Journal of the Korean Vacuum Science & Technology; JKVST
Vol.6, No.1, 2002, pp.36～39

Fractal Structures of Molybdena Thin Films Deposited on Alumina Ceramics

Jizhong Zhang*, Zhu Diaoa*, Haoyang Tiana*

*Department of Materials Science and Engineering, Tsinghua University, Beijing 100084, China
International Centre for Materials Physics, Academia Sinica, Shenyang 110015, China
Chinese Centre of Advanced Science and Technology, P.O. Box 8730, Beijing 100080, China

(Received)

Abstract

Molybdena powder was heated at both 660℃ and 700℃ for half-hour in an evaporation-deposition device. The molybdena thin films deposited on the surfaces of alumina ceramics displayed two kinds of fractal aggregates, i.e., the stackings of ribbon-like crystals and ramified palm-like structures. It is revealed from the experimental results that the microstructures of these fractal aggregates depended strongly on their growth conditions. The dynamics of fractal growth of molybdena thin film is discussed.

1. Introduction

Fractal patterns characterized with self-similarity and scale-invariance can be found everywhere in nature. Examples include clusters of galaxies, the structures of coastlines, and rivers etc [1]. Fractal growth even could be found in some food, and a kind of treated duck egg is one of the examples. Several tree-like branching fractal patterns at three-dimension can be observed easily in every treated duck egg. The branching fractal pattern is much similar with flower of a pine tree. That's why this kind of the treated duck egg is called as pine-flower egg.

Fractal has become an important concept for understanding irregular complex systems in various scientific disciplines. Many theoretical and experimental studies have been carried out in the past 20 years [2-5]. A number of complicated and fascinating fractal patterns were observed by computer simulation and experiments, such as diffusion-limited aggregation, electrochemical deposits, various thin films, aggregation in liquid or gaseous phase, and viscous fingering etc [6-12]. Crystalline growth under nonequilibrium conditions often spontaneously form various fractal structures that were observed in different systems and over many length scales [13-14]. In this paper two kinds of fractal structures of molybdena formed during vapor-solid transition are reported. They consisted of both ribbon MoO_3 crystals and palm-like MoO_3 crystals, respectively.

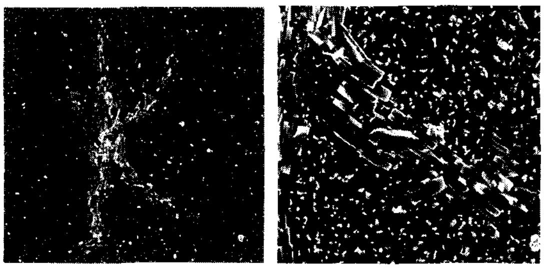
2. Experimental

The experimental set-up used in this work was an evaporation-deposition device. Two grams of high-purity MoO_3 powder was selected as source material of the evaporator, and loaded into an alumina crucible. A piece of alumina ceramics plate was cleaned carefully by alcohol and acetone, and then located above the evaporator with a distance of 35 mm. The evaporation-deposition device was heated both at 660℃ for half-hour and at 700℃ for half-hour, respectively. The molybdena molecules evaporated from the evaporation source moved randomly in the whole space of the deposition chamber. Some of them deposited on the surface of the alumina ceramics plate, and formed MoO_3 thin film. After deposition, the sample was kept in the deposition chamber, and cooled down slowly. It took about six hours to reduce the temperature of the evaporation-deposition device to room temperature. Scanning electron microscopy (SEM) was employed to observe the morphologies of MoO_3 thin film deposited on the surface of the alumina ceramics plates.

3. Results and Discussion

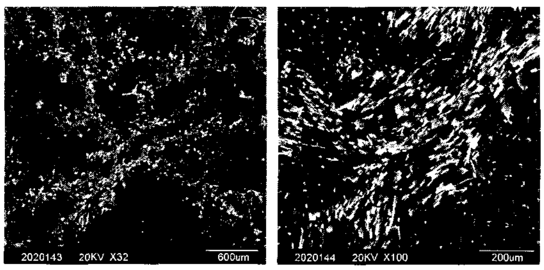
A lot of branching stackings of MoO_3 crystals was observed on the surface of the alumina ceramics plate deposited at 660℃ for half hour. Figure 1(a) shows the SEM image of a branching stacking of ribbon-like crystals. The magnification used in Fig. 1(a) was 150, and the size of the entire stacking was 0.45 mm along the longitudinal direction. It can be seen from Fig. 1(b) that each branch of the stacking consisted of many MoO_3 ribbon-like crystals. There was a layer of MoO_3 thin film underneath the stacking, which consisted of numerous tiny MoO_3 grains. The tiny grains distributed uniformly on the whole surface of the alumina ceramics plate. The average size of the tiny grains was 1.6 μm. It's reasonable to deduce that at the first stage the tiny grains grew up and deposited on the surface of the alumina ceramics plate, and subsequently many ribbon-like crystals formed above the tiny grains and aggregated together to display a branching pattern. The dynamical reason responsible for the fractal aggregation could be due to both fluctuation of temperature and/or MoO_3 molecule concentration at a local growth site, as well as long-range correlation effect.

Some bigger and denser branching stackings of ribbon-like MoO_3 crystals were observed on the surface of alumina ceramics plate that was heated at 700℃ for half-hour. Figure 2(a) shows a bigger and denser branching stacking. It also consisted of many ribbon-like crystals, and revealed that the same growth mechanism with one mentioned above was involved. The size of the branching stacking shown in Fig. 2(a) was 3.7 mm that was eight times larger than one of the branching stacking shown in Fig. 1(a). It's easy to understand because of the higher heating temperature. A closer view of the pattern was shown in Fig. 2(b), which located at the corner of down-left part in Fig. 2(a). An interesting pattern was seen in Fig. 3(a). A ramified palm-like structure was surrounded with several branching stackings of MoO_3 ribbon-like crystals. It



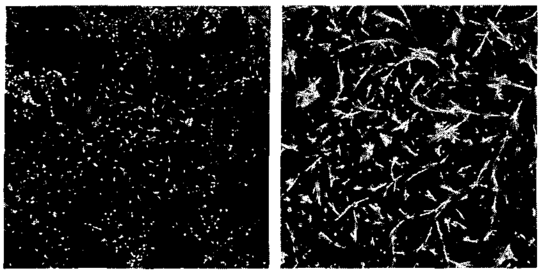
x 150 (a) x 600 (b)

Fig. 1. SEM images of a stacking of MoO_3 ribbon-like crystals that formed after heating at 660℃ for half-hour. (a) General view; (b) Closer view of a branch that was shown at down-right part in Fig. 1(a).



(a) (b)

Fig. 2. SEM images of a branching stacking of MoO_3 ribbon-like crystals that formed after heating at 700℃ for half-hour. (a) General view; (b) Closer view of a branch that was shown at down-left part in Fig. 2(a).



(a) (b)

Fig. 3. SEM images of MoO_3 thin film deposited at 700℃ for half-hour. (a) General view; (b) Closer view of the ramified palm-like structure that was shown at the center in Fig. 3(a).

consisted of many meandering palm-like MoO_3 crystals, and revealed a different growth mechanism occurring during the deposition period. Figure 3(b) is the closer view of the ramified palm-like structure that located at the center in Fig. 3(a). Each branch was thin with a sharp tip. The average size of the palm-like branches was around 186 μm. Several joint points of palm-like crystals could be seen in Fig. 3(b). A possible explanation is as follows. The local concentration of MoO_3 molecules in gaseous phase at the center of the image in Fig. 3(a) was lower than one of MoO_3 molecules outside the center. It resulted in a formation of thin and meandering crystals. Both fluctuation of temperature and/or MoO_3 molecule concentration at a local growth site, as well as long-range correlation effect were still the dominant factors to form the ramified palm-like structure.

It is suggested from the experimental results that the higher heating temperature could result in both the bigger and denser branching stackings, as well as the ramified palm-like structures. The heating temperature played an important role in forming different patterns on the surface of alumina ceramics plate.

4. Conclusions

The branching stackings of MoO_3 ribbon-like crystals formed on the surface of alumina ceramics plate after heating at 660℃ for half-hour. Both the branching stackings of MoO_3 ribbon-like crystals and ramified palm-like structures formed on the surface of alumina ceramics plate after heating at 700℃ for half-hour. The fluctuation of temperature and/or concentration of gaseous MoO_3 molecules, as well as a long-range correlation should be the dominant factors to formation of fractal aggregates of MoO_3.

The higher heating temperature resulted in bigger and denser aggregates because of higher growth rate. Also, the branching stackings of ribbon-like crystals and ramified palm-like structures could coexist on the surface of the same alumina ceramics plate. This result reveals a complicated growth mechanism that occurred during the vapor-solid transition of MoO_3, and needs to be investigated further.

Acknowledgements

This work is supported by the Fundamental Research Foundation of Tsinghua University under contractor numbers JC2000074 and JC2001011, and also supported by the Laboratory Foundation of Tsinghua University (THSJZ) and Student Research Training project of Tsinghua University (SRT), Beijing, China.

References

[1] B.B. Mandelbrot, "*The Fractal Geometry of Nature*," (W.H. Freeman, San Francisco, 1982).

[2] A. Bunde and S. Havlin (Eds.), "*Fractals in Science*," (Springer-Verlag, Berlin, 1994).

[3] L. Pietronero, Physica A **191**, 85 (1992).

[4] H. Inaoka and H. Takayasu, Phys. Rev. E **47**, 899 (1993).

[5] A. Bunde and S. Havlin (Eds.), "*Fractals and Disordered Systems*," (Springer-Verlag, Heidelberg, 1991).

[6] J. C. Russ, "*Fractal Surface*," (Plenum, New York, 1994).

[7] A. Chandra, M. K. Shukla, P. C. Mishra, and S. Chandra, Phys. Rev. E **54**, R2767 (1995).

[8] J. R. Debruyn, Phys. Rev. Lett. **74**, 4843 (1995).

[9] L. Balazs, V. Fleury, F. Duclos, and A. Vanherpen, Phys. Rev. E **54** 599 (1996).

[10] E. Benjacob, O. Shochet, A. Tenenbaum, I. Cohen, A. Czirok, and T. Vicsek, Phys. Rev. E **53**, 1835 (1996).

[11] M. M. Novak and T. G. Dewey (Eds.), *"Fractal Frontiers,"* (World Scientific, Publ. Co., Singapore 1997).

[12] M. M. Novak (Eds.), *"Fractal and Beyond,"* (World Scientific, Publ. Co., Singapore 1998).

[13] E. Ben-Jacob and P. Garik, Nature **343**, 523 (1990).

[14] C. Godreche, (Ed.), *"Solid far from equilibrium,"* (Cambridge University Press, Cambridge, 1991).