



# Realization, calibrations and spatialization of $\beta$ -(Al)Ga<sub>2</sub>O<sub>3</sub> UVC Photodetectors of Extreme Solar Blindness for Space Observations

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## ► To cite this version:

Luc Damé, Pierre Maso, Lucile Conan, Clément Dias, Halima Ghorbel, et al.. Realization, calibrations and spatialization of  $\beta$ -(Al)Ga<sub>2</sub>O<sub>3</sub> UVC Photodetectors of Extreme Solar Blindness for Space Observations. 8th International Conference on Sensors Engineering and Electronics Instrumentation Advances (SEIA' 2022), Sep 2022, Corfu, Greece, Greece. insu-04310805

**HAL Id: insu-04310805**

**<https://insu.hal.science/insu-04310805>**

Submitted on 27 Nov 2023

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**Type of Presentation:**

Oral: ☒  
Poster: ☐  
The same: ☐

In-person: ☒  
Virtual in Zoom: ☐

**Topic:**

Optical Sensors

## **Realization, calibrations and spatialization of $\beta$ -(Al)Ga<sub>2</sub>O<sub>3</sub> UVC Photodetectors of Extreme Solar Blindness for Space Observations**

**L. Damé<sup>1</sup>, P. Maso<sup>2</sup>, L. Conan<sup>1</sup>, C. Dias<sup>2</sup>, H. Ghorbel<sup>1</sup>, P. Gilbert<sup>1</sup>, M. Meftah<sup>1</sup>,  
D. Bolsée<sup>3</sup>, N. Pereira<sup>3</sup>, A. Caria<sup>4</sup>, C. De Santi<sup>4</sup>, M. Buffolo<sup>4</sup>, M. Meneghini<sup>4</sup>,  
P. Bove<sup>5</sup>, V. Sandana<sup>5</sup>, R. Rogers<sup>5</sup> and F. Teherani<sup>5</sup>**

<sup>1</sup> LATMOS, IPSL, CNRS, University Versailles Saint-Quentin en Yvelines, University Paris-Saclay, 11 boulevard d'Alembert, 78280 Guyancourt, France

<sup>2</sup> PIT, OVSQ, 11 boulevard d'Alembert, 78280 Guyancourt, France

<sup>3</sup> Institut royal d'Aéronomie Spatiale de Belgique (IASB), 3 av. Circulaire, 1180 Uccle, Belgium

<sup>4</sup> Dipartimento di Ingegneria dell'Informazione, via Gradenigo 6/b, 35131 Padova, Italy

<sup>5</sup> Nanovation, 8 route de Chevreuse, 78117 Châteaufort, France

Tel.: + 33180285119

E-mail: luc.dame@latmos.ipsl.fr

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**Summary:** There is a surge in interest for the ultra wide bandgap ( $E_g \sim 4.9$  eV) semiconductor gallium oxide (Ga<sub>2</sub>O<sub>3</sub>). A key driver for this boom is that single crystal wide area bulk  $\beta$ -Ga<sub>2</sub>O<sub>3</sub> substrates have become commercially available and that a variety of methods have been shown to give high quality epitaxial growth. Amongst a whole range of potential applications (power/switching electronics, solar transparent electrodes, etc.) extreme solar blindness photodetectors in  $\beta$ -Ga<sub>2</sub>O<sub>3</sub>, the more stable monoclinic phase of Ga<sub>2</sub>O<sub>3</sub>, offer the most exciting perspectives for deep ultraviolet observations of the Herzberg continuum (200-242 nm) in Space. We present an overview of the complete realization process (epitaxy, photolithography, singulation and packaging), performances evaluation and spatialization of a serie of  $\beta$ -(Al)Ga<sub>2</sub>O<sub>3</sub> photodetectors developed (slight Al alloying to enhance ultraviolet response below 253 nm), space qualified and selected for flight on the INSPIRE-SAT 7 nanosatellite (launch planned in early 2023).

**Keywords:** Deep ultraviolet photodetectors,  $\beta$ -Ga<sub>2</sub>O<sub>3</sub> oxide, Space observations, Herzberg continuum, Nanosatellites.

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### **1. Introduction & Scientific Rationale**

Our scientific interest lies in characterising the influence of the Sun on climate. Solar variability has strongly affected the history of the Earth's climate. As a result, the role of solar variability in climate change remains a subject of strong scientific and societal interest [1,2]. On top and more important than variations in total solar irradiance, ultraviolet (UV) solar variations appear to play an important role in regional climate change through their interactions with stratospheric ozone (the photolysis of molecular oxygen by UV is the source of stratospheric ozone). UV solar irradiance and its variability represents key inputs not only for climate but also for solar physics (long term understanding of solar variability, e.g. solar minima decrease?).

Ultraviolet wavelengths within the solar spectrum are more interesting to study than others because they present more variability, in particular wavelengths between 200 and 242 nanometers (Herzberg's continuum). This solar spectral band, absorbed in the stratosphere, causes oxygen to dissociate and creates the ozone layer. These reactions induce temperature

and velocity anomalies which, in turn, cause changes in the local climate (on cloud cover, etc., affecting the water vapor in the atmosphere for example).

This work is an innovative development project with an ambitious science goal: monitoring the Solar Spectral Irradiance (SSI) at 215/220 nm (Herzberg solar continuum: 200–242 nm) with an accuracy better than 0.5% (5 times better than previous measurements in Space [3]).

To achieve this objective we developed disruptive ultra wide band gap semiconductor ( $\geq 4.9$  eV at 253 nm) UVC photodetectors on oxide-based  $\beta$ -Ga<sub>2</sub>O<sub>3</sub> that are intrinsically solar blind, radiation-hard and thermally-robust. Also, authors have recently shown that the bandgap can be engineered upwards through Al alloying,  $\beta$ -(Al)Ga<sub>2</sub>O<sub>3</sub>, so as to obtain optical transitions from 253 down to 200 nm [4].

Furthermore, since UV observations are to be performed in Space, these innovative detectors are to be space qualified to TRL 9 ("flight proven") since part of the payload of the next nanosatellite of LATMOS (following our first, UVSQ-SAT, launched in January 2021 and successfully working [5]), "INSPIRE-Sat 7/UVSQ-Sat+", a "2U" cubesat,

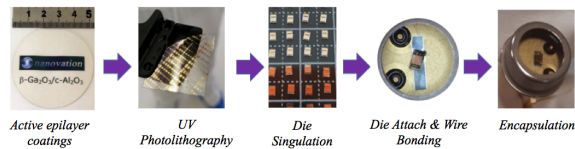
currently under integration and planned for flight in the first quarter of 2023 [6].

In this paper we present the realization process, performances evaluation and qualification tests of these new  $\beta$ -Ga<sub>2</sub>O<sub>3</sub>-based photodetectors. They are developed for New Space observations in the UVC spectral band 200–242 nm of particular interest for climate.

## 2. Realization Process

For detection between 200 and 242 nm, the fluxes being low, a good signal-to-noise ratio is necessary to measure the useful signal. The spectral response of the detector should be sensitive between 200 and 240 nm, centered at 215–220 nm, with a half width at half maximum reduced (of the order of 30 nm) and excellent rejection so that the visible spectrum, which is much more intense, does not disturb the measurement. Oxide materials have this decisive advantage: a significant rejection of the visible (greater than 1000 compared to the peak of sensitivity) adjustable in wavelength as a function of the oxide chosen and its doping, Al in this case [4].  $\beta$ -(Al)Ga<sub>2</sub>O<sub>3</sub> allows a maximum response at 215/220 nm and a high rejection at wavelengths  $\geq 250$  nm, and achieves excellent signal-to-noise ratio (dark current is very low:  $\leq 5$  pA). In practice these detectors are said "Solar Blind" (since insensitive to visible and infrared light). Other properties of detectors are radiation hard (long term performances) and ambient temperature performance (no need for cooling).

In the framework of the ANR DEVINS program, detectors have been realized from the wafer to the final packaged sensors (Fig. 1: device architecture development, epitaxy, photolithography, contacting, probing, singulation and packaging in TO-39 caps).



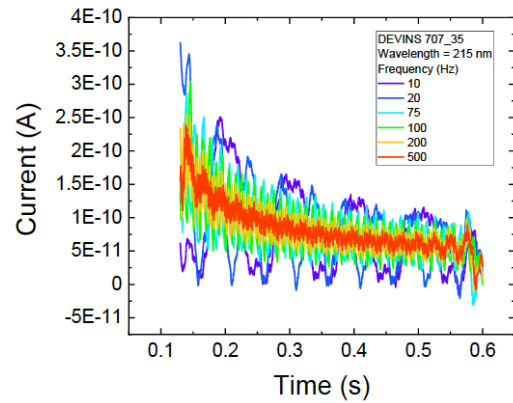
**Fig. 1.** The 5 main steps in the realization process of the DEVINS UVC  $\beta$ -Ga<sub>2</sub>O<sub>3</sub> detectors.

## 3. Performances

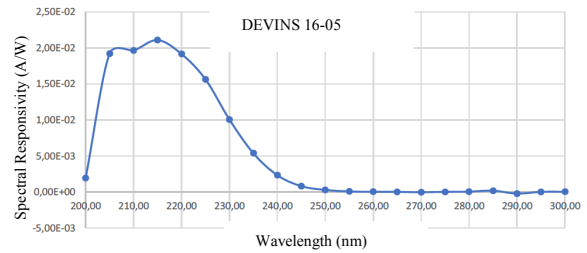
We performed probing tests on hundreds of MSM components to categorize detectors performances. So far, we achieved up to 6 order of magnitude between dark and light currents at only -5V bias voltage. Dark current is very low ( $\leq 5$  pA) and cannot be measured most of the time on "good components". Dynamics is excellent (cf. Fig. 2) with stable response times of 20 ms or so (rise and fall times).

Performances are limited by the bias voltage available on the nanosatellite fixed to -5V. Components would have a better response by a factor 6 to 10 with bias of -30 or -50V in future programs.

Fig. 3 shows a typical spectral response of our Gallium oxide detectors. They reveal a peak response of 10 to 70 mA/W at 215 nm and a FWHM of  $\sim 35$  nm, compatible with the spectral range of interest between 200 and 242 nm (UV above 250 nm is produced by a different process).

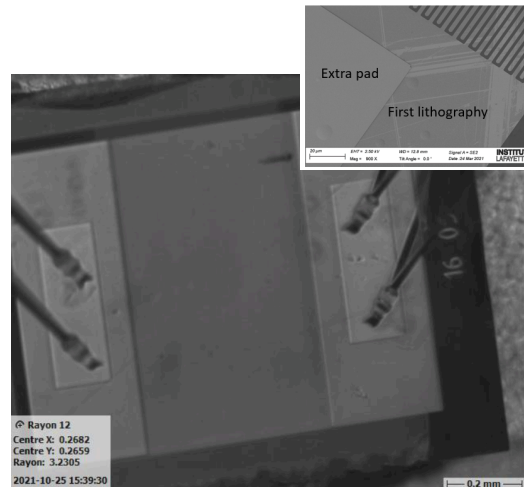


**Fig. 2.** Time dependence of the photoresponse of a photodetector at 215 nm (bias of -5V applied at start; will be permanently applied when in use in Space to avoid decrease observed at start).



**Fig. 3.** Typical spectral responsivity (in A/W) of a photodetector (16-05) with maximum at 215 nm,  $\sim 20$  mA/W, an FWHM of  $\sim 35$  nm and, accordingly, a good rejection at 250 nm.

Fig. 4 shows, with a magnification of 267, the DEVINS detector 16-05 very clean realization and, in particular, the wire bonding on an extra pad to strengthen the process.



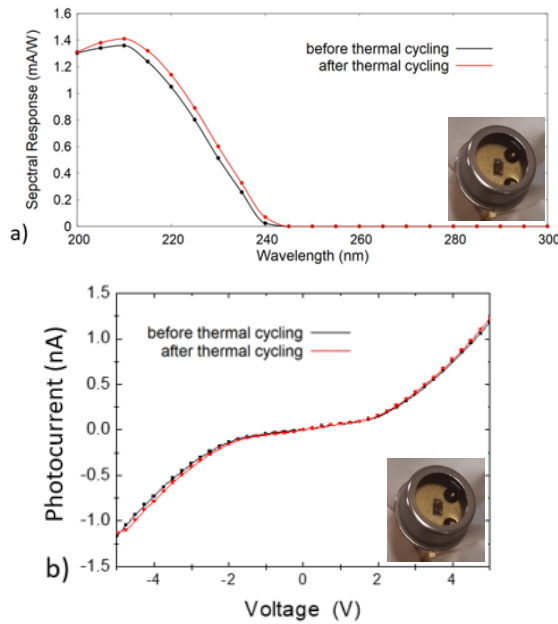
**Fig. 4.** Illustration of the same photodetector 16-05 (magnification 267) showing wire bonding – 25  $\mu$ m wires – on an extra pad (illustrated on top) to strengthen the realization.

#### 4. Space Qualification

We impose a sensitivity minimum of 10 mA/W. Noise of components is very low (< 5 pA, typically even less than 1 pA) but dominated by electronics, with limit set to 0.1 nA.

Peak of sensitivity of the detector has to be centered at 215/220 nm ( $\pm 5$  nm) with a FWHM less than 35 nm to properly measure the Herzberg continuum (minimum rejection of 1000 at 250 nm).

Intensive testing was performed in particular thermal cycling and response tests. They are illustrated in Fig. 5 showing the spectral response and the photocurrent/voltage curves (under 5V bias) at room temperature and after all thermal cycling experiments (from 230 to 340 K, and under vacuum and under synthetic air) at atmospheric pressure.



**Fig. 5.** a) Spectral response (at 5V bias) and (b) IV curves (under polychromatic illumination) at room temperature before (black) and after (red) atmospheric pressure and vacuum thermal cycling of one typical (but with low response) DEVINS UVC  $\beta$ -(Al)Ga<sub>2</sub>O<sub>3</sub> detector.

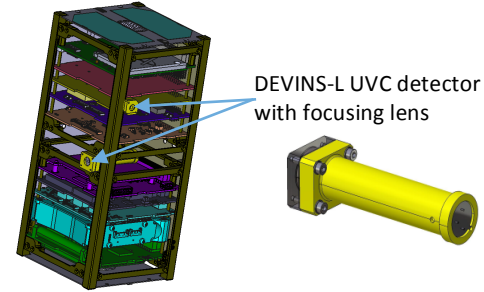
Characteristics of our  $\beta$ -(Al)Ga<sub>2</sub>O<sub>3</sub> detectors are summarized in Table 1.

**Table 1.** DEVINS UVC photodetectors characteristics.

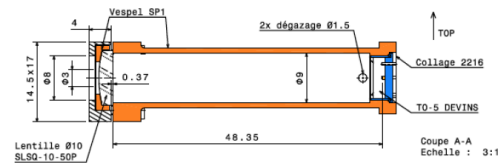
PARAMETER	REQUIREMENT
Radiation flux	$\sim 1.4 \text{ W.m}^{-2}$
Peak response	215/220 nm $\pm 5$ nm
Spectral response @ peak	> 10 mA/W @5V bias
Spectral range	200–242 nm
Rejection ratio (peak/250 nm)	> 1 000
Mean noise level	< 5 pA
Rise and Fall time	$\leq 20$ ms

Detectors are now ready for intensive absolute calibrations (in BIRA-IASB facilities in Brussels) before integration in the INSPIRE-Sat 7 nanosatellite of LATMOS this Summer 2022. Two versions are

prepared in this respect (cf. Fig. 6): a long version (DEVINS-L), with a lens focusing Sun light on the small (500x800  $\mu\text{m}$ ) detector surface to optimize flux collection and increase signal to noise ratio, and a classical one, only with the TO-39 case (with sapphire window), exposed to the Sun (more compact for nanosatellite's accommodation).



Credits: INSPIRE-SAT 7



**Fig. 6.** DEVINS-L  $\beta$ -(Al)Ga<sub>2</sub>O<sub>3</sub> detector mounting design (with focusing lens) for the INSPIRE-Sat 7 nanosatellite.

#### 5. Conclusions

UVC optimized detectors in Gallium oxide have been realized and tested and their unique performances of extreme blindness demonstrated. They are now ready for absolute calibration before integration in the INSPIRE-Sat 7 nanosatellite [6].

#### Acknowledgements

We acknowledge support from the ANR (Agence Nationale de la Recherche) for the development of these detectors of the DEVINS (DEep uV INnovative detector technologies for Space observations) program.

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