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BIPOLAR JUNCTION TRASISTORS

○ The bipolar-junction transistor (BJT) was the first three-terminal device in solid state electronics and continues to a device of choice for many digital and microwave applications. For a decade after its invention, the bipolar device remained the only three terminal device in commercial application. However, as the Si-SiO_2 interface improved, the MOSFET (Metal Oxide Semiconductor Field Effect Transistor) has become dominant. Heterojunction bipolar devices (HBD) now have very high performance in terms of frequency and gain.

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○ In three terminal device the goal is to use a small input to control a large output. In input could be an incoming weak signal to be amplified, or a digital signal. The workings of a three terminal device can be understood by examining how the flow of water can be controlled. In one case, let's say the water was to flow in a pipe of fixed diameter while in another, it could flow over an open channel. In Fig. 9 we show two different ways one could design a system to control the water flow. On the left hand side sequence of Fig. 9 we show how a change in the ground potential can be used to modify the water flow. Only the fraction of water that is above the bump will flow across the potential profile. The value of the potential bump could be controlled by an independent control input.

Water flow can be controlled by a faucet in which the faucet controls the constriction of the pipe and thus the water flow. In a bipolar device one controls the potential profile in the current flow channel by using the base current as a controlling agent. In a FET (Field Effect Transistor) on the other hand one control constriction by applying the gate bias.

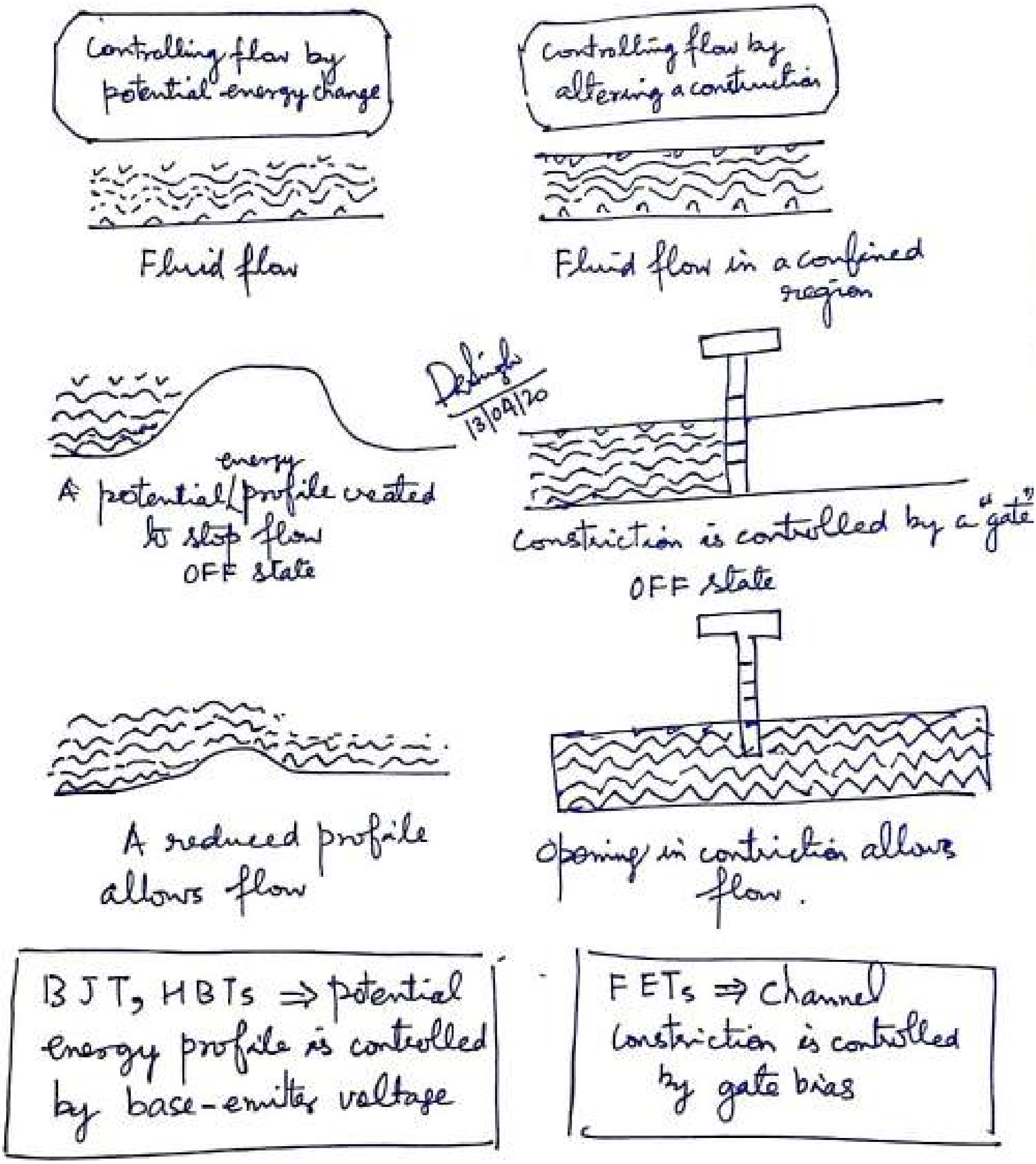

Fig. 9 : Two different ways to control flow of a fluid. The bipolar and field effect transistors use these two approaches to control current flow.

o As noted earlier, an important requirement for an electronic ~~circuit~~ device is that a small change in the input should cause a large change in the output i.e, the device should have a high gain. This requirement is essential for amplification of signal, tolerance of high noise margins in digital devices, and the ability to have a large fan-out (i.e., the output can drive several additional devices. Another important requirement is that the input should be isolated from the output. For the faucet example, these two requirements means we should able to turn the faucet ON and OFF with little effort and the water should not leak out of the faucet head!

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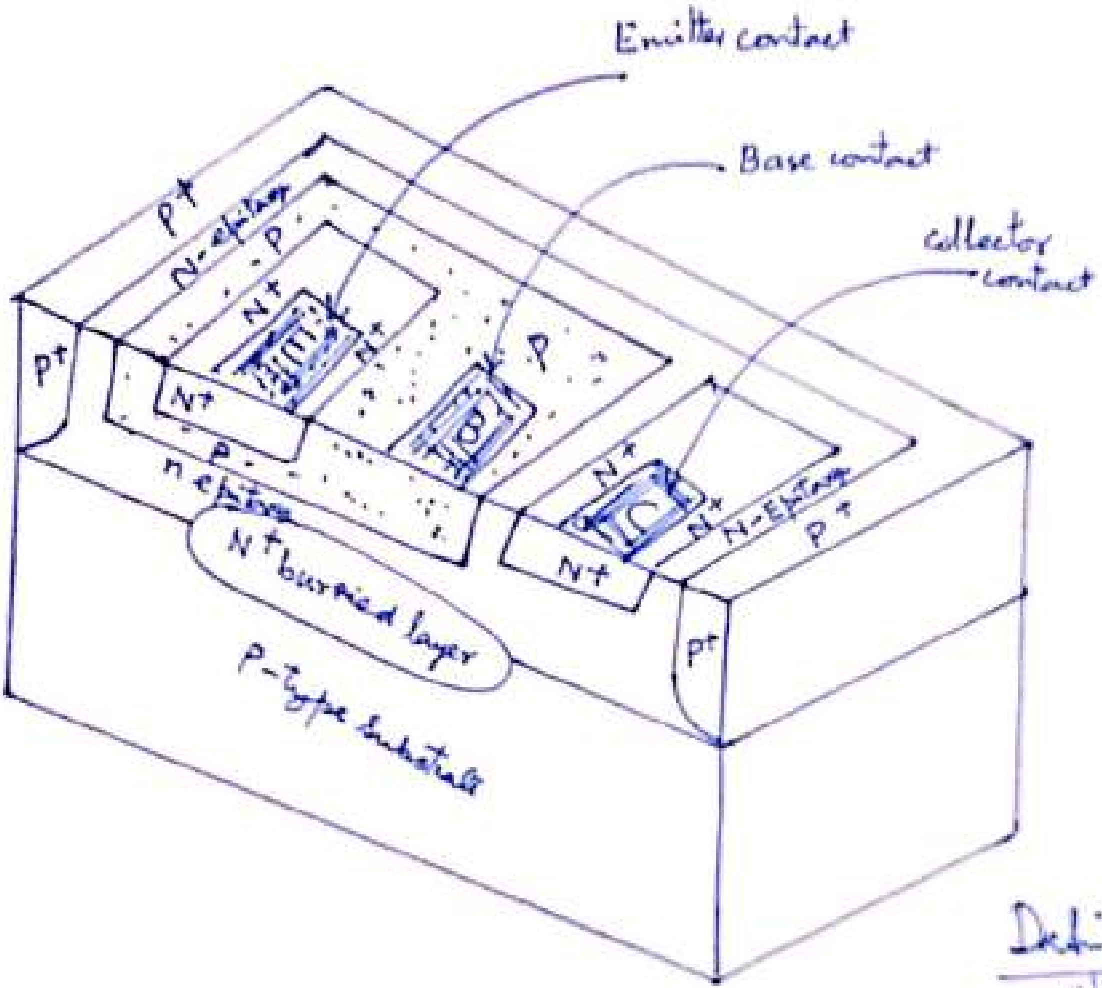
BIPOLAR TRANSISTOR : A CONCEPTUAL PICTURE

The bipolar junction transistor employs two back to back P-N diodes which with clever design rules can have a high amplification and can operate at high frequency. It can also act as a digital device and as a microwave device.

We have shown a state of art bipolar device. A schematic of the device is shown in Fig. 10. The device could have a doping of the form N^+-P-N or P^+-N-P. We will focus on N^+-P-N device. The emitter is heavily doped N-type, the P-region forms the base, and the lower N region is the collector. The emitter doping N_{de} is much larger than the base doping N_{ab} to ensure that the device has a high current gain i.e, that a small base current change produces a large collector current change.

To understand how the device can have gain, let us consider a BJT where the emitter base junction (EBJ) is forward biased and the base-collector junction (BCJ) is reverse biased. This biasing creates the forward active mode. The band profile of the device is shown in Fig. 12



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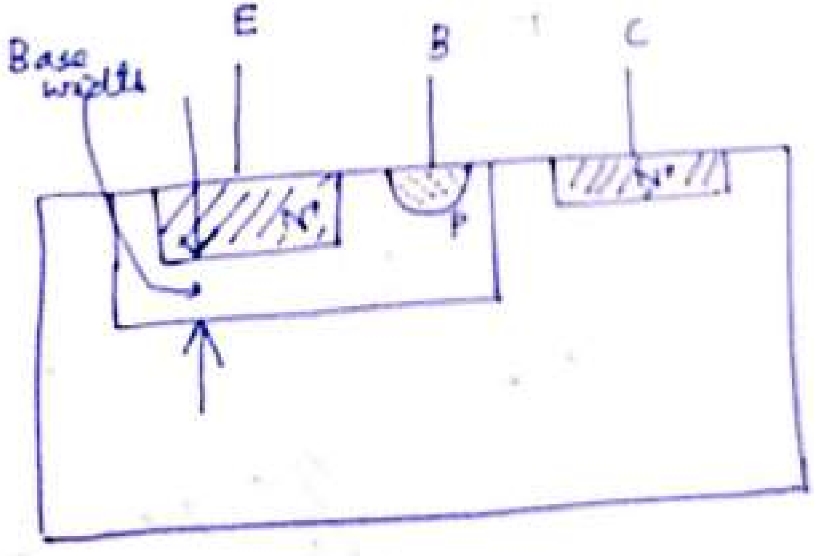
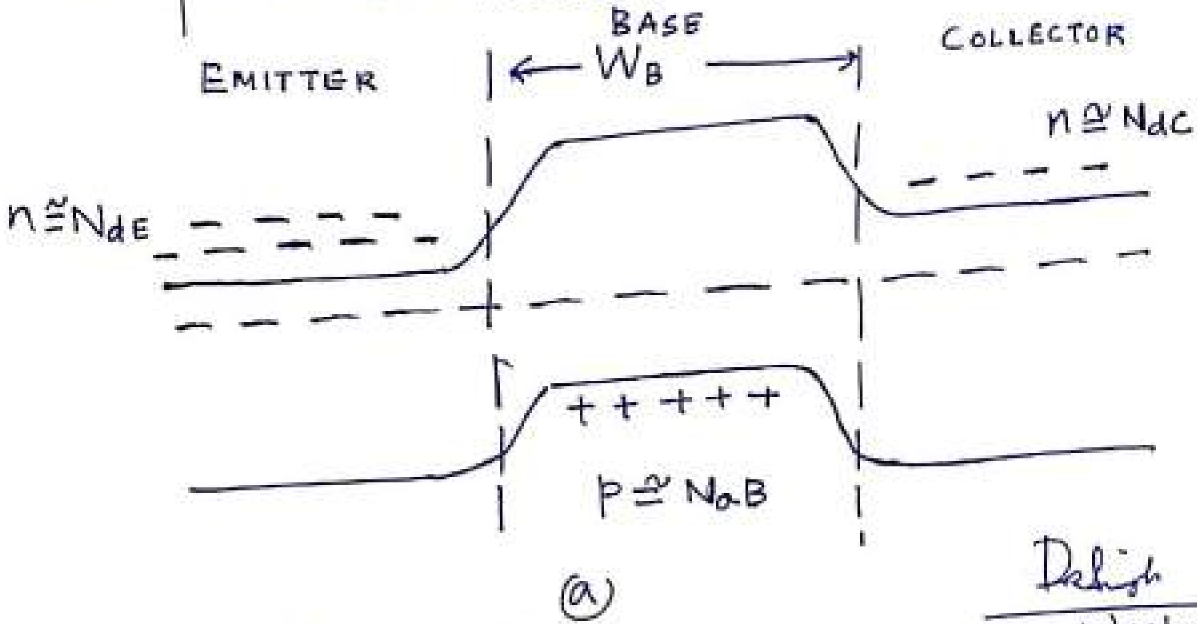


Cross-sectional view.

Fig. 10 A schematic of the structure and doping profiles of a BJT alongwith a simplified view of the cross-section.

NOTE: The base width W_B is smaller than the diffusion length of electron in P-type base region. So that when electrons are injected from the emitter, most cross the base without recombining the holes. The strong electric field then electrons see once they reach the collector, cause them to be swept away and form the collector current.



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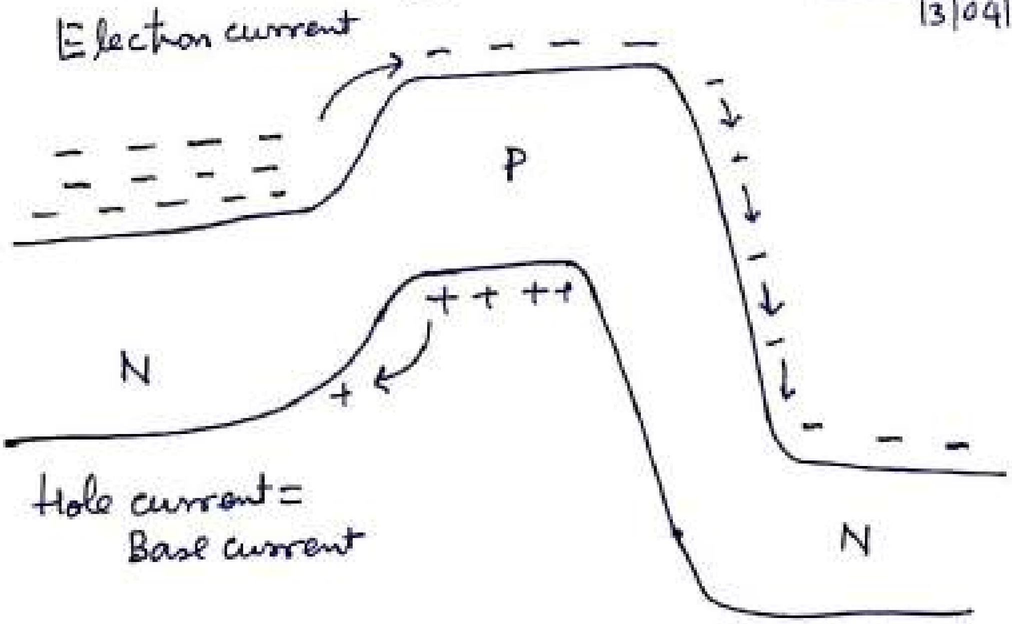

Fig. 11: (a) Band profile of an unbiased N^+-P-N BJT
(b) " " " a BJT biased in the forward active mode, where the EBJ is forward biased and the BJT is reverse biased.

- We remind ourselves that if the EB diode is asymmetrically doped, the forward bias current is essentially made up of injection of electrons into the P-side. This forward-biased current can also be altered by a very small change in forward bias voltage since the current depends exponentially on the forward bias value.
- The forward-biased N^+ emitter injects electrons into the P-base. Some of the electrons recombine in the base with the holes, but if the base region is less than the diffusion length of the minority carriers, most of them reach the depletion region of the P-N base-collector diode and are swept out to form the collector current. The collector current is proportional to the minority carriers (electrons) that reach the edge of the P-N depletion region as shown in Fig. 11(b). Since the injected minority carriers are due to the emitter current, we have

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$$I_C = B I_{En} \longrightarrow (6)$$

where I_{En} is the electron part of the emitter current and the factor B is called the base transport factor

In the absence of e-h recombination, the emitter current is made up of electrons injected from the N- to P-sides (I_{En}) and holes injected from P to N-sides (I_{Ep}). Since the BCJ is reverse biased, the collector current is related only to electron injected and we define the emitter efficiency γ_e as

$$\gamma_e = \frac{I_{En}}{I_{En} + I_{Ep}} \longrightarrow (7)$$

For optimum devices, γ_e and B should be close to unity.

The ratio between the collector and emitter currents is the current transfer ratio α

$$\frac{I_C}{I_E} = \frac{B\, I_{En}}{I_{En} + I_{Ep}} = B\gamma_e = \alpha \qquad (8)$$

This ratio is close to unity in good bipolar devices. In Fig. 12, we show a typical circuit for a B.J.T. in the forward bias active mode.

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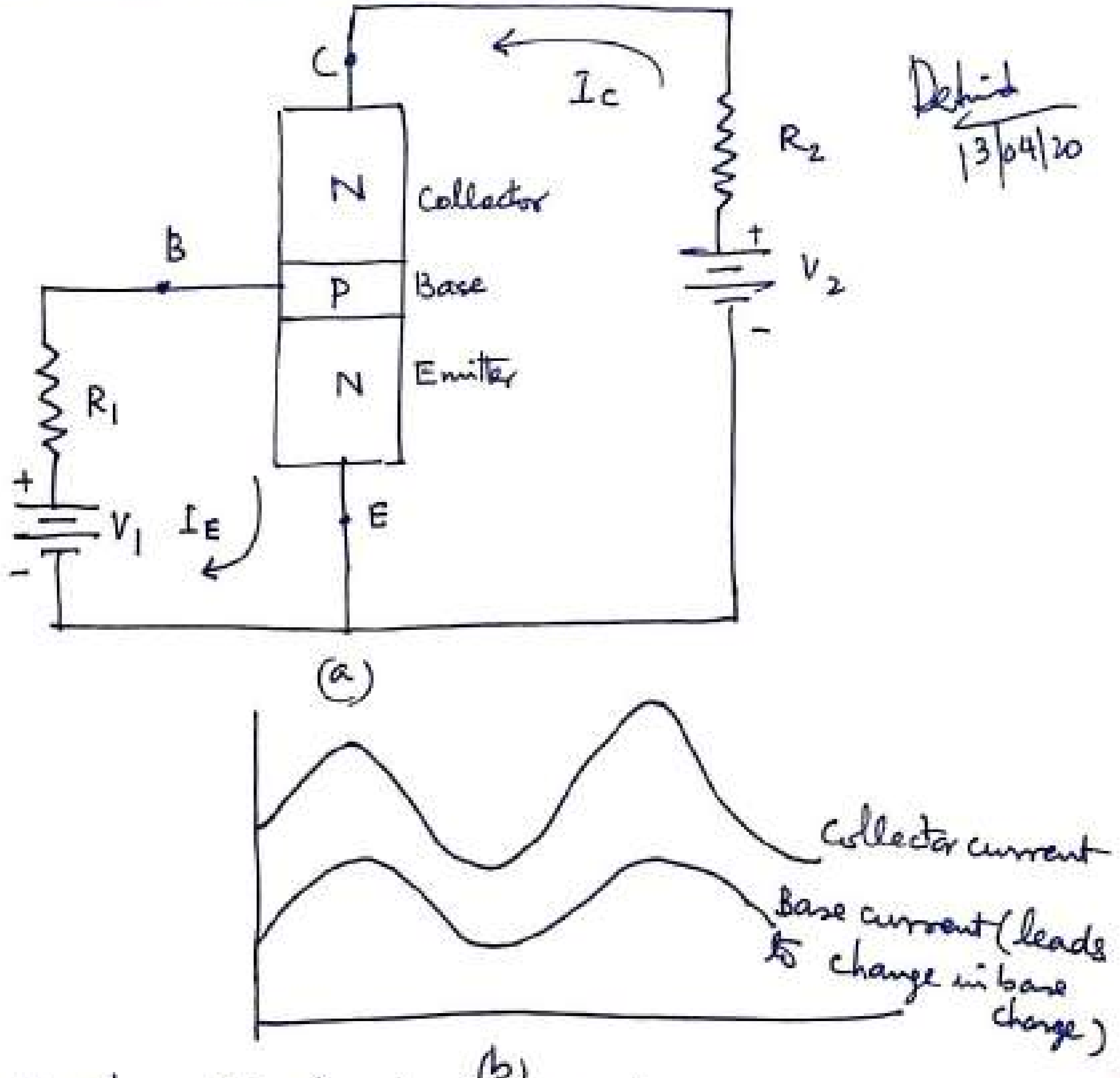

Fig. 12 (a) A schematic showing how the change in base current affects the majority carrier injection density and the collector current in a bipolar device. (a) A circuit using a BJT. (b) The effect of base current variation on the injected minority charge and the collector current. The collector current is much larger than the base current.

A change in the base current alters the minority carrier density n_p in the base and causes a large change in the collector current. The ratio between the collector current and the controlling base current is of great importance since this represents the current amplification. The base current is made up of the hole current injected into the emitter (I_{Ep}) and the hole current due to the recombination in the base with injected electrons from the emitter ($= (1-B) I_{En}$). Thus,

$$I_B = I_{Ep} + (1-B) I_{En} \longrightarrow (9)$$

The base-to-collector current amplification factor, denoted by β, is then

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$$\beta = \frac{I_C}{I_B} = \frac{B I_{En}}{I_{Ep} + (1-B) I_{En}}$$

$$= \frac{B(I_{En}/I_E)}{1 - B(I_{En}/I_E)}$$

$$= \frac{B \gamma_e}{1 - B \gamma_e} \longrightarrow (10)$$

This gives for the current gain

$$\beta = \frac{\alpha}{1-\alpha} \longrightarrow (11)$$

The factor β can be quite large for the bipolar transistor.

(P.T.O.)