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Irradiation effects on the C–V and G/ω–V characteristics of Sn/p-Si (MS) structures

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ABSTRACT

In this paper, we have investigated the effects of ^{60}Co gamma (γ)-ray source on the electrical properties of Sn/p-Si metal–semiconductor (MS) structures using the capacitance–voltage (C–V) and conductance–voltage (G/ω–V) measurements before and after irradiation at room temperature. The MS structures were investigated in the frequency range 20–700 kHz irradiation effects on the electrical properties of Sn/p-Si MS structures before irradiation, and after irradiation, these structures were exposed to ^{60}Co γ-ray source irradiation with the dose rate of 2.12 kGy/h and the total dose range was 0–500 kGy at room temperature. It was found that the C–V and G/ω–V curves were strongly influenced with both frequency and the presence of the dominant radiation-induced defects, and the series resistance was increased with increase in dose. On the other hand, the interface state density (N_{ss}) as depended on radiation dose and frequency was determined from C–V and G/ω–V measurements, and the interface states densities decreased with increase in frequency and radiation dose.

1. Introduction

Silicon (Si) was the first material used for solar cells in space and it has remained the most popular choice ever since due to its history of reliable performance. The investigations in this work are of utmost importance for their applications in space and radiation environments. Thus, the metal–semiconductor (MS) structures, metal–insulator–semiconductor (MIS)-type structures or solar cells and metal-oxide–semiconductor (MOS) capacitors are extremely sensitive to high-energy radiation (such as ^{60}Co gamma (γ)-ray and high-energy electrons, neutrons and ions). The MS structure-based devices are sensitive to the electrical properties of the MS interface and any mechanism that affects the interface also influences the performance of these devices (Aboelfotoh, 1989; Karataş and Türüt, 2006; Kumar and Kanjilal, 2006; Singh et al., 2000).

Radiation effects on MS structures have attracted large attention during the last decades, and a variety of studies have been performed by many authors (Aboelfotoh, 1989; Karataş and Türüt, 2006; Kumar and Kanjilal, 2006; Singh et al., 2000; Feteha, 2000; Feteha et al., 2002; Tataroğlu and Altindal, 2006; Ferraglio and Anderson, 1979; Willoughby, 1994; Karataş et al., 2005). These investigations are of most importance for their applications in space and radiation environment. The studies on the effect of γ irradiation in semiconductor devices are of technological importance and scientific interest. The most common source of γ rays for irradiation processing comes from the radioactive isotope ^{60}Co γ-ray source irradiation. It is manufactured specifically for the γ irradiation process.

The γ rays pass through the materials being irradiated depositing energy causing electrons to be shifted to a higher energy state or removed completely from the atom. This effect, ionization, can produce a number of different characteristics depending on the chemical structure of the material. It is known that ^{60}Co γ-ray irradiation at the interface causes modification of the interface and affects the electrical characteristics of the MS structure formed on the semiconductor. Thus, when irradiative particles (gamma, electrons, protons, etc.) enter the MS, they cause a considerable amount of lattice damage (vacancies, defects, etc.). These defects are mainly acting as recombination centers resulting in a reduction in the carrier's diffusion length (Feteha, 2000; Feteha et al., 2002; Tataroğlu and Altindal, 2006). The diffusion length of the MIS–Si solar cell could be degraded by up to 96% in a manner similar to p–n Si solar cells under the same proton irradiation dose (Ferraglio and Anderson, 1979; Willoughby, 1994).

The capacitance–voltage (C–V) and conductance–voltage (G/ω–V) characteristics of a metal–semiconductor structure are extremely sensitive to interface state density at the MS interface. Deep understanding of the physical properties of the materials

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under the influence of radiation exposure is vital for the effective design of MS devices (Arshak and Korostynska, 2004; Tuğluoğlu, 2007). The electrical characteristics of MS structures in the Schottky barrier diodes have been studied more than that in the MIS-type Schottky diodes due to the existence of a native insulator layer between metal and semiconductor that passivates the surface of the semiconductor. The improvements in radiation resistance of MS, MIS and solar cells are necessary for widespread applications.

In this work, as different from previous works (Karataş and Türüt, 2006; Karataş et al., 2005), we have investigated effects of the ^{60}Co γ-ray source on the electrical properties of Sn/p-Si (MS) structures using the *C–V* and *G/ω–V* measurements before and after irradiation at room temperature. In addition, before and after irradiation, we investigated the effects of the series resistance and interface states, which cause non-ideal behaviour on the electrical properties of the MS structure.

2. Experimental

The MS structures were prepared using p-type silicon wafers with (1 0 0) surface orientation, 2″ in diameter and 6.248 Ω cm resistivity. The wafer was chemically cleaned using the RCA cleaning procedure. The RCA cleaning procedure was as follows: a 10 min boil in NH_3+H_2O_2+6H_2O followed by a 10 min boil in HCl+H_2O_2+6H_2O. The RCA cleaning with HF dip shows a predominant coverage of the surface with hydride groups. The native oxide on the front surface of the substrate was removed in HF:H_2O (1:10) solution for 30 s and finally the wafer was rinsed in deionized water for 30 s. Then, low-resistivity ohmic back contact to p-type Si (1 0 0) wafers was made by using Al, followed by a temperature treatment at 570 °C for 3 min in N_2 atmosphere. The Schottky contacts were formed by evaporation of Sn dots with a diameter of about 1.5 mm (diode area $= 1.76\times10^{-2}$ cm^2). All evaporation processes were carried out in a turbo molecular fitted vacuum coating unit at about 10^{-7} Torr.

The *C–V* and *G/ω–V* measurements were performed by using the HP 4192A LF impedance analyzer (5 Hz–13 MHz) and the test signal of 40 mV$_{rms}$. All measurements (*C–V* and *G/ω–V*) were performed in the dark before and after ^{60}Co γ-ray source irradiation with the dose rate of 2.12 kGy/h and the total dose range was 0–500 kGy at room temperature. The measurements were carried out with the help of a microcomputer through an IEEE-488 ac/dc converter card.

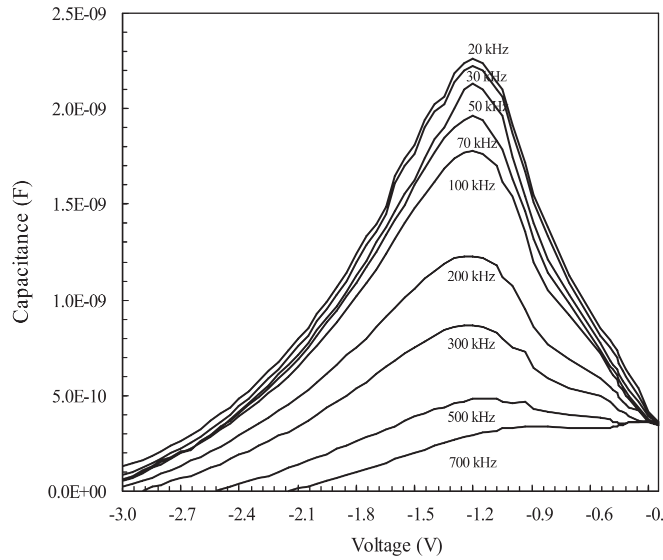

Fig. 1. The *C–V* characteristics of the Sn/p-Si structure at various frequencies.

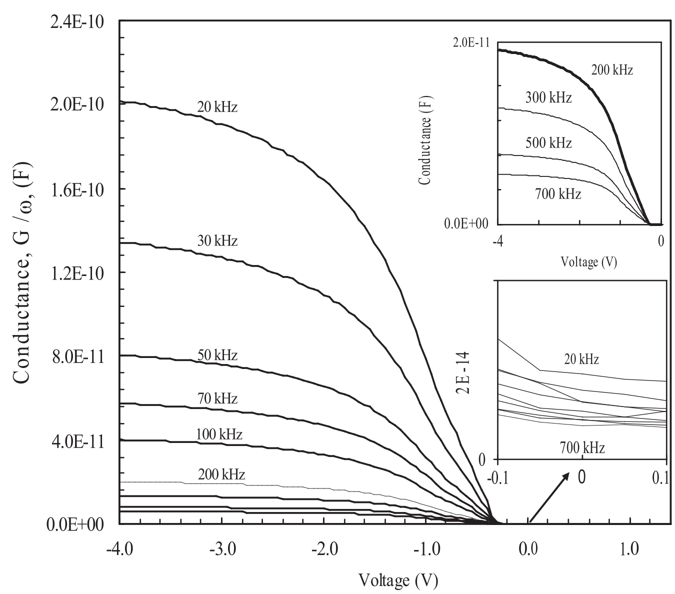

Fig. 2. The *G/ω–V* characteristics of the Sn/p-Si structure at various frequencies.

3. Results and discussion

3.1. Frequency dependency of capacitance-voltage (C–V) and conductance-voltage (G/ω–V) measurements

The *C–V* and *G/ω–V* characteristics of Sn/p-type Si structure at the frequency range of 20–700 kHz at room temperature are shown in Figs. 1 and 2, respectively. As shown in Figs. 1 and 2, the measured *C–V* and *G/ω–V* plots are dependent on both the bias voltage and frequency. In the depletion and accumulation regions for a given applied voltage, the *C* and *G/ω* increase with decrease in frequencies due to the time-dependent response of interface states. In addition, each *C–V* curve has three different regions of accumulation–depletion–inversion region. The *C–V* curves give peak in the depletion region due to the particular distribution of interface states between Sn/p-type Si interface and effect of series resistance. The position of peaks in the *C–V* curves is shifting towards the reverse bias region with increasing frequency and almost disappears at high frequencies. This occurs because at lower frequencies the interface states can follow the ac signal and yield an excess capacitance, which depends on the frequency. In the high-frequency limit ($f\geqslant700$ kHz), however, the interface states cannot follow the alternating current (ac) signal. This makes the contribution of interface state capacitance to the total capacitance negligibly small (Hill and Coleman, 1980; Akkal et al., 2000; Gökçen et al., 2008; Karataş and Türüt, 2004).

Fig. 2 shows the measured G_m/ω–*V* characteristics of Sn/p-type Si structure at different frequencies. Conductance technique is based on the conductance losses resulting from the exchange of majority carriers between the interface states and majority carrier band of the semiconductor when a small ac signal is applied to the semiconductor devices (Nicollian and Goetzberger, 1965). In Fig. 2, when the frequency increases from 20 to 700 kHz, the conductance decreases from 9.55×10^{-15} F ($=0.00955$ pF) to 7.73×10^{-15} F ($=0.00773$ pF) at zero bias, and thus, the *G/ω–V* plots for high frequencies and forward bias voltages became almost constant. From the above argument it can be concluded that