STUDY OF SOME OPTOELECTRONICS CHARACTERISTICS OF InGaAs/InP PHOTODETECTORS.

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ABSTRACT.

InGaAs/InP-photodiodes from different manufacturers have got rather low noise level, a good response uniformity over the sensitive surface and a wide dynamic range. Therefore they are good devices to built radiometers in the NIR spectral region. As in any photodiode, the spectral short-circuit responsivity is determined by the wavelength and the photodiode's reflectance and internal quantum efficiency. Then if these quantities were known, the photodiode's responsivity would be known without being compared to another standard radiometer; i. e. the photodiode would be an absolute radiometer for optical radiation measurements. This idea was firstly developed for silicon photodiodes in the eighties, once the technology was able to produce low defects photodiodes[1]. 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 InGaAs/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 in [2], since InGaAs 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 communication.

INTRODUCTION

The photodetectors are sensors of light or other electromagnetic energy. A photodiode is a type of photodetector capable of converting light into either current or voltage, depending upon the mode of operation .

Photodiodes are similar to regular semiconductor diodes except that they may be either exposed (to detect vacuum UV or X-rays) or packaged with a window or optical fibre connection to allow light to reach the sensitive part of the device [3].

When the light radiation impinges on a detector, various physical processes occur; part of the incident light is reflected by 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. The response of each photodetector is conditioned by a quantity of the converted light power, but for evaluating the incident power one has to know the ratios of the reflected, absorbed, and converted portions.

These photodetectors are chosen as the first device of interest because of their simple structure, and since their analysis is a natural extension, almost an example, of our discussion of p-n diodes. Whereas the field of photodetectors goes far beyond that of semiconductor photodetectors, we restrict ourselves here to such devices. It will be discussed p-i-n diodes, which are also referred to as photovoltaic detectors, photoconductors or solar cells photodetectors. The distinction between the different devices is somewhat artificial since many similarities exist between these devices but it enables to clearly separate the difference in structure, principle of operation and purpose of the devices.

An InGaAs/InP-photodetector is a photodiode based on a p-n or hetero-structure. There is a region, which can be denominated as the depleted or exhausted region, where an electric field sweeps the generated charge carriers and produces an external electrical current. In addition charge generated outside that region also contributes to the photocurrent. Thus, the total photodiode response I can be written as

$$I = \left[1 - \rho(\lambda) \eta \left(\lambda \frac{\lambda q}{hc} \phi \right) \right], \quad (1)$$

where $\eta(\lambda)$ is the internal quantum efficiency, which indicates the number of electrons produced by each absorbed photon, q is the electron charge, h is the Planck constant, c is

the velocity of light, ϕ is the radiant flux, λ is the wavelength and $\rho(\lambda)$ is the photodiode's reflectance. From equation (1), the responsivity R can be obtained as:

$$R = \frac{I}{\phi} = [1 - \rho(\lambda)] \eta(\lambda) \frac{\lambda q}{hc} . \quad (2)$$

This equation shows that the responsivity depends on the wavelength of the incident light by three ways, directly, via the reflectance of the surface, and through the quantum efficiency. This equation indicates also, that the responsivity will be known if both the reflectance and the internal quantum efficiency are known at every wavelength and is the quantity usually measured. It is seen from equation (1), that the photodiode response depends on a set of parameters inherent in the incident light like the spectral distribution, polarization, modulation frequency, angle of incidence, and radiant power. Furthermore, the response is determined by photodetectors features such as the material refractive index and the structure of diode as well as by some environmental factors, such as temperature, for example [4].

OPTOELECTRONICS CHARACTERISTICS OF INGAAS/INP PHOTODETECTORS.

Photodiodes based on InP materials are becoming the most used for different applications in near IR range, since their radiometric characteristics are superior to those of Ge photodiodes. In recent years they also have been studied to develop spectral responsivity scales in the near IR range (800 nm –1600 nm) in different National Laboratories.

In order to do that it is important to know the external quantum efficiency and the reflectance of these photodiodes and try to model them to establish spectral responsivity values at any wavelength. In this work we will present spectral reflectance and responsivity values of three types of photodiodes made by different manufacturers measured between 800 nm and 1600 nm and will compare the results obtained.

SPECTRAL RESPONSIVITY

A set of two photodiodes from the same batch of every manufacturer (three) has been studied in this work, which makes a total of six photodiodes. Two sets of detectors had a round aperture 5 mm in diameter and the third set had a rectangular aperture 8 mm x 8 mm. Spectral responsivity ($R(\lambda)$) has been measured by comparison to an electrically calibrated pyroelectric radiometer (ECPR), obtaining responsivity values with an uncertainty of 1.2 % approximately, roughly the accuracy of the ECPR. The results obtained are shown in figure 1.

Figure 1. Spectral responsivity values of InGaAs/InP photodiodes.

Detector B responsivity is the lowest. This detector corresponds to an old technology and probably to a different internal structure in the photodiode. Both detectors Xotchil and Chacho, from different manufacturers, present the typical low responsivity at wavelengths under 900 nm approximately. Figure 1. Spectral responsivity values of InGaAs/InP photodiodes.

EXTERNAL QUANTUM EFFICIENCY

External quantum efficiency is obtained from the responsivity values according to the equation:

$$Q(\lambda) \equiv \frac{R(\lambda) h c}{\lambda e} \quad (3)$$

where h , c and e are the usual physical constant and λ is the wavelength. The values obtained are presented in figure 2. It can be more clearly seen that the oldest detector (detector B) presents a lower external quantum efficiency than the other and that detector Chacho presents a higher external quantum efficiency and a “roll-off” at a longer wavelength than detector Xotchil, which starts to decrease its quantum efficiency at a shorter wavelength.

Figure 2. External quantum efficiency of InGaAs/InP photodiodes measured.

REFLECTANCE MEASUREMENT

Photodiodes' reflectance has been measured with respect to a standard aluminum mirror [7], so that

$$\rho(\lambda) \equiv \frac{I_p(\lambda)}{I_m(\lambda)} \rho_m(\lambda) \quad (4)$$

Where $I_p(\lambda)$ is the detection system response to the light reflected by the InGaAs photodiode, $I_m(\lambda)$ is the response to the light reflected by the mirror and $\rho_m(\lambda)$ is the reflectance of the standard mirror. The reflectance was measured at an incidence angle of 7° with linearly polarized and non-polarized lights, considering the small change in the standard mirror each time [8].

Figure 3. Reflectance of InGaAs photodiodes measured.

Figure 3 shows spectral reflectance values for the same photodiodes with linearly polarized light. It can be said that the change in reflectance at this incidence angle is lower

than 2 %. Two main features appear in figure 3. In one hand all detectors present an antireflection structure along the long wavelength interval, probably to maximize their performance in the most useful range. In the other hand modern detectors present a lower reflectance than the oldest one.

CONCLUSIONS

The reflectance of some high quality InGaAs/InP photodiodes has been measured at near normal incidence (7.4°) by comparison to a standard aluminum mirror. A specific set-up has been done for these measurements. Within the optical communications spectral range, an antireflection structure has been found on the sensitive surface of 5 mm in diameter photodiodes from two manufacturers. Because of this, the response dependence on optical polarization has been tested at that incidence angle, founding a small dependence (less than 0.5 % in response), what is an interesting result since the radiation impinges usually within a range of incidence angles, even at normal incidence, because of the divergence/convergence of optical beams. A simple layered model has been fitted to measured reflectance values. The fitting goodness is better for photodiodes manufactured by Hamamatsu. For the other photodiodes the fitting is worse although it may be used in the optical communications spectral region. Therefore, it is possible to interpolate the reflectance of the photodiodes at any wavelength of interest within those spectral ranges. The structure model needs some refinement to get a better agreement with experimental values.

The development of a model for the internal Quantum Efficiency needs a more accurate knowledge about the device than it is available. Then a collection efficiency model has been supposed and the internal quantum efficiency function obtained from it has been fitted to the values obtained from the responsivity and reflectance measurements at some wavelengths. The function fits very well in the optical communications interval where the internal quantum efficiency spectral feature is rather smooth. The fitting is not so good in the elbow region where InP becomes transparent. At short wavelengths the derived function fits better to photodiode 1 than to photodiode 5. Perhaps this may be improved by refining absorption coefficient values of doped InP.

Within the spectral region from 1100 nm to 1500 nm the internal quantum efficiency of photodiode 5 may be taken as 1, therefore, measuring the reflectance, the responsivity may be calculated by (1) and this photodiode is an absolute radiometer in this spectral range.

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