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Analysis of the Effect of Adding PNP Phototransistors on Fiber Optic Systems

Faisal Arrasyid
Universitas Panca Budi, Indonesia
faisalarrasyid1505@gmail.com

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***Corresponding Author**

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ABSTRACT

This study analyzes the performance of PNP phototransistors made of Gallium Arsenide (GaAs) and Silicon (Si). Based on the analysis for gallium arsenide and silicon PNP phototransistors, the emitter current at the output is greater than the photon current at the incident. With□= 1017□^{3};□= 1016□^{3}and□= 1019□^{3};□= 1016□^{3}The input current for GaAs material is 1.6865×10^{-7} ., respectively□and 8.0331×10^{-6}A. With the addition of internal gain on the GaAs material, namely; common-base internal gain (□)= 0.9991; 0.8974 and the common-emitter internal gain(□)=1125; 8.7488, then each output current is 1.8973×10^{-4}□and 7.028×10^{-5}□. With the addition of the internal gain on the phototransistor, we get SNR = 26256 and 8022.As for the silicone material with□= 1017m^{3};□= 1016□^{3}and□= 1019□^{3};□= 1016□^{3}the input current and output current are respectively 1.0766×10^{-7}□and 1,266×10^{-6}□. With the internal gain on the silicon material, namely; for common-base internal gain(□)=0.9994; 0.9220 and the common-emitter internal gain(□)= 1563; 11,818, then the output currents are 1.6831×10^{-4}A and 1.4827×10^{-5}A, respectively. With the addition of the internal gain, the SNR for silicon is 8.3766×10^{-5} and 3.3609×10^{-6}, respectively.

INTRODUCTION

The fiber optic system is required to convert the light signal back into the form of an electrical signal at the receiving end for further processing and display of the transmitted information. This task is usually performed by a light detector. The requirements of the detector are very similar to those of light sources, namely; must have high sensitivity at operating wavelength, high accuracy, fast response, test resistance, low noise, low cost. Furthermore, its size must be proportional to the fiber core used in the light connection. These requirements are easily found in detector made of semiconductor materials.

Phototransistor is one component that functions as a light detector. Phototransistor has advantages compared to other components, namely being able to detect and amplify signals with a single component. In this final project, the author will discuss how the performance of the PNP phototransistor as a light detector that functions to convert light energy into electrical energy in optical fiber communication, how much is the input and output current, the resulting optical power, bias voltage at the base-emitter, quantum efficiency, responsiveness, bandwidth on the phototransistor and how much SNR on the PNP phototransistor.

LITERATURE REVIEW

Semiconductors are materials with electrical conductivity that are between insulators and conductors. Semiconductors are very useful in electronics, because their conductivity can be changed by injecting other materials (commonly called doping). Semiconductor materials are divided into two, namely intrinsic semiconductors and extrinsic semiconductors.

Phototransistor is an optical detector that provides internal gain. Phototransistor is a bipolar transistor which is generated by an optical signal and then converts it into photocurrent (current collected in the device). Physically, phototransistors are similar to conventional transistors, only the top surface can be exposed to light which is equipped with In addition, there are several types of phototransistors whose base pins do not exist (so there are only 2 legs). Phototransistor with reverse bias voltage is at the base-collector junction, where most light is absorbed. The phototransistor schematic can be seen in Figure 1. Phototransistors are divided into 2 types just like transistors, namely the NPN-type and the PNP-type.

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Figure 1. Phototransistor Shapes and Symbols

PNP phototransistor is a phototransistor in which there are more hole charges than electron charges, in this case the number of acceptors is greater than the total concentration of donors. In the PNP phototransistor, the positive charge (hole) is on the emitter and collector parts or legs, while at the base the charge is electrons. At the collector, the resulting voltage is a reverse biased voltage, so the current generated at the collector is very small (close to zero).

METHOD

The steps used to perform a phototransistor performance analysis on this fiber optic communication system consist of:

1. Literature study, namely by reading theories related to this research, consisting of books, theses, journals, articles, and articles from the internet.
2. Determine the parameter assumptions needed in calculating the phototransistor performance, namely:

- The atomic concentration of the donor and acceptor of each material is the same, namely $1016cm^{-3}$ for the donor and $1017cm^{-3}$ for the acceptor.
- The atomic concentration of the donor and acceptor of each material is the same, namely $1016cm^{-3}$ for the donor and $1019cm^{-3}$ for the acceptor.

3. Analyzing the phototransistor performance of Gallium Arsenide (GaAs) and Silicon as materials for forming PNP phototransistors.

ParametersThe phototransistor as a photo detector in fiber optic communication used is as follows.

1. Forward Bias Voltage
   The forward bias voltage will greatly affect the amount of light current in the emitter.
2. Light Current Emitter
   The amount of light current in the emitter will determine the amount of electric current that will be generated. Equation of light emitter current.
3. Quantum Efficiency
   Quantum efficiency is a very important parameter in photo detectors, the smaller the reflection coefficient on the semiconductor, the greater the quantum efficiency.
4. Responsiveness
   The amount of responsiveness is very dependent on the amount of power and current generated.
5. Internal Gain and Electric Current at the Emitter
   The amount of electric current contained in the phototransistor depends on the light emitter current and the internal gain contained in the phototransistor.
6. Noise
   The amount of noise is very influential on the current generated, the smaller the noise, the photon flux produced will be very good.

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RESULT

The first step in analyzing the performance of a pnp phototransistor is to calculate the parameters of the semiconductor material used in the PNP phototransistor. Semiconductor parameters assuming that = 1017 3: = 1016 3and NA= 1019 3: = 1016 3 can be seen in Table 1 and Table 2.

Table 1. Semiconductor parameters with = 1017 3: = 1016 3

Parameter	**Semiconductor Material**	
	GaAs	**Si**
Depletion **width (cm)**	$4.33x10^{-5}$	$3.34x10^{-5}$
Width of depletion(cm)	$3.94x10^{-5}$	$3.03x10^{-5}$
Emitter depletion width (cm)	$4.34x10^{-8}$	$3.43x10^{-8}$
Electric field (V/m)	$5.91x10^{4}$	$5.25x10^{4}$
Base diffusion (cm^2/s)	221	39
Emitter diffusion (cm2/s)	10.4	11.7
Flow time(s)	$2.7x10^{-11}$	$1.88x10^{-11}$
Flow speed (cm/s)	$1.5x10^{-6}$	$1.8x10^{-6}$
Base diffusion length (cm)	0.004	0.009
Emitter diffusion length (cm)	0.001	0.005
Diameter(cm)	$2.38x10^{-5}$	$2.09x10^{-5}$
Active area (cm)	$1.03x10^{-9}$	$7.18x10^{-10}$
Material absorption coefficient (cm^{-1})	$8.74x10^{-3}$	$2.98x10^{5}$
Depletion **width (cm)**	$4.33x10^{-5}$	$3.34x10^{-5}$
Width of depletion(cm)	$3.94x10^{-5}$	$3.03x10^{-5}$

DISCUSSION

Semiconductor parameters with the assumption that = 1019 3: = 1016 3 can be seen in Table 2.

Table 2. Semiconductor parameters with = 1017 3: = 1016 3

Parameter	**Semiconductor Material**	
	GaAs	**Si**
Depletion width (cm)	$4.33x10^{-5}$	$3.42x10^{-5}$
Width of depletion(cm)	$4.34x10^{-5}$	$3.42x10^{-5}$
Parameter	**Semiconductor Material**	
	GaAs	**Si**
Emitter depletion width (cm)	$3.94x10^{-6}$	$3.03x10^{-6}$
Electric field (V/m)	$5.41x10^{-4}$	$4.65x10^{-4}$
Base diffusion (cm^2/s)	221	39
Emitter diffusion (cm2/s)	10.4	11.7
Flow time(s)	$3.3x10^{-11}$	$2.42x10^{-11}$
Flow speed (cm/s)	$1.3x10^{-6}$	$1.37x10^{-6}$
Base diffusion length (cm)	0.004	$8.4x10^{-3}$
Emitter diffusion length (cm)	$9.79x10^{-4}$	$4.6x10^{-3}$
Diameter(cm)	$2.62x10^{-5}$	$2.38x10^{-5}$
Active area (cm)	$1.13x10^{-9}$	7.9610^{-10}
Material absorption coefficient (cm^{-1})	$8.74x10^{-3}$	2.9810^{5}

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Parameters of PNP phototransistor as photo detector number = 1017 3: = 1016 3and NA= 1019 3: = 1016 3 can be seen in Table 3.

Table 3. Parameters of Phototransistor as Photodetector ,A= 1017 3: = 1016 3

Parameter	Semiconductor Material	
	GaAs	Si
Bounce coefficient	0.32	0.3
Quantum efficiency	0.46	$3.23x10^{-5}$
Forward bias voltage (volts)	1.06	0.7
Inrush current (amperes)	$1.68x10^{-7}$	$1.07x10^{-7}$
Responsivity (A/W)	0.32	$2.91x10^{-5}$
Common base internal gain	0.99	0.99
Common emitter internal gain	1125	1563
Outflow (amperes)	$1.89x10^{-4}$	$1.68x10^{-4}$
Photon flux (s^{-1})	$5.47x10^{14}$	$3.39x10^{-10}$
Bandwidth (Hz)	$4.8x10^{9}$	$6.55x10^{9}$
SNR	2656	$8.37x10^{-5}$
Optical power (watts)	$5.19x10^{-7}$	$3.7x10^{-3}$

CONCLUSION

Based on the results of the analysis obtained, the following conclusions are drawn:

1. The number of donors and acceptors of semiconductor materials will greatly affect the amount of current generated. For GaAs and Si materials, the output current produced with = 1017 3: = 1016 3 is 1.8973×10^{-4}A and 1.6831×10^{-4}. A Meanwhile, with = 1019 3: = 1016 3 the output currents are 7.028×10^{-5} A and 1.4827×10^{-5} A, respectively.
2. The phototransistor's responsiveness is strongly influenced by the amount of current generated. The responsiveness of GaAs is greater than that of Silicon.
3. The number of electron and hole concentrations greatly affects the depletion region. If the donor concentration is smaller than the acceptor, then the depletion region on the n-side will be larger than the p-side, and vice versa.
4. The smaller the depletion region, the greater the electric field.

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