International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 331-335 www.ijaem.net ISSN: 2395-5252

Investigation on the Possible Set-Back Effect on the Performance of Electronic Devices in Radiation Environment: A case study of Metal-Semiconductor-Metal GaN-Based Radiation Sensor

Muttaka Umar[1], Aminu Saidu[2], Abubakar Usman[3], Sirajo Abubakar[4]

[1,3,4]*Assistant Lecturers, Department of Physics, Sokoto State University,Sokoto, P.M.B 2134, Sokoto, Nigeria*
[2]*Associate Professor,Department of Physics, UsmanuDanfodiyo University, Sokoto, P.M.B 2346, Sokoto, Nigeria*

Submitted: 01-08-2022 Revised: 07-08-2022 Accepted: 10-08-2022

ABSTRACT:Many benefits would be realized if electronics could function properly without the need for radiation shielding or heating/cooling accessories. These benefits include increased efficiency, improved reliability, and decreased system development and launch costs. A gallium nitride-based (GaN) radiation sensor was selected in this study for performance evaluation of the possible setback it may induce after being exposed to X-ray irradiation. The low resistance of the wide band-gap material allows the development of a new generation of transistor devices that switch faster and with greatly reduced losses. The GaN material used in this study is an n-type commercial wafer. The interdigitated electrode pattern was prepared by the DC magnetron sputtering technique. The GaN-based device was exposed to varying accelerating kilo voltages of X-ray fluxes and its current-voltage (I-V) characteristics were measured. The electrical characteristic of the Metal-Semiconductor-Metal radiation sensor based on GaN was investigated. I-V measurements under the X-ray exposure at different distances display some ohmic and resistive behaviour, although the current drop was observed at a 20 cm distance of the device and 90 kV accelerating voltage of the X-ray. The fabricated device showed good sensitivity to X-ray radiation.

KEYWORDS: Gallium Nitride, X-ray irradiation, Meta-semiconductor-metal, Electrical Properties.

I. INTRODUCTION

Amongst the wide bandgap (WBG) semiconductors, GaN has found a wide application in the making of optoelectronic devices. It has been used for photodetection such as solar-blind imaging and X-ray sensing [1]. The WBG III-Nitrides semiconductor material systems have also been used in laser diodes, high-power/high-frequency transistors, and power rectifiers [2, 3]due to their breakdown field [4]. GaN is a promising candidate for 5G cellular-based applications due to its high power density and voltage breakdown limits. Its sensitivity is low to ionizing radiations (like other groups III nitrides) which make it suitable for solar cell array. Military and space applications could also benefit as their devices have shown stability in radiation environments [5].

Currently, semiconductors are widely used for X-ray and gamma radiation sensing and are the most advanced devices for radiation monitoring in industries such as power, engineering and science [6]. The advent of semiconductor sensors has revolutionized the broad field of X-ray spectroscopy. They are originally developed for particle physics, which are now widely used for X-ray spectroscopy in a large variety of fields such as X-ray fluorescence analysis, X-ray astronomy and diagnostic medicine [7].

In comparison to other semiconductor materials, GaN is of particular interest for use in radiation environments due to its high ionic bond strength and large crystal density. These properties suggest that GaN may exhibit greater radiation hardness than other comparable compound semiconductors and will suffer less from the influence of interstitial impurities [8].

Optoelectronic diodes are extensively used in many electronics devices for various applications including devices that require robust performance in a radiation environment. Due to economic and time constraints, commercial diodes are often chosen for ground and space operations [9]. The growth methods for GaN are shifting from foreign substrate epitaxial to free-standing type [10].

Ionizing radiations deposit energy and create electron-hole pairs in GaN. As radiations traverse the GaN device, the irradiation ions lose energy by two main mechanisms known as nuclear and electronic stopping. This is due to the interaction with nuclei and the electrons of the target materials, respectively [11]. Displacement damage is the most common effect observed in irradiated GaN devices and is the result of nuclear interactions which cause lattice defects. Displacement damage is due to cumulative long-term non-ionizing radiation damage in the GaN [12, 13].

Semiconductors which have replaced vacuum tubes are more susceptible to radiation damage. When semiconductor devices are exposed to radiation, they undergo dramatic changes in their properties. These changes can affect the performance of the device. The radiation environment could be space, nuclear environment or environment near nuclear facilities [14, 15].

As a result, it has become imperative to investigate the possible set-back effect of radiation on the performance of semiconductor devices when operated in a radiation environment. Based on the radiation tolerance of GaN, therefore, the experimental work will investigate the changes in electrical performance of the radiation sensor when subjected to X-ray irradiation.

II. EXPERIMENTATION

The GaN used in this study is a commercially undoped n-type GaN grown on a sapphire substrate. The metal-semiconductor-metal (MSM) was produced by patterning nickel (Ni) interdigitated electrode (IDE) on the GaN/sapphire template by DC magnetron sputtering. The Nickel target (99.99% purity) was used as the source. A 200 nm thick Ni contact was sputtered at 180 W at the deposition rate of 1.2 nm/s. The chamber working pressure was 2.57 mbar, and the gas flow rate was 5 sccm. The Ni contacts have a finger length of 8.7 mm, a width of 4.7 mm, and their spacing varying 0.45 to 0.54 mm. A sample image of the fabricated device is shown in Fig. 1.

Contacts establishment

A means of contact was established by connecting a 15 m copper wire to the electrodes on each side of the IDE which was later placed under the X-ray machine for the irradiation process and measurements.

Measurement procedure

The GaN sample was placed under the X-ray tube. The distance between the samples to the X-ray tube was adjusted as 1.0, 2.0, 4.0, 10.0 and 20.0 cm, accordingly. The X-ray kilovolt power (kVp) energy was set from 50 to 90 kVp. For each set of kVp values, the distance was adjusted with an incrementing value while keeping the current (mA) and time (seconds) constant at 50 and 2, respectively.

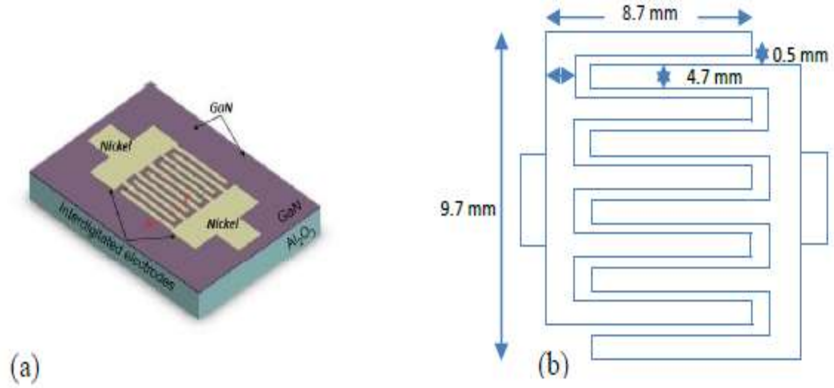

Figure 1: (a) Schematic illustration of the GaN-based radiation sensor; (b) Enlarged view of the interdigitated electrode showing the various dimensions.

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 331-335 www.ijaem.net ISSN: 2395-5252

III. RESULTS AND DISCUSSION

Sweep Voltage measurement

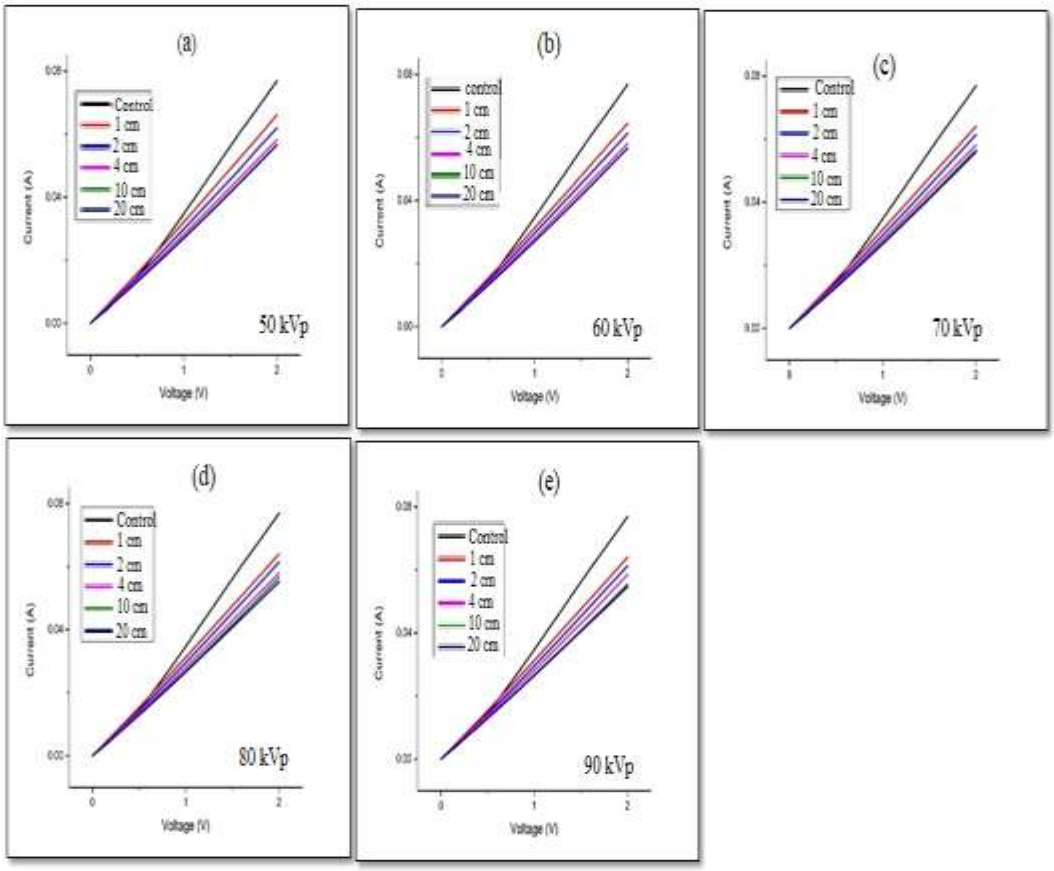

Figure 2: (a) - (e) I-V characteristics graphs at different X-ray kVp energy with varying distances.

Discussion

All the graphs in Fig. 2 show the current versus voltage trend of the GaN device under X-ray irradiation exhibiting ohmic behaviour linearly.The set of graphs obeys the hypothesis that the larger the distance of the radiation source to the MSM device, the weaker the amount of current flowing through the device due to an increase in resistance developed by the device, as can be seen in Table 2. It is however important to note that, the current drop experienced negligible change at higher distances (20 cm) of irradiation. For the control, the observation at 0 cm irradiation gives a higher current and hence the least resistance.

From Fig. 2, the model for observing the electrical behaviour of the GaN device can be extracted based on the relationship between the highest current recorded at the peak and the distance of the device from the X-ray energy source under different kVp X-ray energy values.

Table 1: Highest current at 0 to +2 V sweep voltage under different kVp energy value

kVp	I_{1cm} (mA)	I_{2cm} (mA)	I_{4cm} (mA)	I_{10cm} (mA)	I_{20cm} (mA)
50	66.0	61.9	58.0	56.6	56.5
60	64.3	61.5	58.0	56.6	56.6
70	63.9	61.4	58.1	56.5	55.9
80	63.8	61.4	57.9	56.5	55.1

90	63.7	61.2	58.5	55.5	54.6

Table 2: Resistance of the GaN device at different distances and kVp energy values

Distance (cm)	R_{50kVp} (Ω)	R_{60kVp} (Ω)	R_{70kVp} (Ω)	R_{80kVp} (Ω)	R_{90kVp} (Ω)
1	30.24	30.93	31.14	31.20	31.50
2	32.21	32.50	32.50	32.50	32.55
4	34.27	34.34	34.29	34.39	34.16
10	35.22	35.23	35.27	35.32	36.04
20	35.32	35.27	35.70	36.13	35.48

From Table 1, the resistance of the device can be calculated using the equation of straight line $y = mx + c$. The equation can be transformed into $I = \frac{1}{R}V + c$, where R is the resistance, therefore, $m = \frac{1}{R}$ and $R = \frac{1}{m}$. The device resistance is calculated and tabulated in Table 2.

It can be observed from Table 2 that the resistance (R) of the device varies with increasing kVp energy and significantly with the distance between the source and device. This behaviour is confirmed by the results obtained in Table 1 which shows decreasing current (I) with increasing the device's distance (D) from the source. The resistance of the device was found to increase with the distance from the X-ray irradiation at increasing kVp energy. There is a significant variation in the resistance of the GaN device to the distance of the X-ray irradiation at corresponding kVp. This ascertains that the distance has more effect on the resistive behaviour of the device when exposed to X-ray irradiation than the kVp energy.

IV. CONCLUSION

MSM device based on commercial GaN was fabricated and tested under an X-ray radiation source. The X-ray irradiation was found to cause changes in the I-V characteristics, exhibiting some ohmic behaviour. In conclusion, irradiated devices can show some degradation commensurate to when the distance of exposure from the radiation source is small, at such ionizing radiations can pose a serious threat to electronic devices and circuits operating within a radiation environment.

REFERENCES

[1]. Wang, J., Mulligan, P., Brillson, L., and Cao, L. R. (2015). Review of using gallium nitride for ionizing radiation detection. Applied Physics Reviews, 2(3), 031102.

[2]. Polyakov, A. Y., Smirnov, N. B., Lee, I. H., and Pearton, S. J. (2015). Deep level transient spectroscopy in III-Nitrides: Decreasing the effects of series resistance. Journal of Vacuum Science & Technology B, Nanotechnology and Microelectronics: Materials, Processing, Measurement, and Phenomena, 33(6), 061203.

[3]. Khanna, S. M., Webb, J., Tang, H., Houdayer, A. J., and Carlone, C. (2000). 2 MeV proton radiation damage studies of gallium nitride films through low temperature photoluminescence spectroscopy measurements. IEEE Transactions on Nuclear Science, 47(6), 2322-2328.

[4]. Mishra, U. K., Parikh, P., & Wu, Y. F. (2002). AlGaN/GaN HEMTs-an overview of device operation and applications. Proceedings of the IEEE, 90(6), 1022-1031.

[5]. Lidow, A., Witcher, J. B., and Smalley, K. (2011). Enhancement mode gallium nitride (eGaNTM) FET characteristics under long term stress. GOMACTech11, March.

[6]. Abbene, L., and Gerardi, G. (2012). High Resolution X-ray spectroscopy with compound semiconductor detectors and digital pulse processing systems. Intech Open, 39-64. ISBN 978-953-307-967-7

[7]. Poyai, A., Simoen, E., Claeys, C., Hayama, K., Kobayashi, K., and Ohyama, H. (2002). Radiation effects on the current-voltage and

capacitance-voltage characteristics of advanced pn junction diodes surrounded by shallow trench isolation. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 186(1-4), 409-413.

[8]. Sellin, P. J., and Vaitkus, J. (2006). New materials for radiation hard semiconductor dectectors. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 557(2), 479-489.

[9]. Fauzi, D. A., Rashid, N. M., Karim, J. A., Zin, M. M., Hasbullah, N. F., and Fareed, O. S. (2013, December). Electrical performances of commercial GaN and GaAs based optoelectronics under neutron irradiation. In IOP Conference Series: Materials Science and Engineering (Vol. 53, No. 1, p. 012029). IOP Publishing.

[10]. Trivellin, N., Meneghini, M., Zanoni, E., Orita, K., Yuri, M., Tanaka, T., and Meneghesso, G. (2010). A review on the reliability of GaN-based laser diodes. In 2010 IEEE International Reliability Physics Symposium (pp. 1-6). IEEE.

[11]. Srour, J. R., Marshall, C. J., and Marshall, P. W. (2003). Review of displacement damage effects in silicon devices. IEEE transactions on nuclear science, 50(3), 653-670.

[12]. Pearton, S. J., Ren, F., Patrick, E., Law, M. E., and Polyakov, A. Y. (2015). Ionizing radiation damage effects on GaN devices. ECS Journal of solid state science and technology, 5(2), Q35.

[13]. Chen, J. (2013). Radiation response and reliability of AlGaN/GaN HEMTS (Doctoral dissertation). Vanderbilt University, 1-69. http:hdl.handle.net/1803/12715

[14]. Messenger, G. C., and Ash, M. S. (1986). The effects of radiation on electronic systems, Van Nostrand Reinhold Company, New York (29986). OSTI Identifier: 6335243.

[15]. McClory, J. W. (2008). The effect of radiation on the electrical properties of aluminum gallium nitride/gallium nitride heterostructures. Air Force Institute of Technology.