CHARACTERIZATION AND IRRADIATION DAMAGE TESTS OF AlGaN UV LEDS FOR DETECTOR SPACEBORNE CALIBRATION

B. Giordanengo, S. Gissot, and A. BenMoussa
Solar Terrestrial Centre of Excellence, Royal Observatory of Belgium, Circular Avenue 3, B-1180 Brussels, Belgium

ABSTRACT

Space-based solar UV instruments such as telescopes or radiometers require on-board light sources for the calibration and degradation monitoring of their detectors. For future solar missions, we characterized the degradation of AlGaN-based UV light emitting diodes (LEDs) as well as InGaN LED after proton irradiation at 14.4 MeV energy. It is shown that their average peak wavelength (spectrum peak wavelength) $\lambda_{0.5m}$ and bandwidth $\Delta\lambda_{0.5m}$ are not affected by the proton irradiation, showing a good radiation tolerance up to fluence of 8.10^{11} p.cm^{-2}. The maximum signal and integrated power decrease slightly with irradiation level, but not sufficiently to invalidate the on-board calibration of the detector. The spectral behavior as a function of the forward current and temperature is also investigated, and it is demonstrated that these LEDs are suitable for space applications.

I. INTRODUCTION

Onboard characterization and calibration of photodetectors and imagers is crucial and require the use of onboard light sources typically emitting in visible, infrared and in ultraviolet spectral range depending on the detector sensitivity. This characterization permits to assess the detector degradation and/or contamination and to separate contributions by optical parts (mirrors, filters) from the detector. However there are strong constraints on the light source, electrical consumption, weight, size, reliability and lifetime.
These constraints explain why the majority of spatial observational missions do not have onboard light source.
Light Emitting Diodes (LEDs) are an interesting alternative solution because they do not show these imperfections when compared to lamps. LEDs have been used with success in space instruments, e.g. on the LYRA [1] radiometer and SWAP [2] imager, both onboard the Project for On-Board Autonomy-2 (PROBA 2) Sun observation mission [3]. They will be used in the Extreme Ultraviolet Imager (EUI) [4][5] onboard the future Solar Orbiter ESA mission [6].
In this paper, we report the characterization of ultraviolet (UV) and visible LEDs before and after proton irradiation degradation up to a fluence of 8.10^{11} p.cm^{-2}. We also investigate their response dependence on temperature and forward current.
We conclude with recommendations about the use of LEDs onboard spacecraft for photodetector calibration.

II. EXPERIMENTAL SETUP

A. LED selection

Five LEDs [7] were characterized as reported in Table 1. At the wavelength of the EUI instrument (17.4, 30.4 and 121.6 nm) there exist no LED technology and we choose UV LEDs as well as a visible (blue) to give a visible light flat field, which can then be converted into an EUV flat field if one knows the relationship between visible and EUV degradation [8]. The LEDs from SETI [9] are based on AlGaN material with wavelength peak at 250, 310, 355 respectively. The LED from NICHIA [10] is a GaN LED with wavelength peak at 365 nm. The LED from MICROPAC [11] is an InGaN LED with wavelength peak at 470 nm.

Table 1. Parameters of the five LEDs analyzed.

Model	Company	λ_c (nm)	Current (I_F in mA)	Packaging
LED_FW-250	SETI [9]	250	30	TO39 with flat window
LED_FW-315	idem	315	30	idem
LED_FW-355	idem	355	30	idem
NSHU551B	NICHIA [10]	365	15	TO46 with flat window
61162	MICROPAC [11]	470	20	idem

B. Setup

The LEDs characterization [12] were carried out at the Detector Measurement Laboratory (DeMeLab, STCE) using a mini-spectrometer (model USB4000-UV-VIS) and an integrated sphere from Ocean Optics [13]. The CCD of the mini-spectrometer 1 x 3648 pixels and the spectrum is out as a list of 3648 data. To improve the quality and the reproducibility of the LED spectra due to the background thermal noise, the mini-spectrometer is coupled to a temperature control module (model USB-TC).
The temperature dependence of the LED parameters (see section III.B) is measured between -35 °C and +30 °C inside a custom vacuum chamber. The LED is held in place by a holder, which is electrically isolated from but thermally connected to a refrigerated/heating circulator (model Huber Unistat 405) cooling system via a cold finger. A calibrated resistance thermometer was added close to the LED surface to better estimate the absolute temperature error, which is estimated to be around 1 K. This setup allows us a high temperature stability (± 0.05 °C).
The proton irradiations were performed at the Light Irradiation Facility (LIF) at the Cyclotron Research Center (CRC) at Louvain-La-Neuve (Belgium). The accelerator CYCLONE is a multi-particle, variable energy, isochronous cyclotron capable of accelerating protons up to 65 MeV. The setup, inside the well-shielded cave, is composed of a diffusion foil to reach the needed uniform beam spot, collimators, energy degraders, beam-monitoring detector and positioning system. The irradiations were performed in air and at normal incidence beam. A detailed description of the proton measuring station can be found in [14].

III. LED CHARACTERIZATION

To reduce the Fixed pattern Noise (FPN) and Dark Signal Non Uniformity (DSNU) contributions of the spectrometer's CCD, an average of n (typically n = 1000) spectra is computed. The same measurements and analysis are repeated under "dark" conditions to remove the background signal as follow [12]:

$$LED_{spectrum} = mean_{spectrum}(n) - mean_{dark}(n) \quad (1)$$

Typical spectra without averaging, and with averaging and dark removal are shown Fig. 2.

The parameters that can be extracted from the LED spectra are:

- λ_p: the peak wavelength. Note that the LED spectrum is generally asymmetric.
- $\lambda_{0.5m}$: the average wavelength. $\lambda_{0.5m} = \frac{\lambda_{0.5'}+\lambda_{0.5''}}{2}$,
- $\Delta\lambda_{0.5m}$: the spectral bandwidth at half maximum. $\Delta\lambda_{0.5m} = \lambda_{0.5''} - \lambda_{0.5'}$,
- S_p: the peak signal amplitude,
- P: the integrated power. $P = \int S(\lambda)d\lambda$.

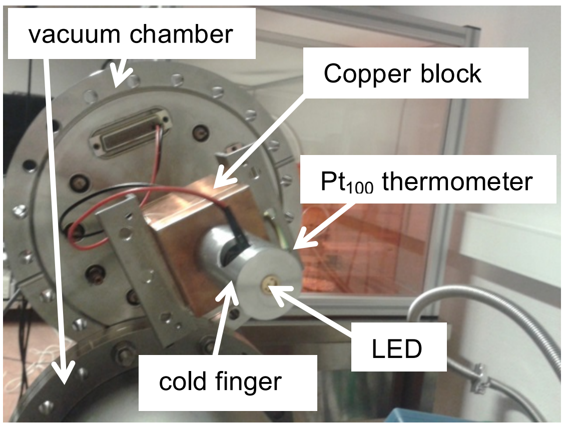

Fig. 1. LED characterization setup at DeMeLab.

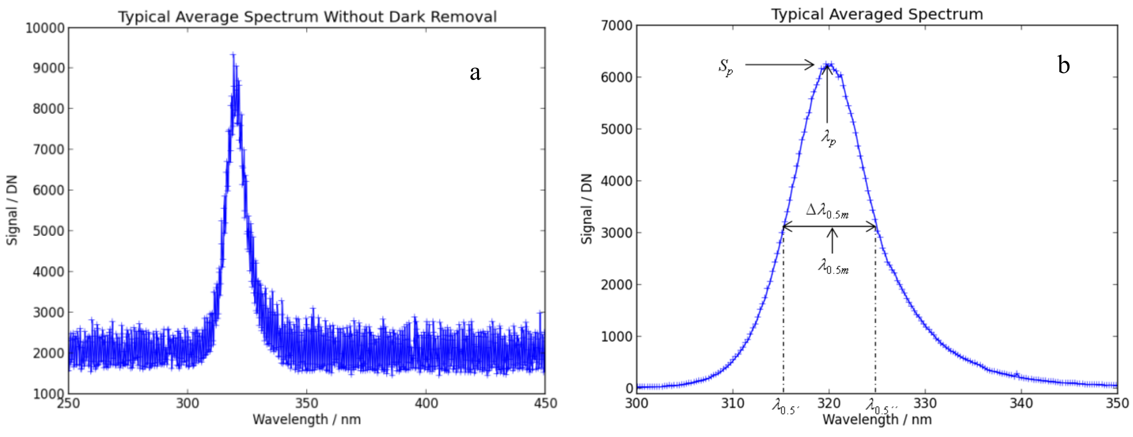

Fig. 2. Typical LED spectra a) without dark removal, b) with dark removal and averaging (n = 1000).

A. Electrical Properties

The LEDs are usually operated at a constant current. The emitted light is a function of the forward current I_F and the compliance voltage U_F. The five LEDs were measured with different forward currents. The spectra and the current versus voltage curves of the five LEDs, both at room temperature (RT), are shown Fig. 3. As an example, the integrated power (P) versus current of LED_FW-315 (from SETI) is plotted in Fig. 4. As expected, S_P and P increase with the forward current (I_F) linearly before saturation. We thus recommend to apply a current within the linear region i.e., $I_F < 50$ mA. The current dependency of the other LEDs parameters is shown in Table 2 up to $I_F = 30$ mA where $\Delta(S_P)$ is the signal peak increase (in %) for 1 mA current increase. It is crucial to use a highly stable current source since all the LEDs parameters are affected by a small variation in I_F.

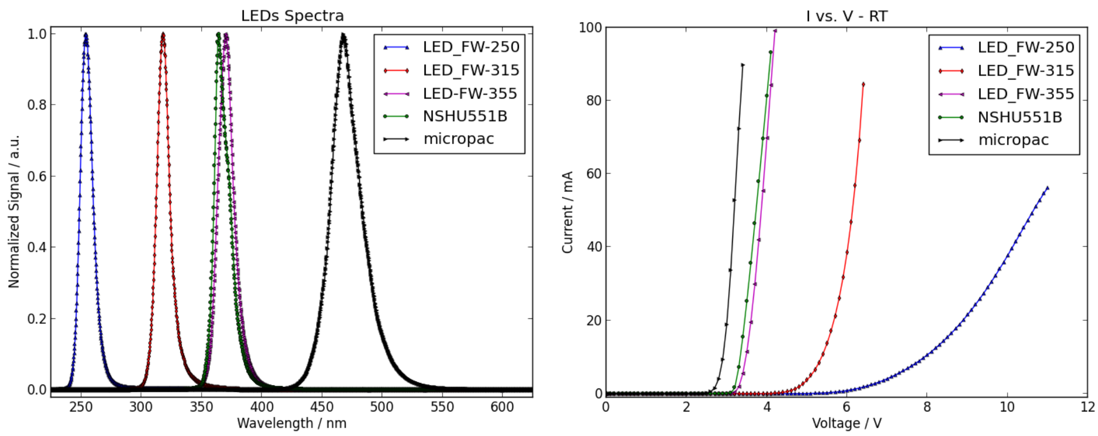

Fig. 3. Left, spectra curves of the five LEDs ($I_F = 30$ mA), right, I-V curves at room temperature.

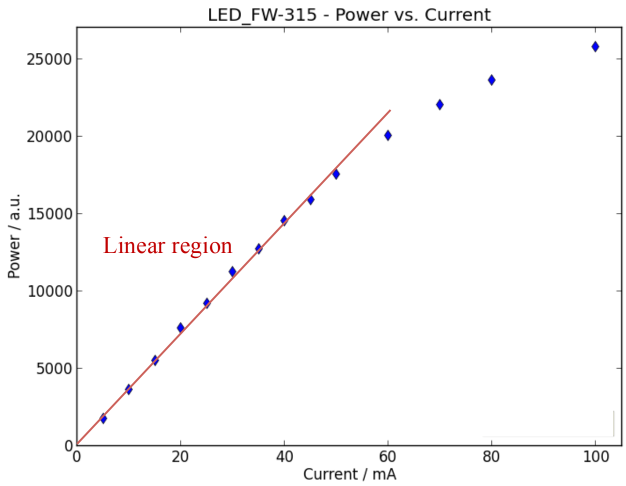

Fig. 4. LED_FW-315 – Integrated power vs current.

Table 2. Current dependency of the spectrum parameters for the five LEDs.

LED Model	$\Delta(S_P)$ (%/mA)	$\Delta(\lambda_{0.5m})$ (nm/mA)	$\Delta(\Delta\lambda_{0.5m})$ (nm/mA)	$\Delta(P)$ (%/mA)
LED_FW-250	1.8	0.04	0.04	4.7
LED_FW-315	3.0	0.02	0.02	3.1
LED_FW-355	2.4	0.05	0.06	2.7
NSHU551B	2.7	0.05	0.05	2.9
62162 (Micropac)	1.5	0.00	0.13	2.0

B. LED Temperature Dependency
For the five LEDs, spectra were measured between -35 °C and +30 °C, with a constant forward current I_F = 30 mA. A typical temperature dependence of a LED is shown in Fig. 5.
The temperature dependency (between -35 °C and +30 °C) of the different LED parameters is summarized in the Table 3 (I_F = 30 mA).

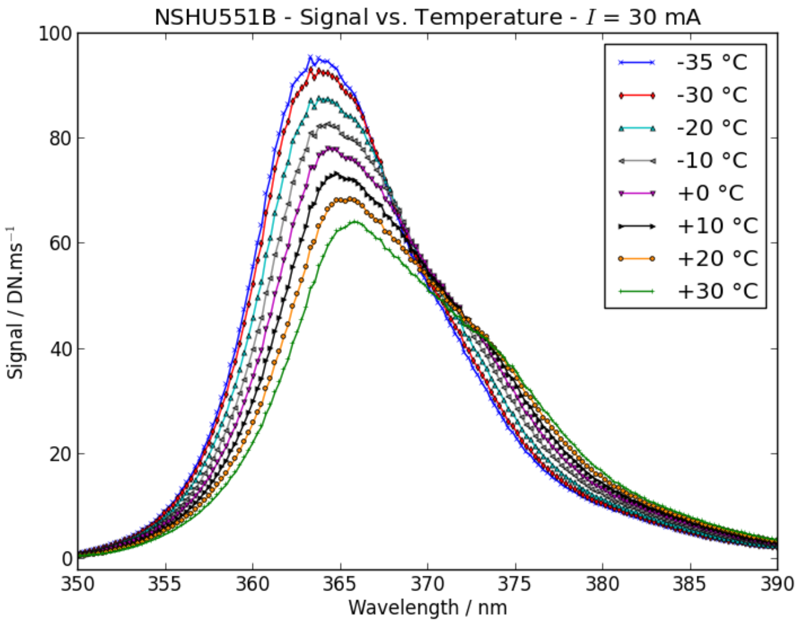

Fig. 5. NSHU551B LED spectrum between 350 and 390 nm as a function of the temperature between -35°C and +30°C.

Table 3. Temperature dependency of the spectrum parameters for the five LEDs. $\Delta(S_P)$ is the signal peak increase (in %) for 1 K temperature increase.

LED Model	$\Delta(S_P)$ (%/K)	$\Delta(\lambda_{0.5m})$ (nm/K)	$\Delta(\Delta\lambda_{0.5m})$ (nm/K)	$\Delta(P)$ (%/K)
LED_FW-250	-0.56	0.015	0.020	-0.50
LED_FW-315	-0.42	0.021	0.012	-0.32
LED_FW-355	-0.33	0.041	0.048	-0.07
NSHU551B	-0.51	0.053	0.049	-0.29
62162 (Micropac)	-0.19	0.027	0.020	-0.09

C. LED Signal Stability

The time needed to stabilize the value of $\lambda_{0.5m}$ was measured. The stabilization time was obtained by fitting the experimental data with an exponentially decaying function. The current was switched "on" and then switched "off" at regular intervals. When the light is switched "on", the light emission reaches a maximum and then decreases down to a stable value. This effect is more pronounced at lower temperature than at higher temperature. It should be noted that when the current is switched "off" the LED emission light disappears very fast (not measurable). A typical stability curve (NSHU551B at -20 °C) is shown in Fig. 6.
The stabilization time is chosen as 5 times the decay time (99.3 % of the decay) and is summarized in Table 4.
Note that the measured LED_FW-250 signal, inside the vacuum chamber, was too small and thus it was not possible to extract the stabilization time.
It is then recommended to wait at least 3x the stability time before to start any measurements during the onboard calibration, i.e., 2 min for the blue LED (Micropac) and 1 min for the UV LED (SETI).

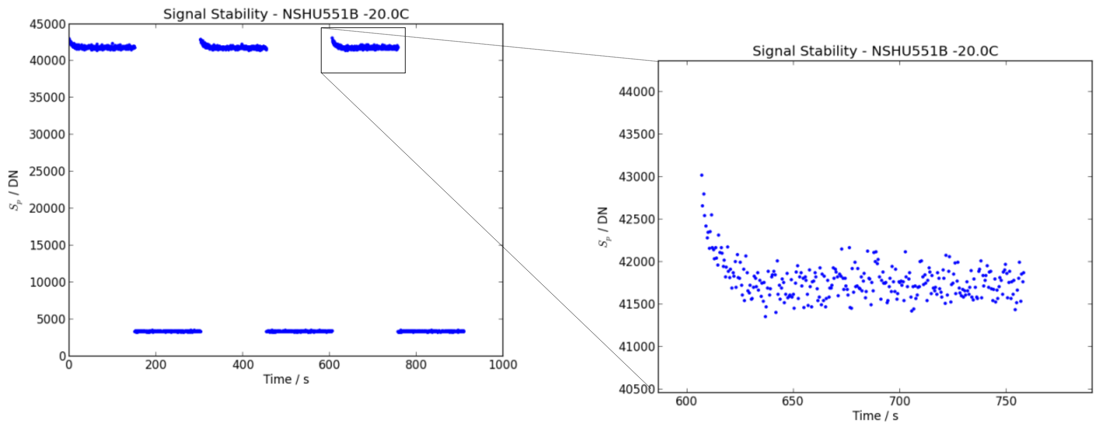

Fig. 6. NSHU551B - signal stability

Table 4. Stabilization times for four LEDs (LED_FW-250 was excluded because the signal was too low).

LED Model	Stab. time @ -30 °C (s)	Stab. time @ +30 °C (s)
LED_FW-315	10	5
LED_FW-355	10	5
NSHU551B	40	20
62162 (Micropac)	35	20

D. Proton Irradiation-Induced Degradation

The five LEDs have been irradiated at the Cyclotron Research Center (CRC) facility at Louvain-la-Neuve (Belgium) with protons (14.4 MeV energy), up to a fluence of 8.10^{11} $p.cm^{-2}$ with respect to the Solar Orbiter (total mission duration), 10 MeV equivalent proton fluence under 1 mm thick Aluminum shielding [15]. A typical spectrum versus irradiation fluence is shown in Fig. 7.

We observe that the proton irradiation (at this energy and fluence) has a small impact on $\lambda_{0.5m}$ and no effect on $\Delta\lambda_{0.5m}$. It is then obvious that the decreases of the maximum signal and the power are identical. However this signal amplitude loss is relatively high for the NSHU551B LED, with a total maximum decrease of -34% after 4.10^{11} $p.cm^{-2}$. The UVTOP LEDs loses approx. 24% of the signal, and the Micropac blue LED loses only 13 % of the signal [16], [17], [18].

Fig. 8 shows the ratio $\frac{S_p(irradiated)}{S_p(0)}$ of the peak signal after irradiation to peak signal before irradiation.

We observed that the relative peak intensity variation after irradiation is much more pronounced for operational forward current $I_F < 20$ mA compared to higher applied current (up to 100 mA). The current dependence of the LEDs performance has been already reported for LEDs [16], [19]. It is assumed that the increased defect density generated during the irradiation increase the non-radiative recombination rates in the active layer. As a consequence, we observed most distinctively the output light variation in the low-current operation regime of the device. In higher-current regime, the degradation is less pronounced because the radiative recombination is dominating the non-radiative, which saturates [19].

We thus recommend for future UV solar radiometers using onboard LEDs to apply a larger current to reduce as much as possible the irradiation-induced LED damages.

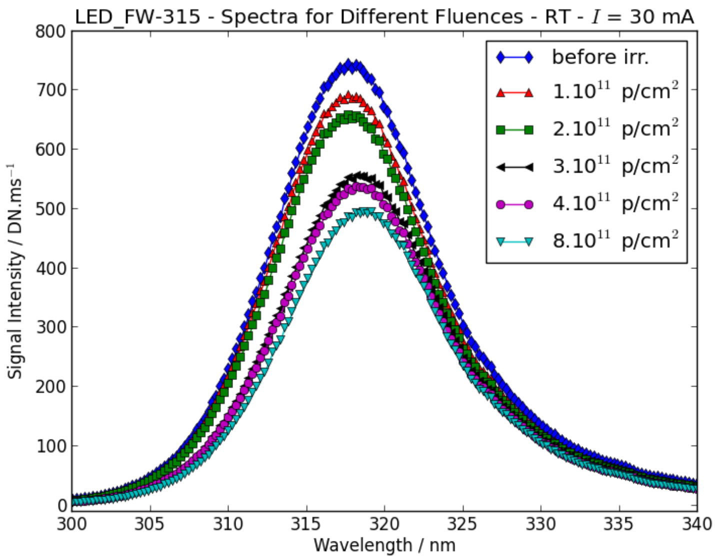

Fig. 7. LED_FW-315 – spectra as a function of the proton fluence up to 4.10^{11} $p.cm^{-2}$ (14.4 MeV)

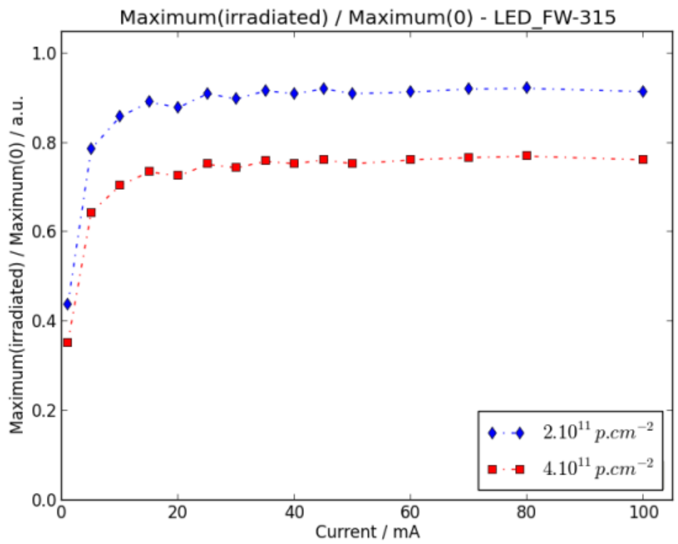

Fig. 8. LED_FW-315 – Ratio of peak signal after irradiation (2.10^{11} and 4.10^{11} $p.cm^{-2}$) to the peak signal before irradiation as a function of the forward current.

IV. CONCLUSION

The LEDs characterization carried out provides crucial information for the operations of the LEDs for the onboard detector calibration. It has been demonstrated that the five studied LEDs show a significant temperature dependence of the emission (S_P and P), as well as of the average wavelength ($l_{0.5m}$). The LEDs temperature onboard should be very stable or, at least, should be measured to be able to perform accurate onboard calibration.
It has been also demonstrated that the LEDs average wavelength ($l_{0.5m}$) and bandwidth ($Dl_{0.5m}$) are not strongly affected by proton irradiation up to a fluence of 8.10^{11} $p.cm^{-2}$ at 14.4 MeV energy with respect to the Solar Orbiter (total mission duration without Al shielding). However the peak signal (S_P) and the integrated power (P) decrease during the irradiation. The Nichia NSHU551B LED shows the highest decrease. Based on the current dependency of the degradation after irradiation, an operational current $I_F > 20$ mA is recommended (ideally 30 mA). Moreover the onboard current source shall be very stable. It is also strongly recommended to wait for a stabilization time after switching "on" the LEDs: 2 min for the blue LED (Micropac) and 1 min for the UV LED (SETI).
We recommend to use two LEDs for the onboard calibration i.e., the blue LED (470 nm) from Micropac as well as the NUV LED_FW-315 from SETI (UVTOP LED) for the future EUI instrument onboard the Solar Orbiter mission.

REFERENCES

[1] M. Dominique, J.-F. Hochedez, W. Schmutz, I.E. Dammasch, A.I. Shapiro, M. Kretzschmar, A.N. Zhukov, D. Gillotay, Y. Stockman, A. BenMoussa, "The LYRA instrument onboard PROBA2: description and in-flight performance", Solar Physics 286, 21-42, 2013

[2] D.B. Seaton, D. Berghmans, B. Nicula, J.-P. Halain, A. De Groof, T. Thibert, D.S. Bloomfield, C.L. Raftery, P.T. Gallagher, F. Auchère, J.-M. Defise, E. D'Huys, J.H. Lecat, E. Mazy, P. Rochus, L. Rossi, U. Schühle, V.A. Slemzin, M.S. Yalim, J. Zender, "The SWAP EUV Imaging Telescope Part I: Instrument Overview and Pre-Flight Testing", PROBA2 Topical Issue Sol. Phys. 286, 43-65, 2013

[3] PROBA2 website: http://proba2.sidc.be

[4] EUI website: http://eui.oma.be

[5] J.P. Halain, A. Mazzoli, P. Rochus, E. Renotte, Y. Stockman, F. Auchère, D. Berghmans, A. BenMoussa, "EUV high resolution imager on-board Solar Orbiter: optical design and detector performances", International Conference on Space Optics ICSO2012 , 2012.

[6] http://www.esa.int/Our_Activities/Space_Science/Solar_Orbiter

[7] R. Gaska, J. Yang, Y. Bilenko, W. Sun, M. Shatalov, X. Hu, A. Lunev, R. Kennedy, A. Sattu, J. Deng, I. Shturm, and M. Shur, "Novel Sources for Optical Sensors: III-Nitride Semiconductor-Based Deep Ultraviolet Light Emitting Diodes", poster Pittcon 2010

http://images.ihscontent.net/vipimages/VipMasterIC/IC/MPIN/MPINS00661/MPINS00661-1.pdf
[8] A. BenMoussa, S. Gissot, U. Schühle and 39 coauthors, "On orbit degradation of solar instruments". Solar Physics, vol. 288, issue 1, p. 389-434, 2013
[9] UVTOP LED Specification Sheets, http://www.s-et.com/uvtop.html
[10] Nichia BSHU551B Datasheet http://pdf1.alldatasheet.com/datasheet-pdf/view/476633/NICHIA/NSHU551B.html
[11] Micropac Blue Light LED Datasheet
[12] Handbook of LED Metrology http://www.instrumentsystems.com/fileadmin/editors/downloads/Products/LED_Handbook_e.pdf
[13] Operation Manual of the mini spectrometer USB4000 http://www.ifa.hawaii.edu/~dmh/WEBSITE-ETRO440/OO-USB4000.pdf
[14] A. BenMoussa, A. Soltani, J.-C. Gerbedoen, T. Saito, Stanislav Averin, S. Gissot, B. Giordanengo, G. Berger, U. Kroth, J-C. De Jaeger, A. Gottwald, "Developments, characterization and proton irradiation damage tests of AlN detectors for VUV Solar Observations", Nucl. Instruments & Methods in Physics Research section B: Beam interactions with Materials and Atoms 312, 48-53, 2013
[15] J. Sorensen, "Solar Orbiter Environmental Specification – Issue 3.0", TEC-EES-03-034/J, 2012
[16] Heidi N. Becker and Allan H. Johnston, "Proton Damage in LEDs with Wavelengths Above the Silicon Wavelength Cutoff", Nuclear Science, 51, issue 6 pp. 3558-3563, 2004.
[17] K.-X. Sun, L. MacNeil, K. Balakrishnan, E. Hultgren, J. Goebel, Y. Bilenko, J. Yang, W. Sun, M. Shatalov, X. Hu, and R. Gaska, "Extreme Radiation Hardness and Space Qualification of AlGaN Optoelectronic Devices", poster IWN 2010
[18] K. Sun, L. MacNeil, and Y. Bilenko, "GaN Radiation Hardness Properties and Detectors", poster SPIE 2010
[19] O. Pursiainen, N. Linder, A. Jaeger, R. Oberschmid and K. Streubel. "Identification of Aging Mechanisms in the Optical and Electrical Characteristics of Light-Emitting Diodes," Appl. Phys. Lett., 79(18), pp. 2895-2897, 2001.