ULTRATHIN TaN_x FILMS PREPARED BY DC MAGNETRON SPUTTERING

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Abstract. Ultrathin Tantalum nitride (TaN_x) films were prepared by dc magnetron sputtering on glass substrates at different nitrogen partial pressures. The crystal structure, compositional, microstructure, surface morphology, and optical properties were investigated. The deposition rate of the films was strongly influenced by the nitrogen partial pressure and it was continuously decreased from 3.1 to 1.8nm/min with increase of nitrogen partial pressure from $1x10^{-2}$Pa to $8x10^{-2}$Pa. The films show very fine grains and homogenous microstructure when the films deposited at nitrogen partial pressure of $4x10^{-2}$Pa. The optical transmittance of the films increased from 83 to 91% in the visible region by increasing of nitrogen partial pressure from $1x10^{-2}$ to $4x10^{-2}$Pa.

Keywords: Tantalum nitride, ultrathin films, Sputtering, Nitrogen partial pressure

I. INTRODUCTION

Tantalum nitride (TaN_x) has become a promising candidate material in many applications such as structural elements in integrated circuits, film resistors, diffusion barrier, anti-corrosive layers, high-speed thermal printing head due to its unique properties like high corrosive resistivity, good optical properties, good chemical and thermal stability, high hardness, high melting point, high electrical and thermal conductivity [1-6]. The TaN_x films were prepared by various thin films deposition techniques such as atomic layer deposition, cathodic vacuum arc deposition and sputtering etc. [7-9]. Among these techniques, sputtering is one of best techniques to prepare stoichiometry films with uniform thickness and good adhesion to substrates. The properties of TaN_x films are strongly depends on the deposition parameters. In the present work ultrathin TaN_x films were prepared on glass substrates under different nitrogen partial pressure using dc magnetron sputtering technique and studied their structural, compositional, microstructural, surface morphology and optical properties.

II. EXPERIMENTAL

Ultrathin TaN_x films were deposited on well cleaned glass substrates using dc magnetron sputtering. Prior to the deposition, the process chamber was evacuated until the base pressure reached under 7.8×10^{-4}Pa. The pure metallic tantalum (99.99%) was used as target. The pure nitrogen and argon were used as reactive and sputtering gases, respectively. The flow rate of argon and nitrogen were controlled by mass flow controllers. Before deposition of each film the tantalum (Ta) target was pre-sputtered in pure argon atmosphere for 20min in order to remove oxide layers formed if any on the target. A shutter was incorporated below the sputtering target to isolate the substrate during the pre-sputtering process. This is essential in the reactive sputtering to obtain the stoichiometry films with reproducible properties. Ultrathin TaN_x films were deposited at different nitrogen partial pressures of $1x10^{-2}$, $4x10^{-2}$ and $8x10^{-2}$Pa by keeping the other deposition parameters such as substrate temperature(303K), sputtering power(100W) and sputtering pressure(2Pa) as constant. During the films deposition, the substrate holder was rotated at 15rpm to obtain homogeneous film thickness. The structural properties were characterized using X-ray diffraction (XRD). The microstructures and surface morphology were analyzed by field emission scanning electron microscope (FE-SEM) and atomic force microscope (AFM), respectively. X-ray photoelectron spectroscopy (XPS) was used to determine the chemical states of the films. The transmittance of the films was recorded by UV-Vis-NIR spectrometer. The films thickness was measured by Ellipsometer measurements and it was around 15nm. Target to substrate distance was about 80mm.

III. RESULTS AND DISCUSSIONS

The deposition rate of the films was strongly influenced by the nitrogen partial pressure and it was continuously decreased from 2.1 to 1.2nm/min with increase of nitrogen partial pressure from $1x10^{-2}$ to $8x10^{-2}$Pa. The decreasing of the deposition rate with increasing of nitrogen partial pressure is often observed in reactive sputtering of tantalum nitride films. At lower nitrogen partial pressures, the deposition rate was high due to the high sputtering yield of tantalum and insufficient availability of nitrogen for reaction with tantalum. The deposition rate of TaN_x films was decreased with increasing the nitrogen partial pressure, due to the target-poisoning effect (i.e. formation of TaN_x phase on the target surface) resulting low sputtering yield. Grosser et al. [10] observed the similar changes in deposition rate by increasing the nitrogen flow rate in dc magnetron sputtered TaN_x films.

Fig.1. shows the XRD patterns of ultrathin TaN_x films at different nitrogen partial pressures. The deposited films exhibited amorphous structure regardless of the nitrogen partial pressures. The films deposited on amorphous glass substrates should have sufficiently thick and there is much more matter which can diffract X-rays and the peak is more intense. In the case of ultrathin films

deposited on amorphous glass substrates, it diffracts less and the noise in the recorded spectra is so important that hides any form of growth orientation [11].

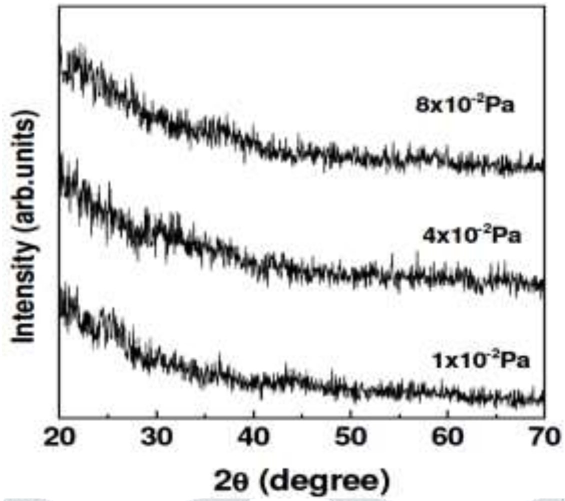

Fig.1. XRD patterns of ultrathin TaN_x films at different nitrogen partial pressures.

The XPS spectra of TaN_x films at different nitrogen partial pressures are shown Fig.2. The binding energy values of Ta4f in TaN_x films are 25.1eV, 26.2eV; 25.17eV, 27.28eV; and 25.09eV, 27.13eV for nitrogen partial pressure of $1x10^{-2}$, $4x10^{-2}$ and $8x10^{-2}$Pa, respectively. The obtained binding energy values of TaN_x films are not coincide with Ta (Ta4f=21.9 eV), TaN_x (22.2 eV, 24.1 eV) and TaO_x (26.4 eV, 28.3 eV) values [12-13].

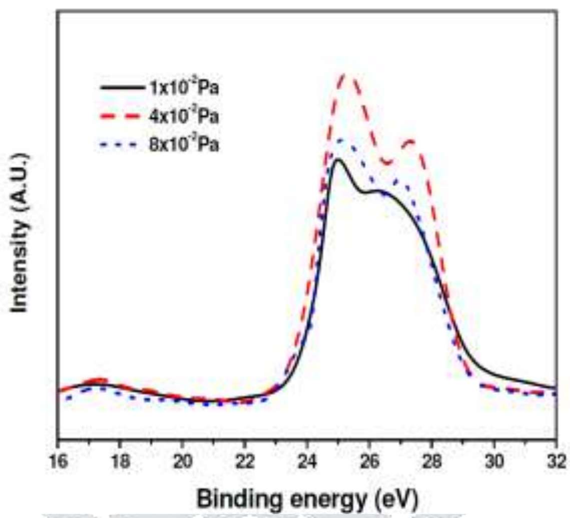

Fig.2. XPS spectra of ultrathin TaN_x films at different nitrogen partial pressures.

The microstructural changes of TaN_x films at various nitrogen partial pressures are shown in Fig.3. The microstructure of the films was highly influenced by nitrogen partial pressures. The films exhibited inhomogeneous microstructure at low nitrogen partial pressure of $1x10^{-2}$Pa due to poor surface mobility of adatoms, consequently, agglomerated and the clusters are nucleated on the substrate. The films show very fine grains and homogenous microstructure when the films deposited at nitrogen partial pressure of $4x10^{-2}$Pa. Beyond this nitrogen partial pressure, the surface of the films exhibited inhomogeneous microstructure, which is due to the excess nitrogen might induce defects in the films, and influenced the nucleation and growth of the films at higher nitrogen partial pressures.

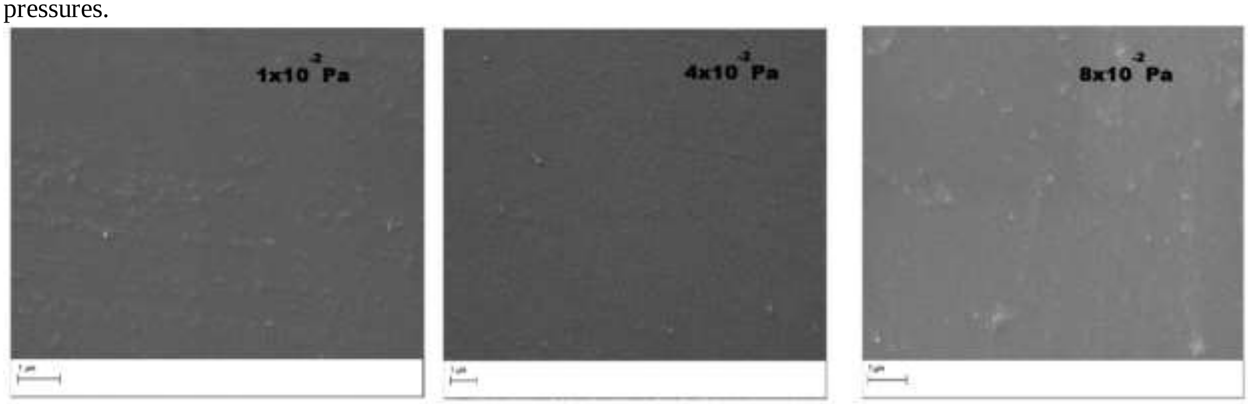

Fig.3. SEM images of ultrathin TaN_x films at different nitrogen partial pressures.

The two-dimensional AFM images of ultrathin TaN_x films at different nitrogen partial pressures are shown in Fig.4. The films surface and RMS roughness was strongly influenced by the nitrogen partial pressures. The films become uniform by increasing of the nitrogen partial pressure from $1x10^{-2}$ to $4x10^{-2}$Pa, thereafter small islands are formed on the surface of the films. The obtained RMS surface roughness values are 2.5, 0.7 and 1.6nm, for the nitrogen partial pressure of $1x10^{-2}$, $4x10^{-2}$ and $8x10^{-2}$Pa, respectively. The RMS roughness decreases with increase of nitrogen partial pressure from $1x10^{-2}$ to $4x10^{-2}$Pa is due to formation of very fine grains and absence of islands. The RMS roughness increased again at higher nitrogen partial pressure of $8x10^{-2}$Pa. The similar variation was observed by Koscielniak et al. [14] in rheotaxial growth vacuum oxidation ultrathin In_2O_3 films.

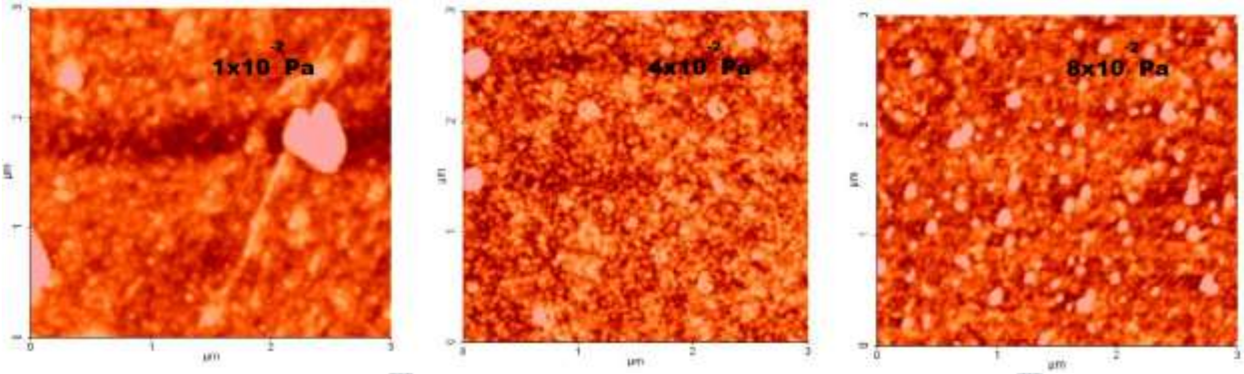

Fig.4. Two-dimensional AFM images of ultrathin TaN_x films at different nitrogen partial pressures.

Fig.5. shows the variation of the optical transmittance of the ultrathin TaN_x films with nitrogen partial pressures. The optical transmittance of bare glass was measured and it was around 92% at wavelength of 550nm. The optical transmittance of the films increased from 83 to 91% in the visible region by increasing of nitrogen partial pressure from $1x10^{-2}$ to $4x10^{-2}$Pa. On further increasing the partial pressure the transmittance was decreased to 87%. The variations in the optical transmittance with nitrogen partial pressure is may due to the changes in surface roughness of the films. The optical band gap of the films was also influenced by the nitrogen partial pressure. The obtained band gap values are 2.52, 2.69, 2.77eV for nitrogen partial pressure of $1x10^{-2}$, $4x10^{-2}$ and $8x10^{-2}$Pa, respectively. The present obtained values are close to the reported values of atomic layer deposition ultrathin TaN_x films by Wu et al. [15]. The obtained values are not near to the band gap values of Ta_2O_5 (Eg=4.5eV), TaO_2 (Eg=3.9-4.5eV), and Ta(NO) (Eg=4.3eV) [16-18]. These results indicate that the films deposited at different nitrogen partial pressures were not contained oxygen.

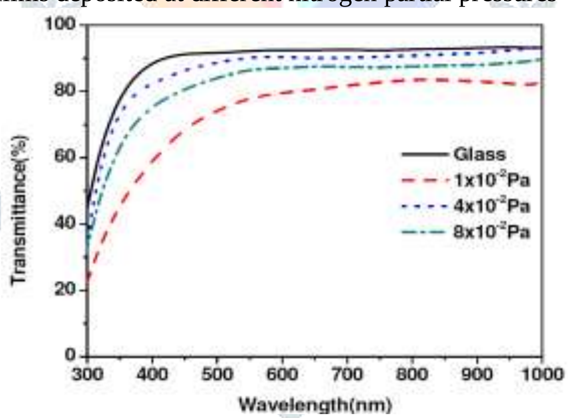

Fig.5. Optical transmittance spectra of ultrathin TaN_x films at different nitrogen partial pressures.

IV. CONCLUSIONS

Ultrathin TaN_x films were prepared by dc magnetron sputtering on glass substrates at different nitrogen partial pressures. The deposited films exhibited amorphous structure regardless of the nitrogen partial pressures. The film surface and RMS roughness was strongly influenced by the nitrogen partial pressures. The films become uniform by increasing of the nitrogen partial pressure. The films deposited at nitrogen partial pressure of $4x10^{-2}$Pa exhibited smooth surface with RMS surface roughness of 0.7nm. The optical transmittance of the films increased from 83 to 91% in the visible region by increasing of nitrogen partial pressure from $1x10^{-2}$ to $4x10^{-2}$Pa. The optical band gap of the films was also influenced by the nitrogen partial pressures.

V. ACKNOWLEDGEMENT

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