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RECENT ROB DEVELOPMENTS ON WIDE BANDGAP BASED UV SENSORS

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Abstract. The next ESA spatial mission planned to study the Sun, Solar Orbiter (SO), necessitates very innovative EUV detectors. The commonly used silicon detectors suffer important limitations mainly in terms of UV robustness and dark current level. An alternative comes from diamond or III-nitride materials. In these materials, the radiation hardness, solar blindness and dark current are improved due to their wide bandgap. This paper presents the new developments on wide bandgap materials at the Royal Observatory of Belgium (ROB). We present also the LYRA instrument, the BOLD project, and the EUI instrument suite.

1 Why Wide Bandgap Materials?

Silicon detectors suffer from important limitations that can be overcome using a wide bandgap material. Wide bandgap materials are more resistant to the degradation arising from: non-ionizing radiations, ionizing radiations, as well as from the UV signal. Some radiations degrade the bulk of the material. The dense and light crystalline structure of the wide bandgap materials makes them more

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resistant to this type of radiation than silicon, in which displacements appear. Other radiations degrade the surface of the material. In silicon, the SiO_2 surface layer is very sensitive to UV radiations. Diamond and cBN do not have an oxide surface layer and AlGaN materials have a thin stable surface layer.

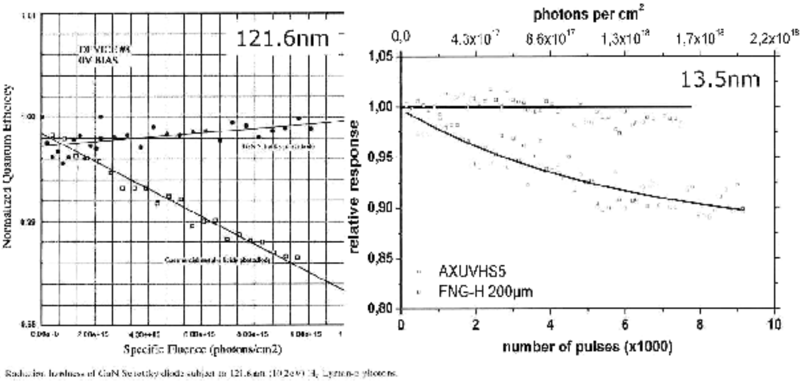

Fig. 1. Relative quantum efficiency of silicon (bottom) and GaN photodiodes. *Left*: data from (Aslam 2005). *Right*: our data (Barkusky 2007).

Figure 1 shows comparative results for silicon detectors and GaN detectors from the literature (Aslam 2005) at Lymanα (121.6 nm) on one hand, and from one of our GaN photodiode at 13.5 nm on the other hand. In both cases, the silicon detector degrades clearly while we could not measure the degradation of the GaN detector. More investigation, for different wavelengths, is necessary to know the maximum UV dose until degradation appears in GaN material. The second interesting property of the wide bandgap materials is their solar blindness. These detectors, due to the wide bandgap of their material, have a cutoff between 180 nm (cBN) and 390 nm (GaN), much lower than silicon (1100 nm). In consequence, the main part of the visible solar continuum is rejected and the number of filters, blocking the unwanted visible radiation, can be reduced and the associated attenuation of the desired UV radiation can be avoided. This point is not very important in the beginning of the mission but is of increasing importance over time. Indeed pinholes appear in filters and the visible light increases with time. The use of a wide band-gap material is an intrinsic protection against this problem.

2 Monopixels Detectors and the LYRA UV Radiometer

LYRA (Hochedez 2000, 2006) is a UV solar radiometer which will embark onboard the ESA PROBA2 mission in 2009. One objective of LYRA is to demonstrate the feasibility and interest of instruments using diamond photodetectors, a wide bandgap material having a gap of 5.5 eV. LYRA is composed of three units. Each unit is composed of four channels. The three units are almost identical and operate on the basis of a redundancy concept. The four LYRA channels large pass bands are: Herzberg (200–300 nm), Lyman alpha (120–123 nm); aluminum filter (17–60 nm), and zirconium filter (1–20 nm). For the LYRA project, two types of diamond detectors were developed: metal-semiconductor-metal (MSM) photoconductors and PIN photodiode detectors. Diamond detector structures were developed in a joint collaboration between IMO-IMOMEC in Belgium, NIMS in Japan, Garching Analytics GmbH in Germany, and ROB. Photographs of the diamond MSM and PIN detectors mounted inside their square ceramic package are shown in Figure 2. Devices operation and fabrication procedure details are given elsewhere (Benmoussa 2006a, 2006b). Diamond sensors exhibits several superior properties in comparison to silicon. C* has a high charge carrier mobility at room temperature with large breakdown electric field, a low dielectric constant (*i.e.* low capacitance) and low intrinsic carrier density (by seven orders of magnitude smaller than silicon), which makes cooling for dark current noise reduction unnecessary. Its dense tetrahedral structure and stable covalent sp3 bonding are the reasons for the much better radiation hardness of diamond detectors than of silicon detectors.

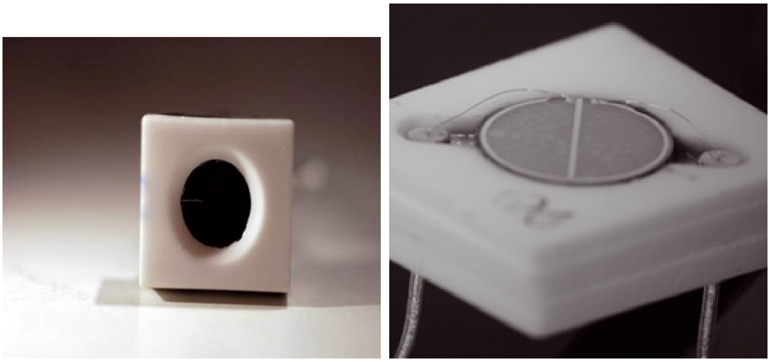

Fig. 2. LYRA ceramic package. *Left*: PIN. *Right*: MSM.

We are also interested by other wide band gap materials. In particular AlGaN is very interesting for two reasons: 1. the cutoff of the pure AlN is lower that that of diamond and 2. the cutoff can be adjusted between 190 and 380 nm by changing the stoechiometry. cBN is also very interesting because it is the semiconductor with the lowest cutoff (180 nm), making it a great material for the study of the UV Sun. Figure 3 shows the relative photoresponse of different photodetectors (Soltani 2008; Benmoussa 2008a, 2008b) From left to right: MSM cBN at +30 V(dark yellow), MSM AlN at +30 V(pink), diamond MSM at +5 V(light blue), MSM $Al_{0.8}Ga_{0.2}N$ at +20 V, $Al_{0.5}Ga_{0.5}N$ at +20 V and Schottky GaN diode at -1V. The very sharp cutoff match with the expected one from the bulk materials (see IOFFE we site) *i.e.* 193 nm for cBN (1974, 2002) 203 nm for AlN (1979), 225 nm for diamond, 230 nm for $Al_{0.8}Ga_{0.2}N$, 270 nm for $Al_{0.5}Ga_{0.5}N$ and 380 nm for GaN (Bougrov 2001). These photodetectors show also a very low dark current: 1.1 pA for diamond AlN, 13 fA for the AlN and 2 pA for the BN. The rejection ratio is between three and four orders of magnitude for all the biases, suggesting the potential to use *these* wide bandgap photodetectos to detect DUV light with only one filter required to attenuate the visible to NIR light.

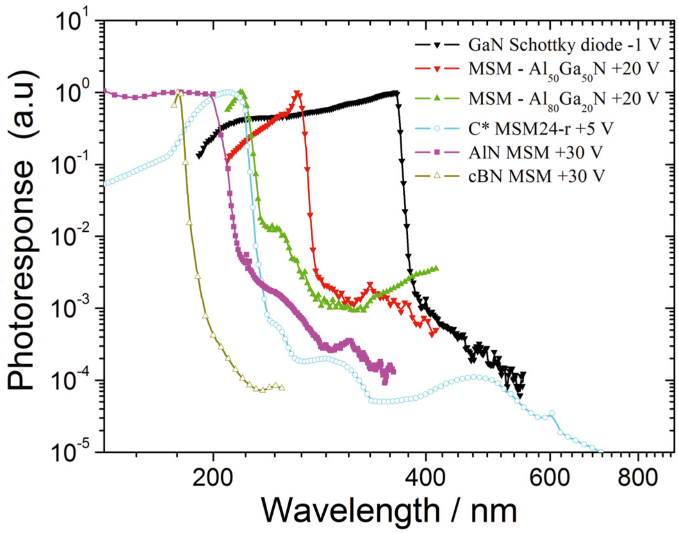

Fig. 3. Photoresponse of different wide bandgap photodetectors. The cutoff matches with the expected one *i.e.* 193 nm for cBN (dark yellow), 203 nm for AlN (pink), 225 nm for diamond (light blue), 230 nm for $Al_{0.8}Ga_{0.2}N$ (green), 270 nm for $Al_{0.5}Ga_{0.5}N$ (red) and 380 nm for GaN (black). The rejection ratio is good, *i.e.* from three to four orders of magnitude.

3 BOLD: Development of Hybrid AlGaN Imaging Device

BOLD, Blind to the Optical Light Detectors, is a R&D project of hybridization of AlGaN membranes onto CMOS imaging devices. BOLD is developed in a joint collaboration between CRHEA in France, IMEC in Belgium, and ROB in Belgium. Backside illuminated GaN Schottky diodes have been fabricated and characterized in NUV wavelength range. Figure 4 shows a schematic drawing of a GaN Schottky diode (Malinowski 2008). Silicon substrate is etched away only under the diode area. This enables backside illumination through the dedicated hole. The light has however to go through the highly doped region. This reduces the quantum efficiency (QE) because the photons absorbed in this region are essentially lost for the signal. Figure 5 shows a SEM image of photodiode cross-section. 1.5 μm GaN membrane is visible (curling up after cleaving the wafer), surrounded by thick (60 μm) silicon substrate. In the etching process part of the substrate gets etched after complete removal of the photoresist layer. This technology enables fabrication of closely packed arrays which can be hybridized to a readout circuit (ROIC).

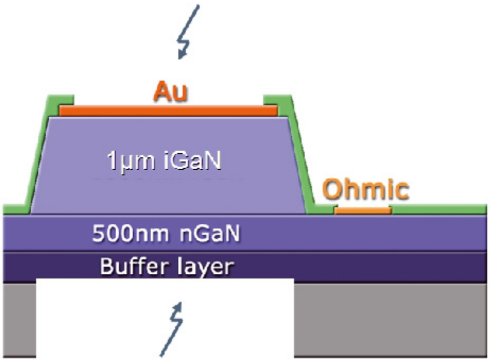

Fig. 4. Schematic cross-section view of the GaN Schottky diode. Silicon substrate is etched away only under the diode area. This enables illumination through the dedicated hole, the light however has to go through the highly doped layer.

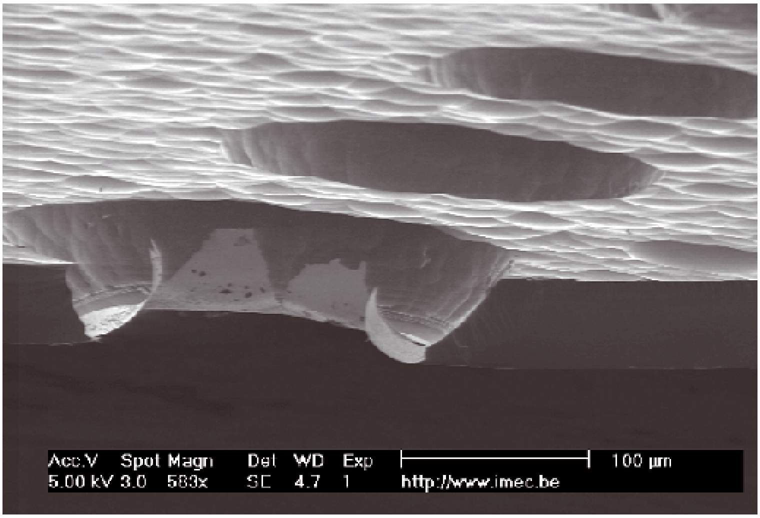

Fig. 5. SEM image of photodiodes cross-section. The 1.5 μm GaN membrane is visible (curling up after cleaving the wafer), surrounded by the thick (60 μm) silicon substrate.

300 μm diameter single pixel photodiodes were used for the optoelectrical characterization. In Figure 6, spectral responsivity curves for the front side and the back-side illuminations are shown. It is clear that when illuminated from backside, recombinations happen in the highly doped area for small wavelengths, resulting in reduced quantum efficiency (QE). However, close to the cutoff, the performance is good, which is promising considering that the layer stack was not yet optimized for the backside concept.

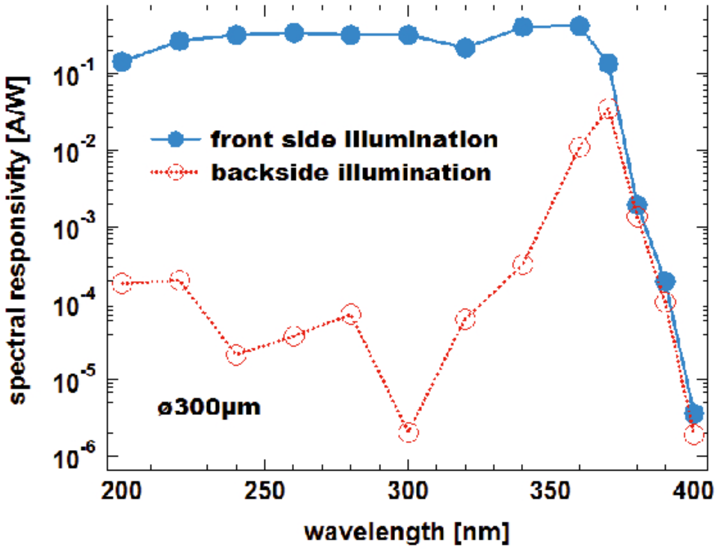

Fig. 6. Spectral responsivity curves for photodiodes illuminated from the front side (blue full circles) and from the backside (red hollow circles). A cutoff is measured at 370 nm. Responsivity at the noise level for the backside illuminated device for the low wavelengths is attributed to the fact that light passes through defective doped layer and is entering the active layer far from the Schottky electrode.

4 EUI and its Need for Detectors

The EUV Imager (EUI) is a suite of imaging telescopes conceived to observe the solar atmosphere, from the S.O. ESA mission. EUI proposal currently includes three co-aligned High resolution Imagers (HRI) and one double bandpass Full Sun Imager (FSI). There are three solutions for the detectors:

1. A baseline solution composed of 2 k $\times$ 2 k backthinned silicon CMOS detectors. A first prototype will be developed in 2009.
2. An augmented solution which is AlGAN hybridized to CMOS devices (*i.e.* BOLD) has yet to demonstrate its feasibility in the time allocated for the development of EUI detectors.
3. A backup solution which is CCD such as ones flown on the NASA SDO-AIA instrument. This solution is existing, but it requires a shutter and is less radiation hard than the other ones.

5 Conclusion

This paper has presented the recent developments at ROB related wide bandgap material UV detectors. It has also been presented the LYRA instrument, the

BOLD project and the EUI suite. Diamond, AlGaN and cBN single pixel photodetectors have been fabricated with very sharp cutoff and matching with the expected values from the bulk materials. They also show low dark current and high sensitivity to UV light. Backside illuminated GaN Schottky diodes were fabricated and characterized in the NUV range for the first time. The results are compared between front and backside illumination. The latter shows less good performance certainly due to a non optimized design. The BOLD project is on going and will provide updated results in 2009.

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