Nuclear Instruments and Methods in Physics Research B 319 (2014) 44–47

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Effects of gamma-ray irradiation on interface states and series-resistance characteristics of $BiFeO_3$ MOS capacitors

Senol Kaya [a,b,*], Aliekber Aktag [a,b], Ercan Yilmaz [a,b,c]

[a] Physics Department, Abant Izzet Baysal University, 14280 Bolu, Turkey
[b] Nuclear Radiation Detectors Research and Development Center, 14280 Bolu, Turkey
[c] Tyndall National Institute, University College Cork, Lee Maltings, Cork, Ireland

ARTICLE INFO

Article history:
Received 4 August 2013
Received in revised form 7 November 2013
Available online 1 December 2013

Keywords:
Radiation effects
Ferroelectric $BiFeO_3$ MOS capacitor
Interface states
Series resistance

ABSTRACT

The effects of radiation on the electrical-interface-state density (D_{it}) and series resistance (R_s) characteristics of $BiFeO_3$ MOS capacitors were studied in this work. To study the response of MOS devices to gamma irradiation over a range of doses, MOS samples were irradiated using a Co-60 gamma-ray source from 0.5 to 16 grays at a dose rate of 0.0030 Gy/s. C–V and G/ω–V measurements were recorded prior to and after irradiation at high (1 MHz) frequency. The effects of the radiation were determined from analysis of the C–V and G/ω–V curves. A slightly decrease in the R_s values with increasing irradiation dose was observed. The total interface-state density was found to decrease because of the reordering and restructuring of radiation-induced defects in the MOS capacitors. The experimental results indicate that the electrical R_s and D_{it} characteristics of $BiFeO_3$ MOS capacitors depend on the gamma-irradiation dose, and the calculated densities of the interface states are on the order of 10^{11} eV^{-1} cm^{-2}. However, the calculated D_{it} values are not high enough to pin the Fermi level of the Si substrate and thereby corrupt device operation over the given dose range.

1. Introduction

Metal-oxide-semiconductor (MOS) capacitors have been intensively investigated because of their technological applications, such as those offered by their excellent compatibility with existing micro- and nanotechnology [1]. The suitability and usability of MOS devices in technological applications depends on the device characteristics, which are directly related to the gate insulators and their interfaces with the underlying semiconductors [1–3]. Thus, high-k systems have been used to enhance the performance of devices [4–6] and to decrease their dimensions. Complex oxide materials such as bismuth ferrite provide a new avenue of research concerning electronic devices and offer a novel nanoelectronics platform for future nanotechnological applications [7].

Because of several possible sources of errors, the electrical characteristics of MOS capacitors deviate from their expected ideal behaviors. These errors may be related to such parameters as the interface-state densities (D_{it}), series resistances (R_s) and fabrication processes of the devices [8–10]. Therefore, these parameters should be taken into account in relevant calculations and fabrication processes. Improvements in MOS processing techniques and reductions in contamination during device fabrication have significantly reduced the adverse effects of fabrication processes on the degradation of the ideal behavior of MOS devices. However, variations in the interface-state density and series resistance still remain important topics with respect to the performance of MOS devices.

It is well known that MOS devices are extremely sensitive to ionizing radiation, and the radiation response of these devices has been found to change significantly when these devices are exposed to irradiation [11,12]. However, little knowledge exists in the literature concerning the effects of radiation on various high-k systems. Especially in low-power systems, novel high-k devices are likely to form the core of advanced MOS integrated circuits in the fairly near future [13]. Therefore, high-k systems could become particularly important for the radiation-hard systems that are utilized for various applications such as space travel, the nuclear industry and radiotherapy.

Ferroelectric and ferromagnetic properties coexist in multiferroic oxide materials. The defect distribution in a ferroelectric device can be shown to vary at the interfaces of domain wall boundaries, and this phenomenon may exhibit attractive behavior for the radiation response of MOS devices. Among multiferroic materials, bismuth ferrite oxides have been most widely studied for their applications [14–16]. Perovskite $BiFeO_3$ is a high-k dielectric material that is thermally stable when in direct contact with Si,

* Corresponding author at: Physics Department, Abant Izzet Baysal University, 14280 Bolu, Turkey. Tel.: +90 374 254 10 00/2751.
E-mail address: senolkaya52@gmail.com (S. Kaya).

0168-583X/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.nimb.2013.11.006

exhibiting an energy gap of approximately 2.75 eV, which is quite small in comparison to ordinary ferroelectrics [17,18]. This feature makes it more sensitive to high-irradiation environments than other ferroelectrics. Because of these properties, the investigation of the effects of radiation on $BiFeO_3$ may yield important knowledge regarding the radiation response of complex oxides. Therefore, we aim to study possible effects of radiation on the electrical R_s and D_{it} parameters of $BiFeO_3$-based MOS capacitors. Capacitance–voltage (C–V) and conductance–voltage (G/ω–V) measurements were performed at high frequency (1 MHz) before and after gamma irradiation, and the results are discussed for various exposure doses.

2. Experimental details

$BiFeO_3$ thin films were grown on p-type (100) silicon wafers following a standard Radio Corporation of America (RCA) cleaning process. $BiFeO_3$ layers with a thickness of approximately 320 nm were grown at 0 °C via RF magnetron sputtering with a power of 150 W. The base pressure before sputtering was 1.1×10^{-5} torr, and the sputtering gas pressure was 6.7×10^{-3} torr. A quasi-reactive Ar gas was used for the desired stoichiometry. The fabricated devices were annealed at 550 °C for 30 min in an atmospheric environment. The back ohmic contacts, which were composed of aluminum (Al), were deposited via evaporation on the annealed samples. The front Al electrodes were formed in circular dots of 1 mm in diameter via Al deposition through a shadow mask at a base pressure of 1.2×10^{-5} torr.

To study the influence of gamma radiation on the electrical D_{it} and R_s characteristics of MOS capacitors, MOS samples were irradiated using a Co-60 gamma-ray source from 0.5 to 16 grays at a dose rate of 0.0030 Gy/s. C–V and G/ω–V measurements of the fabricated $BiFeO_3$ MOS capacitors were recorded prior to and after irradiation at high frequency (1 MHz) using an impedance analyzer (MODEL HIOKI 3532-50 LCR meter).

3. Results and discussion

Variations of capacitance as a function of voltage for the $BiFeO_3$ MOS capacitors at the room temperature were recorded prior to and after irradiation ranging from 0.5 to 16 grays, and the obtained results are depicted in Fig. 1. The devices exhibit MOS-type behavior with three known distinct regimes, namely, accumulation, depletion and inversion, in all measurements. Fig. 1 demonstrates that the C–V characteristics of a $BiFeO_3$ MOS capacitor shift toward more positive voltages after irradiation. Such behavior of a capacitor can be attributed to the enhancement of trapped charge densities, such as interface-trapped charges and especially oxide-trapped charges, in the MOS device caused by irradiation [19,20]. In addition, the measured capacitances slightly increase with increasing irradiation dose, and this may be attributable to series-resistance effects and/or the contribution of interface-state capacitance caused by irradiation to the measured capacitance [13].

The conductance method [1,21,22] is based on the conductance losses that result from the exchange of majority carriers between the interface states and the majority-carrier band of the semiconductor when a small ac signal is applied to MOS devices. The applied ac signal causes oscillation in the Fermi level about the mean positions governed by the dc bias while the MOS devices are in the depletion region [23]. The effects of gamma irradiation on the conductance–voltage (G/ω–V) characteristics of $BiFeO_3$ at various doses up to 16 grays are illustrated in Fig. 2. The conductance curves exhibit dispersion in the accumulation and depletion regions, which slightly increases with increasing radiation dose. It is well known that any small variation in the interface-state density can cause the bias shift and dispersion of the G/ω curves. In addition, early studies of MOS devices have shown that series resistance is also an important factor in determining the noise ratio of the device in terms of radiation dose, which causes changes in the electrical characteristics of the MOS structure [24,25]. Therefore, changes in D_{it} and R_s may be the basic mechanism underlying the variations in the conductance curves.

To examine the response of the series resistance to gamma irradiation over a range of doses, the real series resistances of the MOS structures were calculated before and after irradiation from the measured capacitance (C_{ma}) and conductance (G_{ma}) in the strong accumulation region at high frequencies ($f \geqslant 500$ kHz). The measured admittance (Y_{ma}) in the strong accumulation region of a MOS structure can be found by referring to the parallel RC circuit that is equivalent to the total circuit admittance [1],

$$Y_{ma} = G_{ma} + j\omega C_{ma} \tag{1}$$

The series resistance is found by comparing the real and imaginary parts of the admittance [1]:

$$R_s = \frac{G_{ma}}{(G_{ma})^2 + (\omega C_{ma})^2} \tag{2}$$

where ω is the angular frequency, and C_{ma} and G_{ma} are defined as the measured capacitance and conductance in the strong accumulation region, respectively. The R_s values calculated from Eq. (2) are given in Table 1. These values were used to correct the measured G/ω–V and C–V characteristics of the devices. The voltage-dependent series resistance for each radiation dose is presented in Fig. 3. The results demonstrate that the values R_s slightly decrease with increasing radiation dose. Moreover, R_s peaks are observed in the voltage range between −1.35 and −1.05 V and move toward the inversion region as the dose increases. These behaviors of R_s

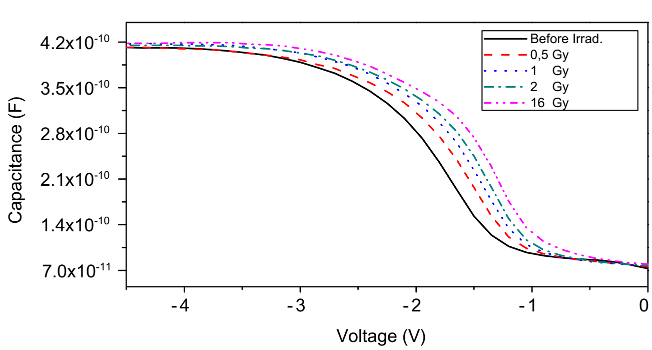

Fig. 1. The measured C–V curves of $BiFeO_3$ MOS capacitor before and after gamma radiation at different doses.

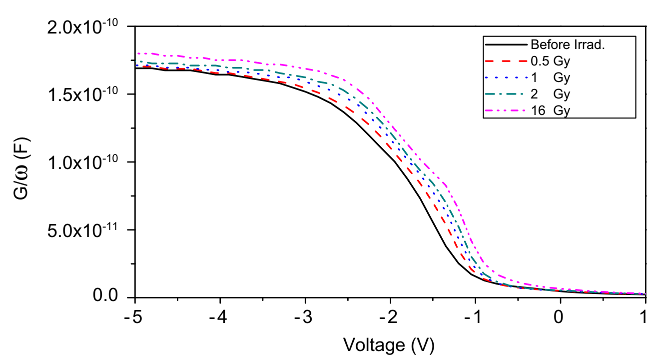

Fig. 2. The measured G/ω curves of $BiFeO_3$ MOS capacitor before and after gamma radiation at different doses.