Effects of Deposition Temperature on Growth and Properties of Pulsed Laser Deposited VO_2 Thin Films and Nanostructures

Komal Mulchandani, Ankit Soni, K. R. Mavani[a)]

Discipline of Physics, Indian Institute of Technology (IIT) Indore, Simrol, Khandwa Road, Madhya Pradesh-453552, India

[a)]Corresponding author: krushna@iiti.ac.in

Abstract. Pure crystalline vanadium dioxide (VO_2) exhibits reversible metal to insulator transition at about 341K, making it suitable for the memory devices. We have deposited thin films and nanostructures of VO_2 on quartz substrate using pulsed laser deposition technique. The effects of deposition temperature on the structural and electrical properties have been investigated. X-ray diffraction spectra show that prepared thin films and nanostructures are oriented along (011) direction and crystallinity of the samples depends on the deposition temperature. Scanning electron microscopy reveals the temperature dependent morphological changes in the nanostructures. Temperature dependent resistivity measurement shows metal to insulator transition.

INTRODUCTION

The first order metal to insulator transition (MIT) in Mott insulator have been intestigated largely from theoretical as well as experimental point of view because of its wide range of applications. Among the strongly correlated materials, vanadium dioxide(VO_2) has been extensively studied from past few years because of sharp, reversible change in its optical, electrical and magnetic properties approximately at 341K[1]. This sharp MIT above room temperature promises a wide range of potential applications, such as fast optoelectric switches, Mott transistors, and memristors[2]. In VO_2 phase transition occurs due to structural changes with temperature in which VO_2 transit from a monoclinic (insulating) to a tetragonal rutile (metallic) phase with increasing temperature. Till now several kinds of crystalline phases of VO_2 have been reported [3]. Among these phases monoclinic VO_2(M) and tetragonal VO_2(R) phases are stable structures whereas monoclinic VO_2(B) and tetragonal VO_2(A) are metastable phases[4]. Nowadays, metastable monoclinic phase VO_2(B) has attracted attention due to its application in lithium-ion batteries as a promising cathode material[5] and infrared detectors[6].

Inspite of many studies a very few attempts have been made to grow nanostructures of VO_2 by Pulsed Laser Deposition (PLD). With this motivation, the VO_2 thin films and nanostructures were deposited on a quartz substrate using V_2O_3 as a target byPLD technique. The effects of deposition temperature on the morphology, structural, and electrical properties of prepared samples were studied.

EXPERIMENTAL

High purity V_2O_3 powder was hard pressedfor making a bulk pellet (target material) of 20 mm diameter and sintered for 24 hrs at 1000ºC.VO_2 thin films and nanostructures were deposited using PLD, KrF (λ=248 nm) excimer laser was used for ablation of the target material. For all the depositions, the laser energy was kept at 100 mJ and the pulse repetition rate was set at 5 Hz. Since vanadium is a multivalent element and very much sensitive to oxygen so during the deposition, oxygen partial pressure was maintained at 4 Pa. Target to substrate distance was keptat 4 cm for all the depositions. To study the effects of deposition temperatures, two samples were grown at 600ºC and 650ºC.

In order to examine the phase purity and crystallinity, synthesized VO_2 films and nanostructures were characterized by X-Ray Diffraction (XRD) with Cu K_{α} radiation(1.54 Å) using a Rigaku Smart Lab X-ray diffractometer.Field Emission Scanning Electron Microscope (FESEM, Supra 55 Ziess) was used to analyze the morphology of grownnanostructures.The thickness of films was measured by X-ray reflectivity measurement and found 68 nm. Temperature dependent resistivity measurement was performed with the four probe method to understand the electronic transport behavior of thin films.

RESULTS AND DISCUSSION

Figure1shows the XRD patterns of VO_2 films and nanostructures grown on a quartz substrate at 600˚Cand 650˚C. For comparison, the XRD pattern of quartz substrate is also present, where shows a peak due to areflection from the sample holder. It can be seen that both films and nanostructures are highly oriented along (011) direction corresponding to the monoclinic phase of VO_2.Full Width at Half Maximum (FWHM) of thin films and nanostructures indicates that samples grown at 650˚C are more crystalline.

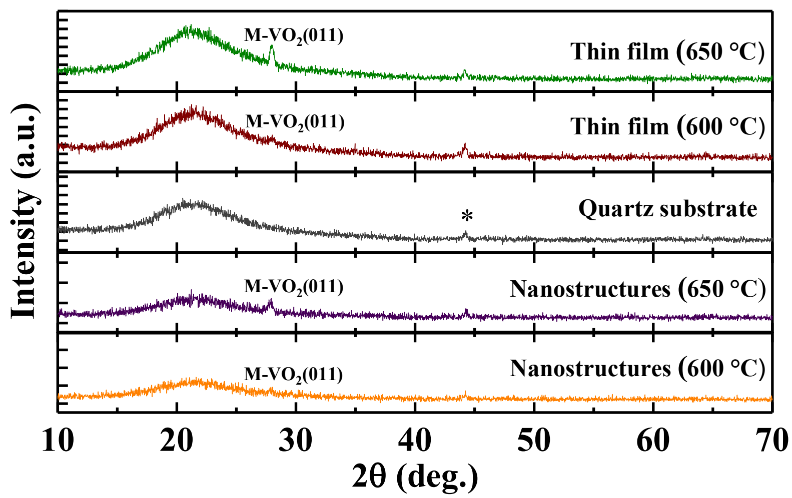

FIGURE 1. X-Ray diffraction patterns of PLD grown VO_2 thin films and nanostructures

Figure 2 shows the SEM images ofPLD grown crystalline nanostructures at 600˚C and 650˚C. A change in morphology was observed with change in deposition temperature. At 650˚C the nanostructures do not show charge conductance, indicating that the connectivity throughout the nanostructures is lost at this temperature and at 600˚C nanostructures show a high resistivity due to a poor connectivity throughout the surface.Thus itcan be concluded that the deposition temperature is playing a very crucial role in the growth of nanostructures.

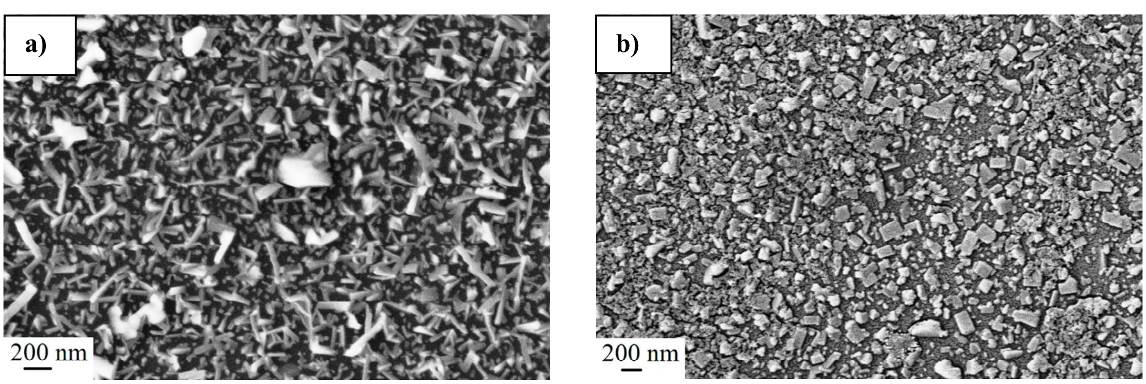

FIGURE 2. SEM images of VO_2 nanostructures grown by PLD at a) 600˚C and b) 650˚.

In order to understand the electronic transport behavior of thin films, temperature dependent resistivity measurements wereperformed byfour-probe method. From Fig.3,a metal to insulator transition(MIT) was observed of the order of 10^3nearly at 353K and 349K for VO_2 films grown at 650˚Cand 600˚C respectively.A minor change was observed in resistivity with the deposition temperature.

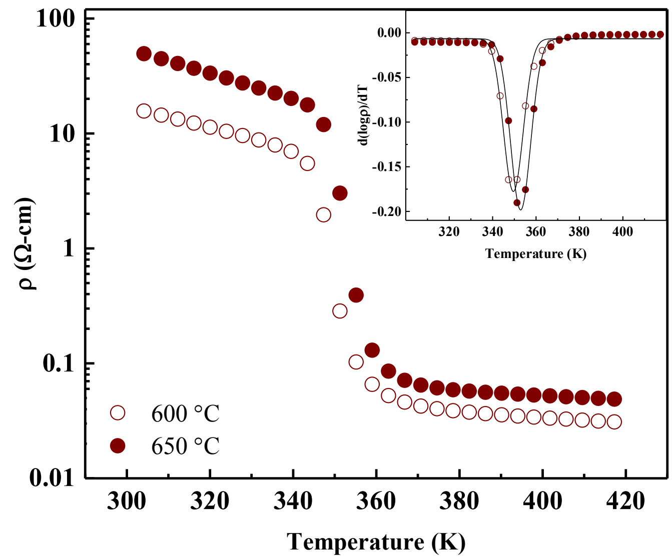

FIGURE3.Temperature dependent resistivity of VO_2 thin films. Inset shows the transition sharpness.

SUMMARY AND CONCLUSION

Crystalline thin films and nanostructures were successfully grown on quartz substrate by using PLD technique at two different deposition temperatures. Structural and electrical properties were characterized of the prepared samples. It can be concluded that the crystallinity and morphology of the samples dependon the deposition temperature and electrical transport behavior shows a very slight change with the deposition temperature.

ACKNOWLEDGMENTS

We acknowledge the XRD facility of Sophisticated Instrument Center (SIC), IIT Indore and Dr. Preeti Bhobhe for extending the high temperature resistivity measurement facility.

REFERENCES

1. Fang Xu, Xun Cao, HongjieLuoc and Ping Jin, *J. Mater. Chem. C***6**, 1903-1919 (2018).
2. Zheng Yang, ChanghyunKo, and ShriramRamanathan, *Annu. Rev. Mater. Res.***41**, 337–367 (2011).
3. Shufen Wang, Minsu Liu, Lingbing Kong, Yi Long, Xuchuan Jiang, and Aibing Yu, *Progress in Materials Science***81**, 1–54 (2016).
4. Aiping Chen, Zhenxing Bi, Wenrui Zhang, JieJian, QuanxiJia, and Haiyan Wang, *Appl. Phys. Lett***104**, 071909 (2014).
5. Changzheng Wu, Yi Xie, Lanyu Lei, Shuangquan Hu, and ChuanziOuYang, *Adv. Mater.***18**, 1727–1732 (2006).
6. Zhuohan Ding, Yuanyuan Cui, Dongyun Wan, HongjieLuo and Yanfeng Gao, *RSC Adv.***7**, 29496–29504 (2017).