Factors Affecting Reliability of Alloy Junction Transistors*

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Summary—**Oxygen and water vapor, when individually in contact with the transistor surface, have been found to cause substantial and generally opposite changes in the characteristics of germanium alloy junction transistors. These changes, however, are reversible: by means of vacuum baking a reproducible set of characteristics can be repeatedly reestablished after water vapor or oxygen has caused a large change in the characteristics. Very pure forms of other ordinary gases, such as hydrogen, nitrogen, and helium, are found to have no effect on these transistors.**

Very nearly ideal time stability of characteristics can be obtained, even under severe aging conditions, when water vapor and oxygen are completely removed and permanently excluded from the transistor surface, although under some circumstances a very pure atmosphere of oxygen (or air) may be desirable for the *p-n-p* transistor.

INTRODUCTION

As a SOLID-state competitor to the vacuum tube, the transistor offers the promise of an extremely high order of stability and reliability, inasmuch as the primary electronic processes occur inside a continuous solid, with no hot cathode or vacuum or delicate mechanical structure to go awry. The expected stability of the interior of the transistor has indeed thus far been borne out by experience, but the extent to which surface effects contribute to over-all behavior was not foreseen at first.

In early experience with transistors excessive water vapor was found to cause transistor deterioration by increasing the collector junction reverse current.[1] A solution to this difficulty appeared to lie in dry room temperature hermetic sealing, a practice which was widely adopted and is still being credited with insuring against transistor deterioration. However, when such hermetically-sealed transistors still exhibited serious deterioration of characteristics during severe aging tests, a more careful and detailed study was undertaken to determine the cause of the deterioration.

In particular, the study was made on freshly-etched germanium alloy or "fused" junction transistors of both the *n-p-n* and the *p-n-p* types, similar in basic structure to those now widely marketed by various manufacturers (particularly of the *p-n-p* type). This basic structure is shown in Fig. 1.

The results of the investigation have disclosed that water vapor and oxygen individually have rather drastic effects on the transistor characteristics, such as junction breakdown voltage (V_B), junction reverse current (I_s), and alpha, whereas the effects of very pure forms of other ordinary gases, such as hydrogen, nitrogen, and helium are essentially nil.

NECESSITY FOR CAREFUL TECHNIQUES

Careful experimental techniques are necessary to separate the effects of oxygen and water vapor: 1) because of the prevalence of these two substances as normally encountered ambients, 2) because of the relative difficulty in completely removing them, 3) because of the large changes which each of them causes on transistor characteristics, and 4) because the effects of the two are generally counteracting. Therefore, to observe what are now believed to be the true individual effects of either water vapor or oxygen, the transistors used in this study were initially cleaned by baking in a high vacuum at as high a temperature as the particular transistor structure would permit.

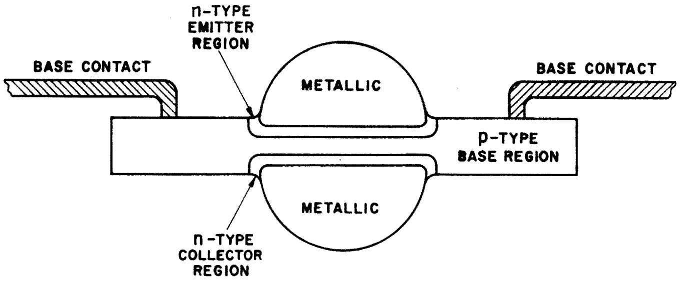

Fig. 1—Basic structure of alloy or "fused" junction transistor.

EXPERIMENTAL TECHNIQUES

Since the *p-n-p* transistor uses indium, whose melting temperature is about 150°C, the baking temperature was held to 135°C. On the other hand, since the *n-p-n* transistor uses arsenic-doped lead, it can be vacuum baked to at least 100°C higher temperature. A significant point of interest on the *n-p-n* is the fact that its characteristics are essentially the same whether the transistor has been vacuum baked at 135°C or 235°C, indicating that essentially all uncombined oxygen and water vapor is removed at the lower temperature insofar as effects on device parameters are concerned.

The vacuum in all cases was about 2×10^{-6} mm Hg. Spectroscopically pure reagent grade oxygen was used from glass bottles sealed to the vacuum station and ad-

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[1] R. M. Ryder and W. R. Sittner, "Transistor reliability studies," PROC. IRE, vol. 42, pp. 414–419; February, 1954.

mitted in measured quantities starting at a pressure of 2×10^{-2} mm Hg. In the case of water vapor, pure deionized distilled water was distilled once in the vacuum station under forepump vacuum into the cold trap and held at liquid nitrogen temperature during the vacuum baking process, then later released to give various vapor pressures by holding the cold trap at various temperatures starting at 0°C. (Before admitting oxygen or releasing water vapor, it was observed that the vacuum station could hold a high vacuum over long periods of time when shut off from the pumps.) When water vapor was used, pumping continued for a short time immediately after removal of the liquid nitrogen in order to remove any gases trapped with the water vapor. Such removal was evidenced by a rapid change in pressure from 2×10^{-6} mm Hg to about 5×10^{-5} mm Hg and back to about 4×10^{-6} mm Hg within about a minute after the liquid nitrogen was removed and before the beginning of the subsequent slow, steady rise in pressure due to release of water vapor. When the latter slow rise in pressure had begun, the system was shut off from the pumps and the temperature of the cold trap was brought up to 0°C by means of an ice water bath. The transistors did not change as a result of the first rapid pressure excursion into the 10^{-5} mm Hg pressure range. Since pumping was always started with a nitrogen atmosphere inside the vacuum station, most of this pressure was quite probably due to nitrogen, which has no effect on these transistors.

The results presented here were obtained with both *n-p-n* and *p-n-p* transistors on the vacuum station at the same time. The *n-p-n* transistors were designed with low α for a particular application. Since they were symmetrical units (emitters and collectors of same area), the α for each transistor was approximately the same in either direction, and the junction reverse currents were in the same range of values for emitters and collectors. On the other hand the *p-n-p* transistors had collector diameter twice the emitter diameter, hence the reverse currents of the collectors were correspondingly higher and the alpha in the normal direction much higher than that in the inverted direction (when emitter and collector are interchanged).

The experimental procedure consisted of taking measurements of the transistors in the sequence of steps shown in Figs. 3 to 8. The "vacuum bake" readings were taken after the transistors had cooled to room temperature but were still in high vacuum. The other readings were taken also at room temperature with the transistors in the various pure ambient atmospheres as shown.

Definition of Measurements

The junction breakdown voltage (V_B) is defined as the voltage at which the reverse current is 20 microamperes higher than the low voltage saturation current. In most cases this measurement was quite well defined, particularly for the *n-p-n* transistors. The reverse junction impedances were high (>10 megohms) and then with increasing voltage broke quite sharply to very low impedances. In general, the effect of the ambient (oxygen or water vapor) was to cause a shift of the characteristic parallel to itself to a different saturation current and different breakdown voltage, leaving the junction impedance essentially unchanged, as shown in Fig. 2.

The reverse current (I_s) was measured at 18 volts reverse bias on the junction being measured and no bias on the other junction.

The α is the dc alpha measured at one milliampere emitter current and very nearly zero collector voltage.

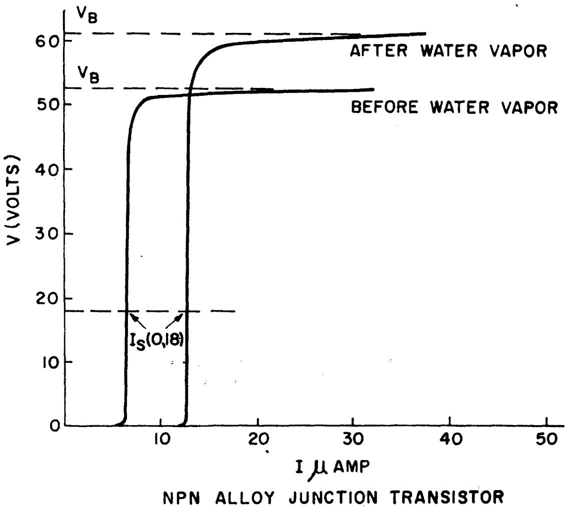

Fig. 2—Definition of I_s and V_B

Experimental Results

Figs. 3 to 8 (pp. 496–497) show how the junction breakdown voltage (V_B), junction reverse current (I_s), and α varied as a function of ambient, starting with a measurement in dry air before the first vacuum bake. Between successive exposures to oxygen and water vapor the transistors were vacuum baked and measured in high vacuum at room temperature.

Figs. 9 to 12 (p. 498) show how the median value of each parameter varied as a function of water vapor pressure or oxygen pressure, starting from a high vacuum after vacuum baking.

From a vacuum-baked reference condition the effects of oxygen and water vapor may be summarized as indicated below.

1) Oxygen
  a) On *n-p-n* alloy junction transistors
    1. Decreases the junction breakdown voltage (V_B)
    2. Decreases the reverse current (I_s)
    3. Decreases α.
  b) On *p-n-p* alloy junction transistors
    1. Increases the junction breakdown voltage
    2. Increases the reverse current
    3. Increases α.

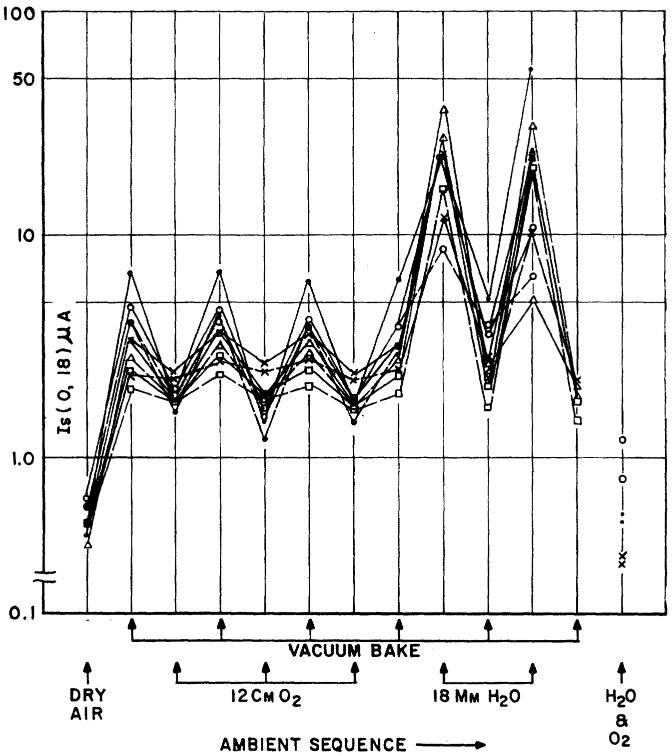

Fig. 3—Oxygen and water vapor effects on I_s of *n-p-n* alloy junction transistors.

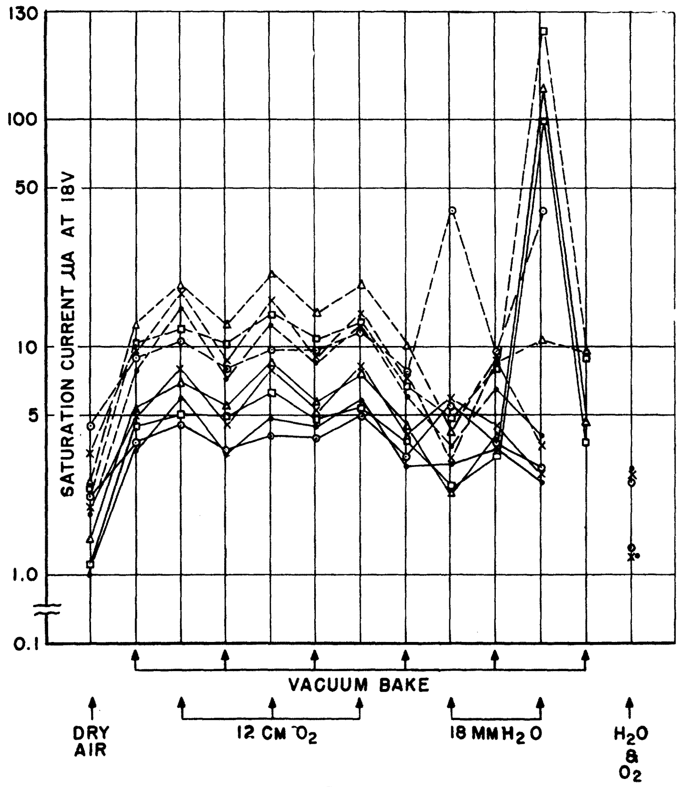

Fig. 4—Oxygen and water vapor effects on I_s of *p-n-p* alloy junction transistors.

2) Water vapor
   a) On *n-p-n* alloy junction transistors
      1. Increases the junction breakdown voltage
      2. Increases the reverse current
      3. Increases α.
   b) On *p-n-p* alloy junction transistors
      1. Decreases the junction breakdown voltage
      2. Decreases the reverse current until rather high vapor pressure is reached, then rapidly increases the reverse current.
      3. Increases α.

Some of the important features of the data shown in the figures are written below.

1) Vacuum baking produces a reference condition which can be re-established repeatedly after either oxygen or water vapor has produced a maximum change.
2) In general, the effects of water vapor and oxygen are counteracting, except that both substances cause an increase in alpha of *p-n-p* transistors.
3) On *n-p-n* transistors the highest reverse currents after vacuum baking are depressed most by oxygen.
4) The *n-p-n* junctions least sensitive to oxygen were actually the most sensitive to water vapor in regard to breakdown voltage.
5) In both types of transistors water vapor produces a greater change in α and I_s than does oxygen.

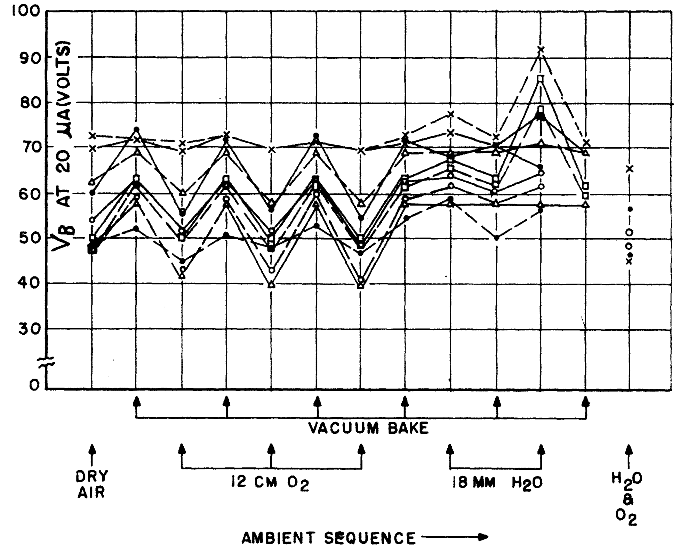

Fig. 5—Oxygen and water vapor effects on V_B of *n-p-n* alloy junction transistors.

6) Relative insensitivity of breakdown voltage to oxygen and water vapor does not necessarily mean that both α and I_s are also insensitive. Other results indicate that the I_s and α may be quite insensitive to water vapor and oxygen while the breakdown voltage can be strongly affected.
7) The effect of oxygen on all three parameters of both types of transistors definitely begins to be observable at a pressure of about 10^{-2} mm Hg,

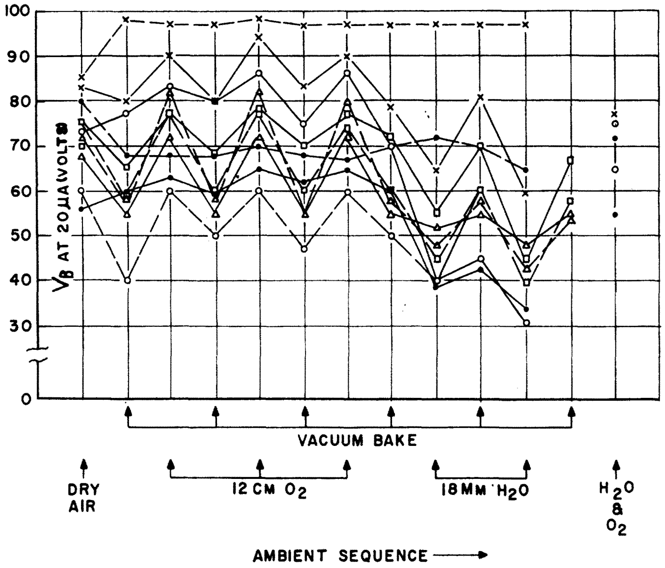

Fig. 6—Oxygen and water vapor effects on V_B of *p-n-p* alloy junction transistors.

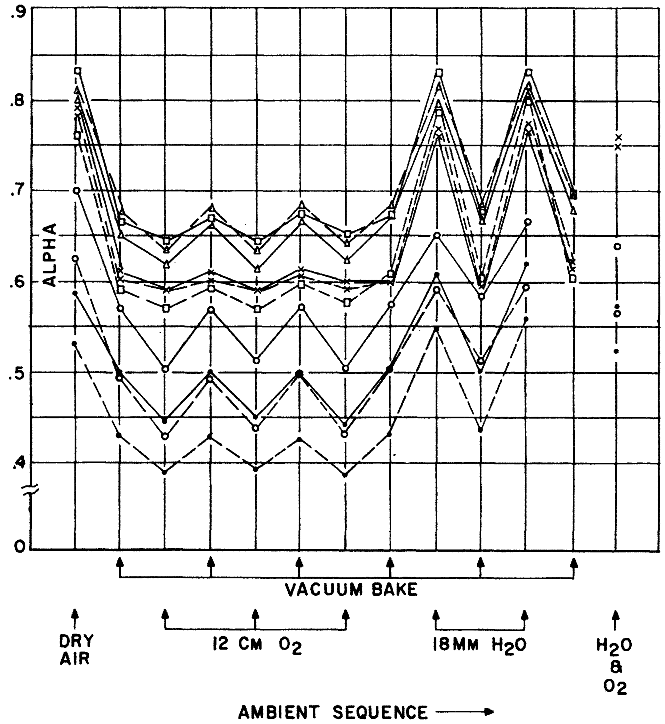

Fig. 7—Oxygen and water vapor effects on alpha of *n-p-n* alloy junction transistors.

which corresponds to the lowest measured quantity of pure oxygen admitted from a high vacuum condition.

8) After cycling with water and oxygen, the initial values of V_B, I_s, and α in dry air before the first vacuum bake can be very nearly regained by a combination of water and oxygen.

Additional observation on the effects of water vapor and oxygen is given as follows:

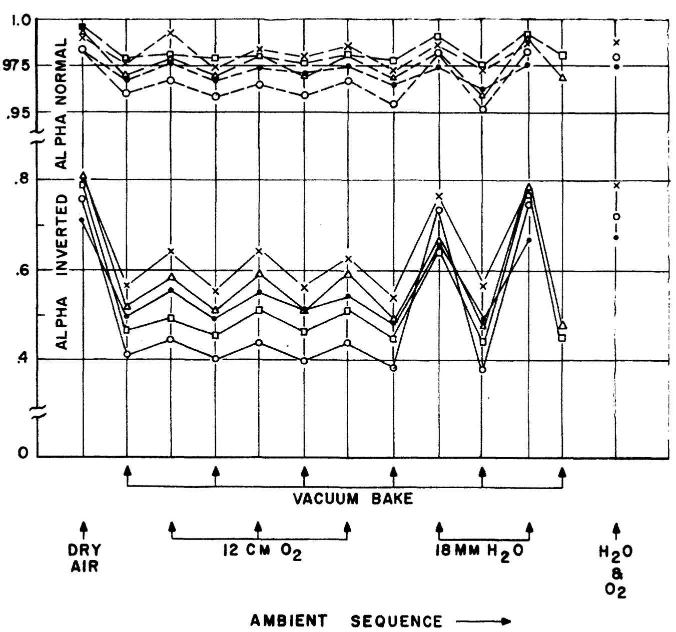

Fig. 8—Oxygen and water vapor effects on alpha of *p-n-p* alloy junction transistors.

1) In the presence of water vapor
   a) On *n-p-n* transistors
      1. Forward bias causes a rapid increase of I_s accompanied by an increase of α. Both I_s and α recede together upon removal of the forward bias.
      2. Reverse bias causes a much slower increase in I_s. The change caused by the reverse bias slowly disappears upon removal of the reverse bias.
   b) On *p-n-p* transistors
      1. Reverse bias causes a rapid increase in I_s. Initial values are regained at the same rate after removal of the bias.
      2. Forward bias causes no noticeable changes; however, when the characteristic is viewed by means of an ac sweep, as for example at 60 cycles for scope presentation, the forward sweep greatly reduces the apparent rate at which I_s increases during the reverse sweep.

The vapor pressure at which these effects begin to occur varies considerably among transistors. Many show very marked effects at 4.5 mm Hg vapor pressure of water when no oxygen is present.

2) In the presence of oxygen: Similar changes in I_s with bias are not observed. The breakdown voltage of *n-p-n* junctions fades to lower values with increase of applied voltage beyond the breakdown voltage; however, the opposite effect on *p-n-p* transistors is not so consistently observed.

3) Neither water vapor nor oxygen in the range of pressures used caused an observable change in junction capacitance, except that a possible slight increase in capacitance may have occurred on

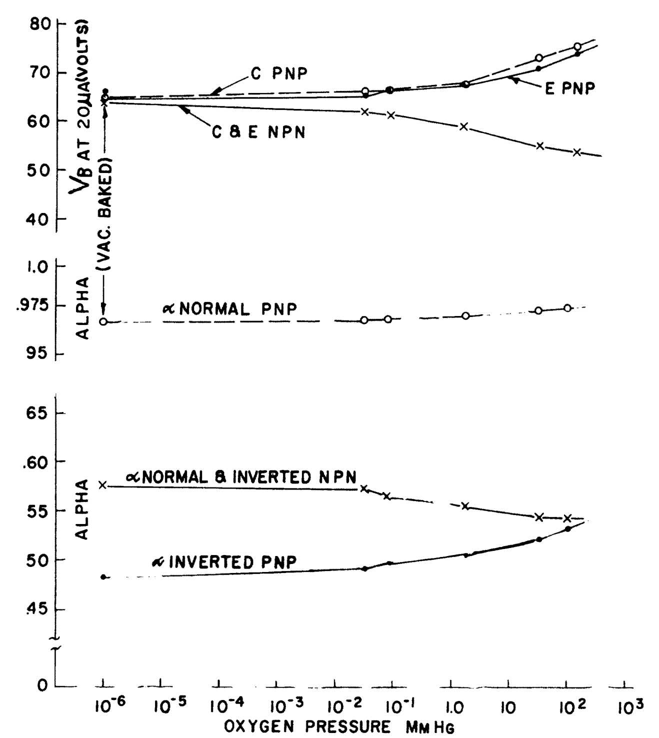

Fig. 9—Effect of oxygen pressure on V_B and alpha of *n-p-n* and *p-n-p* alloy junction transistors.

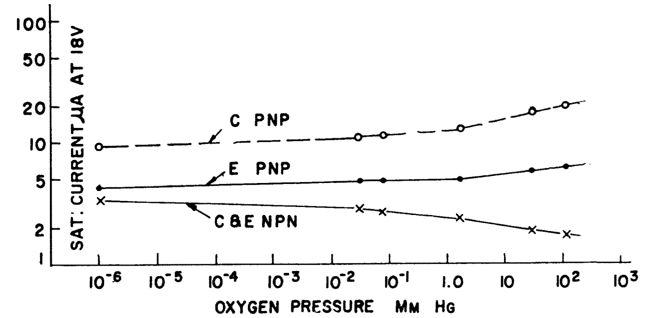

Fig. 10—Effect of oxygen pressure on I_s of *n-p-n* and *p-n-p* alloy junction transistors.

some of the *p-n-p* transistors in oxygen. (Capacitance was measured at 20 kc with 4.5 v reverse bias on the junction.)

Discussion of Experimental Results

The two conditions not very well reproducible both involve water vapor effects: on the I_s of *p-n-p* transistors, and on the V_B of *n-p-n* transistors. The lack of reproducibility in both cases may be to a large extent due to the fact that the effects are very critical in the range of high water vapor pressure. For the *p-n-p*, this is the vapor pressure range where water ceases to decrease the I_s and starts to increase it rapidly. This switch does not occur at exactly the same vapor pressure for all *p-n-p* junctions. A variation in room temperature of a degree or two could affect the results significantly. In the case of V_B increase on *n-p-n*, the effect also occurs in most cases at a rather high vapor pressure, and the amount of increase varies considerably, many junctions showing rather little increase. Sometimes the failure to observe V_B rise was due to the fact that the forward half of the ac sweep voltage with which V_B is measured drove the saturation current to such high values that legitimate observation of V_B was impossible at the high vapor pressures where the V_B enhancement might occur. It was found that if the forward half of the sweep is blocked out by an external diode, good readings of V_B are possible in the high vapor pressure range.

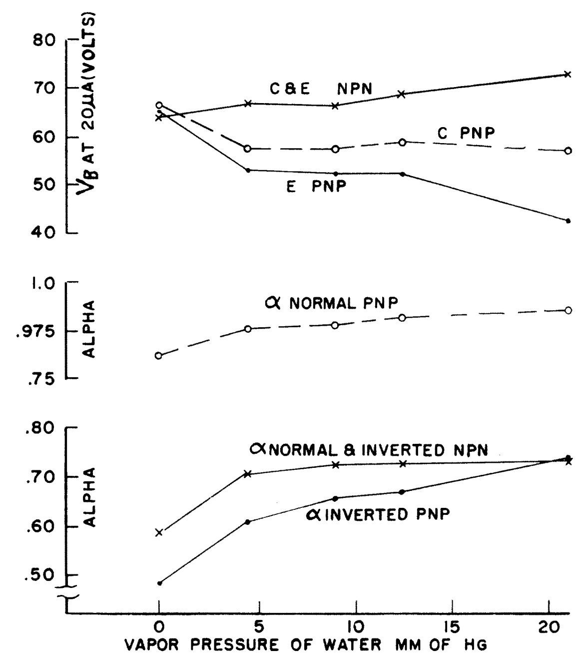

Fig. 11—Effect of water vapor pressure on V_B and alpha of *n-p-n* and *p-n-p* alloy junction transistors.

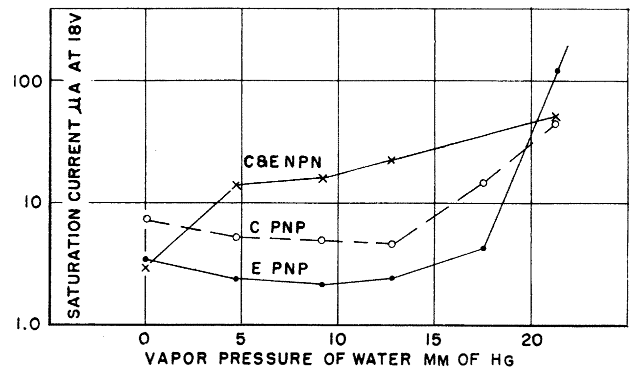

Fig. 12—Effect of water vapor pressure on I_s of *n-p-n* and *p-n-p* alloy junction transistors

Discussion of Mechanisms

A possible explanation for the direction of shift of V_B may be made in terms of the avalanche breakdown phenomenon reported by McKay.[2] In this process the breakdown in the interior is a function of the integrated electric field across the space charge region and of the geometry of the junction. Since the width of the space

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[2] K. G. McKay and K. B. McAfee, "Electron multiplication in silicon and germanium," *Phys. Rev.*, vol. 91, p. 1079; September 1, 1953.

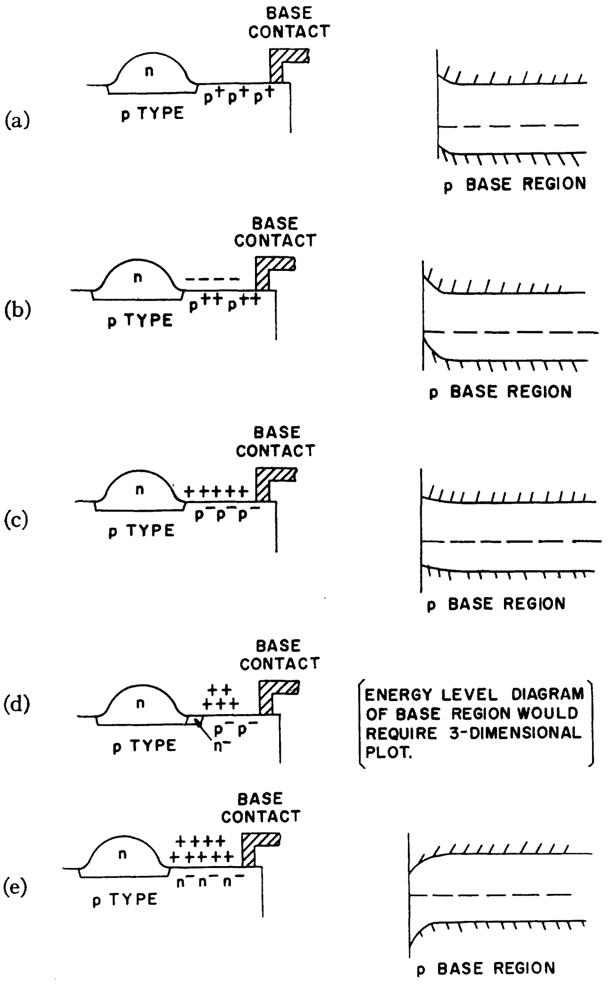

Fig. 13—(a) Normal condition, neutral ambient (surface more *p* type than interior because net V_B<body breakdown), *n-p-n* transistors. (b) Oxygen ambient, no bias, *n-p-n* transistor. (c) Water vapor ambient, no bias, *n-p-n* transistor. (d) Water vapor ambient, reverse bias, *n-p-n* transistor. (e) Water vapor ambient, high vapor pressure, no bias, inversion layer on base region, *n-p-n* transistor.

charge region, for a given geometry, is a function of the resistivity, the breakdown voltage can be related directly to the resistivity. For the kind of junction in these transistors,[3] S. L. Miller[4] has shown experimentally that the body breakdown voltage varies directly with ρ^n, where ρ is the base resistivity and n is about $\frac{3}{4}$. The net V_B, then, is apparently determined by the lowest resistivity path from junction to base contact. Except in cases where base resistivity is purposely made very low, the V_B of these devices nearly always turns out to be much lower than the V_B expected from the resistivity of the bulk base material. One may say that the measured V_B of the junction is usually determined by breakdown occurring across the junction in the surface layers of semiconductor at lower voltage than for the body junction. If one makes a speculative extrapolation of the body behavior to the surface, one can conclude that

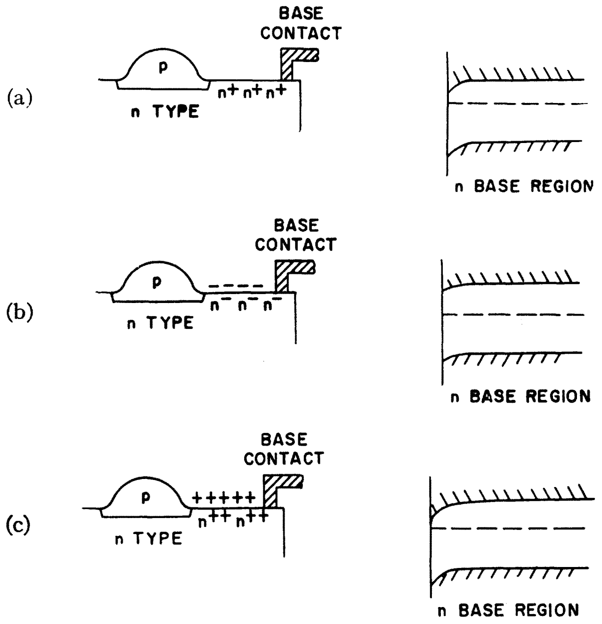

Fig. 14—(a) Normal condition, neutral ambient (surface more *n* type than interior because net V_B<body breakdown), *p-n-p* transistor. (b) Oxygen ambient, no bias, *p-n-p* transistor. (c) Water vapor ambient, no bias, *p-n-p* transistor.

the resistivity near the surface is lower than that of the interior, as depicted in Figs. 13(a) and 14(a). With this picture the effects of ambients can now be considered.

Let us first examine the effects of oxygen on these transistors. Upon contact with the surface the molecular oxygen apparently dissociates into atomic oxygen, which then satisfies its usual hunger for extra electrons and thereby produces negative ions. In the preservation of net charge neutrality the material immediately under the ionized oxygen acquires a positive space charge, which causes its resistivity to shift toward *p* type. On the *n-p-n* this process drives the surface resistivity to still lower *p* type, as shown in Fig. 13(b), thus decreasing the measured V_B. In a similar manner on the *p-n-p* the oxygen ions on the surface of the base region also shift the surface resistivity toward *p* type but not far enough to cause inversion. The net result is simply an increase in the *n* type surface resistivity as shown in Fig. 14(b), thus causing an increase in the measured V_B.

The behavior of water is more difficult to understand. Apparently water acts in such a way as to produce the net effect of positive ions on the surface.[5] In a manner analogous to the oxygen behavior, these positive ions on the surface of the base region induce a negative space charge near the surface, thus causing the surface resistivity to shift in the direction of *n* type. On the *n-p-n* transistor V_B is increased because the shift of surface resistivity toward *n* type has stopped short of actual inversion and merely caused an increase of *p* type resistivity, as shown in Fig. 13(c). On the *p-n-p* water vapor decreases V_B because the negative space charge induced

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[3] Step junctions, with base resistivity at least two orders of magnitude greater than that of the emitter and collector.

[4] S. L. Miller, "Avalanche breakdown in germanium," *Phys. Rev.*, vol. 99, p. 1234; August 15, 1955.

[5] J. T. Law, "A mechanism for water induced excess reverse dark current on grown germanium *n-p* junctions," PROC. IRE, vol. 42, pp. 1367–1370; September, 1954.

by the positive ions on the surface causes the surface resistivity of the base region to shift to still lower *n* type, as shown in Fig. 14(c).

This picture of V_B behavior would also explain how water, which at first enhances V_B on *n-p-n* transistors, eventually causes V_B to fall suddenly to zero as the vapor pressure becomes very high. Such a sequence could happen as the surface layer, in shifting toward *n* type, first goes through high *p* type resistivity until actual inversion takes place, whereupon the junction becomes shorted by an *n*-type bridge to the metal base contact.

Now let us turn our attention to the behavior of I_s and α. If the effect of the ambient on these two parameters is due only to a change in surface recombination, then they should change in opposite directions. The only case in which such a combination of change occurs is that of water vapor on the *p-n-p*. To check this case quantitatively, a set of equations developed by Brattain and Garrett[6] were used. These equations give both I_s and α in terms of surface recombination for a structure similar to that of the transistors used in this study. With the observed data of Figs. 11 and 12 the results show to within about 10 per cent that the I_s and α change can actually be accounted for in terms of surface recombination change alone. In all other cases, however, α and I_s change in the same direction, indicating that one or more other mechanisms are also acting.

One method by which I_s and α could increase or decrease together would be by the formation or elimination of an inversion layer extending from the junction partway over the base region, thereby changing the effective junction area. Such an inversion layer could conceivably be established with the aid of the bias voltage, as shown in Fig. 13(d) if, for example, the water vapor pressure were high enough. However, if the junction area is changed, the junction capacitance should be correspondingly changed, but measurements showed no observable change in capacitance for the range of water vapor pressures used in this study. A slight increase in capacitance may have occurred with oxygen on some *p-n-p* units, but such an increase, even if real and not due to measurement error, would correspond to such a small change in junction area that it could probably not account for the observed changes in I_s and α.

Thus, if the absence of capacitance changes are accepted as a true indication of the absence of inversion layers and if the behavior of I_s and α cannot be accounted for in terms of changes in surface recombination, one must look for some other mechanisms.

This limited qualitative discussion is not intended to be complete or very accurate at this stage. Study of these phenomena in order to lead to an understanding of the mechanisms is a subject well worthy of separate treatment and will not be pursued further in this article. It should be emphasized however, that no claim is made here that inversion layers cannot be established by water vapor or oxygen. In fact, it seems quite logical that for certain kinds of surfaces a high enough concentration of either of these ambients can indeed establish inversion layers, as depicted for water vapor in Fig. 13(e), and this possibility is borne out by observations of other workers for the case of water vapor. In this study, however, the effects observed on I_s, α, and V_B start at very low pressures of oxygen and water vapor, and the changes caused in these parameters are quite appreciable before actual inversion layers are established. Voltage bias on the junctions apparently adds still further complication to the action of these ambients.

PRACTICAL SIGNIFICANCE

The practical significance of these water-oxygen effects lies in the behavior of these transistors under conditions of severe aging. Under nominally dry room ambient conditions, the counteracting effects of water and oxygen usually combine to yield very good transistor characteristics. If an attempt is made to capture and hold these characteristics by the standard type of room temperature hermetic sealing process, the stability of the transistor characteristics may be satisfactory, provided the transistor is afterward never heated much above room temperature. However, if the transistor is held for appreciable periods at an elevated temperature, such as 85°C with or without voltage bias applied, the changes in critical device parameters may be considerable when measured again at room temperature. These changes can usually be attributed to water vapor or oxygen driven off from the inside surfaces, thus upsetting the balance normally existing under nominally dry room ambient conditions.

The best technique known at present for the removal and exclusion of water vapor and oxygen involves vacuum baking and vacuum-tight sealing, leaving the transistor either in vacuum or in a very pure atmosphere of one of the various gases which do not affect it, such as nitrogen,[7] hydrogen, or helium. (The latter two are good heat conductors.) Evacuation without heating has been found to be inadequate because the internal surfaces of a sealed device may later evolve both water and oxygen if during evacuation the whole assembly is not heated to a temperature much higher than that to which it is subsequently subjected after seal-off. Under such circumstances the hermetic seal may be more harmful than helpful because it prevents the excessive contamination from escaping.

An argument can be made that vacuum baking makes the transistor surface extremely sensitive to either water or oxygen. Actually, the true sensitivity of the surface is probably unchanged, but removal of both water and oxygen causes an apparent increase in the

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[6] W. H. Brattain and C. G. B. Garrett, "Experiments on the interface between germanium and an electrolyte," *Bell Sys. Tech. Jour.*, vol. 34, p. 172; January, 1955 (equations A18).

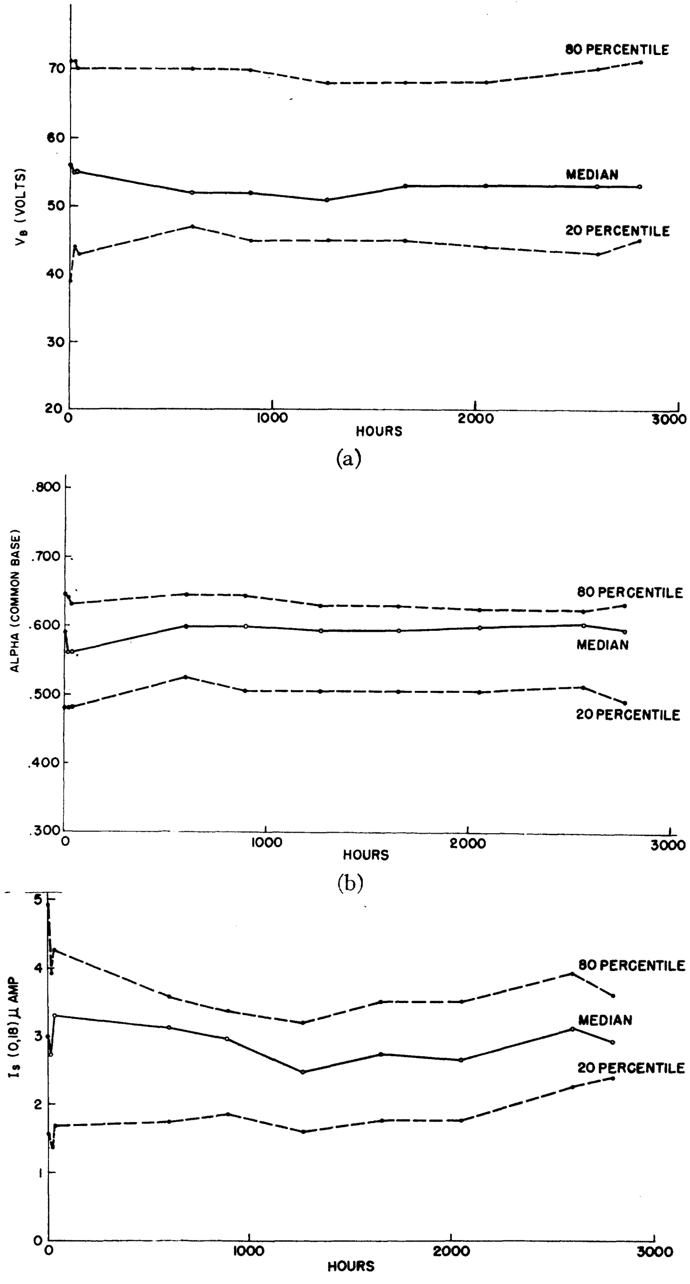
[7] Ordinary tank nitrogen, for example, usually has enough oxygen in it to make a noticeable effect on these devices.

sensitivity to either one of these substances because together, as normally observed under room ambient conditions, they counteract each other. An illusory reduction in sensitivity can be restored by admitting to the surface a little of both, but such a measure also restores the unreliability.

Although the best environment for *n-p-n* transistors is an absence of oxygen and water vapor, under certain conditions an atmosphere of oxygen may be desirable for *p-n-p*'s. For example, if the increase in I_s is tolerable, the oxygen enhancement of V_B and α may be attractive. However, the long term effects of oxygen in the absence of water vapor have not been evaluated.

It is known that certain surface oxides actually do reduce the sensitivity of the transistor to water vapor and oxygen. The use of such oxides, if established in a consistent and controlled manner, would be highly desirable, provided that no adverse results, such as high I_s or low V_B, would be produced on initial characteristics. Unless such oxides offer complete protection, however, the vacuum baking technique or its equivalent for final encapsulation will be necessary where good reliability is required; in fact it may always be necessary for good reliability as an extra safety factor, or particularly where the oxide does not cause complete insensitivity under all conditions and for long periods of time.

The experience of several thousand hours of severe aging tests has shown that the gradual deterioration which is characteristic of transistors hermetically sealed in the usual room temperature dry box environment can be essentially eliminated by the vacuum baking and sealing process in final encapsulation. Figs. 15(a), 15(b), and 15(c) show aging results for a typical batch of fifteen *n-p-n* transistors processed in this way and then held at 85°C with 28v reverse bias on each junction, but interrupted long enough for room temperature measurements.[8] By contrast, Figs. 16(a), 16(b), and 16(c), on the next page, show aging results for a group of ten *n-p-n* transistors hermetically sealed in a dry room temperature environment, then held at 65°C with 28v reverse bias and brought back to room temperature long enough for measurements. But these latter results, may not necessarily be the same as from another group of such transistors. In other cases reverse currents may not come down again with time and may in fact go even higher. Likewise breakdown voltage and alpha may change by different magnitudes. All of these features add to the unsatisfactory nature of the aging results from the transistors hermetically sealed in the ordinary "dry" room temperature environment and then subjected to aging at elevated temperatures. The remaining small fluctuations in the parameters of the vacuum-baked units are quite probably due largely to measurement error and other extraneous factors.



(a)

(b)

(c)

Fig. 15—(a) 15 *n-p-n* transistors, vacuum-baked and sealed, aged at 85°C with 28 v reverse bias, measured at room temperature. (b) 15 *n-p-n* transistors, vacuum-baked and sealed, aged at 85°C with 28 v reverse bias, measured at room temperature. (c) 15 *n-p-n* transistors, vacuum-baked and sealed, aged at 85°C with 28 v reverse bias, measured at room temperature.

CONCLUSION

The major significant changes caused by water vapor and oxygen on vacuum baked *n-p-n* and *p-n-p* germanium alloy junction transistors can be qualitatively summarized in Table I.

TABLE I

	O_2		H_2O	
	n-p-n	*p-n-p*	*n-p-n*	*p-n-p*
V_B	↓	↑	↑	↓
I_s	↓	↑	↑	↓↑
α	↓	↑	↑	↑

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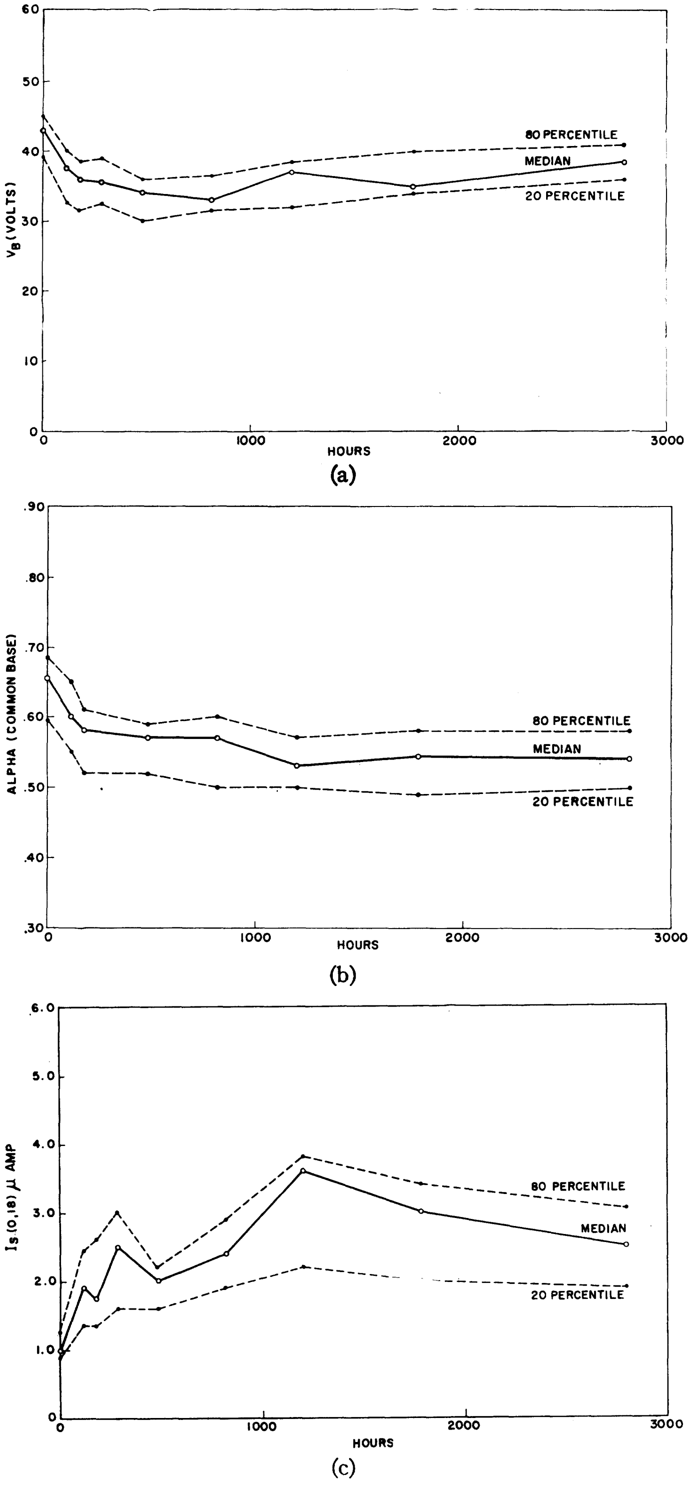
[8] Note again that these transistors, by design, have a low alpha for a special application. They can also be made with high alpha, but for these studies the low alpha units are particularly suitable because the low alpha is more sensitive to changes in the ambient.



(a)

(b)

(c)

Fig. 16—(a) 10 *n-p-n* transistors, hermetically sealed at room temperature, aged at 65°C with 28 v reverse bias measured at room temperature. (b) 10 *n-p-n* transistors, hermetically sealed at room temperature, aged at 65°C with 28 v reverse bias measured at room temperature. (c) 10 *n-p-n* transistors, hermetically sealed at room temperature, aged at 65°C with 28 v reverse bias measured at room temperature.

The results are reversible and reproducible to a very good degree from the first cycle.

Although these observations were made on freshly-etched transistors, other experiments show that the effects are essentially the same for units subjected initially to oxygen atmosphere at room temperature with voltage sweep applied for as long as two weeks after final etching.

For most transistors as normally made at present and then vacuum baked, the effects of oxygen begin to be noticeable at pressures as low as 10^{-2} mm Hg, while water vapor at a pressure corresponding to water held at 0°C (4.6 mm Hg) causes a marked effect on the parameters under observation (V_B, I_s, α).

Excellent aging results have been obtained from those transistors from which oxygen and water vapor have been removed and excluded. Cases of departure from essentially flat aging on such units may be traced to imperfect removal and/or exclusion of oxygen and water. (Small leaks in the container can be a major source of trouble.)

The following conclusions may be drawn from these studies.

1) In ordinary applications where the transistor will not be operated much above room temperature or where extreme stability of characteristics is not required, the dry room temperature hermetic sealing process for final encapsulation may be adequate.
2) In severe applications requiring a high order of stability and reliability while operating for prolonged periods at elevated temperatures, the vacuum-baking process, or its equivalent, is necessary for final encapsulation.
    a) In the case of the *n-p-n*, water vapor and oxygen must be eliminated and excluded, leaving the transistor either in vacuum in a very pure atmosphere of one of the various gases which do not affect its characteristics. (Hydrogen or helium would be best from the standpoint of heat conductivity.)
    b) In the case of the *p-n-p*, similar processing and protection is necessary, particularly against water vapor, but if the increase in reverse current can be tolerated, an atmosphere of pure air or oxygen may be desirable because of the enhancement of α and breakdown voltage. However, the long-term effects of oxygen in the complete absence of water vapor have not been evaluated.

The alternative to the above procedures would be the development of a surface which would make these transistors completely and permanently insensitive to oxygen and water vapor under all conditions of operation.

In general, we conclude that except for the rare case of a sudden failure, the originally expected stability and reliability of these transistors can indeed be realized, but only with a much higher order of surface clean-up and protection than was first believed necessary.