HIGH RELIABILITY POWER GaAs MESFET UNDER RF OVERDRIVE CONDITION

H. Hasegawa, K. Katsukawa, T. Itoh, T. Noguchi and Y. Kaneko

Compound Semiconductor Device Division
NEC Corporation

Abstract

This paper reports on high reliability high power GaAs MESFETs with SiO_2 passivation film. For these MESFETs, no degradation has been observed up to 1500 hours even under 8 dB gain compression condition.

I. Introduction

As the requirement for the output power level of the power GaAs MESFETs becomes higher, the gate electrode and its periphery are stressed by higher drain bias voltage and larger RF input voltage swing.

Up to now, the surface effects on the power GaAs MES FET reliability have been investigated widely with regard to the long-term degradation(1)-(4). The suitable passivation film has proved to be indispensable for GaAs surface protection. No investigation, however, has been reported from, the viewpoint of reliability under RF overdrive operation for the power GaAs MESFETs. In this work, in order to make a diagnostic investigation into effects of passivation films on power GaAs MESFET reliability, two kinds of test devices, which have CVD SiO_2 passivation film and PCVD SiN passivation film, were fabricated and their reliability was investigated, focusing on behavior under the RF overdrive condition. For both passivation films, the deposition temperature was more than 320℃.

SiO_2 film has shown to be a sufficient passivation as contrast with SiN film. No degradation has been observed up to 1500 hours even under 8dB gain compression condition for the high power GaAs MESFETs with SiO_2 passivation film.

II. Experiments and Results

2-1. Device preparation

The test MESFET device structures are shown in Fig. 1. The devices have a simple recessed gate structure with 0.8 um gate length and 5.2 mm gate width. The recess depth is about 0.4 um. The MESFET epilayer structure consists of a 0.6 um thick S-doped active layer with doping concentration of $1.3x10^{17}$ cm^{-3} and a 2 um thick non-doped buffer layer, successively grown by vapor phase epitaxy on a Cr-doped semi-insulating substrate. An Al-Ti gate electrode was formed in the recessed region by applying a lift-off technique. They have SiN or SiO_2 passivation film, respectively.

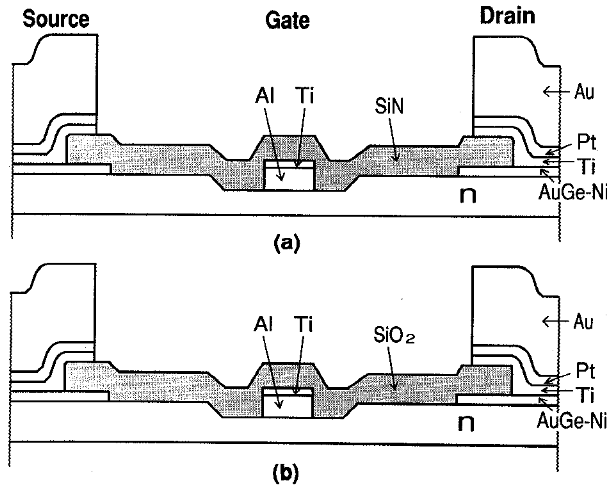

Fig. 1 Cross-sectional view of the test device with (a)SiN passivation film and(b) SiO_2 passivation film.

2-2. RF overdrive test

The RF overdrive operation tests have been performed for the above two kinds of MESFETs at the channel temperature (Tch) of 120 ℃. The V_{DS}=8.5 V, I_{DS}=0.45 A DC set bias condition and three RF input power stress levels, i.e., 3dB, 6dB, 9dB gain compression levels, have been chosen. For both FET groups, 3 samples in each stress level have been tested for 2000 hours. The changes in parameters, i.e., output power(Pout) and gate reverse current (I_{GSX}) under 9 dB gain compression condition are shown in Fig.2. It is clearly seen that the FET with SiN passivation film degraded in the output power (Pout) with the gate reverse current (I_{GSX}) increase. This has been

OF1

caused by the gate breakdown voltage degradation as indicated in Fig.3, where the changes in the gate-to-drain leakage current at -5 V V_{GD} are shown for each compression level. Only small changes, however, have been observed for the FETs with SiO_2 passivation film, as shown in Fig.2 and Fig.3.

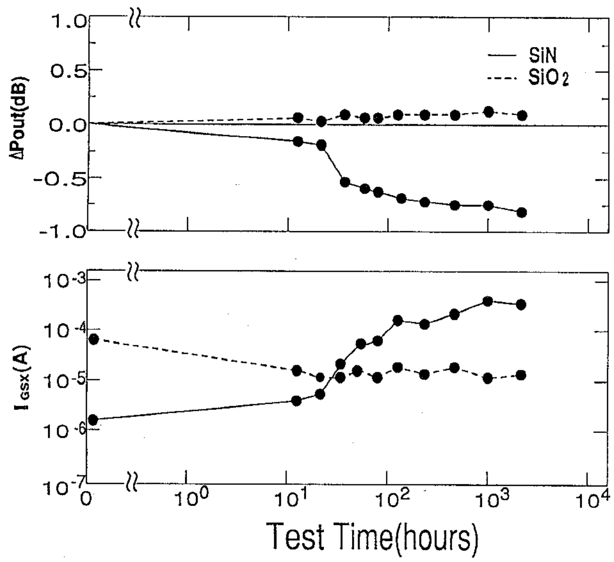

Fig.2 The aging characteristics of output power(Pout) and gate reverse current (I_{GSX}) for the test devices under the RF overdrive condition of 9 dB gain compression level.

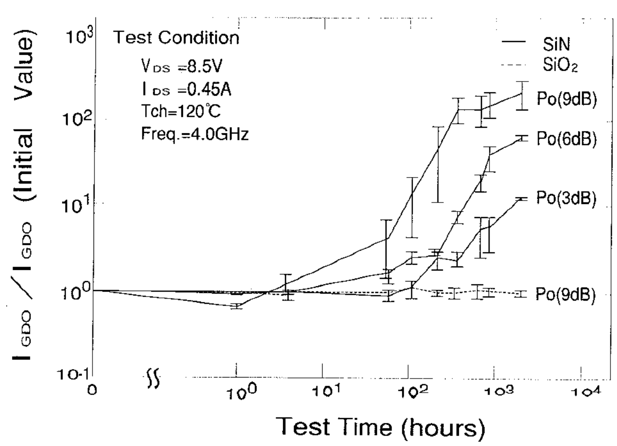

Fig.3 The overdrive stress dependence of the aging characteristics in gate-to-drain reverse current (I_{GDO}) at VGD of -5 V. The test devices with SiN passivation film showed remarkable increase in gate reverse current, depending on the gain compression stress levels.

2-3. EBIC analysis for the degraded device

A biased EBIC (Electron Beam Induced Current) analysis has been performed for the degraded SiN passivation FETs. The circuit for the biased EBIC analysis is shown in Fig.4. Figure 5 shows the biased EBIC image (V_{GSS}=-5 V). This figure shows that the avalanche breakdown occures on the drain side of the gate stripe and not on the source side, although both drain and source electrodes are set to be the same potential in the bias circuit of the EBIC analysis, as shown in Fig.4. The present result indicates that the gate reverse current increase, observed for the FETs with SiN passivation film under the overdrive operation, was caused by a threshold voltage drop of the avalanche breakdown on the drain side of the gate stripe. On the other hand, such phenomenon has not been observed for the FET with SiO_2 passivation film.

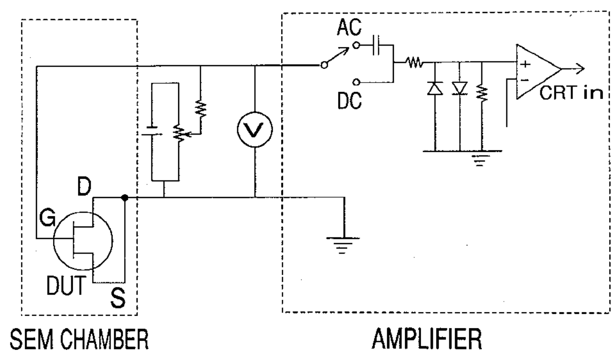

Fig.4 The EBIC test circuit under DC gate reverse biased condition.

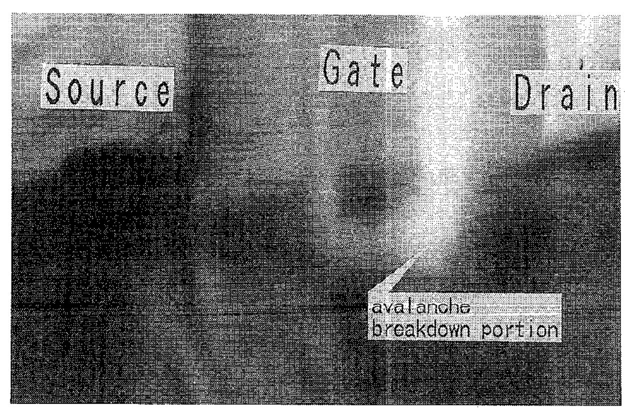

Fig.5 The cross-sectional gate reverse biased EBIC image (V_{GSS}=-5 V) for the degraded SiN passivation MESFET.

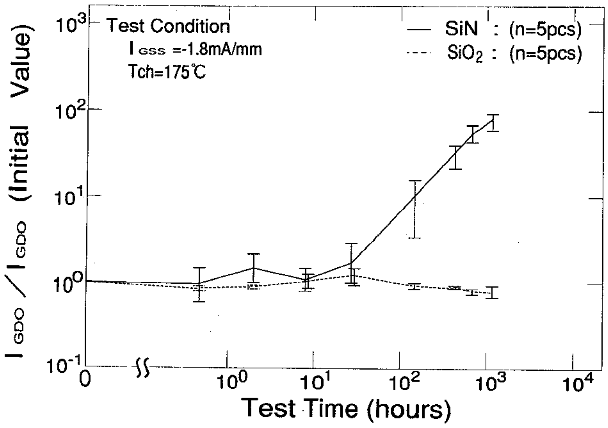

Fig.6 The changes in gate-to-drain reverse current(at V_{GD}=-2 V) on the DC gate reverse bias test.

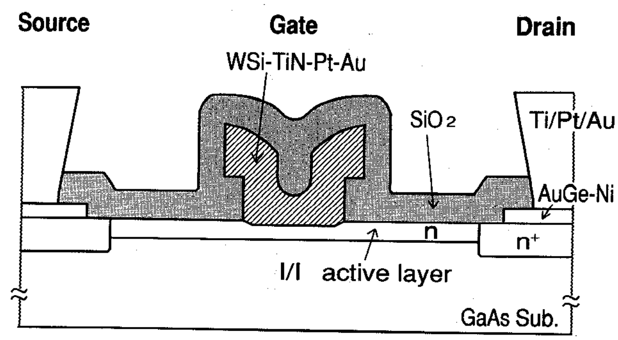

Fig.7 Cross-sectional view of the developed high reliable power GaAs MESFET.

2-4. Gate reverse bias test

As described before, the gate breakdown voltage degradation has resulted in the output power droop. This degradation seems to be caused by the reverse RF voltage swing stress. As a more diagnostic investigation, therefore, the gate reverse bias test has been performed for the both FETs with SiN and SiO_2 passivation film. The test was performed under a condition of constant current, i.e., I_{GSS}=1.8 mA/mm at the ambient temperature (Ta) of 25 ℃. Similar results to those for the RF overdrive test have been obtained, as shown in Fig.6.

Ⅲ. High Reliable Power GaAs MESFETs

Based on these results, we have designed and fabricated high power GaAs MESFETs with the SiO_2 passivation film. The cross-sectional view of the developed MESFET is shown in Fig.7. The gate metal consists of WSi-TiN-Pt-Au, which has been adopted because of its advantages over Al gate in terms of temperature stability and electromigration. Si ion-implantation has been used to form an active layer and an n^+ layer beneath the ohmic contacts. The device has 1.0 um gate length and 58.3 mm total gate width of two chips. 4 GHz RF overdrive test under up to 8 dB gain compression condition was performed for the developed device. The test results are shown in Fig.8. No degradation has been observed up to 1500 hours even under very high stress (8 dB gain compression) condition.

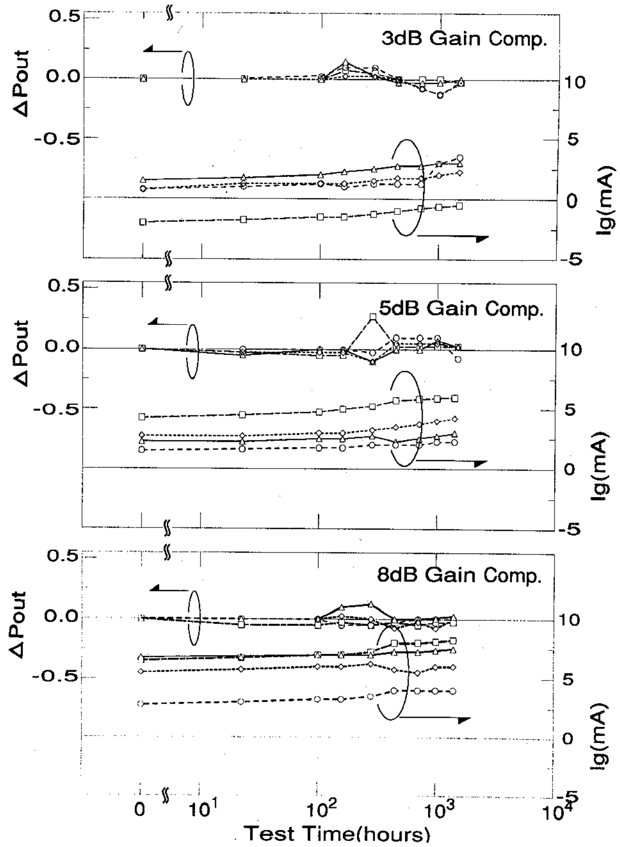

Fig.8 The RF overdrive test results for the developed power GaAs MESFETs. No degradation has been observed up to 1500 hours even under the very high stress, 8 dB gain compression condition.

IV. Discussion

The above data imply that the RF overdrive operation reliability can be evaluated by the gate reverse bias test. From the standpoint of reproducibility, we performed the gate reverse bias test for the devices from many wafers (~20 wafers for each passivation film device). Characteristic behavior of the changes in gate-to-source (short circuited to the drain) breakdown voltage(ΔBV_{GSS}) before and after the DC reverse bias test for 24 hours is illustrated in Fig. 9, showing the ΔBV_{GSS} distribution. The RF overdrive test for the SiN passivation film devices from positive ΔBV_{GSS} wafers showed no degradation in output power, suggesting again the feasibility of the gate reverse bias test evaluation against the output power droop. The implication of the ΔBV_{GSS} distribution is that the SiN passivation technology has inherent problems in terms of high reproducibility as well as high reliability.

It has been reported[1]-[4] that the PCVD SiN film is suitable for the protection of GaAs surface because of its oxygen free process as contrast with SiO_2 passivation film, pyrolitically deposited at relatively low temperatures of 200-300℃. Regarding our results, however, it has been revealed that the FETs with SiO_2 passivation film are very stable as compared with the FETs with SiN passivation film even under overdrive operation. This contrast might be ascribed to the difference of the film deposition conditions such as surface pre-treatments, deposition temperature, etc. Concerning the deposition temperature, in this work, the SiO_2 films were deposited at over 320℃. Thus, the microscopic interfacial properties between GaAs and passivation film must be quite different from those previously reported. Although, the elemental arsenic formation process described by the equation[5][6], $As_2O_3 + 2GaAs \rightarrow Ga_2O_3 + 4As$, has been considered to be the origin of the degradation of the power GaAs MESFETs with SiO_2 passivation film, the present results still suggest the lack of understanding of the surface problem even from the practical point of view.

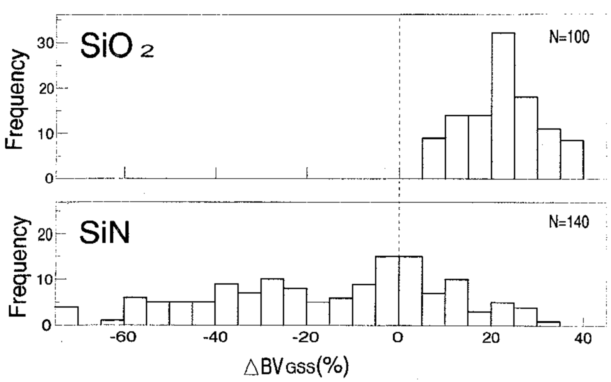

Fig. 9 The distributions of ΔBV_{GSS}, which denotes the changes in BV_{GSS} (at I_{GSS}=1 mA/mm) before and after the DC gate reverse bias test.

V. Conclusion

It has been confirmed that, from the viewpoint of high reliability, the SiO_2 passivation power GaAs MESFETs are very stable compared with the SiN passivation FETs especially in terms of the RF overdrive operation. Based on the overdrive reliability study, focusing on the role of passivation films, the high power GaAs MESFETs were designed and fabricated. No degradation has been observed up to 1500 hours even under the very high stress (8 dB gain compression) condition for the developed power GaAs MESFETs.

Acknowledgement

The authors wish to express their thanks to M. Ohta, K. Okuno, H. Kohzu and T. Furuse for their continuous support in this project. They also wish to thank M. Inagaki and H. Kaiga for their valuable suggestions and comments.

References

(1) S. H. Wemple et al.,"Long-Term and Instantaneous Burnout in GaAs Power FETs:Mechanisms and Solutions," IEEE Trans. on Electron Devices, Vol.ED-28, No.7, pp.834-840, July 1981.

(2) J.M. Dumas et al.,"Long Term Degradation of GaAs Power MESFETs Induced by Surface Effects," Proc. 1983 Int'l Reliability Physics Symposium, pp.226-227, 1983.

(3) J.M.Dumas et al.,"Investigation into GaAs Power MESFET Surface Degradation," Proc. 1985 Int'l Reliability Physics Symposium, pp.39-44, 1985.

(4) S. Igi et al.," The Effects of the Passivation Film on the Reliability of High Power GaAs MESFETs," Proc. ISTFA, pp.302-310, 1983.

(5) G. P. Schwartz et al.,"Arsenic Incorporation in Native Oxide of GaAs Grown Thermally under Arsenic Trioxide Vapor," Appl. Phys. Lett., 34(11), pp/742-744, June 1979.

(6) G. P. Schwartz et al.," Raman Scattering from Anodic Oxide-GaAs Interfaces," Appl. Phys. Lett., 34(3), pp. 205-207, Feb. 1979.