INVESTIGATION OF ELECTRICAL CHARACTERISTICS AND SURFACE MORPHOLOGY OF VANADIUM OXIDE-VO₂ MOS DEVICES

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Abstract. In this study, the electrical characteristics and surface morphology of Vanadium Oxide-VO₂ MOS Devices have been investigated. VO₂ 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 VO₂ 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 VO₂ may have the potential to be used in MOS-based applications.

Keywords: MOS devices, VO₂, 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. VO₂ 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 VO₂, +5 in V₂O₅) [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 VO₂ 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 VO₂ (%99.99) sputtering target. Si wafer was cleaned by the RCA (Radio Corporation of America) technique before the deposition of VO₂ 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 VO₂ 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-deposited sample, while the other samples were...
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 VO₂ 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.

High-frequency (1 MHz) capacitance-voltage (C-V) and conductance-voltage (G/ω-V) characteristics of the Al/VO₂/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.

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 VOx MOS devices may be explained by reduction of the defects with increasing annealing temperature. The obtained results demonstrate that VOx may have potential to be used in MOS-based applications.

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