current magnetron sputtering in an extremely low power deposition regime are presented. In this experiment, heating the substrates to 350 °C resulted in the growth of the hard and brittle tetragonal crystalline structure (β-Ta). Deposited tantalum has a conical structure with large voided boundaries. Sheet resistance of samples is much larger than for the convenient conductors which decreased with increasing the substrate temperature.

1. Introduction

A considerable amount of works has been done on formation of the tantalum (Ta) thin films, mainly because of its varied properties and variety of applications [1].

Sputtered tantalum thin films exhibit two crystalline phases, body-centered cubic (α-Ta) and tetragonal (β-Ta, a metastable phase) tantalum, which differ in both structural and electrical properties [2]. α-Ta is considered as an attractive coating material in many applications for its high toughness, ductility, low electrical resistivity (15–60 μΩ cm), and corrosion resistance [3]. The beta phase of tantalum has been attracting much interest since its discovery in 1965 by Read and Altman. Because of its high resistivity (170–210 μΩ cm) [3], it is the preferred form for fabricating resistors and capacitors. It is also a promising underlying layer to promote the adhesion of copper to dielectrics and diffusion barrier of copper on silicon [2]. In contrast to the tough and ductile α-Ta phase, β-Ta phase is hard and brittle, and its presence compromises the coating integrity under strain. Therefore, α phase is preferred in application where coatings are subjected to both chemical attack and wear, such as protecting gun-bore against erosion [4]. Although the physical properties of β-Ta have not been well characterized, it is known to be thermally unstable, and transforms to the bcc phase at temperatures above 750 °C [5]. The mechanism of the preferential growth of β-phase is not well understood and a broad range of resistivity has been reported [3].

The tetragonal phase of tantalum is predominant in thin films deposited at low temperature and that elevated temperature promotes the growth of the bcc phase [6]. For the growth of α-Ta, the temperature threshold exists for the substrate. The exact temperature threshold is dependent on deposition parameters and the target-substrate geometry. In some works, temperature threshold for the formation of α-Ta has been reported to be about 375–400 °C [6].

Beside these two crystalline phases, Ta films can be deposited in amorphous structure. The main difference between these phases is the large difference in their electrical resistivities. In the case of amorphous films resistivity increases to >250 μΩ cm. The crystalline modifications of thin tantalum films can be used for bonding and electric conduction whereas the amorphous modification takes on a special position [7].

Deposition power is one of the main parameter in the formation of thin films. Structure and phase of deposited films is highly affected by deposition power [8]. In the published reports usually deposition is carried out by applying about 100 W power at about >200 mA sputtering electrical current [9,10]. What happens in lower powers is the subject of this study.

In this paper we present the results of investigation on the effects of substrate temperature below 350 °C in the structural and electrical properties of the tantalum thin film deposited by direct

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Table 1
The temperature of substrates, film thickness of samples deposited on BK7 glass substrate.

Sample	1	2	3	4
Temperature of substrates	Room temperature	150 °C	250 °C	350 °C
Film thickness (nm)	806.0	1320.7	1146.5	1235.5

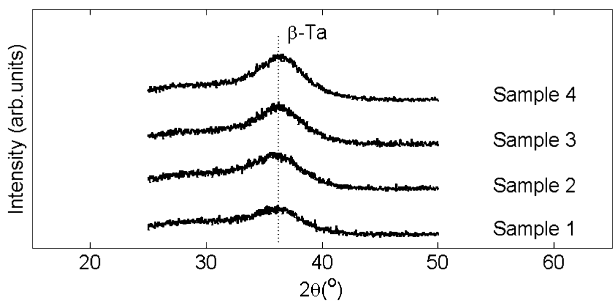

Fig. 1. X-ray diffraction spectra from the deposited films on BK7 glass substrates.

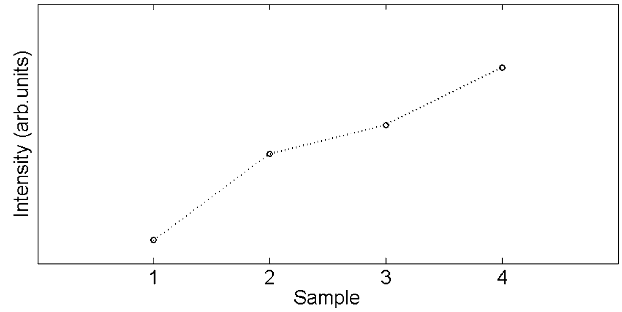

Fig. 2. Rate of phase transition of (410) preferred orientation on the films on BK7 glass substrates.

current magnetron sputtering on BK7 glass substrates in an extremely low power deposition regime. This paper is organized as follow. After this introduction the experimental setup is presented in Section 2. Section 3 is devoted to our results and discussion and conclusion can be read in Section 4.

2. Experimental details

A plane parallel direct current electrode sputtering system was employed to deposit tantalum on BK7 glass substrates. Deposition was made using a 50 mm diameter, 99.9% pure tantalum target, at the base pressure of 10^{-2} Pa and working pressure of 11 Pa of argon gas. The distance between target and substrate was 40 mm. Deposition was carried out in different temperatures. By applying a voltage difference up to 25 V to the 316 steel substrate holder, the temperature of substrates was increased from room temperature to 350 °C, while the temperature could be monitored by a thermocouple. The temperature of substrates in this experiment is presented in Table 1. A magnetic field was generated by six opposite poles of 20 mT magnets lies symmetrically in a parallel plane to target behind the target holder. 20 × 10 mm BK7 glass substrates were cleaned ultrasonically in alcohol and acetone before the experiments. During the deposition process the deposition current was kept to be 10 mA at the voltage of about 2 kV for 60 min deposition on the substrates at different temperature.

The phase and structure of the deposited tantalum films were identified by X-ray diffraction (XRD) with Cu-K_{α} radiation (= 1.54060 Å), using STOE-XRD diffractometer. Atomic Force Microscopy (AFM) micrographs were taken using Auto probe CP from Park Scientific Instrument. Sheet resistance was measured by FPP-5000 Miller Inc. four-point probe at room temperature. The thickness of the grown films was measured by DEKTAK 3 (version 2.13) profilemeter. The composition of the tantalum films was detected by energy dispersive spectrometer (OXFORD). The surface morphology of the films was observed by LEO440i scanning electron microscopy (SEM).

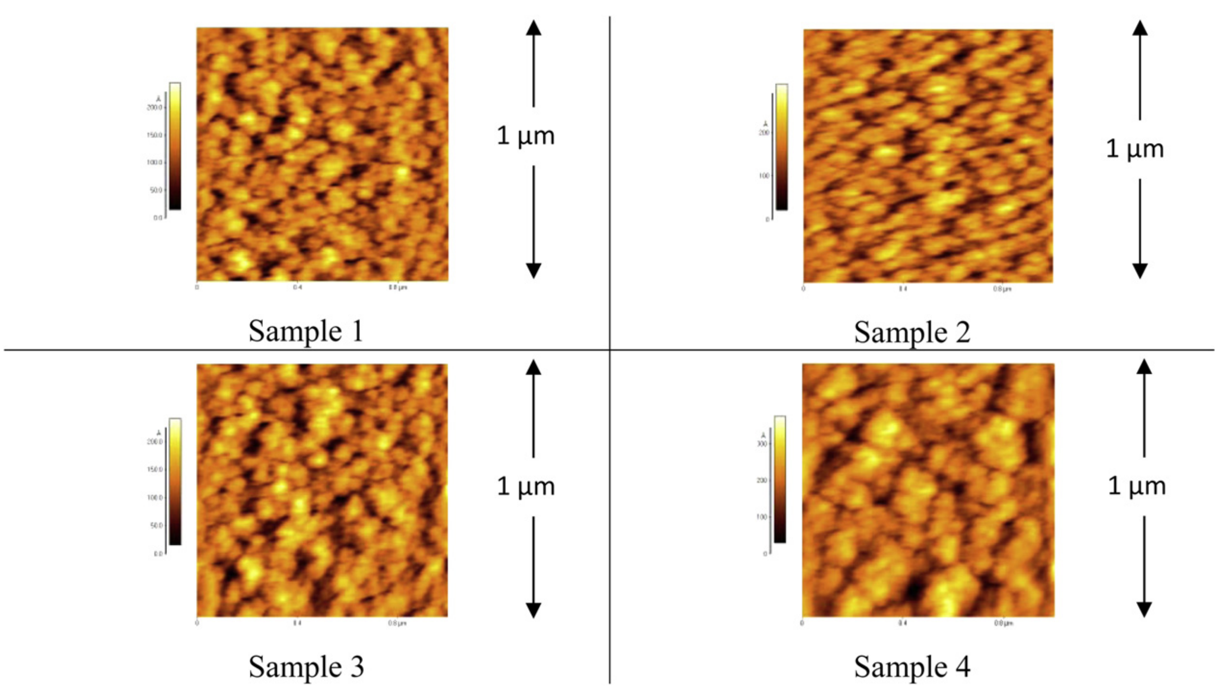

Fig. 3. The 2D AFM micrographs of samples for BK7 glass substrates.