HOT-ELECTRON-INDUCED DEGRADATION OF PSEUDOMORPHIC HIGH-ELECTRON MOBILITY TRANSISTORS

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ABSTRACT—Pseudomorphic high-electron mobility transistors have been found to undergo hot-electron-induced degradation. Due to the negative temperature dependence of hot-electron effects, it will be necessary to conduct electrical and temperature stress tests separately, in order to ascertain the reliability of these transistors under normal operating conditions.

By electrically stressing a GaAs MESFET, hot electrons can be injected into the SiN passivation and form traps [1]. The negatively charged traps reduce the open-channel current of the MESFET without affecting its pinch-off voltage (Fig. 1). We now report that, a GaAs PHEMT can also undergo hot-electron-induced degradation and exhibit mixed behavior between that of a GaAs MESFET and a Si MOSFET. Specifically, both the pinch-off voltage and peak transconductance of a PHEMT are reduced (Fig. 2). In addition, unlike the MESFET case (Fig. 3), the knee voltage of the PHEMT does not change while the drain current decreases at all drain and gate biases (Fig. 4).

The results summarized here are based on SiN-passivated GaAs/InGaAs/AlGaAs PHEMTs. Each PHEMT comprises two gate fingers each 0.25 μm long and 100 μm wide. The gate is centrally located in a source-drain spacing of 4 μm.

Accelerated dc and RF stress experiments were performed on the PHEMTs under room temperature. The dc stress involves a *Vgs* of −4 V and *Vds* of 9 V. Under such conditions, the reverse gate current can be as high as 10 mA/mm and the pinch-off voltage or drain current is reduced by approximately 10% in two hours. The RF stress experiments were performed on-wafer at 2 GHz with *Vgs* = −2 V and *Vds* = 7 V, resembling a typical Class B operation. However, the 50 Ω impedance presented by the wafer probes is not optimum for either gain or power. Figure 5 shows that an input drive of 20 dBm is required for saturated power output while an 8 dB overdrive results in lower output power but accelerated degradation. With *Pin* = 28 dBm, approximately 1 dB reduction in *saturated* output power occurs after 24 h. Figures 6 and 7 show the *Vdg* and *Ig* waveforms, respectively, measured using a novel probing technique [2]. It can be seen that, due to large gate and drain voltage swings, the peak *Vdg* exceeds 13 V for *Pin* ≥ 20 dBm. The large voltage swings are followed by large forward and reverse gate currents.

Figure 8 shows the dc and 2 GHz drain characteristics of the PHEMT, before and after degradation. The RF contours, at *Pin* = 20 dBm, cannot reach the knee region of *Ids* under 50 Ω loading. Yet, the output power decreases due to drain current reduction at all drain voltages. This is in contrast to the case of a MESFET in which the RF contour must reach the knee region to experience the power loss (Fig. 3).

Under *Pin* = 20 dBm or *Vdg* = 13 V, electroluminescence from the PHEMT is visible. Figure 9 shows that, due to hot electrons, the spectrum contains a broad peak around 1.9 eV. This energy is higher than the bandgap of any of the compounds contained in the PHEMT structure, namely, 1.4, 1.2 and 1.7 eV for GaAs, InGaAs and AlGaAs.

Novel high-voltage electron-beam-induced-current (HV-EBIC) imaging [3] was performed on PHEMTs before and after stress. The HV-EBIC of an unstressed PHEMT is symmetrical w. r. t. the source and drain (Fig. 10a). Whereas after degradation it is stronger near the drain side of the gate than near the source side of the gate (Fig. 10b), indicating increased surface depletion by hot-electron-induced traps between the gate and drain. Compared to the case of MESFETs [1], the traps appear to be less sharply defined.

The above observation suggests that, similar hot-electron-induced degradation mechanisms occur in both MESFETs and PHEMTs. However, their detailed behaviors differ due to the structural differences between the MESFET and the PHEMT. It appears that, in addition to the SiN surface passivation, traps can also be formed in the AlGaAs layer under the gate, resulting in a shift of the pinch-off voltage. This makes the PHEMT behave like a MOSFET, as one would expect. The traps in AlGaAs may be slower to respond, causing the drain current to decrease at all drain biases (Fig. 4.) The traps in AlGaAs can also degrade Schottky contact characteristics, making it difficult to distinguish the hot-electron effect from the degradation effect of metallurgical interdiffusion. This is particularly true for PHEMTs that are close to being normally off. In this case, it is necessary to analyze the temperature dependence of the degradation behavior. As the lattice temperature is increased, diffusion accelerates while fewer hot electrons are generated.

In conclusion, hot-electron-induced degradation similar to that of MESFETs and MOSFETs was observed in PHEMTs. Due to the negative temperature dependence of hot-electron effects, it will be necessary to conduct electrical and temperature stress tests separately, in order to ascertain the reliability of PHEMTs under normal operating conditions.

Acknowledgment

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References

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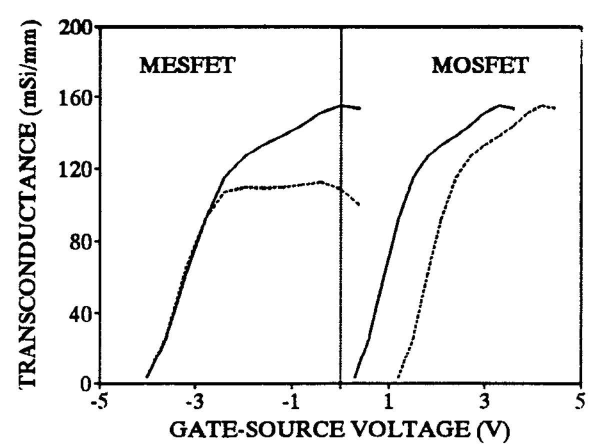


Fig. 1 Hot-electron effects on MESFET and MOSFET transfer characteristics. (—) before. (---) after.

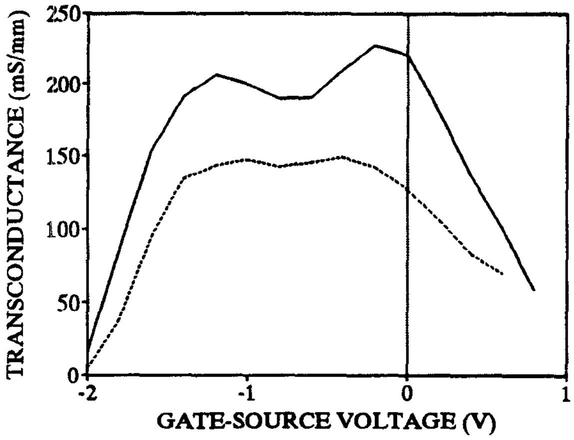


Fig. 2 Hot-electron effects on PHEMT transfer characteristics. (—) before. (---) after.

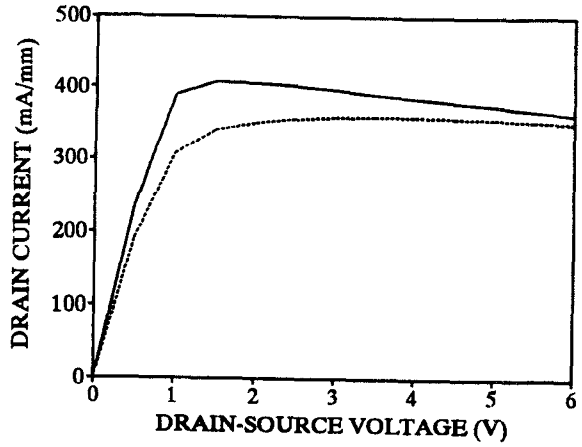


Fig. 3 Hot-electron effects on MESFET drain characteristics. $Vgs = 0$. (—) before. (---) after.

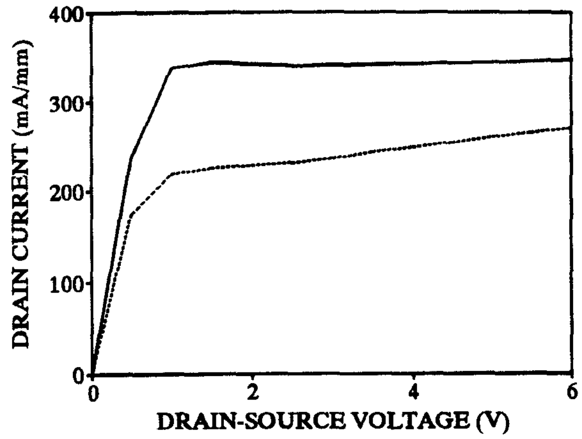


Fig. 4 Hot-electron effects on PHEMT drain characteristics. $Vgs = 0$. (—) before. (---) after.

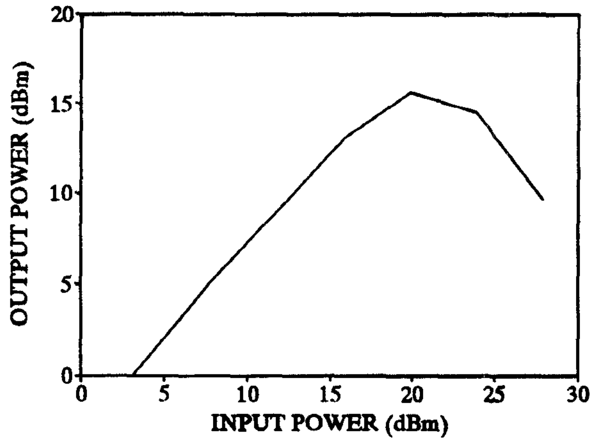


Fig. 5 PHEMT power characteristics at 2 GHz.

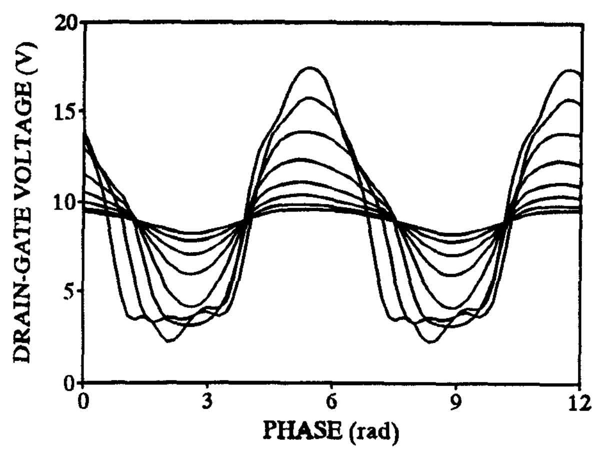


Fig. 6 PHEMT drain-gate voltage waveform at 2 GHz. $Pin = 0, 4, 8, \ldots 28$ dBm. $Vgs = -2$ V. $Vds = 7$ V.

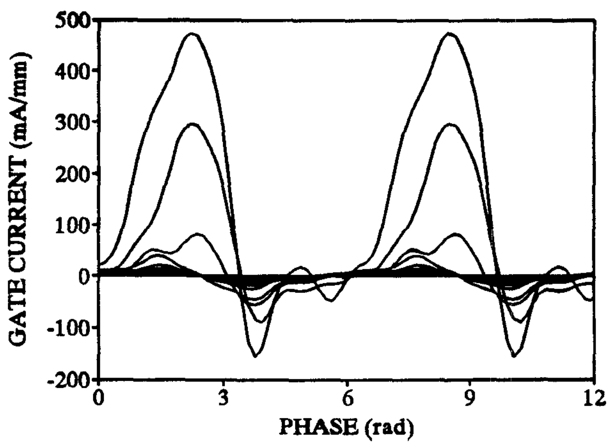


Fig. 7 PHEMT gate current waveform at 2 GHz. $Pin = 0, 4, 8, \ldots 28$ dBm. $Vgs = -2$ V. $Vds = 7$ V.

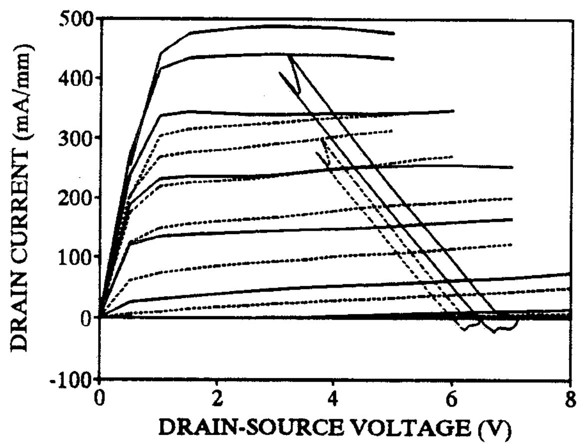


Fig. 8. PHEMT drain characteristics at dc and 2 GHz.
At dc, Vgs = 1.4, 0.5, 0, −0.5, −1.0, −1.5 and −2.0 V.
At 2 GHz, Vgs = −2 V and Vds = 7 V. (—) before. (—) after.

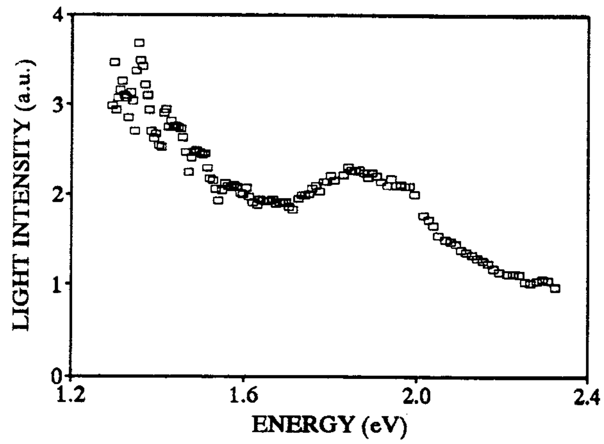
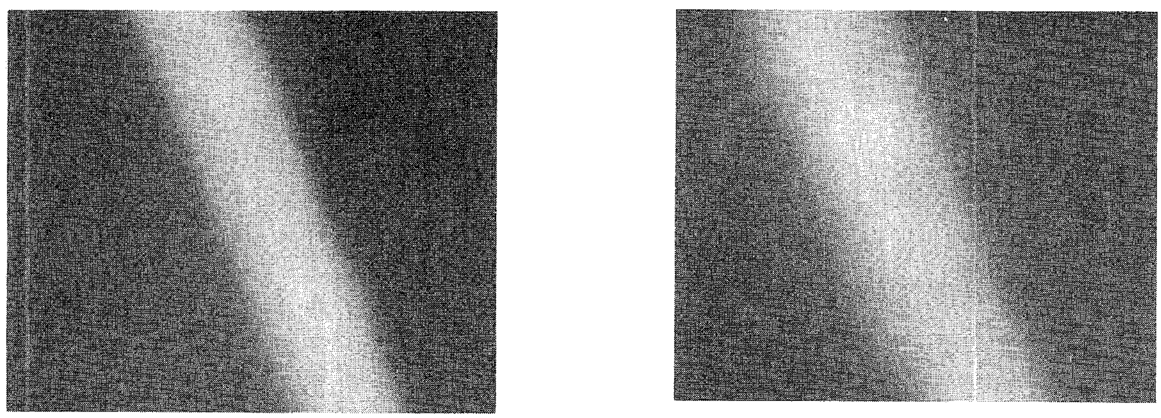


Fig. 9 PHEMT electro-luminescence spectrum.



(a) (b)

Fig. 10 HV-EBIC top-view images of the gate region of (a) unstressed and (b) degraded PHEMTs.