ATLANTIS PRESS

*Advances in Engineering, volume 126*

5th International Conference on Machinery, Materials and Computing Technology (ICMMCT 2017)

# Performance Differences of $Ta_2O_5$ Films under Different Magnetron Sputtering Conditions

Mengchao Li[1,a], Hai–ning Cui[1,2,b,*], He Wang[1,c], Zhenxing Wang[1,d], Yanan Liu[1,e]

[1]Department of Optical and Electronic Information Science and Technology, College of Physics and College of Zhaoqing (526061) , Jilin University, P. R. China

[2]Key Lab. of Chinese Minist. of Edu. for Coherent light and Atomic and Mol. Spect., College of Physics, Jilin University(130021), P. R. China

[a]email: jlulimc@163.com, [*,b] correspondence email: cuihn@jlu.edu.cn,

[c]email: whe15@mails.jlu.edu.cn, [d]email: yimingtongtian@163.com,

[e]email: 2505290632@qq.com

**Keywords:** Magnetron Sputtering; $Ta_2O_5$ films; Impedance spectrum; Transmittance

**Abstract.** $Ta_2O_5$ films are applied widely in semiconductor materials, storage devices, optical devices and many other areas. There are many methods to prepare $Ta_2O_5$ thin films. In this paper, we have explored the effects on the properties of films at different experimental conditions in the process of RF magnetron sputtering. In the experiments, the sputtering time and the $O_2$-Ar flow ratio were changed. Then the properties of the $Ta_2O_5$ films prepared under different experimental conditions were compared, especially their electrochemical impedance characteristics and their optical transmittance properties.

## Introduction

Tantalum pentoxide ($Ta_2O_5$) has a variety of uses in electricity [1] and optics [2], and it can be used as a dielectric material in capacitors [3]， in semiconductor integrated devices [4], as well as in battery and coating materials [5]. And it is also important as a dielectric material in a novel memory device [6]. When tantalum oxide is used as storage medium, the fast switching speed in the sub-nanosecond level and the performance of tolerance are much higher [7]. And $Ta_2O_5$ applying to the resistance switch is also a promising field of research because of its impedance characteristics. Then as an optical film, $Ta_2O_5$ films have high refractive index, small extinction coefficient and high transmittance in the visible light range, and good chemical stability [8], so it has been widely studied and used in optical fiber communications, optical electronic devices and so on.

There are many methods for preparing $Ta_2O_5$ thin films, and the sputtering method is widely used because of its simple process, large film forming area and so on [9]. However, in the sputtering method, the various aspects of properties of the deposition are different for the different process parameters. In this paper, the effects of sputtering conditions on the properties of $Ta_2O_5$ films were investigated. In particular, the impedance characteristics and the transmittance characteristics in the visible range are studied emphatically.

## Experiment

The ITO conductive glass was selected as the substrate. And the substrates were washed, ultrasonic cleaned, and dried. Experimental selection of magnetron sputtering equipment is JCP-450. The RF sputtering was used in the sputtering experiment.

The impedance characteristics of the $Ta_2O_5$ thin film were tested by electrochemical workstation with three electrodes, and the PC solution dissolved $LiClO_4$ was electrolyte. Apparatuses of obtaining transmittance data include a Xe lamp connecting a 500 mm Yvon–Jobin HR460 spectrophotometer which uses a back-thinned CCD detector to optimize scope of the

UV–VIS.

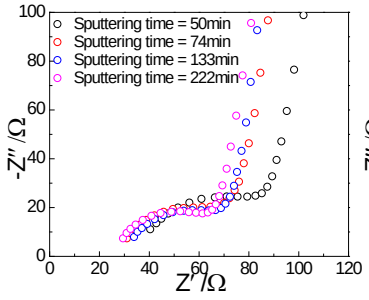


Fig. 1 The EIS of $Ta_2O_5$ thin Films under different sputtering time conditions (Power = 100w, $O_2$ flow rate = 2.5sccm, Ar flow rate = 22.5sccm).

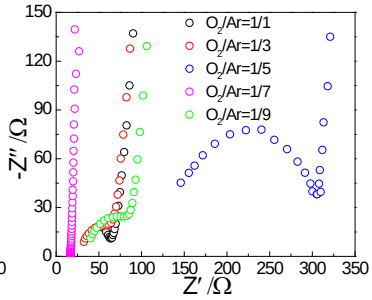


Fig. 2 The EIS of the $Ta_2O_5$ film samples prepared under different conditions of $O_2$-Ar flow ratio ($O_2$-Ar gas flow ratio were 1/1, 1/3, 1/5, 1/7, 1/9).

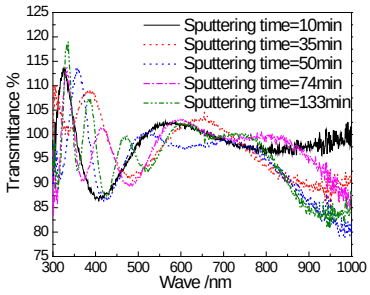


Fig. 3 The transmittance spectrum of the $Ta_2O_5$ film samples prepared under different conditions of sputtering time (Sputtering time were 10min, 35min, 50min, 74min, 133min).

## Results and Discussion

Electrochemical impedance spectroscopy (EIS), known as the AC impedance spectroscopy in the early electrochemical literatures [10]. Electrochemical impedance spectroscopy is an electrochemical measurement method that uses a small amplitude sine wave potential (or current) as the disturbance [11]. Because of the perturbation of the small amplitude electrical signal on the system, on the one hand the great impact on the system can be avoid, on the other hand it also shows approximate linear relationship between the disturbance and the system response. It is a measurement method of frequency domain, which uses the impedance spectrum of wide frequency range to study the electrode system, so that more information on the electrode interface can be obtained. The impedance of the electrode system is expressed as:

$$Z=E/I=E_0/I_0\cdot\exp(-j\theta)=|Z|\exp(-j\theta) \quad (1)$$

$$Z=|Z|(\cos\theta-j\sin\theta)=Z'-jZ'' \quad (2)$$

θ is the phase difference between the disturbance signal and the response signal [12]. The value of Z' is the horizontal axis, and the value of Z" is the vertical axis, then the impedance spectral coordinate system can be established. Through the impedance spectrum, the solution resistance Rs in the electrochemical reaction process can be obtained, that is the impedance of the electrolyte between the counter electrode and the working electrode. The solution resistance corresponds to the intersection between the left side of the semicircular arc in the high frequency region of the impedance spectrum and the real axis. At the same time the induced charge transfer impedance Rct can also be find from the impedance spectrum, the intersection between the right side of the semicircle in high frequency region and the real axis is the value of Rs + Rct. The point on the real axis of the lowest point of the spectral line represents the sum of Rs and Rb (Rs + Rb), and the Rb is the intrinsic impedance of the electrode material and the contact resistance of electroactive substances and current collectors. And the intersection of the fitting straight line and the real axis in the low frequency region represents the sum of the Warburg impedance (Diffusion impedance, Rw) of electrolyte ion in electrode channel and the Rs (Rw+Rs).

Fig. 1 shows the impedance spectrums of the $Ta_2O_5$ film that prepared by RF sputtering at different time, during the sputtering process, the sputtering power was set to 100w, and the oxygen ($O_2$) flow rate was 2.5sccm, the argon (Ar) flow rate was 22.5sccm, and the ratio of $O_2$ to Ar was 1/9. It can be seen from Fig. 1 that with the increase of the sputtering time, the similar semicircle in the high frequency region of the impedance spectrums decreases gradually, that is to say that the induced charge transfer resistance Rct decreases gradually. Then curves move to the left gradually with the sputtering time increases, so the intrinsic impedance and the contact resistance Rb of the film samples are obviously reduced and the Warburg impedance Rw of the samples are reduced distinctly. Since the sample sputtering time increases, the thickness of the film samples is increase,

it can be said that Rct, Rb, Rw of $Ta_2O_5$ film samples are decreased visibly with the thickness increases.

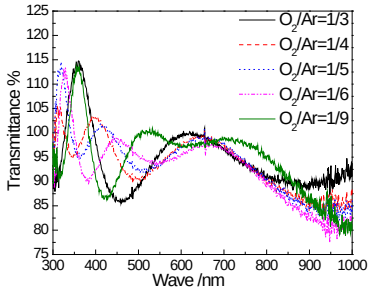


Fig. 4 Transmittance spectrums of the $Ta_2O_5$ film samples prepared under different conditions of $O_2$-Ar flow ratio ($O_2$-Ar gas flow ratio were 1/3, 1/4, 1/5, 1/6, 1/9).

The comparison of the impedance spectra of the $Ta_2O_5$ film samples that obtained at different ratio of $O_2$-Ar is shown in Fig. 2, but the total of gas flow rate of $O_2$ and Ar in each ratio is substantially same. It can be seen that except for the impedance spectra of the $O_2$-Ar ratio of 1/7, the rest of the impedance spectra exhibit the approximate semicircle arc in high frequency region, and Rct, Rb and Rw get the maximum value when the $O_2$-Ar ratio is 1/5. Fig. 3 shows the transmittance spectrums of $Ta_2O_5$ thin film samples that prepared at different sputtering time, but the sputtering power was all 100w, $O_2$ flow rate was 2.5sccm, Ar flow rate was 22.5sccm. We can see that with the increase of sputtering time, the peaks position of transmittance spectrums are moving, but the overall transmittance in the visible range is still very high, and it is basically more than 85%. Even at the condition of sputtering time of 133min, there is the highest transmittance peak in the shorter wavelength region. The transmittance spectrums at different gas flow ratio shows in Fig. 4. And the sputtering power was 100w, the sputtering time was 50min. The peaks position in transmittance spectrums show a certain movement in the visible range with the oxygen argon flow ratio changing, then the overall transmittance is also above 85%.

## Conclusion

The results show that the Rct, Rb and Rw of the $Ta_2O_5$ films decrease with the increase of the sputtering time. At the same sputtering time, but different $O_2$-Ar flow ratio, the $Ta_2O_5$ film samples exhibit different impedance characteristics. Compared to other cases, it gets the maximum impedance value when the $O_2$-Ar flow ratio was 1/5. At the same time, there is little effect on the transmittance of the $Ta_2O_5$ film samples at different experimental conditions, and transmittance of all the samples is more than 85%.

## Reference

[1] Lee, Ah Rahm, Baek, Gwang Ho, Kim, Tae Yoon, et al. Memory window engineering of $Ta_2O_5$−x oxide-based resistive switches via incorporation of various insulating frames. Scientific Reports, 2016, 6.

[2] Zhichao Liu, Yi Zheng, Feng Pan, Qi Lin, Ping Ma, Jian Wang. Investigation of laser induced damage threshold measurement withsingle-shot on thin films. Applied Surface Science, 2016, 382: 294-301.

[3] Thind, Sapanbir S., Chang, Xin, Wentzell, Jordan S., et al. High-performance supercapacitor based on tantalum iridium oxides supported on tungsten oxide nanoplatelets. Electrochemistry Communications, 2016, 67: 1-5.

[4] D.Q. Yu, W.S. Lau, Hei Wong, et al. The variation of the leakage current characteristics ofW/$Ta_2O_5$/W MIM capacitors with the thickness of the bottomW electrode. Microelectronics Reliability, 2016, 61: 95-98.

[5] M.P. Chon, K.B. Tan, C.C. Khaw, et al. Subsolidus phase equilibria and electrical properties of pyrochlores in the $Bi_2O_3$eCuO$eTa_2O_5$ ternary system. Journal of Alloys and Compounds, 2016, 675: 116-127.

[6] Hu Wei, Zou Lilan, Gao Chao. High speed and multi-level resistive switching capability of $Ta_2O_5$ thin films for nonvolatile memory application. Journal of Alloysand Compounds, 2016, 676: 356-360.

[7] Chen Hsin-Wei, Sakai Nobuya, Jena Ajay Kumar. A Switchable High-Sensitivity Photodetecting and Photovoltaic Device with Perovskite Absorber. Journal of Physical Chemistry Letters, 2015, 6(9): 1773-1779.

[8] Manjakkal Libu, Cvejin Katarina, Kulawik Jan. X-ray photoelectron spectroscopic and electrochemical impedance spectroscopic analysis of $RuO_2$-$Ta_2O_5$ thick film pH sensors. Analytica Chimicaacat, 2016, 931: 47-56.

[9] Mannequin Cedric, Tsuruoka Tohru, Hasegawa Tsuyoshi, et al. Identification and roles of nonstoichiometric oxygen in amorphous $Ta_2O_5$ thin films deposited by electron beam and sputtering processes. Applied Surface Science, 2016, 385: 426-435.

[10] Nikolov K., Kaestner P., Klages C. -P., et al. Low-pressure diffusion chromising of thin low-carbon steel sheet for improved surface and bulk properties. Journal of Alloysand Compounds, 2017, 692: 101-107.

[11] Harkonen Emma, Tervakangas Sanna, Kolehmainen Jukka. Interface control of atomic layer deposited oxide coatings by filtered cathodic arc deposited sublayers for improved corrosion protection. Materials Chemistry and Physics, 2014, 147(3): 895-907.

[12] Liu XY, Li YA, Liu S, Wu HL, Cui HN. ZnO/Cu/ZnO multilayer films: Structure optimization and investigation on photoelectric properties. Thin Solid Films, 2012, 520(16): 5372-5377.