Effects of Deposition Temperature on Growth and Properties of Pulsed Laser Deposited VO$_2$ Thin Films and Nanostructures

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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 investigated 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$_2$O$_3$ 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$_2$O$_3$ powder was hard pressed for making a bulk pellet (target material) of 20 mm diameter and sintered for 24 hrs at 1000°C.VO$_2$ thin films and nanostructures were deposited using PLD, KrF ($\lambda$=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 kept at 4 cm for all the depositions. To study the effects of deposition temperatures, two samples were grown at 600°C and 650°C.
In order to examine the phase purity and crystallinity, synthesized VO₂ films and nanostructures were characterized by X-Ray Diffraction (XRD) with Cu Kα radiation (1.54 Å) using a Rigaku Smart Lab X-ray diffractometer. Field Emission Scanning Electron Microscope (FESEM, Supra 55 Zeiss) was used to analyze the morphology of grown nanostructures. 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

Figure 1 shows the XRD patterns of VO₂ films and nanostructures grown on a quartz substrate at 600°C and 650°C. For comparison, the XRD pattern of quartz substrate is also present, where * shows a peak due to a reflection 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 VO₂. 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 VO₂ thin films and nanostructures

Figure 2 shows the SEM images of PLD 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 it can be concluded that the deposition temperature is playing a very crucial role in the growth of nanostructures.

**FIGURE 2.** SEM images of VO₂ nanostructures grown by PLD at a) 600°C and b) 650°C.
In order to understand the electronic transport behavior of thin films, temperature dependent resistivity measurements were performed by four-probe method. From Fig. 3, a metal to insulator transition (MIT) was observed of the order of $10^3$ nearly at 353K and 349K for VO$_2$ films grown at 650˚C and 600˚C respectively. A minor change was observed in resistivity with the deposition temperature.

![FIGURE 3](image)

**FIGURE 3.** 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 depend on the deposition temperature and electrical transport behavior shows a very slight change with the deposition temperature.

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**REFERENCES**