Evaluation of GaN (Si) Scintillator for alpha particles detection

A. ISMAIL, R. SHWEIKANI, B. JERBY
Atomic Energy Commission of Syria, Protection and Safety Department, Damascus, P. O. Box 6091, Syria

The applicability of using the radio-luminescence of Si-doped Gallium Nitride GaN(Si) for the detection of alpha particles was investigated. Different Americium-241 sources with different activities were used. The results showed that GaN(Si) has an excellent linearity with exposure time and activity. The uncertainty of the repeatability test was found to be less than 2%. In addition, the performance of GaN was compared with ZnS(Ag). Results showed that GaN(Si) is more appropriate for wide range of activities and has no saturation like the response of ZnS(Ag).

(Received August 4, 2014; accepted February 10, 2016)

Keywords: GaN(Si), ZnS(Ag), Scintillation, Alpha particules detection

1. Introduction

GaN is a semiconductor material with a wide band gap of 3.4 eV (Pittet, 2009b). It is used as Schottky diode for alpha detection and for High-Resolution Alpha-Particle Spectroscopy (Polyakov, 2009; Wang, 2012; Pullia, 2008). In these studies, only the electrical properties of GaN were applied for alpha detection (radio-electrical principle).

In addition, GaN has remarkable scintillation properties that can be compared to NaI(Tl) and ZnS(Ag). Actually, the light yield of the GaN ($\sim 10^5$ Photons/MeV) is significantly higher than those of scintillating fibers and many conventional scintillating crystals. Moreover, GaN has a very fast response time (raise and decay time <1 ns for its near-band-edge transitions) (Pittet, 2009a). For these reasons, GaN was recently used in the development of in-vivo dosimetric system for the detection of high-energy photons and electrons (Ismail, 2011).

However, Silver-activated zinc sulfide, ZnS(Ag), is one of the oldest inorganic scintillators. It has a high scintillation efficiency. ZnS(Ag) has been widely used for alpha detection especially for environmental samples (radon measurements) (Misdaq, 1997; IAEA, 1979). Nevertheless; This material cannot be used with thicknesses higher than about 60 μm due to its opacity to its own luminescence (LEE, 2011).

In this work, the scintillation properties of GaN(Si) to detect alpha particles were investigated.

The characterization of GaN(Si) response to different flux of alpha particles is carried out and its performance is compared with ZnS(Ag).

2. Materials and methods

Small Si-doped n-type GaN pieces (3mm x 3mm x 0.3mm), provided by LUMILOG, France with doping concentration of 1.5×10^{19} atom.cm^{-3} were used. It is strain-free bulk GaN grown by hydride-vapor phase-epitaxy (HVPE) (Gogovam, 2004).

ZnS(Ag) scintillators were provided by Pylon Electronics Inc. as transparent plastic base coated with ZnS (Ag).

GaN(Si) substrate and ZnS(Ag) sheet were characterized by using Photoluminescence (PL) measurements. The experimental set-up consisted of UV excitation using a 325 nm He/Cd laser, and spectral measurements via a grating monochromator with 1200 groves/mm equipped with a cooled PMT (HAMAMATSU). A long-pass filter was used to reject plasma and laser light from the helium- cadmium laser below 360 nm. Synchronous detection technique was implemented by chopping the laser beam and employing a lock-in amplifier to process the electrical output of the PMT. Via a set of optical devices, the excitation beam was guided and focused on to the tested sample.

The scintillation produced by exposing GaN(Si) and ZnS(Ag) to alpha particles was measured using a nuclear counting system (AB-5) manufactured by Pylon Electronics Inc. The experimental set-up is shown in Fig. 1.

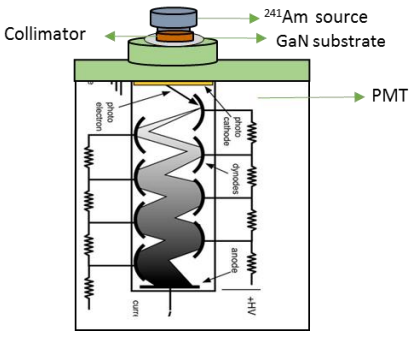

Fig. 1. The experimental set-up for testing the response of GaN

A series of experiments were carried out to evaluate and characterize the scintillation properties of GaN(Si). The repeatability, exposure time response and source activity response were investigated and compared with those obtained using ZnS(Ag).

The repeatability test was performed by exposing GaN and ZnS(Ag) to an alpha source (Am-241 source with activity of (126±4) Bq) for 1 minute fifty times and recording the produced scintillation by the nuclear counting system (AB-5). While, the effect of exposure time was assessed by irradiating GaN(Si) and ZnS(Ag) for different exposure time (ranged from 1 sec to 900 sec) using the same source as above and recording the produced scintillations. In addition, the radioactivity effect was examined using five different Am-241 sources with different activities (ranged from 0.7 Bq up to 55.6 kBq) for constant exposure time (1 min).

3. Results and discussions

3.1 PL characterization

Fig. 2 shows room temperature PL spectra of GaN sample, with $1.5\times10^{19}cm^{-3}$ silicon doping concentration. GaN (Si) exhibits a dominant emission peak at λ = 368 nm (~3.37 eV), which is attributed to band-to-band emission. Similar results were reported by Pittet et al. (Pittet, 2009b).

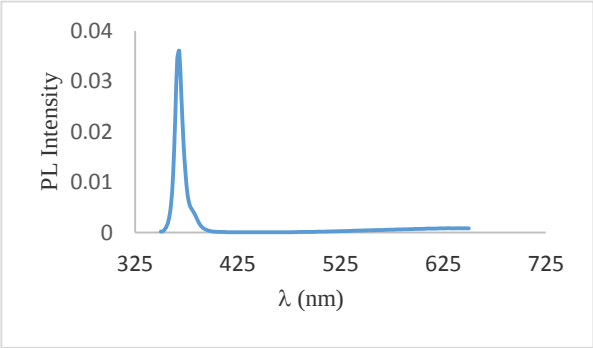

Fig. 2. Room temperature PL spectra of Si-doped GaN

On the other hand, ZnS (Ag) exhibits a wide emission peak centered at 450 nm (~2.76 eV) (Fig. 3). Similar results were reported by Erfurt et al. (Erfurt, 2002).

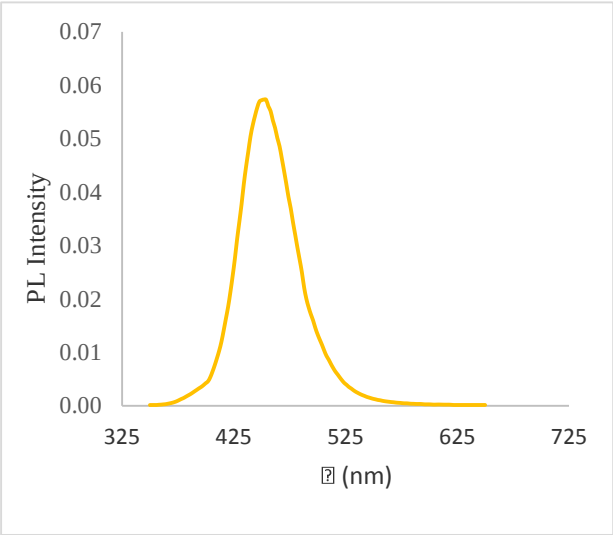

Fig. 3. Room temperature PL spectra of Ag-doped ZnS

3.2 Repeatability

Fig. 4 shows the recorded scintillation counts for the 50 runs using GaN(Si) and ZnS(Ag) which were within ±2.0% and ±1.8% respectively. It is clear that both detectors have good repeatability of measurements.

Student T-test was used to compare the response of the two detectors from statistical point of view. It was found that at 5% significant level, P-value was about 4.3×10^{-92}, indicating no significant statistical differences between the behaviors of the two detectors.

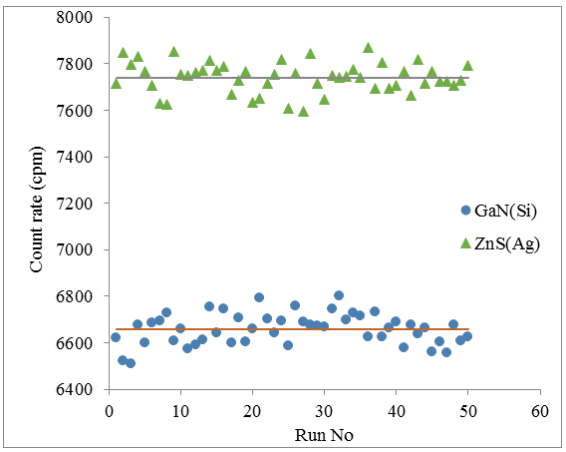

Fig. 4. Repeatability test for GaN and ZnS detectors

3.3 Exposure time response

Fig. 5 shows the counts measured by both GaN(Si) and ZnS (Ag). The two detectors demonstrate excellent linearity (R^2=1) for irradiation times between 1.0 sec and 900 sec. It is worth to mention that the behavior of GaN(Si) is very much comparable to ZnS (Ag) in term of

linearity with exposure time, except the lower response of GaN (about 16%).

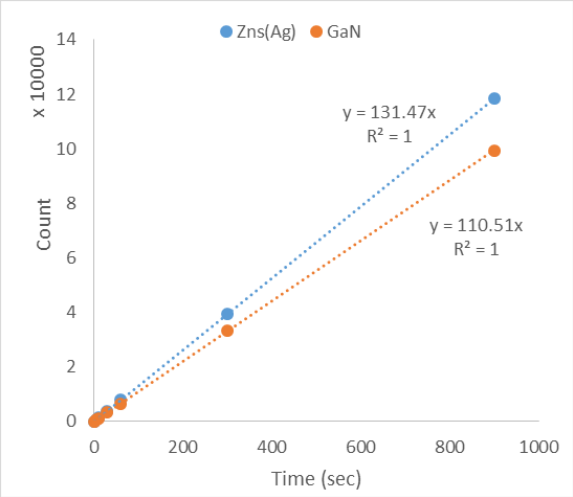

Fig. 5. Exposure tme response of GaN & ZnS(Ag)

3.4 Radioactivity response

Fig. 6 shows the excellent linear response of GaN(Si) detector with source's activity ranged from 0.7 Bq up to 55.6 kBq. In contrast, ZnS(Ag) detector shows a quasi-linear response only up to activity around 25 kBq, afterward the response starts to reach the saturation. It should be noted that the response of ZnS is about 16% more than GaN at lower activities(less than 40 kBq), while GaN response becomes higher and stay linear at higher activities. This can be explained by the big difference in the response time of the two materials, as the response time of ZnS (1.473µs (Tojo, 2000)) is 1000 time higher than GaN (about1 ns) (Pittet, 2009a).

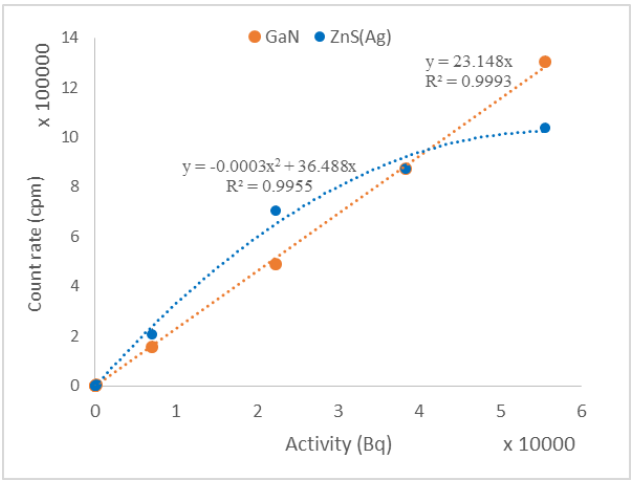

Fig. 6. GaN(Si) and ZnS(Ag) radioactivity dependence

4. Conclusions

The proposed GaN(Si) detector appears as a promising tool for alpha particles detection especially for high activity sources. The uncertainty of repeatability was within ±2.0 % and the response is linear with irradiation time. GaN was found to have an excellent linearity with the activity over a large range (0.7 Bq up to 55.6 kBq). Although the efficiency of GaN(Si) is slightly less that ZnS(Ag) at lower activities, GaN(Si) is more appropriate for the measurements in wide range of activities and has no saturation like the response of ZnS(Ag)..

Acknowledgements

The authors gratefully acknowledge Prof. I. Othman, Director General of AECS, for his invaluable assistance during the progress of this work. Moreover, we would like to thank Prof. M.S. Al-Masri, Head of protection and safety department, for his continuous support.

References

[1] G. Erfurt, M. R. Krbetschek, Radiat. Prot. Dosim.**100**, 403 (2002).
[2] D. Gogovam, A. Kasic, H. Larsson, C. Hemmingsson, B. Monemar, F. Tuomisto, K. Saarinen, L. Dobos, B. Pécz, P. Gibart, B. Beaumont, J. Appl. Phys. **96**, 799 (2004).
[3] IAEA, 1976. Manual on radiological safety in uranium and thorium mines and mills. Safety Series No. 43, Vienna.
[4] A. Ismail, P. Pittet, G. N. Lu, J. M. Galvan, J. Y. Giraud, J. Balosso, Radiat. Meas. **46**, 1960 (2011).
[5] A. Kastalsky, S. Luryi, B. Spivak, Nucl. Instr um. Meth A. **565**, 650 (2006).
[6] S. K. Lee, S. Y. Kang, D. Y. Jang, C. H. Lee, S. M. Kang, B. H. Kang, W. G. Lee, Y. K. Kim, Prog. Nucl. Sci. Technol. **1**, 194 (2011).
[7] M. A. Misdaq, H. Moustaadine, J. Radioanal. Nucl. Ch. **218**, 9 (1997).
[8] P. Pittet, G. N. Lu, J. M. Galvan, J. Y. Loisy, A. Ismail, J. Y. Giraud, J. Balosso, Sensor. Actuat. A-Phys.**151**, 29 (2009a).
[9] P. Pittet, G. N. Lu, J. M. Galvan, J. M. Bluet, A. Ismail, J. Y. Giraud, J. Balosso, Opt. Mater. **31**, 1421 (2009b).
[10] A. Y. Polyakov, N. B. Smirnov, A. V. Govorkov, A. V. Markov, E. A. Kozhukhova, I. M. Gazizov, N. G. Kolin, D. I. Merkurisov, V. M. Boiko, A. V. Korulin, V. M. Zalyetin, S. J. Pearton, I. H. Lee, A. M. Dabiran, P. P. Chow, J. Appl. Phys. **106**, 103708 (2009).
[11] A. Pullia, G. Bertuccio, D. Maiocchi, S. Caccia, F. Zocca, IEEE. T. Nucl. Sci. **55**, 3736 (2008).
[12] T. Tojo, M. Zainuddin, W. Soemad, Widyanuklida **3**, 6 (2000).
[13] G. Wang, K. Fu, C. S. Yao, D. Su, G. G. Zhang, J. Y. Wang, M. Lu, Nucl. Instrum. Meth A. **663**, 10 (2012).

*Corresponding author: prscientific@aec.org.sy