Materials Science in Semiconductor Processing 74 (2018) 1–6

Contents lists available at ScienceDirect

Materials Science in Semiconductor Processing

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

Interface and transport properties of gamma irradiated Au/n-GaP Schottky diode

N. Shiwakoti[a], A. Bobby[a], K. Asokan[b], Bobby Antony[a,*]

[a] Department of Applied Physics, Indian Institute of Technology (ISM) Dhanbad, 826004, India
[b] Inter University Accelerator Centre, Aruna Asaf Ali Marg, New Delhi 110067, India

ARTICLE INFO

Keywords:
Au/GaP Schottky diode
Gamma irradiation
Current transport
Interface
Capacitance

ABSTRACT

The effect of 10 Mrad γ-ray exposure on the interface and transport properties of Au/n-GaP Schottky diode is studied in the 220–400 K temperature range. There is significant alteration in the interface and defect state density after irradiation. The Arrhenius plot of σ_{ac} shows the presence of both shallow and deep trap states corresponding to activation energies 0.073 eV and 0.21 eV respectively. The influence of additional defects is reflected in the charge transport mechanism at low temperature regimes, where tunneling mechanisms are observed. The perceived transport and capacitance/conductance properties are ascribed due to further interfacial and deep defect state formation upon gamma irradiation.

1. Introduction

The radiation resistant electronic components are persistently probed by researchers due to their increasing concerns related to the stability of devices in radiation harsh environments. The continuous exposure of radiation to these devices especially in the field of space crafts, military aircrafts, artificial satellites, nuclear reactors, particle accelerators etc. usually ruin their functionality in due time. Besides, the thermal stability of these devices under radiation environment should also be meticulously considered for wide range applications. The choice of suitable materials under such backdrop is a prime need of growing technology. The Gallium Phosphide (GaP) based junction devices shows some potential features such as low leakage current, high break down voltage, robust thermal stability etc [1–4]. Its use as light emitting diodes, U-V radiation detectors [5,6] and more advanced structures such as window layer of heterojunction solar cells [7,8] etc. draws a level of attention on its reliability and efficiency under radiation harsh environments. The superiority of this wide band gap semiconductor is numerous over Si and other compound semiconductors. It can operate competently as a bipolar device in extended temperature range [1]. Recently, an increase in quantum efficiency of Ni/n-GaP Schottky diode by nano scale surface formation is reported [9]. The simplest of all junction devices is MS or Schottky device, which is investigated both as electronic device and for material characterization [6,10]. Fundamentally, all these devices are common in one aspect. Their terminal characteristics are governed by the interface conditions. Any kind of alterations of the MS interface state properties due to external influences reflect directly on their terminal behaviors. So a thorough understanding of interface states profile is crucial for their feasibility under harsh environments. The effect of γ-ray irradiation is one of such concern which requires systematic investigations in GaP based devices. Furthermore, the high penetrating power of γ-ray is also employed as an effective tool for altering the MS interface state properties [11–14]. The fate of the device after irradiation primarily depends on how the interface state density and defect state energy levels are modulated. The gamma ray irradiation can induce both transient and permanent effects within the device [14–16]. Upon bombardment, the gamma ray photons generate electron-hole pairs which may either recombine or move out of the interface. When an external field is applied, the electrons from the pairs are swept across the interface whereas the holes, being less mobile get trapped and form stationary trap states. In addition, the gamma ray photons may lose energy by photoelectric and Compton scattering processes depending on their energy values. These processes generate high energy electrons which subsequently interact with the atoms of the device, forming some stable point defects or annihilating the existing defects. Such interactions can also change the electronic configuration of the atoms leading to restructuring and reordering of the interface which releases lattice strain and homogenizes interfacial regions causing improvement in device performance [17]. They may also provide tunneling channel for the free charge carriers [18–21]. Thus, at different biases and temperatures, these defect states actively control the free carrier density and mobility and hence affect the transport mechanisms. In GaP crystal, there exist point defects such as phosphorous vacancy (V_P), gallium vacancy (V_G),

* Corresponding author.
E-mail address: bobby.iit.ism@gmail.com (B. Antony).

http://dx.doi.org/10.1016/j.mssp.2017.10.008
Received 30 May 2017; Received in revised form 11 September 2017; Accepted 8 October 2017

gallium-phosphors divacancy with different charge states, phosphorus gallium antisite (P_{Ga}), unintentional impurities and lattice dislocations [22–26]. Upon irradiation, these existing defects along with interface states due to contact inhomogeneity and surface impurities form defect complexes, which change the device characteristics drastically. Several groups have investigated the radiation response of different kinds; such as Swift heavy ion [27–29], electron irradiation [30–32], neutron irradiation [33], γ-ray irradiation [32] on the surface and bulk properties of GaP single crystals. Mostly, all kinds of radiation increase the interface states density which leads to device degradation [34,35]. However, the effect of such irradiation on device structures, particularly of GaP based ones, and their possibility in radiation environment is still in the premature stage.

This work is an extension of our previous works on pristine Au/n-GaP under the influence of gamma irradiation [36,37]. In this work, we have investigated the interface state modification and the related charge transport properties through *C-V* and *I-V* characterization techniques measured at room temperature (RT).

2. Experimental

The Au/n-GaP Schottky diode was fabricated and the detailed description of device structure and measurement techniques has been presented earlier [37]. The diode so fabricated was irradiated with 10 Mrad ^{60}Co γ - ray source installed at IUAC, New Delhi.

3. Results and discussion

3.1. Capacitance and conductance characteristics

The capacitance and conductance measurements are effective tools in understanding the interface state density and carrier life time along with activation energy of defect states. The interfacial states accompanied by series resistance arise due to various reasons. One of which is the unwanted growth of an ultrathin interfacial oxide layer at the metal-semiconductor junction during fabrication, particularly in III-V semiconductor based Schottky diode. The *C-V* and G/ω-*V* characteristics of gamma irradiated Au/n-GaP Schottky diode at different frequencies are shown in Figs. 1 and 2. The capacitance and conductance values decrease in comparison with the pristine diode indicating formation of extra defect levels after irradiation. It is quite normal in such Schottky diodes to observe anomalous peaks in their *C-V-f* characteristics [41,42], which is alike in our case too (Fig. 1). As majority of the interface states cannot follow high frequencies, the interface capacitance decreases with increasing frequency, thereby lowering the total capacitance. The *G/ω-V* plot in Fig. 2 shows drastic change in its characteristic over high to low frequency ramping. The effect of deep

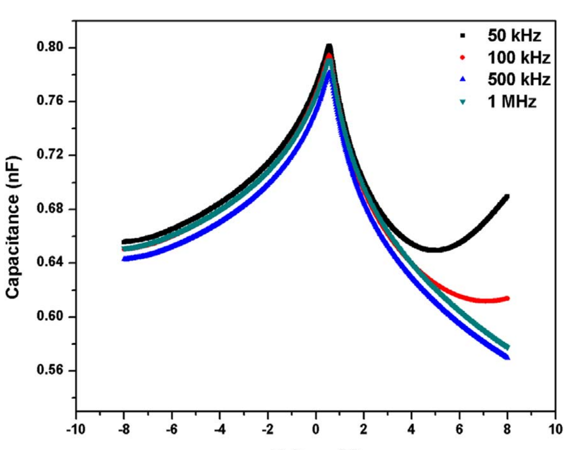

Fig. 1. C–V characteristics of γ-ray irradiated Au/n-GaP Schottky diode measured at RT.

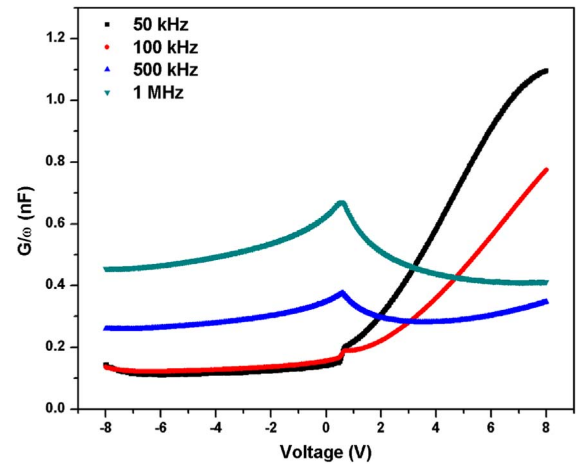

Fig. 2. G/ω-V characteristics of γ-ray irradiated Au/n-GaP Schottky measured at RT.

defect level is visible from the low frequency conductance characteristics at high forward bias region. Under sufficiently strong bias, the deep defect levels are activated, which then can communicate with neighboring interface states effectively at low frequencies and hence increases the conductance. However, the increase in conductance with increase in frequency in the reverse bias region can be looked upon due to particular distribution of the interface states and increase in series resistance after irradiation [44]. The conductance is the measure of various component of a.c. tunnel current, mainly due to potential fluctuation at the semiconductor surface, charging and discharging current at the interface states and the recombination current in the space charge region. Unlike for the pristine sample [37], the increase in conductance with increase in frequency indicates the formation of radiation induced recombination centers or defects which promote recombination current in the space charge region. Furthermore, the conductance may also increase if charging and discharging current or hopping conduction process increases at the interface due to increase in interface state density. The increase in proximity of the interface states may cause well synchronization of the interface states charging and discharging processes even under the influence of high frequency a.c field. In other words, there exists continuum distribution of interface sates with varying time constants.

3.2. Bias dependent interface state analysis

The measured capacitance and conductance values are used to evaluate parallel conductance (G_P) from Nicollian and Brews method [37,43]. The $G_p/\omega-f$ plot under different biases at RT (Fig. 3) exhibits a peak, whose magnitude and position depend on the gate bias voltage. The peak position shifts towards higher frequency region as the bias voltage is incremented from 0 V to 0.6 V, which however, starts shifting towards lower frequency region with further rise in bias voltage. This reverse peak shift is absent in the reported pristine sample [37]. Moreover, the peak value of G_p/ω decreases as the bias voltage increases except at 0.8 V. The bias dependent shift of $G_p/\omega - f$ peaks suggest a change in the time constant of interfaces states. This can be attributed to the particular distribution of the interface state energy levels responding independently with varying bias.

The same G_p/ω – frequency plot is used to evaluate the interface state density (N_{ss}) and relaxation time (τ) as described previously in detail [37]. The values of N_{ss} and the τ are plotted against E_c-E_{ss} as shown in Fig. 4. The E_c and E_{ss} represent energy levels corresponding to the bottom of the conduction band and energy of the interface states respectively.

The value of N_{ss} increases gradually towards the mid of the bandgap varying from $0.58 \times 10^{13}\,eV^{-1}\,cm^{-2}$ to $1.27 \times 10^{13}\,eV^{-1}\,cm^{-2}$,