THE BELL SYSTEM
TECHNICAL JOURNAL

VOLUME XXXIII MAY 1954 NUMBER 3

P-N-I-P and N-P-I-N Junction Transistor Triodes

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(Manuscript received March 18, 1954)

Theory indicates that the useful frequency range of junction transistor riodes may be extended by a factor of ten by a new structure, the p-n-i-p, which uses a thick collector depletion layer of intrinsic (i-type) semiconductor to reduce greatly the collector capacitance and to increase the collector breakdown voltage. This structure will permit simultaneous achievement of high alpha cutoff frequency, low ohmic base resistance, low collector capacitance, and high collector breakdown voltage. Because of the high breakdown voltages and larger areas per unit capacitance, permissible power dissipations appear much larger than for other high frequency junction types. Theoretical calculations indicate that oscillations at frequencies as high as 3,000 mcps may be possible.

Early exploratory models have verified the basic theory. Progress toward initial design objectives has been encouraging. In general, the observed performance has been consistent with the materials used and the structure achieved. The highest frequency of oscillation obtained to date is 95 mcps. Better performance is expected as technical control of materials and structures is improved.

In the five years since the announcement of the junction transistor by Shockley, great steps have been made in extending its useful frequency range and its power-handling capacity. Recent developments, particularly those which have increased the frequency range,[2, 12, 13] have brought the performance of practical devices close to ultimate limits prescribed by structure and material. Further extension of frequency range and, to a lesser degree, of power capability must be sought in new materials or in improved structures. The p-n-i-p* transistor employs a new structure which in theory promises to increase the useful frequency range of junction triodes by a factor of at least ten. In the p-n-i-p, the n region of the base and the p region of the collector are separated by a relatively thick region of i-type (i.e., intrinsic or near-intrinsic, almost free of donor and acceptor centers) semi-conductor. This permits establishment of a thick collector depletion layer at relatively low voltages, thus producing low collector capacitance and several other desirable features.

The advantages of the new structure may be seen by study of the limitations of previous triode structures. In general, high frequency performance of conventional units, such as p-n-p alloy[1] transistors, is improved by making the base region thinner to increase the alpha cutoff frequency (f_α), by using lower resistivity base material to reduce the ohmic base resistance (r_b'), and by decreasing the area of emitter and collector junctions to reduce the collector capacitance (C_c). These equivalent circuit parameters are of nearly equal importance as may be seen from the gain-bandwidth expression discussed below.

The design changes required to improve the parameters involve conflicts, and compromises are necessary. For example, the decrease of base thickness which increases alpha cutoff frequency also increases (less rapidly) the ohmic base resistance.† The decrease in base resistivity which reduces base resistance also increases (again, less rapidly) the collector capacitance and decreases the collector breakdown voltage, thus decreasing power capacity. The reduction of junction area which decreases collector capacitance reduces the current rating and thereby the possible power rating. For transistors having circular electrodes, it may also increase the ohmic base resistance.

For these reasons, conventional junction triodes designed for high frequency application tend to be very small and to have very low voltage, current, and power ratings. Ultimately, the decrease of collector reverse breakdown voltage sets a lower limit to usable base resistivity and thereby to the thickness of the collector depletion region. This sets a lower limit on base region thickness, since average base layer thickness should be two or more times depletion layer thickness. For base layers thinner than this, irregularities in thickness or in impurity distribution may permit the depletion layer to contact the emitter, producing the

* And its homologue, the n-p-i-n.

† In the junction tetrode, this increase of base resistance is overcome by crowding the minority carrier emission close to one of the base contacts, thus producing low ohmic base resistance. See Reference 2.

ac collector-to-emitter short circuit effect called "electrical punch-through." Lower limits of junction areas are set by desired operating currents and by mechanical reasons. Diminishing returns are reached for structures a few mils in diameter and a fraction of a mil thick.

To facilitate comparisons, the limitations described qualitatively above have been interpreted quantitatively in terms of a gain-band figure of merit,*

$$\Gamma_0 \cdot B^2 = \frac{f_\alpha}{25 r_b' C_c}; \qquad (1.1)$$

in which Γ_0 is low frequency available power gain in the common emitter connection† and B is the frequency at which the gain is 3 db down from its low frequency value. A reasonable upper limit on this (power gain) × (bandwidth-squared) product is 4×10^{16}, which indicates that a 0–10 mcps video gain of 26 db may be obtained by improvement of conventional triode structures.

The same figure of merit, for a p-n-i-p of equal junction area, is approximately 10^{19}. Calculation shows that units may be designed to produce 10 db or more gain at 1,000 mcps. Although many of its operating principles are similar to those of the p-n-p and the n-p-n, the p-n-i-p differs from the earlier triodes in that low collector capacitance is obtained by means of a thick collector depletion (space-charge) layer of intrinsic semi-conductor. The section view of a p-n-i-p in Fig. 1 illustrates its major features. The wide depletion layer (electric field region) produces small collector capacitance (C_c) and gives a high reverse breakdown voltage, while the very thin base region of low resistivity gives simultaneously a low ohmic base resistance (r_b') and a very high alpha cutoff frequency (f_α). The design with four regions, emitter, base, depletion layer, and collector, increases the (power gain) × (band-squared) figure of merit ($f_\alpha/25r_b'C_c$) about two decades, thus increasing the useful frequency range about one decade.

The thick collector depletion layer of intrinsic or near-intrinsic semiconductor provides advantages in addition to the reduction of the collector capacitance. Because base layer resistivity does not limit collector breakdown voltage as it does in previous structures, much lower base resistivities may be used, thus producing lower ohmic base resistances. Furthermore, the thick depletion region makes the structure much more rugged for very high alpha cutoff units since the very thin base layer is

* This figure of merit is essentially identical with one described by R. L. Prichard at the A.I.E.E. Winter Meeting in New York City, Jan. 22, 1954.

† It is assumed that the input terminals of the transistor are shunted by an external resistance which determines the input impedance and therefore the bandwidth. Power gain decreases approximately 6 db per octave at frequencies greater than B.

a surface layer on an 0.5–2.0 mil intrinsic layer, rather than a thin and unsupported web.

When operating biases are applied to a p-n-i-p transistor, holes injected at the forward biased emitter diode diffuse across the n region of the base then drift at high velocities through the field region to the reverse biased collector p region just as in a PNP transistor. However, in the p-n-i-p, the drift transit time through the collector field is comparable to the diffusion transit time through the base and contributes to phase shift of the short-circuit current-transfer ratio, alpha. In addition, the emitter depletion layer capacitance, C_{Te}, which is unimportant in previous triodes, is relatively large in the p-n-i-p and degrades performance at very high and microwave frequencies by providing a low impedance shunt around the emitter junction.

The details of structure and operation, design theory, a comparison of p-n-p and p-n-i-p units and some experimental results are discussed in the following sections. The concluding summary reviews the theoretical and experimental work.

STRUCTURE AND OPERATION

Impurity Distribution

In general, device characteristics depend on structure and on operating conditions. However, structure is more basic than operating conditions. The spatial distribution of fixed charge centers (donors and ac-

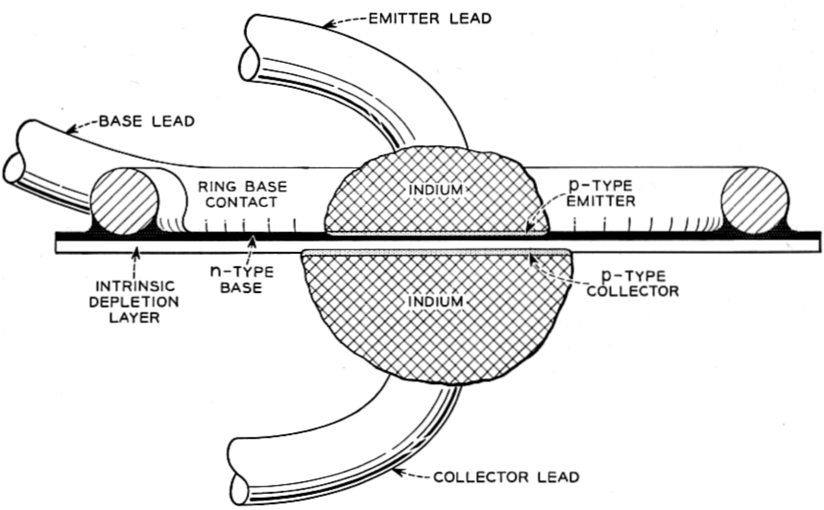
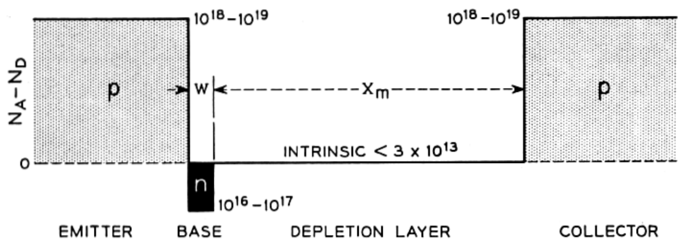


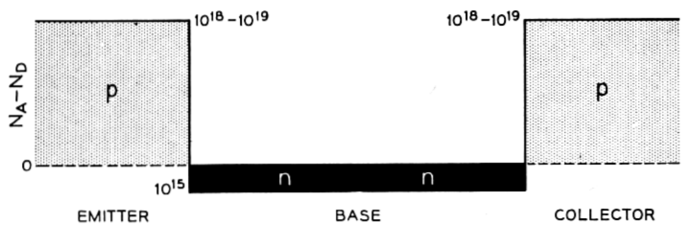
Fig. 1 — Sectional view of a p-n-i-p transistor.

ceptors) is the fundamental structural characteristic of the junction transistor. Fig. 2(a) shows an impurity density profile for a p-n-i-p along an axial line running through emitter, base, collector space-charge layer, and collector. Similar profiles for step junction (alloy) and graded junction (grown crystal) p-n-p's are shown in Figs. 2(b) and (c).

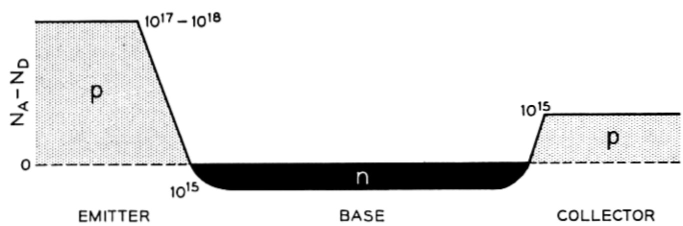
The emitter and collector regions of the p-n-i-p have very high impurity concentrations (low resistivities), while the impurity density in the base is moderately high and the depletion layer is almost free of impurities. The high acceptor density in the emitter forces most of the emitter current to flow as holes, giving an injection ratio (γ) close to unity. The high density in the collector gives a low collector body resistance and fixes the position of one face of the collector depletion layer.



(a) STEP-BASE p-n-i-p



(b) STEP (ALLOY) p-n-p



(c) GROWN (GRADED) p-n-p

Fig. 2 — Impurity density profiles.

The high donor concentration in the base region leads to low ohmic base resistance (r_b') and fixes the position of the base face of the depletion layer. In the depletion layer, the concentration of impurities is so low that the field region (space-charge layer) extends from the n-type base to the p-type collector at low voltages.

Depletion Layer

The properties of the depletion layer which are important at high frequencies are the capacitance across it (C_c) and the carrier transit time through it (τ_c). These are determined primarily by the impurity density, the thickness of the region, and the base-to-collector voltage. Potential and field distributions in the depletion layer for both small and

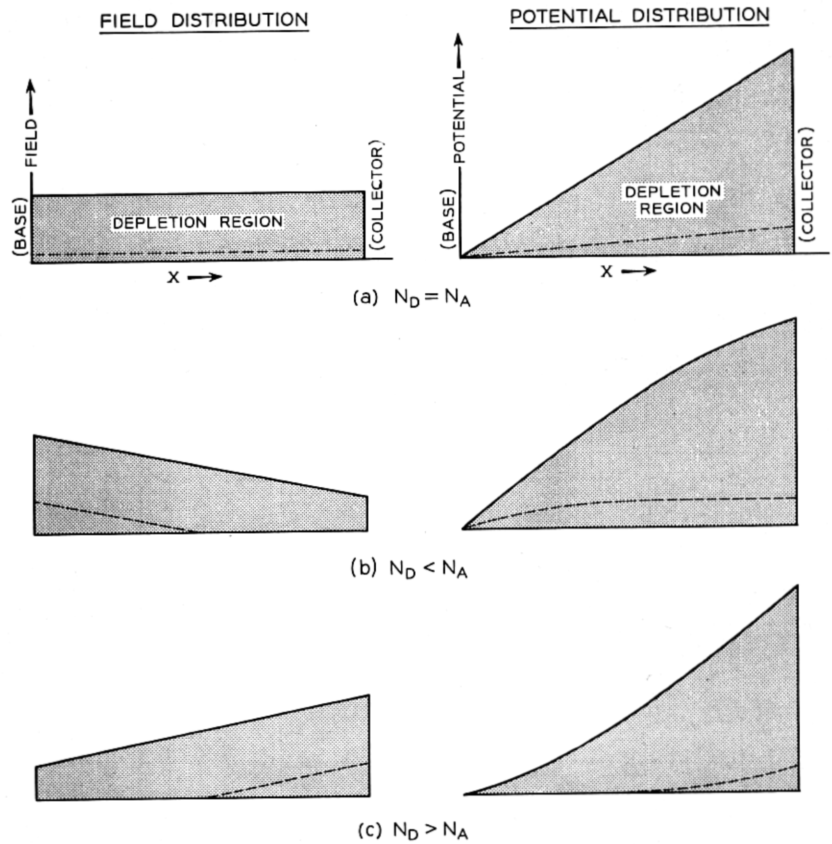


Fig. 3 — Field and potential distributions in depletion region of p-n-i-p transistor.

typical applied voltages are shown in Fig. 3 for p-n-i-p structures in which the depletion layer contains no net impurities (a), a small acceptor dominance (b), and a small donor dominance (c). When collector voltage is increased from zero, the space charge layer thickens until it extends from base to collector. Further increase of voltage simply increases the field strength in the region, without significant further increase in its thickness.

The capacitance initially changes inversely as the square root of collector potential, but becomes constant when depletion region thickness becomes constant. The time required for holes to drift from base to collector decreases with increase of depletion region field until scattering-limited carrier velocities are reached (about 5×10^6 cm/sec for holes, at 10,000 volts/cm).[10] It should be noted that normal operation does not occur until the depletion layer extends from base to collector (particularly if the depletion region is slightly n-type so that effective base thickness is large at low collector voltages, see Fig. 3(c)). The breakdown voltage of the collector is very high,* since the field strength in the depletion region is relatively uniform by comparison with that in older types of units, the region is wide, and strong fields are required to produce carrier multiplication.

Base Region

Base region design seeks the conflicting objectives of short diffusion transit time, requiring a thin region, and low ohmic base resistance, requiring a thick region. In practice, the region is made as thin as feasible, but of low resistivity material, and base contact geometry is chosen to minimize the ohmic resistance. In the p-n-i-p, very low base resistivity is practical, because the collector breakdown potential is fixed by the thickness of the intrinsic depletion layer rather than by the base resistivity as in fused junction p-n-p's.

The large donor density in the base region together with the very high frequencies of operation make the emitter depletion layer capacitance (C_{Te}) both larger and more important than in previous transistors. In order to reduce this capacitance, the emitter junction area is made small, thus leading to emitter current densities of 1 to 100 amperes/cm^2. In general, as the dc current density is increased, the minimum dc collector voltage must also be increased in order to preserve

* An avalanche mechanism similar to a Townsend discharge in gases is now believed responsible for reverse voltage breakdown in junction structures. See Reference 3.

emission-limited current flow. Insufficient voltage may result in space-charge limited operation.[4, 5]

Three structures which may be used to obtain low ohmic base resistance are shown in Fig. 4. Obviously, the base contact ring may be placed arbitrarily close to the emitter, as in Fig. 4(a), so that the base resistance is that of the region beneath the emitter. Since this is somewhat difficult, the ring may be placed at a distance from the emitter, and the emitter imbedded in the base n-region as in Fig. 4(b), reducing the resistance between the emitter periphery and the base ring at only a small cost in alpha cutoff frequency. In addition, as shown in Fig. 4(c), the n-region used may be of graded resistivity such as results from impurity diffusion from the surface. The large impurity concentration at the surface minimizes both edge emission and radial base resistance.

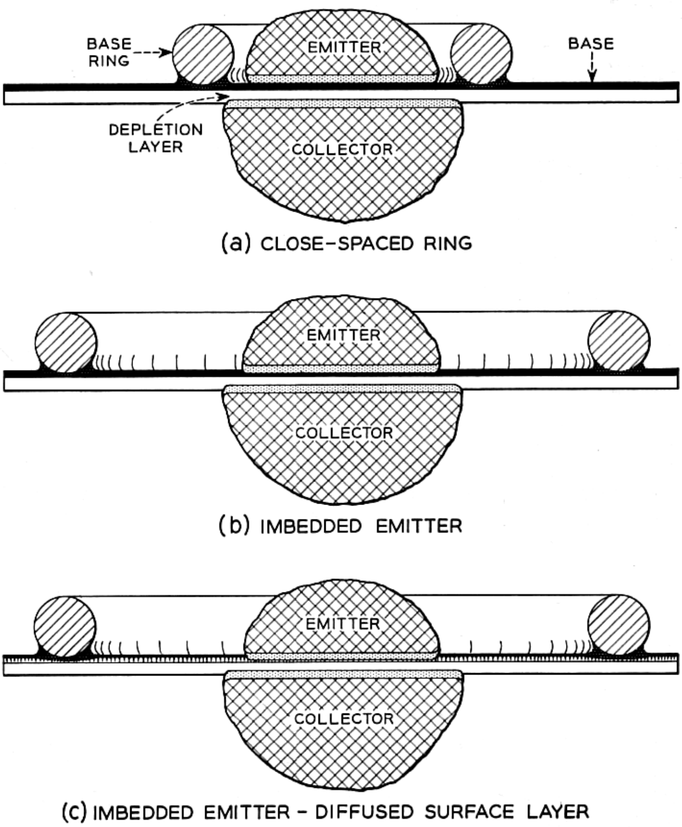


Fig. 4 — Low-base resistance structures.

These advantages are, however, balanced in part by an increase in the emitter depletion region capacitance associated with the low resistivity base material.

DESIGN THEORY

General

The principal objectives in the initial p-n-i-p design have been high alpha cutoff frequency, low collector capacitance, and low ohmic base resistance. The equivalent circuit employed is shown in Fig. 5. The output and feedback admittances which are important in earlier junc-

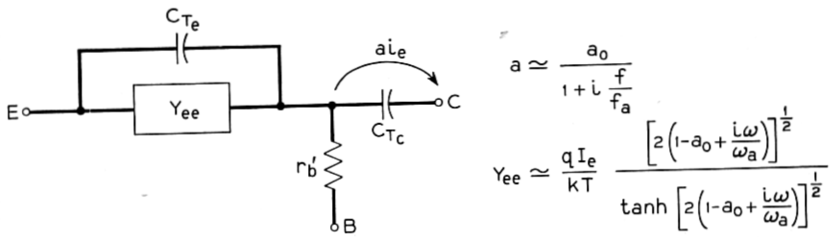


Fig. 5 — Equivalent circuit of the p-n-i-p transistor.

tion triodes are omitted, since the space charge layer widening factor (H_{12} or μ_{ec}, $\frac{kT}{qw}\frac{\partial w}{\partial V_c}$) is very small.[6, 7] The transfer admittance is shown as a current generator (ai_e) with cutoff frequency ($|a^2| \sim 3$ db down) of f_α because this gives explicit recognition to base region diffusion transit time τ_b and allows it to be combined with space charge layer transit time τ_c .

Emitter Region Design

Emitter region acceptor concentration should be very large ($10^{18} - 10^{19}$ atoms/cc) in order to keep the injection ratio γ close to unity at both low and high frequencies.[8] At low frequencies, γ is determined by emitter resistivity and carrier life path or diffusion length, base resistivity and width, as

$$\gamma = \gamma_0 = \frac{1}{1 + \frac{\sigma_b w}{\sigma_e L_{ne}}}$$

At high frequencies, γ is determined by the ratio of acceptor density in the emitter to donor density in the base as

$$\gamma_{\rm hf} = \frac{1}{1 + \frac{N_{\rm Db}}{N_{\rm Ae}} \sqrt{\frac{D_n}{D_p}}}$$

Obviously, since the effective donor density in the base must be large to give low ohmic base resistance, the effective acceptor density in the emitter must be even larger if high frequency γ is to be close to unity.

Base Region Design

Base region thickness, w, and the diffusion constant, D_p, determine the diffusion transit time for holes from injection by the emitter to collection by the field of the depletion layer.

$$\tau_b = \frac{w^2}{2D_p}. \tag{1}$$

For circular electrodes, which are useful, easily made, and easily analyzed, the ohmic base resistance for the active region of the base between emitter and collector depends on base resistivity, ρ_b, and base thickness as follows:

$$r_b' = \frac{\rho_b}{8\pi w} = \frac{1}{q\mu_n N_D 8\pi w}. \tag{2}$$

If w is made small, r_b' can be reduced only by making N_D large. Although large reductions in r_b' can be made, increasing N_D is ultimately a self-defeating procedure for several reasons: as N_D is increased both D_p and the electron mobility, μ_n, decrease, thus increasing hole transit time and also partially off-setting the reduction in r_b' by N_D. In addition, the capacitance of the emitter depletion region varies approximately as $N_D^{1/2}$, thus diverting more ac emitter current from hole injection. This capacitance is

$$C_{\rm Te} = \kappa\epsilon_0 \left(\frac{qN_d}{2\kappa\epsilon_0 V_e'}\right)^{1/2} A_e, \tag{3}$$

where V_e' is the average electrostatic potential across the emitter depletion layer. Equations (1) to (3) show the conflicts which necessarily arise in base region design for very high frequencies. The limiting design combines very small w, large N_D, small emitter area A_e, and relatively large dc emitter current I_e so that the minority carrier emitter admittance y_{ee} is at least of the order of magnitude of $j\omega C_{\text{Te}}$. Total emitter admittance is

$$y_{ee} + j\omega C_{\text{Te}} = \frac{\frac{qI_e}{kT}(1 + j\omega\tau)^{1/2} \coth\left[\frac{(1 + j\omega\tau)w^2}{(D\tau)}\right]^{1/2}}{\coth\left(\frac{w^2}{D\tau}\right)^{1/2}} + j\omega C_{\text{Te}} \quad (4)$$

Depletion Layer Design

As mentioned previously, the most important characteristics of the depletion layer in the p-n-i-p are the transit time for holes, τ_c, and the capacitance, C_{Tc}. The minimum voltage for normal operation, $V_{\min}$, and maximum or breakdown voltage, $V_{\max}$, are also significant.

The minimum voltage for "normal" operation is reached when the electric field between the n-type base and p-type collector is strong enough so that the holes drift at their limiting velocity of 5×10^6 cm/sec.* The collector to base voltage required for normal operation is the product of the minimum field strength for the limiting velocity and the thickness of the depletion layer and is given by

$$V_{\min} = 10{,}000\, x_m \quad (5)$$

in which x_m is depletion layer thickness in cm. The maximum field obtainable before reverse voltage breakdown is not known exactly, but is in practice near 100,000 volts/cm, so that

$$V_{\max} \simeq 100{,}000\, x_m\,. \quad (6)$$

Depletion layer capacitance is nearly independent of collector voltage in normal operation and is inversely proportional to layer thickness.

$$C_{\text{Tc}} = \frac{\kappa\epsilon_0 A_c}{x_m} \quad (7)$$

Transit time for holes increases directly with layer thickness, however, being

$$\tau_c = \frac{x_m}{5 \times 10^6} \quad (8)$$

Since increase of τ_c decreases the alpha cutoff frequency f_α, the choice

* At lower field strengths, the transit time for holes is longer, giving a lower alpha cutoff frequency. The "normal" is the best, rather than the only possible, operating condition.

of x_m is a design balance between C_c and f_α, with any desire for low voltage operation weighting the scales toward smaller x_m.

As collector voltage and therefore field strength is reduced below that required for normal operation, transit time is increased because of the reduced drift velocity. In addition, the holes in transit interact with the ac field of the layer, thus increasing the output conductance g_{cc}. Further, a larger density of holes in the layer is required to carry the same current, disturbing the field distribution. If the voltage is reduced greatly, space-charge limited emission may occur,[4, 5] producing much longer effective transit times.

If output voltage is reduced sufficiently, the collector field will not extend all the way from base to collector. If the layer is somewhat n-type, the field region collapses toward the p-region of collector. If it is somewhat p-type, the field collapses toward the n-region of the base. The latter arrangement has the advantage that f_α is less drastically reduced. Further, in normal operation, the negatively charged acceptor atoms of a slightly p-type layer will neutralize the charge of the holes in transit, thus making the field more nearly constant from collector to base. The effects of low voltage on the collector field distribution are indicated approximately by the dashed lines of Fig. 4.*

Collector Region Design

Acceptor concentration in the collector should be large for several reasons. This gives a low collector body resistance, which virtually eliminates internal series loading of the collector, and it aids operation by fixing the position of the collector edge of the depletion layer. The advantages obtained may be seen by considering a unit in which the collector body is made somewhat p-type and a collector contact is attached at some distance from the depletion layer. If 10 ohm-cm p-material is used for the collector body and a collector contact fastened 2.5 mils from the collector resistance of 250-500 ohms will result. In addition, because of the weak drift field at the collector edge of the depletion layer, the hole transit time is about twice that for a true p-n-i-p.

Alpha Cutoff Frequency

A current transmission cutoff frequency f_α for the p-n-i-p is given approximately by†

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* The field distributions occurring in an intrinsic depletion layer at low field strengths have been discussed in Reference 11.

† It is assumed that alpha is given by $\alpha = \alpha_0(1 + jf/f_\alpha)$. Equation (9) represents the phase of this expression quite well, but the amplitude rather poorly.

$$f_\alpha = \frac{1}{2\pi(\tau_b + \tau_c/2)} \tag{9}$$

Equation (9) implies (correctly) that the delay time for total current passing through the depletion layer is about one-half the transit time for the carriers. This results from the induction of charge on the base and collector electrodes by the carriers in transit. If $\varphi = \omega\tau_c$ is carrier transit angle and $J_c = e^{j\omega t}$ is the *conduction* current of holes entering the depletion layer from the base, the *total* current entering the depletion layer from the base can be shown to be

$$J = e^{j\omega t}\left(\frac{1 - e^{-j\phi}}{j\phi}\right) \tag{10}$$

which reduces for small φ to

$$J \simeq e^{j\omega t - j\phi/2}$$

It may be noted that the total current J of equation (3.6-2), when written in the form $J_{max} \angle \theta$ in which θ is the phase shift of the total current with respect to the conduction current entering from the base, is approximately $0.973 \angle -22.5°$ for $\varphi = 45°$, $0.901 \angle -45°$ for $\varphi = 90°$, and $0.636 \angle -90°$ for $\varphi = 180°$.

DESIGN COMPARISON

General

Comparison of figures of merit is the best, albeit unsatisfactory, means for comparative evaluation of devices. For junction transistors, one non-controversial figure of merit is established — the noise figure. Two transmission figures of merit for junction transistors are suggested at the bottom of Table I. It should be pointed out that the p-n-i-p figures are for theoretical design possibilities, some features of which have already been realized experimentally.

The Units

Table I gives parameters of interest for several types of transistors. Structural, material, and electrical parameters for the Bell Telephone Laboratories' developmental M1778 p-n-p unit are averages for large numbers of units. The electrical parameters of the plated-contact transistor recently announced by Philco were taken from a talk by W. H. Forster before the Philadelphia I.R.E., Dec. 3, 1953.[12] The structural and material parameters have been estimated. The p-n-i-p structures

TABLE I — TRANSISTOR DESIGNS

	M1778	Philco	P-N-I-P (Calculated Values)		
			No. 1	No. 2	No. 3
w_b — mils	1.0	0.2	0.13	0.8	0.04
ρ_b — ohm cm	1.5	0.5	0.14	0.05	0.02
dia_e — mils	15	4	10	6	5
dia_c — mils	30	6	15	8	5
x_m — mils	0.1	0.05	0.63	0.36	0.7
N_b — atoms/cc	10^{15}	3.5×10^{15}	1.4×10^{16}	4.2×10^{16}	1.2×10^{17}
f_α — mcps	2.0	55	100	200	360 (600)*
r_b' — ohms	50	65	34	20	16
C_c — mmf	25	2.5	1.0	0.5	0.1
$\omega_a C_c$ — mhos	—	—	0.023	0.038	0.102
C_e — mmf	—	—	36	22	27
$\omega_a r_b' C_c$	0.0157	0.056	0.0214	0.0126	0.0060
$(f_\alpha/25\, r_b' C_c)^{1/2}$ — mcps	8	115	340	900	3000

* First value calculated by Equation (9); second value is for diffusion through base n-region only (i.e., $\tau_c = 0$).

and materials were assumed and electrical parameters were calculated from them by the Equations (1) to (11). Mobilities measured for low resistivities by M. B. Prince[9] were used in the calculations.

Figures of Merit

The last row of Table I gives $(f_\alpha/25 r_b' C_c)^{1/2}$, which was discussed previously as a gain-bandwidth figure of merit for a broad band common emitter amplifier. It is also related to the maximum frequency at which reliable oscillations may be obtained. The figure of merit $\omega_a r_b' C_c$ is the open circuit voltage feedback ratio at the alpha cutoff frequency and gives some indication of the balance between the two time constants, $1/\omega_a$ and $r_b' C_c$. It is also approximately the ratio of input impedance to output impedance in a common emitter broadband amplifier at high frequencies.

Comments

It should be noted that the emitter depletion layer capacitance is significant in all the p-n-i-p designs and that barrier transit time reduces alpha cutoff frequency some forty per cent in the highest frequency design. Despite this, it is probable that p-n-i-p or n-p-i-n germanium junction triodes will serve as oscillators and perhaps amplifiers at frequencies as high as 3,000 mcps.

EXPLORATORY MODELS

Objectives

While the p-n-i-p transistor will be useful for high voltage and high power operation, our exploratory development work has been directed toward good performance at very high frequencies. The initial electrical objectives set were those of p-n-i-p No. 1 of Table I: $f_\alpha = 100$ mcps, $C_c < 1.0$ mmf, and $r_b' = 34$ ohms. The base thickness of 0.13 mil and base resistivity of 0.14 ohm-cm are the critical structural parameters.

Fabrication

Although p-n-i-p's might conceivably be built in a single operation, one procedure used has two major parts. The first is the production and evaluation of 2-mil thick wafers of intrinsic germanium with a skin or surface layer of 0.1–1.0 ohm-cm n-germanium 0.3-0.5 mils thick. The second step is the alloying of collector, emitter, and base electrodes to these wafers.

Wafers with n-type skins have been made by three methods. Intrinsic crystals growing from a melt by the Teal-Little technique have been doped with arsenic, grown for a few seconds longer (another 0.5–1.0 mils), and snatched mechanically from the melt. The resulting crystal surface has a mirror finish and is relatively flat. N-type skin layers have also been produced by alloying the wafer surfaces with lead-arsenic and lead-antimony mixtures and by the diffusion of arsenic into wafer surfaces.

Collector and emitter electrodes are alloyed by the indium germanium process with times, temperatures, and quantities of indium selected to give desired alloying depths. Ring-base connections of antimony and gold plated kovar have been used.

Measurements

Progress toward the initial design objectives mentioned previously has been encouraging. The predicted behavior has been verified semi-quantitatively. The capacitance of a 15-mil diameter collector is usually less than 1.0 mmf at $V_c = -25$ volts as predicted in design No. 1 of Table 1. Ohmic base resistances generally less than 50 and as low as 5 ohms have been measured. However, the highest alpha cutoff frequency obtained as yet is 25 mcps. This has been limited primarily by the thickness of the base layer. At present this is of the order of 0.30 mils so that an alpha cutoff frequency of 25 mcps is about what would be predicted. Further development of the technology of fabrication seems reasonably straight-forward at least to the design objectives of No. 1 and No. 2 of Table I.

The best unit measured to date showed $\alpha_0 > 0.96$, $f_\alpha \simeq 25$ mcps, $r_b' \simeq 60$ ohms, and $C_c \simeq 1.8$ mmf. These values agree quite well with those expected from the resistivities and layer thicknesses employed. The unit oscillated at 95 mcps with $V_c = -30$, $I_e = 1.0$ ma. Connected in a common emitter video amplifier working from a 75-ohm generator impedance into a load resistance of 2,150 ohms shunted by 5 mmf of capacitance, this unit produced a power gain of 23 db at 500 kc, falling to 20 db at 3 mcps and 15 db at 10 mcps.* In an uncompensated common emitter tuned circuit, this unit gave 20.5 db at 10 mcps with 3 mcps bandwidth between the three db points.* It has been operated with a collector voltage of -90 volts.

SUMMARY

The designed elimination of donors and acceptors from a thick collector depletion layer introduces a new design variable in junction transistor triodes. The new structure (p-n-i-p or n-p-i-n) is believed capable of development into the microwave frequency range. Several factors which were of second order importance in p-n-p and n-p-n units such as emitter depletion layer capacitance and collector transit times become significant in limiting ultimate performance. The thick depletion layer permits operation at higher voltages than were previously possible in any but low frequency units.

Moderately good results have been obtained already. Units having 10 mil emitter diameter, 15 mil collector diameter have produced stable gains without compensation of 20.5 db at 10 mcps and have oscillated at 95 mcps.

The junction transistor now promises to be a serious competitor to high vacuum triodes over a much larger range of frequencies and power levels than before.

ACKNOWLEDGMENTS

J. A. Morton and R. M. Ryder have strongly supported and encouraged this work. J. W. Peterson and W. C. Hittinger have collaborated in and contributed to the experimental studies. The models constructed and tested are the products of the persistent efforts and many useful suggestions of J. A. Wenger, J. McGlasson, and L. P. Meola. Many others, particularly those engaged in semiconductor materials research

* These measurements were made by L. G. Schimpf.

and development, have also assisted us. Discussions with colleagues have been most helpful in preparation of this report.

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