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Degradation mechanisms of GaAs PHEMTs in high humidity conditions

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Abstract

We have studied the degradation mechanisms of AlGaAs/InGaAs pseudomorphic HEMTs (PHEMTs) under high humidity conditions (85 °C, 85% relative humidity). The degraded samples under high humidity conditions show a decrease in maximum drain current (I_{max}) and a positive shift in threshold voltage (V_{th}). Cross-sectional transmission electron microscopy (TEM) images from the deteriorated devices reveal an existence of damaged recess surface region and a peeling of a passivation film (SiN_x). The secondary ion mass spectrometry (SIMS) depth profile at the interface between the passivation film and AlGaAs surface also indicates the diffusion of gallium (Ga), arsenic (As) and aluminum (Al) into the passivation film. The degradation of PHEMTs arises from mainly two mechanisms: (1) the positive shift in V_{th} due to stress change under the gate caused by the peeling of passivation films, and (2) the decrease in I_{max} due to the net carrier concentration reduction of the AlGaAs carrier supply layer caused by the combination of surface degradation at the AlGaAs recess regions and diffusion of Ga, As and Al at the interface between the passivation film and AlGaAs surface. A special treatment just prior to the deposition of SiN_x films on the devices effectively suppresses the degradation of PHEMTs under high humidity conditions without degradation of the high frequency performance.

1. Introduction

In order to reduce the cost of high frequency GaAs devices, the use of non-hermetic packages has been pursued with intensity in the last few years. In order to survive inside non-hermetic packages, GaAs devices must exhibit resistance to humidity. The reliability of GaAs devices under high humidity conditions has been investigated [1–3], however the device degradation mechanisms under high humidity conditions are not well understood. Thicker passivation films and other polymer coatings (e.g. polyimide and benzo cyclo butane (BCB) [4,5]) on the devices without the hermetic sealing have conveniently been used as a primitive method to protect the device surface, despite the fact that these films and coatings degrade the high-frequency characteristics due to

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their parasitic capacitance. In this paper, we have investigated the physical mechanisms behind degradation of AlGaAs/InGaAs PHEMTs under high humidity conditions (85 °C, 85% relative humidity). We have identified two mechanisms. One is the reduction of a drain current (I_{ds}) due to the combination of surface degradation and diffusion of Ga, As and Al at the interface between SiN_x and AlGaAs. The other is a V_{th} shift caused by piezoelectric effect resulting from the peeling of the SiN_x film. In this paper, we present this work and we also discuss how to mitigate these degradation mechanisms.

2. Samples and measurement

The devices studied in this work are single-recessed AlGaAs/InGaAs PHEMTs, as shown in Fig. 1. They have 0.25 μm long and 150 μm wide T-shaped Ti/Al gates. The devices are passivated by silicon nitride (SiN_x) films deposited by plasma-enhanced chemical vapor deposition (PECVD). Typical values of maximum drain current (I_{max}), peak transconductance (g_m), and unity current gain frequency (f_t) are 450 mA/mm, 600 mS/mm, and 65 GHz, respectively. The devices are mounted on packages without a cap.

Unbiased humidity tests were carried out under 85 °C, 85% relative humidity (85 °C/85% test), and 121 °C, 100% relative humidity at 2 atm (pressure cooker test, PCT). A 1000 h 85 °C/85% test is standard in product qualification. We also use PCT for more accelerated test by higher temperature and humidity to shorten the test time in addition to 85 °C/85% test.

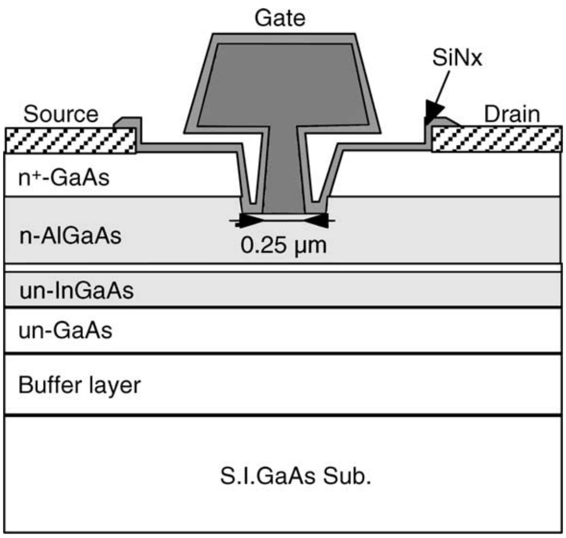

Fig. 1. Schematic cross-section of the AlGaAs/InGaAs PHEMT under test.

3. Results and discussion

3.1. Degradation of PHEMTs under high humidity conditions

Fig. 2 and Table 1 show typical DC characteristics before and after the humidity test (85 °C/85% test for 1000 h). There are two changes: a positive V_{th} shift (+0.06 V) and a decrease in maximum drain current (I_{max}) around −12%. TEM images of the PHEMT before and after the humidity test are compared in Fig. 3. A denatured surface region and peeling of the passivation film are observed after the test. As reported previously in [6], under high temperature large signal operation, a damaged region at the recess surface of AlGaAs/InGaAs PHEMTs caused by an electrochemical reaction leads to the reduction of I_{max}. Based on this results, the I_{max} reduction more than 10% needs the surface damaged layer more than 10 nm, assumed that the I_{max} reduction was originated only by the surface damage. However the level of damage from the humidity test, as seen in the TEM image, is smaller than the expected level, and is not enough to reduce I_{max} by more than 10% measured in this study.

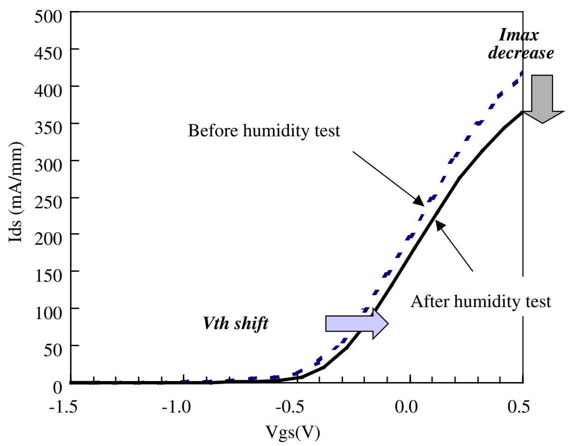

Fig. 2. Typical drain current (I_{ds}) as a function of gate bias (V_{gs}) before (dashed line) and after (solid line) 85 °C/85% test for 1000 h. Drain bias is 3.0 V.

Table 1
DC characteristics after 85 °C/85% test for 1000 h

	Initial	After humidity test
I_{dss} [mA/mm]	200	180
I_{max} [mA/mm]	420	370
V_{th} [V]	−0.63	−0.57
BV_{gd} [V]	7.9	7.5
BV_{gs} [V]	7.3	6.8
R_s [Ωmm]	0.35	0.37
R_d [Ωmm]	0.53	0.54