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ABSTRACT

Visible cameras operating at 1 MGy of γ radiation require radiation tolerant illumination system. Here, commercially available high-power white LEDs have been tested under X and γ radiations. The light power of white commercial LED was shown to slightly decrease (less than 10 %) in post irradiation measurements. A closer analysis, based on the ABC model for efficiency droop, reveals that irradiation essentially increases the amount of trap assisted recombination, impacting the LED quantum efficiency mostly at low supply voltage. This suggests that favoring the LED operation at higher supply voltage could be a good strategy to enhance the radiation hardness of LED-based illumination systems.

PACS Keywords: LED, radiation, ABC model, camera

1 INTRODUCTION

The CAMRAD project [2] aims at designing a visible camera able to operate autonomously in harsh (ionizing radiations up to 1 MGy) and eventually in completely dark environment. It is thus necessary to equip such camera with a proper illumination system. In particular, in order to deal with the issue of radiation induced dark current, it needs to operate at low integration times (typically lower than 2 ms).

In this context, LED based lighting systems offer a very good trade off in terms of portability, power consumption and overall lighting power. However, the question of the impact of γ-radiation on LED remains open. Radiation effects on LEDs have already been studied in the literature, particularly for low-dose space applications [3] [4]. It is admitted that the degradation of LEDs by irradiation is mainly due to atomic displacements caused by particles such as protons or neutrons [5]–[7]. γ-rays are mainly associated with ionization processes but can possibly cause rare atomic displacements. But little is known about the impact of high level of γ-rays on LED performance, which is the aim of this paper.

2 EXPERIMENTAL PROCEDURE

2.1 Irradiations conditions

Gamma radiation irradiation was performed with ^{60}Co at IRMA [8] (IRSN, Saclay, France). X-rays irradiation were performed at the laboratoire Hubert Curien (Saint-Etienne, France) thank to the *LabHC MOPERIX* machine (100 kV X-ray tube with W-target filtered by 4 mm thick of beryllium) that delivers X-rays beam with a maximum at 40 keV. Irradiations were performed at room temperature.

2.2 Sample Characterizations

LEDs emission spectra in W/nm were performed using an integrating sphere and a calibrated lamp for several supply current. In order to ensure that the LED thermalized, a delay of 5 min was let between each current step.

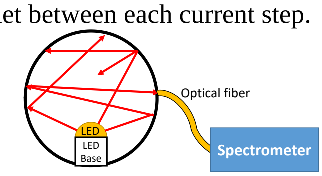

Fig. 1 : Schematic representation of the set up for measuring LED spectral power.

3 RESULTS

3.1 Post-irradiation

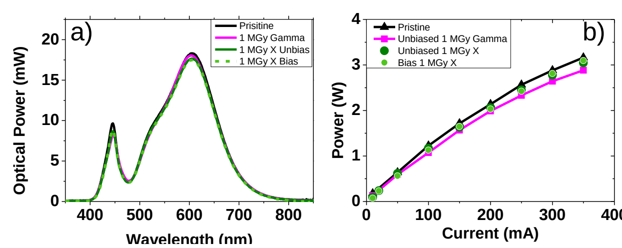

Fig. 2: MKRBWT LED before/after X and **γ** radiation a) Spectral measurements at the nominal current (400 mA) for different irradiation conditions, b) Power vs current before/after radiation.

Fig.2 presents one of the results obtained with one LED type (MKRBWT by CREE) with the comparison between its output powers before and after 1MGy TID. The fact that the LED is biased or not during the exposure does not change the good tolerance of the device. γ-rays cause more damage than X-rays because Compton electrons are more probable at high energies. The LED spectrum is not modified by the radiation.

Table 1 summarizes our results for 5 Commercial Off-The-Shelf (COTS) high-power white LEDs γ irradiated at 1 MGy. For all LEDs, the power decrease remains below 10%.

Brand	LUMI LED	CREE			
Product Number	**LCH1 3090**	**MKR AWT**	**MKR BWT**	**SDW8 4F1C**	**XPEB WT**
1 MGy	-8.2 %	+-1 %	-8.8 %	-4.6	+2.6 %

Table 1: Power decrease for 5 commercial LEDs at 1 MGy γ–rays (nominal voltage and current)

3.2 Result analysis using the ABC Model

The ABC model is a simple and extensively used model to explain the InGaN LED efficiency droop, by the competition between radiative recombination on one side and Auger and trap assisted recombination on the other side. Following [1], in strong injection regime, the external quantum efficiency (EQE) is computed as a function of the diode current density j according to:

$$EQE \propto \frac{Bn^2}{An + Bn^2 + Cn^3} \qquad j \propto (An + Bn^2 + Cn^3)$$

where n is the electron/hole concentration in the emission zone, and An the trap assisted, Bn^2 the radiative recombination, Cn^3 the Auger recombination rate. This model has been used to fit the EQE versus current curves of two different devices, for different levels of irradiation (Fig. 3).

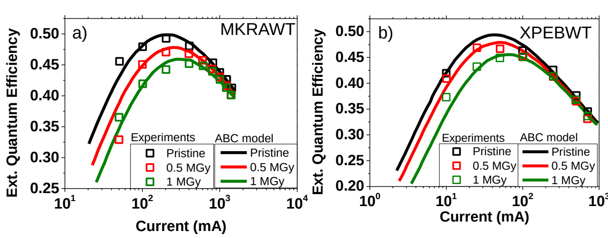

Fig. 3 : EQE versus current for pristine and gamma irradiated a) MKRAWT, b) XPEBWT LED device.

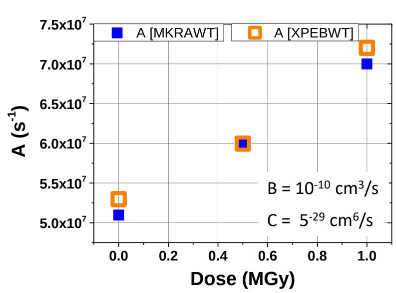

Fig. 4 : Trap assisted parameter A extracted by fitting data of Fig.3 versus irradiation dose for both LEDs.

Interestingly, it was possible to fit all the curves by tuning only the value of the parameter A (which depends on the traps concentration). B and C, which are material dependent parameters, were kept constant, and their value found in good agreement with the literature [9]. Moreover, Fig. 3 shows that *A* has the same order of magnitude in the 2 LEDs, and tends to increase linearly with irradiation dose.

These results suggest that losses in LED are caused by a growing concentration of recombination of traps, bringing insight on the impact of irradiation of the performance of InGaN LEDs.

Moreover, this conclusion has also an impact on the LED selection for radiation tolerant system. Indeed, LED systems are typically composed of several mid-power LED operating at low current, close to the maximum of quantum efficiency, in order to maximize the overall luminous efficiency and to minimize the power consumption. According to previous conclusions, such system is expected to be more impacted by gamma radiation, as an increase of A impacts mostly the low current regime of the EQE versus current curve. An alternative to produce the same amount of luminous flux consists in using a reduced number of power LED operating at high current. If this second solution is usually avoided (it has a higher power consumption), these results suggest that for irradiation purpose, this second option would be less sensitive to damage produced by gamma radiation.

4 CONCLUSION

Commercial high-power white LEDs were irradiated with γ or X-rays at the MGy level. In both cases, the emitted power decrease was measured to be below 10%. Thanks to the ABC model for efficiency droop, gamma radiation were found responsible for an increase of recombination traps, without impacting the LED radiation and auger recombination properties. In consequence, LEDs operating at high current at the expense of power consumption were found less sensitive to radiation effects.

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