EFFECT OF ABSORPTION LAYER THICKNESS ON INTERNAL QUANTUM EFFICIENCY OF ZERO-BIAS WAVEGUIDE PHOTODETECTORS

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Abstract: Side illuminated waveguide photodetectors (WGPDs) are suitable choice for monolithic optoelectronic integrated circuits (OEICs) since the structure of a WGPD is similar to that of laser structure. However, the main disadvantage of a WGPD is the poor coupling efficiency which leads to a low value of external quantum efficiency. The simple way to increase the coupling efficiency is to increase the thickness of the absorption or active layer of a WGPD. In this paper, the effect of active layer thickness on quantum efficiencies (i.e. external and internal quantum efficiencies) of WGPDs is examined experimentally.

Vpliv debeline absorpcijske plasti na kvantno učinkovitost fotodetektorja z valovodom

Kjučne besede: valovodni fotodetektor, kvantna učinkovitost, fotodetekcija, fotodioda s pn-spojem

Izvleček: Valovodni fotodetektorji s stransko osvetlitvijo (WGPDs) so primerni za uporabo v optoelektronskih integriranih vezjih (OEICs), ker je njihova struktura podobna laserski strukturi. Glavna slabost WGPD je slaba sklopitvena učinkovitost, kar vodi do nizke vrednosti zunanje kvantne učinkovitosti. Najlažja pot do povečanja sklopitvene učinkovitosti je povečati debelino absorbcijske ali aktivne plasti WGPD. V tem članku eksperimentalno ugotavljamo vpliv debeline aktivne plasti na kvantno učinkovitost WGPD.

1. Introduction

Through monolithic integration, OEICs are expected to bring higher complexity and new functionality in addition to other advantages usually associated with monolithic integration. It is also expected that the largest application of OEICs would be in the fields of telecommunication and signal processing. Optical detector is an essential component of an OEIC as it ultimately limits the overall system performance. Major trends in photodetectors development are the achievement of higher efficiencies and larger bandwidths /1/. A waveguide photodetector is very attractive device for achieving these goals. Furthermore, these devices have advantage of packaging technology, since waveguide structure, which is similar to laser structure, is suitable for monolithic OEICs. However, as mentioned earlier, efficient optical coupling between the input optical field and the optical field at the input facet of WGPD is a technological challenge because the diameter of an input optical beam falling on the input facet of a WGPD, even focused with a sophisticated lens system, is much higher than the thickness of the active layer of a WGPD. The poor coupling efficiency leads to low value of measured or external quantum efficiency (η_{ext}) in a WGPD and the low value of η_{ext} is often taken as actual conversion efficiency of a WGPD. However, as a matter of fact, η_{ext} is the external conversion efficiency and it does not represent the internal conversion efficiency of the device.

2. internal quantum effieciency of WGPD

A semiconductor laser diode under reverse bias or zero bias conditions can act as a WGPD and the active layer can work as depletion or absorption region. Photocurrent of a WGPD can be obtained as:

$$I_{ph} = S_{in} P_{in} \tag{1}$$

where S_{in} is the internal sensitivity of WGPD and P_{in} is the input power coupled into the active layer of a WGPD. In the case of a waveguide photodetector, the actual sensitivity (i.e. the internal sensitivity) can be given as /2/:

$$S_{in} = \frac{S_{ext}}{\zeta(1-R)} \tag{2}$$

where S_{ext} is the external sensitivity of the detector, z is the coupling efficiency of optical radiation and R is the facet reflectivity. S_{ext} can be defined as:

$$S_{ext} = \frac{\eta_{ext} e\lambda}{hc} \tag{3}$$

and the coupling efficiency can be calculated as /3/:

$$\zeta = \frac{\eta_{ext}}{(1-R)(1-e^{-\Gamma\alpha_{ib}L})} \tag{4}$$

where c is the speed of light in vacuum, h is the Plank's constant, λ is the wavelength of the incident radiation, e is the charge on an electron, η_{ext} is the external differential quantum efficiency, α_{ib} is the interband absorption, Γ is the confinement factor and L is the length of the device. The internal quantum efficiency, η_{in} is given as /4/:

$$\eta_{in} = \frac{S_{in}hc}{e\lambda}\left(1 - \frac{\alpha_o}{\alpha}\right) \quad (5)$$

here α_o represents the residual waveguide losses absorption and α represent the total absorption inside the active layer of a WGPD. α can be calculated as:

$$\alpha = \alpha_o + \Gamma\alpha_{ib} \quad (6)$$

3. Experimental procedure

In order to demonstrate the validity of the proposed technique, three different stripe geometry A. R. coated laser like devices were investigated while a 5 um wide stripe laser was used as the source laser throughout the work reported in this paper. Structural parameters of the various devices used during the work reported in this paper are listed in table-1. Device-1, 2 and 4 were essentially made from the same GaAs/AlGaAs material and for these devices, α_o was measured as 24/cm using the conventional cutback loss measurement technique /5/. Whereas device-3 had an active layer thickness of 0.5 μm and α_o was expected to be the approximately same since α_o depends upon length of the device. The length of all devices was 250 um. This length was quite sufficient for complete absorption of optical radiation coming from the source.

Table -1. Structural parameter of different devices used during the work reported in this paper.

DEVICE NUMBER	STRIPE WIDTH, W (μm)	ACTIVE LAYER THICKNESS (μm)	R_1 (%)	R_2 (%)
1	2.5	0.15	4	4
2	5	0.15	4	4
3	5	0.5	4	4
4 (Source laser)	5	0.15	30	30

All the devices were mounted on separate copper heat sink blocks. Temperatures of the device being tested and of the source laser were controlled independently using thermoelectric Peltier devices and a multi-channel temperature controller. Throughout the work reported in this paper, the test devices were subjected to pulsed input from the source laser which was operated under pulse conditions using a HP8082A pulse generator to avoid overheating in order to achieve more reliable results. The width of current pulses was kept constant at 200ns with a repetition frequency of 10 KHz. This proportion between the pulse width and pulse repetition frequency was sufficient to isolate the transient temperature effects caused by one pulse from other pulses. Along with an optical lens system, a pre-calibrated large area Si detector (LAD) and WGPD (being investigated) were used to measure light output. An infrared camera was used to for alignment of LD and WGPD in place of WGPD and LAD as and when required. The source laser and WGPD were aligned using a free-space alignment technique /6/.

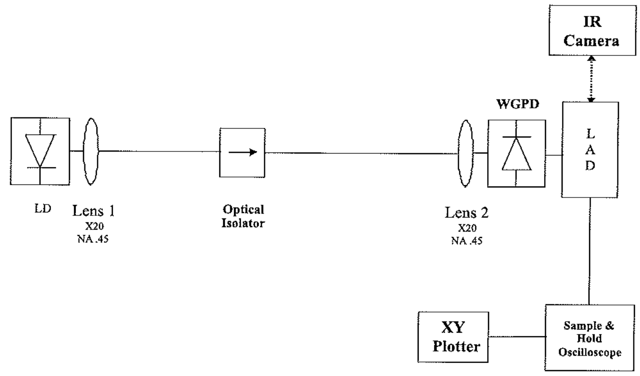

Fig. 1. Schematic representation of experimental set-up used.

Results were plotted using a Tektronix sample & hold oscilloscope and an X-Y plotter. Figure 1 shows the schematic of experimental set-up used during the work reported here.

4. Results and discussion

4.1. Response of WGPD

After achieving the maximum alignment between the source laser and WGPD, the response of WGPD was analyzed by measuring I-L characteristic of the source laser using the device-1 as a WGPD. Also I-L characteristic of the source laser was measured by placing a LAD just after lens-2 (in place of WGPD). Results of both measurements are given in fig. 2. It can be seen from fig. 2 that the response of a pre-calibrated Si LAD and the GaAs WGPD are similar to each other except the sensitivity. This indicates that there was a perfect alignment between the source laser and WGPD.

The same experimental procedure was repeated using a 5μm wide stripe device (device-2) instead of device-1 as an WGPD. The response of both WGPDs (i.e. device 1 & 2) as a function of stripe width is plotted in fig. 3. It can be seen from fig. 3 that the change in the stripe width does not have much effect on the response of GaAs WGPD. This was expected because the minimum achievable spot size achieved by lens-2 was around 1.165μm at λ=860nm and was smaller than the stripe width of 2.5μm. From fig.

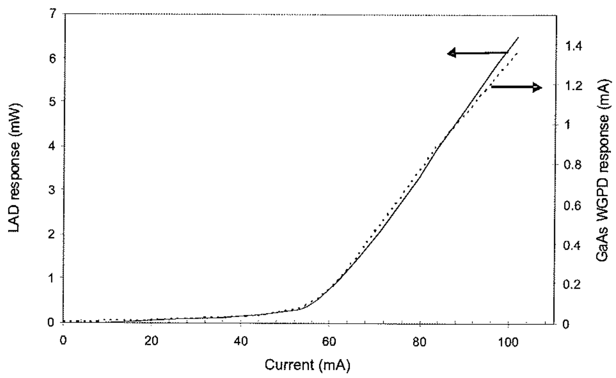

Fig. 2. I-L characteristics of the source laser measured using LAD and GaAs WGPD.

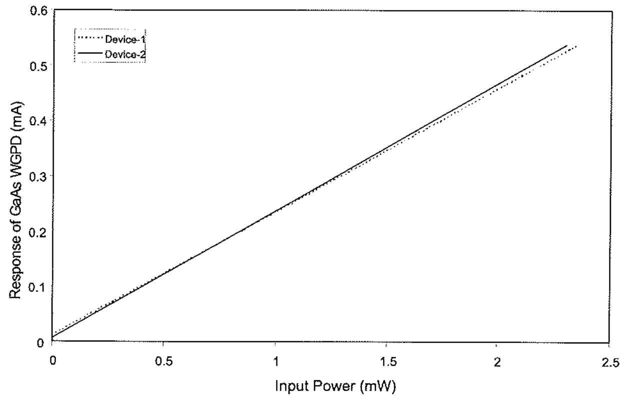

Fig. 3. Response of WGPDs with active layer thickness of 0.15 µm as a function of stripe width.

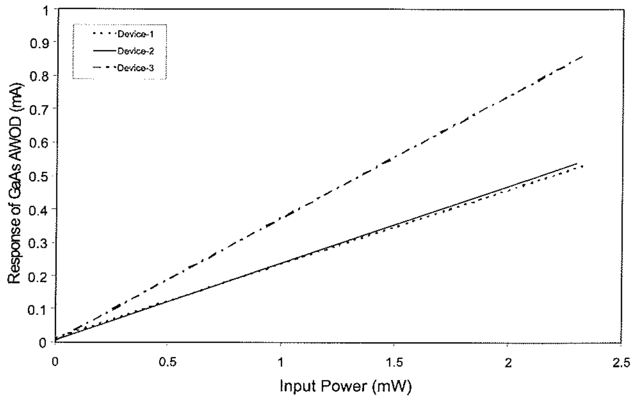

Fig. 4. Response of WGPDs as a function active layer thickness.

3, the external sensitivity, S_{ext} of GaAs WGPD was calculated as around 0.22A/W. This value does satisfy the reported values of refs. 3 and 7. Using eq. (3), the external quantum efficiency was estimated as 31. 8%. For the typical values of η_{ext} = 31.8%, $R_1 = R_2$ = 4%, L = 250 µm and Γ = 46%, α_{ib}= 200/cm /2/, ζ was calculated as 35.26% and S_{in} was calculated as 0.63 A/W. Finally, η_{in} for the devices being investigated was estimated as around 72% by substituting all required values in eq. (5).

4.2. Effect of active layer thickness on the response of WGPD

Generally, the coupling efficiency and hence η_{ext} of a detector can be improved by increasing the thickness of the intrinsic layer. In order to look at the effect of intrinsic layer thickness on the response of the GaAs WGPD, the device-3 was used as an WGPD. This device had a 0.5 µm thick active layer. Figure 4 shows the response of device-1, 2 and 3 as a function of the active layer thickness. Increase in external sensitivity of the GaAs WGPD with an increase in the active layer thickness is in agreement with theoretical and experimental predictions. Figure 4 gives an external sensitivity value of 0.33 A/W for device-3 which corresponds to an external quantum efficiency of 48%. For the typical values of η_{ext} = 48%, $R_1 = R_2$ = 4%, L = 250µm and Γ= 90%, α_{ib}= 200/cm /2/, ζ was calculated as 50.6% and S_{int} was calculated as 0.64 A/W. Finally, η_{in} for the devices being investigated was estimated as 74%. Estimated value of S_{int} and η_{in} are nearly the same in the case of device-1, 2 and 3 because S_{int} η_{in} are independent of active layer thickness.

Conclusion

In conclusion we can say that a WGPD with thick absorption or active layer has higher η_{ext}. However, η_{ext} is the external conversion efficiency and it does not represent the internal conversion efficiency of the device. Hence increase in active layer thickness does not affect the internal quantum efficiency. η_{in} of WGPDs made from the same material with different active layer thickness would be more or less same provided incoming light is fully decayed in waveguide.

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