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Investigation of structural properties, electrical and dielectrical characteristics of Al/Dy_2O_3/porous Si heterostructure

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This paper describes the structural properties, electrical and dielectric characteristics for the first time of the high-k Dy_2O_3 oxide film deposited on the porous Si substrate by electron beam deposition under ultra vacuum. Structural and morphological characterizations are investigated by a scanning electron microscopy (SEM), atomic force microscopy (AFM), transmission electron microscopy (TEM) and X-ray diffraction measurements (XRD). The electrical and dielectric characteristics of the Al/Dy_2O_3/porous Si heterostructure are studied through current- voltage I (V), capacitance–voltage C (V), conductance- and capacitance-frequency dependencies (G (f) and C (f)). Therefore, the dominant conduction mechanisms for the Al/Dy_2O_3/porous Si heterostructure are extracted from the determining of Schottky coefficient (β_{SC}) and Poole–Frenkel coefficient (β_{PF}). The experimental values of β_{SC} and β_{PF} coefficients are calculated from I (V) characteristics and compared with theoretical values, thus, the appropriate model has been proposed. The C (V) characteristics at different frequencies revealed a large frequency-dispersion, indicative of a significant density of interface states. Furthermore, the G (f) characteristics were well fitted by the modified law $G_{AC}\ (f) = A_1 f^{s_1} + A2f^{s_2}$ and the results showed frequency dependent and evidence of two different behaviors in ac conductance i.e. the low-frequency conductivity is due to long-range ordering (frequency-independent) and high frequency

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conduction due to the localized orientation hopping mechanism. The Nyquist diagrams are used to identify the equivalent circuit, so, the Al/Dy_2O_3/porous Si heterostructure is accurately modeled at frequency ranges from 10 Hz to 1000 kHz, as a two parallel elements (RC) network placed in series.

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1. Introduction

High dielectric constant (k) materials have become a necessity for down scaling of metal–oxide–semiconductor (MOS) based devices. Several rare-earth oxides as Al_2O_3 [1], HfO_2 [2], ZrO_2 [3], Y_2O_3 [4,5], La_2O_3 [1,4] have been studied as alternative dielectric material to replace SiO_2 for future Si-based technology due to their excellent dielectric properties and thermodynamic stability with Si. These oxides have major advantages such as, high: resistivity, dielectric constant, recrystallization temperature, large band gap, and thermodynamically stable in contact with Si substrate at high temperature (~800 °C) under high vacuum [6]. Therefore, the high quality dielectric properties and stable chemical and thermal properties of rare earth oxides make them attractive to study their possible technological applications and fundamental physical properties [7]. The rare earth oxides have many applications such as in solid-state electronics, electrical and transparent opto-ionic devices. On the other hand, due to the technical importance of MOS devices, further experimental work is in progress in order to provide the electrical properties for a new fabricated structure to be integrated in microelectronic devices and to make it suitable for several technological applications. Since most of the devices are operated in the ac electrical mode, the investigation of electrical properties of these materials becomes interesting. Among various high-k oxides, the Dysprosium oxide (Dy_2O_3) is a typical rare earth oxide which is considered as a promising candidate for alternative dielectric materials due to their important physical and chemical properties: dielectric constant value in the range 14–18, large energy band of 4.9 eV, and high chemical and thermal stability in contact with Si [8,9]. The electrical properties of Dy_2O_3 film deposited on Si substrate are recently investigated [10,11], while the electrical properties of Dy_2O_3 deposited on porous Si have not been studied until now and can have interesting features. In our previous work [12], we studied the electrical and dielectric properties of Al/Dy_2O_3/p-Si heterostructure. Although, since porous semiconductor materials are attractive because of their specific properties the integration of porous silicon in an active device necessitates an understanding of the structure made on it. In the present work, the electrical and dielectric characteristics of Al/Dy_2O_3/porous Si heterostructure are presented and studied for the first time to our knowledge in order to develop promising device characteristics when Dy_2O_3 is directly in contact with the porous Si substrate. Generally, the porous silicon substrates introduced is beneficial to enhance the bonding strength between the films and the substrates. The use of porous Si as a substrate is reported to develop some electrical performances of the MOS device and it may be helpful for different kinds of research and application. The porous silicon is an intensively studied material, which has characteristics of high resistance, large internal surface and strong absorbability [13]. Due to its special structure we try to deposit the oxide film on porous silicon substrate formed by electrochemical etching technique. Moreover, one of the reasons for using a porous semiconductor as a substrate for depositing oxides is that the nano-patterned porous structure would lead to a reduced extended defect density [14–16] and to achieve further the deposition procedure without the need for any artificially made interfacial layer to improve the electrical behavior. More characterization study is needed to understand the electrical properties, thus in this paper, an effort is made to discuss the structural, electrical and dielectric properties for the new elaborated structure through a complete characterization: I (V), C (V), G (f) and C (f) characteristics measured at room temperature.

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