Impact of Drain Recess Length on the RF Power Performance of GaAs PHEMTs

M. F. Wong\textsuperscript{1}, J. A. del Alamo\textsuperscript{1}, A. Inoue\textsuperscript{2}, T. Hisaka\textsuperscript{2} and K. Hayashi\textsuperscript{2}
\textsuperscript{1} MIT, Room 39-415, Cambridge, MA 02139, USA, \textsuperscript{2} Mitsubishi Electric, Itami, Hyogo, Japan

RF power AlGaAs/InGaAs Pseudomorphic High Electron Mobility Transistors (PHEMTs) are widely used in satellite communication systems, transmit/receive modules for military radar applications, and cellular telephones. A high breakdown voltage (BV\textsubscript{DG}) is a necessary requirement for a device to achieve high P\textsubscript{OUT}. Increasing the gate-to-drain recess length (L\textsubscript{RD}) leads to an increase in BV\textsubscript{DG}, which ought to allow the selection of a higher V\textsubscript{DS} and theoretically yield higher P\textsubscript{OUT}. Contrary to this hypothesis, the experimental evidence in the literature shows that increasing L\textsubscript{RD} degrades the RF large signal behavior [1-3]. The reasons behind this behavior are not fully understood.

In an effort to provide fundamental understanding, we have studied the DC and RF power characteristics of GaAs PHEMTs with different values of L\textsubscript{RD}. We have performed DC, S-parameter, and load-pull characterization on industrial 160 um (4x40) GaAs PHEMT devices with 0.25 um gate width and L\textsubscript{RD} varying between 0.5 and 0.9 um while all other recess dimensions remain constant. The load-pull measurements were carried out on an ATN station utilizing Maury Microwave automated tuners at 10 and 16 GHz. The devices were tuned for maximum P\textsubscript{OUT} at the 3-dB compression point with I\textsubscript{D} = 100 mA/mm and a wide range of V\textsubscript{DS}.

In all of these measurements, we maintained a small signal gain of 15 dB. To limit device degradation, V\textsubscript{DS} was limited to a maximum value of (V\textsubscript{KNEE}+BV\textsubscript{DG})/2 and I\textsubscript{G} was not allowed to exceed –10 mA/mm.

Fig. 1 shows the gain and PAE as a function of P\textsubscript{OUT} for devices with different L\textsubscript{RD} under the same bias of V\textsubscript{DS} = 5 V at 10 GHz. As L\textsubscript{RD} increases, the gain compresses earlier, the peak PAE is reduced, and the maximum P\textsubscript{OUT} drops. Fig. 2 summarizes P\textsubscript{OUT,3-dB} as a function of V\textsubscript{DS} at 10 GHz for the four devices. For every device, P\textsubscript{OUT,3-dB} increases as V\textsubscript{DS} increases. At a given V\textsubscript{DS}, P\textsubscript{OUT,3-dB} decreases as L\textsubscript{RD} increases. If we consider the highest power that can be obtained at any V\textsubscript{DS}, we can see that as L\textsubscript{RD} increases, the maximum P\textsubscript{OUT,3-dB} increases up to the L\textsubscript{RD} = 0.7 um device and then decreases for the L\textsubscript{RD} = 0.9 um device. Hence, there appears to be an optimal value of L\textsubscript{RD}. Fig. 3 shows similar measurements at 16 GHz that reveal an optimal L\textsubscript{RD} of 0.5 um. This implies that the optimal value of L\textsubscript{RD} is frequency dependent; at higher frequencies, the optimum L\textsubscript{RD} is reduced. For the L\textsubscript{RD} = 0.7 and 0.9 um devices, beyond the maximum V\textsubscript{DS} indicated in the figure, the small-signal gain could not be maintained at 15 dB.

In order to understand these results, we have studied the drain and gate currents as a function of RF power drive as shown in Fig. 5. The short L\textsubscript{RD} devices show a sharp rise in negative I\textsubscript{G} as the device enters compression. This suggests that impact ionization is limiting the excursion in V\textsubscript{DS} and interaction with the high impact ionization region of the device is producing a large amount of I\textsubscript{D} self-bias [4]. As L\textsubscript{RD} is increased, the gate current is greatly reduced by the increase in the breakdown voltage and the self-bias goes down. Since a high degree of self-biasing allows the device to operate under optimum power Class A operation, a smaller value of L\textsubscript{RD} leads to a higher P\textsubscript{OUT}.

The slope of the load line determines the gain. For a constant small signal gain, a higher g\textsubscript{m} allows a steeper load line and a smaller g\textsubscript{m} requires a shallower load line. For a given bias point and frequency, we have found that g\textsubscript{m} and f\textsubscript{T} drop as L\textsubscript{RD} increases. Hence, the load line has to get shallower in order to maintain a constant small-signal gain. This also reduces the maximum power the device can deliver.

The drop in g\textsubscript{m} and f\textsubscript{T} can be understood from S-parameter measurements. Following Suemitsu’s technique [5], we have extracted the intrinsic delay time and from it, the delay associated with electron transport through the depletion region on the drain side of the device. Fig. 6 suggests a very strong dependence of drain delay on L\textsubscript{RD} and V\textsubscript{DS}. The wider recess devices allow the depletion region to extend further away from the gate edge,
resulting in increased drain delay. This detracts from the frequency response of the device and hurts the gain.

In conclusion, there is an optimal $L_{RD}$ when it comes to maximizing the $P_{OUT}$ of a RF power PHEMT. This optimum value of $L_{RD}$ decreases with frequency as the drain delay becomes relatively more significant.