Available online at www.sciencedirect.com
ScienceDirect
Nuclear Instruments and Methods in Physics Research B 259 (2007) 889–894
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

On the interface trap density and series resistance of tin oxide film prepared on n-type Si (1 1 1) substrate: Frequency dependent effects before and after ^{60}Co γ-ray irradiation

S. Karadeniz *, A. Birkan Selçuk, N. Tuğluoğlu, S. Bilge Ocak

Department of Nuclear Electronics and Instrumentation, Sarayköy Nuclear Research and Training Center, 06983 Saray, Ankara, Turkey

Received 8 December 2006; received in revised form 5 February 2007
Available online 25 February 2007

Abstract

We report the first investigation of the frequency dependent effects of gamma irradiation on interface state density and series resistance determined from capacitance–voltage (*C–V*) and conductance–voltage (*G–V*) characteristics in SnO_2/n-Si structures prepared by spray deposition method. The samples were irradiated using a ^{60}Co γ-ray source at 500 kGy at room temperature. The *C–V* and *G–V* measurements of the samples were performed in the voltage range −6 V to 2 V and at 10 kHz, 100 kHz, 500 kHz and 1 MHz at room temperature before and after 500 kGy irradiation. The measurement capacitance and conductance are corrected for series resistance. It has been seen that the value of the series resistance R_s of sample decreases from 204 Ω to 55.4 Ω with increasing the frequency before irradiation while it decreases from 248 Ω to 60 Ω with increasing frequency at 500 kGy irradiation. It has been found that and D_{it} values of MOS structure increases up to 100 kHz and then decreases up to 1 MHz while the R_s increases with increasing irradiation dose for our sample. The interface state density D_{it} ranges from 1.83×10^{13} cm^{-2} eV^{-1} for before irradiation to 1.54×10^{13} cm^{-2} eV^{-1} for 500 kGy irradiation dose at 500 kHz and decreases with increasing frequency.

PACS: 61.80.Ed; 61.80.−x; 73.20.At; 73.40.Qv; 84.37.+q

Keywords: MOS diodes; SnO_2; ^{60}Co γ-ray; *C–V*; *G–V*; Series resistance; Interface state density

1. Introduction

The increasing interest in SnO_2 is due to the extensive use of this metal-oxide for gas sensing and gas monitoring devices and in other applications such as solar cells, opto-electronic devices, flat-panel displays, thin film transistors (TFTs), electromagnetic shielding, transparent electrodes or as catalytic support material and anode materials for lithium ion batteries (LIB) [1–5]. SnO_2 films are deposited by various methods such as electron beam evaporation, vacuum arc evaporation, sol–gel, magnetron sputtering, chemical vapor deposition, and spray deposition method, each of which had advantages and disadvantages. The spray deposition method is most commonly used due to the simple process and economic advantages. The spray deposition process presents an easy way to integrate SnO_2 devices into the Si technology. The existence of such an oxide layer (SnO_2) converts the device to a metal-oxide-semiconductor (MOS) diode [1,2,6] and may have a strong influence on the diode characteristics as well as a change of the interface state charge with bias which will give rise to an additional field in the interfacial layer [6]. The existence of an interfacial layer between the metal and the semiconductor play an important role in the determination of the series resistance and interface state density [1,2]. The forward bias *C–V* and *G–V* measurements give the important information about the density or energy distribution of the interface states of the structure. In general, the *C–V* and

* Corresponding author. Tel.: +90 312 815 4300; fax: +90 312 815 4307.
E-mail address: serdar@taek.gov.tr (S. Karadeniz).

0168-583X/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.nimb.2007.02.085

G–V plots in the idealized case are frequency independent [7–9]. However, this idealized case is often disturbed due to the presence of an interfacial layer between the contact materials and interface states at the oxide layer/semiconductor interface [7–9].

Metal-oxide-semiconductor (MOS) structures are extremely sensitive to high-level radiation (ions, electrons, neutron, and gamma-ray) [6–10]. It has been shown that ionizing radiation generates interface traps at the SiO_2/Si interface of a metal–SiO_2–Si (MOS) structure [11–16]. Among the mechanisms that have been proposed to explain this generation process, two have received considerable attention. One of these relies on the release of hydrogen-related centers by ionizing radiation with the subsequent breakage of interfacial bonds [16–18]; the other is associated with the rupture of strained bonds at the interface [12,17–19].

In the present paper, we report the systematic investigation of the frequency dependent effects before and after irradiation dose (500 kGy) on the series resistance and interface state density of Au/SnO_2/n-Si (1 1 1) Schottky diodes from *C–V* and *G–V* characteristics. The electrical properties of Au/SnO_2/n-Si (1 1 1) Schottky diode were investigated at 10 kHz, 100 kHz, 500 kHz and 1 MHz at room temperature before and after 500 kGy. The other purpose of this study was to compare estimates of interface trap densities obtained experimentally dependent on frequency effect for the MOS structures using Hill–Coleman's single-frequency technique [20] before and after irradiation.

2. Experimental procedure

The Au/SnO_2/n-Si (MOS) Schottky diodes were prepared using mirror cleaned and polished (as received from the manufacturer) n-type Si wafers with (1 1 1) orientation, 300 μm thick, and 5–10 Ω-cm resistivity. Before making contacts, the Si wafer was chemically cleared using the RCA cleaning procedure [i.e. a 10 min boil in $NH_4OH \times H_2O_2 + 6H_2O$ followed by a 10 min boil in $HCl + H_2O_2 + 6H_2O$], with the final dip in diluted HF:H_2O (1:10) for 30 s, and then ringed in deionized-water (purity up to 18.2 MΩ-cm). For ohmic contacts, Au–Sb was evaporated on the back of the wafer. After that, low resistance ohmic contacts were formed by thermal annealing at 450 °C for 5 min in flowing N_2 in a quartz tube furnace. Immediately after ohmic contact, a layer of SnO_2 was grown on the Si substrate by spraying a solution consisting of 32.21 wt% of ethyl alcohol (C_2H_5OH), 40.35 wt% of deionized-water (H_2O) and 27.44 wt% of stannic chloride ($SnCl_4.5H_2O$) at 400 °C substrate temperature. The experimental setup used for the films prepared by spray deposition method is described elsewhere [5]. SnO_2 dots were 3 mm in diameter. The Schottky contacts were made by evaporation of Au as dots with a diameter of approximately 1.0 mm onto all of the n-Si surfaces. All evaporation processes were carried out in a vacuum-coating unit at about 2×10^{-6} Torr. The thickness of SnO_2 film obtained from the measurement of the oxide capacitance in the strong accumulation region for Au/SnO_2/n-Si Schottky diodes was 80 Å. The thickness value of ohmic and rectifying contact is 3000 Å. The *C–V* and *G–V* characteristics were measured at 1 MHz using a HP Model 4192A LF impedance analyzer before and ^{60}Co γ-ray source irradiation and total dose range was 0–500 kGy at the room temperature in the dark and test signal of 40 mV_{rms}.

3. Results and discussion

Fig. 1(a) and (b) present the measured capacitance as a function of gate voltage before and after 500 kGy γ-ray irradiation for Au/SnO_2/n-Si MOS diodes prepared at 10 kHz, 100 kHz, 500 kHz and 1 MHz at room temperature. The three distinct regimes of accumulation–depletion–inversion before and after ^{60}Co γ-ray irradiation are

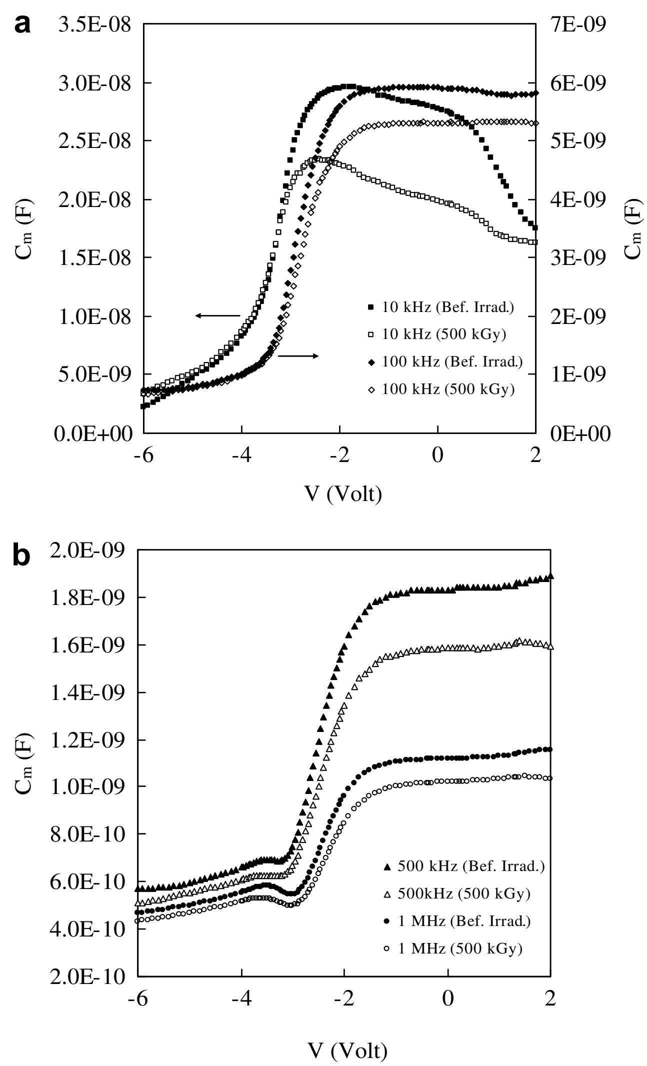

Fig. 1. The measured capacitance (*C*) characteristics versus gate bias (*V*) at room temperature for Au/SnO_2/n-Si MOS structure before and after 500 kGy irradiation dose (a) 10 kHz and 100 kHz, and (b) 500 kHz and 1 MHz.