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Gallium arsenide photodetectors for imaging in the far ultraviolet region

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The aim of the present work is to systematically investigate the response and stability of commercial GaAs devices in the 200–400 nm UV range with a view to establishing their potentiality in imaging devices. The irradiation results of GaAs detectors with various geometries are presented and discussed. The detectors were reverse biased in fully depleted condition and in partially depleted condition (5 V reverse bias) in order to investigate the possibilities of integration with the standard bias values of read-out-integrated circuits. The results show that fabrication technology for nondedicated devices is still immature.
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Most of the latest developments in UV photodetectors have concentrated on new materials to enhance window selective properties and to increase their efficiency.[1] All these developments concern very widespread final military and civil applications, as well as the medical and biological fields. As a final application, we wish to arrive at imaging devices in the far UV region for biological applications. By waiving the energy selectivity requirement, it may still be possible to use materials even if their band gap is not exactly in the 250–270 nm interval, which is of the greatest interest in the case of biological compounds.

There is also much interest in using this photodetector in the 200–400 nm wavelength range, because GaAs is a direct gap semiconductor with an energy threshold of 4.3 eV (corresponding to $\lambda = 288$ nm).[2] We investigated to see if the technology of current GaAs devices on the market is mature enough to constitute a satisfactory alternative to silicon for imaging. It was thus essential to systematically evaluate commercial GaAs devices in terms of their performance in imaging applications.

We purchased samples from several producers and compared the measured performances with silicon devices.[3] We present here the results for detectors from two such sources which it was possible to investigate systematically.

In this work, we discuss measurements of the photocurrent carried out under different experimental conditions, such as fully depleted and underdepleted bulk and responses at different wavelength values. Single pixels, pixel matrices, and linear structures of different areas were tested. We show that the devices fabricated on GaAs present several limitations on their use as imaging devices due to their relatively immature technology.[4]

We characterized different types of GaAs photodetectors: Pixel and linear devices with different bulk, geometry, and surface composition. The devices investigated came from two different constructors: Alenia [Italy Alenia Marconi Systems (AMS)] and ST&T [Slovakia]. These GaAs devices were originally developed for medical physics applications, as x-ray detectors.

The process of fabrication of Alenia devices based on semi-insulating liquid-encapsulated-Choralsky (LEC) grown GaAs substrates, is intrinsically double sided, with silicon nitride passivation on the electrode side and a polyamide protection on the ohmic side. The Schottky contact is made of Ti/Pt/Au layers deposited on the bare GaAs surface. Electroplated Au was used for the bonding pads. The dimensions are $200\ \mu\text{m} \times 200\ \mu\text{m}$ pixels for the AMS detector and $350\ \mu\text{m} \times 1000\ \mu\text{m}$ for the ST&T one.

Irradiation was not specifically directed to a photosensitive area, in order to arrive at the most general consideration for practical applications in which this is not the case. Irradiation therefore covers the regions between the pixels, the borders, and the pixels themselves. The resulting photocurrent is almost all due to the interactions of UV photons at the induced or built-in oxide surface;[5,6] the measured value is an averaged photocurrent.

The ST&T devices on semi-insulating LEC-grown GaAs substrates are line detector chips mounted on a printed circuit board support. A line consists of 32 elements with different geometry dimensions. The contact is made of Ti/Pt/Au layers and each finger is bonded with an Au pad.

Contrary to the AMS structure, here, the irradiated nonmetalized photosensitive area is larger than the metal areas. The ratio of the metalized to the unmetalized area is about

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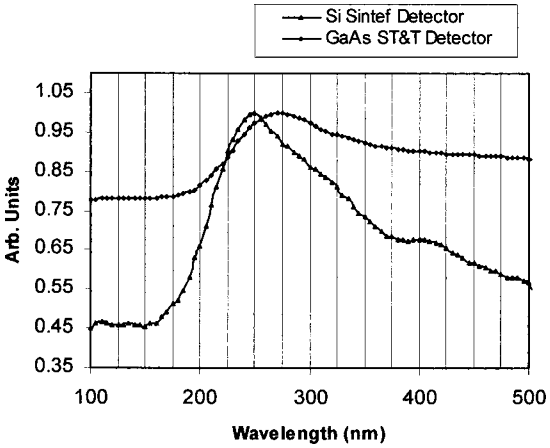

FIG. 1. Comparison between Si and GaAs photocurrents (normalized to a.u.).

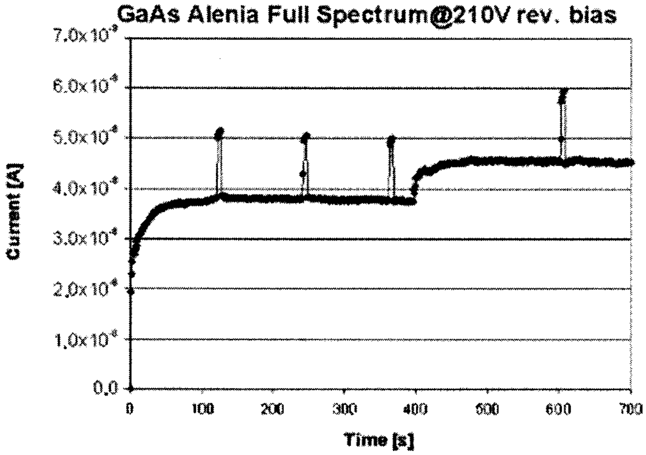

FIG. 3. Time instability for GaAs detectors (AMS).

20:1 for the AMS device and about 5:1 for the ST&T one. These results are sufficient to verify the availability on the market of a reliable component for use in building imaging devices.

Data were collected by automatic acquisition of the detector current in reverse biased condition.[7] A Hamamatsu 30 W, deuterium lamp (200–400 nm), coupled to a Jobin Yvon H 10 monochromator and an optical fiber bundle to direct the light to the detector, was used.

The parameters considered in validating detectors as imaging photodevices were: Their stability versus time, the absolute value of the photocurrent and its ratio to the dark current in reverse bias and, finally, responsivity in evaluating their efficiency. With respect to previous results on silicon detectors[3] we found a ratio of 42% average efficiency with respect to silicon for the ST&T GaAs detector photocurrent in a UV lamp spectrum of 200–400 nm. The different λ gap for GaAs and Si, as expected (288 and 325 nm, respectively), can be seen smeared by the shape of the lamp spectrum in the curves in Fig. 1, where the curve for GaAs is normalized to compare with the Si photocurrent response.

In Fig. 2, we show the dark current as a function of the applied reverse voltage for the two different devices. Depletion voltage was not directly measured in these devices. It was evaluated from measurements on specific structures of the same wafer lots equal to around 200 V or higher (for AMS). The plot clearly shows instability for these GaAs devices, with a sudden rise at 200 V for one (ST&T) and high current with several sudden rises for the other (AMS). In these measurements, we were not interested specifically in the absolute value of the current, but rather in the different jumps of current values corresponding to different structures being depleted as the voltage rises.

Time stability of the detectors under illumination and their capacity to restore the original dark current value without radiation is a crucial parameter in evaluating the potential of these devices for imaging. We, therefore, measured current versus time and at regular intervals we opened the light shutter for 5 s. The data in Figs. 3 and 4 show clear instability even during simple illumination (see especially Fig. 3). This does not allow the use of these detectors in experiments requiring long duration times, stability, and reproducibility or, in general, to any device.

These data were collected at voltages close to or slightly below the underdepletion condition of the detectors. We wished also to investigate the possibility of using detectors at the same typical bias of readout integrated electronic circuits to which they may be bonded when assembled in a hybrid readout structure, although we were aware that free carriers were noticeably present and therefore contributed to the noise. We thus collected a series of measurements at a voltage far below the depletion voltage. The solution of running

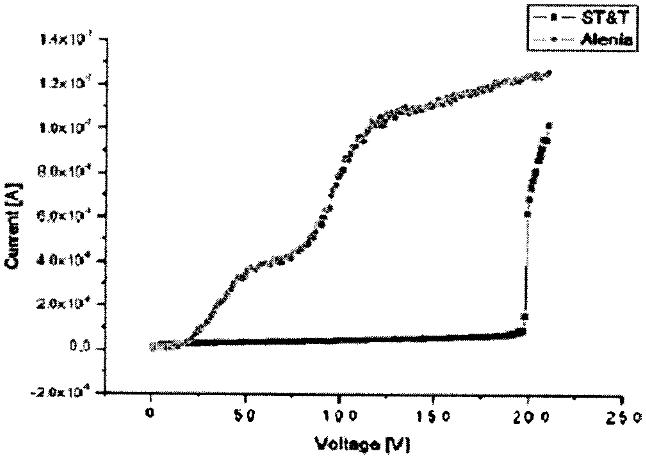

FIG. 2. Current versus voltage curves for ST&T and AMS GaAs detectors.

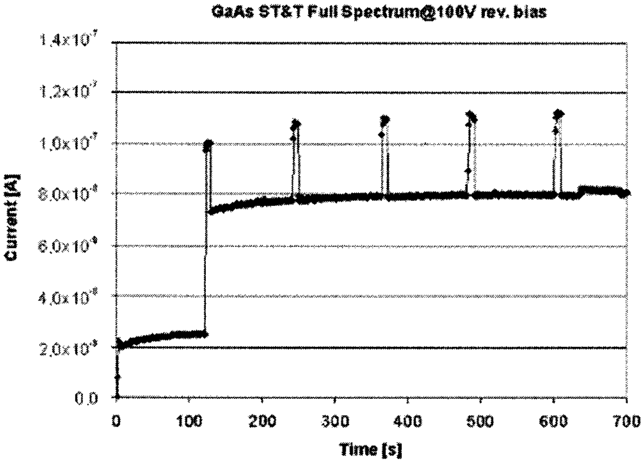

FIG. 4. Time instability for GaAs detectors (ST&T).

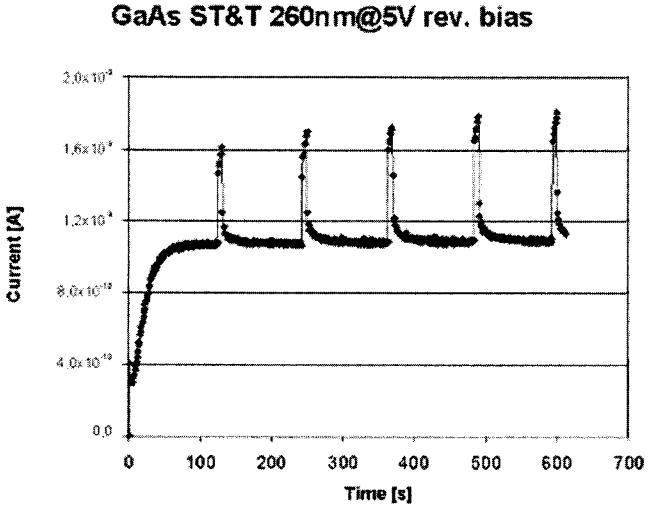

FIG. 5. Photocurrent for an ST&T detector at 260 nm wavelength illumination.

the detectors at very low bias voltage may be of interest in reducing the design complexity of electronics and the dissipated power for several applications.

We measured the current difference between illumination and dark. The results indicate that there are different behaviors between under- and close-to-depletion conditions for both AMS and ST&T devices. The photocurrent measured in the underdepleted condition is very low compared with the one obtained for depletion (or close to) shown in Figs. 3 and 4. Moreover, the photocurrent of the AMS devices is below the detection limit of our instruments (fA), i.e., unsuitable for any integrated readout circuit. As an example, in the curve in Fig. 5, we can see the photocurrent at 260 nm for an ST&T detector at only 5 V reverse bias: the dark current returns to the constant value of ~1 nA and the current during the illumination is approximately 1.6 nA at $t = 150$ s. However, after $t = 600$ s, the photocurrent is raised to 1.8 nA. At bias voltage values far from depletion, there should be less current instability, but this is not the case as instability is still evident and therefore we conclude that the devices are not suitable for imaging applications.

Results from the same type of measurements on similar Si detectors gave us higher stability, reproducibility, and a very good signal-to-noise ratio at the $\lambda = 260$ nm wavelength.[3] Structural defects inside the GaAs crystal are certainly the reason for this difference. Punctual defects and dislocations are more easily created in GaAs than in Si and they act as trapping centres.

Furthermore, the presence of oxide atoms inside the Si bulk induces the ''internal gettering'' phenomenon, thus leaving a zone, some microns thick, with minimal defects at the radiation entrance window, thereby enhancing efficiency. On the contrary, in the case of GaAs since there is no oxidation of the bulk, this effect is not present naturally and more costly processing is required. This effect of instability of GaAs devices has been relatively well known since the early studies showed a ''pulsed behavior'' indicating the presence of the defects.

While gallium arsenide is a very attractive material for imaging in the UV and one that can offer opportunities for selected window detection, we can conclude that our systematic analysis of the behavior of commercial GaAs devices for use in imaging applications indicate that in the 200–400 nm range, the technology of nondedicated devices requires further development.

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