Evaluation of operation lifetime of microwave low noise NPN bipolar junction transistor

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Abstract. In this paper, the lifetime of microwave low noise NPN bipolar junction transistor under three operation modes are deeply investigated. Experiment results show that the electrical parameters keep nearly unchanged when a steady electrical stress is applied over 2000 h at 125℃. The junction temperature (Tj) is found to have a significant influence on the operation lifetime. The samples begin to fail once Tj is higher than 225℃. Furthermore, the higher the junction temperature is, the earlier the failure occurs, and the shorter the lifetime is. The accumulated damages near Si/SiO2 interface around BE junction are contributed to the failure under high temperature. The estimated mean time to failure based on the failure data under high Tj is higher than that from non-failure data under low Tj. HTRB stress are found to be able to result in damages around LOCOS edge under BC junction, but the induced variation of related electrical parameters is still far below the specified failure criterion. All these data obtained here can provide a reliability foundation for bipolar transistors.

1. Introduction
The microwave bipolar junction transistors (BJTs) have experienced rapid growth because of their high speed, high driving power, and low noise, and they have been applied to fields such as wireless communication and low noise amplifier [1]. It is useful to investigate the reliability issue and degradation mechanisms of BJT to achieve a better operation strategy. The bias conditions and temperature are expected to have a significant influence on the reliability or operation lifetime of bipolar transistors [2-4]. The evaluation of operation lifetime of bipolar transistors at arbitrary temperature is vital. In this paper, the reliability/lifetime of microwave low noise NPN BJT under three operation modes are evaluated, and the corresponding mechanisms are discussed in detail.

2. Device under test
The device under test are the silicon microwave low noise NPN BJT with 20 emitter fingers, designed and fabricated by the 55th Research Institute of China Electronics Technology Group Corporation. The transistors are mainly used in small/medium power low noise amplifier (LNA). The typical leakage current for BC junction (ICBO) are 1 nA under VCB=5V, and that for BE junction (IEBO) is 0.5 μA under VEB=1.5 V. The common-emitter current gain hFE under IC=20 mA is about 75. The temperature dependence of ICBO and hFE are depicted in Fig. 1. A significant increase is expected with the temperature increasing.

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3. Result and discussion

The lifetime/reliability is evaluated under three operation modes: (I) steady state under $V_{CE}=3$ V, $IC=59$ mA, (II) elevated temperature of 150°C, 175°C, 200°C, and (III) high temperature reversed bias (HTRB) stress with $V_{CB}=0.8V_{CBO}$. The lifetime is defined as the time when one of following three criterions appears: (a) $|\Delta I_{CBO}|\geq 10$ nA, (b) $|\Delta I_{EBO}|\geq 10$ nA or (c) $|\Delta h_{FE}|\geq 10\%$ of the initial value.

![Figure 1](image1.png)

Fig. 1. Variation of $I_{CBO}$ and $h_{FE}$ for the device under test under different temperature

3.1. Steady-state lifetime

The steady-state lifetime is evaluated at 125 °C over 2000 h at $V_{CE}=3$ V, $IC=59$ mA. The variation of $I_{CBO}$, $I_{EBO}$ and $h_{FE}$ are presented in Fig. 2. No noticeable changes are found on $I_{CBO}$ and $I_{EBO}$ after 2000 h stress are applied, and the average variation are separately only 2.22% and 2.08%, which indicates that BC/BE junction own a good PN junction characteristics. As for $h_{FE}$, the average variation is only 0.26%. The additional mechanical test shows that the bonding strength and shear strength of the tested package chip also keep nearly unchanged after applying 2000h stress. The above electrical and mechanical test demonstrate that a good operation time is maintained under constant junction temperature ($T_j$).

![Figure 2](image2.png)

Fig. 2. Variation of $I_{CBO}$, $I_{EBO}$ and $h_{FE}$ after the electrical stress of $V_{CE}=3$ V, $I_{C}=59$ mA are applied.

3.2. Accelerated lifetime under elevated temperature

The accelerated lifetime tests are carried out under 150°C, 175°C and 200°C, with $V_{CE}=3$ V and $I_{C}=59$ mA. The corresponding $T_j$ are separately 200°C, 225°C and 250°C. The durations of electrical stress are 1000 h for 150°C and 175°C, and 168h for 200°C. Results show that the samples begin to
fail earlier for higher Tj. No failure exists for Tj of 200°C even 1000 h electrical stress are applied. However, some samples start to fail when 340 h electrical stress are applied for the case of Tj = 225°C, and the failure time is only 34 h for Tj of 250°C. The decreased hFE, and increased IEBO are found to contribute to the above observed failure phenomenon, and no any failure related with CB junction is found.

Fig. 3 presents the variation of accumulative failure rate for Tj of 225°C and 250°C. A distinct linear behavior is expected for the two junction temperature. The same fitted slope demonstrates a uniform failure mechanism. These are all due to the accumulated damages near Si/SiO2 interface around BE junction under high temperature.

![Fig. 3](image)

Fig. 3. The variation of accumulative failure rate as a function of failure time.

The characteristic lifetime (\(\eta\)) or mean time to failure (MTTF) for other junction temperatures can be evaluated in two ways. The first method is based on the failure data under Tj of 225°C and 250°C according to Arrhenius equation [5].

\[
\eta = 10^{a + \frac{b}{Tj}}
\]  
(1)

where a and b are fitted coefficients, and are separately -17.14 and 10090.35 according to the results of 225°C and 250°C. The second method is based on the non-failure data under Tj of 200°C. The maximum failure rate \(\lambda\) at arbitrary Tj is written as

\[
\lambda = \frac{\chi_{90\%}^2}{\chi_0^2 \exp \frac{E}{8.63 \times 10^{-5} \left( \frac{1}{Tj} - \frac{1}{T_{ref}} \right)}} t_{total}
\]  
(2)

where \(\chi_0^2\) and \(\chi_{90\%}^2\) are the distribution freedom of non-failure and 90% of confidence level, and the values are separately 2 and 4.61. \(T_{ref}\) is the reference junction temperature of non-failure and here is 200°C. E is the activation energy and can be directly borrowed from the case of 225°C and 250°C. Then the mean time to failure (MTTF) can be given as

\[
MTTF = \frac{1}{\lambda}
\]  
(3)
Fig. 4. The comparison of calculated MTTF from the failure data under high $T_j$ and non-failure data under low $T_j$.

Fig. 4 shows the comparison of the calculated MTTF from above two different ways. It can be seen that the calculated results based on the failure data under high $T_j$ are about 2.6 times higher than that from non-failure data under low $T_j$. It is mainly because the fact MTTF is proportional to the total test time [6]. During the same test time, the more the number of tested devices is, the larger MTTF is, assuming no failure exist. Therefore, the calculated MTTF based on the low $T_j$ non-failure data is underestimated.

3.3. Lifetime under high temperature reverse biased (HTRB) stress
The lifetime under reverse biased stress is characterized under continuous $V_{CB}$ of 0.8 $BV_{CBO}$, where $BV_{CBO}$ is the breakdown voltage of BC junction. The duration time is 1000 h and the environment temperature is 150℃. The variation of $I_{CBO}$, $I_{EBO}$ and $h_{FE}$ for the five tested samples are shown in Fig. 5. It can be seen that $I_{EBO}$ and $h_{FE}$ keep nearly unchanged after 100 h HTRB stress is applied. An obvious increase is found in $I_{CBO}$, however, the absolute value is still very small. It indicates that HTRB stress can results in some damages around LOCOS edge under BC junction. The above variation of related electrical parameters ($I_{CBO}$, $I_{EBO}$ and $h_{FE}$) are far below the specified failure criterion, which indicates that the surface/interface state of the investigated transistors are relatively good.

4. Conclusion
The lifetime of microwave low noise BJT under three operation mode are studied in this work. The junction temperature is found to have a significant influence on operation lifetime. Two kinds of method to estimate the mean time to failure (MTTF) are proposed and compared. The calculated MTTF based on the failure data under high $T_j$ are about 2.6 times higher than that from non-failure data under low $T_j$. The accumulated damages near around BE junction are found to influence the lifetime under high junction temperature, while those near BC junction effects the lifetime under HTRB stress.
Fig. 5. Variation of $I_{CBO}$, $I_{CEO}$ and $h_{FE}$ after HTRB stress are applied.

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