Digest of Tech. Papers The 6th Conf. on Solid State Devices, Tokyo, Sep. 1974

A4-1
(INVITED)

Reliability of Solid State Oscillators

Ken-ich CHINO, Yoshinori WADA, and Kaneharu FUKUDA

Musashino Electrical Communication Laboratory, NTT

Musashino, Tokyo

During the past decade Gunn and IMPATT diodes have been developed as practical solid state oscillators, and they are now taking the place of klystrons in microwave frequency range. However, it has not been confirmed that they have reliability enough to be used for public communication systems.

This paper describes the results of failure analyses mainly on Gunn diodes. The reliability prediction is also given from the life tests of high reliability Gunn diodes, which have been developed for 20 GHz digital radio-relay system. The predicted failure rate is compared with the field data obtained from the experimental link of the system.

Failure Physics

The most typical degradation mode of a Gunn diode is the increase in the low field resistance Ro accompanied by the decrease in the output power. Two mechanisms have been proposed for the increase in Ro. One is the degradation of the ohmic electrode on the n^{++}contact layer,[1] and the other is the introduction of crystal defects in the active layer during the thermocompression bonding (TCB) process.[2] The stress induced dislocations behave as acceptors in GaAs and increase Ro.[3] It is very important to determine which mechanism is operating for the degradation of the Gunn diodes under life test, because the two degradation mechanisms are accelerated differently owing to the large temperature difference between the contact region and the active layer.

We found that for the diodes deteriorated due to the electrode degradation, Ro becomes less dependent on temperature and that for the diodes damaged with bonding, Ro shows the same temperature dependence as the normal diodes. By reducing both pressure and tempreture in the TCB process, the problems on die bonding have remarkably been improved, and the electrode degradation is now the dominant failure mode in the life test, especially at rather highly accelerated temperature levels.

We have also found that the electrode degradation is accompanied by the increase of the thermal resistance R_{th} as well as of the low field resistance Ro. On the basis of some experimental results, the increase in R_{th} can be explained by the formation of Cu alloys from the heat sink metal system, Cu-Ni-Au, which have in general higher thermal resistance than their constituent metals.

High temperature storage tests of the Gunn diode chips without package were made to confirm the ideal life which is affected neither by bonding process nor by any other factors introduced through packaging. The results obtained from this experiment indicate that the ideal Gunn diodes hardly degradate up to 10^6 hours, assuming the operating temperature of 200°C.

Plated heat sink techniques have been expected to be very suitable for GaAs devices since neither mechanical nor thermal stresses are applied on the GaAs crystal during the preparing process of the heat sink. However, we have found that the stress due to the difference between the thermal expansion coefficient of the metal and GaAs crystal causes the degradation of the devices at the operating temperature.

The degradation mode of IMPATT diodes, so far confirmed, is the increase in R_{th}. The use of type II-a diamond is expected to improve it effectively.[4,5]

Life Tests

We are now carrying out several sorts of life tests on the Gunn diodes, high temperature storage, high temperature DC operating, RF operating tests and others. In the accelerated life tests the degradation failures are fairly dominant over the random failures. Extraporation of the MTTF-1/T plots shows it necessary to reduce the operating temperature less than 200°C, in order to obtain the MTTF of 10^6 hours.

Reliability as well as performance of 20 GHz digital radio-relay system is now under investigation utilizing the experimental link constructed between Musashino and Yokosuka. In this experimental link 156 Gunn diodes are used and four devices failed, accumulating about 10^6 device test hours to the end of 1973.[6]

Acknowledgements

The authors are indebted for helpful discussions with Dr. R. Nii. They also wish to thank those people of Nippon Electric Co. and the Yokosuka and Musashino Electrical Communication Laboratories who co-operated throughout this work.

References

1) T. Nakanishi and K. Hirai: Paper of Technical Group on Electron Devices, ED-71-48 (1971), IECE.
2) S. Mitsui and O. Ishihara: Japan. J. Appl. Phys. 11 (1972) 603.
3) F. Hasegawa and H. Ito: Appl. Phys. Lett. 21 (1972) 107.
4) M. Yamamoto, M. Shinoda, Y. Toyama, and S. Yoshioka: Paper of Technical Group on Semiconductors and Semiconductor Devices, SSD-72-28 (1972), IECE.
5) H. Nagao, N. Kitagawa, and S. Katayama: ibid. SSD-73-13 (1973), IECE.
6) S. Kita et al: ECL Tech. J. 22 (1973) 1923; H. Yamamoto et al: Jap. Telecom. Rev. 16 (1974) 124.