RAP CONFERENCE PROCEEDINGS, VOL. 5, PP. 11–14, 2020
ISSN 2737-9973 (ONLINE) | DOI: 10.37392/RAPPROC.2020.04
RAP-PROCEEDINGS.ORG

INVESTIGATION OF ELECTRICAL CHARACTERISTICS AND SURFACE MORPHOLOGY OF VANADIUM OXIDE-VO_2 MOS DEVICES

Umutcan Gürer[1], Ercan Yilmaz[1,2*]

[1]Nuclear Radiation Detectors Applications and Research Center, Bolu Abant Izzet Baysal University, Bolu, Turkey
[2]Physics Department, Bolu Abant Izzet Baysal University, Bolu, Turkey

Abstract. *In this study, the electrical characteristics and surface morphology of Vanadium Oxide-VO_2 MOS Devices have been investigated. VO_2 thin films were deposited onto n-type (100) silicon wafers by using the RF magnetron sputtering system. Thin films were annealed at different temperatures in the Argon environment. The FTIR and XRD measurements were performed to check the surface morphology, crystal structure and bond structures of VO2 thin films, respectively. Except from the sample that was annealed at 700°C, the VO_2 thin films showed amorphous structure. In the ATR-FTIR analysis, V-O-V bending mode at 617 cm^{-1} and V=O stretching vibrations at 990 cm^{-1} were seen on vanadium oxide thin films. While analyzing the electrical characteristics, it has been noticed that annealing had effects on the C-V and G/w-V curves. The obtained results demonstrate that VO_2 may have the potential to be used in MOS-based applications.*

Keywords: *MOS devices, VO_2, XRD, FTIR, electrical characteristics, annealing*

1. INTRODUCTION

Nowadays, technological devices based on semiconductor materials provide many advantages [1]. Many studies have been published [2]–[5] that deal with improving sensor characteristics such as in radiation detection. To understand the mechanism behind sensor performance, different metal oxide materials have been investigated [6], [7]. One of the interesting metal oxide materials, vanadium oxide, has drawn an increasing interest due to its potential application as a catalyst, sensor, and electrode during the last decade. VO_2 is an n-type material that is known as MIT (metal-to insulator) phase change material at 67°C (e.g. changing structural phase monoclinic to tetragonal) [8], [9]. Also, vanadium oxide is known for multiple oxidation states (e.g. +4 in VO_2, +5 in V_2O_5) [10]. The studies have reported a possible usage of vanadium oxide in e.g. radiation environment [11], [12].

Therefore, the aim of this study is to investigate the electrical characteristics of VO_2 as well as to investigate the surface characteristics under different annealing temperatures for the purpose of using vanadium oxide in a radiation environment (e.g. thermochromic coating, responsive material for RF and THz radiation control [13]). For this purpose, vanadium oxide films were enlarged on the n-type Si with an RF magnetron sputtering system and the annealing process has been done with an RTA (Rapid Thermal Annealing) system under Argon ambient. The structural characteristics analysis was performed with the X-Ray Diffraction Method (XRD), whereas the chemical bond structure analysis was performed with ATR-FTIR (Attenuated total reflectance-Fourier transform infrared spectroscopy) spectroscopy. Also, the electrical characteristics analysis has been performed by analyzing C-V (capacitance-voltage) and G/w-V (conductance-voltage) curves.

2. EXPERIMENTAL DETAILS

Vanadium oxide was deposited onto 6-inch n-type (100) Si wafer with the RF Magnetron sputtering system using a 4-inch VO_2 (%99.99) sputtering target. Si wafer was cleaned by the RCA (Radio Corporation of America) technique before the deposition of VO_2 transition metal oxide material in order to prevent any contamination on the surface of the Si wafer. Right after the cleaning procedure, Si wafer was loaded into the reaction chamber of the RF Magnetron sputtering system and the pressure inside the reaction chamber was reduced to $6x10^{-4}$ Pa (Pascal). In order to remove the contamination on the VO_2 target, the pre-sputtering has been done for 1 h at 250 W. After that, the sputtering has been done for 15 min at 250 W. During the sputtering procedure, the Argon gas flow was set to 16 sccm (standard cubic centimeters per minute). After the deposition of Vanadium oxide material, the thickness of the film was determined with the spectroscopic reflectometer. Then, the deposited Si wafer was divided into 5 pieces. The first piece was held as as-deposited sample, while the other samples were

* yilmaz@ibu.edu.tr

annealed under Argon environment in the RTA system for 10 sec. The reason of choosing annealing time cause is vanadium oxide can undergo quickly phase change [14]. The annealing temperatures were set as 100°C, 300°C, 500°C, and 700°C. Then, MOS (Metal-Oxide Semiconductor) devices have been produced with the deposition of Al for both sides of thin films. The chemical bonding types in vanadium oxide thin films were determined by using the Perkin Elmer Spectrum Two FTIR-ATR spectrophotometer. The XRD analyses of the films were performed in the diffraction angle range of 10°-60°. The C–V and G/ω–V characteristics were obtained by the HIOKI 3250 LCR meter with 0.125 voltage steps in dark conditions at 1 MHz.

3. Results and discussion

The XRD measurements of the vanadium oxide thin films were performed at a diffraction angle between 10°-60°. The XRD spectra of as-deposited sample and annealed samples are depicted in Fig. 1. The as-deposited sample and the samples annealed below 700°C showed amorphous structure. On the other hand, samples that were annealed at 700°C showed a polycrystalline structure which is depicted in Fig. 2. Except from the "18.048" peak, the analysis showed that the peaks belonged to vanadium dioxide with the monoclinic phase, which is in good agreement with the ICDD (International Centre for Diffraction Data) data card of 43-1051. In contrast, the "18.048" peak showed that it was a different form of vanadium oxide, in tetragonal phase. In addition, the grain size calculation of the sample annealed at 700°C was done by the widely used Scherrer's equation [15]. The calculation of the grain size was performed using the strongest peak of VO_2 and it was 12 nm.

The ATR-FTIR measurements have been performed to investigate the type of chemical bonds of as-deposited and annealed vanadium oxide thin films. Results of the ATR-FTIR analysis are depicted in Fig. 3. The peak at 617 cm^{-1}, related to the V-O-V bending modes [16], shows increased intensity with annealing temperature. Also, the peak at 990 cm^{-1} is associated with V=O stretching vibration [17]. Therefore, it was seen that vanadium oxide formation occurred at higher temperatures.

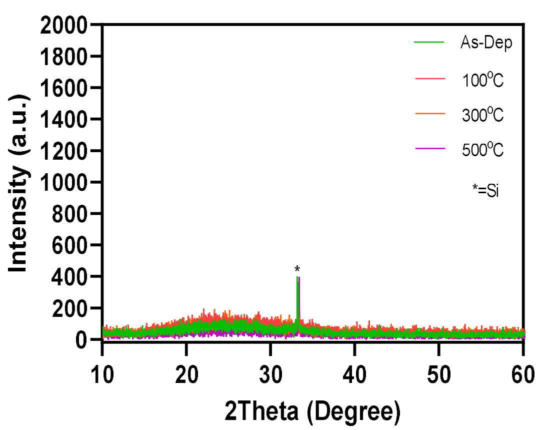

Figure 1. XRD Measurement results of As-Dep (As-deposited), 100°C, 300°C and 500°C VO_2 thin films.

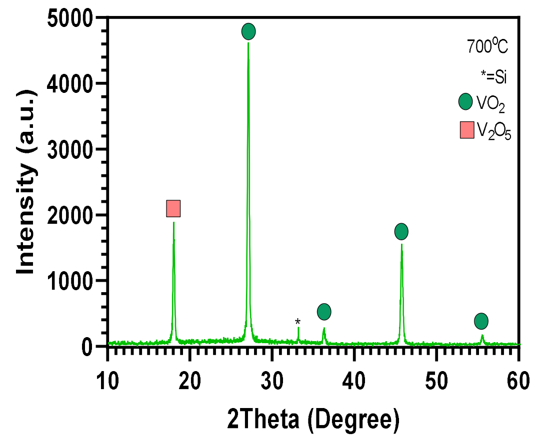

Figure 2. XRD measurement results of thin films annealed at 700°C.

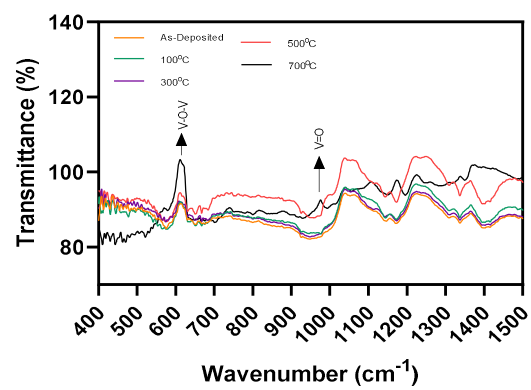

Figure 3. FTIR analysis results of Vanadium Oxide thin films.

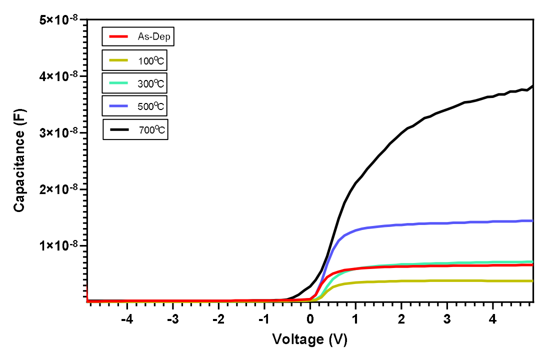

Figure 4. The Capacitance-Voltage graph of VO_2 MOS devices.

High-frequency (1 MHz) capacitance-voltage (C-V) and conductance-voltage (G/ω-V) characteristics of the Al/VO_2/n-Si MOS devices are shown in Fig. 4 and Fig 5. The capacitance and conductance values of the MOS devices showed monotonic behavior with increasing annealing temperature except 100°C annealed sample. It is well-known that post deposition annealing (PDA) has reduces the number of defects and impurities in the thin film structure [18]; this can explain the observed increase of capacitance and conductance. Also, considering grain size calculations the 700°C annealed sample showed more dense concentration than other samples as seen in Fig.3 and

Fig.4. Likewise, increasing annealing temperature may cause the reduction in the oxide, interface fixed oxide charges [13], [19]. Therefore, these causes may introduce the increase in the capacitance and the conductance values.

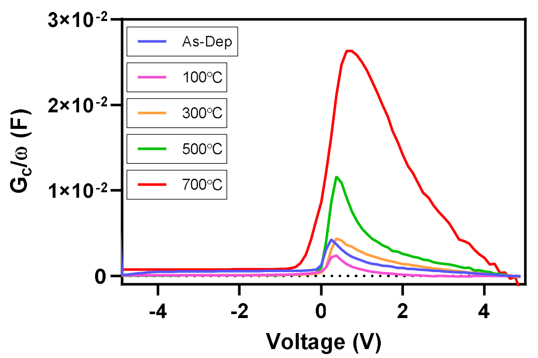

Figure 5. The Conductance-Voltage graph of VO_2 MOS devices.

4. Conclusion

The investigation of the Vanadium oxide MOS devices have been done within the scope of electrical characteristics and surface morphology. As seen from the XRD measurements, the crystallinity of vanadium oxide showed intense peaks when annealed at 700°C. The samples annealed below 700°C showed amorphous structure. Also, the ATR-FTIR analysis revealed that the peaks belong to V-O-V bending modes and V=O stretching vibrations showed an increment with the increasing annealing temperature. Likewise, an increase in capacitance and conductance values in VO_2 MOS devices may be explained by reduction of the defects with increasing annealing temperature. The obtained results demonstrate that VO_2 may have potential to be used in MOS-based applications.

Acknowledgements: *This work is supported by the Presidency of Turkey, Presidency of Strategy and Budget under Contract Number: 2016K12-2834.*

References

[1] O. Pakma, C. Özaydın, Ş. Özden, I. A. Kariper, Ö. Güllü, "Synthesis and characterization of vanadium oxide thin films on different substrates," *J. Mater. Sci.: Mater. Electron.*, vol. 28, no. 15, pp. 10909 – 10913, Aug. 2017.
DOI: 10.1007/s10854-017-6870-1

[2] R. Lok, S. Kaya, H. Karacali, E. Yilmaz, "A detailed study on the frequency-dependent electrical characteristics of Al/HfSiO4/p-Si MOS capacitors," *J. Mater. Sci.: Mater. Electron.*, vol. 27, no. 12, pp. 13154 – 13160, Dec. 2016.
DOI: 10.1007/s10854-016-5461-x

[3] A. Kahraman, "Understanding of post deposition annealing and substrate temperature effects on structural and electrical properties of Gd2O3 MOS capacitor," *J. Mater. Sci.: Mater. Electron.*, vol. 29, no. 10, pp. 7993 – 8001, May 2018.
DOI: 10.1007/s10854-018-8804-y

[4] A. Kahraman, U. Gurer, R. Lok, S. Kaya, E. Yilmaz, "Impact of interfacial layer using ultra-thin SiO2 on electrical and structural characteristics of Gd2O3 MOS capacitor," *J. Mater. Sci.: Mater. Electron.*, vol. 29, no. 20, pp. 17473 – 17482, Oct. 2018.
DOI: 10.1007/s10854-018-9847-9

[5] A. Kahraman, H. Karacali, E. Yilmaz, "Impact and origin of the oxide-interface traps in Al/Yb2O3/n-Si/Al on the electrical characteristics," *J. Alloys Compd.*, vol. 825, article no. 154171, Jun. 2020.
DOI: 10.1016/j.jallcom.2020.154171

[6] S. Abubakar, S. Kaya, H. Karacali, E. Yilmaz, "The gamma irradiation responses of yttrium oxide capacitors and first assessment usage in radiation sensors," *Sens. Actuator A Phys.*, vol. 258, pp. 44 – 48, May 2017.
DOI: 10.1016/j.sna.2017.02.022

[7] R. Lok, E. Budak, E. Yilmaz, "Radiation response of zirconium silicate P-MOS capacitor," *Microelectron. Reliab.*, vol. 109, article no. 113663, Jun. 2020.
DOI: 10.1016/j.microrel.2020.113663

[8] J. Liang, J. Li, L. Hou, X. Liu, "Tunable Metal-Insulator Properties of Vanadium Oxide Thin Films Fabricated by Rapid Thermal Annealing," *ECS J. Solid State Sci. Technol.*, vol. 5, no. 5, pp. P293 – P298, Mar. 2016.
DOI: 10.1149/2.0281605jss

[9] H. Yin et al., "Self-assembled vanadium oxide nanoflakes for p-type ammonia sensors at room temperature," *Nanomaterials*, vol. 9, no. 3, article no. 317, Mar. 2019.
DOI: 10.3390/nano9030317
PMid: 30818822
PMCid: PMC6473898

[10] A. Rakshit, D. Biswas, S. Chakraborty, "Deposition and characterization of vanadium oxide based thin films for MOS device applications," in *Proc. DAE Solid State Physics Symposium (DAE SSPS 2017)*, Mumbai, India, 2018.
DOI: 10.1063/1.5029064

[11] D. Yılmaz, B. Güzeldir, T. Akkuş, T. Öznülüer, "X- and gamma-ray irradiation effects on vanadium pentoxide thin films," *Spectrosc. Lett.*, vol. 51, no. 6, pp. 297 – 301, 2018.
DOI: 10.1080/00387010.2018.1475397

[12] I. G. Madiba et al., "Effects of gamma irradiations on reactive pulsed laser deposited vanadium dioxide thin films," *Appl. Surf. Sci.*, vol. 411, pp. 271 – 278, Jul. 2017.
DOI: 10.1016/j.apsusc.2017.03.131

[13] S. M. Sze, K. K. Ng, *Physics of Semiconductor Devices,* 3rd ed., Hoboken (NJ), USA: J. Wiley and Sons, 2006.
DOI: 10.1002/9780470068328.fmatter

[14] M. Zhu et al., "New route for modification of thermochromic properties of vanadium dioxide films via high-energy X-ray irradiation," *Ceram. Int.*, vol. 45, no. 2, pp. 1661 – 1669, Feb. 2019.
DOI: 10.1016/j.ceramint.2018.10.043

[15] Y. Waseda, E. Matsubara, K. Shinoda, *X-Ray Diffraction Crystallography: Introduction, Examples and Solved Problems*, 1st ed., Berlin Heidelberg, Germany: Springer-Verlag, 2011.
Retrieved from:
http://library.lol/main/FED836C9F6CF8C06C6CC ECDEC62CE07F
Retrieved on: Sep. 13, 2019

[16] I. Derkaoui et al., "Structural and optical properties of hydrothermally synthesized vanadium oxides nanobelts," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 186, article no. 012007, 2017.
DOI: 10.1088/1757-899X/186/1/012007

[17] S. Pavasupree, Y. Suzuki, A. Kitiyanan, S. Pivsa-Art, S. Yoshikawa, "Synthesis and characterization of vanadium oxides nanorods," *J. Solid State Chem.*, vol. 178, no. 6, pp. 2152 – 2158, Jun. 2005.
DOI: 10.1016/j.jssc.2005.03.034

[18] A. Kahraman, E. Yilmaz, S. Kaya, A. Aktag, "Effects of post deposition annealing, interface states and

series resistance on electrical characteristics of HfO2 MOS capacitors," *J. Mater. Sci.: Mater. Electron.*, vol. 26, no. 11, pp. 8277 – 8284, Nov. 2015. DOI: 10.1007/s10854-015-3492-3

[19] S. Abubakar, E. Yilmaz, "Optical and electrical properties of E-Beam deposited TiO2/Si thin films," *J. Mater. Sci.: Mater. Electron.*, vol. 29, no. 12, pp. 9879 – 9885, Jun. 2018. DOI: 10.1007/s10854-018-9029-9