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γ-rays irradiation effects on dielectric properties of Ti/Au/GaAsN Schottky diodes with 1.2%N

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ABSTRACT

Dielectric properties of As grown and irradiated Ti /Au/GaAsN Schottky diodes with 1.2%N are investigated using capacitance/conductance-voltage measurements in 90–290 K temperature range and 50–2000 kHz frequency range. Extracted parameters are interface state density, series resistance, dielectric constant, dielectric loss, tangent loss and ac conductivity. It is shown that exposure to γ-rays irradiation leads to reduction in effective trap density believed to result from radiation-induced traps annulations. An increase in series resistance is attributed to a net doping reduction. Dielectric constant (ε') shows usual step-like transitions with corresponding relaxation peaks in dielectric loss. These peaks shift towards lower temperature as frequency decrease. Temperature dependant ac conductivity followed an Arrhenius relation with activation energy of 153 meV in the 200–290 K temperature range witch correspond to As vacancy. The results indicate that γ-rays irradiation improves the dielectric and electrical properties of the diode due to the defect annealing effect.

1. Introduction

The search for new high speed devices that resist radiation is required for a number of useful applications. Among these semiconductor materials candidates, dilute nitride gallium arsenide (GaAsN) has been recently proposed (Shafi et al., 2011). Its electrical properties can be improved by adding a small nitrogen fraction, and can be tailored for many applications such as solar cells fabrication (Yamaguchi et al., 2012), infra-red lasers devices (Kondow et al., 1997), terahertz emitters and detectors (Park et al., 2009) and so on. The presence of some percent of nitrogen (N) induces an impressive diminution of forbidden band gap of GaAs semiconductor. Due to large electronegativity of nitrogen and its small covalent radius, forbidden band gap decreases by approximately 0.1 eV for each percent of nitrogen (N) in the alloy. Researchers (Tisch et al., 2002) suggested that this dependence of energy gap on small nitrogen fraction (0 < x < 5) can be calculated using empirical expression:

$$E_G^{GaAs1-xNx} = E_G^{GaAs} - 18.7*x + 210*x^2 \quad (1)$$

For GaAsN alloys with 1.2%N concentration, the band gap is 1.22 eV. Furthermore, GaAsN show an increase in effective mass and decrease in life time carriers and their mobility. These changes make dilute alloy candidate to possible optoelectronic applications (Riechert and Steinle, 2005; Weltya et al., 2005; Yoona et al., 2005).

Lately, irradiated Ti/Au/GaAsN Schottky diodes have attracted attention. Workers (Al Saqri et al., 2015) have investigated gamma irradiation effects on Ti/Au/GaAsN Schottky diodes using Laplace Deep Level Transient Spectroscopy (LDLTS). The gamma dose was 50 kGy (dose rate of 5.143 kGy/h). They showed that for samples with N content between 0.2% and 0.4%, the number of traps decreased after irradiation, whereas for samples with N content between 0.8% and 1.2%, the number of traps remained the same. Workers (Bachir Bouiadjra et al., 2014) have investigated the electrical properties of same Schottky diodes at room temperature. They found that ideality factor and series resistance increase with increasing N% dilution in GaAs accompanied by a decrease in Schottky barrier height. They stated that interface states density increased when dilute nitride concentration increased. Researchers (Klangtakai et al., 2015) have also investigated gamma-ray irradiation effects on structural properties of $GaAs_{1-x}N_x$ films (N between 1.9 and 5.1 at%). They found that gamma-ray

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irradiation causes structural changes including displacement damage and gamma-ray heating.

In our previous work (Teffahi et al., 2016) we have characterized electrical properties of Ti/Au/$GaAs_{1-x}N_x$ Schottky diodes at room temperature using I-V and C/G-V-f techniques, The investigated parameters are ideality factor (n), series resistance (Rs), barrier height (Φ_B), doping concentration (N_D), relaxation time and density of interface states (Nss). We have shown a decrease in measured barrier height and an increase in extracted Ideality factor and the series resistance. The density of interface states distribution increase after radiation due to irradiation-induced defect (Al Saqri et al., 2015).

However, workers (Bobby et al., 2014) have deduced that irradiation with a cumulative dose of 10 Mrad improves electrical characteristics of Au/n-GaAs diodes. They found a decrease in series resistance and in ideality factor. Researchers (Yu and Walukiewicz, 2002) stated that pulsed laser annealing improves N incorporation in GaN_xAs_{1-x} thin films with synthesized films being thermally stable.

All above studies show that electrical properties of GaAsN Schottky diodes are complex and still raise numerous questions related to N concentrations and irradiation effects. In this paper, electrical and dielectric properties of as grown and γ-rays irradiated Au/Ti/GaAsN 1.2% N Schottky diodes are analyzed. The effect of γ-rays on interfaces states density, series resistance, permittivity, dielectric constant, loss factor (tan δ) and ac conductivity are examined over a wide temperature range [90–290 K] and frequency range [10 kHz to 2 MHz].

2. Experimental details

As previously described (Teffahi et al., 2016), Schottky diodes are made of an n-GaAs substrate on top of which is grown a 0.1 µm thick Si-doped (2.10^{18} cm^{-3}) epitaxial buffer layer of GaAsN followed by a 1 µm thick Si-doped (3.10^{16} cm^{-3}) epitaxial active layer of GaAsN. At this stage, structures were ion irradiated at room temperature in a gamma cell Cobalt irradiator at a dose of 50 kGy with a 5.143 kGy/h dose rate. Then devices are processed in the form of circular mesas with different diameters for electrical characterization. A Ge/Au/Ni/Au sandwich layer was evaporated and alloyed to form an Ohmic contact to the bottom of n- GaAs substrates. Schottky contacts were formed by evaporation of Ti/Au on top of doped epilayer. Capacitance/Conductance-Voltage (C/G–V-T) measurements were carried out using an Agilent LCR meter (E4982a). Device temperature was changed using an ARS Closed Cycle Cryostat.

3. Results and discussions

1.2% N content Au/Ti/GaAsN Schottky diodes are dc biased from −2 to 0.8 V with an added small ac sine signal at 1 MHz to allow deep traps to capture and release electrons. Fig. 1 shows capacitance variation against bias voltage before and after irradiation at some preselected temperature. Capacitance decreased after irradiation. This is attributed to a decrease in donor concentration and to a change in dielectric constant at metal semiconductor interface after gamma irradiation (Shiwakoti et al., 2017). Capacitance also decreased with decreasing temperature due to a continuous distribution of density of interface states (Nss) and change in series resistance (Bobby et al., 2016).

Fig. 2 shows conductance variation bias voltage before and after irradiation at some preselected temperature. Conductance increases with increasing voltage and with decreasing temperature for both samples. However, its value decreased after gamma irradiation. This effect can be attributed to a decrease in net ionized doping concentration (Behle and Zuleeg, 1972; Karataş et al., 2005; Uğurel et al., 2008).

Series resistance temperature-voltage dependence in Fig. 3 is obtained from C–V–T and G–V–T measurements according to (Bachir Bouiadjra et al., 2014; Nicollian et al., 1982):

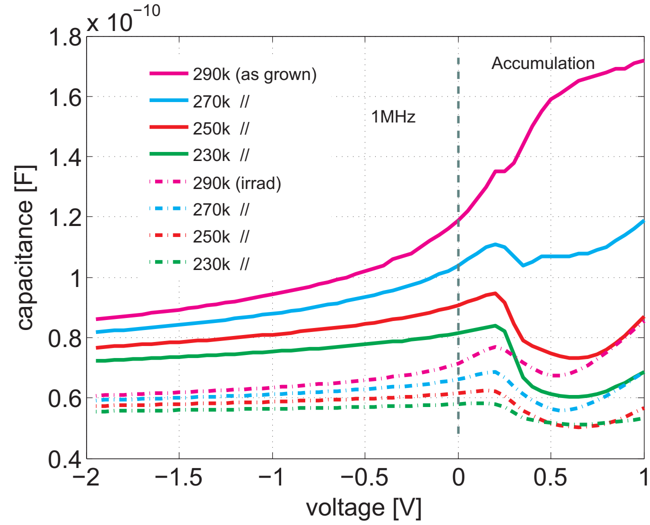

Fig. 1. Capacitance-voltage dependence of Ti/Au/GaAsN Schottky diodes at some preselected temperature.

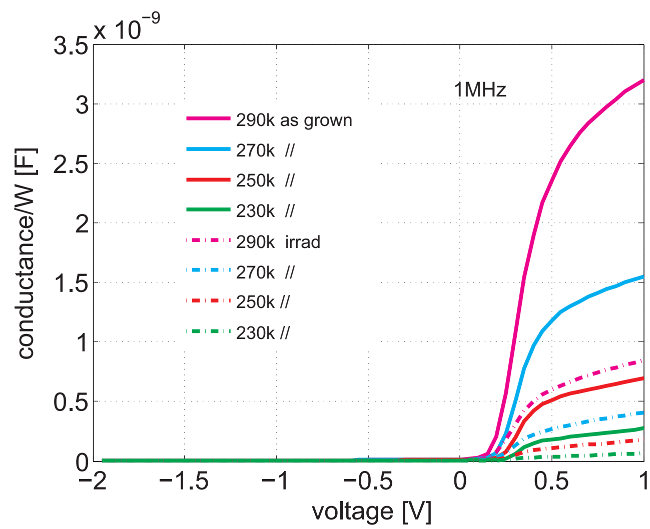

Fig. 2. Conductance-voltage dependence of Ti/Au/GaAsN Schottky diodes at some preselected temperature at some preselected temperature.

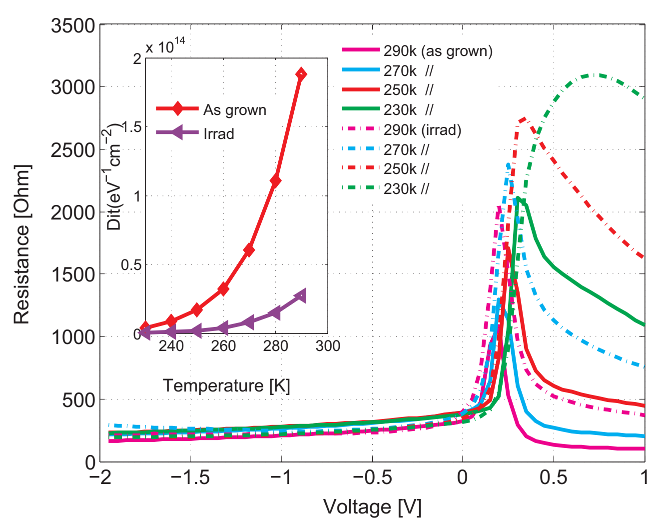

Fig. 3. Series resistance -Temperature dependence of Ti/Au/GaAsN Schottky diodes. The inset shows the interface states density change for Ti/Au/GaAsN Schottky diodes.