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Full Length Article

Effects of gamma irradiation on non-polar GaN films deposited on sapphire using pulsed laser deposition

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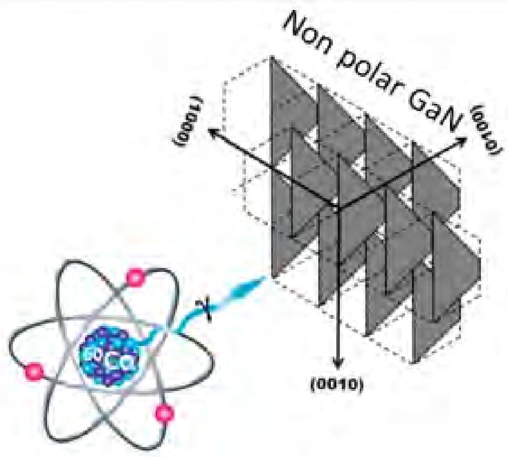
Abstract

The GaN films/layers exposed to γ-radiations is known to harvest defects and vacancies in the crystals producing donor, acceptor and recombination centers within the bandgap. Therefore, it is important to investigate and study the γ- ray irradiation effects on various physical and chemical properties of a material before any optoelectronic and/or electronic devices are being fabricated. To avoid Stark effect which is observed in most of the optoelectronic devices fabricated using GaN films grew along polar face, use of non-polar GaN films is suggested by researchers. To address such issues the article reports the investigations of physical and chemical properties of non-polar GaN films grown on polar substrate using pulsed laser deposition, which were exposed to the ^{60}Co gamma rays varying dose values. Resistive nature against the impairment of the films caused by γ-rays observed herewith is highly encouraging, suggesting the use of non-polar GaN films as radiations harden material suitable for fabricating new generation γ-ray detectors. To our knowledge very limited information is available that report such investigations.

Graphical abstract



Introduction

For detecting high energy radiations expensive detectors such as gas filled counters and scintillation counters are widely used even today. The gas filled detectors are fragile and operates at very high voltages, whereas scintillation counters are fabricated using Thallium-doped sodium iodide, zinc sulphide, cesium iodide, etc. and has poor resolution. Hence cannot be a viable option for identifying gamma rays having a frequency if they have complex form. Along with this the supporting accessories needed to operate these detectors makes them very expensive and bulky to handle. On the contrary, detectors fabricated using semiconductor materials e.g. Ge, Si, GaAs, etc. has high energy resolution, smaller footprints, low costs and can be mass produced. However detectors fabricated using these semiconductor materials are facing performance problems [1], [2]. For example, the dark current of detectors is observed to degrade when exposed them to the high energy radiations. Reason behind is the deteriorating properties of materials (mainly the smaller band gap, mechanical strength and the rate of energy dissipation) when exposed to high energy radiations. This has created a room to use the compound semiconductors to fabricate such detectors [3], [4]. Thus use of III-nitride semiconductors especially GaN has received a considerable attention. Researches have already proved the excellency of GaN by demonstrating various electronic and optoelectronic devices such as UV detectors, high power and high frequency devices, high voltage switching devices, light-emitting diodes, etc.[5], [6]. Unique properties of GaN i.e. its wide band gap, high electron mobility, high thermal conductivity, hardness, high Seebeck coefficient and excellent temperature stability at high temperatures, etc.[7], [8], [9], [10] are main reasons behind these advancements. Doped GaN has played a vital role in terms of achieving the required selectivity and sensitivity of such devices [11]. It also serves as an ideal material for the detection of gamma rays, x-rays as well as thermal neutrons mainly due to the isotope enrich environment, density of the material and the reaction cross section for responses that occurs after interacting with these radiations [12], [13], [14]. Several research groups has already demonstrated GaN devices that detects gamma rays [15], [16], [17], [18]. However the responses of such detectors to gamma-rays is observed to be complicated and dose dependent [18], [19]. Most of these devices were fabricated using polar i.e. c-GaN, they are observed to suffer from quantum confinement Stark effect [20], [21]. To improve the efficiency of devices use of non-polar (for e.g. s, m and a- crystallographic planes) GaN films is suggested [22]. So far researchers have demonstrated the growth of non-polar GaN along m and a- crystallographic planes [23], [24], however very few reports are available reporting s-plane growth of GaN on c-Al_2O_3 substrate [25]. To the best of our knowledge very limited information is available that reports study of these films exposed to high energy radiations for e.g. Gamma rays.

The research article presented herewith thus has two clear aims. First we demonstrate the quality growth of non-polar GaN films especially along s-plane on the polar substrates using pulsed laser deposition. Second we investigate the properties of these films when exposed to [60]Co gamma radiations varying dose values from 40 kGy to 260 kGy under atmospheric conditions. The investigations reported herewith are very important considering the fact that GaN films exposed to gamma radiations harvest defects and vacancies in the crystal affecting the properties of layers. The critical investigations of the exposed films reported herewith clearly demonstrate resistive nature of non-polar GaN films against high energy radiations. The result suggests the use of s-plane GaN films can be one of the options to fabricate next generation gamma ray detectors, where stability of devices is of prime importance.

Section snippets

Experimental

For the growth of non-polar GaN films, gallium nitride target (purity 99.99 %) was mounted in the deposition chamber and ablated using KrF excimer laser (wavelength λ = 248 nm, energy density = 3 J/cm^2, pulse duration = 9 ns, repetition rate = 15 Hz). Prior to start any deposition the substrate i.e. c-Al_2O_3 was ultrasonically degreased using trichloroethylene, acetone, methanol and finally DI water for a minute each and dried with nitrogen jet. Cleaned substrate was then mounted on the

Results and discussion

Fig. 1 show the X-ray diffractogram recorded on pristine GaN film and the films exposed to gamma radiations varying dose values. In XRD spectra peak positioned at 41.9^0 observed for all specimen is due to the substrate used i.e. c-Al_2O_3. Along with it additional two peaks positioned at 38.29^0 and 58.89^0 can be assigned to (1 0 $\bar{1}$ 1) and (1 1 $\bar{2}$ 0) crystallographic planes of wurtzite GaN (JCPDS card No: 79-2499, 74-0243) respectively.

Structural parameters namely lattice stress, grain sizes,

Conclusion

Set of non-polar GaN films was deposited on the polar substrate using PLD under optimized conditions. Film growth along (10 $\bar{1}$ 1) and (11 $\bar{2}$ 0) crystallographic planes have been confirmed using XRD. The AFM images confirm the growth of elongated grains that are slightly inclined at an angle ~ 50^0 to the substrate surface. To investigate if nonpolar GaN film exposed to energetic radiation harvests defects and vacancies in the crystals, films were then exposed to ^{60}Co Gamma radiations under

Ethical approval

Articles doesn't include any kind of clinical trials, neither has it involved any identifiable human subjects and well as animal experimentation.

CRediT authorship contribution statement

Tahir Rajgoli: Formal analysis, Investigation, Methodology, Project administration. **Tushar Sant:** Conceptualization, Formal analysis, Methodology, Writing – original draft. **Suhas M. Jejurikar:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Sandip Hinge:** Data curation, Methodology, Resources. **Arun Banpurkar:** Conceptualization, Resources. **S.S.**

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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