Chapter 5

Photodiodes as Optical Radiation Measurement Standards

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Additional information is available at the end of the chapter

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1. Introduction

Photodiodes for optical radiation measurements are used without reverse bias in most applications since this operation yields the lowest dark current. To obtain photodiodes that operate at a low bias and have a low dark current, it is necessary to produce epitaxial layers that are pure and have few defects (such as dislocations, point defects, and impurity precipitates). Furthermore, a planar device structure requires that a guard ring be used to keep the electric field around the photoreceptive area from increasing too much. Fabrication and processing technologies such as impurity diffusion, ion implantation, and passivation play important roles in the production of reliable photodetectors.

From a radiometric point of view, the photodetectors important characteristics are: Speed of response (characterized by the bandwidth of the frequency response or the Full Width Half Maximum (FWHM) of the pulse response), responsivity (determined as the ratio of current out the detector to the incident optical power on the device), sensitivity (defined as the minimal input power that can still be detected which, as a first approximation, is defined as the optical power which generates an electrical signal equal to that due to noise of the diode) and response linearity. These quantities defined the basic radiometrical behavior of any detector. For those detectors having large area, as it may be the case for some photodiodes, knowing the response uniformity of the sensitive area is important too, especially when the incident beam diameter is much smaller than the detector sensitive surface. A high nonuniformity would produce measurement errors when the detector is used at different positions, errors that have to be taken into account for the final accuracy of the measurement.

To determine those radiometric features in photodiodes and learn how they change with wavelength, for instance, it is a good approach to start by analyzing. The physical phenomena involved in the detection. When light impinges on a detector, various physical processes occur; part of the incident light is reflected at the sensitive surface, while the rest passes inside the detector, where can be partially, because of losses due to absorption, converted into an electronic signal. Then the photodetector response is conditioned by the amount of absorbed light, but for evaluating the incident power one has to know the ratios of the reflected, absorbed, and converted power as well. Taking into account these phenomena, the short circuit response of a photodiode can be written as

$$I(\lambda) = I_0 + (1 - \rho(\lambda))\varepsilon(\lambda)\frac{\lambda}{k}\varnothing(\lambda) \quad (1)$$

Where I_0 is the dark response, $\varrho(\lambda)$ is the photodiode's reflectance, λ is the radiation wave length, ε (λ) is the photodiode's internal quantum efficiency,k is a constant that takes into account other fundamental physical constants and ϕ (λ) is the spectral radiant flux incident on the photodiode. According to this equation, the incident radiant flux can be determined from measuring the photodiode's response as far as its spectral reflectance and internal quantum efficiency are known. Then photodiodes are good devices for radiant flux standards.

Silicon and InPphotodiodes from different manufacturers have got rather low noise level, good response uniformity over the sensitive surface and a wide dynamic range. Therefore they are good devices to build radiometers in the visible and NIR spectral region in many different applications, particularly for building up spectroradiometric scales for radiant flux measurements.

Back to equation (1), if photodiode's reflectance and internal quantum efficiency were known, the photodiode's responsivity would be known without being compared to another standard radiometer; i. e. the photodiode would be an absolute standard for optical radiation measurements [1, 2, 3].

This idea was firstly developed for silicon photodiodes in the eighties, once the technology was able to produce low defects photodiodes [4]. Following this reference, the reflectance could be approached from a superimposed thin layers model. By knowing the thicknesses of the layers and the optical constants of the materials, it is possible to determine the device reflectance. However, this information is not completely available for InP photodiodes: the actual thickness of the layers is not known and optical constants of materials are only approximately known for bulk. Nevertheless it's possible to measure reflectance at some wavelengths and to fit the thicknesses of a layer model that would reproduce those experimental values.

The internal quantum efficiency cannot be determined as for Si. Since InP photodiodes are hetero-junctions rather than homo-junctions as silicon photodiodes are. In the other hand, since the internal structure is not accurately known, it is not possible to model the internal quantum efficiency without having experimental values for it.

Therefore the attainable scope at present is just to obtain a model to be able to calculate spectral responsivity values at any wavelength. To get this, a model has been developed to calculate reflectance values from experimental ones at some wavelengths and another model has been developed to interpolate spectral internal quantum efficiency values from some values got from reflectance and responsivity measurements at some wavelengths. Both models will be presented in this chapter.

2. Spectral responsivity scale in the visible range based on single silicon photodiodes.

A spectral responsivity scale means that the responsivity is known at every wavelength within the response range of interest and it would be desirable to know it for all the other parameters associated with a beam: angle of incidence, divergence or polarization.

Aspectral responsivity scale in the visible range can be created by calibrating a silicon trap detector at several laser wavelengths against ahigh accuracy primary standard such as an electrically calibrated cryogenic radiometer. This method provides a very certain value for the responsivity at specific wavelengths as those of lasers (for instance 406.7 nm, 441.3 nm, 488.0 nm, 514.5 nm, 568.2 nm, 647.1 nm and 676.4 nm). From there single elements detectors, most suitable for some applications, can be calibrated against that trap detector at those wavelengths to define the working scale.

The spectral responsivity of silicon photodiodes is given by the well-known equation

$$R(\lambda)=(1 - \rho(\lambda))\varepsilon(\lambda)\frac{\lambda}{k} \tag{2}$$

This chapter describes the results obtained for the responsivity of the photodiodes by using a model to calculate the diode's reflectance from experimental measurements and a model for the internal quantum efficiency, which is also fitted to experimental values. Based on the models, the fitting errors and the uncertainty of reflectance and responsivity measurements, the uncertainty of the responsivity scale is calculated according to the ISO recommendations.

3. Reflectance evaluation of silicon photodiodes

From the reflectance point of view, a silicon photodiode can be considered as a system formed by a flat transparent film over an absorbing medium. The flat film is the silicon oxide and the absorbing medium is the silicon substrate. The reflectance of such a system is given by [5]

$$\rho = \frac{\left[r_{12}^2 + \rho_{23}^2 + 2r_{12}\rho_{23}\cos(\phi_{23} + 2\beta)\right]}{1 + r_{12}^2\rho_{23}^2 + 2r_{12}\rho_{23}\cos(\phi_{23} + 2\beta)} \tag{3}$$

where $r12$ is the amplitude of the reflection coefficient from air to silicon oxide, $\rho 23$ is the amplitude of the reflection coefficient from silicon oxide to silicon, $\varphi 23$ is the phase change at the interface silicon oxide–silicon and $\beta = 2\pi n2h$ $\cos(\theta 2)/\lambda 0$, with h the thickness of SiO2, $n2$ the refractive index of SiO2 and $\theta 2$ the refraction angle at the air–oxide interface. These variables change with the angle of incidence and the light polarization, so the reflectance value will be known if the silicon oxide thickness, the angle of incidence, the refractive index and the light polarization status are known. This reflectance model has been already tested for another type of silicon photodiode from the same manufacturer [6].

Spectral values of the refractive index are available in the literature. In this work values have been obtained from those given in [7]. The index of refraction of silicon oxide has been interpolated by fitting a polynomial to data; the real part of the refractive index of silicon has been obtained by fitting a polynomial in $1/\lambda$ and the imaginary part by fitting an exponential decay in λ.Reflectance was measured with an angle of incidence of 4 in our reference spectrophotometer, using p-polarized light, at the laser wavelengths for which the diodes were calibrated against the trap: 406.7 nm, 441.3 nm, 488.0 nm, 514.5 nm, 568.2 nm, 647.1 nm and 676.4 nm. By fitting equation 3 to measurement results, the silicon oxide thickness was obtained for every photodiode, as shown in table 1. The fitting error in this table is the parameter given by the fitting software.

Photodiode	SiO2 thickness/nm	Fitting error/nm
CIRI	29.58	0.19
SiN	28.84	0.17
Si1	29.93	0.19

Table 1. Silicon oxide thickness fitted to reflectance measurements

The fitting is very good for wavelengths longer than 500 nm, getting worse for shorter wavelengths, as can be seen in figure 1 for one of the photodiodes studied. The same results are obtained for the three photodiodes studied in this work.

This agrees also with [2]. Probably it is due to the measurement bandwidth. For convenience, the reflectance was measured in our reference spectrophotometer with a bandwidth of 5 nm in order to have a good signal-to-noise ratio at the shortest wavelengths. But in this region the first and second derivatives of reflectance are higher than in the middle visible, so the increased bandwidth produces an effective reflectance value that differs significantly from the spectral value. For this reason, reflectance values below 500 nm were not used in the final fitting process to obtain the thickness.

Using thickness values given in table 1, the reflectance of the photodiodes at normal incidence can be calculated, and from them and the responsivity values measured against the

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trap detector, the photodiodes' internal quantum efficiency can be calculated according to (2). Using a model based in physical laws rather than experimental equations allows obtaining the physical quantity for different circumstances, such as different angles of incidence, for instance.

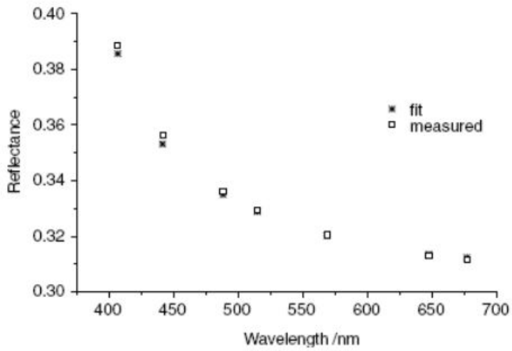

Figure 1. Spectral reflectance values of photodiode CIRI and fitted values according to equation (3).

5. Internal quantum efficiency of silicon photodiodes

To spectrally know the internal quantum efficiency we have used the model developed by Gentile *et al* [2], based on that from Geist and Baltes [14] and improved by Werner *et al* [15]. The internal quantum efficiency is given by

$$\varepsilon(\lambda)=P_f+\frac{1-P_f}{\alpha(\lambda)T}\{1-\exp[-T\alpha(\lambda)]\}-\frac{1-P_b}{(D-T)\alpha(\lambda)}\{\exp[-T\alpha(\lambda)]-\exp[D\alpha(\lambda)]\}- P_b\mathrm{expexp}[h\alpha(\lambda)]+R_{back}\exp[h\alpha(\lambda)]P_b \tag{4}$$

where Pf is the collection efficiency at the front, T is the junction depth, Pb is the collection efficiency at the silicon bulk region, which starts at depth D, h is the photodiode's length, Rback is the reflectance at the photodiode's back surface and α is the absorption coefficient.According to Gentile *et al* [2] a simplified model can be used if the model is to be applied to wavelengths shorter than 920 nm. This model is obtained from the previous equation by deleting the last two terms. Then, the quantum efficiency can be obtained from

$$\varepsilon(\lambda)=\mathrm{Pf}+(1-\mathrm{Pf})/\alpha(\lambda)\mathrm{T}\ \{1-\exp[-\mathrm{T}\alpha(\lambda)]\}-(1-\mathrm{Pb})/((\mathrm{D}-\mathrm{T})\alpha(\lambda)\ )\ \{\exp[-\mathrm{T}\alpha(\lambda)]-\exp[\mathrm{D}\alpha(\lambda)]\} \tag{5}$$

This model has been fitted to the calculated internal quantum efficiency values by a non-linear squared method.

The parameters' initial values were taken from Gentile *et al* [2]. The goodness of the fit can be seen in figure 2, where values for one of the studied photodiodes are shown. The same results are obtained for the three photodiodes studied in this work. The main difference between the fitted values of the internal quantum efficiency and those calculated from the responsivity and reflectance measurements is about 10^{-3}, which agrees well with results given by other authors, e.g.[2,9].

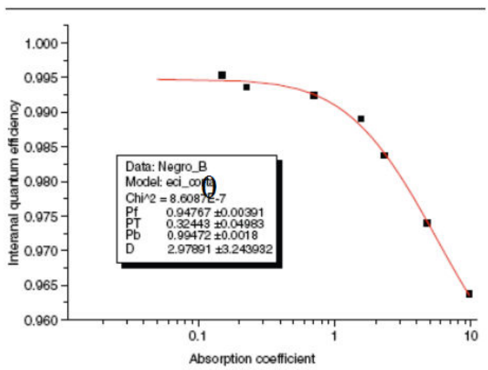

Figure 2. Experimental internal quantum efficiency values ofphotodiode SiN and fitted values according to equation (5) againstthe absorption coefficient.

Another point that can be discussed is how far the internal quantum efficiency can be extrapolated. Using this simplified model and fitting with values corresponding to wavelengths shorter than 700 nm, quantum efficiency values continue to increase very slightly to 900 nm at least. This is not what really happens in the photodiode, so there will be an upper limit for the extrapolation. This limit will depend on the uncertainty allowable to the responsivity value and will be discussed in the following section.

6. Spectral responsivity values of silicon photodiodes

Responsivity of detectors has been calculated with the model described previously and the parameters obtained by the fitting process by using (2), (3) and (5). The agreement between the calculated values and those measured against the trap is excellent as can be seen in figure 3 for one of the photodiodes studied. This result is just a check of the consistency of the method. Nevertheless, it can be seen that most calculated values are smaller than the measured ones. This might be due to the independent fitting of reflectance and quantum efficiency values and their functional forms, but it may also be due to the presence of a systematic error in the measurements. Some research will have to be done in the future to clarify this.

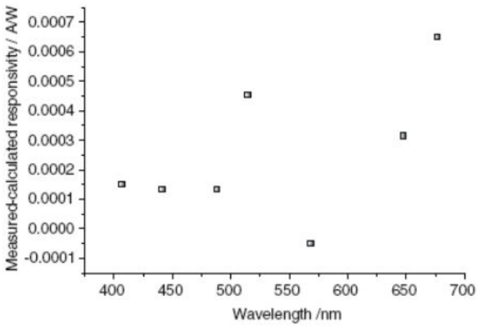

Figure 3. Spectral Difference between calculated and measured spectral responsivity values for photodiode CIRI as a function of wavelength.

7. Spectral responsivity scale in the near IR range based on single InP/InGaAs photodiodes

As in the visible range, semiconductor photodiodes are the best choice for establishing spectral responsivity scales in the near IR range. The first attempt was to use germanium photodiodes, since its gap allowed to obtain a device responding to wavelengths lower than 1.6 μm, approximately, depending on temperature. However germanium photodiodes have got a rather high dark current and lower shunt resistance than silicon, then they are not so useful for optical radiation detection. Since optical communications were demanding better detectors to enlarge their use, other photodiodes were developed in this spectral region of great interest. Since no other single element semiconductor was possible, semiconductor hetero-junctions were developed. A hetero-junction is a junction formed between two semiconductors with different band-gaps. Of course building such devices is not straightforward since the lattice parameters have to be matched, but this is not the subject of this chapter and many good references may be found in literature [17].

The group known as III-V hetero-structures has yield different photodiodes in the near IR range, particularly those based on InP/InGaAs has yield very good devices for the spectral range covered by germanium photodiodes. This hetero-structure has got two junctions in fact. The InGaAs material, having a lower gap, is kept in between two layers on InPwhose gap is bigger and hence transparent to the wavelength region used in optical communications: the nondispersion wavelength (1.3μm) and the loss minimum wavelength (1.55μm). The radiometric characteristics of these InP-based photodetectors are superior to those of conventional photodiodes composed of elemental Germanium. Because of that they have replaced germanium in almost every application.

By using a hetero-structure, which hadn't been used in group IV elemental semiconductors such as Si and Ge, new concepts and new designs for high performance photodetectors have been developed.For example, the absorption region for a specific spectral range can be confined to a limited inner layer, avoiding typical high recombination rates of charge carriers at the first interfaceof the photodiode and getting a higher internal quantum efficiency.

Recently InGaAs/InP avalanche photodiodes (APDs) with a SAM (separation of absorption and multiplication) configuration have become commercially available. The SAM configuration is thought to be necessary for high performance APDs utilizing long wavelengths.

InGaAs/InPphotodetectors are used for maintaining the scale of spectral responsitivityup to 1.7 μm in many laboratories [17, 19].In addition they are exploited in instruments for measuring optical radiation within the near infrared (NIR) range (800 nm -1600 nm). From this point of view, these photodiodes are like other and their response is given by equations (1) and (2). Therefore to know their reflectance and internal quantum efficiency is the key for defining the spectral responsivity scale in this range.

Next experimental values for those properties measured in our laboratory for devices built by different manufacturers will be presented.

8. Measurement of InP photodiode's reflectance

To realize our experiments related to measuring the reflectance of InGaAs/InP photodiodes the experimental set-up presented in figure 4 hasbeen arranged.

An incandescence lamp is the white light source imaged at the input slit of the monochromator. This lamp was able to cover the spectral range from 800 nm to 1600 nm and appropriate blocking filters for second – order wavelengths were added to the monochromator. After the monochromator, a linear polarizer and a beam splitter, which serves to monitor temporal power fluctuations,were placed. A germanium photodiode was used as the monitoring reference photodetector. More details can be seen in reference [20].

The experimental set-up included an optical system of mirrors, which consists of two parts. An upper part (see mirror 7 and germanium photodiode 9) realized monitoring temporal fluctuations of light power. A bottom part (see mirrors 8, 11; InGaAs/InP-photodiode 10, and and germanium photodiode 12) formed an image of the monochromator's exit slit on the sensitive surfaces of photodiodes. The angle of incidence was equal to 7.4 º which was accepted as the normal incidence in this train of measurements.

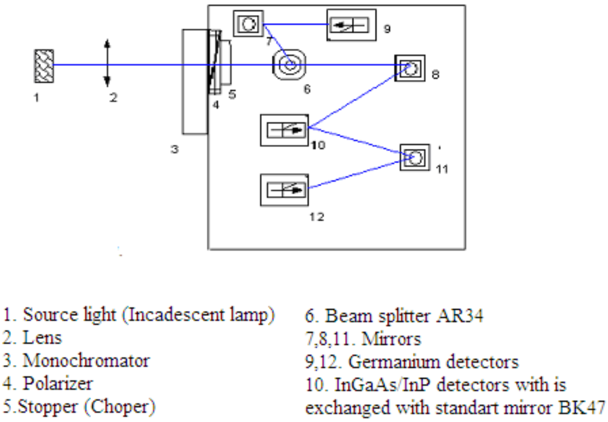

Figure 4. Experimental set-up for measuring the reflectance InGaAs/InP photodiodes

The measurement method consists in comparing the response from a germanium photodiode to the radiation reflected by the InGaAs/InP photodiode with the response from an aluminum standard mirror whose reflectance is measured as in [21], so that [20]:

$$\rho(\lambda) = \frac{I_p(\lambda)}{I_m(\lambda)} \rho_m(\lambda) \tag{6}$$

Here,$I_p(\lambda)$ is the response to the light reflected by

the InGaAs/InP, $I_m(\lambda)$is the response to the light reflected by the mirror, and $\rho_m(\lambda)$ is the reflectance of a standard mirror. With this method the reflectance of photodiodes from different manufacturers hasbeen measured. One part of detectors had a round active area of 5 mm in diameter and the other part had a quadratic active area of 8 mm x 8 mm.

9. Analysis of Reflectance of InP Photodiodes

The polarization degree of light at the output the monochromator was different with varying the wavelength.The figures 5and 6 illustrate spectral dependences of the reflectance, which had been obtained from photodetectors belonging to three different manufacturers. Two types (photodiodes 1 and 4 and photodiodes 2 and 5) are 5 mm in diameter sensitive area and the third is an 8 mm in diameter sensitive area especially commercialized some years ago for developing spectral responsivity scales and no longer available in the market. Figure 5a, and 5b show that the reflectance of 5 mm in diameter detectors from both manufacturers has got a minimum in the region 1000 nm to 1600 nm, and they both are related to a structure of layers providing maximal responses in the spectral interval of mayor utility of these detectors in near IR:Optics communication [17]. The first photodiode, see Figure 5a, whose reflectance was minimized, is more efficient that the second one, see figure 5b.

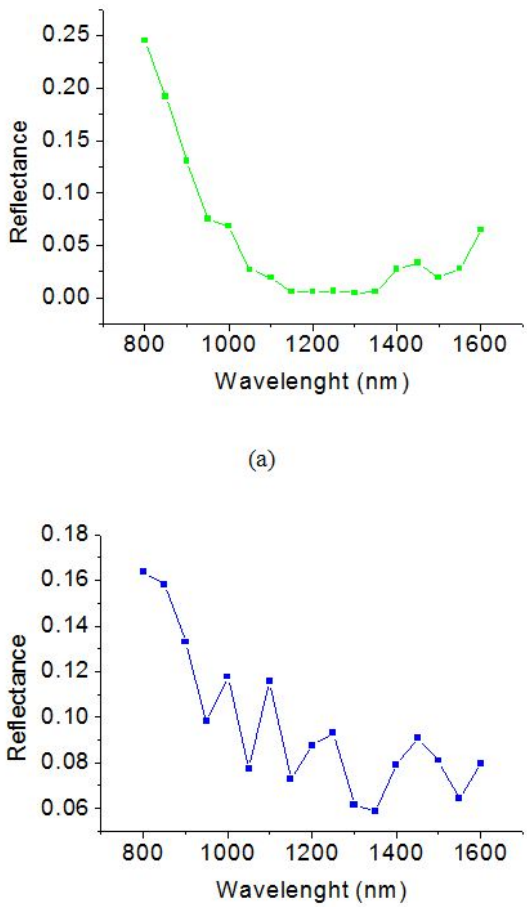

Figure 5. Detector with an active area 5 mmin diameter

Reflectance in figure 6 is associated with a photodiode with rectangular active area. In this case the reflectance has two minima at 1000 nm and 1600 nm, but the reflectance has a maximum between these minima. This photodiode is older than previous ones, and it was produced by another manufacturer. One can remark that maybe it was produced without good enough control, because the structure of layers on the sensitive surface modifies the reflectance.

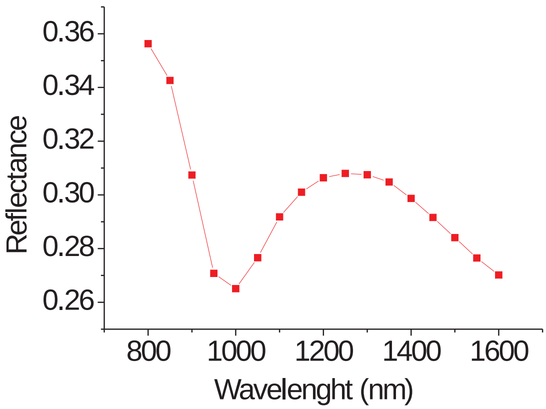

Figure 6. Detector with a rectangular aperture of 8 x 8mm

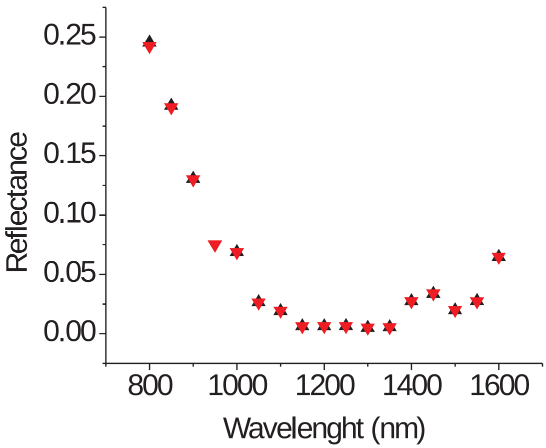

Figure 7. Spectrum of reflectance for photodiodes 1 and 4 from the same manufacturer.

The spectrum of reflectance for photodiodes 1 and 4, manufactured by the same company, is presents in figure 7. The reflectance was measured with linearly polarized and non-polarized lights, and these pair of measurements gives quite similar results. In fact, the difference was equal to approximately 2% for the angle of incidence used in this work. The same results are depicted for the photodiodes 2 and 5, manufactured by a second company. It is important that the results do not depend on the polarization state of the incident light when the angle of incidence is smaller than 10 degrees [22].

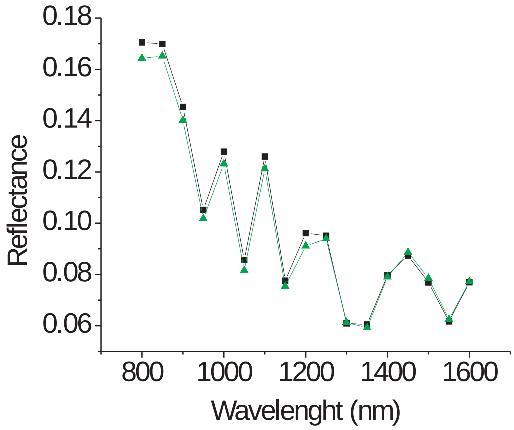

Figure 8. Spectrum of reflectance of photodiodes 2 and 5 from the same manufacturer.

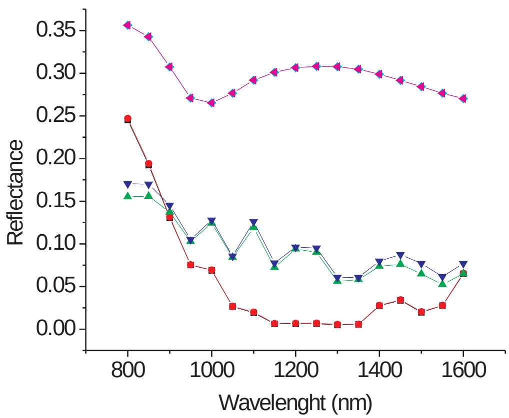

Figure 9. Comparison of reflectance of all photodiodes measured in this work.

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All spectrums of reflectance are presented in Figure 9, with linearly polarized and non polarized light, so that it is possible to see the different behavior of the photodiodes in the near infrared wavelength. In fact, in this chapter we are studying the behavior of the photodetectors in the near infrared with the linearly polarized and non polarized light in the case of the polarized light the angle of incidence is smaller 10 angular degrees and is possible to observe the reflectance doesn’t change its spectral behavior.

10. New Quantum Internal Efficiency Model of some InPphotodetectors.

To determine the internal quantum efficiency of a photodiode it is necessary to know its responsivity (2). In this work, the responsivity, R(λ), was measured by direct comparison to an electrically calibrated pyroelectric radiometer (ECPR), obtaining responsivity values with an uncertainty of 1.2 % approximately, roughly the uncertainty of the ECPR. Spectral responsivity values of one photodiode from every manufacturer obtained from measurements are shown in figure 10 (analogous results are obtained for the other photodiode from the same manufacturer). From now on, the photodiodes will be identified as Ham, GPD and POL. Ham and GPD are photodiodes from different manufacturers and were identified before as photodiode 2 and photodiode 1, respectively. Both have got a 5 mm in diameter active area. Photodiode POL was identified before as photodiode 4 and has got an 8 mm side square active area. Figure 10 shows there is a noticeable difference in responsivity between them.

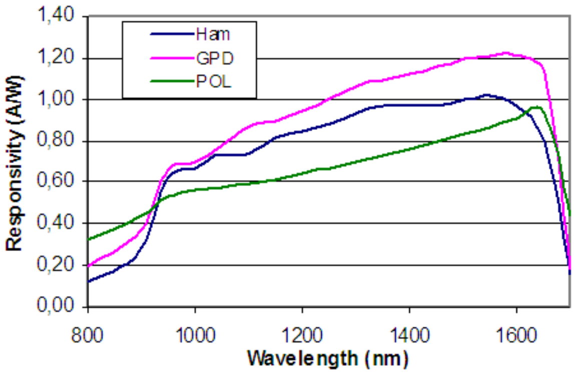

Figure 10. Spectral responsivity values of InPphotodiodes.

10.1. External quantum efficiency

It is obtained from the responsivity values according to the equation:

$$Q(\lambda) = \frac{R(\lambda)\, hc}{\lambda\, e} \qquad (7)$$

Where *h*, *c* and *e* are the usual physical constants and$\lambda$is the wavelength.Values obtained are presented in figure 11 for the same detectors as before. It can be clearly seen that the oldest detector (identified as POL) presents a lower external quantum efficiency than the other and that detector GPD presents a higher external quantum efficiency than detector HAM, which starts to decrease its quantum efficiency at a shorter wavelength. However, detector POL decreases less its quantum efficiency at wavelengths lower than the corresponding to the InGaAs gap. Perhaps this is mainly due to the tailoring of the hetero-structure done by the manufacturer. Detector POL was developed for realizing spectral responsivity scales, while the other two were developed for a better performance in the optical communications spectral range.

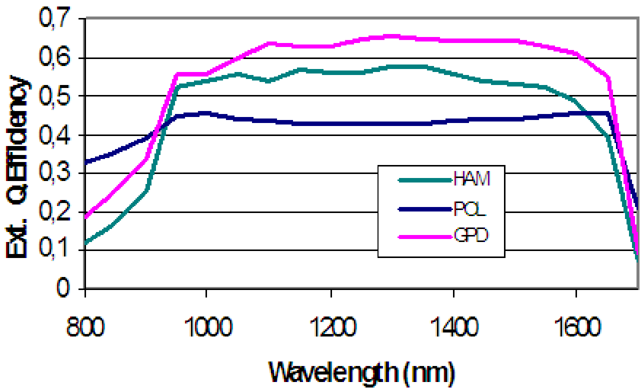

Figure 11. Spectral external quantum efficiency obtained from responsivity values

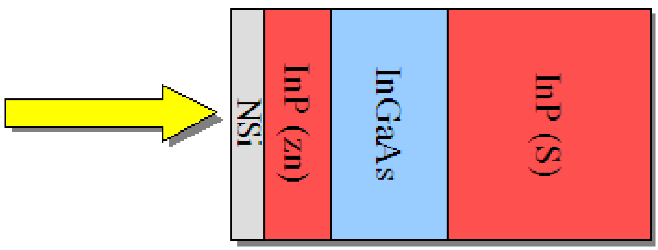

Figure 12. Internal Structure used in this work to model internal quantum efficiency of InP photodiodes

10.2. Internal quantum efficiency

Internal quantum efficiency is obtained from responsivity and reflectance by using (2). However those quantities have been measured at some wavelengths only, then it is necessary to develop a model to interpolate them at every wavelength within the response range. To develop such a model it is necessary to know the internal structure of the photodiode, as it was done for the silicon photodiode, but a enough precise structure is not available in the open literature. Since a structure has to be assumed to develop the model, the simplest one from literature has been adopted in this work (Fig. 12). It is more than likely that detector POL has particularly got a different structure.

The first layer made on NSi is transparent in the wavelength range considered in this work. Probably it is placed in the photodiode as a passivation layer. Its thickness may be tailored by the manufacturer to spectrally adjust the device's reflectance.

Considering a structure as shown before (Fig. 12) and a simple model for the collection efficiency of carriers in every region given by a constant value: P_f,lower than 1 in the first region, 1 in the depletion region (mainly InGaAs) and P_b in the back region, and an "infinite" thickness for the diode, ε (λ) can be calculated by [23]:

$$\begin{aligned}\varepsilon(\lambda) = P_f\left(1-\exp(-\alpha T)\right)+\exp(-\alpha T)-\exp(-\alpha T')+\exp(-\alpha' T')\\ -\exp(-\alpha' D')-\exp(-\alpha D')+\exp(1-P_b)\exp(-\alpha D)\end{aligned} \tag{8}$$

Where T is the thickness at which collection efficiency becomes 1, T′ is the thickness at which InGaAs region starts, D′ is the the thickness at which the InP (S) starts and D is the thickness at which depletion region ends. By fitting this model to internal quantum efficiency values, the following parameters are obtained for every photodiode [23].

Photodiode	P_f	T	T′	D′	D	P_b
HAM	0	0.44	2.19	2.19	11.96	0.844
GPD	0	0.32	1.65	1.62	4351.16	0.960

Table 2. Parameters fitting the model to experimental internal quantum efficiency

Internal quantum efficiency values calculated from responsivity and reflectance (dots) and adjusted values following (8) are shown in figures1 3 and 14 for photodiodes HAM and GPD, respectively. It can be seen that photodiode GPD has got an internal quantum efficiency very close to unity in the region from 1 μm to 1.6 μm, approximately. Both photodiodes have got internal quantum efficiency in this region nearly independent of wavelength. These two results are very important in order to try to develop an absolute radiometer based on InP photodiodes in the future.

The model does not fit well in the short wavelength region. Possibly this is because the structure of the detector is actually more complex or, perhaps, refraction index are not accurately known.

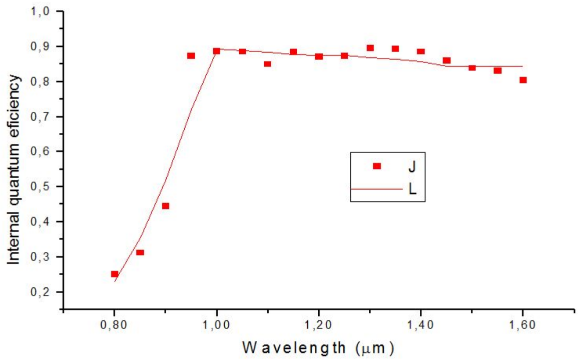

Figure 13. Internal quantum efficiency of photodiode HAM experimental values (dots) and fitted values (solid line) according to the model shown below.

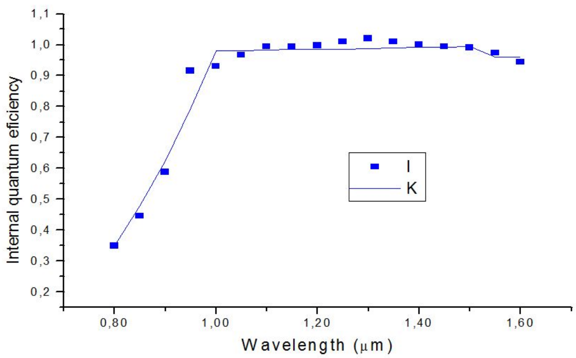

Figure 14. Internal quantum efficiency of photodiodes GPD experimental values (dots) and fitted values (solid line) according to the model shown below.

11. Interpolation of spectral reflectance

Finally, to have the spectral responsivity scale, it is necessary to interpolate spectral reflectance at any wavelength, what can be done by using a multilayer model [11]. Complex refraction index of the materials and thickness of the layers have to be known for interpolation. Refraction index has been obtained from [13] and other sources cited in there and are shown in figure 15.

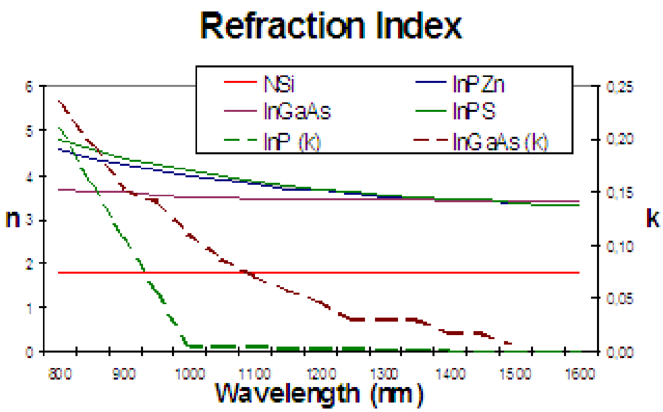

Figure 15. Materials' refraction Index

Thickness of the different layers is obtained by a nonlinear fitting of the experimental values of reflectance to a multilayer model. The model did not worked out well for photodiode POL, then results are not given for it. Perhaps its structure is very different from that of figure 12. Table 3 shows the thickness obtained from the fitting for photodiodes Ham and GPD. The last layer, the deeper one regarding light absorption, was considered to be infinite.

Photodiode	NSi	InP (Zn)	InGaAs
HAM	162.17nm	1213.35nm	1593.2nm
GPD	159.99nm	1200.54nm	1536.7nm

Table 3. Thickness of layers of InGaAs photodiodes

12. Conclusions

Silicon photodiodes in the visible up to 950 nm and InP/InGaAs photodiodes in the NIR up to 1.6 μm are widely used for optical radiation measurements in many different applications because of their good radiometric properties. They have got high internal quantum efficiency, therefore they are very useful for realizing spectral responsivity scales.

Perhaps in a near future a model be developed for the internal quantum efficiency of InP/InGaAs photodiode as it was done for the silicon, so that its responsivity may be accurately known in their spectral interval of response. Some more work is also needed to know the structure of the device and improve the fitting of reflectance via a multilayer model.

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