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OPTICAL AND ELECTRICAL CHARACTERISTICS OF FABRICATED THREE-LAYER $Al/Er_2O_3/Eu_2O_3/SiO_2$/N-Si/Al MOS CAPACITORS FOR RADIATION SENSORS

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Abstract. *In the development of radiation sensors based on MOSFET devices, the process of enhancing gate dielectric radiation response should be considered, as the gate dielectric is a sensitive area. In this study, optical and electrical characteristics of fabricated three-layered $Al/Er_2O_3/Eu_2O_3/SiO_2$/n-Si/Al MOS capacitors for radiation sensors were comprehensively investigated. MOS capacitors with 15 nm thin SiO_2, 25 nm thin Eu_2O_3, and 110 nm thick Er_2O_3 stacked gate oxide layers were grown on the n-Silicon substrate by thermal oxidation and electron beam evaporation systems, respectively. The aluminum gate and back contacts of the capacitors were formed by RF magnetron sputtering. The optical and electrical properties of the thin films and capacitors were analyzed by studying the reflection, transmittance, refractive index and absorption coefficient, Capacitance–Voltage, Conductance–Voltage, and Current density–Voltage measurements. It is observed from these studies that interfacial layers, which appeared to cause interfacial dipoles, are used to reduce the interface trap charge density and oxide trap charge density in order to improve the charge storage capacity of the device.*

Keywords: *n-Si/SiO_2, Eu_2O_3, Er_2O_3, MOS Capacitors, Reflection, Capacitance–Voltage, Conductance–Voltage*

1. Introduction

Metal-Oxide-Semiconductor (MOS) capacitors are the foundation of metal-oxide-semiconductor field-effect transistors (MOSFET) devices, such as radiation field effect transistors (RadFETs) and nuclear radiation field effect transistors (NürFETs), which are used as radiation sensors and radiation dosimeters [1–6]. For years, researchers have been working on how to replace single gate dielectric in order to improve the sensitivity and reliability of these devices. The main factors that affect the sensitivity and reliability of the gate dielectric are their electrical and optical properties.

Many studies on optical and electrical properties of MOS devices have been reported [7–12]. However, this paper will be the first study to present the optical and electrical characteristics of three-layered $Al/Er_2O_3/Eu_2O_3/SiO_2$/n-Si/Al MOS capacitors. The selection of rare earth oxides is due to their attractive properties and a potential to replace other oxides as dielectric materials in MOS-based applications [13]. They have large band-gap, high dielectric constants, stable with silicon up to 900 °C, and a conduction band offset greater than 2 eV.

Introducing the stack layer structure can improve the instability and control the trap states. The channel mobility carriers enhance in stack gate having multiple dielectric oxide layers.

This study presents optical and electrical characteristics of fabricated three-layered $Al/Er_2O_3/Eu_2O_3/SiO_2$/n-Si/Al MOS capacitors for radiation sensors. To assess whether these multiple-layer capacitors perform better than single-gate capacitors, we obtained the reflection, transmittance, refractive index and absorption coefficient, Capacitance–Voltage, Conductance–Voltage and Current density–Voltage measurements. We investigated, analyzed, and compared our data with previous studies.

2. Experimental details

The substrate we used in this study was a n-type silicon (n-Si) wafer. Before the deposition of the oxides, we cleaned the wafer following a standard radio corporation of America's (RCA) cleaning procedures. We oxidized the n-Si using thermal oxidation to have the SiO_2 layer of 15 nm onto the n-Si. After obtaining SiO_2/n-Si, we deposited 25 nm Eu_2O_3 and 115 nm Er_2O_3 using electron beam evaporation (E-beam) system. We annealed the fabricated thin films at 700 °C for one hour in Nitrogen ambient. To examine the optical properties of the films, we measured the reflection (R), transmission (T), and absorption (A) in 400–1000 nm wavelength range. We transformed the fabricated thin films into MOS capacitors by depositing aluminum (Al) onto the films using the sputtering system. We also deposited aluminum on the backside of the MOS capacitors in order to form back contact, which is used to eliminate possible signal noise. The cross section of the fabricated $Al/Er_2O_3/Eu_2O_3/SiO_2$/n-Si/Al MOS capacitors is illustrated in Fig. 1.

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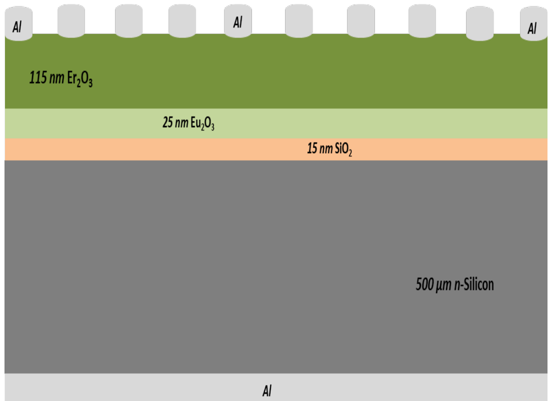

Figure 1. Cross section of the fabricated $Al/Er_2O_3/Eu_2O_3/SiO_2/n$-Si/Al MOS capacitors.

We measured capacitance (C-V) and conductance (G/ϖ-V) characteristics of the capacitors at various frequencies using Keithley 4200-SCS parameter analyzer. We used measured capacitance and conductance values to calculate series resistance of MOS capacitors.

3. Results and discussion

Figure 2 shows the reflection as a function of incident wavelength obtained for the films. It is observed that the reflection increases with increasing the wavelength from 400 nm to 550 nm, then decreases from 550 up to 750 nm. This may be due to the decrease in surface scattering, which is related to decrease in surface roughness. This shows that the films have low amount of defects, thanks to the interface layers.

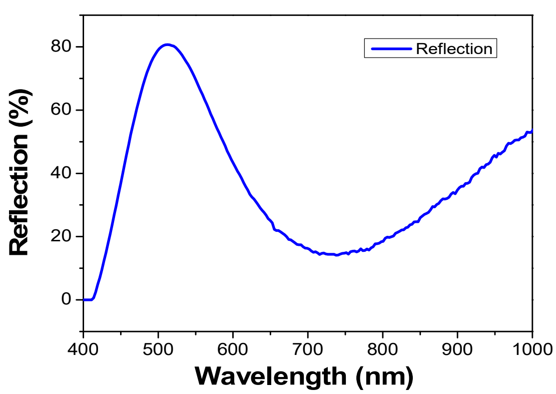

Figure 2. Reflection as a function of wavelength for $Er_2O_3/Eu_2O_3/SiO_2$ thin films grown on n-silicon substrate.

Figure 3 shows an optical transmission spectrum of the films. The transmission decreases in the 400 nm to 500 nm range; however, it increases in the 500 nm to 750 nm range. This variation may be due to the reduction of the surface resistance of the stack structure. Strong absorption is observed between 450 nm to 550 nm incident wavelength as illustrated in Figure 4. This occurred due to the sharp drop in the transmission and increase in the reflection, which is due to transition of electrons from valence to conduction band.

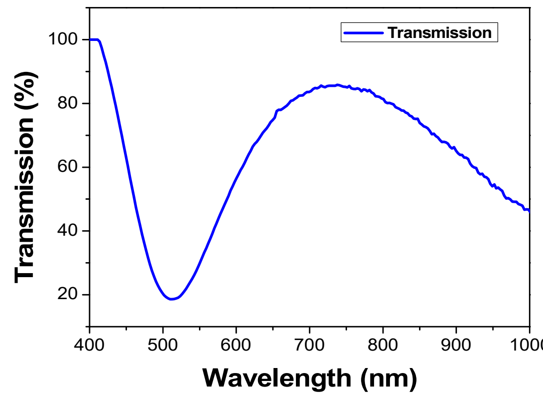

Figure 3. Transmission as a function of wavelength for $Er_2O_3/Eu_2O_3/SiO_2$ thin films grown on n-silicon substrate.

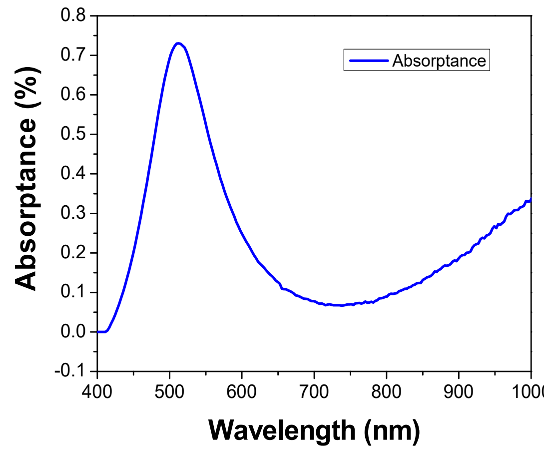

Figure 4. Absorption as a function of wavelength for $Er_2O_3/Eu_2O_3/SiO_2$ thin films grown on n-silicon substrate.

We compare the reflection, transmission and absorption spectra in Figure 5. It can be clearly seen that between 450 and 550 nm of incident wavelengths, there is a sharp increase in the reflection and a sharp drop in the transmission, which allow the absorption to reach its peak. These variations indicate that the $Er_2O_2/Eu_2O_3/SiO_2$ structure exhibits good optical properties, which may be used for optoelectronic applications.

We measured the capacitance versus applied voltage and conductance–voltage characteristics of the $Al/Er_2O_3/Eu_2O_3/SiO_2/n$-Si/Al MOS capacitors at various frequencies, as shown in Figure 6 and Figure 7, respectively. As seen in Figure 6, the capacitance increases with decreasing frequency and the flat-band voltage is closer to zero. This implies that multiple layers have a great impact on the electrical characteristics of the capacitors. To confirm this claim, we compared this study with previous studies [14–17]. The C–V curves show that this stack structure can be used as a future gate dielectric for radiation sensor applications.

We also measured conductance-voltage (G/ω-V) characteristics at various frequencies. We investigated the impacts of frequencies and applied voltage on the capacitors. The conductance increases with increasing frequencies, as Figure 7 illustrates. The conductance increases in the accumulation and inversion region, while there is a shift to negative voltages in the depletion regime. Peaks are observed at the frequencies below 500 kHz, and there are no peaks at the frequencies above 500 kHz. This behavior may be caused by the interface structure and a series resistance, which are strongly affected by the interfacial layers [7,8,12,18,19].

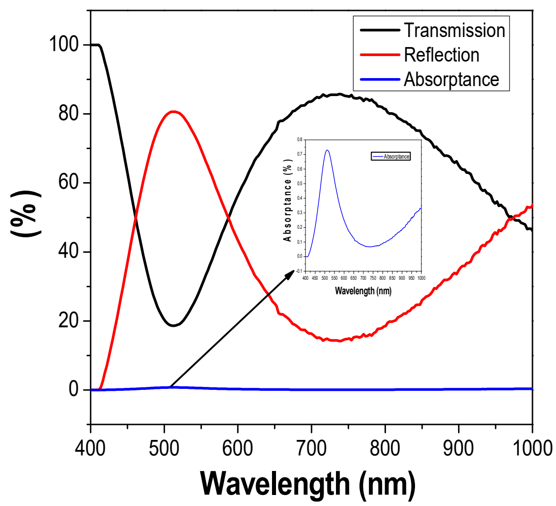

Figure 5. Reflection, transmission and absorption of $Er_2O_3/Eu_2O_3/SiO_2$ thin films grown on n-silicon substrate.

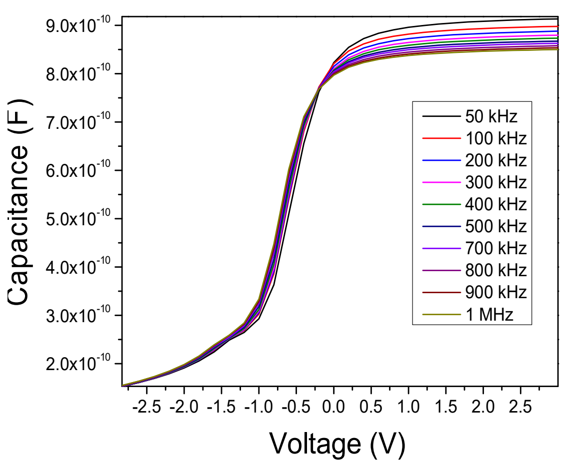

Figure 6. Capacitance–voltage (C_m–V) characteristics of $Al/Er_2O_3/Eu_2O_3/SiO_2/n$-$Si/Al$ MOS capacitors at various frequencies.

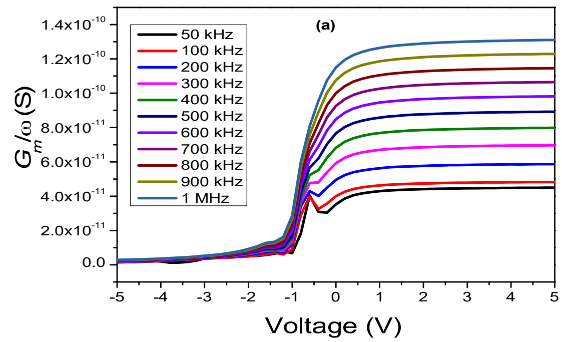

Figure 7. Conductance–voltage (G_m/w–V) characteristics of $Al/Er_2O_3/Eu_2O_3/SiO_2/n$-$Si/Al$ MOS capacitors at various frequencies.

4. Conclusion

We have studied optical characteristics of the fabricated $Er_2O_3/Eu_2O_3/SiO_2$/n-Si thin films and electrical characteristics of $Al/Er_2O_3/Eu_2O_3/SiO_2$/n-Si/Al MOS capacitors. From optical characteristics, in the 450-550 nm wavelength range, there is a sharp increase in the reflection and a sharp drop in the transmission, and a corresponding peak in absorption. Regarding electrical characteristics, the capacitance and conductance depend primarily on the frequency and the applied voltage. The C–V curves show higher capacitance values at lower frequencies. The conductance increases with frequency in the accumulation, depletion, and inversion regions. Small peaks are observed at lower frequencies, whereas no peaks are observed at high frequencies. The causes of this behavior may be related to the interface state density, series resistance, and the frequency of the AC signal. It is observed that the series resistance Rs values decrease with increasing frequency. This demonstrates that the stacked gate dielectric reduces the interface trap charge density. This is due to the formations of dipoles of "−/+" polarity and "+/−" polarity at the $Er_2O_3/Eu_2O_3/SiO_2$ interface.

The obtained results are in good agreement with today's metal-oxide-semiconductor based technologies.

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