EFFECTS OF GAMMA IRRADIATION AND LOW TEMPERATURE OPERATION OF InGaN SINGLE QUANTUM WELL LIGHT EMITTING DIODES

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Introduction: A novel new monolithic radiation dosimeter package for applications in space science is currently being developed. It will combine a sapphire (Al_2O_3) chip that exhibits the phenomenon of optically stimulated luminescence (OSL) [1], an InGaN light emitting diode (LED) [2], and a photodiode into one package that can be easily read *in situ* during possible manned missions to Mars. Alternative uses of the InGaN diodes in space applications include their use in instrumentation for OSL dating of Martian sediment (Optical Dating Instrument, ODIN). The InGaN LEDs to be employed in each dosimeter are relatively new [2] and among their un-researched characteristics are the diodes' responses to high levels of radiation and their behavior at extremely low temperatures. As both of these conditions could be encountered in a space environment, their behavior under such conditions must be quantified. The purpose of this research is to detail the response of InGaN LEDs to high doses of gamma radiation and their behavior at temperatures below room temperature.

Experimental Setup: The study was performed using green LEDs manufactured by the Nichia America Corporation (type NSPG500S). Measurements of the emission spectrum and emission intensity were made on a Jobin-Yvon ES-3-22 Fluorolog spectrometer. Further optical power measurements were also using with a Newport 1830C optical power meter and 818-UV attachment. Power to the diodes was supplied by a Hewlett-Packard 6038A power supply, and was measured by a Keithley 197 multimeter. The diodes were irradiated using a ^{60}Co (19 Gy/hr) gamma cell. Low temperature experiments were performed in a liquid nitrogen cryostat, at temperatures from 25 to −160 °C while under vacuum.

Results: Radiation Effects Measurements of the peak of the emission spectrum and the intensity of the electroluminescent (EL) output of the diodes were studied, as changes in either of these properties would have detrimental effects on the accuracy of the radiation dose readings from the monolithic dosimeter package. The diodes were measured for spectrum and power output, and then subjected to radiation for a known amount of time in the gamma cell. They were then re-measured for those properties. They were put back in the gamma cell for further irradiation.

Doses of radiation were measured with thermoluminescence (TL) dosimetry of topaz powder adhered to aluminum disks which were placed in the gamma cell with the diodes as they were irradiated.

The shift in the peak of the emission spectrum (Fig. 1) was analyzed by taking the difference of the initial emission peak for the diodes, at an operating voltage of 3.5 V, and the peak of the emission spectrum at the same voltage following irradiation. Data for the EL intensity of the diodes (Fig. 2) was analyzed by taking the ratio of the initial intensity at 3.5 V and the intensity after the irradiation period at the same voltage. In both situations, no significant change in the behavior of the diode was found in radiation dose up to 228 Gy. All changes found can be attributed to experimental error, as all changes occurred in a random manner well within the bounds of standard deviation.

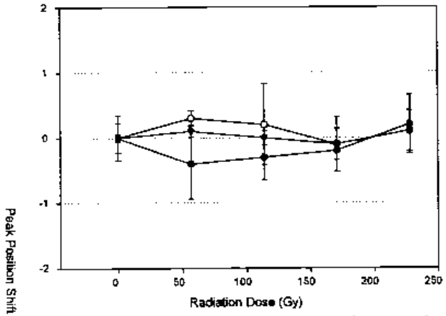

Fig. 1 – The effects of high gamma radiation doses on the peak of the emission spectrum of green InGaN LEDs.

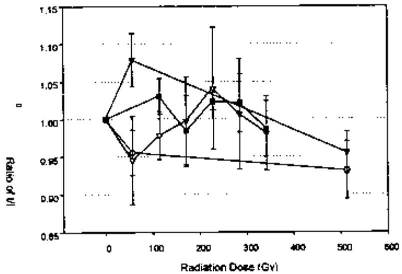

Fig. 2 – The effects of high gamma radiation doses on the optical power output of InGaN LEDs.

Results: Operation at low temperature The diodes were attached to the copper cold stage of the cryostat by means of a wire loop, which was pressed against the stage, as well as thermal paste to ensure good contact and thermal transfer. Temperatures were recorded through a type T thermocouple that was held next to the diode by the same wire that secured the diode in place. The results were obtained for two different modes of operation of the diodes. In the first experiments, the diodes were operated at a constant voltage of 2.6 V for the duration of the experiment, and both the peak of the emission spectrum and the intensity of the EL were recorded with the spectrometer. In the second set of experiments, the device was operated at a constant current of 2.0 mA for the duration of the experiment. The spectrum and intensity were obtained using the spectrometer. In addition, the voltage change with respect to temperature was recorded.

The results of the constant voltage experiments are shown in Figs. 4 and 5. A decrease in EL intensity and a red-shift in the peak of the emission spectrum as the temperature decreased were observed.

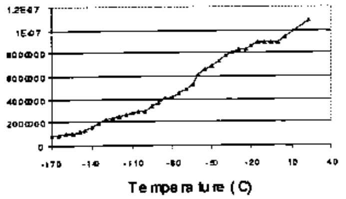

Fig. 4 – The optical power output of green InGaN LEDs operated at 2.6 V from –150 to 20 °C.

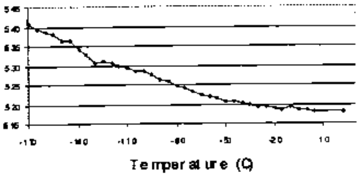

Fig. 5- Changes in the peak of the emission spectrum of green InGaN LEDs operated at 2.6 V, –150 to 20 °C.

The results of varying the temperature at constant current had previously been reported by Hori, et al. [3]. Similar results were obtained (Fig. 3) in this work.

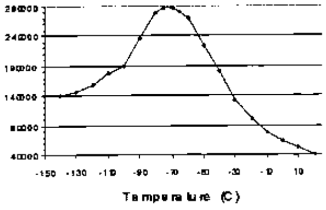

Fig. 3 - The optical power output of green InGaN LEDs constantly operated at an injection current of 2.0 mA at temperatures from –150 to 20 °C

A significant rise in optical intensity was observed, and this intensity increase peaked at approximately –78 °C. The reason for this intensity increase can be attributed to "enhancement of the radiative recombination efficiency."[3] Based on the work of Hori et al., near threshold voltages and currents were used to "avoid carrier heating."[3] In addition, their work experienced a peak in the intensity rise at approximately –130 °C, a difference from our work of about 50 degrees. This is probably due to differences in the substrate on which the diodes in each study were based on. It is of interest that no significant change in the position of the emission spectrum peak was recorded in the constant current experiments.

Conclusions: Since there is no significant change in the behavior of the diodes in their post irradiation behavior, it can be concluded that the diodes are "hard" to gamma radiation.

In addition, since the behavior of the diodes in constant current operation experiences no significant shift in the peak of their emission spectrum they can be used as the stimulation light source in the Martian dating instrument ODIN.

Discussion: The radiation effect study presented here is in need of further research using high-energy proton radiation, as that form of radiation is heavily encountered in a space environment. Other forms of diodes (SiC, GaAs) have been reported to suffer significant changes in their performance under the influence of proton radiation [4, 5], but damage based on gamma radiation is much more rare [6]. As far as the application of these diodes in the ODIN dating instrument, the present data shows that any instrument design should incorporate the use of a constant current electrical system. This will eliminate the need to carefully quantify the shift in the peak of the emission spectrum, which would be necessary and extremely detrimental to overall accuracy were a constant voltage electrical system employed. It is also noted that the spectra obtained from the LEDs at low temperatures (-170 °C) was, with the exception of noise, smooth. There was a complete lack of fine-structure, though previous work by Hori, et al. reports that the fine structure should have been evident from –50 to –170 °C [3]. No reason for this has yet been found

References: [1] Stephen W.S. McKeever (2001) Nuclear Instruments and Methods in Phys. Research B 184. [2] S. Nakamura and G. Fasol, *The Blue Laser Diode* (Springer, Berlin, 1997). [3] A. Hori, D. Tasunage, A. Satake, and K. Fujiwara (2001) App. Phys. Letters 22. [4] Allan H. Johnston (2001) IEEE Trans. on Nuc. Science 5. [5] P.F. Hinrichsen, A.J. Houdayer, A.L. Barry, and J. Vincent (1998) IEEE Trans. on Nuc. Science 6. [6] J. Söderqvist, L.O. Eek, J. Collot, et. al (1997) IEEE Trans. on Nuc. Science 44.