UV LED operation lifetime and radiation hardness qualification for space flights

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UV LED Operation Lifetime and Radiation Hardness Qualification for Space Flights

Ke-Xun Sun, Nick Leindecker, Sei Higuchi, John Goebel*, Sasha Buchman, and Robert L. Byer

Hansen Experimental Physics Laboratory, Stanford University, CA 94305, USA
*Code RET, NASA Ames Research Center, Moffet Field, CA 94035, USA

kxsun@stanford.edu

Abstract. We report measurements of ultraviolet light emitting diode (UV LED) performance under conditions simulating operation in an orbiting satellite. UV LED light output maintained within less than 3% observational uncertainty, over more than 19,000 hours of operation in a nitrogen atmosphere, and over 8,000 hours operation at a pressure of less than 10^{-7} torr vacuum. In addition, irradiation with 63 MeV protons to a total fluence of 2×10^{12} protons/cm^2 does not degrade the UV light output. Spectrally, the emissive center-wavelength and spectral shape are unchanged after proton irradiation within the precision of our measurement. These results qualify the UV LED operation lifetime and radiation hardness for space flights

1. Introduction

A radiation-hard, high-reliability ultraviolet (UV) light emitting diode (LED) will be of great value to future satellite missions requiring charge management technology employed in drag-free flights.

In drag-free control systems, the inertial reference of a satellite is a free-falling mass. The proof mass housing or satellite body shields this proof mass from external forces other than gravity. However, this isolation from external forces is poor if the housing itself exerts significant forces on the proof mass. Cosmic ray caused net electric charge on the proof mass will couple undesirable disturbance forces Minimization of surface differences of electrical potentials between the proof-mass and housing is thus crucial for optimal drag free operation.

Through Au surface photoelectron generation, UV light at ~255 nm renders an effective tool for charge management of the proof-mass and housing system. The recent breakthrough development of the deep UV LED based on gallium nitride (GaN) provides an attractive source. Compared with the traditional mercury vapor discharge lamps, the UV LED is lighter in weight, more compact in volume, lower in power consumption, and faster in time response. These advantages are more substantial when a UV source is required on a satellite where power and mass are at a premium. We have demonstrated successful AC charge management using a modulated UV LED in 2005 [1-4]. Since then, several groups have demonstrated similar UV LED utilization in precision experiments.

For deployment in extended duration space flights, the long term power and spectral stabilities, and radiation hardness of the UV LEDs need further verification. The operating lifetime of visible light LEDs have been quoted as long as 100,000 hours by industrial vendors. GaN materials and devices have been suggested insensitive to lattice defects and radiation [5]. UV LEDs emerged very recently, and there have been no prior tests for radiation hardness.

We report experimental results that conclusively demonstrate the long term power and spectral stabilities, and radiation hardness of GaN/AlGaN based UV LEDs. In the ongoing measurements at Stanford, we have reliably operated UV LED under the AC charge management working parameters for more than 19,000 hours in nitrogen and more than 8,000 hours under vacuum while observing no significant power loss and spectral emission wavelength shift. We have further demonstrated radiation hardness of a UV LED with 63 MeV fast proton irradiation doses up to a fluence of 2×10^{12} protons/cm^2. Our experimental results indicate that the reliability of UV LEDs exceeds that of gas lamps, and therefore UV LEDs are appropriate for extended space missions such as LISA, and beyond.

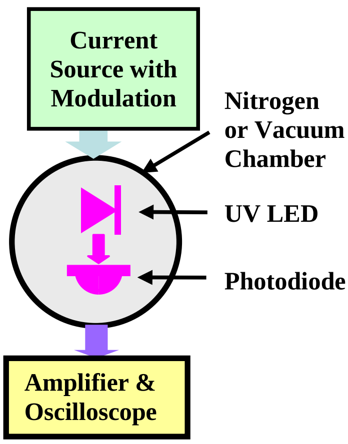

Figure 1. Experimental setup for UV LED operational lifetime tests.

2. UV LED Operation Lifetime Measurements

2.1. Long term power stability for operation in nitrogen

The experimental setup for UV LED operation life time test in a nitrogen purged chamber is shown in Fig. 1. It remains the same as presented at LISA 6th symposium [2]. The nitrogen atmosphere was chosen for more rigorous testing in a space-like environment, as there have been claims that oxygen may "clean" the surface contaminated with molecules disassociated by UV light.

The devices being tested is a nominally 255 nm deep UV LED (UVTOP255) available from Sensor Electronic Technology. The UVTOP LED is packaged with a flat UV grade fused silica window. A UV enhanced detector (OSI UV-20) is used to monitor the UV LED light output continuously. The detector is operated with zero bias in a transimpedance configuration for reduced dark current and lower temperature sensitivity. The UV LED is driven with ~10% duty cycle pulses of ~2 mA at a rate of 1 kHz. These settings represent those used for AC charge management experiment, in which phased light and bias voltage modulations direct electron movements [1].

As shown in Fig. 2, the UV LED light output power level is stable for more than 19,000 hours, with an uncertainty of 3% or less. A few early hiccups were due to temperature fluctuation during the test. The minute power drop later was possibly caused by lab move, during which the test apparatus was disassembled and assembled again.

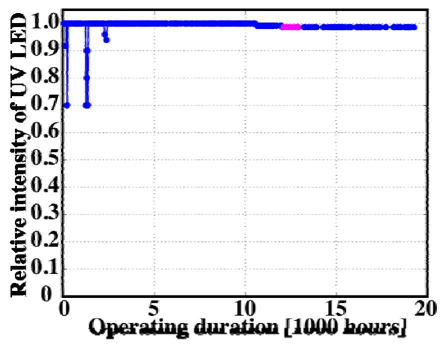

Figure 2. UV LED operational lifetime test in nitrogen reaches more than 19,000 hours

2.2. Long term power stability for operation in vacuum

To fully simulate space vacuum environment, we have placed a UV LED and a UV detector in an ion-pumped vacuum chamber with a pressure maintained at lower than 10^{-7} torr. The UV LED is packaged with a ball lens which substantially collimates the light output. The driving current was modulated at 20 kHz, using an improved electronics box built in-house. Figure 3 shows the ball-lens UV LED

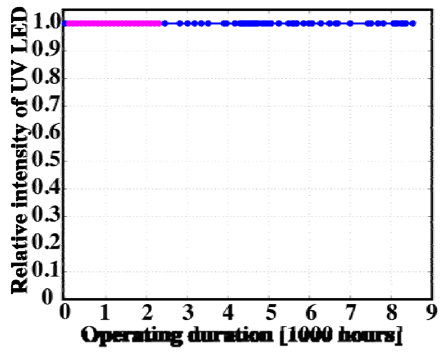

Figure 3. UV LED operational lifetime test in vacuum reaches more than 8.000 hours.

light output level during the test. The UV LED has been operated for more than 8,000 hours in vacuum while maintaining its initial power level within 3% measurement uncertainty. The UV LED in the high vacuum environment shows that the UV LED is on track for excellent long-term power maintenance.

2.3. Long-term spectral stability

The UV LED emission spectral stability is another important parameter for successful charge management. If the emission spectrum shifts to longer wavelengths, quantum efficiency for photoelectron generation will be reduced.

For the flat window UV LED maintained in the nitrogen-purged chamber, the UV LED emission spectrum was measured at several points during the test. The UV LED was removed from the chamber for these measurements. The UV spectrum was recorded using a grating UV monochromator (Resonance Research) coupled through UV transmissive 400 μm optical fiber to a photoconductive detector biased at -15V.

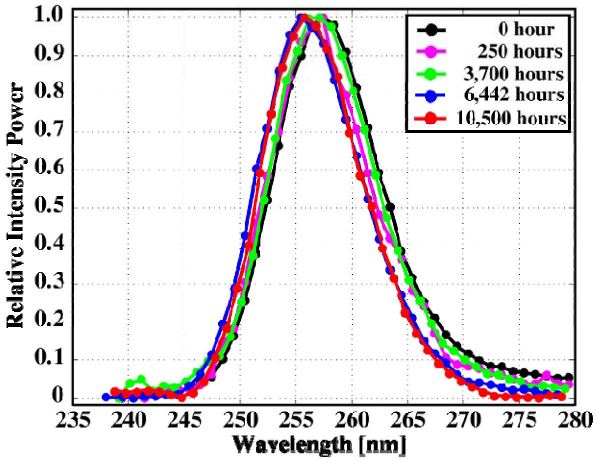

Figure 4. UV LED spectral measurements during the first 10,500 hours of operation.

Figure 4 shows the spectral measurement results from the beginning (0^{th} hour), and at 250, 3700, 6442, and 10,500 hours of operation. In the first three measurements, the spectral center maintained its original peak wavelength position at ~257 nm within 0.5 nm. For the measurement at 6,442 and 10,500 hours, the central spectral peak shifted to 255-266 nm. The measurement is estimated as +/- 1 nm, due to the instrumentation spectral resolution, but mostly due to the mechanical rotational backlash of the grating element in the spectrometer. The small shift to shorter wavelength, if it is real, will not affect the charge management based on Au photoelectric effects.

2.4. Other laboratory uses of UV LEDs

In addition to these intentional lifetime tests, we have used several UV LEDs as UV light sources for other tests such as investigation of mirror coating degradation by UV light irradiation. In these usages, the UV LEDs were driven to produce ~10-15 times higher UV light output than that for charge management for several months. From these routine uses of UV LEDs, we have not observed appreciable UV output power degradation.

3. UV LED Radiation Hardness Measurement

3.1. Radiation hardness of the LED and particle detectors

Hardness against ionizing particle radiations is a necessary requirement for space-borne instruments. The components on the satellite must operate robustly or maintain its basic function in the presence of the high fluence particle radiation. There have been excellent studies on visible light and infrared (IR) LED radiation hardness by Johnston et al (see [6] and references therein) who compared performances of LEDs from several vendors. They used the 50-MeV protons from the 76” cyclotron Crocker Nuclear Laboratory at the University of California at Davis, and tested several LEDs emitting in the visible and near IR region. LEDs that were radiation hard for from high 10^{10} to 10^{11} protons/cm^2 were considered well suited for use in space flight. Particle detection in a large accelerator facility such as LHC has generated more intense interest in GaN detector. There have been hopes to use a GaN detector at 10^{15} neutrons/cm^2 fluence [7]. However, there has been no report for AlGaN UV LED radiation hardness measurement.

3.2. Experimental setup for radiation hardness measurement of UV LEDs

To determine the radiation hardness for the UV LEDs, we have used the same proton source as that in reference [6], i.e. the Crocker cyclotron at UV Davis. However in our experiments, most significant exposure was conducted with 63 MeV protons. Figure 5 shows the experimental setup. Two 255 nm UV LEDs were placed in the proton beam path formed by the cyclotron beam output aperture and by an aperture in a piece of thick aluminum block. Further, to reduce potentially serious radiation induced artefacts in the monitor photodiodes, the UV LEDs were obliquely oriented to allow the UV detectors to be placed outside of the primary proton beam. Further, to further reduce the radiation effects due to migrated particles from cascaded scatterings, we elected to use a SiC photodiode for detection of light from one UV LED. SiC has similar crystal structure as that of GaN, and has been considered radiation hard compared with Si or Ge materials. The selection of a SiC photodiode will practically enhance the radiation hardness of the UV LED charge management system. The second monitoring photodiode was a silicon detector (UV-20).

The UV LEDs were operating electrically during the proton radiation, to better simulate the space flight working conditions. We again used 10% duty cycle, 20-kHz modulated drive current for UV LEDs. The UV light emission from the UV LEDs was continuously monitored during the proton beam time. The average DC value of the photocurrent was recorded for the UV light emission measurement. The protons passed obliquely though the bottom of the UV LED TO-39 package before encountering the LED die. The average proton energy at the die is thus likely slightly less than the nominal 63.8 MeV. For the high flux measurement, the Crocker facility calibrated the proton fluence. For the low flux measurement, in which our experiment is a secondary package, the proton flux entering our apparatus was measured with a Faraday cup.

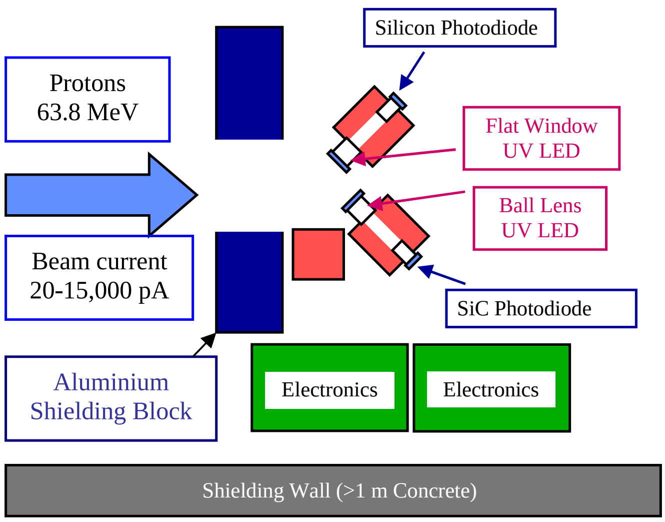

Figure 5. Experimental setup (top view) for UV LED proton radiation tests.

3.3. UV LED light output level during the proton irradiation

Figure 6 shows the measurement result for the UV LED light output level detected by the SiC detector, while the proton flux was accumulatively increased to 2×10^{12} protons/cm^2. SiC detector was used for detecting UV LED output level. We have four runs of the cyclotron. The first three were for purposes of the primary experiment. The first is a very low fluence calibration run to set the proton flux. In the second run, the proton fluence was increased to 1×10^{10} protons/cm^2. In the third run, the proton fluence was increased to 6.3×10^{10} protons/cm^2. The fourth run was a very high beam current (15,000 pA) dedicated to our UV LED experiment. We did not observe an appreciable UV LED light output drop during real time monitoring of the photodiodes for the UV LED and SiC detector pair. This experiment result demonstrates the extreme radiation hardness for the GaN/AlGaN UV LEDs.

There was a small photocurrent drop (~10%) from the silicon photodiode. It is suspected that the drop was due to radiation damage of the silicon photodiode by scattered protons through the mounting block of the photodiode. We are planning more tests for different UV LEDs and UV detector pairs.

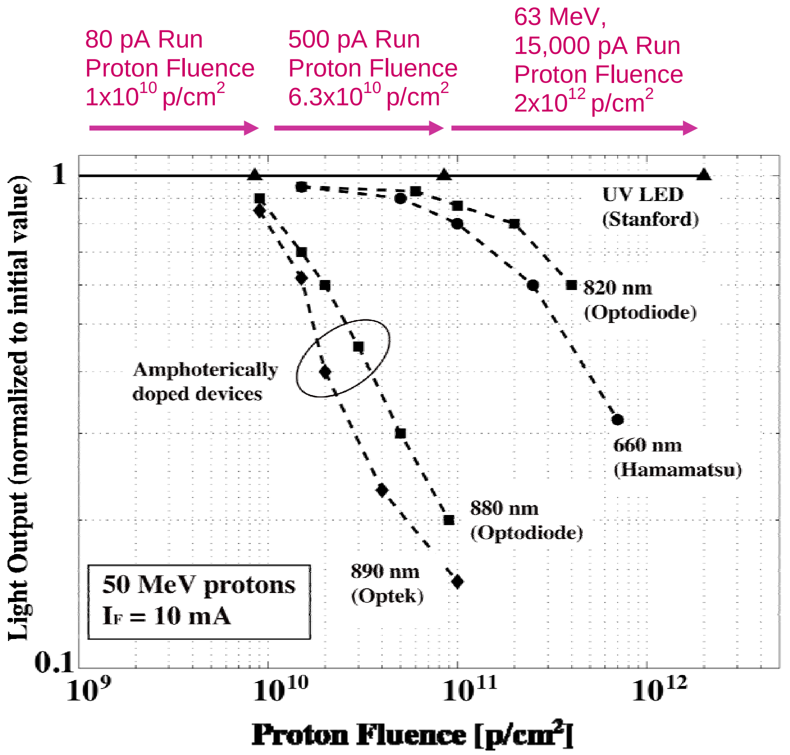

Figure 6. UV LED light output vs. proton fluence. The SiC photodiode was used. Data points other than UV LED are from reference [6]

3.4. UV LED emission spectrum measurements before and after the proton irradiation

Both of the UV LEDs were characterized before and after the proton irradiation. The latter was conducted when UV LEDs further cooled off from the high fluence proton activation. The same spectrometer described earlier was used for the spectral measurement. Figure 7 shows the measurement result. These measurements reveal no shift of either the center wavelength or the spectrum half-width in either device.

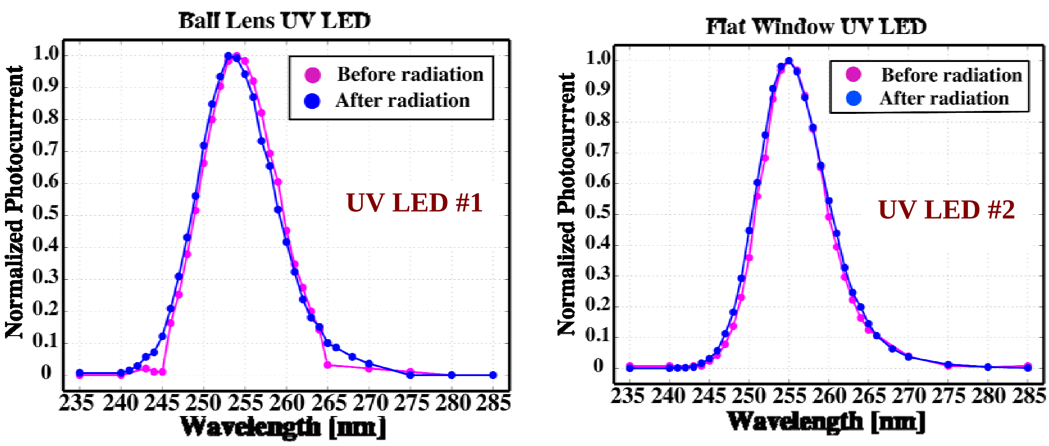

Figure 7. UV LED emission spectrum measured before and after proton irradiation with a fluence of 2×10^{12} protons/cm2. Central wavelength 255 nm for both, no shift

4. Summary and conclusion

Our long term measurements show that optical power emitted by AlGaN UV LED is stable to within 3% over 15,000 hours in gaseous nitrogen. Equivalent observations of a similar device in high vacuum show essentially no effect in 5,000 hours. From a system engineering point of view, this result is especially encouraging given that we observe only the monitor photocurrent which lumps in all possible effects of reduced UV LED output, increased absorption in the ball lens or photodiode window, or reduced detection efficiency of the detector. Thus ~3% represents a worst case contribution from the UV LED itself.

Spectral measurements made periodically as the device is aged show convincingly that a critical device characteristic, the center emission wavelength, does not change to long wavelength as the device ages. The consistent center wavelength and spectral width ensure that there is no disproportionate drop of photons at the short wavelength end of the spectrum.

Two UV LEDs were irradiated with ~63MeV protons to an accumulated fluence of 2×10^{12} protons/cm^2, or ~100 years of radiation dose in the LISA orbit. Measurements of the light output and the spectrum show that there are no significant changes in UV LED light output. Spectral measurements before and after proton irradiation also reveal no significant shift in center wavelength or spectral width.

The reliable long term operations of AlGaN UV LED in either dry nitrogen or high vacuum, and under high flux radiation are critical steps for space qualification of UV LED as high reliability devices in the space environment. A system based on UV-emitting LED thus appears to be an attractive alternative to mercury discharge lamp for LISA proof mass charge control, as well as other precision space missions requiring minimized charge induced noise and damages.

Acknowledgement

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References

[1] K.-X. Sun, B. Allard, S. Williams, S. Buchman, and R. L. Byer, "LED Deep UV Source for Charge Management," presented at Amaldi 6 Conferences on Gravitational Waves, June 2005, *Classical and Quantum Gravity*, 23(8):S141-S150, 2006.

[2] K.-X. Sun, S. Higuchi, A. Goh, B. Allard, D. Gill, S. Buchman, and R. L. Byer, "Spectral and Power Stability Tests of Deep UV LEDs for AC Charge Management," 6th LISA International Symposium, GSFC June 2006, AIP proceeding vol. 873, pp.215-219

[3] K.-X. Sun, S. Higuchi, B. Allard, D. Gill, S. Buchman, and R. L. Byer, "LIGO Test Mass Charging Mitigation Using Modulated LED Deep UV Light, " LIGO Science Collaboration (LSC), OWG & SWG Joint Meeting, Hanford, Washington, March 22, 2006, LIGO Documentation G050143-00-Z

[4] Stanford University Patent Application on Charge Management with Modulated UV Light Sources (K.-X. Sun, B. Allard, S. Buchman, and R. L. Byer)

[5] Osinski, "Short wavelength visible light emitters based on group III nitrides and their potential for space applications", SPIE Proc. CR-66, p. 92-120 (1997)

[6] A. H. Johnston and T. F. Miyahira, "Characterization of Proton Damage in Light-Emitting Diodes", IEEE Trans. Nuclear Science, p. 2500-2507, Vol. 47 (2000)

[7] J. Grant et al, "GaN as a radiation hard particle detector", Nuclear Instruments and Methods in Physics Research A vol. 576 p.60–65 (2000)