Available online at www.sciencedirect.com
SCIENCE DIRECT®
Nuclear Instruments and Methods in Physics Research B 242 (2006) 26–29
NIM B
Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Effect of tantalum content of titanium oxide film fabricated by magnetron sputtering on the behavior of cultured human umbilical vein endothelial cells (HUVEC)

J.Y. Chen [a], Y.X. Leng [a,b], X. Zhang [a], P. Yang [a], H. Sun [a], J. Wang [a], G.J. Wan [a,b], A.S. Zhao [a], N. Huang [a,*], P.K. Chu [b]

[a] *Laboratory of Surface Engineering of Artificial Organs of Sichuan, Key Laboratory of Advanced Technologies of Materials, Ministry of Education, Southwest Jiaotong University, Chengdu, Sichuan 610031, China*

[b] *Department of Physics and Materials Science, City University of Hong Kong, Kowloon, Hong Kong*

Available online 21 September 2005

Abstract

In this work, we synthesized titanium oxide thin films containing different tantalum using magnetron sputtering to meet the challenge of enhanced biocompatibility. The structure characteristics of the films were characterized using X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS) and atomic force microscopy (AFM). The biological behavior of human umbilical vein endothelial cells (HUVECs) on the film surface was investigated by in vitro cell culture. Study of cultured HUVEC onto films revealed that the growth and proliferation behavior of EC were varied significantly due to the different Ta content which resulting the characterization of films is different. The adherence, growth, shape and proliferation of EC on Ti–O film with high Ta content and smoother surface was excellent.
© 2005 Elsevier B.V. All rights reserved.

PACS: 81.15.Cd; 87.17.Ee

Keywords: Titanium oxide film; Tantalum content; Magnetron sputtering; Characteristics; Endothelial cells

1. Introduction

The behavior of titanium oxide and its interaction with blood have been investigated [1]. The surface induced thrombo-embolism remains an important clinical complication issue [2], because in many cases the surface of prostheses organ is not recognized by blood. To minimize thrombi and emboli generation and to increase the lifetime, a number of different surface treatment processes have been adopted [3]. The thin solid film technique is an extensively employed method for surface modification of biomedical inorganic materials to improve and control biocompatibility for blood and cell attachment [4,5]. However, this study revealed that its biocompatibility is still far from ideal. It is believed that seeding with endothelial cells on vascular prostheses may overcome this problem because of non-thrombogenic properties of the cells in nature state in contacting with blood [6,7]. Therefore endothelialization of cardiovascular device surfaces has been regarded as an important means to prevent thrombogenicity. In this work, we focus on experimentally investigation of the biological behavior of ECs on titanium oxide film containing tantalum with a range from 1 at.% to 5 at.% to meet the challenge of enhanced biocompatibility.

2. Experimental

2.1. Film preparation and characterization

Titanium oxide films containing different Ta were synthesized on (1 0 0) silicon wafers using a UBMS500

* Corresponding author. Tel./fax: +86 28 87600625.
E-mail address: huangnan1956@163.com (N. Huang).

0168-583X/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.nimb.2005.08.098

magnetron sputtering system by sputtering a high-purity inlaid Ti–Ta complex target of 170 5136 mm in size and sustaining an oxygen partial pressure by a flow monitor system. Changing Ta content of target can easily control the composition of the film. The film thickness is about 1.2–1.6 μm measured by α-step measurement system. The structure, composition and surface morphology of the Ti–O films containing Ta were characterized using XRD (X'Pert Pro MPD), XPS (XSAM-800) and AFM (SII, Autoprobe SPA400).

2.2. Biological investigation of HUVECs

HUVECs were harvested from freshly obtained human umbilical cord using the collagenase isolation technique described by Jaffe et al. [8] with slight modification. After harvesting ECs, cells were resuspended in complete growth medium 199 contained similar component described in [9]. All samples were subject to autoclaving at 120 °C for 30 min before seeding the ECs. Sterilized samples were placed in the wells of a 6-well culture plate. The above complete medium 199 was seeded onto these samples surface at a drop of 1 ml. All EC incubations were at 37 °C in a humidified atmosphere containing 95% air and 5% CO_2 for 3 days. The samples were subsequently rinsed, fixed, dehydrated and critical point dried as described in [10]. The specimens were then coated with a gold layer 10–20 nm thick and examined by scanning electron microscopy (SEM, JSE-5900LV type, Japan). All experimental conditions are identical to different film material for better comparable results.

3. Results and discussion

3.1. Characterizations of the films

With the Ta content increasing, the microstructure of the films is obviously different. Fig. 1 shows the XRD patterns of the prepared films. It is clear that, the structure of

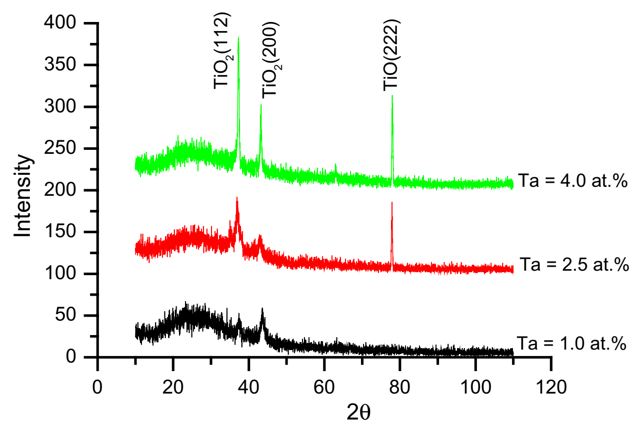

Fig. 1. The XRD patterns of the as-deposited Ti–O films containing Ta.

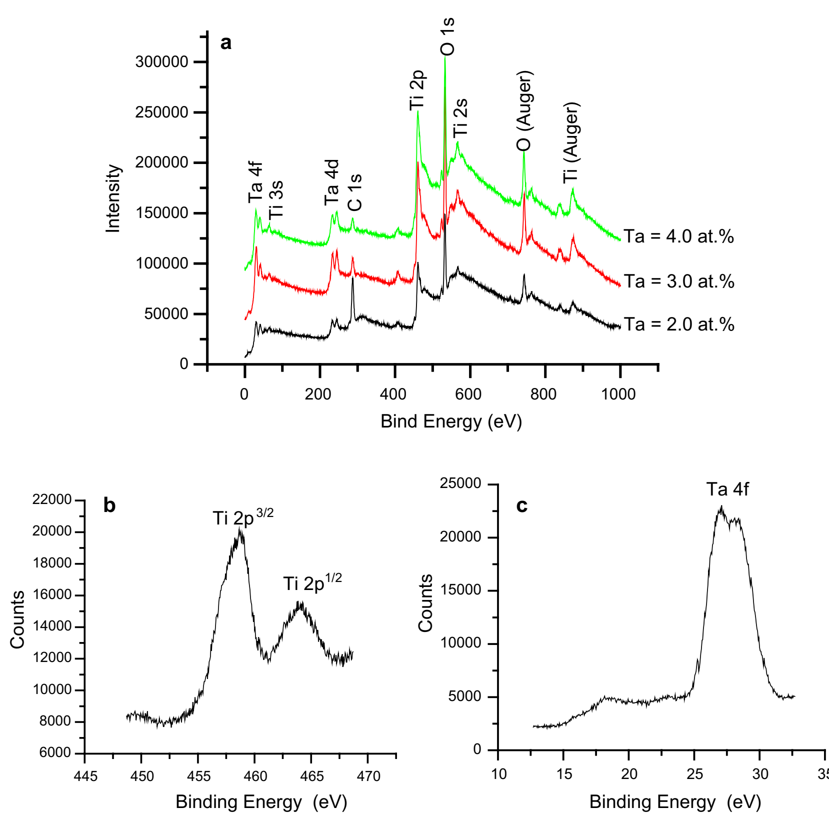

Fig. 2. XPS spectrum of the as-deposited Ti–O film containing Ta (a) XPS spectrum, (b) Ti_{2p} and (c) Ta_{4f}.

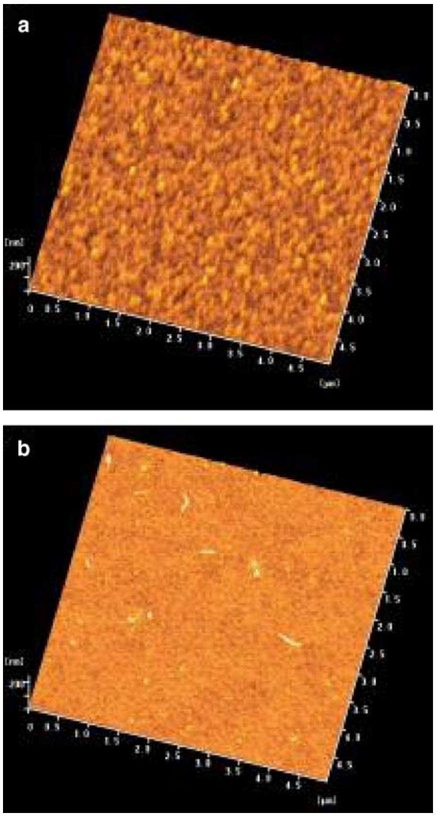

Fig. 3. The AFM surface morphology of the (a) low and (b) high Ta content Ti–O film.

the Ti–O film containing Ta has been transferred from low index $TiO_2(2\,0\,0)$ to a mixture of high index $TiO_2(1\,1\,2)$ and non-stoichiometric suboxides of TiO(2 2 2) etc. poly-crystalline type with Ta content increasing. Fig. 2 displays the XPS spectra of the film. XPS narrow scan of titanium and tantalum peaks indicate that the valence state of Ti and Ta is Ti^{4+}, Ti^{2+} and Ta^{0+}, respectively. Different titanium oxides of the film are identified as TiO_2 and TiO which verified the results of XRD. It existed no evidence of Tantalum oxide in films. The surface morphology of the films was appeared in Fig. 3. In each case, we show representative images of these films. The high Ta content Ti–O film surface is slightly flatter than the low Ta content film. Many acute peaks were appeared on the surface of low Ta content Ti–O film. The results imply that, the Ta atom was helpful to grain growth of as-deposited Ti–O film because Ta atom accelerate diffusion of Ti atom and O atom during film deposition and grain growth.

3.2. Biological investigation results of HUVECs

The biological properties of the films were also different significantly due to the different Ta content. The SEM morphology of ECs adhesion and growth behavior on Ti–O film surface containing different Ta is displayed in Fig. 4, which are from the random SEM field. After incubation in complete medium 199 for 3 days, the ECs are of different

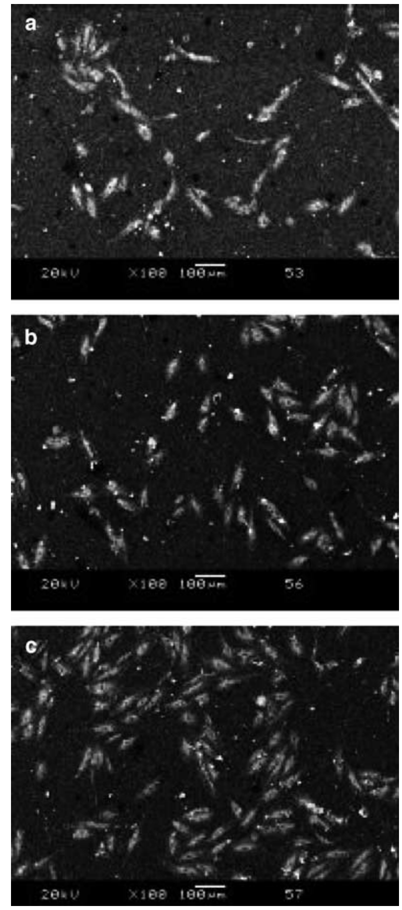

Fig. 4. The SEM morphology of the adherent ECs of the (a) 1 at.% Ta, (b) 2.5 at.% Ta and (c) 4.0 at.% Ta (cultured time: 3 days).

biological behavior onto different materials surface. With the Ta content increasing, the ECs on film surface are progressively growing in quantity and gradually forming a single layer, keep the natural original shape and display the cobblestone road metal rank, as seen in Fig. 4(c). Our experiments thus unequivocally indicate that the ECs are significantly amicable with the proper Ta content Ti–O film materials. It further implies that special Ti–O film containing Ta is of good tissue (ECs) compatibility and of good endothelialization property.

4. Conclusion

We synthesized Ti–O film containing different Ta using magnetron sputtering technique with different inlaid Ti–Ta complex target. The different characterization of the Ti–O films such as structure, composition and surface morphology etc due to the different Ta content would influence significantly biological behavior of EC. The ECs are significantly amicable onto the optimized Ti–O film containing proper Ta with excellent biological behaviors of adherence, growth, shape and proliferation. Our study further implies that special Ti–O film containing Ta is of good endothelialization property. This work supplies a new path for improving thromboresistance or biocompatible surface of inorganic materials.

Acknowledgements

This work was financially supported by the Key Basic Research Project No. 2005CB623904, National Natural Science Foundation of China Project No. 30300087# and NSFC-RGC 30318006#.

References

[1] N. Huang, P. Yang, Y.X. Leng, J.Y. Chen, H. Sun, J. Wang, G.J. Wan, P.D. Ding, T.F. Xi, Y. Leng, Biomaterials 24 (2003) 2177.
[2] S.L. Goodman, K.S. Tweden, R.M. Albrecht, J. Biomed. Mater. Res. 32 (2) (1996) 249.
[3] P. Favia, R. d'Agostino, Surf. Coat. Technol. 98 (1998) 1102.
[4] P.K. Chu, J.Y. Chen, L.P. Wang, N. Huang, Mater. Sci. Eng. Rep. 36 (5–6) (2002) 143.
[5] N. Huang, P. Yang, X. Cheng, Y.X. Leng, X.L. Zheng, G.J. Cai, Z.H. Zhen, F. Zhang, Y.R. Chen, X.H. Liu, T.F. Xi, Biomaterials 19 (1998) 771.
[6] S.L. Sanborn, G. Murugesan, R.E. Marchant, K.K. Marchant, Biomaterials 23 (2002) 1.
[7] P. Zilla, M. Deutsch, J. Meinhart, Seminar Vasc. Surg. 12 (1999) 52.
[8] E.A. Jaffe, R.L. Nachman, C.G. Becker, R. Minick, J. Clin. Invest. 52 (1973) 2745.
[9] J.Y. Chen, G.J. Wan, Y.X. Leng, P. Yang, H. Sun, J. Wang, N. Huang, Surf. Coat. Technol. 186 (1–2) (2004) 270.
[10] J.Y. Chen, Y.X. Leng, X.B. Tian, L.P. Wang, N. Huang, P.K. Chu, P. Yang, Biomaterials 23 (12) (2002) 2545.