STRUCTURAL PROPERTIES AND RADIATION RESPONSE OF NEODYMIUM OXIDE

Ramazan Lok¹, Erhan Budak²,³, Ercan Yılmaz¹,³*

¹Nuclear Radiation Detector Research and Applications Center, Bolu Abant Izzet Baysal University, Bolu, Turkey
²Department of Chemistry, Faculty of Art and Science, Bolu Abant Izzet Baysal University, Bolu, Turkey
³Department of Physics, Faculty of Art and Science, Bolu Abant Izzet Baysal University, Bolu, Turkey

Abstract. Neodymium oxide (Nd₂O₃) was deposited by the sol-gel method on a P-type (100) silicon wafer. The chemical characterization of neodymium oxide was performed by Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), energy-dispersive spectra (EDS), and atomic force microscopy (AFM), and surface morphology was examined by the scanning electron microscopy (SEM). In order to examine the neodymium oxide radiation response, samples were irradiated using a Co-60 gamma-ray source from 1 to 100 Gy at a dose rate of 0.015 Gy/s. A dramatic variation was observed in the capacitance and conductance with increasing radiation dose. Irradiation creates a large number of e-h pairs and defects in the structure. For this reason, significant changes can occur in the electrical characteristics of the device. Consequently, neodymium oxide may have significant usage for microelectronic technology for radiation sensors.

Keywords: Nd₂O₃ MOS capacitors, irradiation response, interface states, oxide trapped charges

1. INTRODUCTION

The basic structures of MOSFETs are MOS capacitors. Since MOSFETs are widely used in many areas, MOS capacitors are being studied extensively. SiO₂ is used as an insulator in conventional MOS capacitors. SiO₂ is a limiting factor in reducing device size due to the properties of the dielectric material. The thickness of the SiO₂ layer decreases with the reduction in dimensions, which causes the dielectric property of SiO₂ to be insufficient [1]. In order to overcome these problems, search has been made for new materials that can be used instead of SiO₂ [2,3]. For this reason, many dielectric materials have been extensively studied in recent years [4–6].

MOS capacitors can be used for radiation measurement systems due to trapping of radiation-induced charges in the dielectric layer. The purpose of this study is to examine the radiation-dependent properties of neodymium oxide dielectric material.

2. EXPERIMENTAL DETAILS

Nd₂O₃ was deposited on a P-type silicon substrate (100) by the sol-gel dip coating. All reagents were analytically available and were used without further purification. For the sol-gel preparation, 0.1 g of NdCl₃ powders was dissolved in 50 ml of concentrated acetic acid at 50°C. After dissolving the powder, the temperature of the solution was kept between 60-70°C and stirred for two hours. Then, 50 ml of ethylene glycol was added to the solution and mixed at the same temperature for an extra four hours. After 3 days of aging, the silicon wafer was placed into the pre-coated film was annealed in air at 650°C for 2 hours.

Types of chemical bonding in Nd₂O₃ were determined by a Perkin Elmer Spectrum Two FTIR-ATR spectrophotometer. Crystallinity of Nd₂O₃ was analyzed by a Rigaku Multiflex Diffractometer employing CuKα radiation, while the cross-section of the films was obtained by a Jeol JSM 6390LV Scanning Electron Microscope. In addition, the energy-dispersive X-Ray (EDX) was used to determine the average chemical composition of Nd₂O₃. For the electrical characterization, back and front aluminum (Al) contacts were done; front side Al electrodes were formed through a shadow mask in circular dots with a 1.5 mm diameter by using the sputtering technique.

Neodymium oxide MOS capacitors were irradiated with a 60Co source. After each irradiation step, up to the maximum dose of 200 Gy, the capacitance-voltage (C–V) measurements were taken.

3. RESULTS AND DISCUSSION

The elemental analysis of the Nd₂O₃ thin film, EDS, was performed and the results are shown in Figure 1. High proportions of oxygen and neodymium were found in the structure. Neodymium ratio was found to be approximately 59.41%. The oxygen concentration corresponding to neodymium in the building was
calculated to be approximately 10.21%. The source of the excess oxygen is due to the formation of cristobalites. As seen in Figure 2, after the FTIR analysis, a small shoulder peak around 3608 cm\(^{-1}\) and a sharp peak around 653 cm\(^{-1}\) were labeled as Nd-O vibrations. The presence of a strong peak O-H (water) around 3344 and 1639 cm\(^{-1}\) has been shown [7,8].

According to the XRD results given in Figure 3, a low crystalline cubic (c) phase Nd\(_2\)O\(_3\) was observed.

Due to the traps caused by radiation in the neodymium oxide MOS capacitor structure, the C-V curve shifted to the right, as seen in Figure 4. C-V measurements were taken at high frequency to eliminate frequency-dependent charges. The positive charges, which shift the C-V curve to the right, are trapped in greater numbers than negative charges. For this reason, the flat band voltage was shifted to the right with radiation dose.

The variation of the flat band voltage calculated from the C-V curves is shown in Figure 5. The flat band voltage shift is relatively linear up to 20 Gy and reaches saturation at higher doses.

The evolution of interface states with radiation dose is shown in Figure 6. Density of radiation-induced interface states are calculated from Equation 1 [9]:

\[
\Delta N_i = \frac{C_m (\Delta V_{fb} - \Delta V_{ox})}{q A}
\] (1)

The evolution of oxide traps with radiation dose is shown in Figure 7. Density of radiation-induced oxide traps are calculated from Equation 2 [10]:

\[
\Delta N_{ox} = \frac{C_m (\Delta V_{fb} - \Delta V_{ox})}{q A}
\]
where in Equations (1) and (2), A and q are the capacitor area and the electric charge, respectively, Cox is the oxide capacitance. $\Delta V_{gg}$ is the mid-gap voltage shift, and $\Delta V_{fb}$ is the flat band voltage shift.

Figure 7. Variation of the radiation-induced oxide traps of the Nd$_2$O$_3$ p-MOS Capacitor with total gamma dose.

While the radiation-induced interface states increase up to 100 Gy, their density decreases after that. This behavior can be explained by the formation and transformation of interface traps/border traps or by passivation of interface traps at higher radiation doses. Interface states can be of the acceptor and donor type [11]. When donor-like conditions are more dominant, the C-V curve shifts to negative values, otherwise to positive values. The oxide traps increase continuously during irradiation.

4. CONCLUSION

According to the results of the structural analysis, neodymium oxide structure has been successfully produced. The capacitance-voltage measurement results have illustrated that the curves of the irradiated MOS capacitors shifted to the left with irradiation. It is concluded that neodymium oxide is suitable for electronics applications in radiation measurement.

Acknowledgements: This work was supported in part by Presidency of Turkey, Presidency of Strategy and Budget under Contract Number: 2016K12-2834, in part by Bolu Abant Izzet Baysal University, Bolu, Turkey, under contract BAP. 2014.03.02.764.

REFERENCES