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Phototransistor: The Story So Far

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Abstract— The research paper prospects the theory of phototransistor ranging from the history of the device to its application in the real world. The research paper deep dives into the characteristics of the phototransistor while discussing its dependence on bias drive, bias voltage, and illumination intensity. The research paper includes a comparative study between the various types of phototransistors based on optical gain, spectral range, and efficiency. It also concludes the best illumination method for the phototransistor based on the optical gain parameter.

Keywords: BJT; phototransistor; illumination; intensity; current gain; base current; optical

I. INTRODUCTION

There are numerous events in which it is helpful to supplant the human eye with some kind of electronic gadget to perform the desired task. For instance, in gas-or oil heaters where fire outbreak would establish a serious peril, it isn't monetary to use a human, only to recognize the fire and raise the alarm. This is where the optical-electronic devices come in handy. These devices detect the light in the surrounding and control the working of the electronic circuitry. One such optical device is a phototransistor. The phototransistor comes under the category of photoconductive electronic devices. The phototransistor is an electronic switching and amplification device whose working depends on the exposure to light. The phototransistor is a combination of a traditional transistor and a photodiode, in which the base current of the transistor depends on the intensity of light falling on the photodiode. The phototransistor has a slower response speed as compared to a photodiode but it is much more efficient in operation.

II. HISTORY

The phototransistor was invented by John Shive in the year 1948 in Bell Laboratories. Shive joined the laboratory in the year 1939 and started his research on physical components initially. Later he was shifted to the training and education department where Shive started working on developing transistor. This later became the main principle in the development of a transistor. He then tried to use the disclosure to build a point-contact semiconductor whose contacts were made of bronze on the front and back part of the germanium. Through this, he was able to demonstrate that the gaps can also diffuse from mass germanium rather than just the surface. In that very year, Shive used a light emission rather than a live wire to create electron-hole pairs to flow to the collector. After some more developments and research, the Bell laboratories announced this invention in the year 1950. The other scientists were pretty confident that after some strong developments, the phototransistor will have some serious application and will completely transform the real world. While the phototransistor was being announced its was proposed to use the transistor in a then developing 'toll dialing machine' in which the telephone operator dials a distant telephone automatically.

III. PHOTOTRANSISTOR AND ITS FABRICATION

Phototransistors are basically a combination of photodiode and amplifier integrated on a single silicon strip. It has been designed to overcome the major limitation of the photodiode that is the unity gain. The use of a single phototransistor turns out to be much more cost-effective and simple as compared to using a photodiode and an Op-amp in the circuit.

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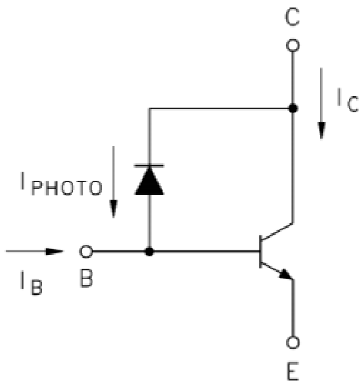

Fig. 1: Phototransistor Equivalent Circuit [7]

A. FABRICATION

The phototransistor is very similar to that of a traditional transistor just instead of a voltage source connected through a wire. The collector and the emitter are connected to a voltage source like a normal transistor but to generate the base current we take the help of the detector that is photo one.. The current that comes from a place known as base is generated by the light falling on the base which is made of a photosensitive material. The phototransistor package is provided with a window to allow light to fall on the photosensitive base region. The phototransistor in the active region acts as an amplifier in which the collector current is dependent on the value of base current which is further dependent on the intensity of illumination. So we can easily conclude the emitter and the collector current of the transistor is dependent on the intensity of illumination. The current coming from a place known as base is somewhat proportional that to directly to the parameter intensity. Higher the intensity, higher is the value of base current. The phototransistor can either have two-pin or three-pin configuration. In a two pin configutraion, the base current is generated by illumination while in the case of three-pin the base current can be generated by either voltage source or through illumination.

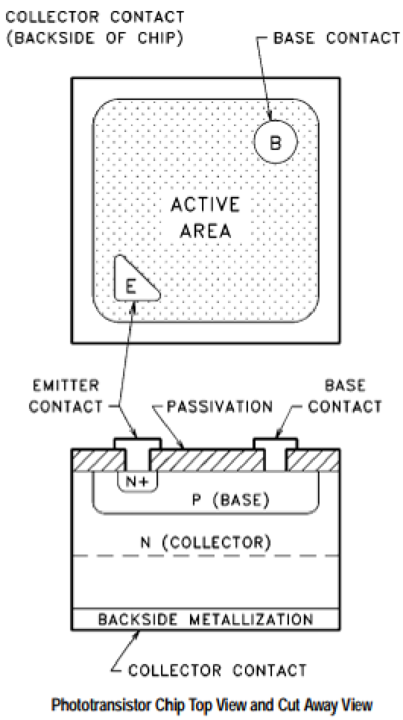

Fig. 2: Top view and Front view of Phototransistor [7]

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IV. WORKING OF PHOTOTRANSISTOR

The photo-transistor has similar working like a traditional transistor and has the same operation modes which are the region that is when it is in cut-off, the active region, the reverse active region, and the region in which it is in the saturation. Just like the traditional transistor, the emitter of a photo transistor is connected to a voltage source but in case of the base, it is provided with a window for illumination instead of a voltage source. The base current is generated by the illumination of the photosensitive base region which further becomes the deciding factor for the output current. For the illumination of the phototransistor the transistor is provided with a window for the base to trap the incoming light. When no light falls on the window of the phototransistor, no light is incident on the base region of the transistor, hence there is no base current. Only a small current flows due to movement of the minority of charge carries which is the reverse flowing which is in the wire is which is current also termed as dark current. The it is a current which is highly temperature-dependent. This mode of operation is the cut off region mode of the photo-transistor in which the collector or the output current like the base current is zero because of zero illumination. The phototransistor in the active region acts as an amplifier in which the collector current is dependent on the value of base current which is further dependent on the intensity of illumination. So we can easily conclude the emitter and the collector current of the transistor is dependent on the intensity of illumination. In the saturation region, the value of the collector current is at its maximum for the given values of the transistor and cannot increase any further on the increase of base current. In the reverse active region, the emitter of the transistor which plays the role or what we can say is act collector of the active state phototransistor and the collector acts as the emitter of the active state phototransistor. It is to the equal sum of the emitter and base current. This state is not useful as the current gain is very high in this case as compared to the active state photo-transistor.

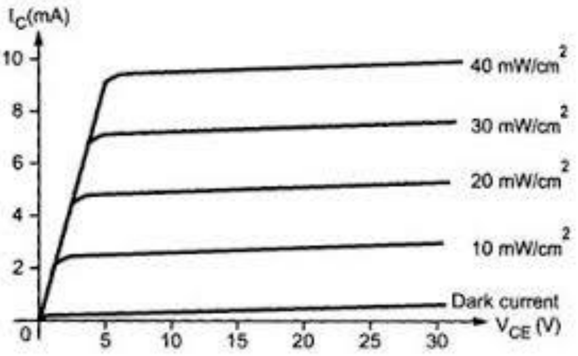

Fig. 3: I-V curve of phototransistor [3]

V. CHARACTERISTICS OF PHOTOTRANSISTOR

A. Spectral response:-

The output depends upon the 'Frequency'/'Wavelength' of the incident light. Just like any other optical device, phototransistor responds to the wavelength spectrum ranging from the near UV to the IR region of the wavelength spectrum. Over the range of wavelength the phototransistor show varying spectral response and thus varying efficiency. It is at the peak of it graph or what we can say is value is around the near IR region at approximately 840mm which is somewhat at a shorter wavelength as compared to a typical photodiode. Sources of light but show poor coupling efficiencies, this essentially is more clear visible when they are seen with Infrared Light ED.

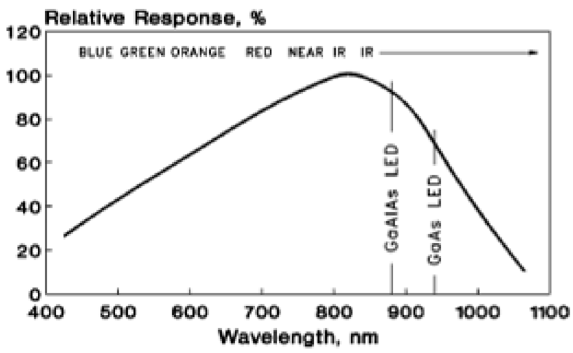

Fig. 4: Sensitivity of the phototransistor [7]

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B. Dependence on the area of base region

Just like other photoelectric devices the output of the phototransistor changes with changing the area exposed to illumination. In the case of phototransistor, the area exposed to illumination is the emitter-base junction, it acts as a photodiode. The base current flow soon as the emitter-base junction is exposed to the appropriate lighting condition. With the increase in the area of the base region, the base current also increases (make are somewhat double of base region and what we see is doubling the base current). The phototransistor base current then gets amplified according to the current gain of the transistor to give the output current.

C. Transistor gain

The current gain is dependent upon the base drive, bias voltage, and temperature. The current gain is low at low light and increases with increasing illumination and reaches a peak value and then again somewhat goes down or decrease and reaches its low but not that low.

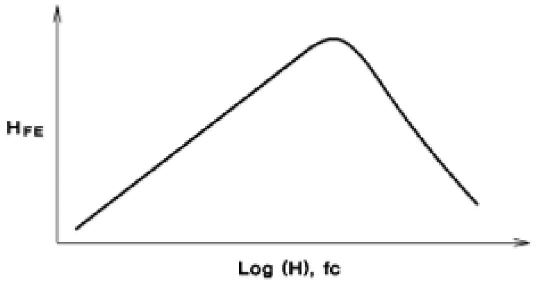

Fig. 5: Transistor gain vs light intensity [7]

The current gain is also dependent on the potential between collector and emitter region (Vce). The increase in potential between the collector and emitter leads to an increase in the voltage gain. The Current gain also increases with the increase in temperature.

D. Speed of response

The speed of response of the phototransistor is the time it takes to respond to the change in intensity of light. It is completely. So for a device with the same active region, the speed of response decreases with an increase in gain of the phototransistor. The response of the transistor is usually expressed in terms of rise and fall time.

VI. TYPES OF PHOTOTRANSISTOR

A. BJT phototransistor

The BJT transistor triggered by photos is similar to a simple BJT transistor in the construction According to the type of material used and structure, the BJT phototransistor is further classified into two types.

1)Homo-junction:

A homo-junction could be a semiconductor having equal band gaps with somewhat different doping level or like that only. The entire structure is made up of the same material, to increase the efficiency they are dopes with other material. The homo-junction is used more as compared to a hetero-junction transistor.

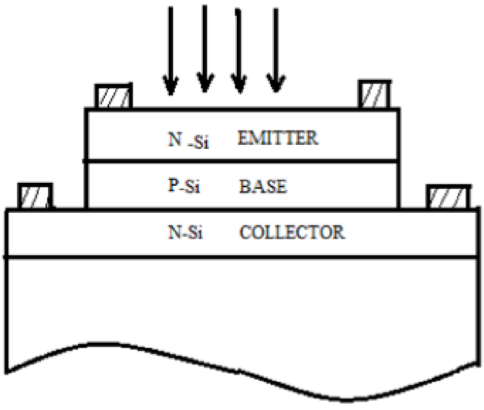

Fig. 6: Homo-junction Phototransistor [8]

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2) Heterojunction:

The hetero-junction phototransistor uses different materials to make the emitter-base and the collector junction of the semiconductor. This increases the performance of the transistor to several frequency ranges. The materials which can be used to make the hetero-junction phototransistor are AlGaAs, InP, InGaAs, Si-SiGe.

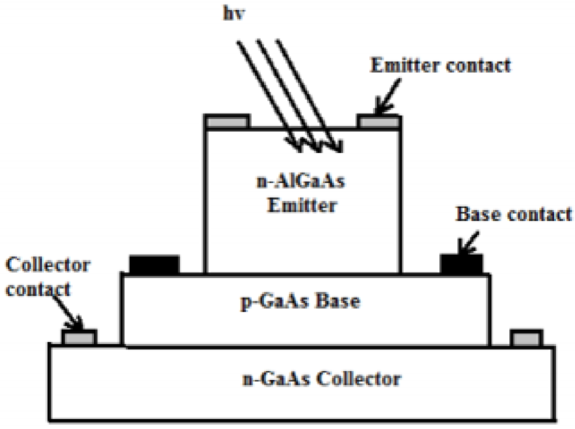

Fig. 7: Hetero-junction Phototransistor [4]

The characteristic curve of hetero-junction phototransistor is shown in fig. 8, the graph shows the active, cut-off, and saturation region of the hetero-junction transistor. It clearly shows the active region is higher in hetero-junction as compared to the homo-junction transistor.

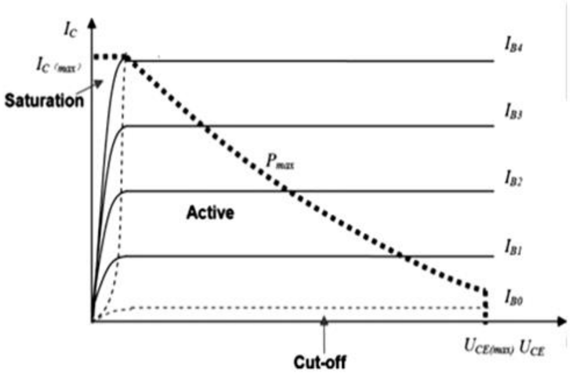

Fig. 8: Characteristic curve of the hetero-junction phototransistor [2]

B. FET Phototransistor –

The field effect phototransistor or the field effect transistor triggered by photo has bascically a source drain and a gate the current flows from the sourse to the drain. In FET phototransistor the only diffrence is that the gate current is generatede through light. This the control the current flowing between gate and source. The FET phototransistor are generally more sensitive as compared to BJT phototransistor. With increase in light intensity the gate current and hence the biasing increases, this increases the currrent between source and drain but decrease the width simultaneously. This leads to saturation of source current. According to the material of which the transistor is constructed, there are two type of transistor- P-channel and N-channel. In p-channel, the phototransitor is constructed, the tranistor is constructed of n-type semicoductor. The channel is the path between source and drain through which current flows.

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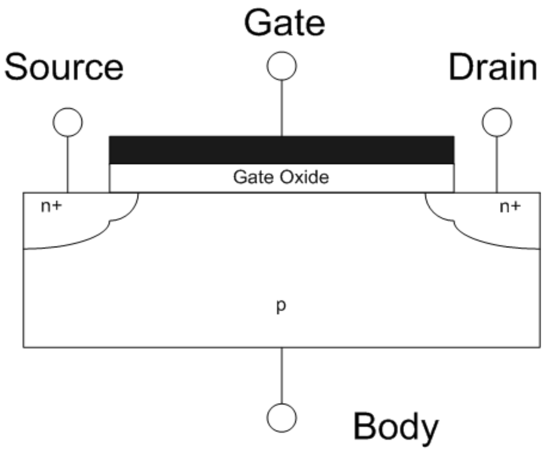

Fig. 9: FET Phototransistor

C. Photo-darlington

Photo-darlington just like a darlington transistor is a combination of two transistors in which the emitter current of one transistor is fed as base current into the other. The only difference is that in the case of Photo-darlington, a phototransistor is used instead of a traditional transistor. The first phototransistor which is basically what u can say acting as the photo-detector which is coupled in the place which is known of the base of the studied second transistor through an emitter.

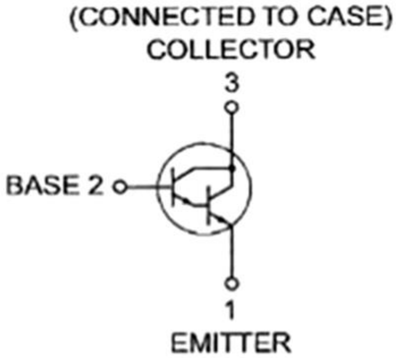

Fig. 10: Photo-darlington transistor symbol

Photo-darlington is only used where low frequencies are required in the circuit. The lower frequency response of the phototransistor may only have a bandwidth of a few tens of kHz. It has a higher active emitter and collector voltage as compared to other transistors.

VII. TYPES OF ILLUMINATION:-

A transparent window is used in the encapsulation of the light that falls on the phototransistor. Based upon the direction of illumination there are three different types of illumination based upon which the transistor performs to different efficiency levels. The different types of illumination are as follows.

a> Vertical face illumination,
b> Rear face illumination
c> Lateral face illumination.

All three illuminations are studied under ideal conditions whereby the electron and holes are generated uniformly all over the body when the lights fall on it.

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A. Vertical surface illumination

It is the most basic method or what we can say is that it is the most traditional method of illuminating the surface of the transistor. The light essentially falls directly and vertically on the base and obviously fight fall on it will create electron hole pairs which will essentially create current and hence the current will start flowing tin the transistor and it will start operating in either of the three mode of or region of operation in which generally transistor operates. But it may also operate in the fourth operating region that is essentially the reverse active region which is essentially the opposite of active region.

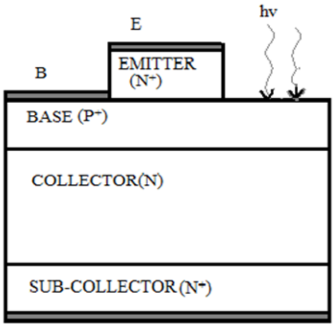

Fig. 11: Vertical face illumination [8]

B. Rear –face illumination

The rear face illumination in the BJT phototransistor takes place at the collector. The photo-carriers generation takes place in the active region of the transistor. Its efficiency and current gain are a bit higher as compared to vertical illumination but lower than lateral face illumination. The current gain is also dependent on the potential between collector and emitter region (Vce). The increase in potential between the collector and emitter leads to an increase in the voltage gain. The Current gain also increases with the increase in temperature

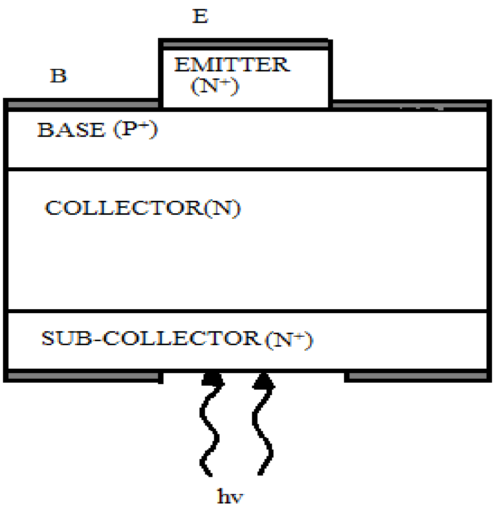

Fig. 12: Rear face illumination [8]

C. Lateral illumination

In this illumination technique, the light falls parallel to the layer of the transistor. The current gain is also dependent on the potential between collector and emitter region (Vce). Like in the vertical illumination, the photons and the charge carriers no longer move in the same direction. The biasing is provided when the electron pairs are created due to illumination. The lateral illumination method has a better speed response as compared to rear face or vertical face illumination. The injection efficiency of the lateral face illuminated transistor is around 50-90%. In the case of lateral illumination, the absorption volume is higher and each photon can interact with more silicon atoms due to which it has a higher current gain and efficiency as compared to the other two cases.

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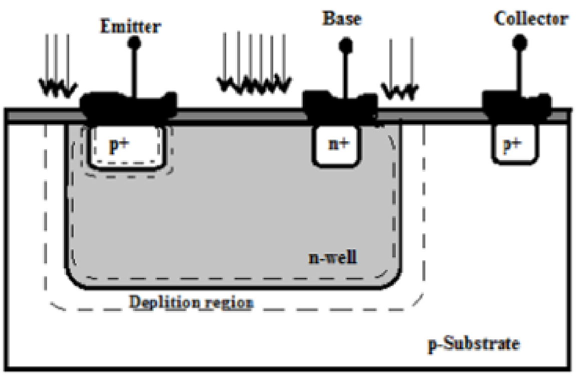

Fig. 13: Lateral face illumination [8]

According to the experimental data, there is the highest current gain in lateral face illumination followed by rear face illumination and then vertical face illumination. The above results hold for all frequency ranges. This proves the efficiency of lateral face illumination over other illumination methods. For better understanding, the results have been plotted in the following graph

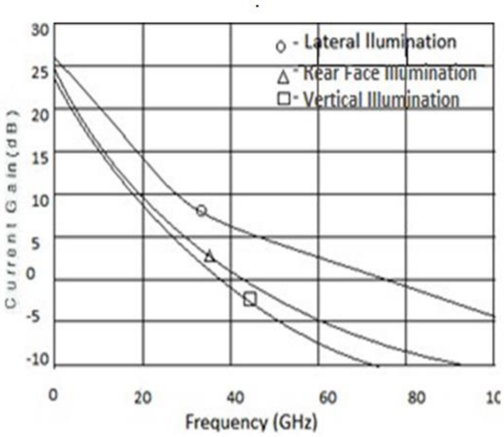

Fig. 14: Current gain for lateral, rear-face, and vertical Face illumination [5]

VIII. APPLICATIONS

The phototransistor has transformed the human world due to its numerous applications. The phototransistor is used in every field of life, ranging from industries and hospital to our day to day activities.

A. Industrial

The phototransistor is used in the security system. Here the phototransistor detects the presence of a person based on interruption in the path of light falling on it from the source. The Phototransistor is also used in the counter circuit in industries and banks for counting coins, currency, and any such stuff. It is used as an encoder for measuring speed and direction. It is also used in the Opto-coupler.

B. Medical

The phototransistor is used in medical devices for efficient and light controlled performance. The phototransistor is used to provide an electrical isolation between the patients and hospital equipments. The phototransistor is also used in the radiation monitor which is based on its variation in performance depending upon the frequency of light. The phototransistor also finds its application in hospitals as counters where they are used to monitor and keep an exact count of rates of intravenous injections

C. Other Applications:

Apart from these, the phototransistor has several other applications in our day to day life. The phototransistor is used in the remote controller of toys, audio-video appliances. It is used to monitor the position of the joystick. It

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is also used as laser tags in gaming. It is used to indicate the level of a working system that plays an important role in relays and punch cards.

IX. CONCLUSION

The phototransistor is a revolutionary invention in the history of mankind. A device that found its application while being in its developing stage proves the strong potential it withholds. The phototransistor is similar to traditional phototransistor to all extent except that the base current is generated by illumination. Out of the various phototransistor available in the market, the hetero-junction phototransistors made from group III-V elements are the most efficient when it comes to performance. In the case of types of illumination techniques, the lateral illumination out-performs the vertical and the rear face illuminated phototransistor in both current gain and efficiency. In a nutshell, even after having numerous applications, the phototransistor still has several pages to unfold and possess immense scope of research in the coming future.

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