QUALITY CONTROL OF TRANSISTORS WITH RADIOACTIVE KRYPTON FOR THE ABSENCE OF LEAKAGE

By

Z. G. DEMJÉN and O. J. ORIENT

Department of Chemical Technology and Department of Atomic Physics, Technical University, Budapest

(Received July 19, 1968)

Presented by Dr. I. SZEBÉNYI

I. Introduction

The failure of proper sealing is a recurrent defect in semiconductor diode and transistor manufacturing. The problem of safe and quick checking of semiconductor electronic components for taking air has been discussed for some time. Transistors that take air are liable to age much earlier than those properly sealed. A transistor when switched on, warms up to a certain degree. If it has a leakage, part of the air in the envelope leaves and, as the transistor is switched off and cools down, it takes air from the atmosphere again. Air taken in unavoidably introduces components such as water vapour, strongly deleterious for the semiconductor layer. Though the transistor proper is surrounded with silicon grease or some other layer to protect the sensitive structure, harmful matters, for instance moisture, cannot be prevented from penetrating to the sensitive components. The higher the number of switchings on and off the greater the amount of contamination that will have access to the inside of the device, and finally the process results in early ageing.

From those said above it is clear that a leaking transistor will sooner or later break down and some adequate method must be found for its sorting out.

For the detection of big holes, literature [1] describes test methods with the use of liquids. Water, alcohol or some detergent is applied. The transistors are immersed in the liquid, subjected to a pressure of 5 to 20 atm for a short time, and the drops of the main electronic parameters of the device are tested. For instance, the firm SGS Fairchild [1] immerses the transistors in 2 per cent aqueous detergent solution and applies 7 atm pressure to them for 15 minutes. If after this test the characteristic of the transistor is found unaffected, a helium leak test is applied to detect finer holes.

In a helium leak tester the transistors are subjected to He gas pressure of 5 to 20 atm, and helium oozing out of the transistor is examined by mass spectrometry. The transistor may be considered as free from leakage if the gas streaming out is not more than 10^{-18} atm cm^3/sec [1, 3]. COOPER [2] states that by this method holes of the same size as those detectable with the radioisotope method can be detected. Helium leak test, however, is of much poorer productivity than the radioisotope test and the quality control of the entire production of a factory by this method is quite out of the question.

Another method of high sensitivity is the bubble test in which the transistors are tested in oil under vacuum [2]. A significant drawback of this method is the need of piece-by-piece examination.

The application of radioactive materials to detect faulty pieces has been also considered. Namely, if the transistors are subjected to pressure in a radioactive gas, say, in radioactive xenon or krypton, defective transistors under pressure will take in more or less radioactive material. As a consequence, they become radioactive themselves, and the drop of their activity is in proportion with the amount of the gas leaking out from them. For the purposes of the test only radioactive inert gases are used, in the first line krypton, as inert gases will not enter into reaction with the material of the transistor and even if a leakage happens to occur in the equipment, this does not imply any significant radiation hazard to the workers. Papers on this topic have been published in literature [2, 4]. A number of commercial test apparatus to this end is available in the U.S.A. and so are catalogues to them. The apparatus described in the folder of the firm Consolidated Electrodynamics [5] uses krypton* as a radioactive rare gas, yet neither the folder, nor literature available states the specific activity of the gas. According to information given by the manufacturers, 750 transistors can be tested in an hour and, under favourable conditions, the number can be increased as high as to 2500 per hour. The whole apparatus is not larger than a biggish writing desk and, of course, is equipped with adequate protection. It is a point of importance that the apparatus, though working with radioactive krypton gas, is absolutely safe as regards radiation hazard, even if the whole activity happened to get into the atmosphere of the room all of a sudden. This means that with the application of suitable exhaustion, the equipment is perfectly safe even in the case of a total failure.

The authors have set the aim to develop a test apparatus *a)* suitable for the quality control of the whole production, fairly considerable, in Hungary, and *b)* that can supply information for a scientific analysis method fit for the estimation of the sizes of the holes and of the cavities behind them, etc.

2. Test apparatus

The most important parts of the apparatus are two identical saturating tanks, one of them holding radioactive gas. This arrangement permits batches of transistors to be subjected to pressure in alternation. To our knowledge

---

* Only Kr-85 of $t_{1/2} = 10.6$ years can be considered.

this arrangement and method of operation can be considered as new. Their application results in the cutting down of the number of pumpings over to half.

In an industrial test apparatus the use of a hand pump deemed inadequate. Tests with a refrigerator motor piston pump compressor have been set up, as the specifications required by the operation conditions of a refrigerator seemed to suit our purposes. The diagram of the apparatus is represented in Fig. 1.

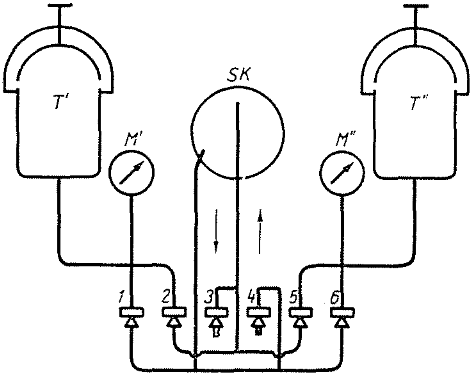

Fig. 1. Outline diagram of equipment

Transistors are introduced into tanks T' and T'' in cylindrical wire net baskets. Pressure gauges M' and M'' read the pressures prevailing in the tanks. The zero points of the pressure gauges have been shifted so that they are fit to indicate vacuum, at least qualitatively. Suction compressor SK is placed between the two tanks. The piping on the delivery end of the compressor carries taps 1, 4, 6 and that on the suction end taps 2, 3, 5. To fill the apparatus with radioactive gas to the pipe stub on the three taps a backing-vacuum pump and an ampoule of Kr 85 with a breaking seal, for backwash an argon bottle are connected. The system is complete with a closed mercury pressure gauge.

Taps 1, 2, 3, 5 and 6 are turned open, the system is evacuated and the SK pump put into operation. The high-vacuum pump is shut off with a glass tap. Also taps 2, 5 and 6 are shut off and the breaking seal is broken open. Radioactive krypton flows through the SK pump *via* tap 1 into the tank T'. Tap 3 is shut and the glassware is filled with argon to near-atmospheric pressure, the valve of the argon bottle is closed, and through tap 3, pump SK (and tap 1, kept invariably open) the gas from the apparatus is rinsed into tank T'. Having repeated this procedure 8—10 times on the Kr 85 ampoule no activity is signalled any more, the whole amount of radioactive gas has been transferred to tank T' and pressure gauge M' reads a pressure of 5 atm or so. Taps 1 and 3 are turned shut, the glassware cut off, and the apparatus is ready for test.

The transistors to be tested, placed in a metal basket, are introduced into tank T'', the *SK* pump is started, taps 4 and 5 opened and air from T'' evacuated. This takes a few minutes' time. Tap 4 is closed, 2 opened, and through taps 2 and 5 the difference of pressure in tanks T', T'' equalized. Tap 5 is shut off, tap 6 opened (with taps 2 and 6 open), the *SK* compressor evacuates tank T' to a vacuum of 150 Torr, while the pressure in tank T'' reaches about 6 atm. All taps are closed, the motor stopped and the apparatus allowed to rest for 23 hours.

Next day the evacuated tank T' is vented through taps 1 and 4, then opened and, if work is continuous, the basket full of transistors to be tested is introduced into it. Tank T' is shut off again and evacuated to atmosphere (Tap 1 closed, tap 2 open). This takes place after the pump *SK* has been started. Tap 4 is closed, tap 5 opened and pressure equalized. Tap 2 is shut and tap 1 opened. The pump *SK* now evacuates tank T'' and builds up pressure in tank T'. When this has been reached, all taps are shut and pump *SK* is stopped. To get access to the transistors put under pressure on the day before tank T'' is vented through valves 4 and 6, after which it can be opened and the transistors in the basket are removed. In non-continuous work, when the tank into which radioactive gas is driven has not been charged with transistors, the respective pressure gauge does not read the usual value either.

The activity of the Kr-85 gas in the ampoule is 50 mCi, and the normal volume belonging to it is 70 mCi/ml. With the volumes and pressures used the volume of the radioactive material may be neglected. 3000 transistors were placed in the tank, their overall volume was 760 ml. The free volume for the radioactive gas is 3520 ml. Calculating the activity for 1 ml volume of the tank we find

$$A_1(1/\mathrm{ml}) = \frac{50 \times 3.7 \cdot 10^7}{3520} = 5.27 \cdot 10^5 \,\mathrm{tps/ml}$$

3. Test method

Considering the relatively thin transistor walls the measurement of beta radiation deemed best. Beta radiation was measured with an end-window GM counter, the thickness of the window was 3 mg/cm^2.

With regard to the great number of transistors to be tested a preliminary quick activity measurement with a ratemeter seemed the best, as by this means to ascertain directly with an instrument whether a transistor is or is not radioactive takes not more than 5—10 seconds.

From among the transistors tested 27 were found to be radioactive. We wish to point out that all of the transistors coated with lacquer outside were found radioactive, and we think that this comes from radioactive gas having been diffused into the lacquer. Considering this, the method is unsuitable for the testing of lacquer-coated transistors.

The 27 transistors sorted out were subjected to a closer examination. As their activity was relatively low, for measurements of higher accuracy the use of a scaler seemed advisable. The activity of each transistor was measured for 20 minutes and background also was measured for 20 minutes in a similar way. To make an assessment possible the absolute activity of the radioactive material contained in the transistors had to be determined. In this test a radioactive preparation Tl 204 was used as a reference,* whose activity in the course of the measurement, in the whole solid angle was $N = 473\ 000$ tpm. With this reference the solid angle was determined in the following way: Let the number of impulses per minute measured with the reference be n, and the activity of the reference throughout the whole solid angle N, then the geometrical factor is

$$f_g = \frac{n}{N} = \frac{10\ 843}{473\ 000} = 0.02295$$

The transistor wall absorbs beta radiation to a larger or smaller extent, and for the determination of the absolute activity, of the material of the transistor wall, originally 0.3 mm thick, thinner absorbent laminae (of 0.0495 and 0.0895 mm) had to be made to determine the absorption coefficient.

One of the radioactive transistors was used as a radiation source. This was a good method, as this way the absorption coefficient was determined under a beta radiation of the same energy. From the activity measured without absorption (I_0) and that found with absorbent (I) the absorption coefficient (μ) results as

$$\mu = \frac{\ln I_0 - \ln I}{d} \tag{1}$$

where d is the thickness of the absorbent. The calculations have given the absorption coefficients as 19.3 and 23.2 mm^{-1} and we have used the arithmetical mean of the two values, i.e. 21.25 mm^{-1}.

From the known absorption coefficient the absorption factor can be calculated as:

$$f_a = \frac{I'}{I'_0} = e^{-\mu d'} \tag{2}$$

where I' is the radioactivity reduced by the wall of the transistor under test, μ the absorption coefficient already worked out, I'_0 the activity in the transistor and d' the wall thickness of the transistor. The absorption factor results as $f_a = 1.69 \cdot 10^{-3}$.

---

* As the energy of β is a little higher than that of Kr-85 to be used.

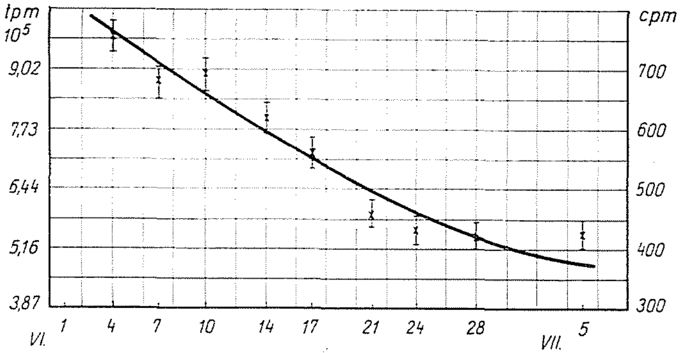

Fig. 2. Variation of activity of transistor No. 16 in time

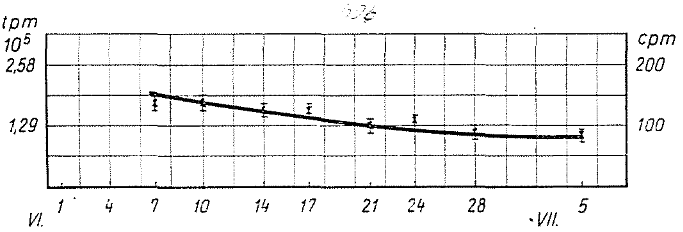

Fig. 3. Variation of activity of transistor No. 25 in time

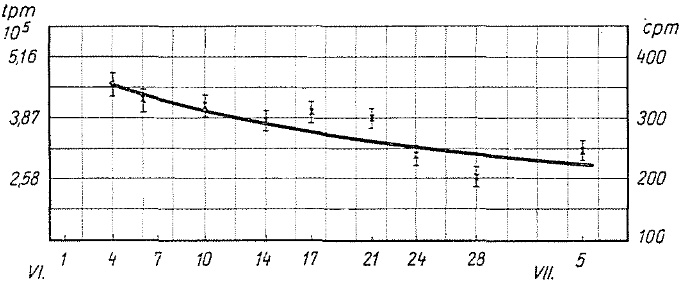

Fig. 4. Variation of activity of transistor No. 26 in time

Let the activity measured be a and the absolute activity A. Then the absolute activity in tpm is given as

$$A = \frac{a}{20 \cdot f_g \cdot f_a} \text{ imp/min}$$

The result has to be divided by 20 because the measurements lasted 20 minutes.

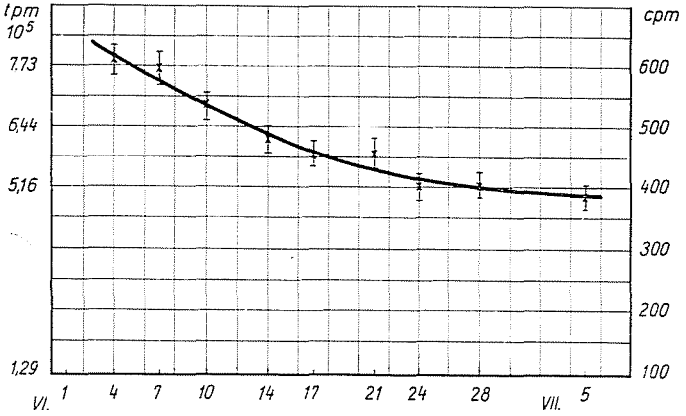

Fig. 5. Variation of activity of transistor No. 27 in time

In spite of the fact that the absorption factor, f_a, diminishes the measured activity by three orders of magnitude, the β measurement has proved to be the more accurate and reliable, as background is here very low (cf. the numerical difference between the two ordinates in the figures).

From the 1000 transistors tested 27 that showed radioactivity were sorted out and measured. Their activity is represented with the deduction of the background as an average of daily three measurements of 20 minutes each, with the indication of the measurement errors. As an example four such diagrams are shown (Figs 2, 3, 4, 5). The figures in their sequence correspond to the data of the transistors listed in Table 1 as Nos 15, 25, 26 and 27. In the quick activity measurement a problem arose: if the cavity in the transistor is not symmetrically located, the measured activity of the transistor will vary depending on the position. The cavities of the transistors may be expected to be oriented at random. The method of measurement had to be fixed unequivocally. By bending the outlets of the transistors in the same direction, a definite position was fixed. We measured the activity in this position, and the transistors turned about the long axis by 180°, under otherwise identical geometrical conditions. The measurement results obtained in the two positions, as a rule, were not the same. Our assumptions have been confirmed. Further on, we measured the radioactivity of the transistors always in that position in which a higher value was found.

Mathematical analysis

The development of a production quality control method requires the checking of the method by mathematical means and the analysis of the results. The extent of leakage as a figure does not give information enough on the size of the hole through which an air exchange may take place. The determination, at least as a fair approximation, of the possible equivalent circular hole size seemed desirable.

The measurement of leakage on the surface of a transistor is required in case of invisible microscopic point imperfections and cracks. Considering the small size of the holes we have considered a gas pressure of 1 atm as such to which in the neighbourhood of room temperature (20° to 80 °C) the Hagen—Poiseuille law applies, irrespective whether the filling gas is air or it contains some other gas, too. For the purposes of the calculations we have accepted the Hagen—Poiseuille law only for a short length of the channel so that

$$Q = \frac{R_s^4}{8\,\eta}\,\varrho\,\frac{dP}{dl} \tag{1}$$

where Q is mass flow, the mass of gas flowing through in unit time, R_s the radius of the equivalent circular channel, η the viscosity of the gas, P the pressure of the gas, ϱ the density of the gas and l a coordinate taken along the length of the channel. Assuming that the gas is an ideal gas, which at room temperature holds true also for air (the more so for rare gases) and considering that the same quantity of gas flows through each cross-section of the channel, from Equ. (1) we obtain for the pressure distribution:

$$P\,\frac{dP}{dl} = \frac{1}{2}\,C' \tag{2}$$

Namely, $Q =$ constant, and at constant temperature, by substituting P in the place of ϱ and combining all the other constants into a single constant term, from Equ. (1) Equ. (2) is obtained.

Integrate Equ. (2):

$$p^2 = p_0^2 + C'\,l \tag{3}$$

For an ideal gas, we may write:

$$\frac{\bar{\varrho}}{\bar{P}} = \frac{\varrho + K}{P + P_K} \tag{4}$$

and when temperature is constant:

$$\varrho\,\frac{dP}{dl} = \frac{1}{2}\;\frac{\varrho}{P}\,C' = \frac{1}{2}\,\frac{\varrho + \varrho_K}{P + P_K}\cdot\frac{P_K^2 - P^2}{l} = \frac{\varrho + \varrho_K}{2}\cdot\frac{P_K - P}{l}$$

where Equ. (3) has been taken into consideration and the symbols ϱ, P, ϱ_K and P_K stand for the density and pressure of the gas at other one and the end of the channel. Transpose this into (1). The result is

$$Q = \frac{R_s^4}{8\,\eta} \cdot \frac{\varrho + \varrho_K}{2} \cdot \frac{P_K - P}{l} \tag{5}$$

To describe the extent of leakage in vacuum techniques the expression

$$L = \frac{dP}{dt} \cdot V \tag{6}$$

is used. V is the inner volume of the transistor. Apply the equation of state of the ideal gas in this form:

$$V \cdot P = \frac{m}{M} RT \tag{7}$$

and differentiate with respect to time. Using Equ. (5) we obtain:

$$\begin{aligned} L &= V \frac{dP}{dt} = \frac{dm}{dt} \cdot \frac{RT}{M} = Q \cdot \frac{RT}{M} = \\ &= \frac{RT}{M} \frac{R_s^4}{8} \frac{\pi}{\eta} \cdot \frac{\varrho_K + \varrho}{2} \cdot \frac{P_K - P}{l} = \frac{R_s^4}{16\,\eta} \cdot \frac{P_K^2 - P^2}{Vl} \end{aligned} \tag{8}$$

hence

$$\frac{dP}{P_K^2 - P^2} = \frac{R_s^4}{16\,\eta \cdot l \cdot V} \cdot \mathrm{dt} \tag{9}$$

This equation presents two alternatives for integration and following from this, there are two sets of solutions:

$$\begin{aligned} P &= P_K \,\mathrm{th}\ [\lambda(t + a)] \qquad & P < P_K \\ P &= P_K \,\mathrm{cth}\,[\lambda(t + a)] \qquad & P > P_K \end{aligned} \tag{10}$$

and

$$\lambda = \frac{P_K \cdot R_s^4 \pi}{16\,\eta \cdot l \cdot V} \tag{11}$$

Using the two solutions found in (10) the pressure prevailing inside the transistor may be written as

$$P = P_K \,\mathrm{cth}\, \lambda(t + a) = P_K \frac{P_0 + P_K \,\mathrm{th}\, \lambda t}{P_K + P_0 \,\mathrm{th}\, \lambda t} \tag{12}$$

where P_K, a and P_0 are integration constants. P_K means the final pressure that prevails in the transistor when equilibrium has been reached, P_0 the pressure existing at the beginning of the time measurement. If the function $P = Pf(t)$ is known empirically (the data are tabulated) or, if this function though unknown, another function in proportion to it and of the same course, such as the activity of the tracer gas applied, is available (we wish to remark that the absolute activity is not essential in the calculation for measurements performed under identical conditions the count is sufficient; λ can be calculated.

From the measurement points the time dependence of the activity as well as the initial and final activities can be determined. It should be noted that the measurement points themselves are not used in the calculation, and

Table 1

No.	l · Torr/sec	$\varnothing$ μ	Volume, ml	Choking, %
1	$5.2 \cdot 10^{-9}$	0.5	0.12	90
2	$2.46 \cdot 10^{-8}$	0.2	0.25	66
3	$3.91 \cdot 10^{-9}$	0.8	0.04	93
4	$3.9 \cdot 10^{-8}$	0.8	0.40	72
5	$7.9 \cdot 10^{-9}$	0.5	0.05	77
6	$7.5 \cdot 10^{-8}$	1	0.41	46
7	$3.8 \cdot 10^{-8}$	0.8	0.10	72
8	$1.9 \cdot 10^{-8}$	0.6	0.18	68
9	$4.1 \cdot 10^{-9}$	0.4	0.06	89
10	$2.7 \cdot 10^{-7}$	1.3	0.51	29
11	$4.6 \cdot 10^{-8}$	0.8	0.32	56
12	$2.9 \cdot 10^{-8}$	0.8	0.14	61
13	$2.6 \cdot 10^{-8}$	0.7	0.26	90
14	$2.1 \cdot 10^{-8}$	0.7	0.11	66
15	$7.9 \cdot 10^{-9}$	0.5	0.06	100
16	$3.2 \cdot 10^{-8}$	0.4	0.06	87
17	$1.7 \cdot 10^{-8}$	0.6	0.13	75
18	$2.3 \cdot 10^{-8}$	0.7	0.17	70
19	$1.6 \cdot 10^{-8}$	0.6	0.11	71
20	$1.4 \cdot 10^{-8}$	0.4	0.04	100
21	$1.8 \cdot 10^{-8}$	0.6	0.04	62
22	$2.5 \cdot 10^{-8}$	0.7	0.27	76
23	$7.3 \cdot 10^{-8}$	0.5	0.11	93
24	$3.6 \cdot 10^{-8}$	0.25	0.25	69
25	$5.9 \cdot 10^{-9}$	0.5	0.02	86
26	$1.1 \cdot 10^{-8}$	0.6	0.07	75
27	$4.0 \cdot 10^{-8}$	0.8	0.15	66

the constants are determined by the curve best fitting to them. In Figs 2 to 5 corresponding to transistors No. 16, 25, 26, 27 the continuous curves represent the results best fitting to the calculations and measurement data. When the absolute activity is known, from the curves also the volume of the cavity can be determined.

Select a value of P^0 along the curve, where it best fits the measurement points (or, considering the deviation of the points, the middle of the measurement interval), preferably in the middle section of the curve. As in the solution there is a constant a that can be selected at will, fix the starting point of the time measurement here.

To an equal distance h to the right and left of point P_0 read the values of P_+ and P_- on the curve. As in the calculation we invariably find the ratios of pressures, and in Equ. (12) P is proportional to P_K, it suffices to calculate with activities, and even they may be substituted by the scale of the axis in proportion to activities. Considering this, further on also this value will be designated by P. These data calculated give the following expressions:

$$P_0^2 = \frac{P_+ \cdot P_- - P^0 P_s}{P_s - P^0} P^0 \tag{13}$$

$$\text{th}\,(\lambda h) = \frac{2\, P_K (P_s - P^0)}{P^0 (P_- - P_+)} \tag{14}$$

where

$$Ps = \frac{P_+ + P_-}{2} \tag{15}$$

is the arithmetical mean of the values taken on the curves belonging to the end points of the two intervals h.

P_0 and th(λh) may be calculated along the above or the product λh found in a hyperbolic-tangent table. h being known λ is directly obtained.

When the time that has passed from the filling is known, the initial activity may be calculated. The ratio of initial to final activities is the same as that of initial to final pressures and their quotient is higher by one than the ratio of the volume of radioactive gas taken up to the volume of the transistor after filling. (Because originally the transistor was filled with an inactive gas, air.) Then the volume may be calculated from the relationship

$$V = C \frac{P_0 \cdot P_K}{P_0 - P_K} \tag{16}$$

where P_0 is the initial pressure. The constant C includes the factors of absolute activity and those needed for the transition from absolute activity to gas quantity. The volume inside the transistor is given in Table 1, column 3, in terms of millilitres.

With the volume of the cavity inside the transistor and the wall thickness (0.3 mm) known, assuming a circular hole, the radius of the latter can be calculated from the formula

$$\lambda = \frac{P_K \cdot \pi \cdot R_s^4}{16\,\eta \cdot l \cdot V} \tag{17}$$

where $P_K = 1$ atm. Here η stands for the viscosity of argon gas. Equivalent circular sizes are given in Table 1, column 2. Column 1 of the table lists the hole sizes in terms of vacuum technical units.

As the transistor is removed from the argon gas of high pressure and placed in an air space of atmospheric pressure, the size of the hole undergoes a change. Under the effect of the higher internal pressure silicon grease entrained from the cavity narrows the hole down. From the extent of filling up, the choking produced by the gas rushing out can be quantitatively assessed on the basis of similar calculations. Table 1, column 4 lists the choking of the holes in terms of percentages. (This means that the size of the hole of a transistor with point imperfection decreases after filling up with an inert gas, if further on gas oozes in only under the effect of variation of pressure due to heating.)

In the knowledge of the size of the cavity and of the hole in the wall of a transistor, under normal operating conditions an upper limit can be estimated for the replacement of the inside, dry atmosphere with contaminated external atmospheric air.

The calculation goes along the following model: keep a transistor switched on for a number of t hours, then switched off for a longer time. When switched off, the temperature of the air space in the transistor will be higher by ΔT than the absolute temperature T. If the subsequent spells of operation are of the same duration, then the maximum number of switchings on is given by the formula

$$n = 3000\,\frac{V}{d^4 t}\left(\log \frac{k}{k - b_n}\right) \frac{1 + \frac{x^2+1}{x} \cdot 8 \cdot 10^{-4}\,\frac{t \cdot d^4}{V}}{\frac{x^2-1}{x}} \tag{18}$$

where d is the diameter of the hole, in microns, V the volume of the transistor cavity in ml and t the time of a single switching on, in hours. The ratio x of internal and external temperatures

$$x = \frac{T + \Delta T}{T} \tag{19}$$

b_n is the relative contamination of the air before the $n + 1$th switching on, k the relative contamination of the surrounding atmosphere.

After the nth switching on the contamination of the air inside the transistors [Equ. (20) is the expansion in series of Equ. (19) where we stopped at the second term] is

$$b_n = k(1 - \alpha^{-n}) \tag{20}$$

Here $\alpha = \Delta V/V$, ΔV the quantity of air streaming out of the transistor in the course of a single operation of t hours. From the logarithms of this equation, for the number of switchings on we obtain

$$n = \frac{\log k - \log (k - b_n)}{\log \alpha} \tag{21}$$

and

$$\frac{n}{\log \dfrac{n}{k - b_n}} = \frac{1}{\log \alpha} \tag{22}$$

The values of $1/\log \alpha$ are also tabulated for operation times of two hours and 20 °C temperature difference for room temperature, taking a 10 per cent contamination into account. Table 2 shows that the hole size at which a 10 per cent contamination will take place at about 10 000 switchings on and off, considering the real volume of about 0.1 ml, lies between 0.25 and 0.5 micron. This size is properly put in evidence by our measurement method, as seen in Table 2. In case of a too small cavity volume 10 per cent contamination means the introduction of a smaller quantity of moisture.

Formula (18) gives a good approximation only for relatively short switching on times (as long as $\lambda t < 3$). This, however, in case of the sizes applied may extend to several days.

Table 2

μ ∅ / V ml	0.1	0.25	0.5	0.75	1.0	1.25	1.50
0.01	$4.5 \cdot 10^5$	$1.2 \cdot 10^4$	$7.2 \cdot 10^2$	$1.4 \cdot 10^2$	54	27	18
0.02	$9 \cdot 10^5$	$2.3 \cdot 10^4$	$1.4 \cdot 10^3$	$2.9 \cdot 10^2$	90	48	26
0.05	$2.3 \cdot 10^6$	$6 \cdot 10^4$	$3.8 \cdot 10^3$	$7.5 \cdot 10^2$	$2.4 \cdot 10^2$	98	55
0.102	$4.5 \cdot 10^6$	$1.2 \cdot 10^5$	$7.2 \cdot 10^3$	$1.4 \cdot 10^3$	$4.5 \cdot 10^2$	$1.8 \cdot 10^2$	90
0.20	$9 \cdot 10^6$	$2.3 \cdot 10^5$	$1.4 \cdot 10^4$	$2.9 \cdot 10^3$	$9 \cdot 10^2$	$2.8 \cdot 10^2$	$1.8 \cdot 10^2$
0.30	$1.3 \cdot 10^7$	$3.4 \cdot 10^5$	$2.2 \cdot 10^4$	$4.2 \cdot 10^3$	$1.3 \cdot 10^3$	$5.5 \cdot 10^2$	$2.6 \cdot 10^2$
1.00	$4.5 \cdot 10^7$	$1.2 \cdot 10^6$	$7.2 \cdot 10^4$	$1.4 \cdot 10^4$	$4.5 \cdot 10^3$	$1.8 \cdot 10^3$	$9 \cdot 10^2$

In the table we find the term $1/\ln \alpha$

In our calculation we have disregarded the fact that silicon grease or other filling material present in the transistor case may bind the contaminations of the gas, and assumed all contamination taken up from the environment as being accumulated in the cavity.

Conclusions

By the designing and construction of the equipment discussed above we have solved the problem envisaged.

Our method with the application of two equivalent tanks and a radioactive isotope can be readily adapted for production quality control or for scientific purposes alike, depending on the further checks the transistors tested under pressure are additionally subjected to. In production control a single worker with a ratemeter can test 3000 transistors in an eight-hour shift without any particular effort. The size of the apparatus can be increased without difficulty, for instance, the volume may be doubled, in which case two persons are needed for the test. For scientific use, if the variation of the activity and the absolute activity of the transistors are measured systematically for a long time, from the measurement results the leakage (1 Torr/sec and the equivalent circular hole size μ, can be determined by mathematical means.) In addition, the free volume inside the transistor (ml) can be worked out and the extent of the produced choking estimated.

The numbers of switchings on and off after which the inside of the transistor will be contaminated to 10 per cent with water vapour coming from atmospheric air of 100 per cent relative humidity can be calculated for various hole sizes and internal volumes, taking as a basis 10 000 switchings on and off, as specified. The results obtained testify to the sensitivity of the method being adequate, as an active charge of 50 mCi is sufficient for the detection of a hole of this size. The sensitivity of the measurement may be further improved by increasing the activity and, in consequence of this, the size of the smallest hole that still can be detected can be brought further down. Such inferences can be drawn solely from the results of tests performed with radioactive gases and, as outlined above, this is the only method suitable for the permanent production control of larger quantities of transistors.

Acknowledgement. The authors are indebted to Dr. János GIBER for raising the issue and for its drafting with respect to the reliability of semiconductor devices.

Summary

The authors have developed a method and equipment for the testing of transistors for point imperfection. The equipment lends itself to test 3000 transistors under pressure at a time. The duration of the pressure test varies between 20 and 24 hours. Pressure tests of batches of 3000 transistors can be performed alternatingly in two tanks of identical design and function.

The checking of a batch of 3000 transistors with a ratemeter for point imperfection takes not more than 8 hours. The absolute activity of the transistors and the decrease of the activity in time are measured. From the test results the leakage (1 Torr/sec) and the equivalent circular hole cross-section can be determined by mathematical means. Ways for the determination of the inner free volume and of the extent of choking produced by the gas streaming out are open. As an order of magnitude, the hole diameter at which the inside of the transistor under the effect of 10 000 switchings on and off, of not too short duration will get contaminated with moisture taken up from the atmosphere of 100 per cent relative humidity to an extent of not more than 10 per cent is 0.5 micron. With the filling of radioactive gas of 50 mCi activity a hole of such size can be detected for sure, and by increasing the activity the sensitivity of the equipment can be substantially increased. A comparison with other methods reveals that the testing of transistors for point imperfection with a radioactive gas supplies the largest amount of scientific information and is of the highest productivity when put to use in industry.

References

1. S. G. S. Fairchild, Tentative Specification, January, 1967
2. COOPER, R. I. B.: IRE, February, 1962
3. RCA UHF Transistors File No. 202, March, 1966
4. CASSEN, B., BURUHAM, D.: Int. J. Appl. Rad. Isotopes **9**, 54 (1960)
5. Consolidated Electrodynamics, April, 1961. Pasadena (California)

Dr. Zoltán G. DEMJÉN
Dr. Ottó J. ORIENT
Budapest XI., Budafoki út 8, Hungary