Applied Mechanics and Materials Vols. 475-476 (2014) pp 1266-1269
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doi:10.4028/www.scientific.net/AMM.475-476.1266

Research of influence thickness of nanocrystalline VOx films on their electrical properties

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Keywords: nanotechnology, nanomaterials, nanocrystalline thin films, VO_x, pulsed laser deposition.

Abstract. Nanocrystalline VO_x thin films were manufactured by using pulsed laser deposition. The influence of deposition time on electrical parameters of VO_x thin films were researched. It was determined that changes in deposition time lead to significant changes in properties of thin films, including resistivity in the range from 5 Ohm·cm to 70 Ohm·cm. The possibility of controlling physical properties of VO_x nanocrystalline films obtained in the experiments has been shown.

Introduction

Vanadium oxide (VO_x) is a material which is used for creation of different types of sensing elements: uncooled infrared detectors, gas sensors, etc.[1]. Nanostructuring of the surface of the sensitive layer are used to improve the performance of the sensors.

Pulsed laser deposition method (PLD) allows obtaining Nanocrystalline VO_x films in a wide range of properties, due to the variety of control parameters [2]. Advantages of this method are 1) low rate of deposition, 2) accuracy of thickness control, 3) congruent evaporation of all the chemical elements contained in the target, 4) low temperatures of depositions due to the growth of high-energy particles in the plasma, 5) ability to control the stoichiometric composition [3]. There are several stable forms of VO_x with different properties [4]. The composition of the films manufactured by PLD depends on the large number of mutual process parameters, making it difficult to control physical properties of VO_x films. The thickness of films depends on the duration of the deposition, with the latter not affecting other process parameters. This article shows the effect of the thickness of nanocrystalline VO_x films on their electrical properties.

Experiment

Experimental studies of the effect of the thickness of nanocrystalline VO_x films on their electrical properties were held in the modular pulsed laser deposition system (Neocera Co., USA) at Nanotechnology multi-functional complex NANOFAB NFC-9 (NT – MDT, Russia). Surface morphology of VO_x thin films was studied by Atomic Force Microscopy (AFM) Probe Nanolaboratory NTEGRA (NT - MDT, Russia). Obtained AFM images were processed using the Image Analysis computer software system («NT – MDT», Russia). Electrical measurement was performed using Hall Effect measurement system HMS-3000 (EcopiaCorp., Korea). The dependence of resistance on the temperature of the VO_x films was measured by the two-probe method.

In the PLD method, the duration of film deposition is controlled by a number of pulses. In the experiment the number of pulses varied in the range from 10000 to 55000. Pulse frequency rate was set at 10 Hz. Energy density on the target surface was 2 J/cm^2.

The VO_x films were manufactured at Si (110) – wafer. The films were formed at the substrate temperature of 300 °C. Gas pressure in the growth chamber (95%-pure oxygen) was set at $3 \cdot 10^{-2}$ Torr.

Results and discussion

It was determined that increasing the target number of pulses varied in the range from 10000 to 55000 thickness of nanocrystalline films increases from (20±2.2) nm (120±2.2) nm. Dependence of surface roughness, grain density, and grain area on thickness is shown on Fig. 1.

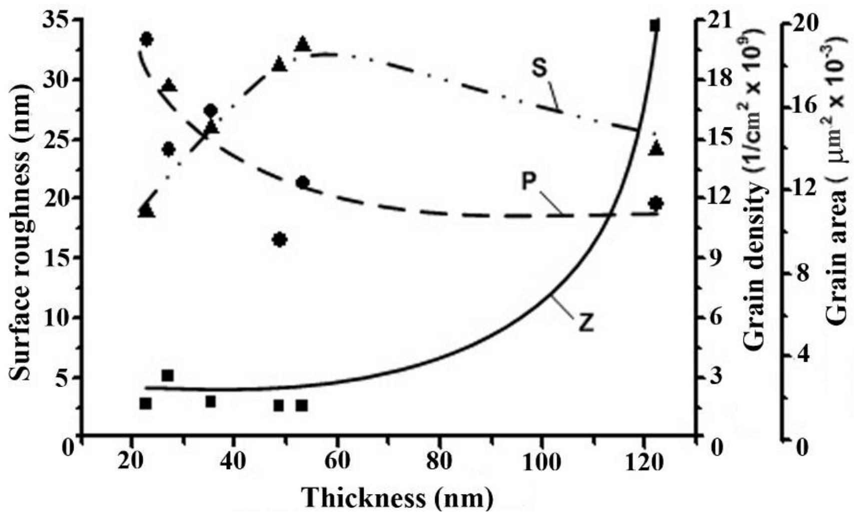

Fig. 1 – Dependence of grain parameters of nanocrystalline VOx films on thickness

The results show the characteristic curve of grain area depending on films thickness. Dependence of charge carriers‘ concentration on film thickness is complex, reaching its maximum at about 50 nm, which is in turn determined by the change in the shape of grains and their location to each other (Fig. 2).

PLD method allows changing the duration of deposition, which results in changes of morphological parameters of nanocrystalline films, though other PLD process parameters (temperature, background gas pressure) remain unchanged. Not changing PLD parameters is especially important when films are manufactured on partially formed structures.

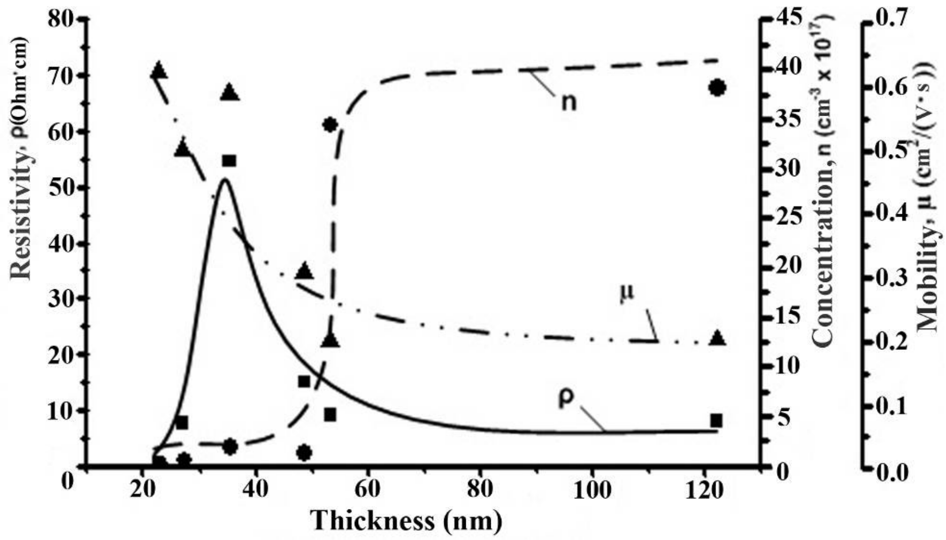

Fig. 2 – Dependence of electrical properties of nanocrystalline VOx films on film thickness

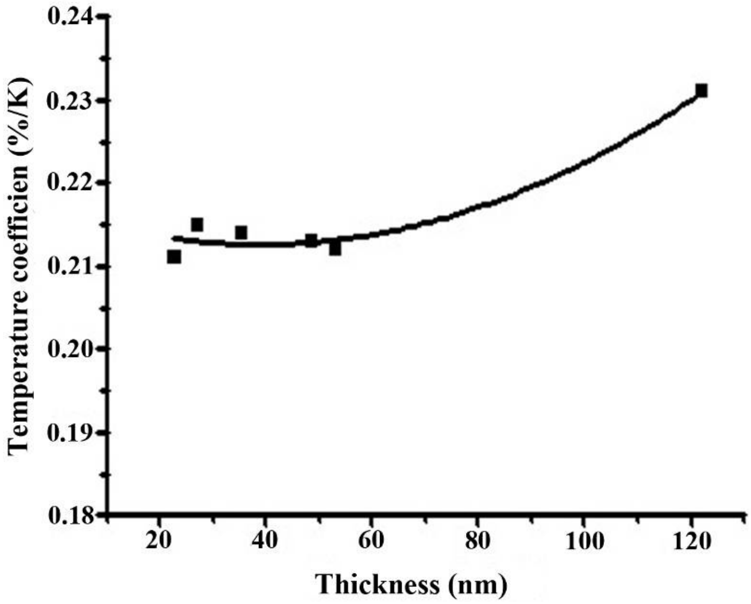

Fig. 3 – Dependence of the temperature coefficient of nanocrystalline VOx films on film thickness

Changing of VOx films‘ thickness from 30 nm to 40 nm leads to the increase in resistance. It was found out that dimensional effect of VOx thin films allows varying resistivity of films.

The area of the grain boundaries (areas of conductivity) and the concentration of charge carriers increase with increasing grain density (i.e. the number of grains per unit area). It may be due to the fact that the charge carriers are focused on the capture centers of grain boundaries, providing the conductivity.

Conclusion

Summarizing the results, the properties of VOx thin films can be controlled by changing the duration of PLD process, with other process parameters remaining unchanged. This is a fairly simple way to control the properties of VOx films. It’s important to deposit the oxide on the already formed structures (topology), which are critical to other parameters of the method. In addition, the change in thickness controls resistivity of films. Also PLD method allows to manufacture nanocrystalline VOx films in a wide range of thicknesses. This allows to avoid the hysteretic effect on the characteristic curve of temperature and resistance of the films. It complicates the creation of uncooled infrared radiation sensors.

The experiment results show that changing films thickness from 23 nm to 122 nm leads to the increase resistivity of the films from 5 ohm • cm to 70 ohm • cm It is possible to manufacture nanosructured VOx films in a wide range of thickness.

The possibility of producing nanocrystalline films VOx in this range of thickness. It was found out that polycrystalline areas of VOx films provide conductivity, as they are located close to the grain boundaries.

Acknowledgements

This work was financially supported by the Program of Development of Southern Federal University, Federal Program "Scientific and scientific-pedagogical personnel of innovative Russia" for 2009-2013, contract №14.A18.21.0900, and the Russian Foundation for Basic Research №12-08-90045-Bel_a.

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