HIGHLY RELIABLE GaAs MESFETs WITH A STATIC MEAN NF_{min} OF 0.89 dB AND A STANDARD DEVIATION OF 0.07 dB AT 4 GHz

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Abstract

Optimization of structure and configuration of GaAs MESFETs for high performance and high reliability was investigated. GaAs MESFETs with the $\overline{NF}_{min}$ of 0.89 dB and the standard deviation of 0.07 dB at 4 GHz, the CW and pulse input power capability more than 0.4 W and 2 W, respectively and the failure rate less than 180 Fit have become practical.

Introduction

In GaAs MESFETs, MTTF of 10^8 hours at 70 °C was deduced by thermal acceleration tests.(1) However, reliability supported by field data is practically more important. Considering that the failure of MESFETs in the field is often caused by an accidental large RF power input and DC surge pulse, a high input power capability is indispensable for high reliability.

High performance is achieved by a submicron gate with reduced resistance.(2) However, technology to form the submicron gate has not been sufficiently established, consequently the low productive yield and the low reproducibility make GaAs MESFETs expensive.

In this paper, the device structure to provide high reliability and high performance is proposed. Techniques to reproducibly form a submicron gate with an increased thickness using a practical 1 µm gate photo mask are described. Reproducibility is confirmed by examining the static distribution of NF value of numbers of GaAs MESFETs. Screening conditions to assure high reliability are made clear. Reliability is evaluated by the field operation tests and input power capability tests.

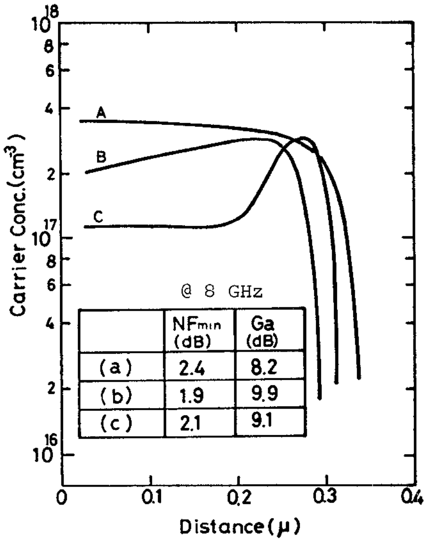
High Performance GaAs MESFETs

Optimization of Carrier Profile

As a low noise GaAs MESFET is operated at a drain current as low as 10 to 15 mA under noise matching conditions, the crystal quality and electrical characteristics of the active layer at the semiinsulating buffer layer-active layer interface are very important. The high net carrier density in the active layer and abrupt change of carrier profile are required.

Using GaAs MESFETs fabricated from three kinds of epitaxial GaAs wafers with different carrier profiles typically shown in Fig. 1, the minimum noise figure, NF_{min} and associated gain, G_a depending on the carrier profile were investigated. In the table inserted in Fig. 1, typical NF_{min} and G_a corresponding to the three carrier profiles are summarized.

The best results regarding NF_{min} and G_a are both obtained from the profile (b) which shows the carrier profile gradually increasing from the surface to the interface.



	NF_{min} (dB)	Ga (dB)
(a)	2.4	8.2
(b)	1.9	9.9
(c)	2.1	9.1

Fig. 1 Carrier profiles of three kinds of epitaxial GaAs wafers and typical NF_{min} and G_a values corresponding to these three carrier profiles.

Improvement of Process Technology

Technology to form a submicron gate using an 1 µm gate photo mask was developed. Increased gate resistance due to submicron length was compensated by the increase of the gate thickness. Formation of the submicron length gate with the increased thickness was achieved by appropriately controlling the photolithographic process for lift-off. As a practical 1 µm gate photo mask was used, the process was easy and reproducible. An Al gate of 0.7 µm length and 0.7 µm thickness was formed with a high yield. A practical method to stabilize the Al gate on GaAs for assuring drift free characteristic and a Au-Ge/Ni metallization system to provide the specific sheet resistance as low as 3×10^{-7} ohm-cm^2 were also developed.

Electrical Characteristics and Their Reproducibility

In Fig. 2, typical NF_{min} and G_a depending on frequency are compared for GaAs MESFETs produced by the newly developed technology and by the conventional technology both using a practical 1 µm gate photo mask.

In comparison to NF_{min} of 1.7 dB and G_a of 9 dB at 4 GHz for the MESFETs produced by the conventional technology, NF_{min} of the 0.9 dB and G_a of 13 dB are obtained at the corresponding frequency for the MESFETs produced by the new technology.

In Fig. 3, distribution of NF_{min} values is shown for 700 pieces of GaAs MESFETs randomly picked up from three lots. The static mean NF_{min} is 0.89 dB and the standard deviation is 0.07 dB. From the distribution, 99 % of MESFETs provide NF_{min} less than 1.1 dB at 4 GHz. As shown in inserted table, the static mean NF_{min} and

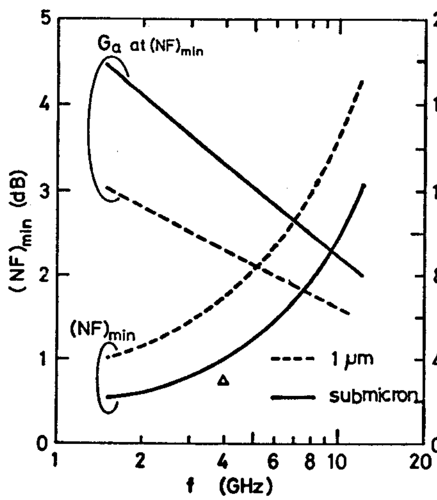


Fig. 2 Typical RF characteristics of GaAs MESFETs fabricated by the new technology (solid line) and the conventional technology (dashed line). Triangle mark shows the state of the arts results.

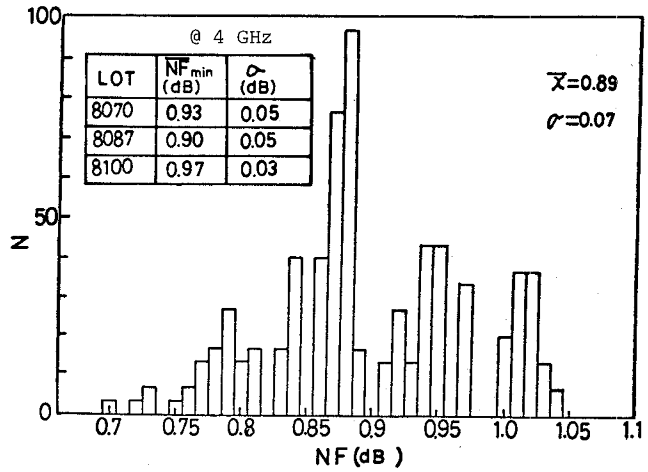


Fig. 3 Distribution of NF_{min} values for 700 pieces of GaAs MESFETs randomly picked up from three lots.

the standard deviation are from 0.9 to 0.97 dB and 0.04 to 0.05 dB, respectively for these three lots.

Stabilization of Electrical Characteristics

Figure 4 shows the change of the gate to source voltage, V_{GSO} by power burn-in. The MESFETs were biased by the conditions of I_{DS} = 30 mA and V_{DS} = 4 V. Remarkable change of V_{GSO} was observed for the first 24 hours burn-in, but the change after 24 hours becomes negligible. The gate metallization was supposed to be stabilized by power burn-in. For other electrical characteristics, both DC and RF, conclusive change by the power burn-in were not observed.
Basing on the results, especially the power burn-in is indispensable for gate stabilization.

Reliability of GaAs MESFETs

Failure Mode Analysis and Reliable MESFETs Structure

GaAs MESFETs were intentionally burned-out by excess RF power and DC surge pulse and then observed by SEM. Short circuit between gate and drain near the gate pad was found to be the primary failure mode.
It was therefore understood to be effectual to place the gate off the drain for preventing the short circuit. A reliable MESFET structure was developed, which was characterized by the unsymmetric configuration that the gate to drain distance was longer than the gate to source distance and by the structure that the gate was located in the recess.

Power Capability of MESFETs

Power capability against CW and pulse input power was examined. In Fig. 5, change of RF characteristics of MESFETs are shown against CW input power (a) and pulse input power (b). In the pulse power tests, pulse of 1 μsec width and 1000 Hz repetition was used. Degradation was found about 0.4 W for CW and 2 W for pulse respectively, which was more than 5 times as high as that of the conventional MESFETs for CW and 10 times for pulse. Concerning the DC surge pulse capability, burn-out energy of MESFETs was measured by a condenser discharge method. The MESFETs were assured against the DC surge pulse as high as 1.2 erg.

Failure Rate Calculated by Field Data

For 173 pieces of MESFETs operating in the field detailed data have been followed up. These MESFETs have been used either in low noise amplifiers under the noise matching conditions or in small power amplifiers under the gain matching conditions. Results are summarized in Table I.

No failure has been observed for 173 pieces of MESFETs. The total component hour is at present 2,730,000 hours and the failure rate of 330 Fit is calculated at a 60 % confidence level. If the test results in the laboratory are considered, the failure rate will be less than 180 Fit.

Conclusion

Optimization of structure and configuration of GaAs MESFETs for high performance and high reliability was investigated. Practical technology to reproducibly form a submicron gate with a good productive yield was developed and screening conditions to assure high reliability were established.

As the results, GaAs MESFETs with NF_{min} of 0.7 dB at 4 GHz, the CW and pulse input power capability more than 0.4 W and 2 W, respectively and the failure rate less than 180 Fit have become practical.

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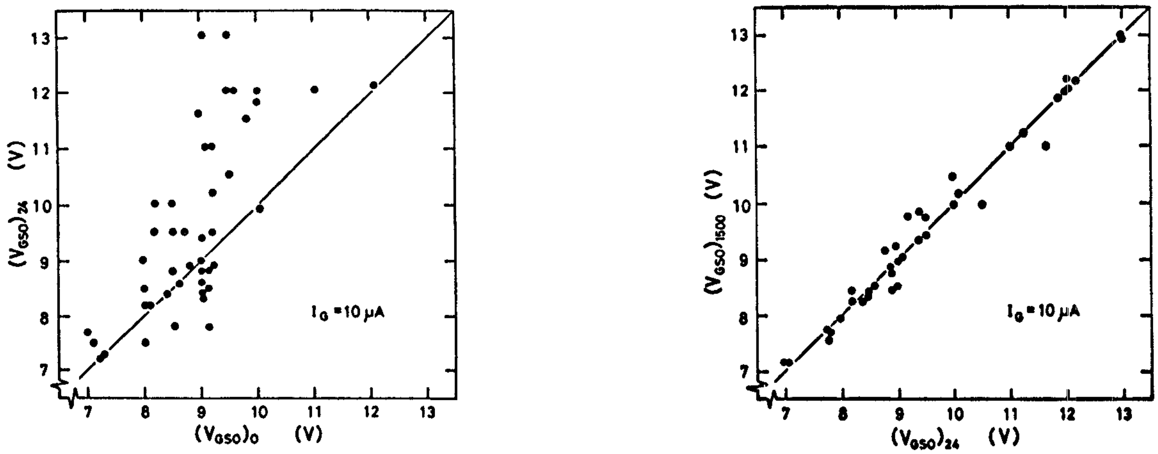
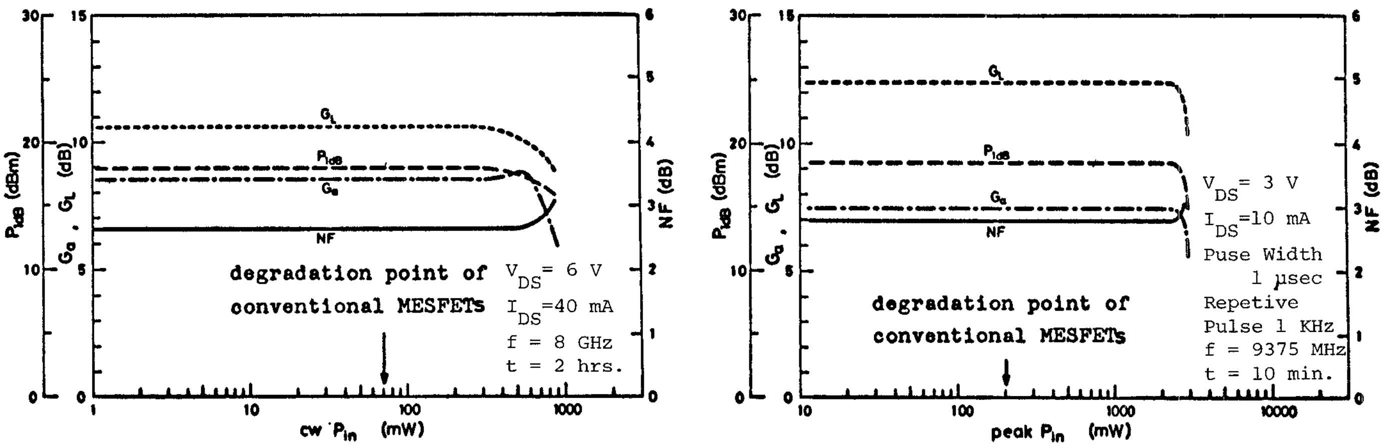


(a) (b)

Fig. 4 Change of the gate to source voltage by power burn-in.
(a) Change of V_{GSO} for the first 24 hours
(b) Change of V_{GSO} after 24 hours



(a) (b)

Fig. 5 Power capability of the GaAs MESFETs against CW input power(a) and pulse input power(b).

Table I Operating reliability of GaAs MESFETs installed in 4 GHz multichannel radio communication equipments.

Representative equipment	4 GHz multichannel radio communication equipment
Operating condition	V_{CC}= 3 V, I_D= 15 - 25 mA
Environmental condtion	Ground, fixed
Number of devices	173
Operating time	10,000 - 27,250 hours
Component hour	2,730,000 hours
Number of failure	0
Failure rate	330 FIT, 60% confidence level