HEWLETT hp PACKARD

COMPONENTS

APPLICATION NOTE 959-2

Reliability of Silicon IMPATT Diodes

INTRODUCTION

During the development of Hewlett-Packard IMPATT diodes, reliability problems were traced to several specific steps in the manufacturing process. As the development proceeded, each of these problems was solved so that the final production process provides a highly reliable diode. The process is monitored by screening methods which have been developed to detect these specific defects.

FAILURE MECHANISMS

IMPATT diodes are used at higher junction temperatures and higher reverse bias than other semiconductor devices. This has required the elimination of potential failure mechanisms which might not develop at lower temperatures.

Surface contamination can cause excess reverse leakage current. Devices with surface contamination are eliminated during a high temperature reverse bias screen conducted on all Hewlett-Packard IMPATT diodes. Process cleaning steps have also been developed to minimize yield loss.

Bonding and metallization are generally responsible for a high percentage of semiconductor failures. For IMPATT diodes, 100% thermal resistance testing and 100% high temperature reverse bias testing effectively screen devices with marginal die attach, metal contact or bonding. Process controls developed through feedback from 100% testing have minimized these fabrication defects. The result is a highly uniform and reliable product.

Diffusion of the contact metal into the semiconductor material is another cause of failure. This failure mode is controlled by the choice of metals used in the contacting system, the control exercised while applying those metals, and the junction temperature. For any given metallization system, the diffusion of the contact metal into the semiconductor is an electrochemical process. The failure rate due to this diffusion can be described by the Arrhenius equation:

$$\lambda = \lambda_0 e^{-(\phi/kT)}$$

Where λ = Failure Rate
λ_0 = A Constant
ϕ = Activation Energy in eV
T = Temperature in °K
k = Boltzman's Constant (8.63×10^{-5} eV/°K)

The Arrhenius equation has been widely used and its validity has been demonstrated for many semiconductor failure mechanisms. The value of ϕ depends on the specific failure mechanism and is about 1.8 eV for metal diffusion into silicon.[1] For a known mechanism, the activation energy can be used to project the failure rate at one temperature to a corresponding failure rate at another temperature. The acceleration factor is the ratio of failure rates at each temperature, and is:

$$\frac{\lambda_{T1}}{\lambda_{T2}} = e^{-\frac{1.8}{k}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

A plot of this equation for $T_2 = 473°K$ (200°C) is given in Figure 1.

Failure rate due to surface leakage also follows the Arrhenius equation. However, the associated activation energy is 1.0 eV. Thus, if ionic contamination is present, failure will result before metal diffusion occurs.

RELIABILITY TEST RESULTS

Silicon Double Drift IMPATT Diodes

All Hewlett-Packard silicon double drift IMPATT diodes are burned in for at least 48 hours at a junction temperature exceeding the maximum rating of 250°C.

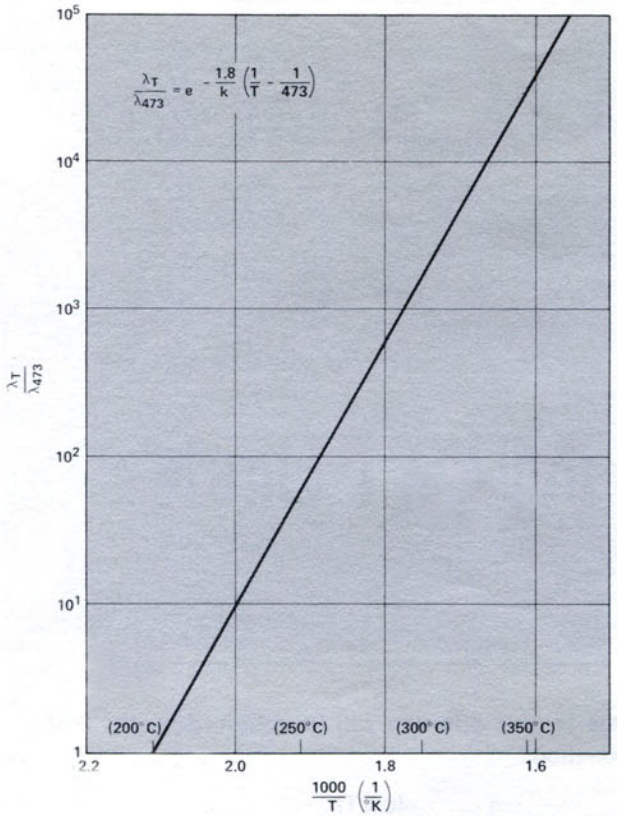

Figure 1. Effect of Junction Temperature on Failure Rate for ϕ = 1.8 eV.

The following tests were performed on standard production units taken from inventory:

TEST I – Accelerated Life Test. Units were tested at a junction operating temperature far exceeding the recommended maximum in order to accelerate failure mechanisms.

350°C Junction Operating Temperature
Total Diodes Tested: 12
Total Device Hours: 77,000
Failures: 3
1 Unit < 48 Hours
1 Unit < 96 Hours
1 Unit ≃ 6700 Hours
Failure Rate: 3.9%/1000 Hours
MTBF: 25,667 Hours

TEST II – Operating Life Test. Units were tested at the maximum recommended junction operating temperature.

250°C Junction Operating Temperature
Total Diodes Tested: 29
Total Device Hours: 249,400
Failures: 0
Failure Rates: ≤ 0.4%/1000 Hours
MTBF: ≥249,400 Hours

TEST III – Operating Life Test.

225°C Junction Operating Temperature
Total Diodes Tested: 29
Total Device Hours: 246,500
Failures: 0
Failure Rate: ≤ 0.41%/1000 Hours
MTBF: ≥ 246,500 Hours

In Test I, the failure rate is 3.9% per 1000 Hours at T_j = 350°C. Extrapolating this result to T_j = 250°C gives a failure rate less than 0.01% per 1000 hours (MTBF > 10^7 hours).

Tests are continuing.

Silicon Single Drift IMPATT Diodes

All Hewlett-Packard silicon single drift IMPATT diodes are burned in for at least 48 hours at a junction temperature exceeding the maximum rating of 200°C.

The following tests were performed on standard production units taken from inventory:

TEST I – Operating Life Test. Units were tested at the maximum recommended junction operating temperature.

200°C Junction Operating Temperature
Total Diodes Tested: 104
Failures: 2
Total Device Hours: 344,000
Failure Rate: 0.58%/1000 Hours
MTBF: 172,000

TEST II – Storage Life Test. Units were tested at the maximum recommended junction operating temperature.

150°C Storage Temperature
Total Diodes Tested: 54
Total Device Hours: 153,000
Failures: 0
Failure Rate: ≤ .65%/1000 Hours
MTBF: ≥ 153,000 Hours

CONCLUSION

Reliability information obtained from rated junction temperature tests and extrapolated from accelerated tests indicate that a failure rate between .6% and .01% per 1000 hours can be expected from Hewlett-Packard silicon IMPATT diodes.

REFERENCE

1. Peck & Zierdt, "The Reliability of Semiconductor Devices in the Bell System," Proc. of IEEE, Vol. 62, No. 2, Feb. 1974, pp. 185-211.

See also HP Application Note AN959-1, "Factors Affecting Silicon IMPATT Diode Reliability and Safe Operation."

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