

Characterization of Quantum Well Infrared Photodetector grown by Metalorganic Vapor Phase Epitaxy

K. A. Alves^a, G. S. Vieira^b e R. M. Castro^b

^aInstituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brasil

^bInstituto de Estudos Avançados, São José dos Campos, São Paulo, Brasil

Abstract — In this work, we present experimental results on the characterization of n-type InGaAs/InAlAs quantum-well intersubband photodetectors. The InGaAs/InAlAs multiple quantum well structure were grown on an InP substrate by Metalorganic Vapor Phase Epitaxy (MOVPE). We present results on spectral responsivity, absolute responsivity and the dark current. The detector shows low dark current, 77 K, of a few nA, and a peak polarized light responsivity of $R = 60$ mA/W for an incidence angle of 45° , with applied bias of 4.0 V. Considerations also are made on the methods of characterization and techniques used.

Key-words — QWIP, MOVPE, Responsivity, dark current.

I. INTRODUCTION

Although infrared sensors are of great interest for many areas of Brazilian private economy, governor sectors, and general society, there is no company producing infrared sensors, and it has been relatively little research and development on infrared sensors in Brazil. Quantum well infrared photodetectors, QWIPs, use intraband transitions and were proposed as an alternative to the most used infrared sensors, based on HgCdTe. They were first demonstrated in 1987 by Levine et al. (1), and proved to be cheaper, more stable, have greater design flexibility and allow the fabrication of large bi-dimensional arrays with great uniformity. They became a commercial reality at the beginning of 2000s (2), large bi-dimensional arrays, with unmatched uniformity were demonstrated (3), and many of them are nowadays routinely fabricated by many companies (4). Today developments focus new capabilities like multicolor detection and very long wavelength detection, going up to terahertz region (5). All detectors QWIPs produce a parasitic current called dark current, which must be minimized to achieve high performance. The dark current is the current flowing through the detector when it is in darkness (i.e. with no photons impinging on it) and is ideally zero. In this work, dark current and responsivity characterization of a quantum well infrared photodetector, grown by MOVPE is presented, with considerations about device performance. We have used two methods of characterization for the measurement of responsivity. Discussions are also made about this characterization methods.

K. A. Alves, kenyafisica@gmail.com, G. S. Vieira, gsvieira@ieav.cta.br, R. M. Castro, rmcastro@ieav.cta.br.

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II. EXPERIMENTAL

Samples and experimental setup

The sample used in this study was grown by Metalorganic Vapor Phase Epitaxy (MOVPE) on (100) semi-insulating InP substrate. This sample consists of a highly doped $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ buffer layer of thickness 500 nm thick, grown on the InP semi-insulating substrate. The buffer is doped to $n \sim 2 \times 10^{18} \text{ cm}^{-3}$ to enable ohmic contacts to be made to the device. The quantum well structure consists of 50 periods of an $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ quantum wells (doped with Si to $n \sim 2 \times 10^{18} \text{ cm}^{-3}$) and of thickness 3 nm sandwiched between undoped $\text{In}_{0.52}\text{Al}_{0.48}\text{As}$ wide barriers of thickness 30 nm; finally a top $\text{In}_{0.53}\text{Ga}_{0.47}\text{As}$ cap layer of thickness 500 nm, again doped to $n \sim 2 \times 10^{18} \text{ cm}^{-3}$ is grown to enable top ohmic contacts to be made to the device.

All dark current and responsivity measurements were made at 77 K. The dark current measurements were made with sample inside a metallic box immersed in liquid nitrogen, LN_2 .

The photocurrent measurements, for determining responsivity, were done with the sample in vacuum, refrigerated by contact with a LN_2 reservoir. The sample was surrounded by a radiation shield with an open to the ZnSe window.

The absolute spectral responsivity was determined by two methods. In one, we directly measure the spectral responsivity, by just comparing the spectral photocurrent taken from the Device Under Test (DUT) with the signal generated by the same spectrum on a calibrated infrared sensor (a HgCdTe sensor). In the second method, a relative responsivity (normalized to maximum equals to one) was determined in a similar way as in the previous method. Then the integral responsivity was measured, and the peak value of the spectral responsivity was taken from a deconvolution of the relative spectral response of the DUT and the known black body (BB) spectral emissivity, as follows:

The integral, or black body, responsivity may be written as equation (1):

$$R(T_{BB}) = \frac{I_p}{W_{BB}(T_{BB})} \quad [A/W] \quad (1)$$

Where I_p is the measured photocurrent and W_{BB} is the incident power on the detector, coming from the black body. The T_{BB} inside the brackets is to stress that the measured responsivity is dependent on the BB temperature. The spectral responsivity can be written in a similar way, shown on equation (2), but with monochromatic incident power.

$$R(\lambda) = \frac{I_p}{W_\lambda} \quad [A/W] \quad (2)$$

The power reaching the detector, coming from a black body, has a spectral dependence, characteristic of the BB temperature, $W(T_{BB}, \lambda)$. The photocurrent generated on the detector by such polychromatic light can be written as:

$$I_{p(BB)} = \int_0^\infty W(T_{BB}, \lambda) R(\lambda) d\lambda \quad (3)$$

Writing the responsivity as its peak value times the relative responsivity, $R(\lambda) = R_{max} r(\lambda)$, and following from equation (3), one can get the spectral responsivity peak as shown equation (4):

$$R_{max} = \frac{I_{p(BB)}}{\int_0^\infty W(T_{BB}, \lambda) r(\lambda) d\lambda} \quad (4)$$

The last approach is more time demanding, but is less sensibly to alignment than the first one.

I. RESULTS AND DISCUSSION

Dark current measurements

Fig. 1 shows a typical dark current versus voltage curve, I-V, taken at 77 K. In Fig. 1b, the negative bias of I-V curve is mirrored for seeing its symmetry.

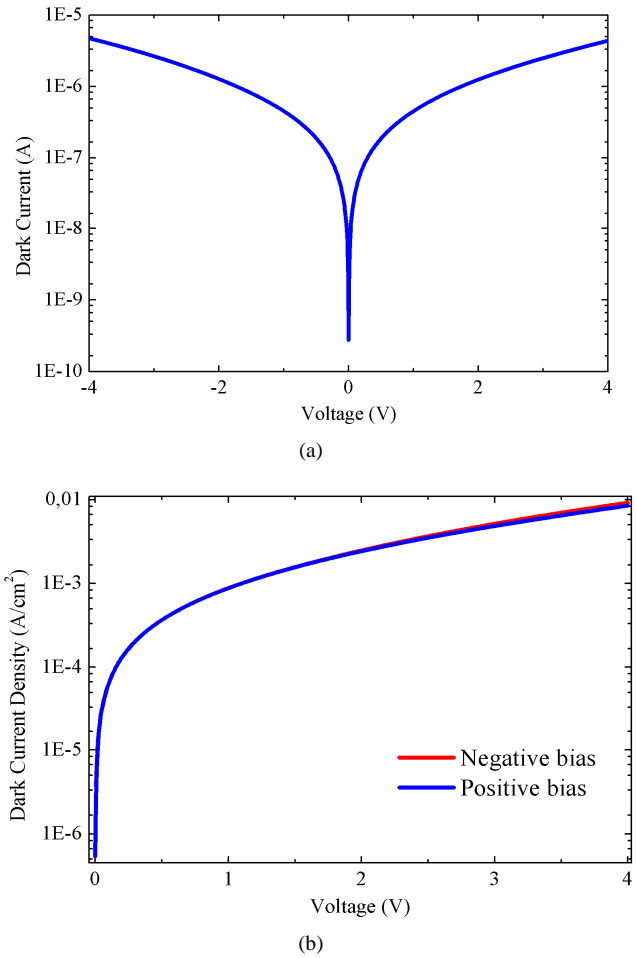


Fig. 1. Dark current as a function of applied bias, measured at 77 K. In b) the current density is presented instead of the current with negative part of curve mirrored for better seeing its symmetry.

This I-V curve is reasonably symmetric, but it presents some asymmetry. The structures are nominally symmetric with respect to the layers sequence, so it should, in principal, results in a symmetric I-V curve. Although that, some asymmetry is frequently observed, and are many times attributed to the different density of defects on the hetero-interfaces at each side of the quantum wells (6). The small asymmetry is then an indicative of good interface quality.

Responsivity measurements

Fig. 2 shows responsivity measurements for many applied voltages, done by direct comparison of DUT measured spectral photocurrent with the measured signal from a known spectral detector measured at the same setup (not the same time). The CO₂ absorption peak can be seen in the spectra. It means that the absorption of atmosphere is not completely removed out in the comparison.

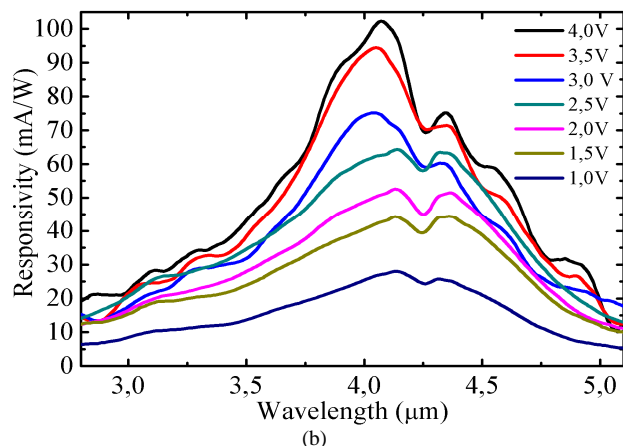
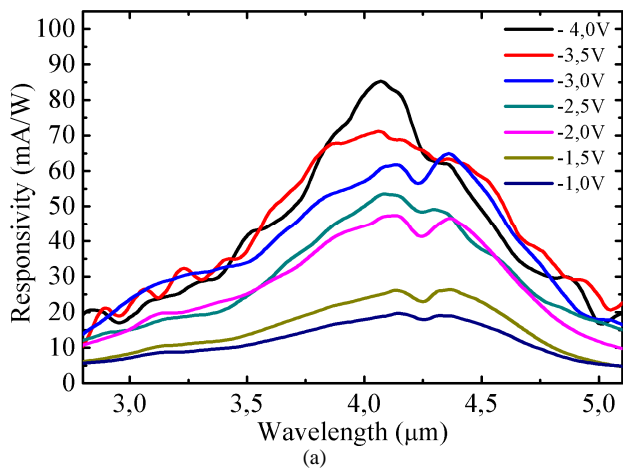


Fig. 2. Responsivity measurements done by direct comparison between DUT measured spectral photocurrent and the measured signal from a known detector at the same setup. a) Negative bias are applied and b) positive bias are applied.

Let now take the normalized responsivity spectra, find the peak value according to the measurements with the BB, and compare the results. If the atmosphere absorption can be neglected, the radiation power incident on the detector coming from the BB should be proportional to $1/d^2$, where d is the distance between the BB and the detector. The integral responsivity can, in principle, be measured by taking the photocurrent at just one distance, but, averaging among many distances, it is possible to get a better result with better uncertain estimation. If this average is done by plotting $I_p \cdot d^2$ versus d and fitting a constant line, one can visualize if the atmospheric absorption is or is not attenuating the signal significantly. In Fig. 3 two plots of $I_p \cdot d^2$ versus d are shown, one with the optical path purged and another with the optical path at uncontrolled atmosphere. It is evident from the graphics that the atmospheric absorption is playing an important role in this case, so the remaining measurements were done purging the optical path.

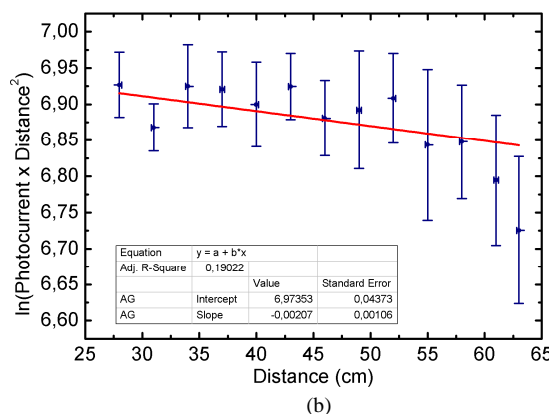
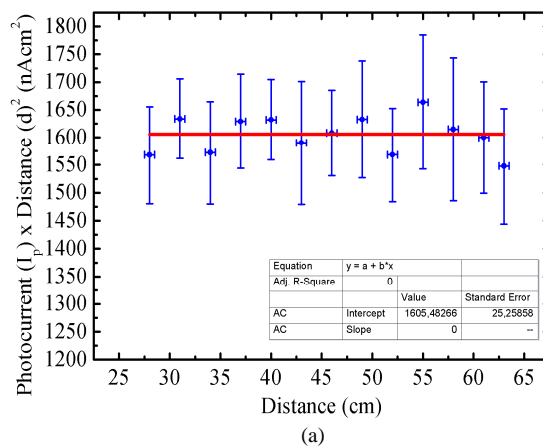


Fig. 3. $I_p \cdot d^2$ versus d , where I_p is the measured photocurrent and d is the distance between the BB and the detector. a) With purging, b) uncontrolled atmosphere.

The responsivity peak was calculated, from integral responsivity measurements, for many biases and using 3 different BB apertures. The results are shown on Fig. 4. The asymmetry on responsivity is larger than on dark current. The difference on peak responsivity measured using different apertures are inside a 10% error.

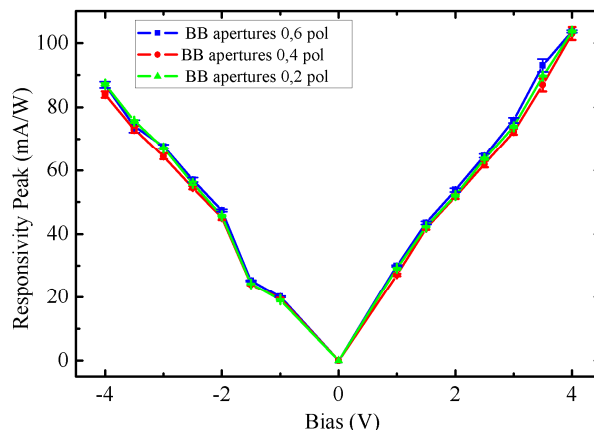


Fig. 4. Responsivity peak as a function of applied bias for three different BB apertures.

The average peak responsivity value for each bias was calculated and compared to the one taken from the previous spectral responsivity curves. Fig. 5 shows this comparison.

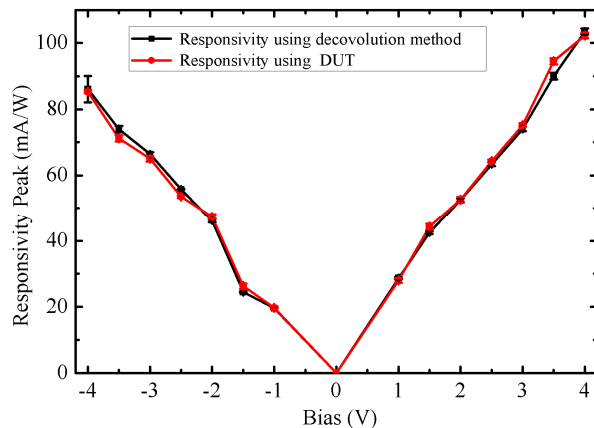


Fig. 5. Comparison of responsivity peak as a function of applied bias obtained from the two previously described methods.

Although the alignment is certainly a risk of the first method, the measurements presented here did not show an associated error larger than what was found on the integral measurement. This result indicates the good approximation and this increases the reliability of methods used.

III. CONCLUSIONS

The dark current and responsivity characteristics of a QWIP grown by MOVPE were measured. The results show good sample quality. Also two spectral responsivity methods were compared showing good agreement.

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